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Distribution and characters of the mud diapirs and mud volcanoes off southwest Taiwan

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ABSTRACT

In order to identify the mud diapirs and mud volcanoes off SW Taiwan, we have examined ~1500 km long MCS profiles and related marine geophysical data. Our results show ten quasi-linear mud diapirs, oriented NNE–SSW to N–S directions. Thirteen mud volcanoes are identified from the multibeam bathymetric data. These mud volcanoes generally occur on tops of the diapiric structures. Moreover, the active mud flow tracks out of mud volcanoes MV1, MV3 and MV6 are observed through the high backscatter intensity stripes on the sidescan sonar images. The heights of the cone-shaped mud volcanoes range from 65 m to 345 m, and the diameters at base from 680 m to 4100 m. These mud volcanoes have abrupt slopes between 5.3° and 13.6°, implying the mudflow is active and highly viscous. In contrast, the flat crests of mud volcanoes are due to relative lower-viscosity flows. The larger cone-shaped mud volcanoes located at deeper water depths could be related to a longer eruption history. The formation of mud diapirs and volcanoes in the study area are ascribed to the overpressure in sedimentary layers, compressional tectonic forces and gas-bearing fluids. Especially, the gas-bearing fluid plays an important role in enhancing the intrusion after the diapirism as a large amount of gas expulsions is observed. The morphology of the upper Kaoping Slope is mainly controlled by mud diapiric intrusions.

1. Introduction

A mud diapir is an intrusive structure characterized by a slowly upward migrating mass of clay-rich sediment and fluid discharge (Kopf, 2002). A mud volcano usually occurs above the diapir, as a result of fluid migration directly along the body of the mud diapir or through faults (fractures) connected to the mud diapirs (Milkov, 2000; Kopf, 2002). Cone-shaped mud volcanoes with central vents are common features (Brown, 1990; Kopf, 2002). Mud volcanoes represent the last manifestation of diapirism (Brown and Westbrook, 1988; Pérez-Belzuz et al., 1997; Kopf, 2002). They are the most important pathways for methane emission from deep marine sediments into atmosphere (Dimitrov, 2002, 2003). They have been studied intensively because they are closely related to the occurrence of hydrocarbons (e.g. gas hydrate) and fluid discharge (mainly methane and CO_2), an important component of global carbon cycles (Milkov, 2000; Kopf, 2002).

Mud volcanism and diapirism are well-known geological phenomena occurring in the areas of ongoing collisional tectonics or extensional settings. The majority occur in accretionary wedges, where the main tectonic forces are of compressional, such as in the Mediterranean Ridge (Limonov et al., 1996; Camerlenghi et al., 1995; Robertson et al., 1996; Kopf et al., 1998, 2000), Barbados (Brown and Westbrook, 1988; Sumner and Westbrook, 2001), Gulf of Cádiz (León et al., 2007; Somoza et al., 2003) and Nankai Trough (Kobayashi et al., 1992; Morita et al., 2004). Some occurs in extensional provinces, such as in the Black Sea (Krastel et al., 2003; Limonov et al., 1997) and Southeastern Tyrrhenian Sea (Gamberi and Rovere, 2010). Some mud diapirs and mud volcanoes have been linked to both extensive and compressive contexts, such as in the Western Alboran Sea area (Pérez-Belzuz et al., 1997; Sautkin et al., 2003; Talukder et al., 2003). In addition to high overpressure in sedimentary layers due to rapid sedimentation and gas generation (Dimitrov, 2002; Milkov, 2000; Talukder et al., 2007; Brown, 1990; Hovland and Curzi, 1989; Hovland et al., 1997), tectonic processes are considered to be the main driving mechanism for the development of mud diapirism and volcanism (Milkov, 2000; Talukder et al., 2007; Limonov et al., 1996).

The offshore area of SW Taiwan belongs to an accretionary wedge setting that is caused by the southeastward subduction of the Eurasian Plate beneath the Philippine Sea Plate. Many

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submarine mud volcanoes, gas seeps and mud diapirs have been reported (Fig. 1) (Sun and Liu, 1993; Liu et al., 1997; Huang, 1995; Chang, 1993; Chuang, 2006; Tseng, 2006; Chiu et al., 2006; Lin et al., 2009; Chen et al., 2010; Hsu et al., 2013a,b). Onland mud volcanoes have also been documented in southern Taiwan (Shih, 1967; Yang et al., 2004; Sun et al., 2010). The formation of mud volcanoes onshore and offshore may be linked (Yeh, 2003; Yang et al., 2004; Sun et al., 2010). Some submarine diapiric ridges are also suggested to be structurally correlated with the similar anticlinal structures in SW Taiwan (Hsieh, 1970; Sun and Liu, 1993; Huang, 1995; Liu et al., 1997; Chuang, 2006). However, due to lack of detailed marine geophysical data, the characteristics of the submarine structural features, mud volcanoes and diapirs are still poorly understood in the offshore area of SW Taiwan.

For the past six years, new marine geophysical data have been collected in the offshore area of SW Taiwan, giving a good opportunity to better understand the accurate distribution and characters of the mud diapirs and mud volcanoes. In this paper, we use the newly collected multibeam bathymetry, multichannel seismic reflection (MCS) and deep-towed sidescan sonar data to map the structures of the mud diapirs and mud volcanoes in the offshore area of SW Taiwan.

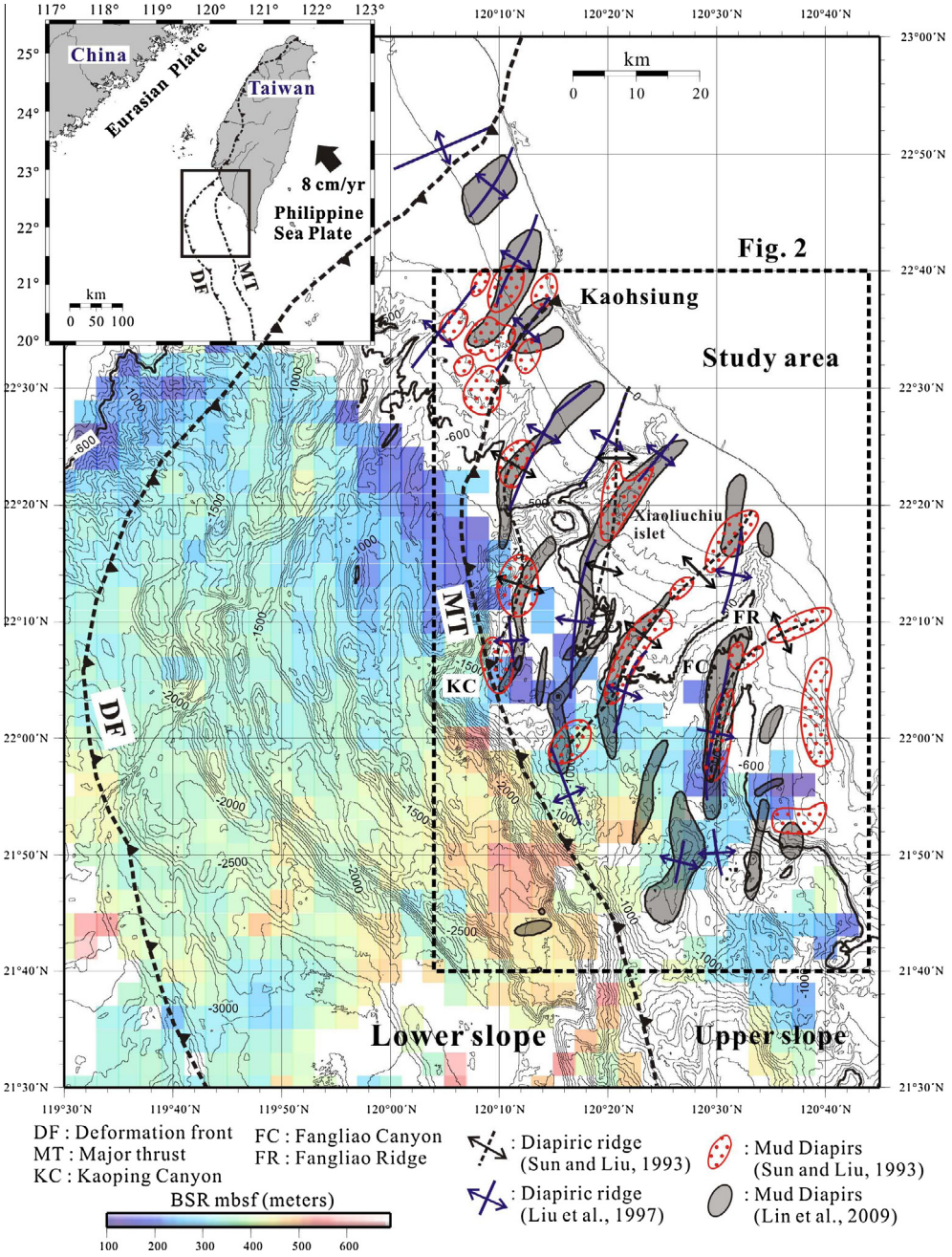

Fig. 1. Tectonic features and bathymetry off SW Taiwan. Inset shows the regional topography and tectonic features. The deformation front (DF) separates the passive South China Sea (SCS) continental margin in the west and active accretionary wedge in the east. The major thrust (MT) separates the lower slope and upper slope of the accretionary wedge. The different distributions of the mud diapirs or diapiric ridges off SW Taiwan are plotted for comparison. The dashed box indicates our study area. The distribution of the bottom simulating reflector (BSR) (in 2′ × 2′ grids) is indicated by the color scale. mbsf: meters below seafloor.