Journal of Asian Earth Sciences 92 (2014) 245–253

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Two dimensional fluid flow models at two gas hydrate sites offshore southwestern Taiwan

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ARTICLE INFO

Article history:
Received 28 March 2013
Received in revised form 6 January 2014
Accepted 7 January 2014
Available online 23 January 2014

Keywords:
Fluid migration
Geothermal gradient
Finite-element
Bottom-simulating reflectors

ABSTRACT

Fluid migration patterns are important for understanding gas hydrate and hydrocarbon systems. However, conducting experiments on or below the seafloor is difficult because crustal fluid flow rates are usually very slow, so long term observations are needed. Temperature can be used as a good tracer for studying fluid flows. Temperatures derived from bottom-simulating reflectors (BSRs) might help to understand fluid migration patterns in shallow marine sediments. In this study, we studied 2D fluid flow patterns in two potential gas hydrate provinces offshore southwestern Taiwan: the Yung-An Ridge in the active margin and Formosa Ridge in the passive margin. We used 2D bathymetry, average seafloor temperatures and regional geothermal gradients measured by thermal probes, as constraints to construct 2D theoretical conductive temperature fields using finite element methods. We then compared the BSR-based temperature with the theoretical conductive temperature field. The results show a temperature discrepancy attributed to advective heat transfer due to fluid migration. For the Yung-An Ridge, the BSR-based temperatures are about 2 °C higher than the model: Especially in (1) near a fault zone, (2) under the eastern flank where there are strong seismic reflectors in a pseudo-3D seismic dataset, and (3) near a fissure zone. For the Formosa Ridge, our results showed a distinct decrease in temperatures around the southern peak of the ridge, where an active gas plume was found. BSR-based temperatures predict on average 2 °C lower than the model. At these two sites, the shallow temperature fields are strongly affected by 2D bathymetry. However, new insights regarding fluid flow patterns can be obtained using this model approach.

1. Introduction

Fluid flow will affect heat transport processes and perturb crustal thermal structures. These thermal perturbations can be used to study fluid migration parameters, which are important geophysical parameters for regional tectonics, hydrocarbon reservoir simulations, and thermal energy research. In offshore southwestern Taiwan, heat flow data can be obtained by thermal probe measurements (Shyu and Chang, 2005) in very shallow sediments (<6 m), but it is difficult to infer temperature fields and fluid flow patterns at depths greater than hundreds of meters under the sea floor using thermal probes. Drilling operations can provide ground truth information, but the costs are high. In this study, we developed a 2D procedure to simulate temperature fields to study regional fluid flow patterns in shallow marine sediments using in situ geothermal measurements and temperature fields derived from a Bottom Simulating Reflector (BSR) using seismic reflection data.

There are wide-spread BSRs in the area offshore southern Taiwan (Liu et al., 2006; Chi et al., 1998). The relationships between pressure (*P*) and temperature (*T*) of the gas hydrate phase change and the depth of BSR have been used to calculate geothermal gradients and heat flow (Shipley et al., 1979; Yamano et al., 1982; Davis et al., 1990; Hyndman et al., 1992). In Taiwan, BSRs were used to derive heat flows to investigate crustal thermal structure (Chi and Reed, 2008) and regional 1-D fluid flow rates (Chen et al., 2011a). In many cases, the general agreement between thermal probe data and BSR-based heat flow suggests that it is possible to study thermal structures using BSRs (Schnuerle and Liu, 2011).

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http://dx.doi.org/10.1016/j.jseaes.2014.01.004
1367-9120/

2. Background

2.1. Geological setting

Offshore southwestern Taiwan (Fig. 1) is an area where the Luzon subduction system (south of 20°30′N) transforms into an incipient arc-continent collision system (20°30′N–21°15′N) from south to north, as the Luzon subduction complex encroaches on the passive China continental margin (Reed et al., 1992). Distinctive morphotectonic features in the area represent the transition from subduction to collision (Liu et al., 1998). Within the region are fold-and-thrust structures of the convergent zone and horst-and-graben structures of the passive margin. These two zones are separated by a deformation front that extends further north from the northern end of the Manila Trench. BSRs have been observed in both the passive margin of the continental slope of the South China Sea and the Taiwan submarine accretionary wedge and are most concentrated underneath anticlinal ridges in the accretionary wedge terrain and underneath the slope ridges of the passive continental margin, from water depths of 500 to over 3000 m (Chi et al., 1998; Liu et al., 2006). Previously, we found a dramatic increase in fluid flow rate when the continental slope of the Chinese passive margin enters into the trench, and reduced fluid flow rates in the hinterland, from estimating the vertical fluid flow rate in this region (Chen et al., 2012). Here, we selected the Yung-An and Formosa Ridge as our fluid simulation targets to compare the fluid migration patterns in active and passive regions, respectively.

2.2. Yung-An Ridge

The Yung-An Ridge offshore southwestern Taiwan is located in the accretionary complex of the Luzon subduction–collision system (Figs. 1 and 2a). The ridge is formed by several west-vergent thrusts, folds, and their associated slope basins. There are also a series of mud diapirs found in the upper slope domain near the coast of southwestern Taiwan (Sun and Liu, 1993) which can be traced to adjacent onshore structures in the fold-and-thrust belts (shown as purple symbols in Fig. 1). The presence of mud volcanoes both offshore (Chiu et al., 2006) and onshore in Taiwan (Yang et al., 2004) indicates active fluid expulsion in the accretionary wedge, and chemical analyses of the gases from onshore mud volcanoes (Yang et al., 2004) suggests that most of the gas originates from deeper crust. BSRs are widely recognized in this region, with active fluid migration from seismic data and observed from authigenic carbonate deposits and other geochemical evidence on the seafloor (Yang et al., 2006). Because of these strong hydrate-related signatures, the Yung-An Ridge has been proposed as a high priority drilling site for gas hydrate investigations.

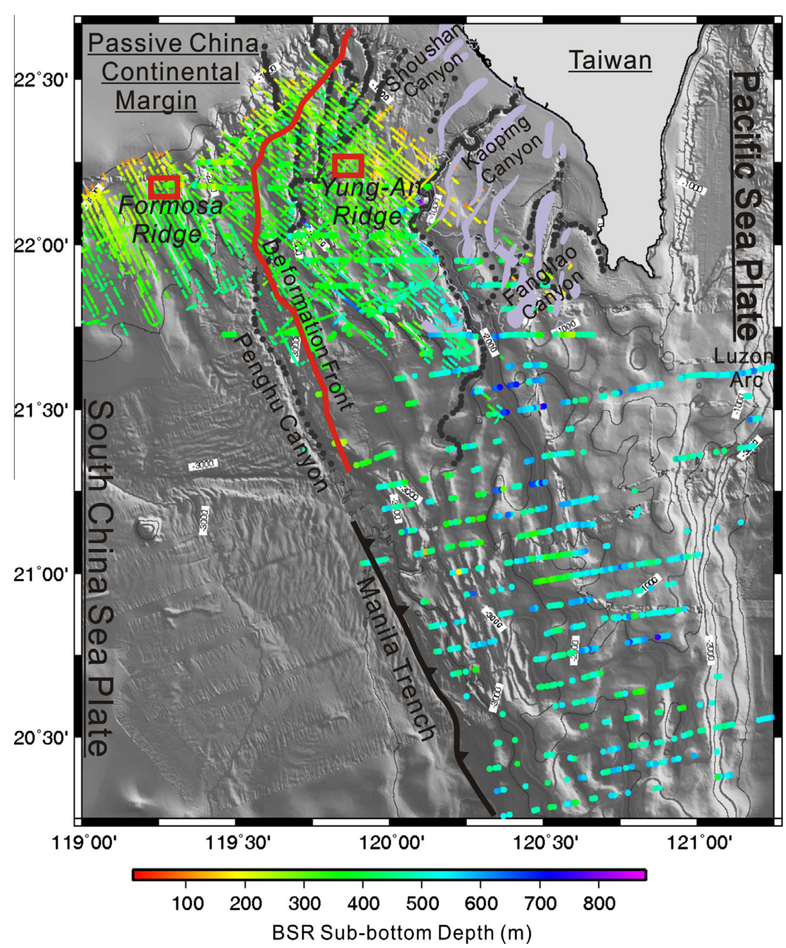

Fig. 1. *Study area:* Distribution of the BSRs offshore southwestern Taiwan and their sub-bottom depths. In this region to the south, the South China Sea lithosphere is subducting underneath the Philippine Sea lithosphere, forming the Manila Trench Subduction System. The subduction changes into collision where the Passive China Continental Margin enters into the convergent zone. For this study, we examined the thermal structures of two hydrate prospect sites (marked by two red boxes), including the Yung-An Ridge in the active margin, and the Formosa Ridge in the passive margin.