USING BROADBAND IN THE BANDA ARC

Peter Baillie, CGG, reveals how broadband data has begun to unlock the secrets to finding hydrocarbons in the Banda Arc.

The Banda Arc (Figure 1) is one of the most geologically complex and controversial areas on Earth, comparable in some respects to the Caribbean. The horseshoe-shaped ‘arc’ (in the geometric rather than the geological sense), lying north of Australia in East Indonesia and Timor Leste, represents the collision zone between the continental crust of the Australian tectonic plate and the Indonesian archipelago. It comprises the deep and ultra-deep Banda Sea enclosed by a volcanic inner arc (the Inner Banda Arc), outer arc islands (the Outer Banda Arc) and a series of fore-deeps (the Seram, Tanimbar and Timor troughs) marginal to the edge of the Australian continental crust and more-or-less parallel with the outer arc.[1]

The area is of great interest to petroleum explorers because of abundant onshore and offshore oil and gas seeps and similarities with geologically contiguous Mesozoic and Cenozoic successions in Australia where numerous petroleum systems exist and have been exploited (the Mesozoic basins are collectively termed the ‘North West Shelf’). Exploration of the offshore Banda Arc has previously been limited because of water depths, remoteness and seismic

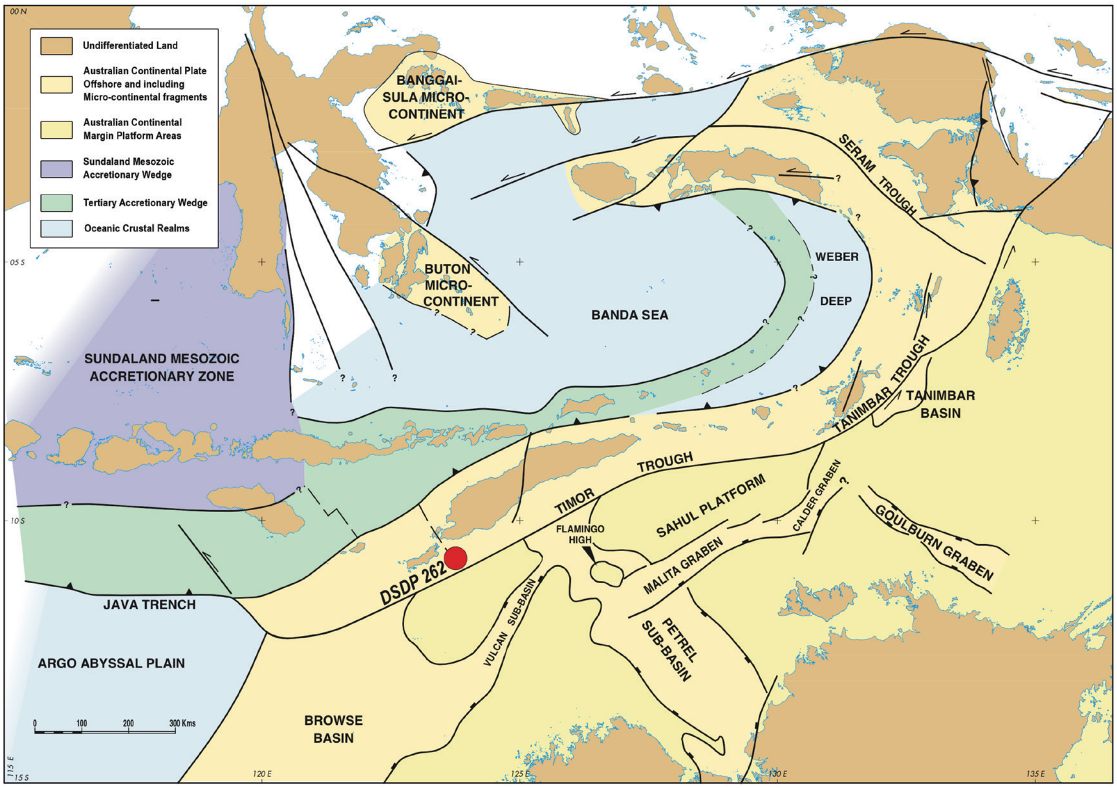

Figure 1. *Geological setting of the Banda Arc showing Inner Banda Arc lying between Banda Sea and Webber Deep and Outer Banda Arc comprising curved edge of Australian continental plate: DSDP 262 indicated (modified after Baillie et al., 2004).*

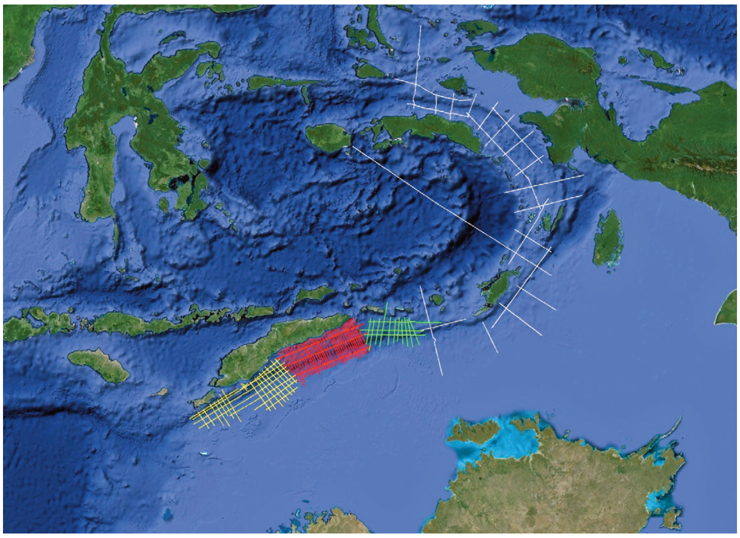

Figure 2. *Google Earth image showing BandaSeis seismic survey components (Phase 1, West Timor, yellow; Phase 2, east of Timor, green; Phase 3, white; Phase 4, Timor Leste, red).*

imaging problems associated with a zone of deformation occurring between the fore-deeps and the Banda Sea.

BandaSeis project and observations

In co-operation with the Indonesian Directorate General of Oil and Gas (Migas) and the Timor Leste National Petroleum Authority (ANP), CGG has acquired four phases of multi-client seismic data around the Banda Arc; collectively, these surveys are known as the BandaSeis Project (Figure 2). The data has been acquired with CGG BroadSeis™ broadband technologies and processed in depth: the regional Phase III data is currently being processed and will not be discussed in this article.

Outboard of the fore-deep system (that is, away from the Banda Sea in the geometric sense and south of the island of Timor), relatively undeformed sedimentary successions contiguous with Australia's Bonaparte Basin flex down towards the trough and continue towards the Banda Sea (Figure 3). The succession extends in age from Late Paleozoic to Recent and shows the typical horst and graben extensional features as seen elsewhere on the North West Shelf. Preliminary analysis of the data indicates the presence of regional Late Triassic inversion, and late Jurassic fault-controlled deposition, together with Cretaceous and Cenozoic extension. Large fault scarps attest to very recent movements, probably related to wrenching, in some areas.

Inboard of the fore-deep system (that is, on the Banda Sea side) a spectacular thin-skinned fold-and-thrust belt has formed on a series of basal detachment faults or décollements (Figure 4). The bathymetric depression (that is, the Timor Trough) marks the zone where the distal end of the fold-and-thrust belt has either accreted onto, or incorporated down-flexing continental material.

BroadSeis technologies have enabled the thin-skinned fold-and-thrust belt to be imaged for the first time. The fold-and-thrust belt absorbs the entire higher-frequency signal and the section below can only be seen at very low frequencies, less than 5 Hz. A prominent bottom-simulating reflector (BSR) confined to the fold-and-thrust belt is commonly observed.

The data shows in great detail the complex interplay between sedimentation and tectonics from Jurassic to Recent times. Prominent delta foresets high in the section indicate that shallow water conditions existed until the last 2 - 3 million years, consistent with observations at DSDP 262 where deepwater Quaternary and upper Pliocene planktonic ooze overlies upper Pliocene shallow marine dolomitic mud and Pliocene very shallow marine dolomitic shell calcarenite.[2] The common presence of about 100 m of undeformed pelagic or hemipelagic sediments draped over the deformed zone indicates that, in large part, the fold-and-thrust belt is no longer forming (Figures 3 and 6), an observation supported by lack of modern earthquakes in the region.

Prospectivity

Ample testament to the presence of a working petroleum system in the Banda Arc is provided by onshore and offshore oil and gas seeps. Onshore oil and gas seeps occur commonly throughout the islands of the Outer Banda Arc: oil from both Seram and Timor has been typed to a Late Triassic or Jurassic carbonate source.[3,4] Numerous oil and gas seeps occur in the offshore realm:[5] a short distance east of Timor the 12 km diameter Raksasa mud volcano (Figure 5; Raksasa = giant in Bahasa Indonesia) has yielded oil typed to a probable Jurassic source.[6]

South of the trough, exploration drilling has shown that much of the Mesozoic (and in particular, the Jurassic) is immature for hydrocarbon generation. The formation of the fold-and-thrust over relatively undeformed Mesozoic section has pushed Jurassic (and older) source rocks into the oil window and explains the presence of oil seeps such as Raksasa.

Potential traps north of the Timor Trough include horsts and fault-related features in the Mesozoic section beneath the fold-and-thrust belt (Figure 3) and structural highs associated with probable strike-slip faults observed to be present within the deformed zone (Figure 6).

Discussion

It has been suggested that the Banda Arc largely results from Neogene subduction that commenced around 15 Ma when active Java subduction tore eastwards into a Jurassic oceanic embayment, which largely occupied the area of the present Banda Sea.[7] There is general consensus that Banda Sea subduction, a continuation of that currently occurring in the Java Trench, ceased with the arrival of buoyant Australian continental crust at the subduction trench. With the arrival of the Australian continental crust (the trench and volcanic arc collided with the southern embayment margin in the northern Timor region) around 3.5 Ma, subduction quickly slowed and ceased. Finally, at around 2 Ma, the Weber Deep was created, marking the complete consumption of the embayment by rollback.[7]

Although it seems likely that development of the fold-and-thrust belt over down-flexed Australian continental material and subsequent Timor Trough formation took place shortly after subduction ceased, it seems highly unlikely that these events are unrelated to what was happening in the Banda Sea. The cessation of subduction cannot be a simple process.

Unfortunately there is no seismic data linking the new data and the island of Timor. Emergence of the island took place in a series of phases commencing in the Late Miocene around 5.7 million years ago.[8,9] Foraminifera indicate that a deep foreland basin, the precursor to the present Timor Sea, had developed by 5.7 Ma with uplifted areas to the north in an emerging island.[8]

Palynology of exhumed Pliocene marine turbidites and marl beds on Timor provide important insights to the ongoing tectonic processes.[10] Between ~4.5 and ~3 Ma, palynomorphs were sourced primarily from Australia and New Guinea, with increasing swamp and mangrove elements sourced from an emerging proto-Timor. Following ~3.1 Ma, pollen and charcoal evidence track the rapid uplift of Timor to a high island, with the progressive appearance of montane and dry, lee-side floristic elements.[10] Early- to mid-Pliocene uplift rates of 0.5 - 0.6 mm/yr increased to 2 - 5 mm/yr in the latest Pliocene, consistent with the observations made offshore relating to the deepening of the Timor Trough and formation of the

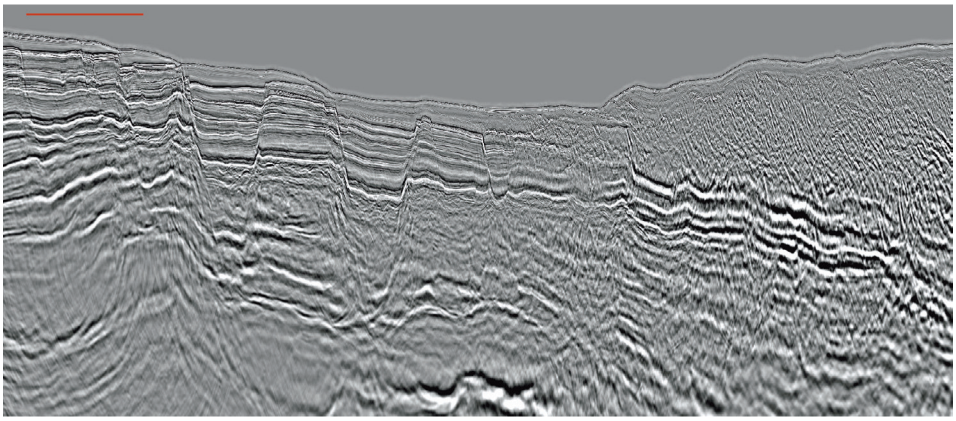

Figure 3. *Seismic depth section south of Timor: red bar 8 km, vertical scale in km.*

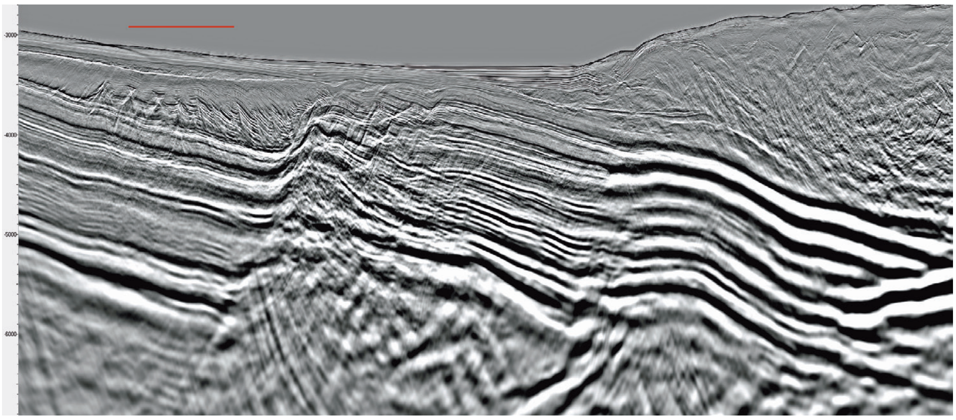

Figure 4. *Seismic depth section showing Timor Trough detail; red bar 2 km, vertical scale in km. Note frequency contact change beneath fold-and-thrust belt.*

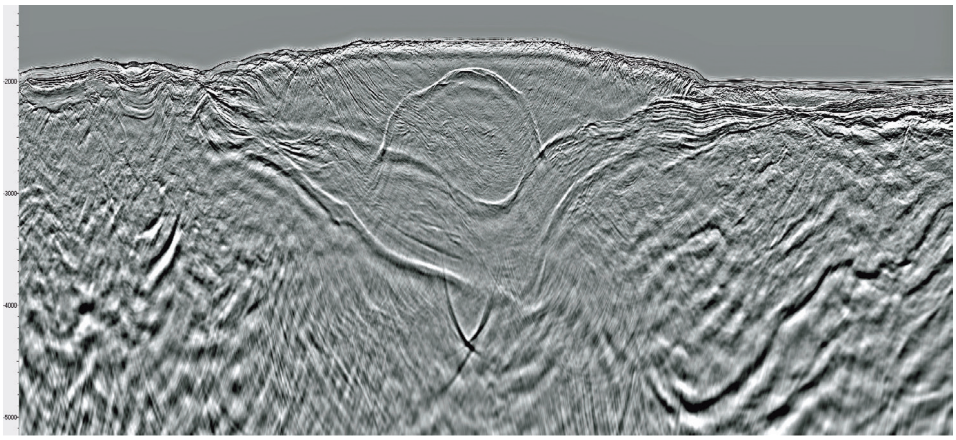

Figure 5. *Seismic depth section showing Raksasa mud volcano; volcano is 12 km in diameter, vertical scale in km. Prominent downward-curving feature cutting mud volcano is interpreted as interface between gas hydrates and free gas, normally parallel with sea bottom (reflecting the geothermal gradient) but deflected here by upwelling fluids which carry oil being generated at depth.*

fold-and-thrust belt at the same time. It is also noted that Timor's emergence from the marine environment is closely correlated with the timing of closure of the Indonesian seaway to deep-dwelling foraminifera.[8,10] In view of the overall synchronicity of offshore and onshore events, it seems likely that the processes resulting in the formation of the offshore fold-and-thrust belt were also responsible for the uplift of Timor.

The exact processes resulting in the formation of the fold-and-thrust belt are not yet fully understood but are clearly related to the arrival of a thick body of continental material at the site of subduction.

CGG has commenced comprehensive geological studies in the region in an attempt to understand the geological evolution of this remarkable area.

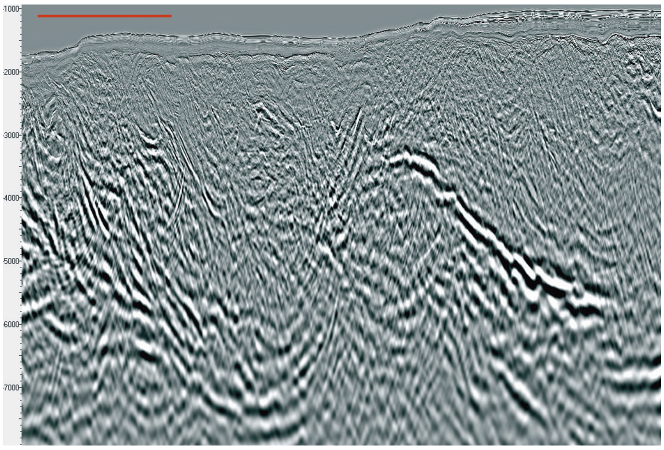

Figure 6. *Probable strike-slip fault within fold-and-thrust belt; red bar 6 km, vertical scale in km.*

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