Marine and Petroleum Geology 51 (2014) 197–209

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Nature and significance of the West Baram and Tinjar Lines, NW Borneo

Andrew Cullen*

Chesapeake Energy, 6100 N. Western, Oklahoma City, United States

ARTICLE INFO

Article history:
Received 1 July 2013
Received in revised form
12 November 2013
Accepted 15 November 2013
Available online 17 December 2013

Keywords:
NW Borneo
Sarawak
Baram Line
Tinjar Line
South China Sea
Tectonics

ABSTRACT

A key consideration in tectonic models for SE Asia and opening of the South China Sea is the role that the West Baram and Tinjar Lines of NW Borneo may have played in accommodating the motion of crustal blocks displaced from Asia following India's collision. There are few studies that focus on these "lines". Using onshore geological studies and offshore seismic data to address the origin and tectonic significance of these, this paper concludes that rather than a major transform boundary between Luconia and the Dangerous Grounds, the West Baram Line marks the boundary between domains of continental crust that underwent differential extension in the Eocene. The Baram Basin is underlain by hyperextended continental crust on the NE side of the Baram Line. The strong contrast in the geological features across the Tinjar and West Baram Lines likely reflects ancient differences in crustal rheology with Luconia being the more rigid block. Although lack of significant strike slip faulting along the West Baram Line poses problems for tectonic models in which a wide proto-South China Sea is subducted beneath NW Borneo, intra-plate deformation, such as partial inversion of the Dangerous Grounds rift, offers a potential mechanism to mass balance blocks displaced from Asia with the reduced strike slip motion along the West Baram Line.

1. Introduction

The extent and origin of intra-continental rifting prior to the onset of sea floor spreading in the South China Sea (SCS) are important, but poorly understood aspects in the Cenozoic tectonic evolution of SE Asia. SE Asia's major tectonic elements and fault zones of (Fig. 1) are fairly well established (Lee and Lawver, 1995; Hall, 1996; Pubellier et al., 2005) and the age and geometry of SCS spreading are relatively well defined (Taylor and Hayes, 1983; Briais et al., 1993; Barckhausen and Roeser, 2004). There is considerable divergence, however, with respect to geodynamic and kinematic models to explain these features. These models fall into two principal end-members: Subduction-Collision and Collision-Extrusion. In the Subduction-Collision model (Fig. 1a), Borneo rotates counter-clockwise and SCS rifting is driven by slab-pull owing to subduction of the proto-SCS beneath Borneo, which continues until blocks of continental crust (e.g., Luconia, Dangerous Grounds, Reed Bank) collide with NW Borneo and Palawan (Hall, 2002; Hall et al., 2008; Clift et al., 2008). In the Collision-Extrusion model (Fig. 1b), instead of subduction beneath Borneo, it is the displacement of blocks away from India's collision with Asia that drives opening of the South China Sea as Borneo rotates clockwise to form a large triangular pull-apart basin (Briais et al., 1993; Replumaz and Tapponier, 2003). A key consideration in these tectonic models is whether SE Asia's intra-continental strike-slip faults, such as the Red River Fault, extend beyond the South China Sea to link with the "great lines" of Borneo. Of particular importance is whether the West Baram Line served as a dextral transform boundary during subduction of the proto-South China Sea (Fig. 1a).

In the context of Borneo's geology, the term 'line' is widely used to denote more or less linear zones across which there are significant structural and/or stratigraphic changes that lack a clear explanation. This paper examines the nature of the West Baram Line, as well as its possible onshore extension as the Tinjar Line, as shown on some reconstructions. Neither of these lines feature in early regional tectonic models (Hamilton, 1979; Holloway, 1982; Daly et al., 1991). It is only in subsequent, more detailed intraplate reconstructions that these lines became significant. How the West Baram Line links to SE Asia and whether or not the Tinjar Line is its onshore extension are subject to a wide range of interpretations (Fig. 2). Offshore, the West Baram Line separates Luconia from the Baram Basin and Dangerous Grounds (Figs. 1 and 3a). There is broad consensus that the West Baram Line represents a dextral transform fault that accommodated passage of the proto-

* Tel.: +1 405627 3040.
E-mail address: abcullen@hotmail.com.

0264-8172/$ – see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.marpetgeo.2013.11.010

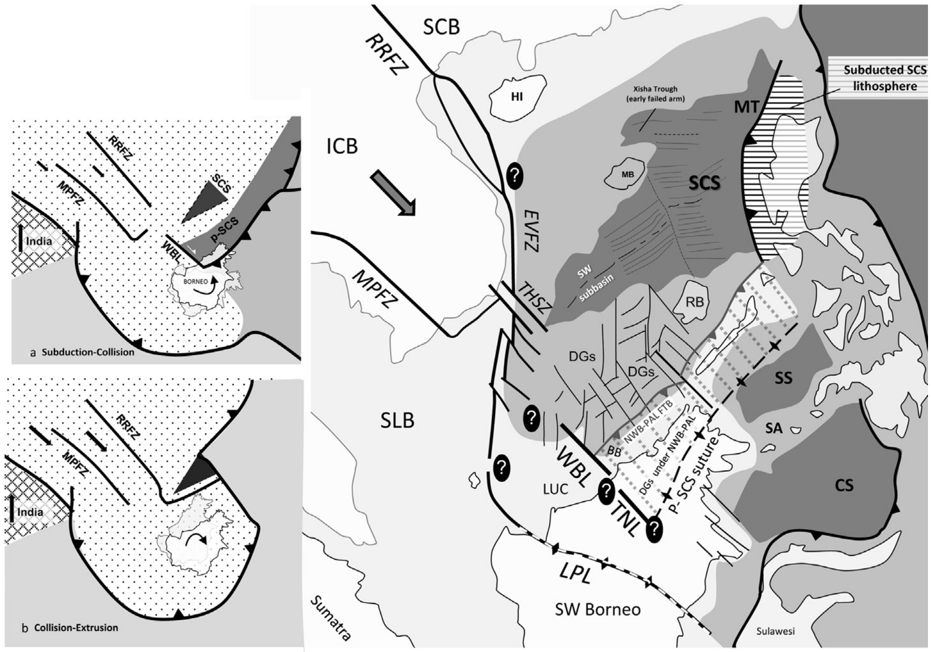

Figure 1. Regional tectonic and geological features. ICB Indochina Block, SCB South China Block, SLB Sundaland Block, CS Celebes Sea, SS Sulu Sea, and SCS South China Sea. Fault patterns are simplified from Morley (2002), Pubellier et al. (2005), Fhyn et al. (2010) and Cullen et al. (2010), heavy lines with triangles mark subduction zones, gray lines with gray triangles mark deepwater thrust belt, solid lines with diamonds mark tectonic sutures. DGs Dangerous Grounds, WBL Baram Line, EVFZ East Vietnam Fault Zone, HI Hainan Island, LUC Luconia, LPL Lupar Line, MB Macclesfield Bank, MPFZ Mae Ping Fault Zone, MT Manila Trench, NWB-PAL-FTB Northwest Borneo Palawan deepwater fold thrust belt, RB Reed Bank, RRFZ Red River Fault Zone, SA Sulu Arc, THFZ Tua Hoa Shear Zone, TNL Tinjar Line. White question marks (?) show uncertain relationships linking major fault zones. Outline of oceanic crust and sea floor spreading anomalies in SCS in dashed lines from Barckhausen and Roeser (2004) and Hsu et al. (2004). Figure 1a and b inset to left show end-member Late Cenozoic tectonic models; modified from Cullen et al. (2010) with arrows showing sense of rotation for Borneo.

South China Sea during Eocene to Early Miocene subduction beneath NW Borneo (Fig. 1a). Some workers however, interpret younger deformation. Sapin et al. (2011) present a weakly-supported model in which the onshore extension of the West Baram Line is the south side of a crustal salient that collided with Borneo during Middle Miocene subduction. Ingram et al. (2004) extended the West Baram Line into Kalimantan as a major tectonic feature that accommodated left-lateral Pliocene motion during the development of the NW Borneo deepwater fold and thrust belt; the opposed sense of oroclinal bending in the highlands and continuity of fold axes along the coast (Figs. 3a, 4b and 5a) renders that interpretation invalid.

Despite the increasing significance assigned to the West Baram and Tinjar Lines, little documentation has been published to specifically support this “mission creep”. Using 2D and 3D seismic data integrated with prior published and recently completed geological studies, this paper addresses the geological history of the area along the West Baram and Tinjar Lines. Specific questions addressed are:

1. How are the West Baram and Tinjar Lines expressed?
2. Should these lines be linked and treated as a composite tectonic feature?
3. What is the evidence for large-scale strike slip faulting along these lines?
4. What is the origin and tectonic significance of the West Baram and Tinjar Lines?

2. Geo-tectonic elements

Although models addressing Borneo’s geological history and tectonic evolution have conflicting, and changing interpretations, regarding the timing of collisions (Longley, 1997; Hall, 2002, 2012; Cullen, 2010; Hall, 2012), the size of the proto-SCS (Hall, 1996; Rangin et al., 1999; Hall et al., 2009), and the rotation of Borneo (Murphy, 1998; Fuller et al., 1999; Cullen et al., 2012), these models share 6 basic geo-tectonic elements (Fig. 3). The boundaries of these elements are not precisely established, however, burial under younger sedimentary younger basins and limited outcrops in the rugged heavily vegetated interior of the island.

1. SW Borneo is cored by a fragment of continental crust rifted from Australia. Its collision along the Boyan suture with other terranes of Gondwana affinity previously accreted to SE Asia marks the final amalgamation of Sundaland (Metcalfe, 2010; Hall, 2012). Cretaceous granites of the Schwaner Mountains were part of a Pacific-facing Mesozoic continental arc complex with which the Dangerous Grounds-Luconia block(s) collided bringing an end to subduction under SE Asia (Fig. 3b). The timing of this collision is not well established and may have occurred between the Early Cretaceous (Hall, 2012) and the latest Paleocene (Fhyn et al., 2010). Morley (2012) suggests that subduction was brought to an end as the result of back arc spreading and the collisional event was of minimal magnitude.
2. Dangerous Grounds, a term that originated with sailors describing an area of reefs and shoals on the SE side of the South China Sea, refers herein to a broad region of extended continental crust, including the Reed Bank, comprising the SE conjugate margin of the SCS rift. In the area of the Dangerous Grounds and Northern Luconia rifting commenced in the Eocene, *ca.* 45 Ma, and was followed by a younger Oligocene phase of rifting (Thies et al., 2005; Madon et al., 2013; Iyer et al., 2013). On 2D seismic data rifted Dangerous Grounds crust can be traced far beneath sedimentary cover sequences of the Baram