# Petroleum Systems of the Simeulue Fore-arc Basin off Sumatra, Indonesia*

**Ruediger Lutz[1], Christoph Gaedicke[2], Kai Berglar[2], Dieter Franke[2], Stefan Schloemer[2] and Yusuf S. Djajadihardja[3]**

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[1]BGR, Hannover, Germany (r.lutz@bgr.de)
[2]BGR, Hannover, Germany
[3]BPPT, Jakarta, Indonesia

## Abstract

Fore-arc basins develop as a result of plate subduction and are situated offshore, between an outer-arc high and the main land. So far these regions are not considered as important petroleum provinces because low heat flow does not necessarily support relevant petroleum generation. The Simeulue fore-arc basin extends between Simeulue Island and northern Sumatra, Indonesia. Multichannel seismic data show bright spots above potential hydrocarbon reservoirs in carbonate platforms. AVO/AVA analyses indicate the presence of gas in sediments. Surface geochemical prospecting suggests thermal hydrocarbon generation within deep sediment strata. Heat flow in the Simeulue Basin ranges between 40 mW/m$^2$ and 60 mW/m$^2$ as deduced from 1-D petroleum systems modelling of well data and bottom-simulating reflector depths. Two source rocks (Eocene and Early-Middle Miocene) were assumed for 3-D petroleum system modelling in the Simeulue Basin. Calculated heat flow scenarios (40 mW/m$^2$ and 60 mW/m$^2$, respectively) reveal that hydrocarbon generation is possible in the main depocenters of the central and southern Simeulue Basin. In the model with the higher heat flow the carbonate buildups were charged with oil and gas. This study shows that deep burial of source rocks can compensate for low heat flow and that fore-arc basins may be in general more prolific than previously thought. Consequently, fore-arc basins may become areas of future oil and gas exploration and production.

## Geologic Setting

The western Indonesian fore-arc basins extend for more than 1800 km from northwest of Aceh to southwest of Java. The width of the basins varies from less than 70 km south of the Sunda Strait to about 120 km west off northern Sumatra. The basins form a strongly subsiding area between the elevated Paleozoic-Mesozoic Sumatra arc massif, cropping out along Sumatra and Java, and the rising outer-arc high (Karig et al., 1980; Schlueter et al., 2002; Susilohadi et al., 2005).

The Simeulue fore-arc basin is bounded to the west by Simeulue Island. The Banyak Islands separate the Simeulue Basin from the southerly located Nias fore-arc basin. The northern end of the Simeulue Basin is formed by a morphological ridge corresponding to a change in water depth of more than 1500 m (Berglar et al., 2008; Izart et al., 1994). The studied area (Figure 1) is part of a classic example of a subduction system, composed of the downgoing Indo-Australian slab along the Sumatra trench, an accretionary wedge, the outer-arc ridge emerging above sea level with Simeulue Island forming the most elevated part (Pubellier et al., 1992; Samuel and Harbury, 1996), and the Simeulue fore-arc basin in front of the volcanic arc. Convergence along the Sunda Arc becomes increasingly oblique from south to north resulting in large-scale, dextral strike-slip fault systems within the fore-arc basins and on Sumatra (Malod and Kemal, 1996; Sieh and Natawidjaja, 2000).

The Simeulue Basin extends over 260 km in NW-SE direction and 100 km in SW-NE direction. It contains a Neogene sedimentary fill of up to 5 s two-way travel time (TWT), approximately 7 km. The water depth is at maximum 1300 m (Figure 2). Until the Early Miocene the geologic evolution of the Simeulue Basin shows striking similarities to the evolution of the North Sumatra Basin (Figure 1; Barber et al., 2005).

North-south oriented horsts and grabens developed in the North Sumatra Basin during a Late Eocene rifting phase. A subsequent Late Oligocene-Early Miocene basin sag phase resulted in widespread carbonate deposition and reef growth (Clure, 2005). Initiation of Mid-Miocene wrench tectonics led to uplift of the Barisan Range and separated the North Sumatra Basin from the modern fore-arc region, including the Simeulue Basin. Ongoing compression since the Plio-Pleistocene formed the coastal fold belt of Sumatra (Clure, 2005).

The present day back-arc area of Sumatra comprises the North Sumatra, Central Sumatra and South Sumatra Basins, where prolific petroleum systems exist (e.g. Cole and Crittenden, 1997; Schiefelbein and Cameron, 1997). Oil in the North Sumatra Basin was generated from both terrigenous and marine source rocks. Biomarkers indicative of both environments were found in oil samples (Schiefelbein and Cameron, 1997). The Central Sumatra Basin (Figure 1) is the most prolific petroleum system in Indonesia and is sourced by the Brown Shale Formation. (Clure, 2005; Peters et al., 2005). Source rocks of both basins are of Eocene-Oligocene age.

## Data

During 2006 a total of 1500 km of multi-channel seismic (MCS) coincident with high resolution sediment echo-sounding, bathymetry, gravity and magnetic data were collected in the Simeulue Basin (Figure 2) using the German RV SONNE. MCS data were acquired with a 240 channel, 3 km streamer and a tuned airgun array comprising 16 airguns with a total capacity of 50.8 litres. Record length was 14 s with a sample interval of 2 milliseconds. A shot interval of 50 m resulted in a fold of 30 (6.25 m CMP distance).

Additionally, sediment samples for hydrocarbon analysis were collected from cores taken with gravity (SL) and piston (KL) corers as well as samples from multicorers (MUC). Sampling sites were selected according to interpretation of the seismic data mainly above carbonate buildups and faults.

Figure 3 illustrates the conceptual model of the Simeulue Basin with a deep basin center, where hydrocarbons are generated and subsequently migrate into adjacent carbonate buildups, forming the reservoirs. Bright spots above potential hydrocarbon reservoirs indicate gas bearing sediments, sourced either directly by thermally generated hydrocarbon gas in the basin center or by leaking of hydrocarbon gas out of the carbonate buildups.

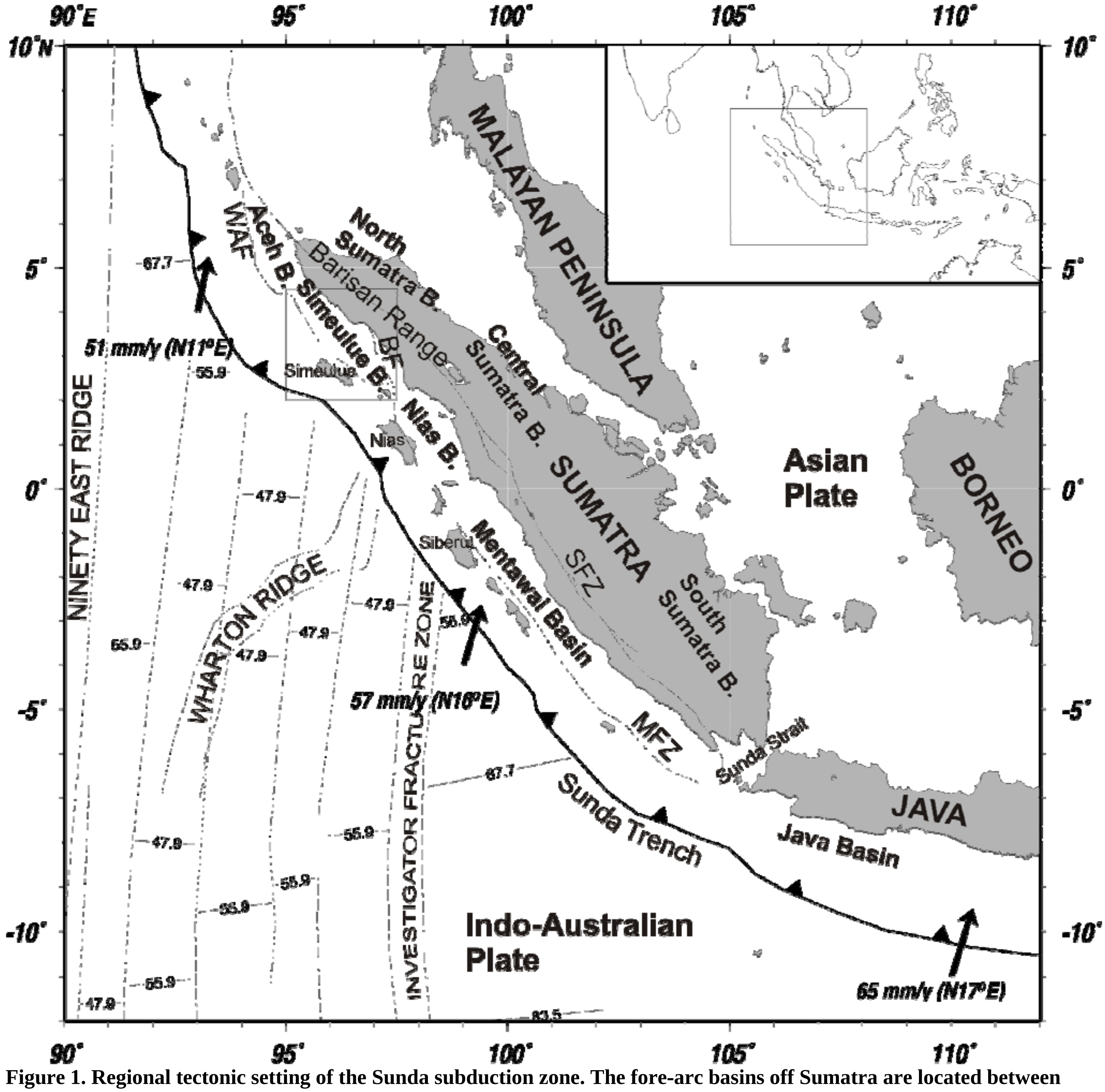

**Figure 1. Regional tectonic setting of the Sunda subduction zone. The fore-arc basins off Sumatra are located between Sumatra mainland and the outer-arc high that occasionally emerges above sea level forming the island chain west of Sumatra. Abbreviations: SFZ: Sumatran Fault Zone, MFZ: Mentawai Fault Zone, BF: Batee Fault, WAF: West Andaman Fault.**

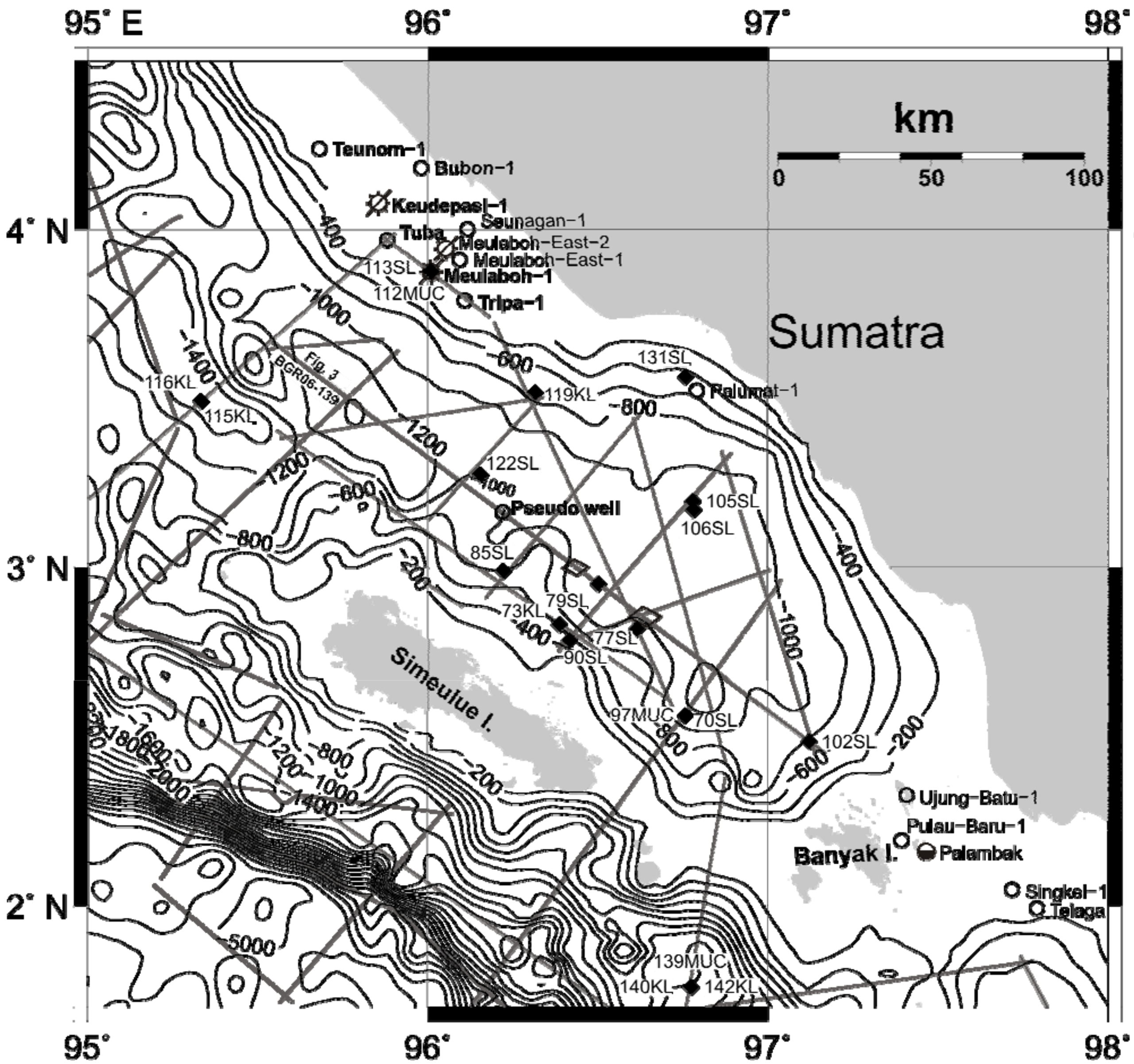


**Figure 2. Location of multi-channel seismic profiles covering the Simeulue Basin between Simeulue Island and Sumatra. Isolines depict bathymetric contours (Smith and Sandwell, 1997) and circles show locations of wells (Beaudry and Moore, 1985; Rose, 1983). Filled diamonds mark the locations of surface core gas samples. Hollow diamonds mark sections of seismic lines used for AVO/AVA analysis.**

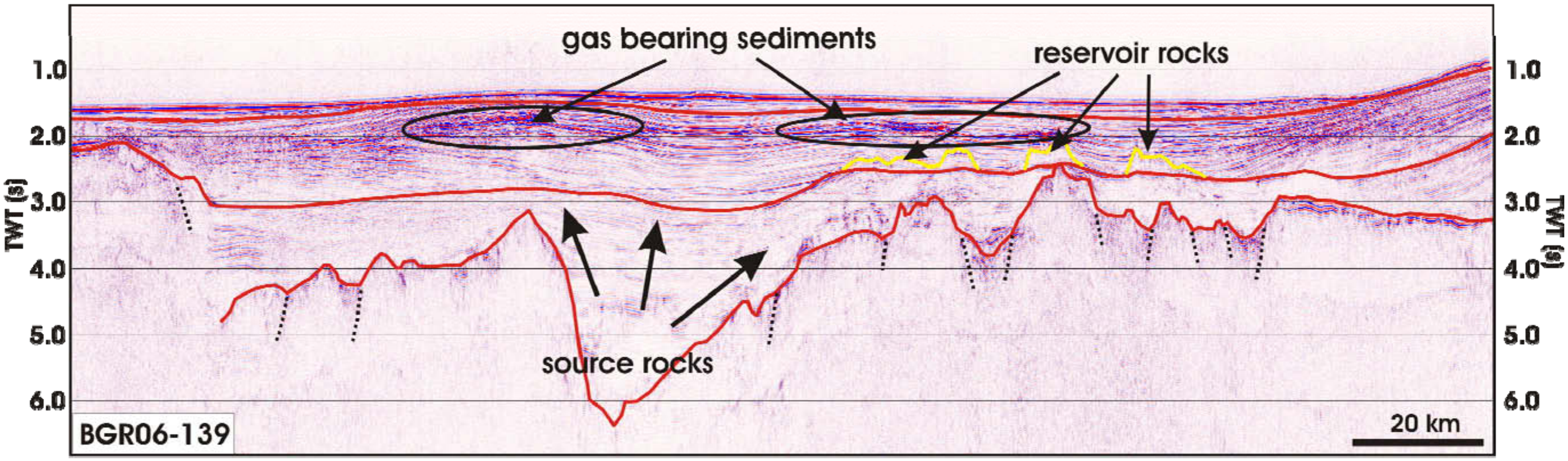

Figure 3. Conceptual model depicted on seismic profile BGR06-139. See Figure 2 for location of profile.

## Summary

Interpretation of the seismic data, AVO/AVA modelling, surface geochemical analysis and petroleum systems modelling reveal:

- Bright spots occur widespread in the central Simeulue Basin in Late Miocene/Pliocene sediments and are most likely caused by gas-bearing sediments as supported by AVO/AVA analysis.
- Heat flow in the basin ranges between 37 $mW/m^2$ and 74 $mW/m^2$, according to 1-D modelling of six wells and BSR depths. Higher heat flows were measured at active fault zones.
- Hydrocarbons potentially migrated from the depocenter into the proposed reservoir rocks.
- Surface geochemical data suggest a thermal origin of hydrocarbon gas from marine source rocks.
- Carbonate buildups can serve as reservoirs and were charged with oil and gas in the 60 $mW/m^2$ model; additionally Late Miocene/Pliocene sediments might act as reservoirs.
- The 40 $mW/m^2$ model predicts significantly less hydrocarbon generation. Here, the amount of generated hydrocarbons is sufficient to explain the bright spots but the carbonate reservoirs are not charged with significant amounts of hydrocarbons.


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