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Seismic images of a collision zone offshore NW Sabah/Borneo

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Abstract

Multichannel reflection seismic data from the southern South China Sea, refraction and gravity modelling were used to investigate the compressional sedimentary structures of the collision-prone continental margin off NW Borneo. An elongated imbricate deepwater fan, the toe Thrust Zone bounds the Northwest Borneo Trough to the southeast. The faults separating the individual imbricates cut through post-Early Miocene sediments and curve down to a carbonate platform at the top of the subsiding continental Dangerous Grounds platform that forms the major detachment surface. The age of deformation migrates outward toward the front of the wedge. We propose crustal shortening mechanisms as the main reason for the formation of the imbricate fan. At the location of the in the past defined Lower Tertiary Thrust Sheet tectonostratigraphic province a high velocity body was found but with a much smaller extend than the previously defined structure. The high velocity structure may be interpreted either as carbonates that limit the transfer of seismic energy into the sedimentary layers beneath or as Paleogene Crocker sediments dissected by remnants of a proto-South China Sea oceanic crust that were overthrust onto a southward migrating attenuated continental block of the Dangerous Grounds during plate convergence.

Keywords: Northwest Borneo margin; Sedimentary succession; Seismic data

1. Introduction

The NW Borneo continental margin lies within a broad zone of lithospheric deformation at the boundary between Borneo to the south, the Sulu Sea and Celebes Sea regions to the east, and the South China Sea to the northwest (Fig. 1). A striking onshore structural element of this wide and highly complex deformation belt is the Crocker-Rajang mountain belt which extends along the central part of Borneo, from Sabah to central-south Sarawak (Fig. 1; Hamilton, 1979; Benard et al., 1990; Hutchison et al., 2000). It is generally assumed that this mountain belt formed as an accretionary complex during south-directed subduction of a proto-South China Sea (Hamilton, 1979; Hall, 1996; Hutchinson, 1996; Meng, 1999; Pubellier et al., 2003). The closure of the proto-South China Sea began at ~44 Ma (e.g. Hall, 1996, 2002). Collision of the proto-South China Sea crust is believed to have first occurred in the SW (Luconia Shoals) during the Late Eocene and commenced progressively later towards the NE until the Early Miocene (Hutchinson, 1996). A large deepwater foreland fold and thrust belt, ~100 km wide is present adjacent to the NW Borneo Trough (Figs. 1 and 2). The origin of the 5–8 km thick imbricate fan in this Thrust Zone remains uncertain. Hinz et al. (1989) and Ingram et al. (2004) attribute the development of the Thrust Zone to crustal shortening while Tan and Lamy (1990), Hazebroek and Tan (1993) and Hutchinson (2004) interpret the thrusts as gravitational induced compressive deformation at the toe of the Tertiary delta system from NW Borneo. An important argument favouring the latter interpretation is that oceanic spreading in the South China Sea basin, which is commonly interpreted to be coincident with the plate convergence at the NW Borneo continental margin, ceased in the Early Miocene or early Middle Miocene (Barckhausen and Roeser, 2004; Taylor and Hayes, 1980; Briais et al., 1993). However, the crustal shortening hypothesis is strengthened by the observation of Miocene and Pliocene (post oceanic spreading) fault reactivation and inversion

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throughout the shelf and onshore regions of Brunei, NW Sabah and North Sarawak (Morley et al., 2003), the GPS-derived 4 cm (?) convergence rate in NW Borneo (Ingram et al., 2004) and presently NW–SE orientated maximum horizontal stress orientation in NW Borneo (Tingay et al., 2005).

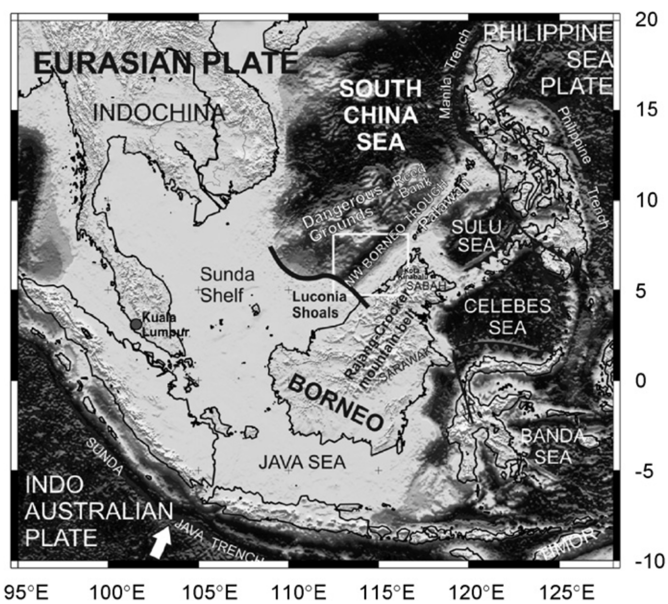

Fig. 1. Nomenclature and plate tectonic framework of SE Asia. The study area is indicated with a white rectangle.

The northeastern part of the Thrust Zone shows a more compressional tectonic style. Hinz et al. (1989) first proposed that this zone is dominated by two Major Thrust Sheets, with a width between 25 and 70 km, which are superimposed one on top of the other. An older thrust system, called Major Thrust Sheet System, overrides the younger Lower Thrust Sheet System. Although evidence for the suggested structure relies solely on a change in the seismic reflection pattern this interpretation is widely accepted (Tan and Lamy, 1990; Rice-Oxely, 1991). However, while Hinz et al. (1989) suggested movements related to plate convergence as origin it has in the following been interpreted as a nappe of allochthonous masses of Crocker or equivalent pre-Middle Miocene sedimentary rocks that resulted from gravity sliding when the Crocker-Rajang fold-thrust belt was uplifted (Fig. 1; Rice-Oxely, 1991; Hazebroek and Tan, 1993; Madon, 1999).

In this paper, we investigate the origin and evolution of the deepwater NW Borneo Thrust Zone using gravity, reflection and refraction seismic data. New seismic data acquired with a 6 km long streamer clearly images the shape and characteristics of the steep faults separating the individual thrust wedges and the underlying décollement. These data allow evaluation of possible mechanisms leading to the evolution of the toe Thrust Zone. Seismic

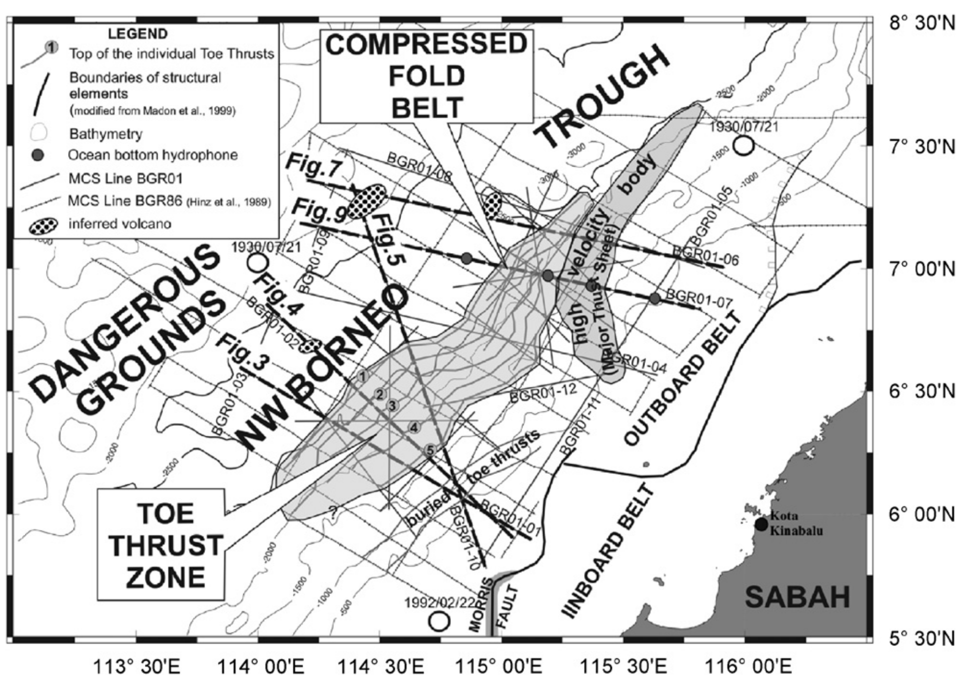

Fig. 2. Reflection seismic lines in the study area (BGR86 and BGR01surveys) and interpreted sketch. The location of the example seismic sections shown and discussed in the following is indicated. The top of the individual toe thrusts is shown as grey lines and the numbers correspond to those shown in the example seismic sections in Figs. 3–5. Note the difference in the structural style from the southwestern Toe Thrust Zone to the northeastern Compressed Fold Belt. The extension of a high velocity body as derived from gravity/refraction modelling is indicated. Its western end coincides with the previously defined ''Major Thrust Sheet'' (e.g. Hinz et al., 1989) but the width is much smaller than in earlier interpretations (see text). Adjacent to the east and only sparsely covered by data from this study the tectonostratigraphic provinces Outboard Belt and Inboard Belt are located (Rice-Oxely, 1991). These structurally complex areas are characterized by compressional folding and strike-slip faulting associated with mobile clay movement (Tan and Lamy, 1990; Rice-Oxely, 1991; Hazebroek and Tan, 1993).