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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

A. Vignesh, N. Ramanujam, P. Prasad, S. H. K. Murti, Qazi Akhter Rasool, Swapan Kumar Biswas, Chandrakanta Ojha and Janarthana Boobalan

Department of Disaster Management, Pondicherry University, Port Blair, Andaman Islands

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ABSTRACT

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 sections 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 show very high resistivity values of 192.0 Ω m, 250.0 Ω m, and 1666.0 Ωm in three mud volcanoes at Pusi , Rajathgarh and Mirchitikiri respectively. The higher resistivity implies 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 eruptions 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 greenhouse gas. Worldwide distribution of mud volcanoes was 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 are 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 methane volcanoes eruption. Gas emitted from the on shore mud volcanoes are primarily methane

(70-99%) and CO_2 (Kopf, 2002). The traditional exploration workflow relies on indirect evidence to locate hydrocarbon and seismic methods are mainly sensitive to rock structure and not to the fluids within them .In contrast, controlled source of electromagnetic (CSEM) methods are sensitive to resistive fluids and can indicate hydrocarbon directly. Furthermore CSEM data can be correlated with seismic and other geological information. Logging of refracted energy of high power EM energy collected from subsurface layers indicate the areas of high electrical resistivity - a direct indicator of hydrocarbons. Using traditional technique it has been reported that the success rate were only 25 % , whereas CSEM test prospects before drilling achieve far higher success rates (www.engineerlive.com). 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) . The aim of the present study is to map the subsurface electrical nature of gas and gas hydrate filled 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).with controlled source electromagnetic experiment. Seep structures in these areas are controlled by faults which can be imaged by Ground Penetration Radar. Distributions of gas hydrate which has accumulated beneath the seeps of the mud volcanoes revealed through CSEM data. Observations are confined to the shallow sediment section with depth rage of the entire sensitive to the presence and amount of gas hydrate.

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 enhanced fluid pressure and the expansion of dissolved methane (Kopf, 2002). Mud volcanoes in Baratang Island are aligned along lines of weak zones following 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).

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 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 HashinShtrikman bounds (HS bounds) (Schmelisng, 1986). The HS lower bound σHS- corresponds to resistive spherical inclusion within a conductive matrix and the HS upper bound σHS + 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). The physical parameters derived from Controlled Source Electromagnetic (CSEM) data is electrical conductivity or reciprocal electrical resistivity. The electrical conductivity is the foremost marine sediments, the pore fluids is also seawater , typical resistivity values for the mud sediments are between 4.0 Ωm and 6.3 Ωm Hydrate filled sediments and gas electrically insulating and enhance the bulk resistivity in areas where they form sufficient quantities. Because of its high resistivity the gas hydrate along the fissures and cracks are detected through CSEM techniques. 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 (winters et al 2003) and free gas accumulated along fault plane and to cracks and fissures on Opouawe Bank indicate the resistivty anomalies (Schwalenberg et al ; 2009). 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 in the study area. The free gas accumulated exhibit the higher resistivity. The methane gas is transported upwards through the sediment section and gas hydrate will be formed within the gas hydrate stability zone from dissolved methane. The dissolved gas derived from the gas hydrate accumulated in the gas chambers and fracture zones and veins exhibited the highest resistivity values in three mud volcanoes as 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. 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. Of the three mud volcanoes, Mirchitikiri in its dormant stage shows highest variation between the gases accumulated in mud chambers with mud sediments. The highest resistivity values obtained for the gas hydrate accrued in the chambers and veins and fissures of the Mirchitikiri mud volcano. Consequent to gas pressure accumulated in the pressure chamber and vertical pipe increased the resistivity of the Mirchitikiri gas hydrate than the other two mud volcanoes. 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 .

Table 1 A: 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	Rajathghargh Tx and Rx loop size: 90*90 m NE
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 = 4.0235Ωm
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 = 250Ωm
Remarks	Mud volcanoes erupting mud and gases through orifice and release gas pressure accumulated. The resistivity variation gas hydrate with host sediments =250/4.0235=62.14

Table 1 B : Resistivity values retrieved for host sedimentary formations and gas hydrates accumulatedin 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*90 m N E
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 1.43658 Ωm to 5.73066Ωm(696.1mS/m to 174.5mS/m) The average resistivity values for the host sediments= 3.5836Ωm
Depth wise distribution pattern of gas hydrate	Gas hydrate occurs in pipes extended from 250m to 800m. the resistivity values for gas hydrate exhibits as 1666.67Ωm (0.6mS/m) The average resistivity values of gas hydrate =1666.67 Ωm
Remarks	In this location no visible mud volcano is seen in the surface outcrops but fracture extended in N-S trend The resistivity variation of the gas hydrate with host sediments = 1666.67/3.5836=465.08

Figure 1: Location Map of the Study Area

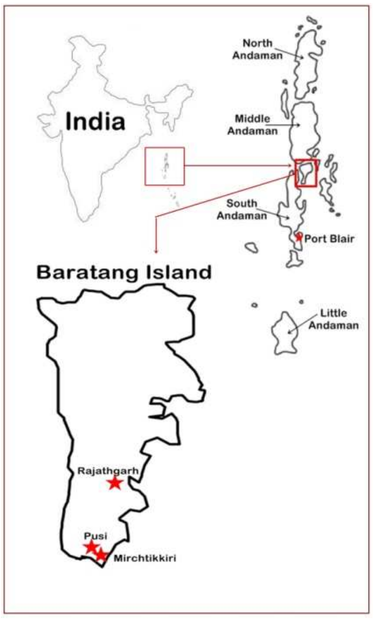


Figure 2: Eruption of mud volcano with gas and organic matter in Pusi Mud volcano.

Table 1 C: Resistivity values retrieved for host sedimentary formations and gas hydrates accumulatedin 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*90 m N E
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 10.02Ωm (383.7mS/m to 99.8mS/m). The average resistivity of the host sediments =6.313Ωm
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 192.3Ωm. (5.2mS/m). The average resistivity of the gas hydrate = 192.3Ωm
Remarks	Mud volcano erupted with 5 m thickness of sediments. The resistivity variation of the gas hydrate with host sediment = 192.3/6.313= 30.46

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

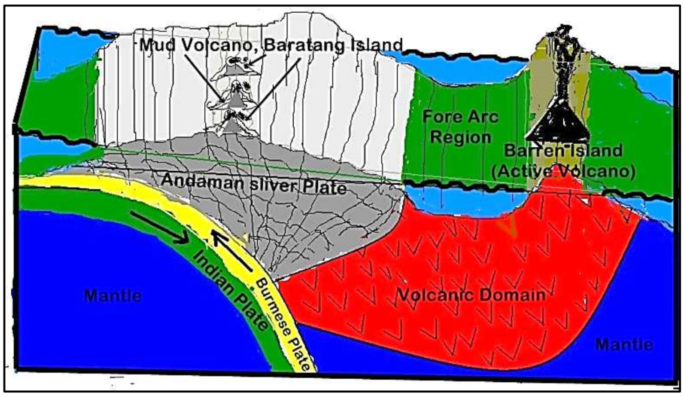


Figure 4: Pseudo section showing the distribution of vertical pipes of gas hydrates and horizontal layers of sedimentary deposits in Rajathgarh

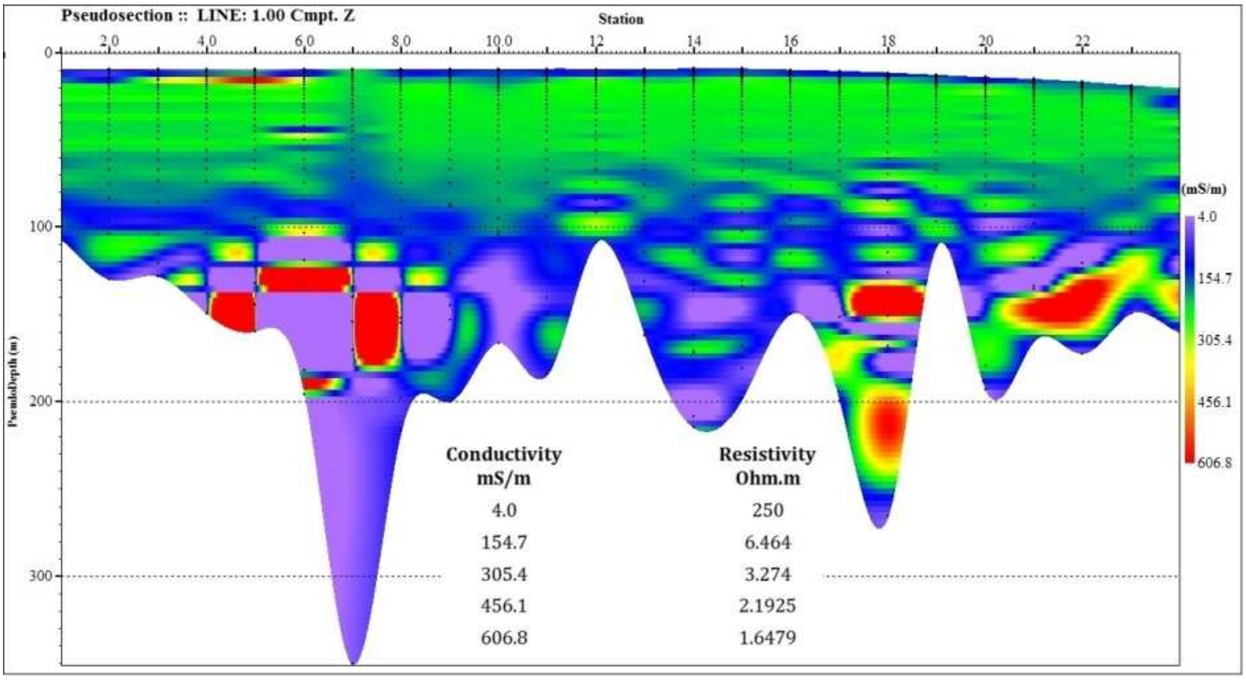


Figure 5: Pseudo section showing the distribution of vertical pipes of gas hydrates and horizontal layers of sedimentary deposits in Mirchitikiri.

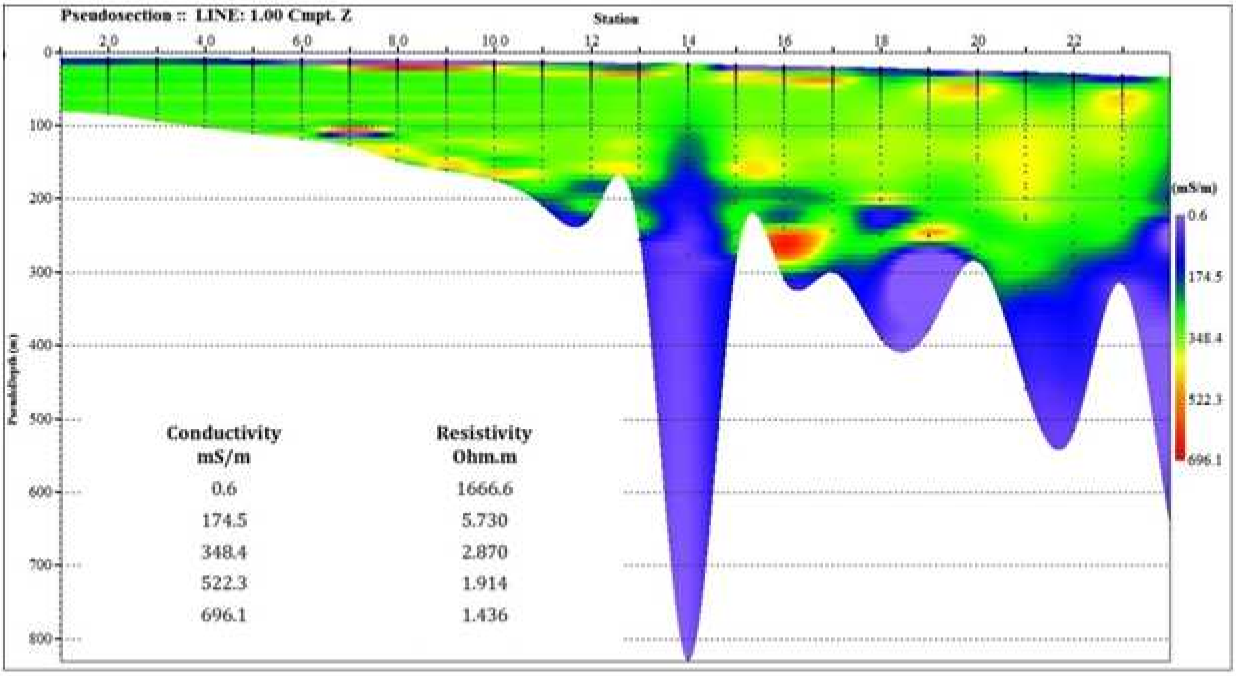
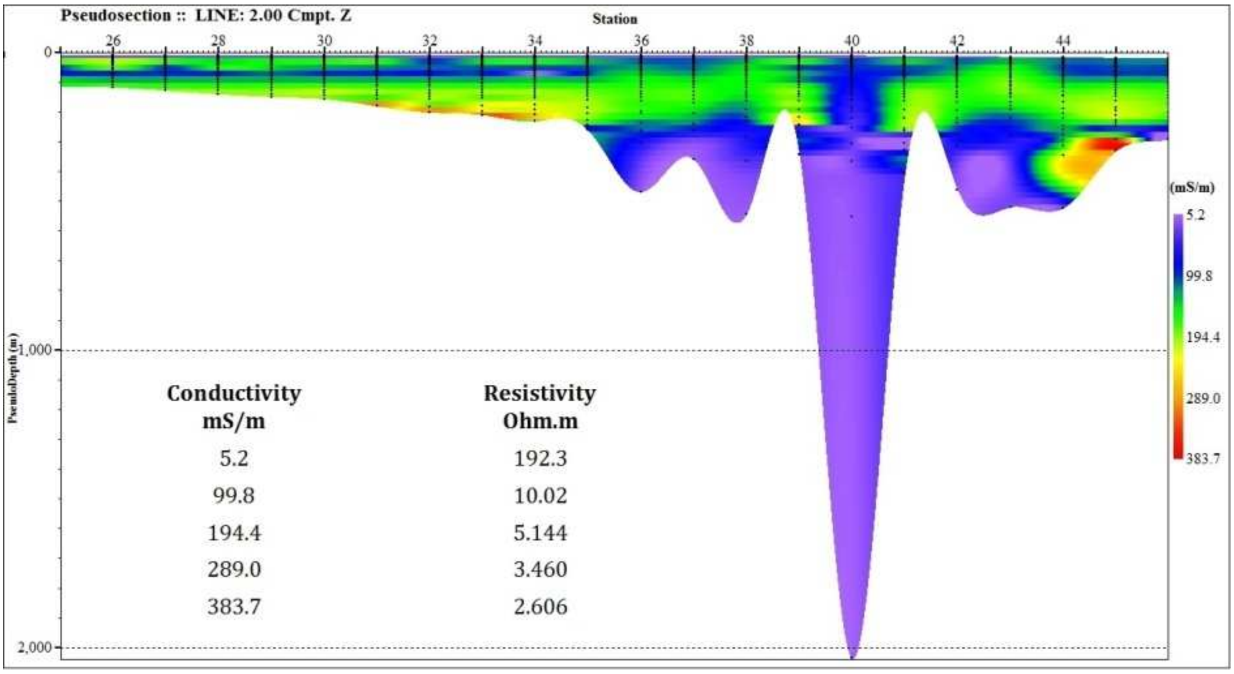


Figure 6: Pseudo section showing the distribution of vertical pipes of gas hydrates and horizontal layers of sedimentary deposits in Mirchitikiri.



CONCLUSION

Gas hydrates exhibit higher electromagnetic resistivity than their surrounding in the realm of mud volcanoes at Rajathgarh, Mirchtikiri and Pusi in Baratang Island, Andaman. Controlled source of electromagnetic (CSEM) technique has been used to measure subsurfaceresistivity related to marine hydrocarbon exploration in recent years verysuccessfully. The indication of high resistivity is not sufficient to distinguish the gas hydrate or oil from the other geological features which can display high resistivity including salt, volcanic, carbonates and fresh water. Pseudosection obtained from TEM technique clearly reveals that gas hydrates distribution in vertical pipe structures and chambers in horizontal layers an aligned to the deep seated faults in N-S and E-W direction. Furthermore the shape of the structures and surrounding sediments and regional geological knowledge have obviously indicate that presence gas other the high resistivity features such as fresh water , carbonate etc . 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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