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# Marine controlled source electromagnetic method used for the gas hydrate investigation in the offshore area of SW Taiwan

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ABSTRACT

Bottom simulating reflectors (BSRs), high methane flux, shallow sulfide/methane interfaces, fluids venting from the seafloor, authigenic carbonates within sediments, methane reefs, and self-biomes are common seafloor features in the area off southwest Taiwan. The geophysical and geochemical signatures of these features suggest a high potential for gas hydrate (GH) reservoirs in the region. The BSRs are typically interpreted as the boundary between free gases and solid hydrate, whereas the upper reaches of the hydrate stability zone and the distribution of gas hydrate in shallow sediments are not well understood. This study shows the first results of a marine controlled-source electromagnetic survey, conducted in the offshore area of SW Taiwan in 2010. The survey aimed to provide electrical resistivity information of the shallow sediments. Three target areas were surveyed: (1) an area to the southeast of the Xiaoliuchiu Island (gas seep G96), (2) an area in the west of the Yung-An Ridge (YAR) and (3) an area in the northwest of the Good Weather Ridge (GWR). In total, fourteen survey lines with a total length of 72 km were completed. Our preliminary results show that relatively high resistivity anomalies occur within pockmarks and at gas seepage sites. The apparent resistivity is estimated to be about 1 Ohm-m higher than background in G96 and YAR sites, while an anomaly up to 2 Ohm-m is found in the GWR. At gas seep site G96, the high resistivity anomaly may be due to the existence of authigenic carbonates; whereas, the high resistivity anomaly in the NW of the GWR site may also be due to the existence of gas hydrate in the shallow seabed. Based on the resistivity anomaly, the gas hydrate saturation is about 16% in the shallow sediments below the pockmark area in the northwest side of the GWR site.



## 1. Introduction

A widespread distribution of bottom simulating reflectors (BSRs) (Chi et al., 1998; Liu et al., 2006), high methane concentrations in the bottom water (Chuang et al., 2006), a shallow sulfate/methane interface (Lin et al., 2006), active methane venting from submarine mud volcanoes (Hsu et al., 2013), mud diapirs and gas seepages (Chen et al., 2010) in the offshore area of southwest Taiwan all suggest a high potential of gas hydrates resources. However, crystallized methane hydrate (MH) has not yet been observed in over 60 piston core samples, including 4 giant piston cores by R/V *Marion Dufresne* (Liu et al., 2006).

BSRs from marine seismic reflection surveys are generally linked to the occurrence of MH-bearing formations. The presence of BSRs is typically interpreted to correspond to the base of the hydrate stability (BGHS) zone, marking a boundary between free gases and the solid hydrates. Thus, the BSR might be used as an indicator of a methane hydrate (MH) deposit. As a matter of fact, the BSR is a better indication of the existence of free gas beneath the BGHS (Paull and Ussler, 2001).

The upper boundary of the hydrate stability zone is poorly understood and is greatly influenced by fluid advection (e.g. Xu and Ruppel, 1999). In convergent margin settings, fluid flux is especially high as a result of the squeezing of sediments, resulting in mud volcanoes (Milkov, 2000) and other gas seepage systems. Important chemical fluxes of methane (e.g. Hovland and Judd, 1988; Hovland et al., 1993) and groundwater in coastal settings also pass through shallow sediments into the ocean. Thus, the upper bound of MH in shallow sediments still remains uncertain in areas where hydrate potential is only based on the location of a BSR (e.g. Liu et al., 2006).

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Because the gas hydrate is generally associated with high resistivity, marine electromagnetic techniques are considered to be an effective way to image gas hydrates (GH) in the shallow portion of the seabed (Edwards, 1997; Evans, 2007; Ellis et al., 2008; Goto et al., 2008; Schwalenberg et al., 2010; Chiang et al., 2011, 2012; Weitemeyer et al., 2011). We therefore carried out the first marine controlled source electromagnetic (MCSEM) survey off southwest Taiwan in order to better understand the potential gas hydrate in this region (Fig. 1).

## 2. Data acquisition and processing

In order to image the shallow section of sediment, we use a towed electromagnetic (EM) system manufactured by Woods Hole Oceanographic Institution (Evans, 2007). The towed EM system is a frequency-domain, magnetic dipole–dipole array (Fig. 2). The system is composed of 3 receivers and a transmitter forming an array with a total length of ~40 m on the seafloor. The system is pulled along the seafloor at speeds of 1–2 knots. The 3 receivers are

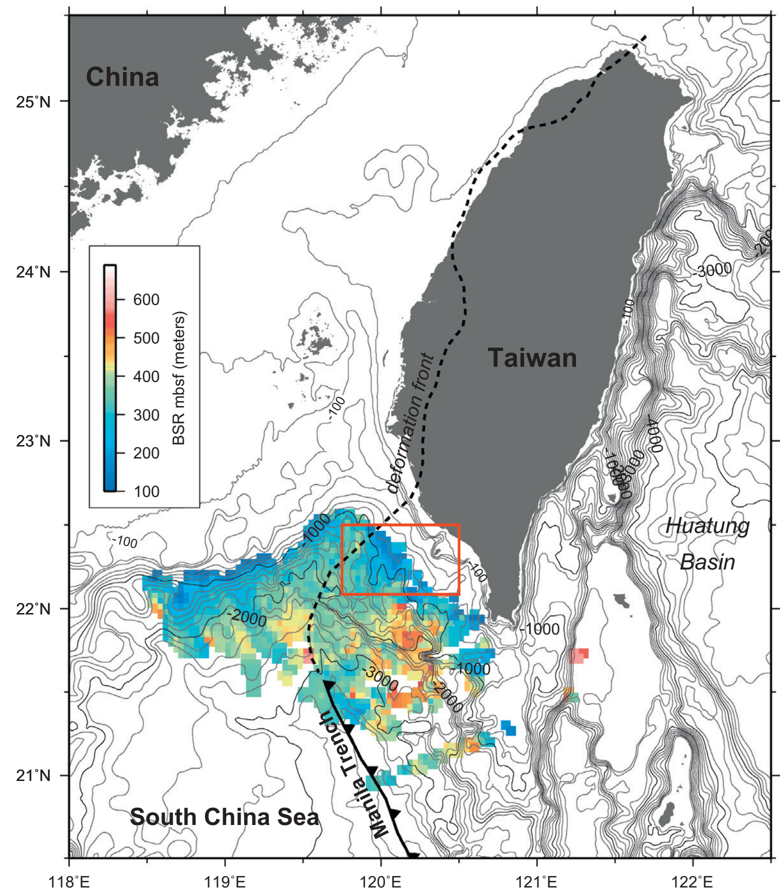


**Fig. 1.** The BSR distribution off SW Taiwan is superposed on the bathymetry. The red box indicates the study area. mbsf: meters below sea floor. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

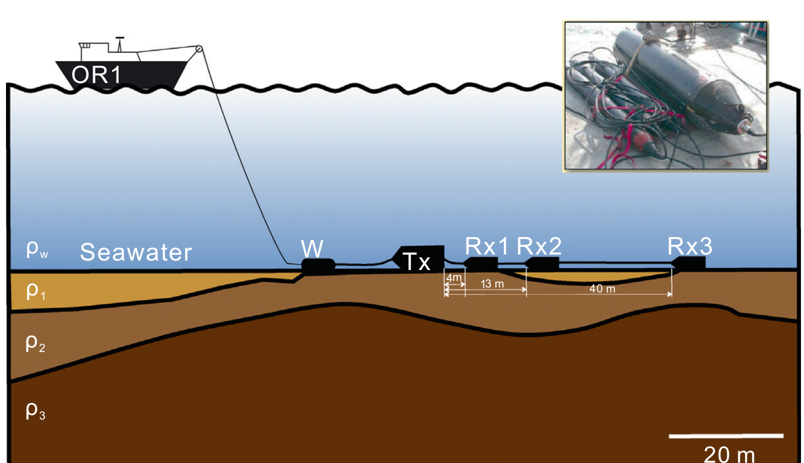


**Fig. 2.** Schematic configuration of towed EM system (modified from Evans et al., 1999). *W*: a weight as a depressor unit; *Tx*: transmitter; $\sigma$: conductivity. Rx1, Rx2 and Rx3 and three different receivers. Up-right panel shows the real instruments.