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Research paper

Neogene igneous intrusions in the northern South China Sea: Evidence from high-resolution three dimensional seismic data

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ABSTRACT

Igneous intrusions emplaced within the prospective intervals of sedimentary basins can exert a significant impact on petroleum systems and hence are of considerable interest particularly when risking exploration plays. A number of discordant high amplitude seismic anomalies (DSAs) with a range of geometries are documented in high resolution 3D seismic data in the northern South China Sea. Their distribution and seismic characteristics are analysed and compared with similar seismic anomalies documented within sedimentary basins in the Atlantic margins and other locations. The DSAs occur mainly within Early Miocene strata and are interpreted as igneous intrusions that were emplaced close to the palaeo-seabed and are dated as early Middle Miocene using seismic-stratigraphic methods. A number of vents are also identified above the intrusions within early Middle Miocene strata. Several geometrical forms are observed, referred to here as saucer-shaped, lensoid-shaped, stacked and composite intrusions. The seismic expression of these is increasing complex towards the palaeo-seabed, with a tendency for the saucer-shaped sills to be the deepest intrusive forms. The igneous intrusions observed in this study only could be identified using 3D seismic data and they are important for the future evaluations of petroleum systems, basin evolution and tectonic analysis in the Pearl River Mouth Basin.

1. Introduction

Sheet-like intrusions that are crudely concordant to bedding (sills) have been widely described from a number of petroliferous basins along continental margins, including the NE Atlantic and South Atlantic margins (c.f. Eldholm, 1991; Skogseid et al., 2000; Planke et al., 2000; Smallwood and Maresh, 2002), offshore NW Australia (Holford et al., 2013), offshore southern Australia (Jackson, 2012, 2013) and offshore western Ireland (Magee et al., 2014). More recent studies based on 3D seismic data have found that igneous sills commonly link to form interconnected sill complexes that can extend for many 1000s of metres vertically from basement rocks and across the entire span of a basin fill succession (Cartwright and Hansen, 2006). 3D seismic imaging has also revealed that sills emplaced at shallow crustal levels in basins commonly adopt a bowl or saucer shape (Thomson and Hutton, 2004; Hansen et al., 2004; Hansen and Cartwright, 2006a; Polteau et al., 2008) and can exhibit complex lobate geometries (Thomson and Hutton, 2004; Hansen and Cartwright, 2006b; Miles and Cartwright, 2010). These shallow-level sills are commonly overlain by forced folds (Hansen and Cartwright, 2006a; Jackson, 2012, 2013; Magee et al., 2013). Onlap of these folds by younger strata can be used to date sill emplacement (Trude et al., 2003).

One of the most diagnostic acoustic characteristics of these types of igneous intrusion is their very high amplitude relative to the host sedimentary reflections (Berndt et al., 2000; Smallwood and Maresh, 2002). The combination of the high P-wave velocities of basic intrusive rock types (e.g. dolerite) and the high densities means that acoustic impedance contrasts with host sediments are large, thereby giving rise to their high amplitudes. Scattering and attenuation of the wave field by igneous bodies is a common problem, and introduces many imaging artefacts directly beneath them, which can impede imaging of underlying feeder systems (Smallwood and Maresh, 2002; Hansen et al., 2004).

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In this study, we use 3D seismic data from the Pearl River Mouth Basin, northern South China Sea, to describe a cluster of high-amplitude, discordant to concordant seismic anomalies. These anomalies occur within Early Miocene strata at present day depths ranging from 3800 to 4300 m, in an interval that is important for petroleum exploration. By providing a rigorous description for these anomalies, and by comparing their acoustic characteristics with previous descriptions of igneous intrusions, we aim to examine whether these anomalies are indeed best interpreted as igneous in origin. Alternative origins for these anomalies are considered and discussed, and possible explanations are assessed in the context of the basin tectonic history. Finally, we discuss the implication that these anomalies have for petroleum system development and tectonic history of this segment of the PRMB.

2. Geological setting

2.1. Basin evolution and tectonic events

The South China Sea (SCS) is the largest (more than 3,500,000 km^2) and deepest (more than 5000 m water depth) marginal sea in the western Pacific Ocean. The study area is situated in the Baiyun Sag of the Pearl River Mouth Basin (PRMB), in the northern SCS (Fig. 1). The geological evolution of the PRMB is divided into three main stages (c.f. Feng and Zheng, 1983; Jin et al., 1984; Ru and Pigott, 1986; Su and He, 1987; Gong et al., 1989; Yu, 1994): (1) rifting stage: basement rifting and basin subsidence (Late Cretaceous–Early Oligocene), (2) transition stage: faulting, subsidence and deposition within the sub-basins (Late Oligocene–Early Miocene) and (3) subsidence stage: subsidence and filling of the entire basin (since middle Miocene) (Fig. 2).

Three tectonic events, namely the Zhuqiong Event, the Nanhai Event and the Dongsha Event occurred in the PRMB in the Cenozoic (Fig. 2) (Pang et al., 2008; Dong et al., 2009). The Zhuqiong Event occurred from Paleocene to Late Eocene and spans the rifting of the PRMB (Pang et al., 2008). The SCS started to extend during the Nanhai Event (ca. 32 Ma) and the boundary between the syn-rift and post-rift sequences is dated as ca. 23 Ma (Dong et al., 2009). The Dongsha Event commenced in the Late Miocene (ca. 10.5 Ma), had one peak of activity at ca. 5.5 Ma (Miocene/Pliocene boundary) and has an important influence on the study area (Lüdmann and Wong, 1999). For example, this event is associated with magmatic

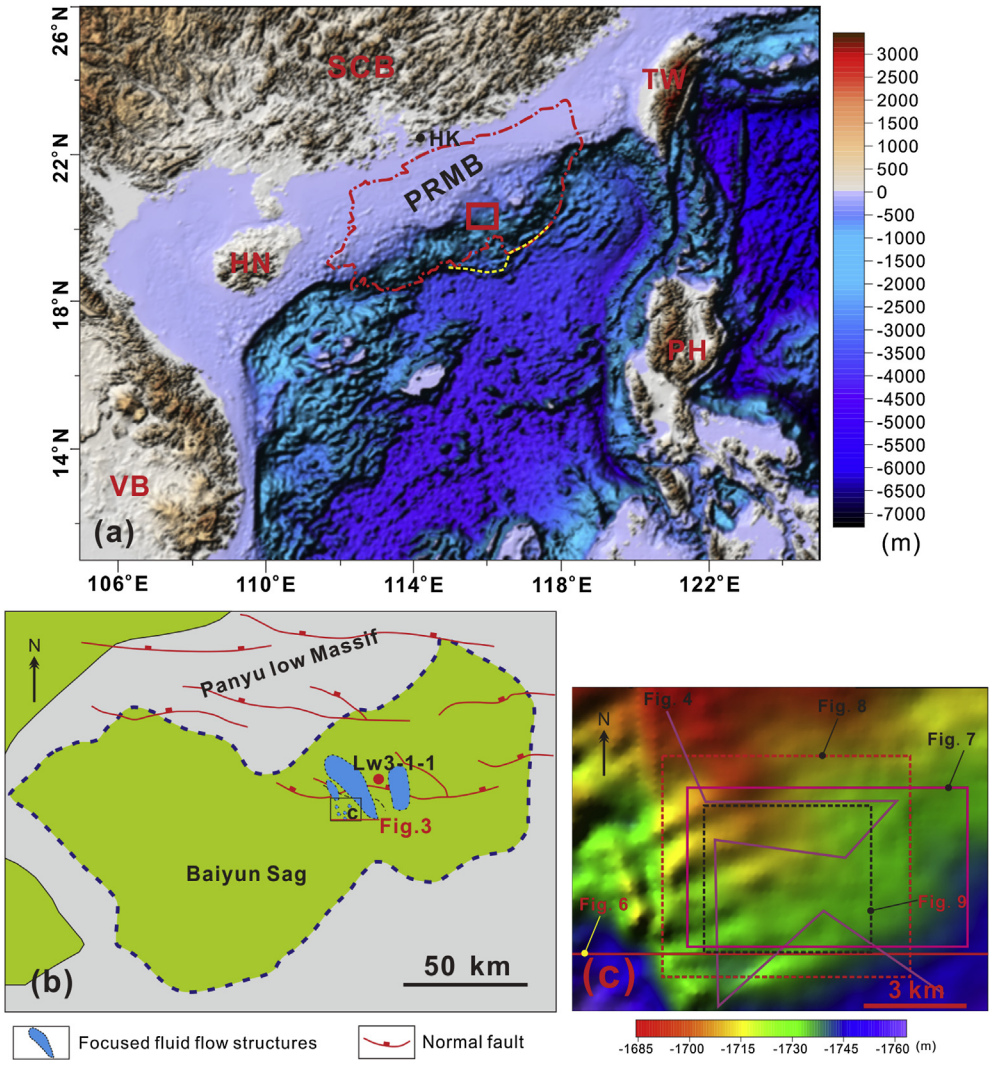

Figure 1. (a) Regional location of the study area. PRMB: Pearl River Mouth Basin; SCB: South China Block; TW: Taiwan; HN: Hainan Island; PH: Philippines; VB: Vietnam Block; HK: Hong Kong; the red dashed line outlines the boundary of the PRMB. The yellow dashed line outlines part of the continent-ocean boundary (COB). The scale is topographical relief. The red square is the location of (b). (b) The enlargement of Baiyun Sag. The focused fluid flow structures (modified from Sun et al., 2012) and borehole location (red circle) are superimposed. (c) The multibeam bathymetric map of the study area. The scale is water depth. The locations of figures referred to the following sections are labelled. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)