THE PETROLEUM POTENTIAL OF EAST TIMOR

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ABSTRACT

The hydrocarbon prospectivity of East Timor is widely considered to be only moderate due to Timor island's well-known tectonic complexity, but in the present study a much higher potential is interpreted, with structures capable of hosting giant hydrocarbon accumulations. High quality source rocks are found in restricted marine sequences of Upper Triassic-Jurassic age. The most likely reservoir target is shallow marine siliciclastics of Upper Triassic-Middle Jurassic age encountered in the Banli–1 well in West Timor, comparable to the Malita and Plover Formations of the northern Bonaparte Basin, and sealed by Middle Jurassic shales of the Wai Luli Formation. The Wai Luli Formation also forms a major structural décollement level which detaches shallow level structural complexity from a simpler structural régime beneath.

The principal exploration targets are large, structurally simple inversion anticlines developed beneath the complex shallow-level fold and thrust/mélange terrain. Eroded-out examples of inversion anticlines, such as the Cribas, Aitutu and Bazol anticlines, are typically several tens of kilometres long and up to 10 km broad. Comparable structures in the subsurface of southern East Timor are interpreted north of Betano, and probably also near Suai, Beaco, Aliambata and Iliomar. Other potential targets include a possible non-inverted rollover anticline at Pualaca, stratigraphic and structural traps in the south coast syn/postorogenic basins, and possibly large structural domes beneath extensive Quaternary reef plateaux in the extreme east of the island.

INTRODUCTION

Newly independent Timor Loroasa'e (East Timor) is situated in the southern Banda island arc, facing the Australian North West Shelf across the Timor Trough (Figs 1 and 2). Timor island is divided almost equally between Indonesian West Timor (part of Nusa Tenggara Timur province) and East Timor. The political entity of Timor Loroasa'e, with an area of 14,874 km^2, occupies the eastern half of Timor island, together with the small enclave of Oecusse-Ambeno on the north coast of western Timor, and the islands of Atauro to the north (part of the Banda volcanic arc) and Jaco off the eastern tip of Timor. The present study is concerned only with the hydrocarbon prospects of the onshore area of eastern Timor island. This is a broadly triangular region some 100 km wide north-south near the West Timor border, and approximately 250 km long east to west. Offshore to the south is the East Timor-Australia Zone of Co-operation (ZOC) and the Australian territorial northern Bonaparte Basin, which together form a regional focus for hydrocarbon exploration and production. In contrast, onshore East Timor has received very little hydrocarbon exploration through the period of annexation by Indonesia since 1975–6, although active exploration was underway in the territory up until that time.

The Banda Arc marks the Neogene zone of collision between the southeast margin of the Eurasian plate and the formerly passive continental margin of northwestern Australia. Timor island consists essentially of a fold and thrust belt, with the most distal parts of the Australian continental margin thrust southward towards the more proximal continental shelf. Remnants of the pre-collisional Banda forearc complex (the allochthon) are preserved in the north of Timor, structurally overlying the Australian-affinity, para-autochthorious, thrust belt. It is the para-autochthorious succession which is thought to have potential for petroleum exploration in Timor, a continuation of the northern Bonaparte petroleum province into an explorationally more challenging structural setting.

EXPLORATION HISTORY

Numerous oil and gas seeps (Fig. 3) have encouraged hydrocarbon exploration in East Timor since early in the 20th century. The earliest wells were drilled at Aliambata to a depth of 140 m in 1910, at Pualaca and Ranoco, and at Mata-Hai (Matai) to 170 m in 1914. All these wells were drilled on the basis of nearby surface oil seeps. The first Aliambata well reportedly flowed at a rate of 37 BOPD from a zone at a depth of about 100 m (Cross, 2000). In 1926–28 a further well was drilled at Aliambata to a depth of 800 ft (244 m), with two horizons yielding oil and gas at a rate of a few barrels per day (van Bemmelen, 1949, Fig. 237).

Reconnaissance geological fieldwork in East Timor was undertaken in 1936 on behalf of Allied Mining Corporation (Wittouck, 1937). In the period of Japanese occupation during World War Two, crude oil was produced from shallow timbered shafts near Matai, Pualaca and Aliambata (Audley-Charles, 1968; Cross, 2000). After the war, Escher and Grunau made further reconnaissance studies in East Timor for Companhia Ultramarine do Petroleo/Shell in 1947–1948, and Gageonnet and Lemoine (1958) reported on fieldwork carried out on behalf of l'Insistitut Français du Pétrole in 1955. Regional gravity data was also acquired by Shell during 1947–48.

A new phase of exploration was initiated by Timor Oil in 1956. A third well at Aliambata (Aliambata–1) was drilled to 1,270 m in 1957 (Crostella and Powell, 1976). Subsequently some 20 further wells were drilled by Timor Oil in East Timor, in the Aliambata area, near Suai

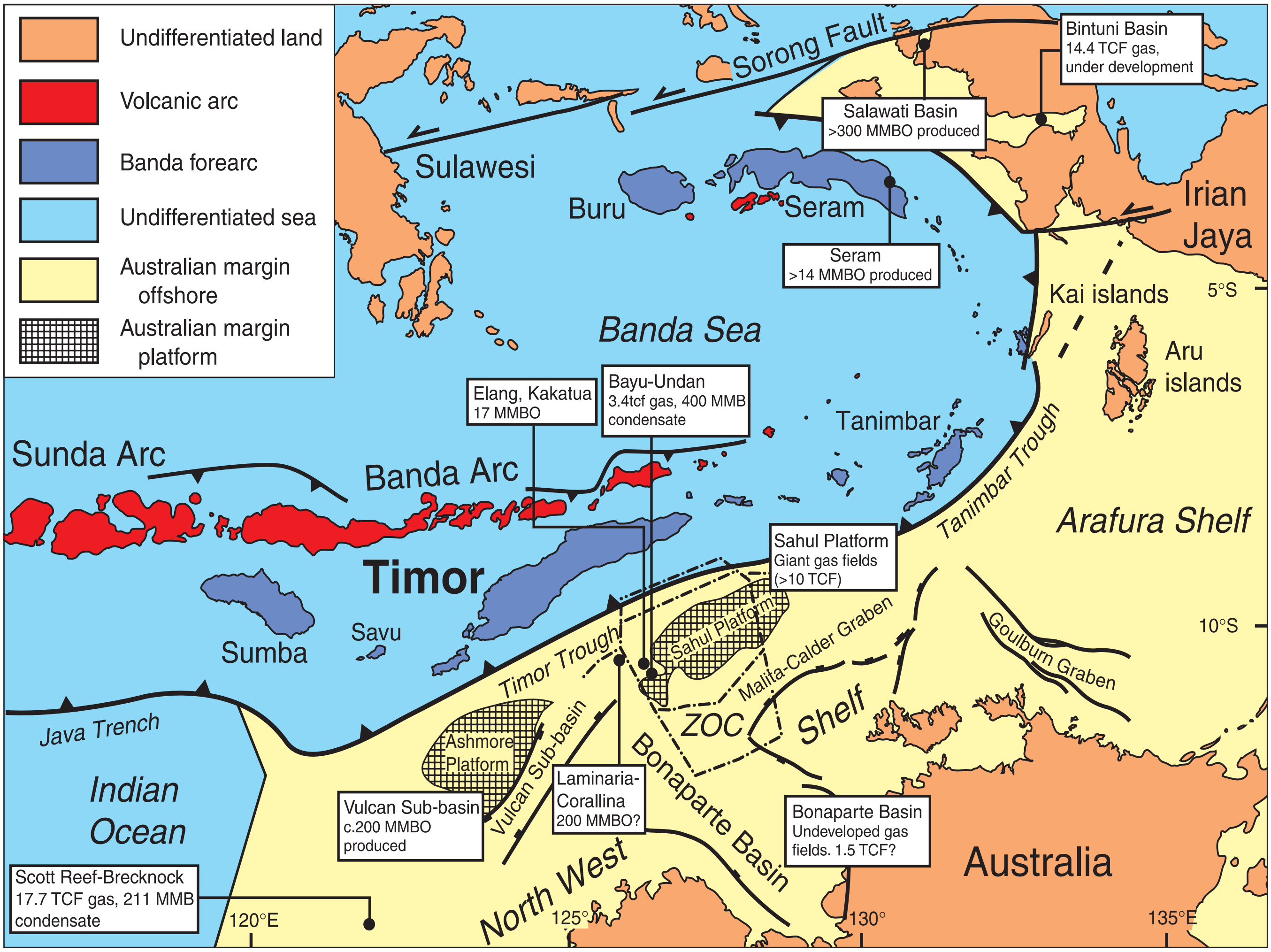

Figure 1. Timor structural setting and regional oil and gas occurrences. ZOC: East Timor/Australia Zone of Co-operation.

in southwestern East Timor, and near Betano (Fig. 3). Exploration in these areas, particularly in the early years, was again encouraged by the presence of surface oil and gas seeps (Boutakoff, 1968), but was increasingly based more firmly on field mapping, gravity surveys and, in the later wells, on seismic reflection profiling. No wells, however, discovered economic hydrocarbon accumulations, although many significant oil and gas shows were encountered. Matai–1 in the Suai area yielded 160 BOPD, and Cota Taci–1, 200 BOPD.

In 1968 International Oil commenced oil exploration in West Timor with an offshore seismic survey along the south coast. Further offshore surveys on behalf of Timor Oil and International Oil in 1970 and 1972 focussed on several areas including offshore Aliambata, Beaco and Suai south of East Timor, and areas south of West Timor and around Savu island further west.

In 1974 Adobe Oil and Gas of Texas was awarded an exploration block covering the eastern tip of Timor and offshore areas, and Oceanic of Denver, through a Portuguese subsidiary, was granted an offshore contract area beyond the 200 m shelf limit, in water then (and now) under dispute with Australia. No significant geological results have come from these licences.

Also in 1974, Woodside-Burmah Oil NL joined Timor Oil and International Oil in exploration of both political halves of Timor, with the Woodside-Burmah subsidiary BOCAL assuming operatorship in both joint ventures. Further seismic reflection data was acquired offshore, and this was followed in 1975 by the drilling of the first offshore well in the region, Mola–1, located east of Suai. A second well, Savu–1, was drilled on the northern point of Savu island in late 1975. Further exploration in the Timor region was suspended as a result of political uncertainty leading up to the annexation of East Timor by Indonesia in 1976.

A further phase of exploration in the Timor region was initiated in 1990 when Amoseas entered into a Production Sharing Contract (PSC) with Pertamina covering most of West Timor, together with an offshore area to the south of the island. This Soe PSC generated an extensive field geological program, together with the gathering of

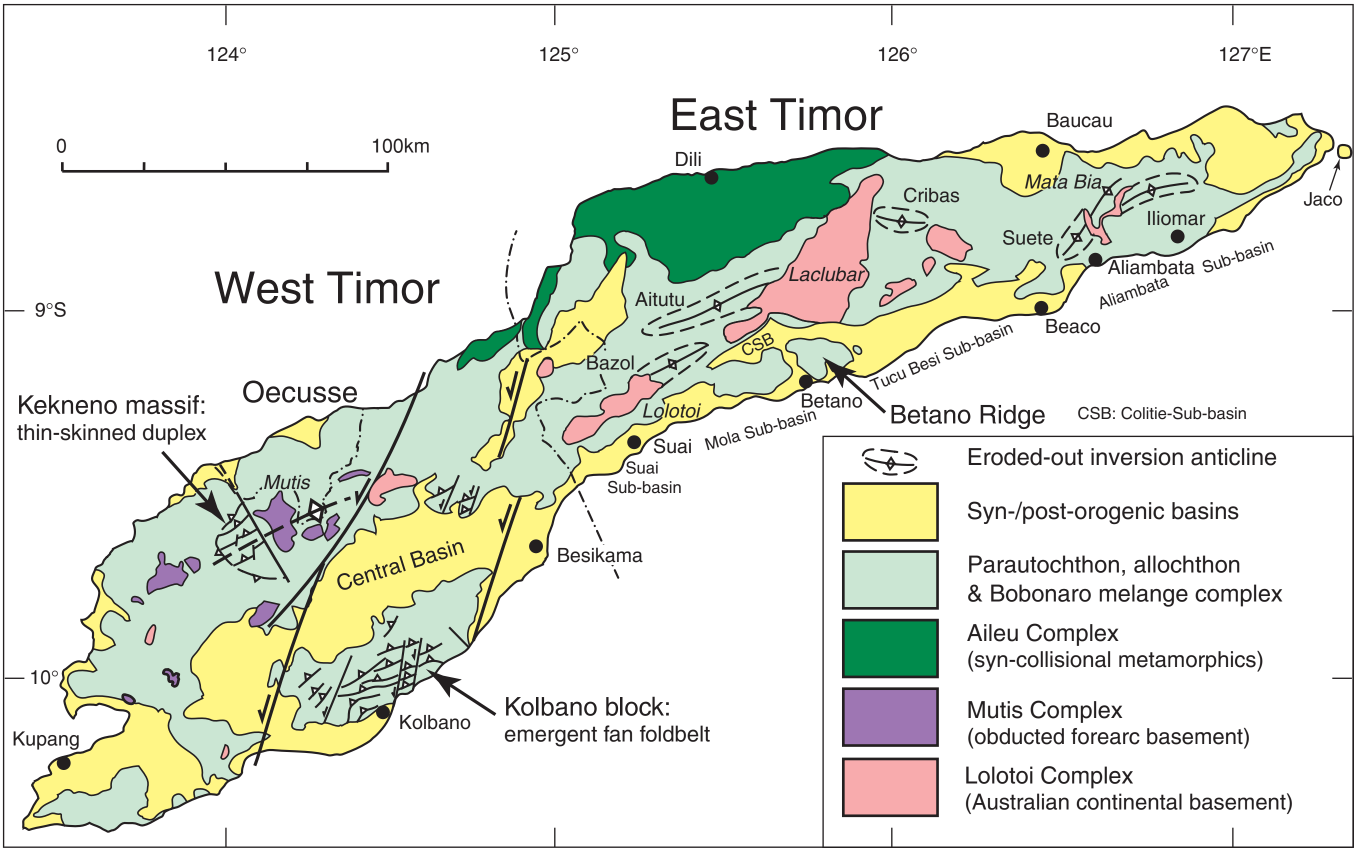

Figure 2. Simplified structure/location map of Timor. Assignment of metamorphic complexes after Charlton (in press).

magnetic, gravity, vibroseis and marine seismic reflection data (Sawyer et al, 1993; Sani et al, 1995). The culmination of this program was the drilling of the Banli–1 well in 1993–1994, located in the Kolbano area of southern West Timor (Fig. 3). Amoseas subsequently relinquished the Soe PSC in 1995. The results of Amoseas's investigations and interpretations were reconsidered in detail by Charlton (2002).

Reed et al (1996) reported the results of a reconnaisance field investigation in East Timor carried out on behalf of Mobil Oil Indonesia Inc. in 1994. At the time of Indonesia's relinquishment of its claim to East Timor, Pertamina was operating the Timor PSC covering western East Timor and adjacent parts of eastern West Timor. A widely spaced grid of exploration seismic lines was acquired offshore south of East Timor in 1992 (Sitompul et al, 1993; Hardjono et al, 1996), but no information is available on any work undertaken onshore.

PETROLEUM GEOLOGY

The stratigraphy of the Timor parautochthon is directly comparable to that of the adjacent northern Bonaparte Basin (Fig. 4), and source and reservoir characteristics are likely to be broadly comparable (Fig. 1). Additional close comparisons can be made with hydrocarbon-productive Seram island in the northern Banda Arc.

Source rocks

The main potential source rocks in Timor are believed to be Late Triassic–Jurassic restricted marine mixed carbonate and clastic sequences. Based on geochemical studies, A.R. Livsey (P.T. Robertson Utama Indonesia, oral comm., October 2000) has described these source rocks as world class.

Peters et al (1999) analysed oil from one of the Aliambata seeps (Fig. 3). The oil is low sulphur (0.08%) and 25°API gravity. It is thought to be derived from a marine source rock containing mixed type II/III organic matter, primarily marine organic material deposited in a suboxic clay-rich environment, but with some terrigenous input. The lack of oleanane indicates an absence of flowering plants, interpreted by these authors as indicating a Jurassic or older source. Biomarkers are similar to those from the Upper Jurassic Dingo Formation in the Barrow Sub-basin of Western Australia. A second seep from Pualaca in central East Timor was interpreted as sourced from an Upper Triassic–Middle Jurassic sequence based on biomarkers (Ware and Ichram, 1997).

Similar aged source rocks have been interpreted for oils in Seram island in the northern Banda Arc (Fig. 1). According to Price et al (1987) and Peters et al (1999), biomarkers for Seram oils suggest a Late Triassic or Early Jurassic micritic limestone source, deposited under

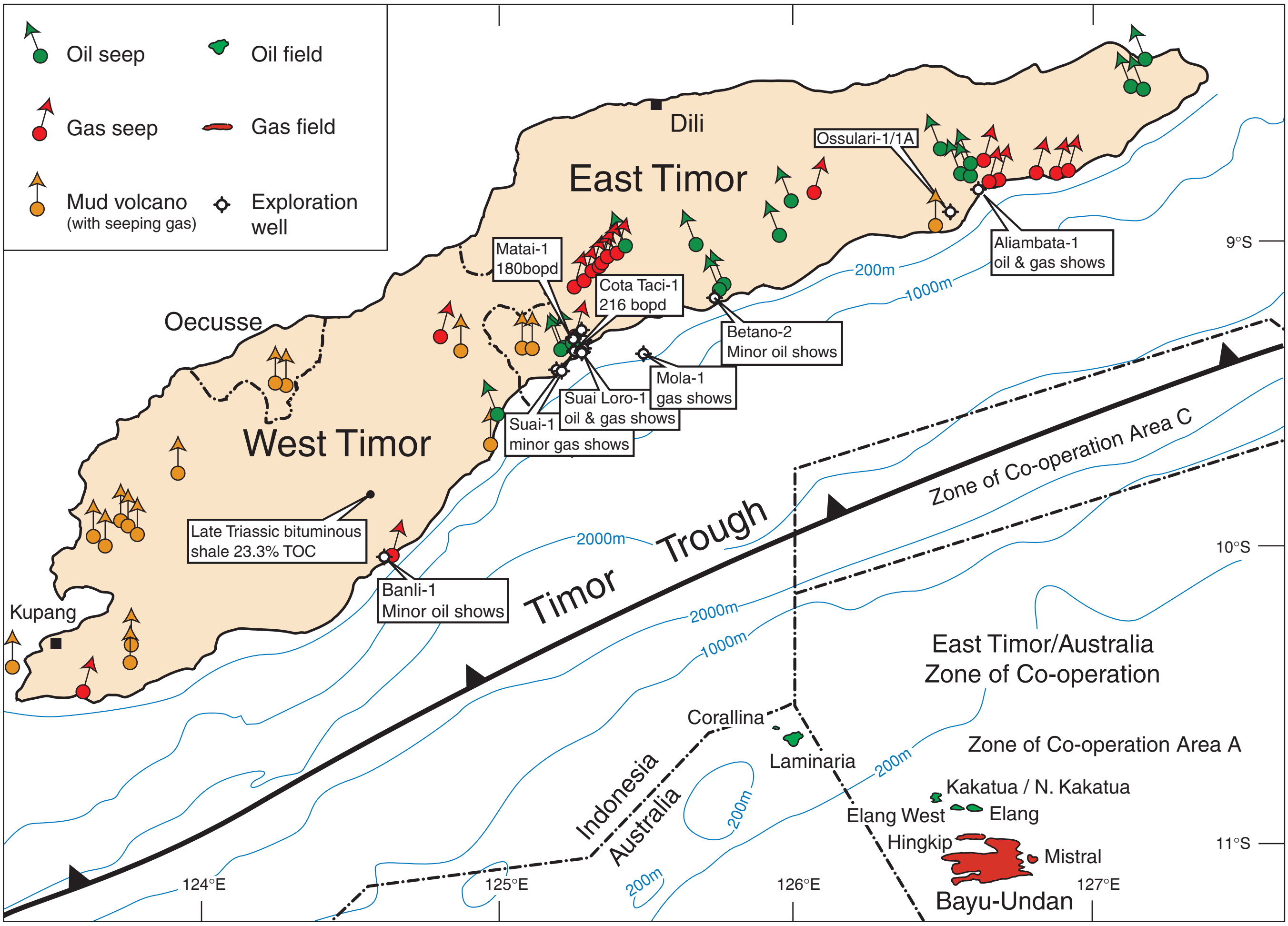

Figure 3. Petroleum highlights of Timor.

highly reducing or anoxic conditions. This source facies would be a lateral equivalent of the reefal-oolitic Manusela Limestone of Seram and its deeper water equivalent, the Saman Saman Limestone. A similar range of facies types is found in the Upper Triassic of Timor, and these have been suggested as potential source rock sequences by Audley-Charles and Carter (1974) and Livsey et al (1992).

Jurassic shales are interpreted as the primary source rocks on the Australian North West Shelf. In the northern Bonaparte Basin biomarker and isotope data from oils and condensates suggests two source sequences, one major and one minor (Preston and Edwards, 2000). The major source is interpreted to comprise intra-formational marine claystones within the Elang and Plover formations, which also form the reservoirs for these oils. The secondary source is the Lower Cretaceous Darwin Formation, with these oils restricted to reservoirs in the succeeding Darwin Formation. In the Vulcan Sub-basin, the Upper Jurassic Vulcan Formation contains moderate to good quality source rocks, with TOC values commonly over 1% in section thicknesses exceeding 1,000 m (Botten and Wulff, 1990). The environment of deposition for the Vulcan Formation was a relatively deep, restricted marine basin with a strongly reducing environment, deposited in grabens that developed during extension in the late Middle-Late Jurassic. The age-equivalent Flamingo Group in the ZOC, in contrast, is more open marine and more prone to clastic dilution, which somewhat reduces the relative source rock potential of the Upper Jurassic section in that area.

The Wai Luli Formation in Timor is the lateral equivalent of Middle Jurassic shales in the Plover Formation (Fig. 4). Audley-Charles (1968) interpreted the Wai Luli Formation in East Timor as deposited in very shallow marine environments, at least locally anaerobic, and possibly in a series of closed stagnant basins. The Aliambata oil analysed by Peters et al (1999) could be sourced from this restricted marine succession.

The Upper Jurassic in East Timor is less likely to contain significant source rocks than equivalent sequences on the North West Shelf. In East Timor Upper Jurassic shales tend to be red coloured (Brunnschweiler, 1977), while in West Timor the Oe Baat Formation is an open marine sandstone succession (Charlton and Wall, 1994). This continues the trend from restricted marine conditions with good source potential in the Upper Jurassic of the Vulcan Sub-basin, to more open marine sediments with lesser potential in the equivalent sequence of the ZOC. The equivalent of the Lower Cretaceous Echuca Shoals Formation source rocks in the northern Bonaparte Basin is an even less likely source sequence in Timor, as the Wai Bua Formation comprises very deep marine, perhaps even abyssal, red shales and radiolarites.

Source rock quality has been reported for some Permian and Mesozoic field samples from East Timor by Reed et al (1996). Most samples had TOC values <1%, hydrogen index values <100 mg/g, and S2 values <0.5. A few samples, reportedly from the Triassic 'Niof Formation' (incorrectly used by these authors as a sack term for the Permian Cribas and the Triassic Niof and Babulu Formations), together with samples from the Upper Triassic Aitutu Formation and blocks in the Bobonaro mélange complex, indicated better source quality. These samples contain type II and type III kerogens (type III dominant), indicating that these source rocks are likely to be gas prone. At first sight these data do not appear particularly encouraging to exploration. It should be borne in mind, however, that Timor is a fold and thrust belt, and that rocks exposed at the ground surface are mostly derived from the outer edge of the pre-collisional continental margin. They are not representative of the present-day subsurface of Timor, where more proximal lithofacies may be expected. As will be described subsequently, the pre-collisional Australian continental margin in what is now East Timor had a horst and graben structure, and it is the Mesozoic grabenal basins still in the unexposed subsurface of Timor which are likely to host the best source rocks.

Reservoir Rocks

For exploration in East Timor up to 1975, the primary reservoir targets were lightly compacted sandstones within the late Neogene post-orogenic basins along the south coast, while deeper drilling failed to establish potential reservoir sequences. In the exploration program leading up to the drilling of the Banli–1 well in West Timor, the principal reservoir target was sandstones of the Upper Jurassic Oe Baat Formation, with a secondary target in turbiditic sandstones in the Triassic Babulu Formation (Sani et al, 1995; Fig. 4). Banli–1, however, additionally demonstrated the subsurface occurrence of an important potential reservoir sequence, comprising Upper Triassic–Middle Jurassic shallow marine sandstones. These were described by Sani et al (1995) as the Malita-equivalent and Plover-equivalent, after the Malita and Plover Formations of the North West Shelf.

In Banli–1 the Malita-equivalent consists of Upper Triassic shallow marine siliciclastics (Sani et al, 1995), and is therefore,perhaps, better equated with the marine Nome or Challis Formations of the Londonderry High and Ashmore Platform (in the terminology of Mory, 1988) rather than with the non-marine, fluvial red beds of the Malita Formation. No data has been released on the potential reservoir characteristics of the Malita-equivalent in Banli–1. On the Australian margin, however, the fluvial Malita Formation is a potential reservoir target, and Middle-Upper Triassic marginal marine strata form the main reservoirs in the Challis and Talbot fields of the Vulcan Sub-basin (Wormald, 1988; Bourne and Faehrmann, 1991). In the Challis field the reservoir consists of marginal marine sheet sands formed by coalescing channel units, interbedded with tidal flat to shallow marine claystones, siltstones and carbonates (Wormald, 1988). Reservoir quality is described as excellent, with effective porosities in the main reservoir sand averaging 29%, and horizontal permeabilities ranging between 500–7,000 md.

Sani et al (1995) only briefly described the Plover-equivalent in Banli–1, indicating a shallow marine siliciclastic facies. Again no information on the potential reservoir quality has been released. In the northern Bonaparte Basin the Plover Formation consists of fluviodeltaic sandstones with variable proportions of shale and minor coal, ranging in age from Sinemurian to Bathonian and locally Callovian (Lower-Middle Jurassic) (Mory, 1988; Pattillo and Nicholls, 1990; Whittam et al, 1996). The Plover Formation forms part of the reservoir sequence in the Jabiru field of the Vulcan Sub-basin (MacDaniel, 1988) and the Laminaria and Corallina fields immediately south of Timor (Smith et al, 1996). In Jabiru, Lower Jurassic beach, barrier island and tidal channel sands of the Plover Formation average 21% porosity and have permeabilities in the range 600–10,000 md (MacDaniel, 1988). In the Laminaria-Corallina fields the Plover Formation contains excellent reservoir quality sandstones, with porosities of about 17% and permeabilities up to 2,500 md (Smith et al, 1996).

Seal

The primary sealing horizon in Timor is Middle Jurassic shales of the Wai Luli Formation, which immediately succeeds the main potential reservoir sequences of the Malita- and Plover-equivalents. The Wai Luli Formation has measured stratigraphic thicknesses of up to about 1000 m locally in East Timor (Audley-Charles, 1968), but in the Banli–1 exploration well it was only about 100 m thick. In Banli–1 the reduction in thickness may be the result of significant structural thinning, as these shales also form the primary décollement horizon separating shallow-level structural complexity from a deeper, less intensely deformed structural domain (Charlton, 2002). From a sealing perspective, however, it is significant that despite the fairly intense structural thinning of the Wai Luli Formation in Banli–1 a substantial thickness of shales was still encountered. The sealing quality of the Wai Luli shales is demonstrated by overpressuring within this formation in Banli–1 (Sani et al, 1995).

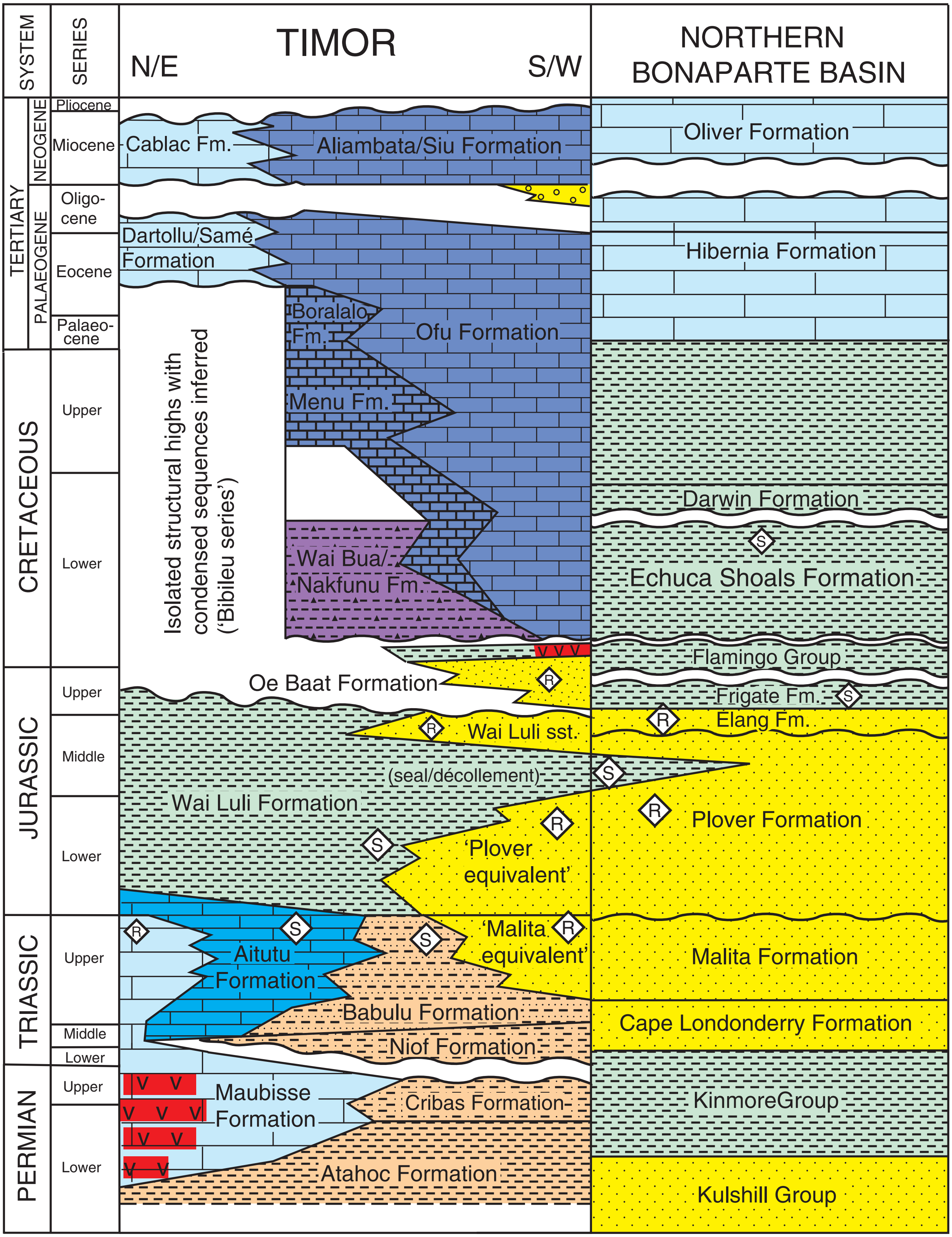

Figure 4. Stratigraphic correlation between the para-autochthorious (Australian-affinity) succession of Timor and the northern Bonaparte Basin (the wider North West Shelf for the deeper stratigraphic levels), showing the main source (S) and reservoir (R) levels.

STRUCTURE

A long-standing academic debate concerns the nature of metamorphic complexes in Timor: do they represent material derived from the pre-collisional Banda forearc, or are they fragments of Australian-affinity continental basement? This argument is, of course, also fundamental to hydrocarbon exploration. Elsewhere Charlton (in press) has reviewed the evidence from East Timor which gives support to the interpretation developed by Grady and co-workers (Grady, 1975; Grady and Berry, 1977; Chamalaun and Grady, 1978) that the Lolotoi Complex of East Timor represents Australian continental basement (Fig. 2). This implies a basement-involved style of deformation for East Timor, which contrasts with West Timor where an essentially thin-skinned style of thrusting predominates (Charlton et al, 1991), at least at superficial levels in the collision complex. In West Timor metamorphic bodies mapped as the Mutis Complex are primarily (but probably not exclusively: Fig. 2) fragments of allochthonous forearc basement, occupying an overthrust position structurally on top of the thin-skinned para-autochthorious fold and thrust belt. The Lolotoi and Mutis Complexes in East and West Timor are therefore not synonymous as has been widely interpreted, but represent, respectively, parautochthonous Australian continental margin basement and allochthonous Banda forearc basement. A third metamorphic complex in Timor, the Aileu Complex of northern East Timor (Fig. 2), developed during arc-continent collision, and is not considered further here.

The geological differences between East and West Timor, reflected both in the structure (Fig. 2) and in the distribution of hydrocarbon indicators (Fig. 3), is the result of a number of interlinked factors. The first is that East Timor is, in general, more deeply eroded than West Timor. This in turn is the result of two further factors: the age of arc-continent collision, and the structure of the pre-collisional Australian margin domain that subsequently formed Timor island. As can be seen from Figures 1 and 2, East Timor lies further north than West Timor, and this probably reflects the shape of the pre-collisional Australian margin in this area. Consequently, as Australia moved northward through the Neoegene, collision with the Banda Arc commenced somewhat earlier in East Timor than in West Timor. As a result, orogenic processes including uplift and erosion are somewhat more advanced in the eastern half of Timor island.

Additionally, however, there were fundamental structural differences between the future eastern and western halves of Timor prior to collision. West Timor lies along trend from the Sahul Syncline and Petrel Sub-basin (Fig. 1), which overlie an aulacogenic rift that developed during the mid-Palaeozoic (Lee and Gunn, 1988). This Palaeozoic rift probably passed northwards through what is now western Timor. In contrast, future East Timor occupied a higher-standing position on the flank of the Bonaparte rift during the mid-Palaeozoic. Further rifting during the Permo-Triassic led to the development of a series of approximately east–west trending horsts and grabens within the higher standing eastern flank of the Bonaparte rift, but perhaps induced less structuring within the northern Bonaparte rift itself (Fig. 5; Charlton et al, in press). Subsequently, through the period from the Permian to the early Neogene, western Timor formed an essentially basinal area accumulating thick sequences of dominantly fine grained clastic and very distal carbonate sediments, whilst eastern Timor formed a block-faulted domain of alternating structural highs and relatively small intervening grabenal basins.

During arc-continent collision, the structure of the developing collision complex closely reflected the fundamental pre-collision structure of the underthrust Australian margin. Western Timor, with its thick and little structured cover sequence, developed a thin-skinned fold and thrust belt. In contrast, eastern Timor, with its relatively shallow and strongly structured basement, developed a basement-involved style of deformation, with formerly extensional basement faults reactivated as low-angle thrusts. The relatively small grabenal basins between the basement horsts were folded and inverted on high-angle reverse faults, which reactivated former graben-bounding normal faults. The interpreted collisional structure and pre-collisional palinspastic restoration of a north–south section through East Timor is shown in Figure 6.

The most significant consequence of the different structural styles in the two halves of Timor is that exposed anticlines are predominantly small and structurally complex in West Timor, but are larger and structurally much simpler in East Timor. Eroded-out examples of inversion anticlines in East Timor include the Cribas, Aitutu and Bazol anticlines (Fig. 2), which are typically up to 10 km broad and several tens of kilometres long. It is suggested here that comparable structures within less-deeply eroded parts of southern Timor have the potential to host giant hydrocarbon accumulations, given the right combination of source, reservoir, seal and maturation.

THE NORTH BETANO STRUCTURE

The North Betano structure (Fig. 6) is the primary example in East Timor of a possible subsurface inversion anticline with potentially high hydrocarbon prospectivity. The evidence for this structure is somewhat circumstantial due to insufficiently detailed field investigation, but is consistent with presently available geological and geophysical data. In addition, the interpreted subsurface structure is similar in style to eroded-out examples of anticlines further north in the island, and is comparable to the structure drilled by the Banli–1 well in West Timor as interpreted by Charlton (2002).

The North Betano structure is located on a regional structural high, the Betano Ridge (Fig. 2), situated between two Late Miocene/Pliocene to Quaternary syn/postorogenic basins, the Colitie Sub-basin to the north and the Mola Sub-basin offshore to the south. The Betano

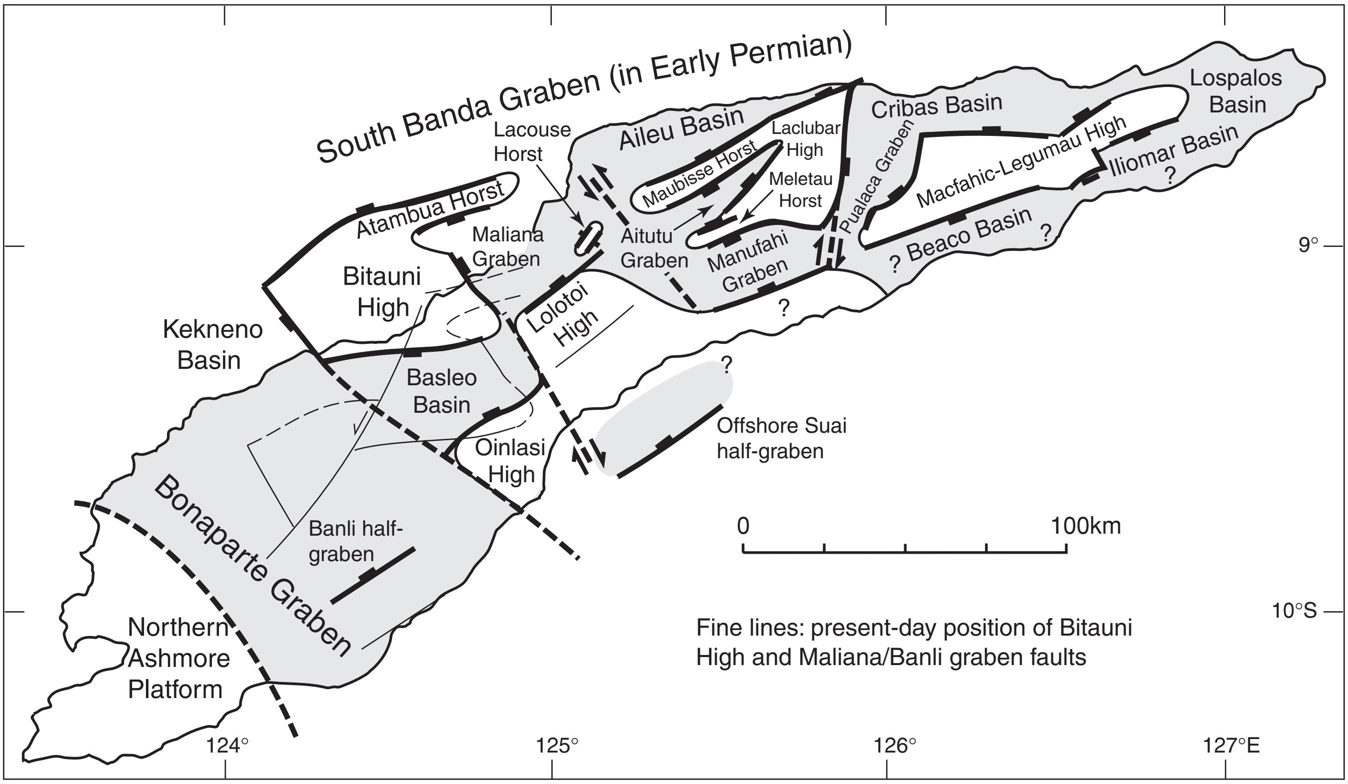

Figure 5. Interpreted structure of proto-Timor at the end of Permo-Triassic extension. This essential structure was retained through to the onset of Neogene collisional deformation. Basinal areas are shaded. The map is palinspastically restored to the limit of geological knowledge at the south coast.

Ridge has already been drilled by two exploration wells, Betano–1 and Betano–2. Betano–1, drilled to a depth of 782 m, did not encounter any potential reservoir rocks, and no hydrocarbon shows were reported. Betano–2, which was drilled to 1,344 m, encountered minor oil shows (Cross, 2000). Betano–2 drilled a structurally complex section of mainly deepwater Cretaceous and Palaeogene limestones, marls and radiolarites, comparable to the section encountered in the upper 900 m of the Banli–1 well in West Timor.

The first indication of a possible subsurface inversion anticline comes from gravity data. Comparing the regional geological mapping of Audley-Charles (1968) with the gravity mapping of Kaye (1989) indicates a gravity high over the southern part of the Betano Ridge, and a low over the northern part of the ridge (Fig. 6). It is particularly significant that the gravity minimum occurs over the outcropping Betano Ridge, and not over the Colitie Sub-basin. This indicates that the low density rocks producing the gravity low are present in the subsurface of the Betano Ridge, and that the low does not originate primarily from the presence of low density sediments in the postorogenic Colitie Sub-basin.

The two Betano wells were drilled in the southern part of the Betano Ridge, and it is likely that the wells were sited to target the crest of the gravity high, the Wai Luli horst of Chamalaun et al (1976). In West Timor the Banli–1 well was also drilled on a gravity high, but as discussed by Charlton (2002), the Banli gravity high probably corresponds to the denser footwall block of an inversion structure. Banli–1 drilled through the complex imbricated upper section of Cretaceous and Palaeogene deepwater strata, into a section of regularly southward-dipping Upper Triassic-Lower Cretaceous shallow marine clastics, interpreted (Charlton, 2002) as the frontal limb of an inversion anticline developed beneath the shallow-level imbricates. The two Betano wells may similarly have been drilled over the footwall block of an inversion structure, with the more prospective crest of the complementary inversion anticline lying to the north in the area of lower gravity values.

At outcrop the Betano regional high consists of the Wai Luli Formation (Jurassic shales), Wai Bua Formation (Lower Cretaceous deepwater radiolarian shales and marls) and the Bobonaro Complex. The latter is a tectonic mélange, the product of repeated tectonic shearing within highly plastic shale-dominated sedimentary sequences, particularly (in this area) shales of the Wai Luli Formation and the younger overlying succession. Topographic relationships in this area suggest that the Bobonaro Complex essentially overlies the Wai Bua Formation, which in turn overlies the Wai Luli Formation, the latter contact presumably stratigraphic. However, the description of this area by Audley-Charles (1968) suggests that this threefold division is probably a

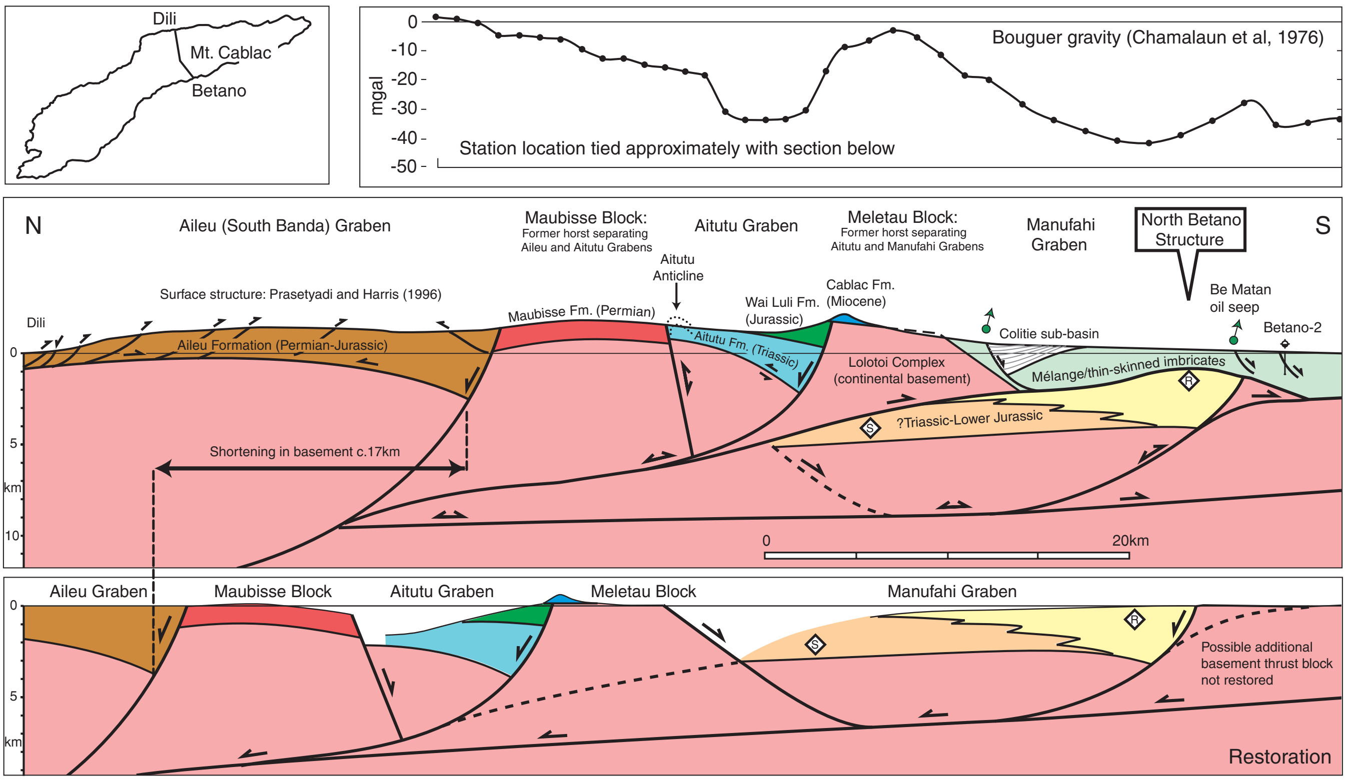

Figure 6. North-south cross-section through East Timor (Dili-Betano), and the North Betano inversion structure. The upper box shows part of the Bouguer gravity profile of Chamalaun et al (1976), which follows a line close to, but not precisely coincident with, the line of section.

simplification, and that in reality there is a much higher degree of intershearing than his mapping indicates. It is significant, however, that no section older than the Wai Luli Formation is exposed on the Betano Ridge.

The North Betano inversion anticline is interpreted as developed beneath the thin-skinned imbricates and mélange exposed on the Betano Ridge. The décollement level for these superficial imbricates is Middle Jurassic shales of the Wai Luli Formation, which are the oldest rocks exposed on the Betano Ridge. The inversion anticline itself is developed within the underlying (?Permian-) Triassic-Lower Jurassic stratigraphic section, as with the sub-Kolbano inversion anticline drilled by Banli–1 in West Timor (Charlton, 2002). The Early Jurassic and older succession of East Timor was deposited within a series of grabens and half-grabens that developed during extensional phases commencing in the Early Permian (Charlton et al, in press) and in the Late Triassic (Audley-Charles, 1988). The North Betano structure developed from inversion of the Manufahi Graben indicated in Figures 5 and 6. During initial development of the Timor collision complex, the shallowest stratigraphic levels down to the Wai Luli Formation were detached from the deeper stratigraphic section, and were incorporated into a structurally complex thin-skinned foldbelt/mélange terrane. Only in the later stages of collision were the deeper stratigraphic levels incorporated into the foldbelt through the development of thrust structures within the former continental basement, and complementary inversion of the deeper cover sequences beneath the superficial thin-skinned foldbelt.

The precise structural style of the inversion anticline is not known. The interpretation illustrated in Figure 6 shows a footwall shortcut structure, with the steep section of the inverted listric normal fault by-passed through the development of a new, less steeply inclined thrust fault within the basement footwall block. Alternatives to that shown in Figure 6 may include fault-bend folding as a consequence of the basinal sequence being thrust over the step at the top of the pre-existing extensional fault; and fault-propagation folding where reversed movement on the intra-basement fault propagates up into the cover sequence rather than along the basement-cover interface. The footwall shortcut interpretation shown in Figure 6 is preferred as it also provides an explanation for the raised basement in the footwall, as indicated by regional gravity mapping.

To the north the Colitie Sub-basin is a Late Miocene/ Pliocene to Quaternary piggyback basin developed unconformably on top of the fold and thrust belt (Fig. 6). Depth contouring by Crostella and Powell (1976, Fig. 8) suggests that this basin contains over 2000 m of sedimentary fill, and that the basin is asymmetrical with a steeper northern margin. To the north of the Colitie Sub-basin is the Meletau massif, a ridge of Lolotoi

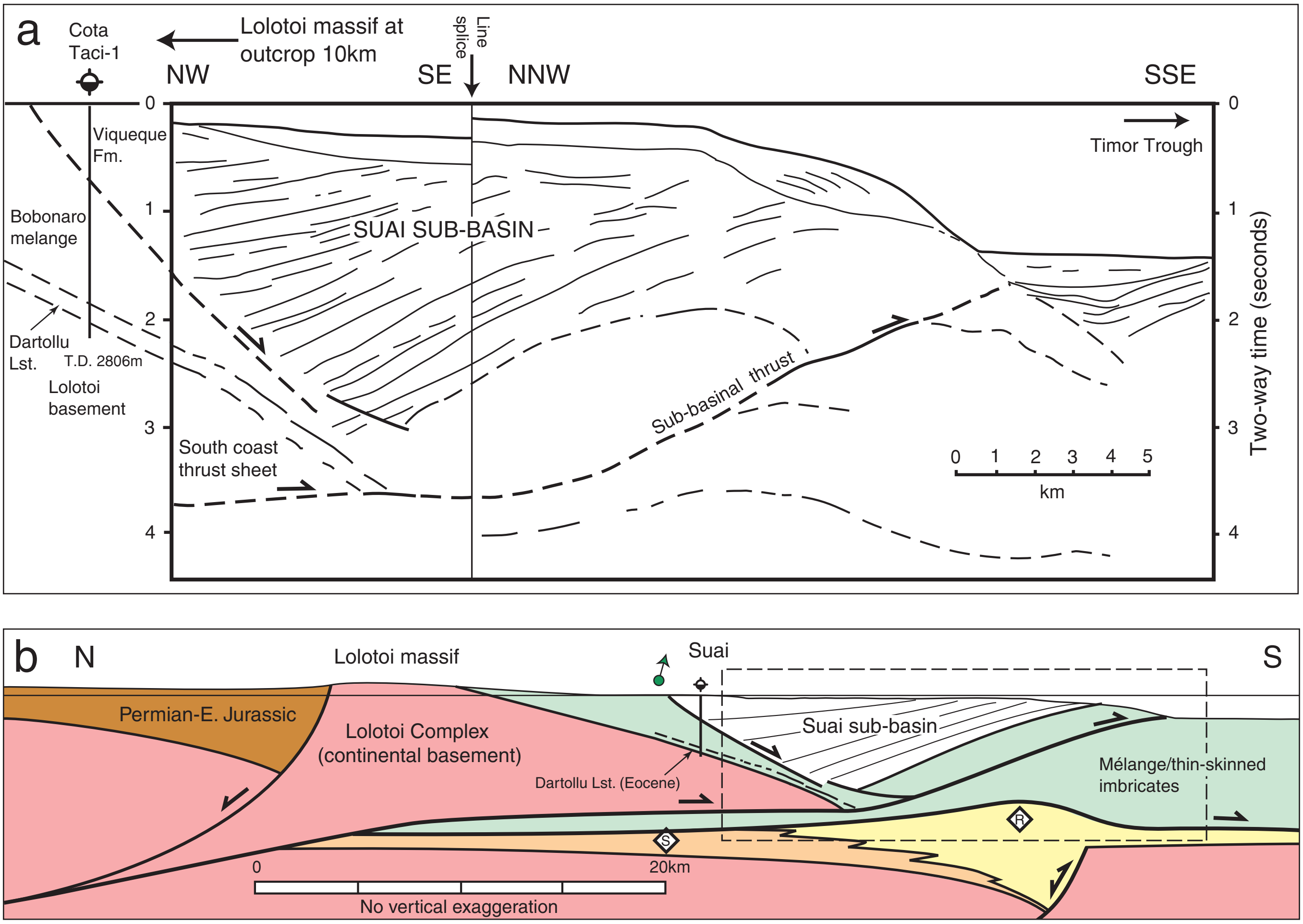

Figure 7. (a) Cross-section through the Suai Sub-basin, offshore SW East Timor, based on seismic data (Crostella and Powell, 1976, Fig. 10), with an onshore extrapolation to the Cota Taci–1 well. (b) Natural scale extension of the upper section across the Lolotoi metamorphic massif to the north. The area covered by the upper section is indicated by the box in the lower section. The interpretation of the sub-basinal inversion structure is based on analogy with the North Betano structure (Fig. 6), but with a pre-inversion half-graben rather than a full graben. Modified from Charlton (in press).

metamorphic complex extending westward from the main Laclubar massif. The Lolotoi Complex is interpreted in this study as upthrust Australian continental basement (Charlton, in press). The Colitie Sub-basin is interpreted as a syn-orogenic basin formed by rotational collapse where the Lolotoi basement block ramped up onto the Wai Luli Formation. Similar features can be seen on seismic sections elsewhere along the south coast of Timor, e.g. in the Suai Sub-basin, Figure 7. The northern margin of the Colitie Sub-basin is interpreted in Figure 6 as a listric normal fault which roots down into the forward extension of the basal Lolotoi thrust. Into the foreland this normal fault may link into a surge or landslip-like thrust. This thrust may plausibly correspond to the boundary between the Bobonaro Complex and the underlying more coherent Wai Bua and Wai Luli Formations as mapped by Audley-Charles (1968). This is not certain, however, and is not indicated on the cross-section.

Figure 6 shows the grabenal succession as essentially uniform in thickness between the northern and southern bounding faults. An alternative which should be considered, because of implications for the occurrence and volume of potential source rocks, is that the ?Permian–Lower Jurassic succession was deposited in a half-graben rather than the full graben shown. The full graben interpretation for the North Betano structure contrasts, for instance, with the sub-Kolbano inversion anticline intersected in the Banli–1 well in West Timor, which is probably better interpreted as an inverted half-graben rather than a full graben (Charlton, 2002). In the Betano area a full graben interpretation is compatible with preliminary gravity modelling, but no doubt modifying the model density values could equally accommodate a half-grabenal subthrust basin. The main reason for interpreting a full graben rather than a half-graben is the stratigraphy of the cover sequences overlying the Meletau massif to the north.

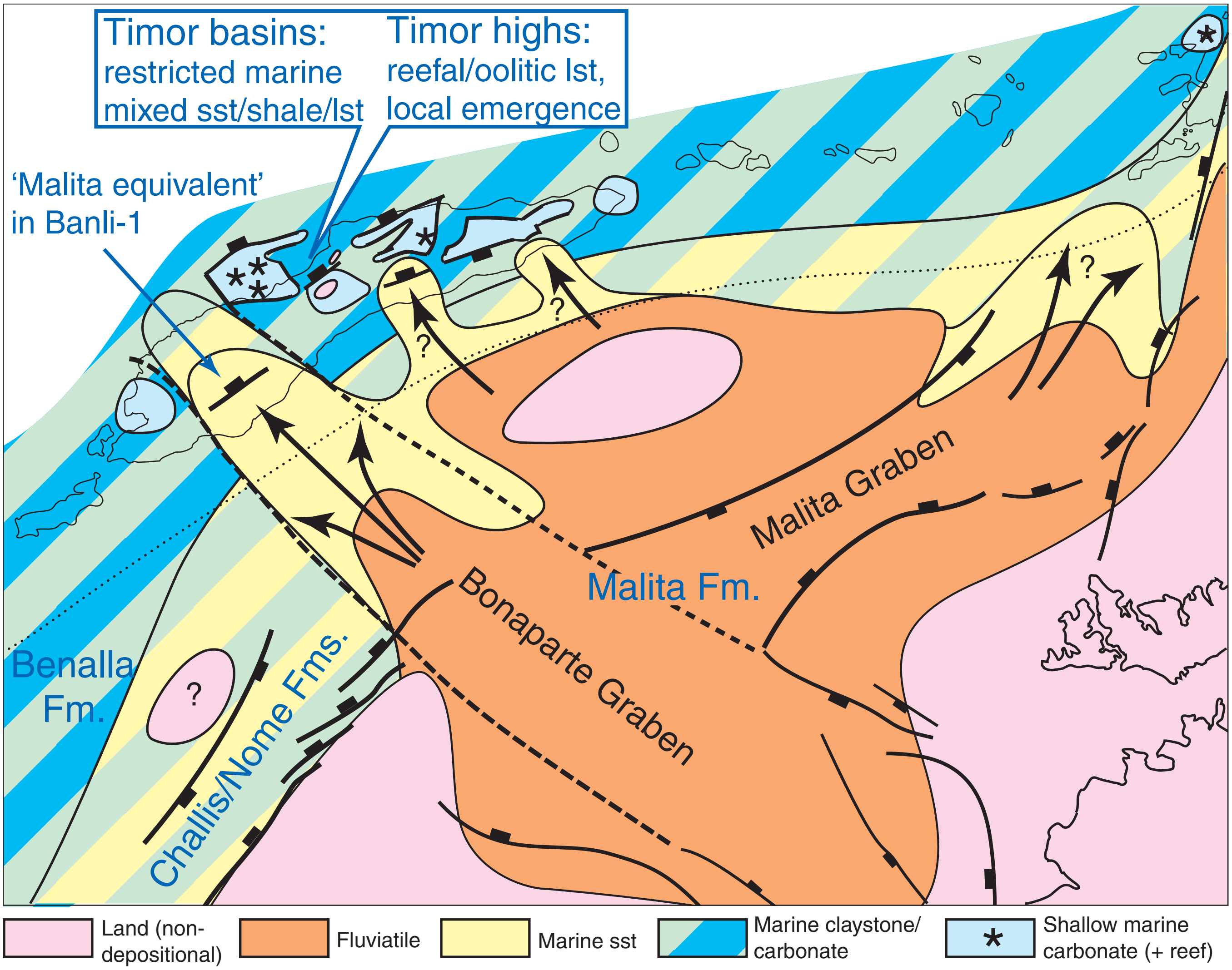

Figure 8. Late Triassic palaeogeography of the Timor-North West Shelf region.

A geological map of Melatau-Cablac area by Carter et al (1976) shows shallow marine limestones of the Cablac Formation unconformably overlying the Lolotoi Complex on the northern flank of the Meletau massif. This suggests that this basement block formed a structural high during the Miocene, upon which the Cablac Formation accumulated. On the southern flank of the Meletau massif, Carter et al (1976) interpreted the sedimentary sequence lying north of the Colitie Sub-basin as part of the Palelo Group, which in West Timor is a forearc sequence of Cretaceous-Palaeogene age overlying allochthonous basement. However, Carter et al (1976) described this sequence as consisting of conglomerate, siltstone, cherty limestone and chert, in contrast to the volcanics, turbidites and cherts which typify the Palelo Group proper. This sequence was assigned to the Bibileu series by Gageonnet and Lemoine (1958), and closer analogy might be made with condensed Early Cretaceous sequences found on structurally isolated parts of the outer North West Shelf (parts of the Bathurst Island Group). Gageonnet and Lemoine (1958) also described their Samé series (Eocene nummulitic limestones) from this area, and these shelf limestones may also have accumulated on a structurally isolated horst block. The geology of the Meletau block therefore suggests that it formed a structural high, presumably a horst, prior to collision, and this is consistent with the Manufahi Basin to the south being a full-graben as opposed to a half-graben basin.

Considering the Mesozoic history of the proto-Timor area, the sedimentary fill of the Manufahi Graben is likely to comprise a mixed carbonate-clastic basinal succession developed under restricted marine conditions (Fig. 8). During the Late Triassic–Early Jurassic, shallow marine clastic wedges built out from the North West Shelf into the Timor area, as demonstrated in the Banli–1 exploration well in West Timor (Sani et al, 1995). Equivalent sequences could also be present in the southern half of the Manufahi Graben, fed from the

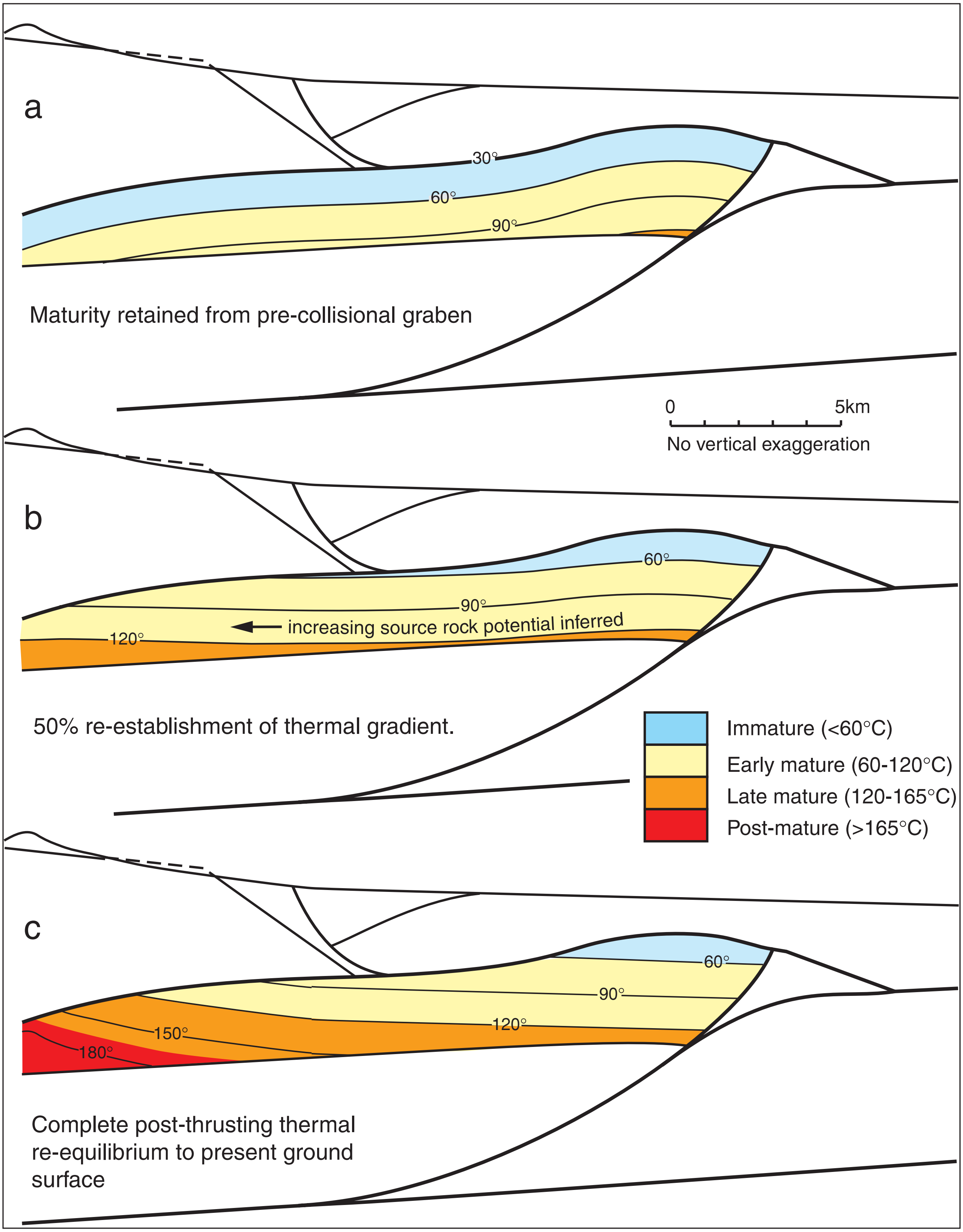

Figure 9. Thermal maturity of the Manufahi inverted graben (cf. Fig. 6). 30°C/km thermal gradient and 1 km original post-rift cover sequence assumed.

emergent Sahul Platform to the south. As outlined above, equivalent shallow marine clastic sequences are proven reservoir horizons on the North West Shelf.

Source rocks are predicted to be present in the Manufahi Graben basinal succession, particularly in the northern half of the basin more distal to primary clastic input from the south. This ?Permian–Lower/ Middle Jurassic sequence is likely to contain shales and carbonates deposited under restricted marine conditions. Regional palaeogeography (e.g. Robertson, 2000) suggests the likelihood of restricted marine conditions from the Middle Triassic through to the Middle Jurassic, with the Triassic sequences corresponding to contemporaneous source rocks in geologically similar Seram.

The timing of hydrocarbon migration is critical in a structurally complex sub-thrust play as suggested here for Timor. In the northern Bonaparte Basin thermal maturation and migration is believed to have peaked during the Cretaceous, with remigration or compaction-driven expulsion taking place during renewed extension in the Miocene/Pliocene (Botten and Wulff, 1990; Kennard et al, 1999). In East Timor, in contrast, Harris et al (2000) found that Mesozoic field samples collected from exposure had not reached thermal maturity by the onset of arc-continent collision, presumably due to the much thinner post-breakup stratigraphic succession on the distal Australian margin. However, simple thermal modelling for this study suggests that the interpreted source rocks in the northern half of the Manufahi Graben may have entered the oil window as a result of the late Neogene orogenesis, and will now be actively generating hydrocarbons.

Figure 9 shows interpreted thermal conditions in a series of cross-sections through the inverted Manufahi Graben under a range of assumptions. In all three sections it is assumed that immediately prior to orogenesis the Permian–Jurassic section was overlain by a 1,000 m stratigraphic succession, comparable to distal parts of the present-day outer Australian margin. Present-day geothermal gradients on the Australian North West Shelf range from <30°C/km to >50°C/km, with thermal gradient maps (e.g. Botten and Wulff, 1990, Fig. 17) suggesting values at the lower end of this range towards Timor. Crostella and Powell (1976) reported a heat flow value of 30°C/km from the Betano–2 well located on the southern edge of the interpreted Manufahi Graben structure. An equilibrium thermal gradient of 30°C/km is therefore assumed for the Manufahi Graben succession in Figure 9 prior to orogenesis.

One of the key unknown factors in this area is the degree to which thermal equilibrium has been restored following orogenesis. Harris et al (2000) suggested a period of the order of 10 million years to restore thermal equilibrium. This figure is close to the age for the entire cycle of orogenesis in Timor, and so the degree of re-equilibration is uncertain. Figures 9a and 9c show the end-members in the range of possible thermal conditions in the Manufahi Graben succession under the assumptions outlined above. In Figure 9a it is assumed that the thermal gradient established immediately prior to orogenesis has been retained through to the present day. At the other extreme, Figure 9c shows the thermal maturity of the Manufahi Graben basinal succession assuming that the 30°C/km gradient has been re-established to the present topographic surface. Figure 9b shows an intermediate situation, with a 50% restoration of thermal equilibrium.

It can be seen in Figure 9a that under the thermal conditions assumed the grabenal succession would be largely either immature or only in the early mature stage (early maturity assumed here to be bounded by the 60°C and 120°C isotherms). This also implies that, under the assumptions outlined, the bulk of the basinal sequence had not reached thermal maturity prior to orogenesis, as demonstrated by Harris et al (2000) for outcrop samples. If thermal equilibrium has been partially (Fig. 9b) or fully (Fig. 9c) re-established following orogenesis, it can be seen that a large volume of the grabenal succession will have entered the oil generation window after orogenesis, which in East Timor was probably largely completed in the Pliocene. Post-orogenic thermal maturation is likely to be particularly marked in the northern half of the graben beneath the overthrust Meletau massif, which is also considered the most likely location for high quality source rocks.

The Manufahi Graben basinal succession may consist of interbedded sandstones and shales, including turbidite horizons sourced from the southern margin of the graben. Laterally extensive sandstones may form carrier beds from the source region in the north to reservoir rocks in the trap to the south. Migration would be updip from north to south as a consequence of tectonic loading associated with overthrusting by the Lolotoi block in the north. The separation of source and trap in this system is of the order of 15 km, comparable to or less than migration distances from the broadly analogous Swan Graben to the Jabiru and Challis fields in the Vulcan Sub-basin.

Figure 6 indicates the presence of active oil seeps immediately south of the North Betano structure. Audley-Charles (1968) described these seeps from Be (river) Matan as several small oil seepages from the Wai Bua Formation, which seem to be associated with faulting. The oil is heavy, black, and accompanied by a little gas. Some of the seeps yield a little water, and hydrogen sulphide is associated with one seep. In Figure 6 the Be Matan oil seeps are interpreted as fed from the spillpoint of the North Betano structure. Additional minor seeps also occur along the northern edge of the Colitie Sub-basin, along strike from the line of section in Figure 6 (Audley-Charles, 1968). These are interpreted as fed from the northern bounding fault of the Colitie Sub-basin, which below the basin may intersect the mature ?Permian-Early Jurassic source beds, or the basal Lolotoi thrust which may form a conduit for the expulsion of oil from the sub-Lolotoi source kitchen.

In the absence of seismic data it is difficult to estimate precisely the area and vertical closure of the North

Betano structure. Potentially, however, an anticlinal trend up to 50 km long and 5–10 km wide is entirely possible, comparable to similar eroded-out inversion anticlines further north in East Timor (e.g. the Cribas, Aitutu and Bazol anticlines: Fig. 2). Vertical relief on the North Betano structure could be measurable in hundreds of metres. Potentially, therefore, the North Betano structure is capable of hosting a giant hydrocarbon accumulation.

FURTHER POTENTIAL STRUCTURES

Inversion anticlines

The potential for additional hydrocarbon targets in East Timor hosted in inversion anticlines is high, but these are at present incompletely defined by available geological data. Three main variants on the inversion structure can be identified. Firstly there is the type of structure recognised north of Betano, where the target anticline is located beneath surficial Bobonaro mélange complex, and the surface expression of the deeper structure is largely masked by the mechanical incompetence of the mélange. Secondly there are the closely related structures exemplified by the sub-Kolbano structure in West Timor intersected by the Banli–1 well (Charlton, 2002), in which an imbricate thrust stack is more clearly refolded into a surface antiform above the inversion anticline. In both these types the target inversion structures are entirely subsurface features with only an indirect surface expression. The third group of potentially hydrocarbon-bearing structures are along-strike continuations of upthrust Lolotoi basement blocks, where lesser amounts of thrusting on the flanks of the basement thrust block has allowed the preservation of the inverted basinal succession as an anticline plunging away from the basement massif. These latter inversion structures are exemplified by the Bazol and Suete anticlines in East Timor (Fig. 2). In these structures additional cross-faulting or the development of secondary culminations on the fold crest are required to produce a hydrocarbon trap.

The closest analogue to the North Betano structure so far identified is located north of Beaco and the Ossulari-1/1A wells (Fig. 2). As at Betano, this area is situated on a regional structural high bounded by syn/postorogenic basins to north and south. The Ossulari wells, drilled respectively to 2,056 m and 1,402 m, did not encounter significant oil shows, and the latter well did not reach its target (Cross, 2000). Audley-Charles's (1968) geological map suggests that these wells were located on a N–S trending surface anticline defined by bedding dips in Quaternary reef limestones. However, the map also suggests that this anticline may be a secondary feature, and that a more significant anticlinal crest trends approximately E–W about 3 km to the north of the Ossulari wells. The latter anticline is defined by outcrop patterns and bedding dips in the Quaternary reef terraces and the underlying Viqueque Group (Upper Miocene-Quaternary), while the Bobonaro mélange complex occupies the exposed core of the anticline. A relatively simple inversion anticline similar to that interpreted for the North Betano structure can be reasonably postulated beneath the Bobonaro Complex in this area.

The Aliambata area (Fig. 2) was a particular target for early exploration in East Timor on account of the oil seeps in that area (see Exploration History section). The geology of this region as described by Audley-Charles (1968, and later work) suggests a structure broadly comparable to the Kolbano area of West Timor: that is, a deep-seated antiform superimposed on a shallow-level imbricate thrust stack. The Aliambata–1 well (TD 1,269 m, oil and gas shows: Cross, 2000) was drilled at the core of this surface antiform. According to Brunnschweiler (1977), the well penetrated Palaeogene and Upper Cretaceous limestones of the Borolalo Formation, and then an overturned repeat of this section down to 550 m. Below this was about 25 m of Triassic Aitutu Limestone, and then further Upper Cretaceous limestone. The well was finally abandoned (at a depth of 1,355 m according to Brunnschweiler) without reaching the base of this overthrust complex.

It seems likely that beneath the complex surficial geology of the Aliambata area is a coherent anticline analogous to that penetrated by the Banli–1 well in West Timor. The location of the Aliambata well is also probably comparable to that of Banli–1, being located at the coast, and therefore likely over the southern limb of the subthrust anticline (see Charlton, 2002). The more prospective crestal region of the inferred subthrust anticline would lie within the topographically higher-standing area some 5–10 km north of Aliambata.

Audley-Charles's (1968) mapping in the Iliomar area east of Aliambata (Fig. 2) again suggests a Kolbano-type antiformally refolded imbricate thrust stack, which as at Aliambata comprises repetitions of the Upper Cretaceous-Palaeogene Borolalo Limestone and the Triassic Aitutu Formation. If a subthrust inversion structure underlies this region, its crest is likely to lie some distance inland, to the north of Iliomar village. However, no surface oil seeps have been reported from the Iliomar area.

The Bazol Anticline, along strike to the NE from the Lolotoi 'type' massif (Fig. 2), is the location of the greatest number of oil seeps in East Timor (Fig. 3). These seeps occur along the northern flank of the anticline, and presumably result from active migration from source rocks buried at depth to the north. The close spacing of seeps along the entire northern flank of the Bazol Anticline probably indicates that no significant traps have developed in this region to impede the migration of oil to the present ground surface. It is likely that any significant trapping potential that the Bazol Anticline formerly possessed has been destroyed by deep erosion over this structure.

In contrast, the Aitutu Anticline, en echelon with the Bazol Anticline to the northeast, might have some hydrocarbon potential. If oil is migrating from a present-day source kitchen to the north of the Bazol Anticline, then it may also be migrating updip to the northeast along the southwest-plunging crest of the Aitutu Anticline. There are, however, no reports of oil seeps from the Aitutu Anticline. Optimistically this might be interpreted as indicating that hydrocarbons have been trapped within the Aitutu Anticline. Audley-Charles's (1968) mapping of the anticline indicated segmentation of the crestal region by cross-faulting. If any of these faults have normal offsets throwing against the plunge of the anticline (i.e. downthrowing to the NE), then potential hydrocarbon traps may have developed. Potential reservoir sequences would be clastics of Early/Middle Triassic or Permian age (if the latter is present), sealed either by shales within the clastic succession or in the overlying Aitutu Formation.

The Suete Anticline (Wittouck, 1937; reproduced in van Bemmelen, 1949, Fig. 238) is interpreted as a secondary closure on an inversion anticline plunging away from the southeasterly thrusted basement block beneath the Mata Bia Range. Two seeps are recorded from the Triassic core of the Suete Anticline, while further seeps at Iriamo are near the southern end of the exposed basement block, and another seep is located immediately east of the Mata Bia Range. The seeps from the Suete anticlinal core are probably sourced from a breached anticlinal trap. Some hydrocarbon potential may remain in the deeper part of this structure, but the possibility of biodegradation must be strong.

Non-inverted rollover anticlines

Some of the strongest oil seeps in East Timor are found at the village of Pualaca near the eastern flank of the Laclubar basement massif (Fig. 2). The geology of this area (Fig. 10) suggests a further potential structural trap type: a non-inverted rollover anticline. Stratum contours at the boundary between metamorphic basement and the main cover sequence to the east indicate a shallow contact dipping eastward, with the dip of the contact decreasing eastwards from about 20°E to 9°E over a distance of 2.5 km. Bedding dips in the cover sequence oppose the dip of the basement-cover contact, ranging from approximately 30°W in the extreme west, to 55–65°W further east. The basement-cover boundary is interpreted in the cross-section as the relatively deep segment of a listric normal fault downthrowing to the east. The bedding dip pattern, opposing the dip of the bounding fault and increasing into the hangingwall, is the usual pattern associated with a growth rollover anticline in the hangingwall of a listric normal fault. The hangingwall cover sequence consists of Jurassic Wai Luli Formation shales overlying Triassic Aitutu Formation limestones and interbedded shales with minor sandstones. The Pualaca oil seeps emanate from greyish-green sandstones within the Aitutu Formation (Hirschi, 1907). As mentioned previously, the Pualaca seeps are believed to be sourced from Upper Triassic–Middle Jurassic source beds (Ware and Ichram, 1997).

The Pualaca seeps are located in a structurally more complex zone to the south of the simple rollover anticline shown in the cross-section of Figure 10. The seeps occur along a straight structural lineament trending nearly north–south. This is probably a steep fault, most likely a normal fault downthrowing to the east. Limestones as old as Lower Triassic (Scythian) to the west of the lineament are upfaulted against younger Triassic (Ladinian-Carnian) *Daonella*-bearing shales, marls and marly shales, and then Toarcian (Lower Jurassic) Wai Luli Formation shales to the east. The outcrop geometry in Figure 10 suggests that the area of the oil seeps is probably a transfer zone between two linked segments of the listric normal fault system, one to the north and one to the south of Pualaca village. The northeastern rollover anticline appears from Figure 10 to be too deeply eroded to have significant hydrocarbon potential, but the rollover anticline to the southeast of Pualaca may form a possible target if it is not too deeply eroded. Coral-bearing, possibly reefal limestones are reported from the Upper Triassic Aitutu Formation near Pualaca (Yamagiwa, 1963), and these could potentially form reservoir rocks, sealed by the Wai Luli shales.

Syn/postorogenic basins

The syn- to post-orogenic basins along the south coast of East Timor have been the principal focus for hydrocarbon exploration to date. In this study the petroleum prospectivity of these basins is considered lower than for the inversion structures outlined above, but their potential is nonetheless still significant. However, the bulk of any oil hosted within the post-orogenic basins is likely to be sourced from the Mesozoic section below or adjacent to the basins rather than from the basinal successions themselves (cf. Boutakoff, 1968), based on the geochemistry of the oil seeps, and on the postorogenic basins in most cases being insufficiently thick and with too low a thermal gradient (Crostella and Powell, 1976) to have reached thermal maturity.

The most likely play within the basins is suggested by Figure 7, which is a sketch interpretation of a seismic line across the Suai Sub-basin (Crostella and Powell, 1976, Fig. 10), with an extrapolation onshore to the Cota Taci–1 well near Suai (Fig. 7a), and a regional true-scale extension of this section (Fig. 7b). As with the oil seeps on the northern margin of the Colitie Sub-basin discussed above, oil seeps in the Suai area are interpreted to be fed by migration along the listric normal fault forming the northern boundary of the Suai Sub-basin. At depth this fault probably intersects the basal thrust of the Lolotoi block, and this thrust itself may be channelling migrating hydrocarbons from a subthrust source kitchen. The northward dip of the basinal sediments in the hangingwall of the listric normal fault makes it likely that migration will additionally take place updip along individual permeable horizons until sedimentary pinchout updip produces stratigraphic traps.

Beneath the zone of sedimentary pinchout near to the shelf/slope break in Figure 7a is an antiformal culmination located below the basinal succession, but above the sub-

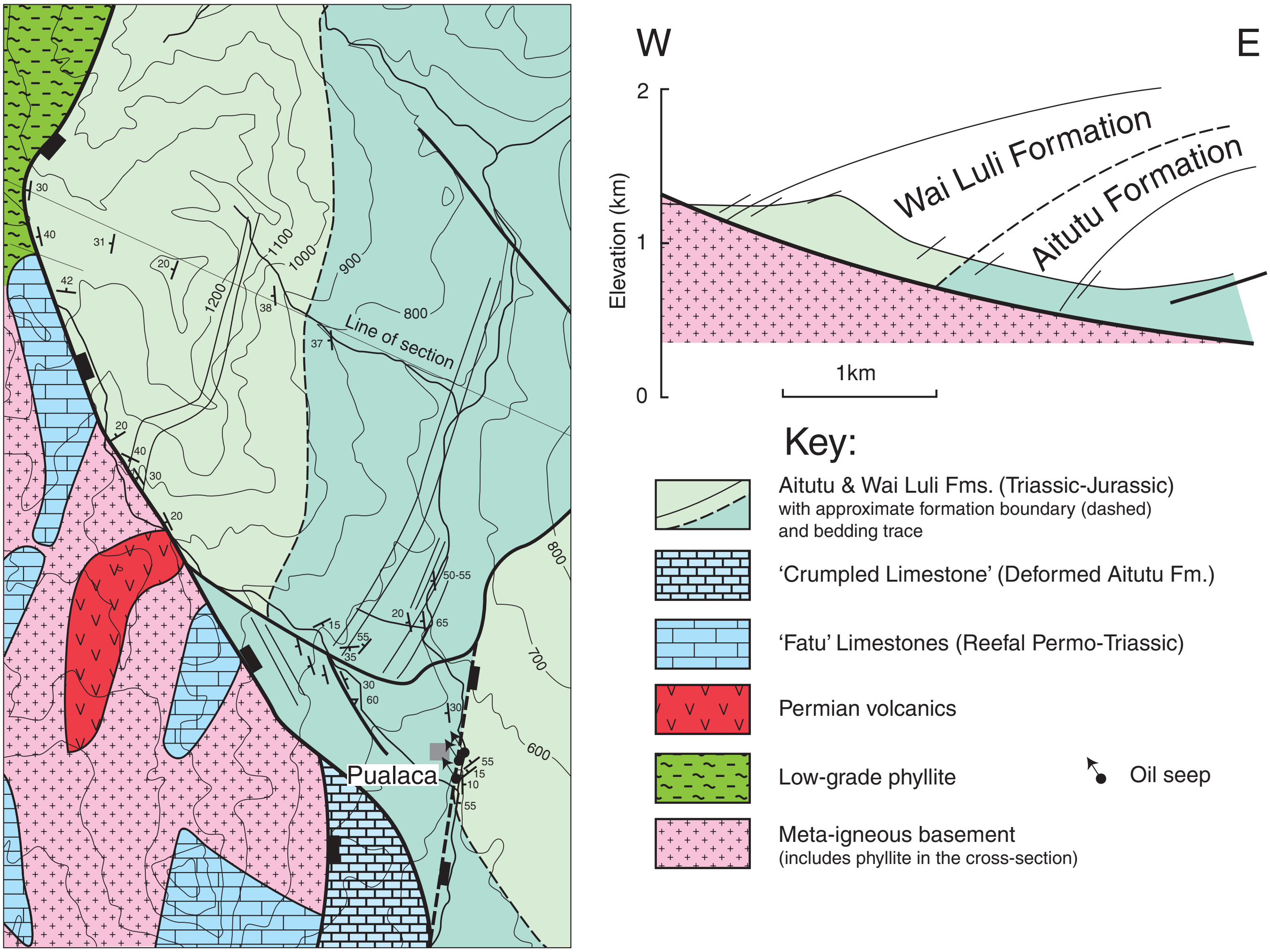

Figure 10. Geological sketch map and interpretative cross-section of the Pualaca area, East Timor. Field data from Hirschi (1907), Wittouck (1937), Grunau (1953) and Nakazawa and Bando (1968).

basinal thrust. This antiform might potentially form a further trap for hydrocarbons migrating along the thrust plane. However, it is likely that the antiform will be developed within the Bobonaro Complex, and any reservoir-quality rocks present will be almost randomly distributed within the mélange complex, possibly in isolated blocks completely sealed by the enveloping mélange shale matrix. The likelihood of commercial hydrocarbons in this type of structure is, therefore, probably small, but might be worth testing as a secondary target in addition to the pinchout traps in the overlying basinal succession.

Deeper still, a further antiformal crest may be present beneath the sub-basinal thrust (Fig. 7a). This is provisionally interpreted (Fig. 7b) as a further inversion anticline, essentially comparable to the North Betano structure (Fig. 6). One key difference, however, is that the pre-inversion basin south of Suai may have been a half-graben rather than the full graben interpreted north of Betano, based primarily on the much gentler leading edge of the overthrust basement block (compare the steepness of the southern margins of the Melatau and the Lolotoi (type) basement blocks in Figs 6 and 7). If the inversion structure south of Suai is real (and at present the evidence is at best circumstantial), this could prove a further exploration target, although the depth of the structure (5 km as reconstructed in Fig. 7b) might make it too deep for economic drilling.

Additional trapping mechanisms in the Viqueque basins of southern East Timor may include structural anticlines over shale pillows or around shale diapirs due to diapiric remobilisation of the Bobonaro Complex (Crostella and Powell, 1976; cf. Barber et al, 1986; Harris et al, 1998), and rollover anticlines above the basin-bounding listric normal faults (Crostella and Powell, 1976; Khozin and Ridwan, 1993).

Quaternary domes

A final structural feature that at least warrants consideration with regard to hydrocarbon exploration is the large domal culminations beneath the extensive Quaternary reef plateaux in the extreme northeast of East Timor. The topography in several of these plateaux indicates a clear domal form to these former reef terraces, with maximum elevations in excess of 500 m. Jaco island off the eastern tip of Timor may also represent such a culmination. It is possible that these domes have developed above late-stage backthrusts (i.e., thrusts with a northward sense of override), comparable to the backthrusts identified from the BIRPS deep seismic profiles run east of Timor (Richardson and Blundell, 1996). It is notable that at least with regard to the easternmost domes in the Lautem Plateau, several oil seeps occur off the domal crests, and it is possible that these seeps could be from the spillpoints of substantial structural traps beneath the domes.

The feasibility of this play could be assessed more fully by fieldwork at Mount Laleno, which appears to form one such domal culmination where the crest has been eroded to below the Quaternary cover, exposing (according to the mapping of Audley-Charles, 1968) Permian Maubisse Formation and Jurassic Wai Luli Formation. It is possible that the Wai Luli Formation overlies and may formerly have sealed reservoir within the Maubisse Formation. However, Audley-Charles's mapping interpreted the Maubisse Formation to overlie the Wai Luli Formation above a flat-lying thrust plane.

CONCLUSIONS

East Timor shows considerable potential for hydrocarbon exploration, with structures sufficiently large to potentially host giant hydrocarbon accumulations. Hydrocarbons have clearly been generated in East Timor, as evidenced by the abundance of oil and gas seeps. The trap type with the greatest potential is interpreted to be large, structurally simple anticlines developed through inversion of Permo-Mesozoic graben and half-graben basins. The inverted grabens are separated from shallow-level structural complexity by an important décollement level in Middle Jurassic shales of the Wai Luli Formation. The Wai Luli shales are also likely to provide an effective top seal to the deeper structures. The primary reservoir targets are Upper Triassic–Lower Jurassic sandstones equivalent to the Malita and Plover Formations of the northern Bonaparte Basin, comparable to sequences intersected in the Banli–1 exploration well in West Timor.

Inversion anticlines are identified in the subsurface of both West (Charlton, 2002) and East Timor, although the majority occur in East Timor. East Timor also has by far the greater number of oil seeps, whilst gas seeps predominate in West Timor. These two factors are probably linked, in that the best source rocks for oil accumulated within the subsequently inverted grabens, and these grabens developed mainly in the eastern half of proto-Timor. In contrast, western Timor formed a less structured basinal area prior to collision, which led to a predominant thin-skinned style of deformation, and source rocks which tend to be more gas prone.

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