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New reef targets for oil and gas exploration in Fiji, Southwest Pacific

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Abstract: Fiji forms part of the Southwest Pacific island arc system which marks the boundary between the Indo-Australia and Pacific plates. The territorial waters cover almost 1.3 million km^2 and contain two shallow water Tertiary sedimentary basins. Bligh Water Basin, covering some 9500 km^2, has sediment thicknesses in excess of 5 km and has excellent potential for hydrocarbons. Bau Waters Basin is also prospective, having a shallow water area of about 1600 km^2, with sediment thicknesses up to 4 km.

Fiji lies on the same regional play trend of Miocene reefs which produce oil in Irian Jaya, Indonesia and gas/condensate in offshore Papua New Guinea. Indeed Fiji's basins have many similarities with the oil and gas producing, arc-related basins of Southeast Asia.

Source rocks of Oligocene, Miocene and Pliocene age are exposed onshore in Fiji and have been encountered by drilling in the offshore basins. An oil seep in Bligh Water Basin and oil and gas shows in wells provide evidence that hydrocarbons have been generated in the basins. Modelling studies indicate peak oil generation to be at about 2.6 km below sea floor. Miocene and Pliocene reefal limestones form spectacular outcrops in Fiji and represent the best potential reservoirs. Reefs of the same age have been identified on seismic data from the offshore basins and represent attractive targets for exploration. Common forms are reefal mounds and prograded platforms.

Over twenty structural reefal traps have been identified on seismic lines in the Late Miocene and Pliocene sequences, mostly in Bligh Water Basin. Estimates of potential unrisked recoverable reserves are 270 million barrels of oil per structure. If structural-stratigraphic trapping occurs, recoverable reserves could increase to over 1 billion barrels of oil per structure. There is considerable scope for more reefal structures in the deeper Oligocene-Middle Miocene interval which cannot be resolved on the existing seismic data, and in areas where seismic coverage is sparse. Limestone turbidite lobes have also been identified on seismic data. These constitute a secondary play and may contain estimated recoverable reserves of 100-200 million barrels of oil per structure.

There are no exploration or production licences at present. Fiji has comprehensive petroleum legislation and the Government seeks to encourage exploration investment by oil companies. All reports and data are available in the Fiji Petroleum Data Package which may be ordered from the SOPAC Petroleum Data Bank, Canberra.

HISTORY OF EXPLORATION

Fiji first gained attention as an area of petroleum potential in 1968 following the discovery of oil seeps in neighbouring Tonga. Subsequently, there have been two stages of exploration. The first period from 1969 to 1977 commenced with reconnaissance mapping by Shell Internationale and Magellan Petroleum in 1969 and 1970, which provided the first assessments of source rocks and reservoirs. Following this, the first exploration licence, covering Bligh Water Basin (Fig. 1), was awarded to a partnership with Southern Pacific Petroleum as operator in 1969. A total of 1590 km of regional seismic data were acquired from which sediment thicknesses and general basin depocentres were established.

In 1971 three licences were awarded to Offshore Oil Exploration, Atlantic and Oceanic Resources, and Investment Corporation of Fiji; and a fourth to International Petroleum in 1972. These licences covered the western Yasawa Platform, central Lau Ridge, Bau Waters Basin and Baravi Basin respectively (Fig. 1). A total of 1585 km of seismic data were acquired in these concessions from 1971 to 1975. A further 4433 km of regional speculative seismic data were acquired by Amoco and Western Geophysical in 1972 and 1973. From these surveys the Bau Waters Basin and western Bligh Water Basin were outlined and general sediment thicknesses determined on the Lau Ridge. By 1977 all licenses granted during the first period of exploration had expired.

Encouraged by high world oil prices, the second period of exploration took place from 1977 to 1987. In 1977, Dakota Exploration was awarded a concession in the Bau Waters Basin and western Koro Sea. Over 1400 km of seismic data were

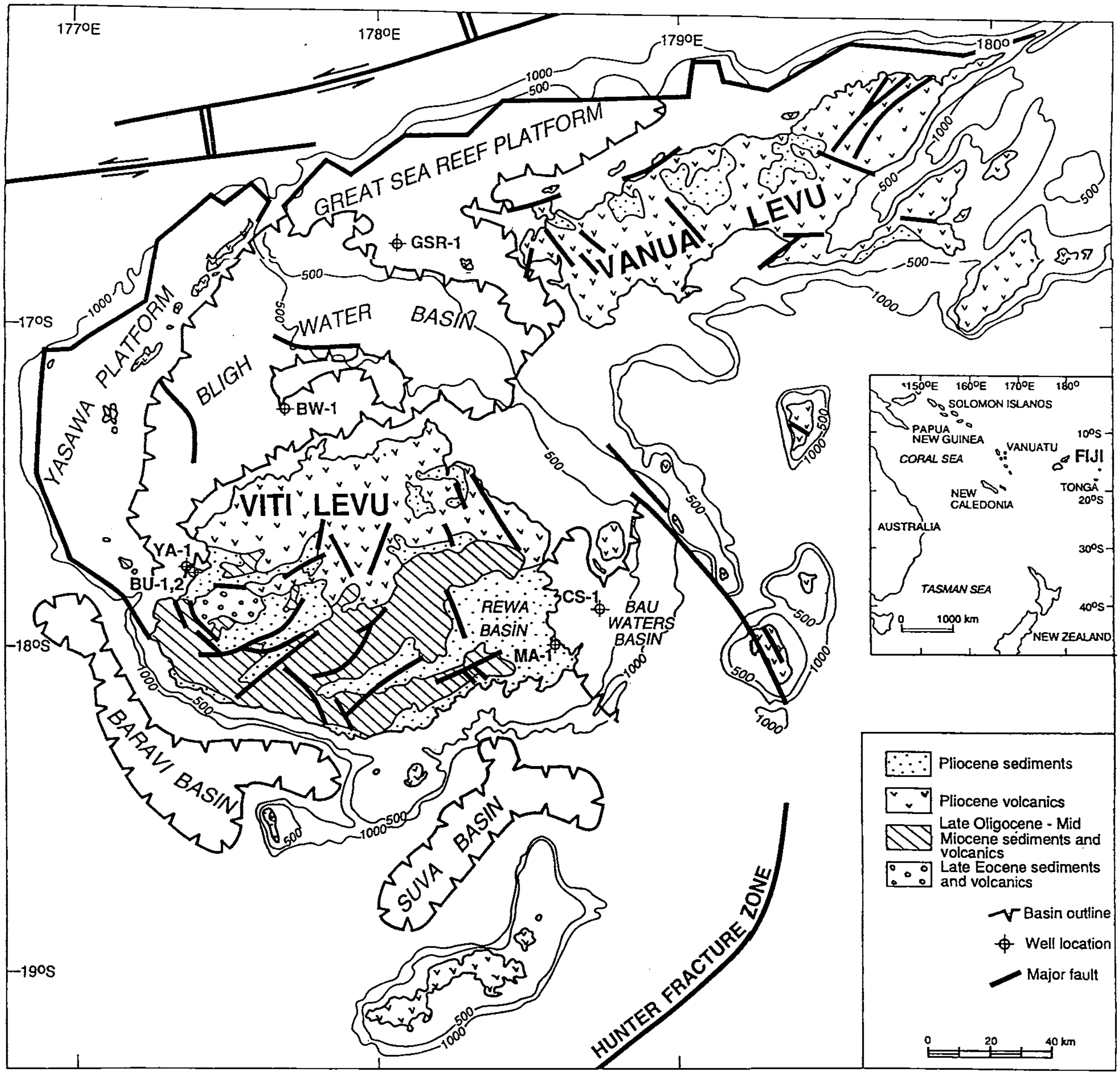

Figure 1. Geological map of Fiji.

acquired offshore which permitted more detailed structural interpretation. In 1978 three exploration licenses were awarded to Pacific Energy and Minerals covering Bligh Water Basin, the Yasawa Platform and Great Sea Reefs Platform. Following farm-out agreements with, or options taken by, Bennet Petroleum, Chevron and Mapco, 6050 km of seismic data were acquired which formed the basis of more detailed structural interpretations. Geochemical investigations of sea-bottom sediments in Bligh Water showed one pentane anomaly indicating thermogenic, migrated hydrocarbons.

Exploration drilling followed with Chevron's wells Bligh Water-1 and Great Sea Reefs-1 in 1980 (Fig. 1). During 1981 and 1982 Bennet Petroleum drilled four wells: Buabua-1 and Buabua-2 located on islands in western Bligh Water Basin, followed by Maumi-1 and Cakau Saqata-1 in Bau Waters Basin. Finally, Worldwide Energy as operator for the Pacific Energy and Minerals group drilled well Yakuilau Island-1 in 1982 in western Bligh Water Basin.

All seven wells were drilled to test Tertiary reefal limestone objectives, however, none of the wells reached its target and a re-evaluation of seismic data shows that six of the wells did not drill valid structural traps. Consequently, Tertiary reefal limestones are still an untested play with considerable potential. On a more positive note, drilling has shown the presence of source rocks and shows of oil and gas in the offshore basins of Fiji (Fig. 2; see Petroleum Geology).

By 1987 the second group of licences had expired. In the same year the Fiji government's Mineral Resources Department completed a major source rock sampling programme. Two earlier evaluations by SOPAC (Pflueger, 1989; Johnson, 1991) have been superseded by a major new evaluation (Rodd, 1992), the results of which are summarised here. Further details of Fiji's exploration history are given in an earlier publication (Eden and Smith, 1984).

At present (April 1993) there are no exploration concessions held in Fiji.

GEOLOGY

Regional Tectonic Setting

Fiji is situated at the boundary of the Australia-India Plate and the Pacific Plate. It is the complex interaction of these plates that provides the framework for understanding the geology and petroleum potential of Fiji.

The most recent plate tectonic reconstructions (Falvey *et al.*, 1991; Rodda, 1993) show that from the Early Eocene to Late Miocene, Fiji formed part of the continuous Outer Melanesian Arc which extended from Papua New Guinea through the Solomon Islands, Vanuatu, Fiji and Tonga/Lau, to New Zealand (Fig. 3). This was a migratory arc system (Wessel, 1986) that moved eastwards as the Pacific Plate was subducted beneath it. Several back-arc basins developed, including the South Fiji Basin, which separated the Outer Melanesian Arc from the rifted continental block of the Norfolk Ridge.

In the Late Miocene, the oceanic Ontong-Java Plateau collided with the Solomon Islands section of the Outer Melanesian Arc (Fig. 3). Several major events followed that resulted in the breakup of this arc. Firstly, the direction of subduction beneath the Solomon Islands and Vanuatu arcs was reversed. Subduction of the Pacific Plate ceased, to be replaced by eastward subduction of the back-arc basins beneath the Solomons and Vanuatu Arcs. This was followed by rapid opening of the North Fiji Basin. The Hunter Fracture Zone acted both as a transform and as a oblique subduction zone to accommodate the breakup of the Outer Melanesian Arc. Finally, subduction of the Pacific Plate beneath the Tonga Ridge from the Pliocene onwards has resulted in the opening of the Lau Basin which now separates the Lau and Tonga Ridges.

Geology of Fiji

Fiji's geological history can be divided into three distinct periods of island arc development: Eocene, Late Oligocene-Early Miocene and Late Miocene-present day (Fig. 4).

In the *Early Eocene* Fiji probably originated as part of the Outer Melanesian Arc (Fig. 3). However, the oldest rocks actually exposed on Fiji are of Late Eocene age (Fig. 4). These form the Yavuna Group consisting of island-arc volcanics which were uplifted to permit the deposition of shallow-water, platform limestones. The subsequent initiation of the South Fiji Basin in the Early Oligocene coincides with a stratigraphic break.

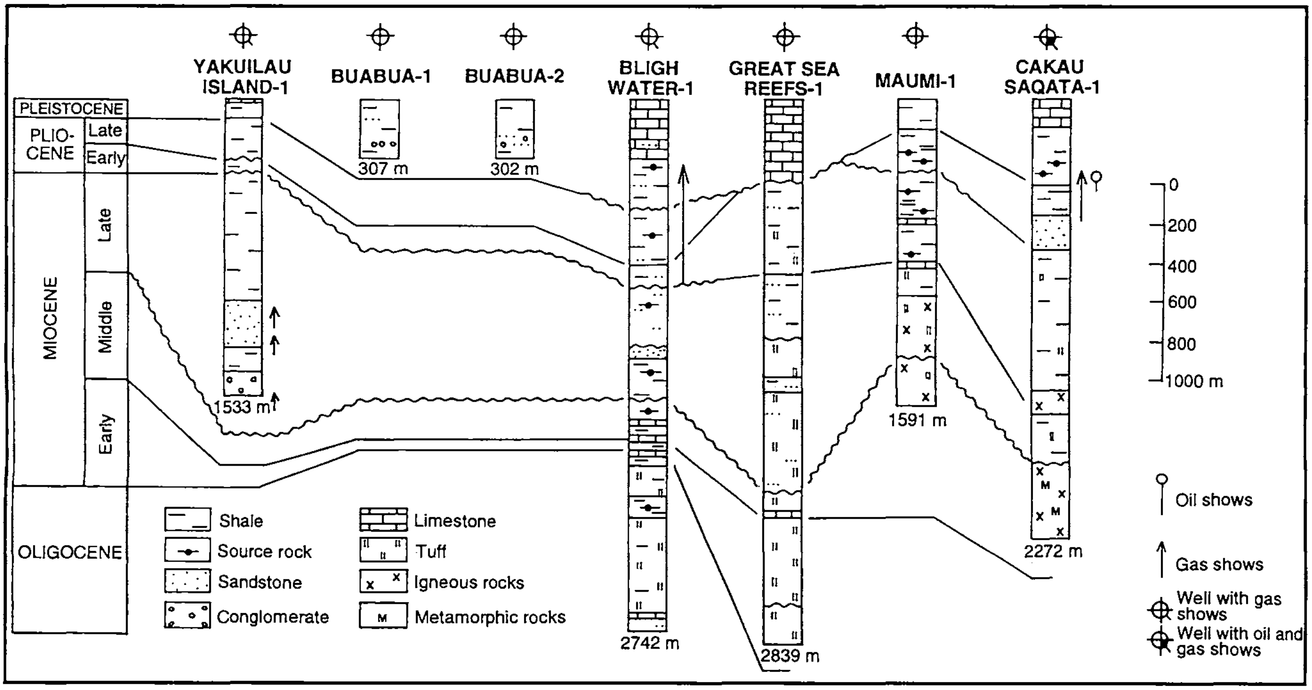

Figure 2. Well correlation.

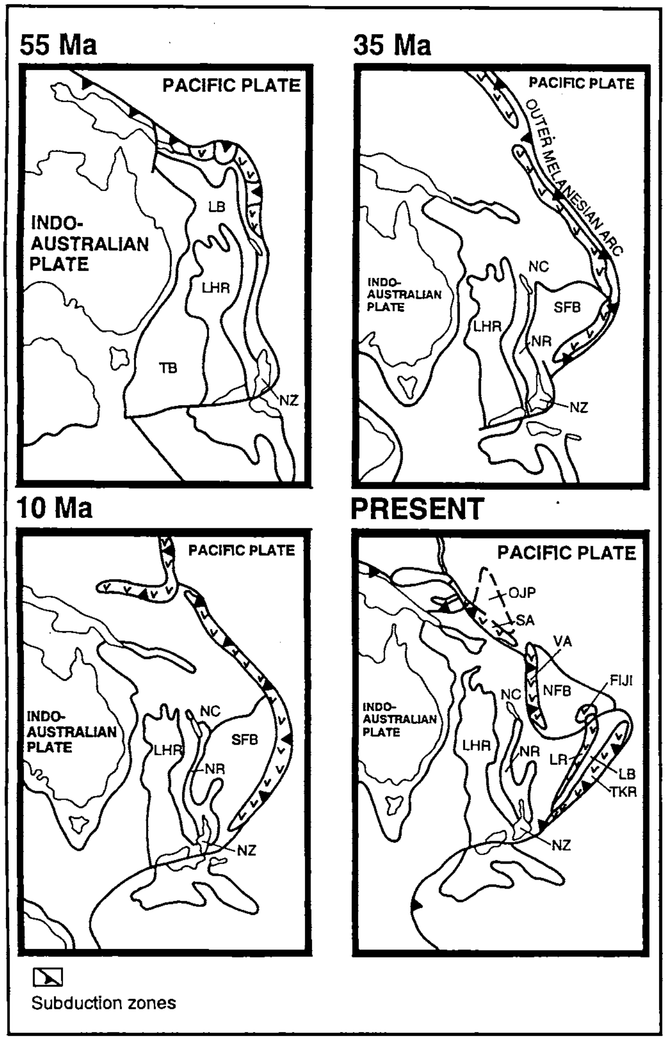

Figure 3. South Pacific plate tectonic evolution (modified from Falvey *et al.*, 1991). LB Lau Basin, LHR Lord Howe Rise, LR Lau Ridge, LB Lau Basin, NC New Caledonia, NFB North Fiji Basin, NZ New Zealand, OJP Ontong Java Plateau, SA Solomons Arc, SFB South Fiji Basin, TB Tasman Basin, TKR Tonga-Three Kings Ridge, Va Vanuatu, V island arc.

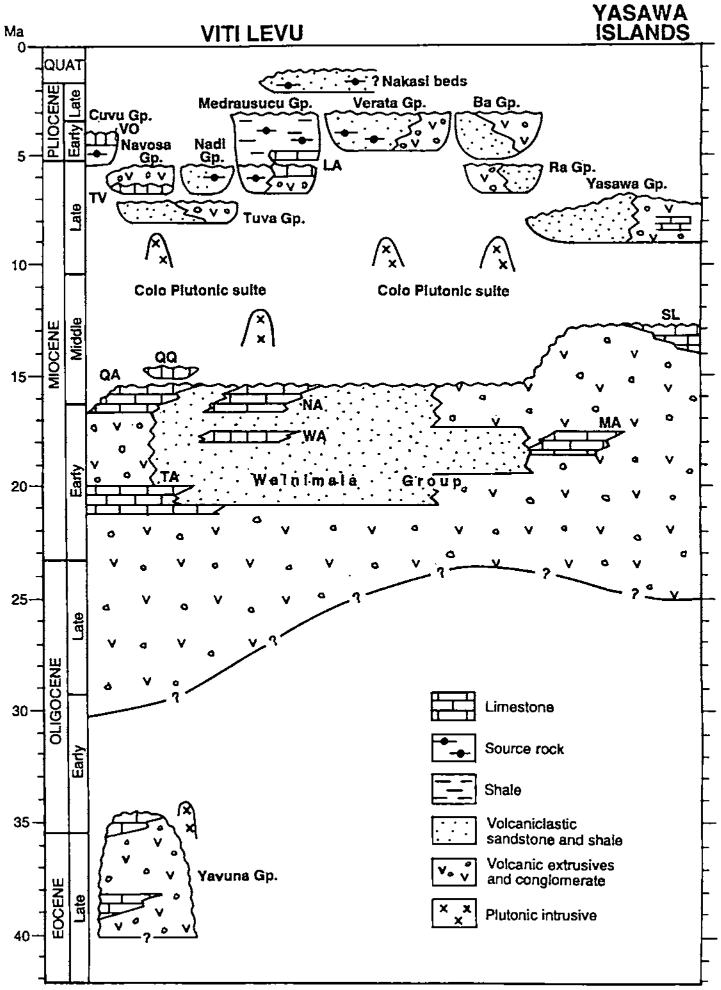

Figure 4. Stratigraphic column for onshore Fiji. Abbreviations for reef and platform limestones are LA Lami Formation, MA Malolo, NA Nakorowaiwai, QA Qalimare Limestone, QQ Qaraqara Member, SL Sawa-i-Lau, TA Tau, TV Tuvu, VO Volivoli, WA Wailotua.

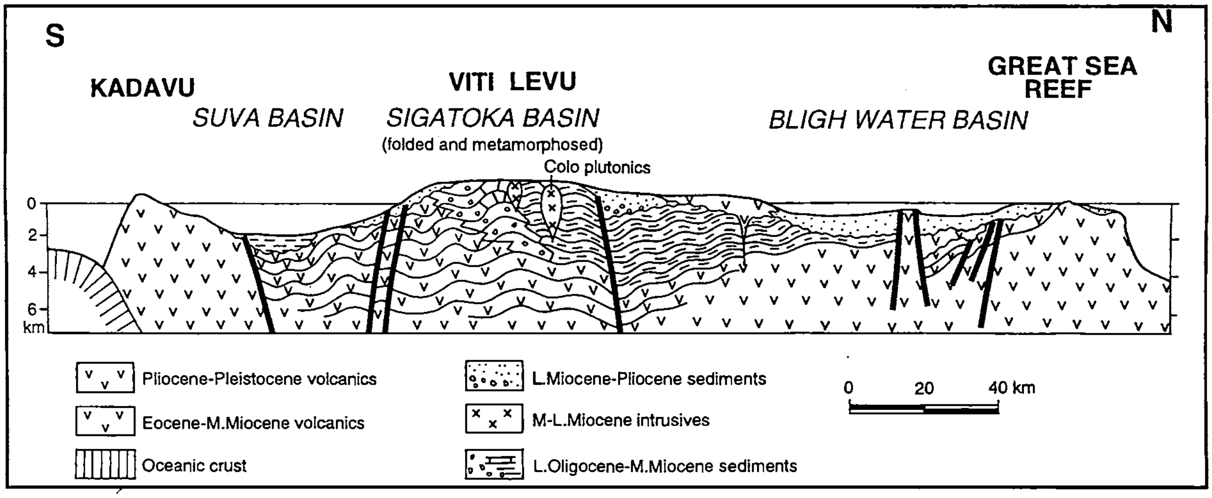

Figure 5. Geological cross section of Fiji.

This hiatus was followed by the second phase of arc development represented by the *Late Oligocene to Middle Miocene* Wainimala Group (Fig. 4). This forms the southern half of Viti Levu and is exposed in islands of the Yasawa Platform. Age equivalents of the Wainimala Group have also been encountered in the offshore basins by wells Bligh Water-1, Great Sea Reefs-1, Maumi-1 and Cakau Saqata-1 (Fig. 2). During this period the axis of the Outer Melanesian Arc passed through southern Viti Levu. A fore-arc basin developed to the north of the volcanic arc axis. Coral-algal reefs formed on the edge of a shallow water platform north of the arc axis, across the width of Viti Levu (Fig. 5). The best exposed example is the Qalimare Limestone which comprises mounds at least 300 m thick. The occurrence of massive fore-reef limestones on the northern Yasawa Platform at Sawa-i-Lau suggests that reef development associated with structural highs may have been widespread in the offshore fore-arc basin. A deep-water basin developed to the north of the platform. Low-grade regional metamorphism is restricted to areas adjacent to the volcanic axis in the south.

The present day shallow-water offshore basins, Bligh Water Basin and Bau Waters Basin, are superimposed on the larger Late Oligocene to Middle Miocene fore-arc basin. Seismic correlation across Bligh Water Basin suggests that it contains over 1,300 m of Late Oligocene to Early Miocene strata (Fig. 5), whilst Bau Waters Basin contains at least 750 m. Both basins contain several structural highs which were extant in the Late Oligocene-Middle Miocene fore-arc basin and may thus have provided centres for reef growth. Seismic data suggest that the deep-water Suva Basin (Fig. 6) probably contains up to 1,500 m of the Late Oligocene-Middle Miocene volcaniclastics. Situated to the south of the arc axis, this is a back-arc basin.

During the Middle to Late Miocene, a major hiatus in Fiji coincides with the intrusion of the basic to intermediate Colo Plutonic Suite and uplift of the arc axis (Fig. 4). Ensuing erosion of the arc produced breccias and conglomerates (Tuva Group) which were dumped in the fore-arc basin to the north to form submarine fans. Other large structural highs were active in the Bligh Water and Bau Waters Basins resulting in deposition of up to 1,500 m of Late Miocene sediment in restricted half-grabens. The large, densely vegetated land areas would have provided an abundant source of plant material.

The third period of arc development, from the *Late Miocene to the present day*, coincides with the breakup of the Outer Melanesian Arc and the opening of the North Fiji Basin. During this time Fiji remained in a back-arc setting. Initial rifting of the arc was accompanied by folding and faulting, often induced by wrench tectonics: the *Colo Orogeny*. This deformed the older Wainimala and Tuva Groups and Colo plutonics. Calc-alkaline volcanic activity associated with breakup of the arc occurred in Vanua Levu and northern Viti Levu.

Subsequently, deposition occurred in several basins situated to the north and south of the uplifted Late Oligocene-Early Miocene arc (the Medrausucu, Nadi and Rewa Basins); and between the new volcanic centres (e.g. on Vanua Levu). Coral-algal reefs developed during the Late Miocene and Early Pliocene around the margins of, and on structural highs within, the larger basins, e.g. Lami, Tuvu and Volivoli reefal limestones (Fig. 4). Volcaniclastics were deposited in the basin centres.

From the Late Miocene onwards, Bligh Water Basin evolved, bounded to the north and west by the deformed structural highs of the Great Sea Reef Platform and the Yasawa Platform respectively, and to the south by the new Pliocene volcanic centres (Fig. 1). The basin probably contains a maximum thickness of 2,800 m of Late Miocene to Recent sediment which overlies older, Late Oligocene to Middle Miocene strata (Fig. 6). Numerous structural highs have been activated during and since the Colo Orogeny. Seismic data indicate that these highs, together with other volcanic highs, favoured reef growth in both the Late Miocene and the Early Pliocene.

Bau Waters Basin represents the offshore extension of the Rewa Basin (Fig. 1). It contains up to 2,800 m of Late Miocene to Recent sediment which overlies deformed Late Oligocene to Early Miocene strata. Several fault-bounded structural highs have also given rise to reef growth.

The deep-water offshore Baravi and Suva Basins contain maximum sediment thicknesses of 2,700 and 1,500 m respectively, which is probably of Late Pliocene to Pleistocene age (Fig. 6; Brocher and Holmes, 1985). These basins developed in a back-arc setting in response to subduction of the South Fiji Basin along the Hunter Fracture Zone during the Pliocene to Late Pleistocene (Gill *et al.*, 1984).

The shallow-water Lau Ridge situated to the east of Viti Levu originated as part of the Outer Melanesian Arc, probably in the Eocene (Fig. 3; Woodhall, 1985), and exhibits a Miocene to Early Pliocene geology that is similar to Viti Levu. However, major uplift associated with opening of the Lau Basin in the Late Pliocene has resulted in exposure of the Middle Miocene to Early Pliocene reef limestones on the Lau islands. Although several narrow grabens have survived uplift, the total sediment thickness is typically less than 500 m.

PETROLEUM GEOLOGY

Prospective Basins

The largest prospective offshore basin is Bligh Water Basin covering some 9,500 km^2. Shallow water depths combine with sediment thicknesses in excess of 5,000 m and favourable geology to make this the most prospective basin in Fiji (Fig. 6). Water depths are mostly less than 100 m in the western half of the basin, whilst most of the eastern half is between 200 and 600 m deep (Fig. 1). Bau Waters Basin is the offshore extension of the Rewa Basin. The shallow water area (less than 500 m water depth) is restricted to a nearshore zone some 25 km wide with an area of 1,600 km^2. Water depth increases dramatically eastwards to over 2,000 m. Sediment thicknesses reaching over 4,000 m and promising geology make this the second most prospective basin in Fiji.

Other areas have either excessive water depths or unsuitable geology rendering them unattractive for hydrocarbon exploration. The Baravi and Suva Basins to the south of Viti Levu have water depths in excess of 2,000 m. The Great Sea Reefs and Yasawa Platforms have insufficient sediment thicknesses to generate hydrocarbons, whilst uplift and erosion of the Lau Ridge has generally exposed the potential Tertiary reef reservoirs at the surface (Pflueger, 1989; Johnson, 1991).

Source Rocks

The potential of arc-related basins to accumulate source rocks and generate oil and gas is conclusively demonstrated by the basins of Southeast Asia. Source rocks containing Type II and Type III kerogen, and with TOC in the range 0.5-2% generate waxy crudes and gas found in oil fields of Sarawak and Sabah, Malaysia, Indonesia and the Philippines. Source rock data from Fiji indicate that similar source rocks are present in the offshore Fiji basins. Furthermore, oil seeps and source rocks elsewhere in the Southwest Pacific region indicate that carbonate algal source rocks are also present in island-arc basins. Biomarker analysis of oil seeps in neighbouring Tonga indicate these to be derived from a marine carbonate source rock, probably from kerogen Type II (Summons *et al.*, 1992). In Vanuatu, algal-derived carbonate source rocks with Type II kerogen have been sampled, containing 1.4-1.8% TOC (Glickson, 1988).

In Fiji, hydrocarbon source rocks ranging in age from Oligocene to Pleistocene crop out on Viti Levu and have been encountered in exploration wells (Figs. 2 and 4). Defined by having a total organic content (TOC) which exceeds 1%, the source rocks are dominated by kerogen Types II and III and thus may generate oil and gas.

Late Oligocene to Middle Miocene source rocks in the Wainimala Group were encountered by well

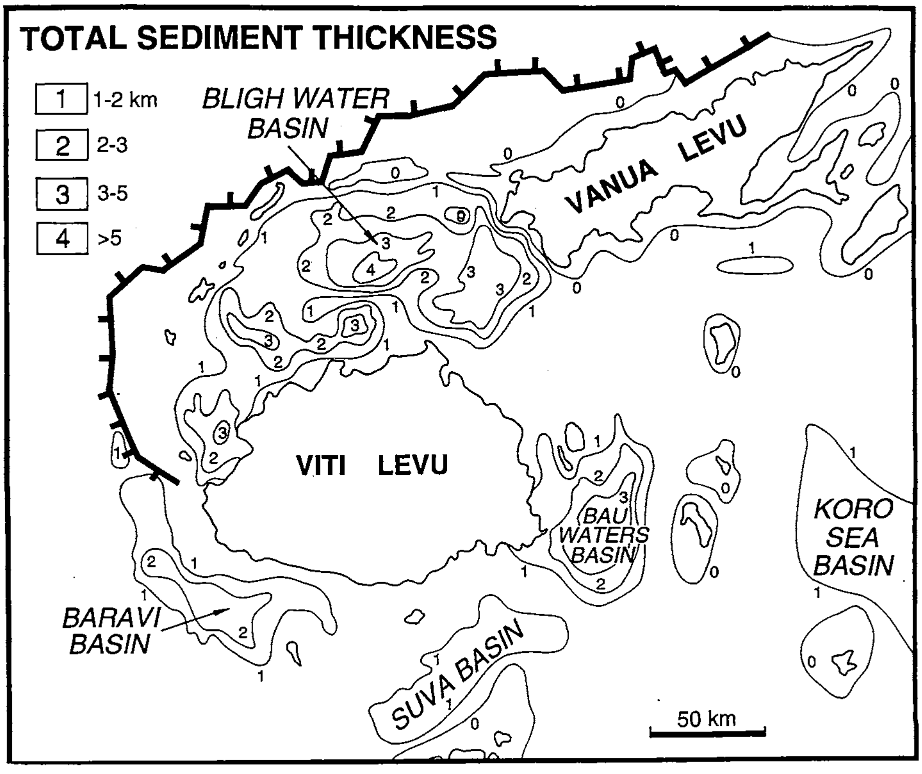

Figure 6. Sediment thickness in offshore basins, as determined from seismic data.

Bligh Water-1 in Bligh Water Basin (Table 1). TOC is in the range 1-2.2%. During this period, prior to the breakup of the Outer Melanesian fore-arc basin, the vast regional extent of the fore-arc basin (Fig. 3) may have favoured widespread deposition of individual source rock intervals. Consequently, the source rocks found in well Bligh Water-1 (Fig. 2) may be regionally extensive.

Source rocks of Late Miocene to Pliocene age occur in the Medrausucu Group and the Cuvu, Nadi and Verata Sedimentary Groups on Viti Levu, and in Bligh Water Basin and Bau Waters Basin. Average TOCs for these Groups are in the range 1.3-2.7% (maximum is 8.2%) with kerogen Types II and III. Individual coal-rich layers in the Nadi Sedimentary Group have up to 54.4% TOC. Following the breakup of the Outer Melanesian Arc in the Late Miocene, deposition occurred in a number of small, often fault-bounded basins. Such basins may have been silled, with the resulting anoxic conditions giving rise to excellent potential for the accumulation of source rocks.

Maturity

Oil and gas shows and seeps provide conclusive evidence that hydrocarbons have been generated in Fiji's offshore basins. A large pentane anomaly in sea-bottom sediments occurs in the south of Bligh Water Basin (Fig. 7, HRLI, 1979). Preliminary geochemical analysis indicates that the oil has migrated from mature source rocks (Stahl, 1979). Strong gas shows were recorded throughout the Pliocene sections drilled by Bligh Water-1 and Yakuilau Island-1 (Fig. 2). In Bau Waters Basin there were strong oil and gas shows in the Pliocene section drilled by Cakau Saqata-1. A bright spot on seismic line D-23 coincides with a small structural lead (Fig. 8).

Maturity modelling of source rocks shows that sediment thicknesses in both Bligh Water and Bau Waters Basins are sufficient to generate oil and gas, and that substantial Pliocene and Miocene kitchens could exist (Fig. 9). Well Bligh Water-1, situated on the flank of a major structural high in Bligh Water Basin, encountered Middle and Late Miocene source rocks which were immature. Seismic correlation and maturity modelling predict that, deeper in basin centres to the north and south, these source rock intervals could reach the top of the oil window at 1,750 m below sea floor, whilst peak oil generation could occur at 2,600 m (Fig. 10). Hydrocarbon generation could be continuing today. Pliocene source rocks are buried deep enough to be in the oil window in depocentres in the south and west of Bligh Water Basin where thicker Pliocene sections are developed (Fig. 9).

In Bau Waters Basin, Early Pliocene source rocks in Maumi-1 (Fig. 2) situated on the edge of the basin are immature. However, these source rocks could reach the oil window in the deeper, offshore parts of the basin (Fig. 11). The top of the oil window is predicted at 1,800 m below sea floor and maximum oil generation at 2,700 m. Should Miocene source rocks be present, as in Bligh Water Basin, these would have reached peak oil generation.

Reservoirs

There are two general prospective intervals of reefal limestone yet to be drilled in Fiji: Early to Middle Miocene and Late Miocene to Early Pliocene. Both intervals are well exposed onshore and exhibit numerous leads identified on seismic data in the offshore basins.

Early to Middle Miocene reefal and platform limestones were developed on an arcuate, east-west trending palaeo-shelf edge across Viti Levu, which formed part of the Outer Melanesian fore-arc basin (Fig. 12). The coral-algal Qalimare Limestone is the best exposed example. The

Table 1: Stratigraphic intervals containing source rocks (TOC greater than 1%).

Age	Group	Average TOC % (range)	Kerogen type
Pleistocene	Nakasi beds1.5 (1.0-1.8)	nd	
Pliocene	Cuvu Sedimentary Group	1.7 (1.0-2.3)	nd
	Medrausucu Group*	1.3 (1.0-2.0)	III
	Verata Sedimentary Group	2.7 (1.0-8.2)	II, III
Late Miocene	Medrausucu/Tuva Groups*	1.6 (1.0-2.9)	nd
	Nadi Sedimentary Group	54.4 (coal)	III
Mid Miocene-Oligocene	Wainimala Group*	1.9 (1.0-2.2)	nd

* includes source rocks from age-equivalent formations drilled offshore; nd = not determined.

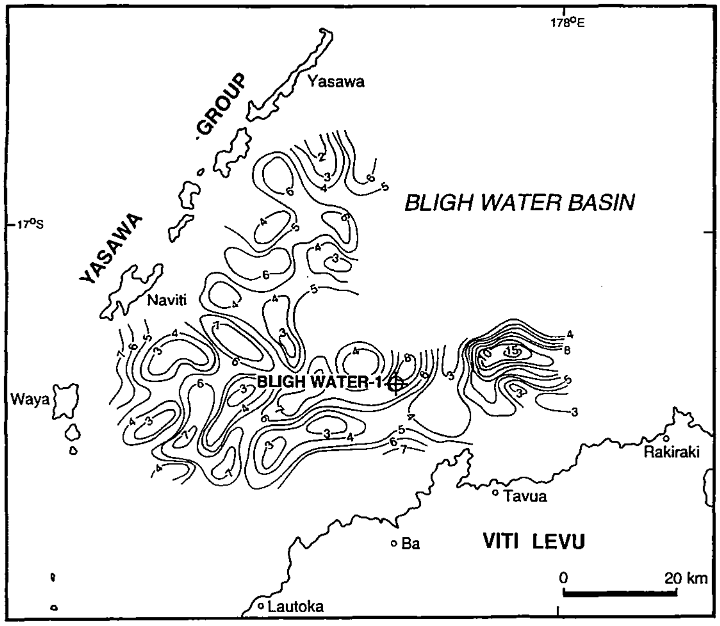

Figure 7. Bligh Water Basin pentane anomaly. Residual absorbed pentane in seabed sediments, in ppb above background (modified from HRLI, 1979).

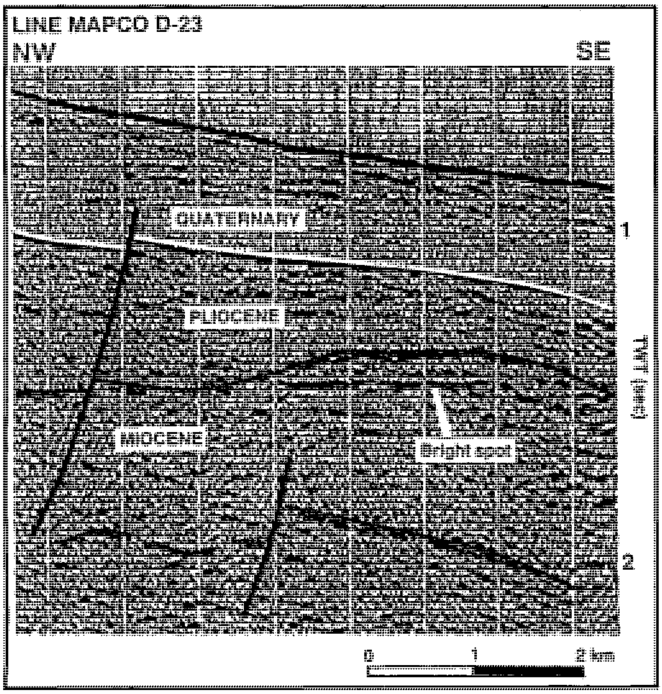

Figure 8. Seismic line D-23 Bau Waters Basin, showing bright spot. See Figure 18 for location.

limestone reefs and platforms coincide with eustatic sea-level highstands at 18 and 16 Ma (Fig. 13). Highstands are known to be generally conducive to reef growth and platform development (Sarg, 1988; Schlager, 1992). It is likely, therefore, that these limestone intervals may be regionally extensive, as is supported by the occurrence of Early to Middle

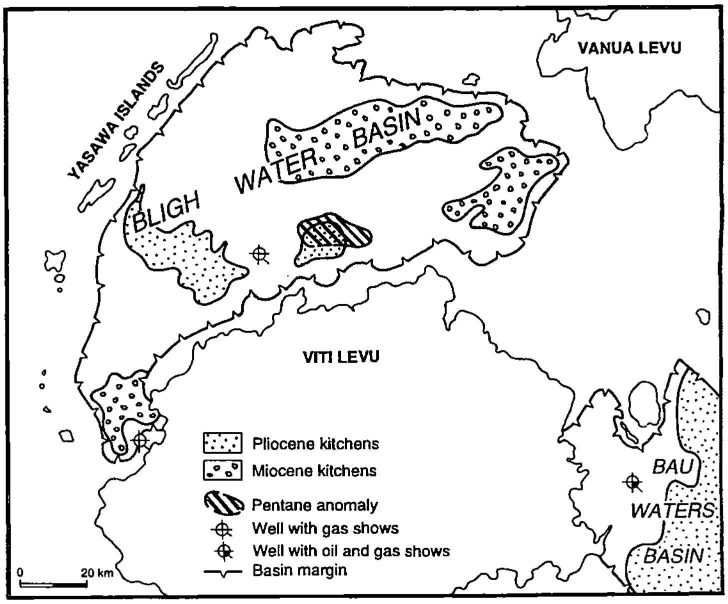

Figure 9. Bligh Water and Bau Waters Basins kitchens.

Miocene reefal and platform limestones in the Yasawa islands. The characteristic mounded geometry of the reefal mounds is easily detected on seismic data, making them the most attractive exploration targets. Platform limestones, which include grainstones and packstones, are also good potential reservoirs.

Reservoir porosity is likely to be good, judging from Pasca and Pandora Fields in offshore Papua New Guinea where average porosities of similar Miocene reef limestone reservoirs are 10 and 27% respectively (Durkee, 1990). In Fiji, karstification and leaching of the Middle Miocene limestones occurred during uplift in the Middle to Late Miocene (Fig. 4) and sea-level lowstands at 16.5 and 15.5 Ma (Fig. 13). This may have further enhanced porosity and permeability.

Redeposited turbidite limestones provide another potential reservoir. These may form either fore-reef talus deposits, or be the result of tectonic uplift and sea-level lowstands when the exposed shelf sediments are eroded. Massive fore-reef limestones form the island of Sawa-i-Lau in the Yasawa islands (Fig. 12), whilst the Middle Miocene Qaraqara Member provides an excellent example of a lowstand limestone turbidite (Fig. 13). It is possible that such deposits may be widespread in Bligh Water Basin.

Late Miocene to Pliocene reefal and platform limestones constitute the second prospective interval (Figs. 4 and 12). These shallow-water limestones developed around structural highs formed during the Late Miocene Colo Orogeny. Periods of reefal and platform limestone development coincide with sea-level highstands at 6.8, 5.8, 5 and 4 Ma (Fig. 13) and may be widespread

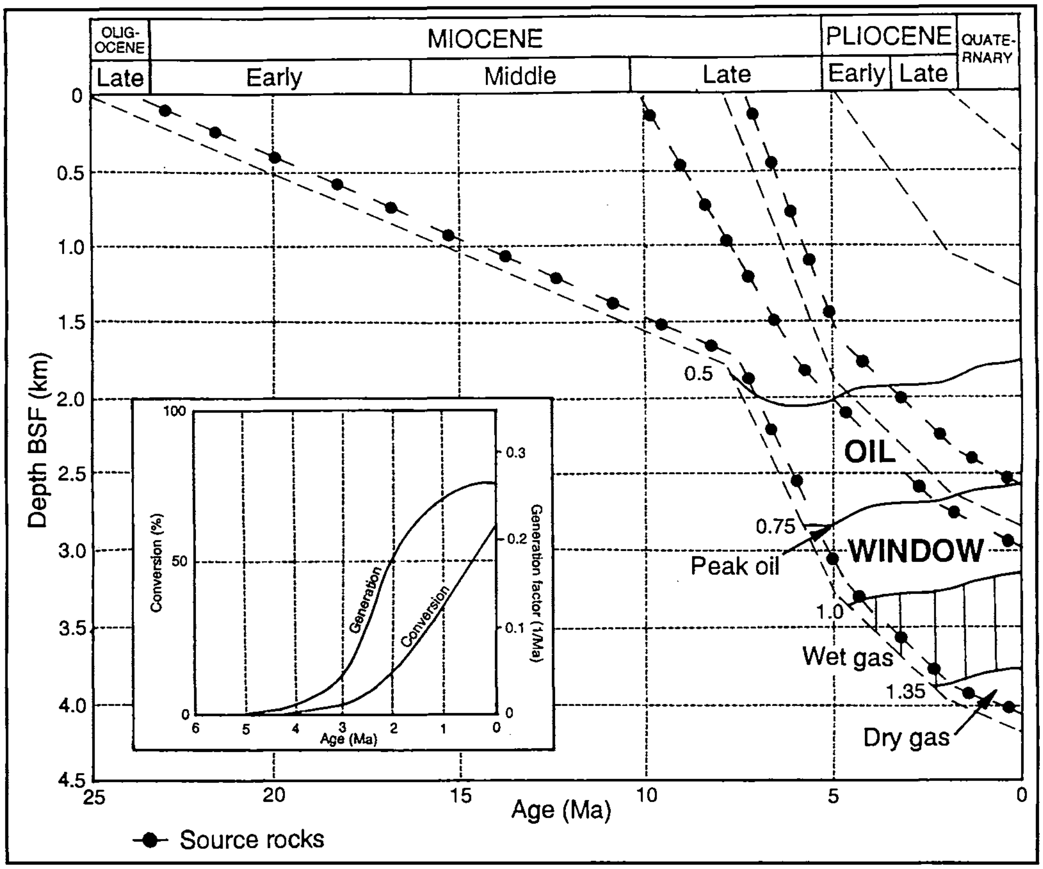

Figure 10. Bligh Water Basin source rock maturation history.

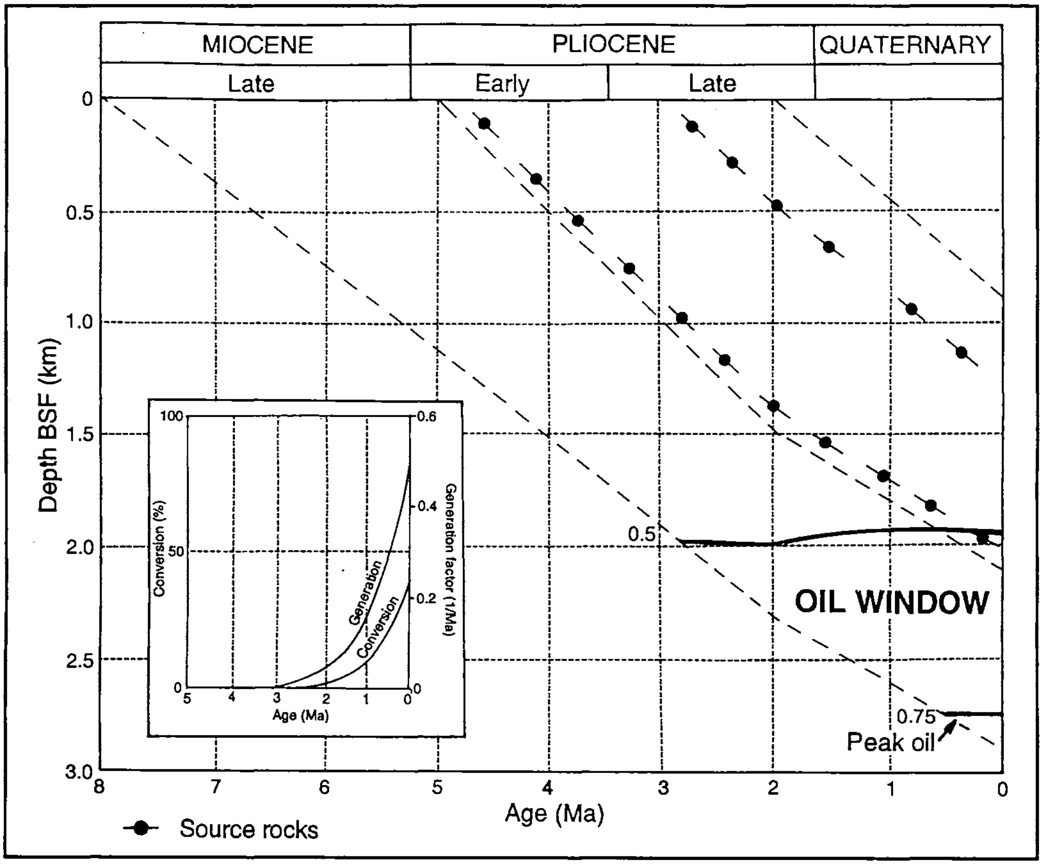

Figure 11. Bau Waters Basin source rock maturation history.

in the offshore basins. This is supported by many reefal anomalies identified on seismic in Bligh Water and Bau Waters Basins (see Plays and Prospective Areas).

Pliocene limestones drilled off-structure in well Maumi-1 had porosities of 20-25%. Most of the reef and platform limestones exposed onshore have unconformities at their tops, marked by leaching and karstification which has further improved their reservoir potential. Deep water turbidite limestones provide additional reservoirs for this stratigraphic interval.

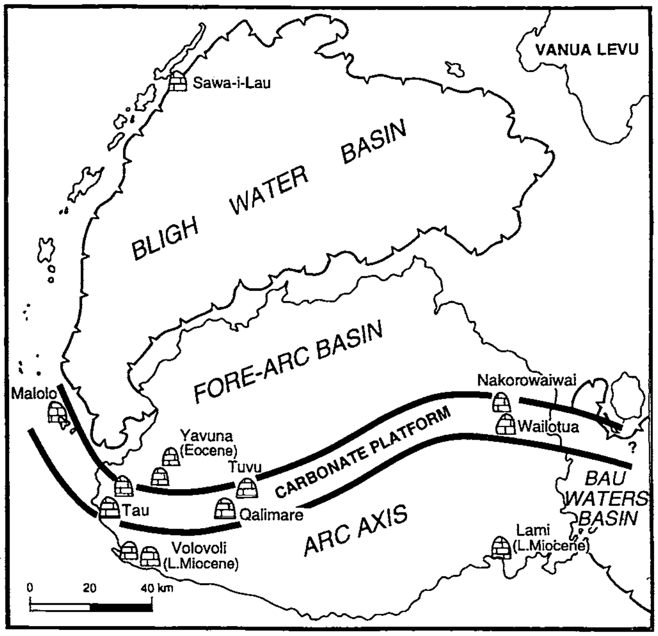

Figure 12. Map showing outcrops of reefal and platform limestones.

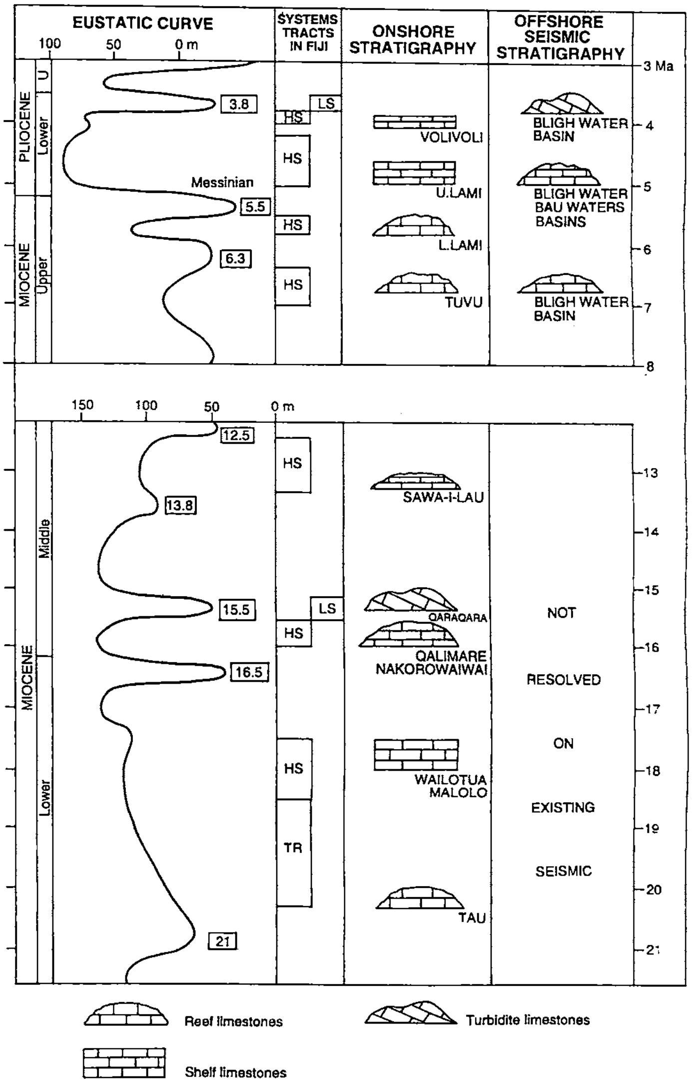

Figure 13. Miocene-Pliocene limestones and eustatic sea level.

Seals

The stratigraphic column abounds in potential seals ranging from shales and fine grained volcaniclastics to extrusive volcanic rocks (Fig. 4). Most importantly, all the potential reef and limestone-turbidite reservoir objectives are overlain by sealing lithologies. The thick, massive nature of the sealing lithologies means that they may provide effective lateral seals for combination structural-stratigraphic traps, and cross-fault seals for faulted traps.

Plays and Prospective Areas

Several decades of exploration has established Tertiary reefs as one of the major petroleum producing reservoirs in Southeast Asia. Reefs of Miocene and Pliocene age produce oil and gas in the Philippines, Malaysia, Indonesia and in Papua New Guinea. Figures 14 and 15 show that the same Tertiary reef play extends from the producing oil fields of Irian Jaya, Indonesia, through the gas/condensate fields of eastern offshore Papua New Guinea and continues through the island-arc basins of the Southwest Pacific, as attested by outcrops on the islands themselves. Regionally, the Miocene reefs are the most extensive and the most productive for oil and gas, but the Eocene and Pliocene reefs are also important.

Oil seeps in Fiji and Tonga, together with the presence of source rocks on Fiji and throughout the Southwest Pacific, provide conclusive evidence that oil is present and that the arc-related basins are prospective for oil and gas.

The reservoirs, seals and source rocks in Fiji outlined above give rise to two distinct plays in the offshore basins of Fiji (Fig. 16). Neither of the plays has been tested by drilling.

Miocene-Pliocene Reef Play

During periods of tectonic quiescence and/or sea-level highstands, reef growth may have been widespread throughout the offshore basins in favourable shallow water conditions. Typically, these would have been located on structural highs and near shelf edges. Onlapping and overlying shales and volcaniclastics would have provided effective seals to create traps. During burial, hydrocarbons generated from basinal and/or lagoonal Miocene and Pliocene source rocks deeper in the basin may have migrated into the reefal traps.

There are two main prospective intervals of reef development in Fiji: the Early to Middle Miocene and the Late Miocene to Pliocene (Fig. 2). Twenty Late Miocene to Pliocene reefal leads have been identified on the existing seismic data in Bligh Water Basin and two in Bau Waters Basin (Figs. 17 and 18). There is additional scope for this play in the deeper Early to Middle Miocene interval. However, this cannot be resolved at present due to the poor quality of seismic data and lack of seismic coverage in certain areas, e.g. central and eastern Bligh Water Basin.

In southwest Bligh Water Basin, reefal leads with mounded geometries typical of patch reefs occur at the edge of a palaeo-shelf (Figs. 19 and 20). Elsewhere in Bligh Water Basin, reefal leads are situated on structural highs and show evidence of progradation characteristic of reefal platforms (Figs. 21 and 22). Figure 23 shows an example of a similar lead in Bau Waters Basin. The interpretation of these features as reefs is supported by their location on shelf edges or structural highs. Furthermore, the leads coincide with sea-level highstands at 6.8 and 5 Ma (Fig. 13). Such highstands are generally known to be conducive to reef growth (Sarg, 1988; Schlager, 1992).

All of the reefal leads are true structural traps with mapped structural closures. However, additional trap volume may exist due to lateral seals below the structural spill-point (e.g. Fig. 21), giving rise to combined structural-stratigraphic trapping. Estimates of potential unrisked recoverable reserves for typical reefal leads are about 270 million barrels of oil per structure (Table 2). If stratigraphic trapping occurs, the larger reefal leads could contain upwards of 1 billion barrels recoverable per trap. Particularly attractive is the fact that the leads are often clustered (Fig. 17) such that development and production facilities may eventually be shared by several fields, and thus significant cost economies could be made.

The gross rock volumes are determined from mapped structural closures for structural leads. Lateral seals give rise to much greater vertical closures and trap areas for structural-stratigraphic traps. Potential unrisked reserves are estimated from likely average reservoir parameters (ranges are shown in parentheses in Table 2).

Miocene-Pliocene Limestone Turbidite Play

During tectonic uplift and/or sea-level lowstands exposure and erosion of the reefal and platform carbonates occurred. The eroded sediment would have been redeposited as deep water turbidite lobes and mounds at the base of slope to form potential reservoirs (Fig. 16). Onlapping and overlying basinal shales and volcaniclastics could provide effective seals. During burial, hydrocarbons generated from Miocene and Pliocene source rocks within the basin may have migrated into the turbidite traps.

Such deep-water limestone turbidites form oil and gas reservoirs in several major petroleum

Table 2: Estimates of potential unrisked reserve volumes for reefal and turbidite leads.

	Reefal Leads		Turbidite Leads	
	structural	stratigraphic*	structural	stratigraphic*
Area (km^2)	18	39	20	30
Vertical closure (m)	240	460	70	100
Gross rock volume (x10^{9}m^3)	1.9	7.7	1.0	2.1
Net/gross (%)	75 (65-80)		60 (50-70)	
Porosity (%)	14 (10-25)		12 (10-15)	
HC saturation	65 (60-70)		65 (60-70)	
Formation volume factor	0.833		0.833	
Oil in place (mmbo)	660	2760	240	520
Recovery factor	40 (30-50)		40 (30-50)	
Recoverable reserves (mmbo)	**270**	**1100**	**100**	**210**

*Assumes combined structural-stratigraphic trap mmbo = million barrels of oil

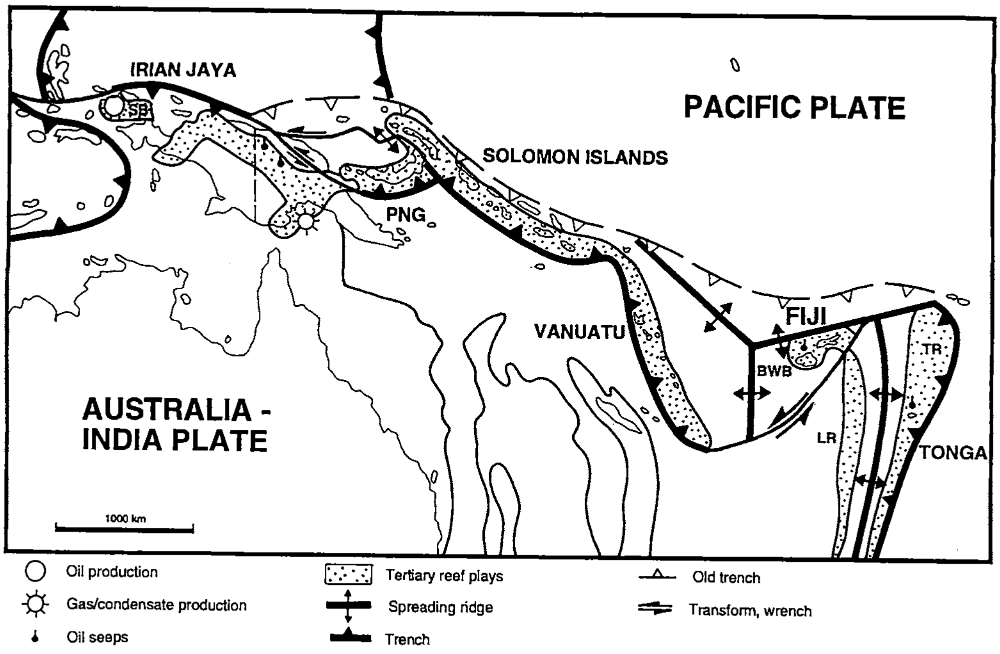

Figure 14. Map showing regional Tertiary play trend. BWB Bligh Water Basin, LR Lau Ridge, PNG Papua New Guinea, SB Salawati Basin, TR Tonga Ridge.

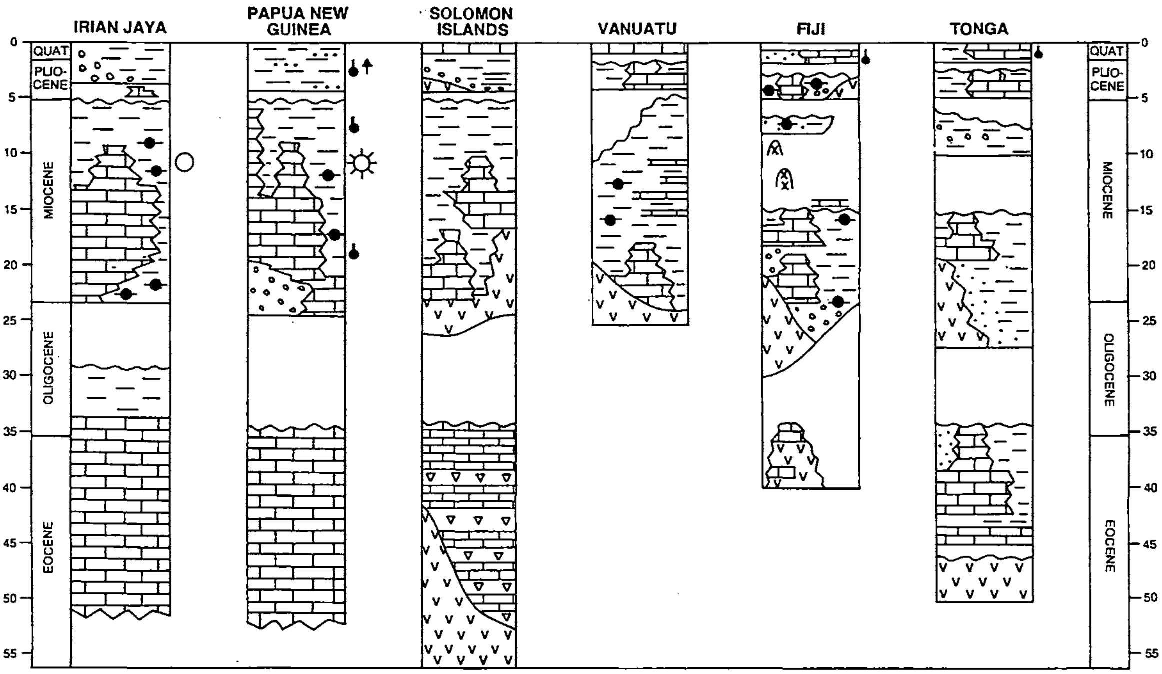

Figure 15. Stratigraphic columns for the South West Pacific, key for lithology is given in Figure 4.

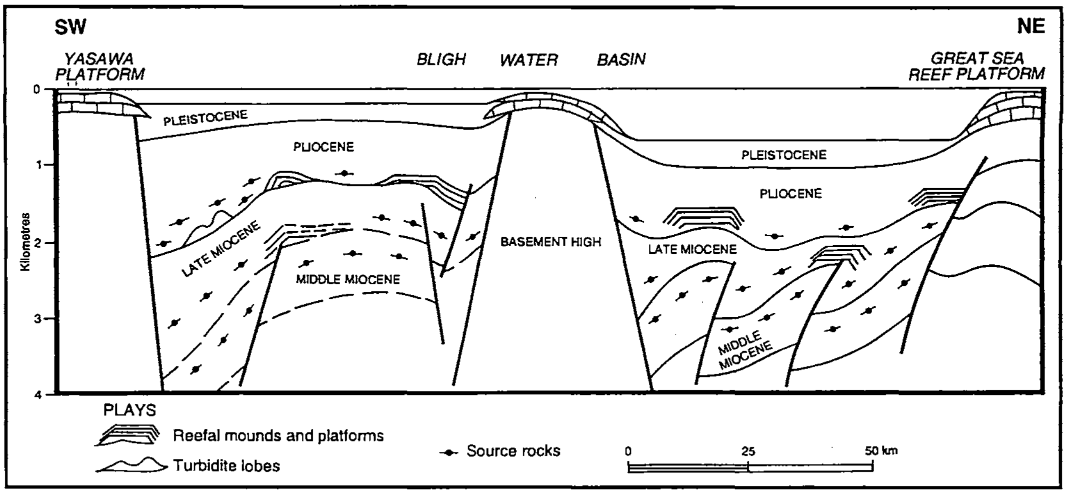

Figure 16. Schematic cross-section showing plays in Bligh Water Basin.

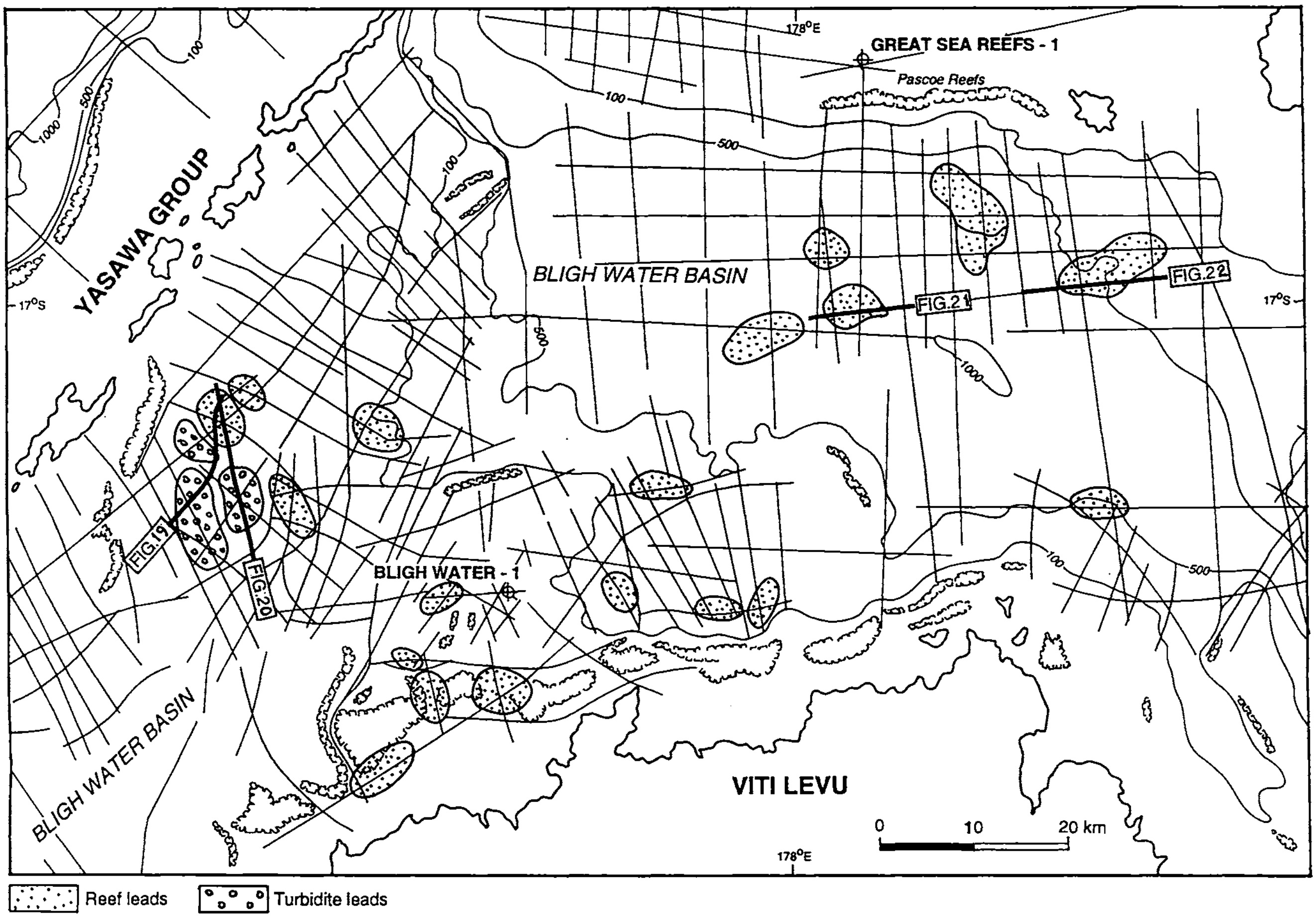

Figure 17. Map showing reefal and turbidite leads in Bligh Water Basin.

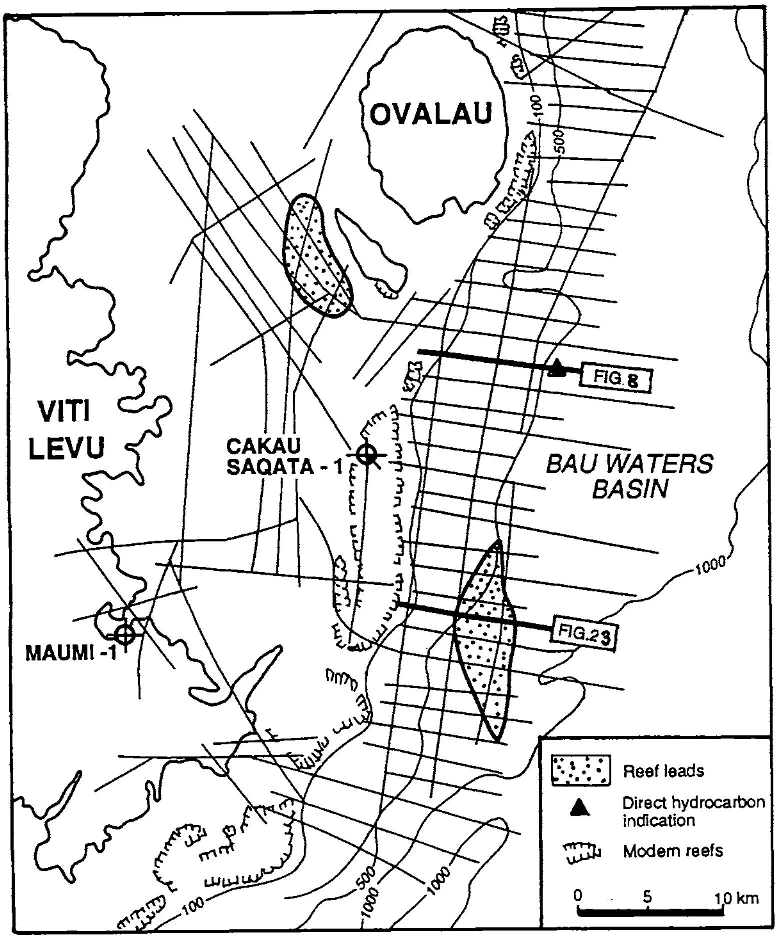

Figure 18. Map showing reefal leads in Bau Waters Basin. Contours show water depth in meters.

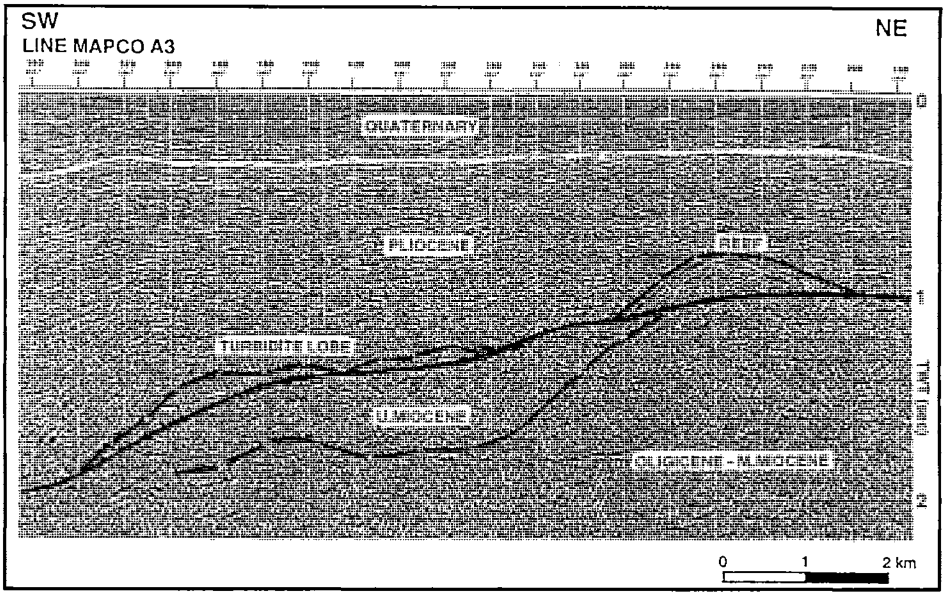

Figure 19. Seismic line Mapco A3, southwest Bligh Water Basin. See Figure 17 for location.

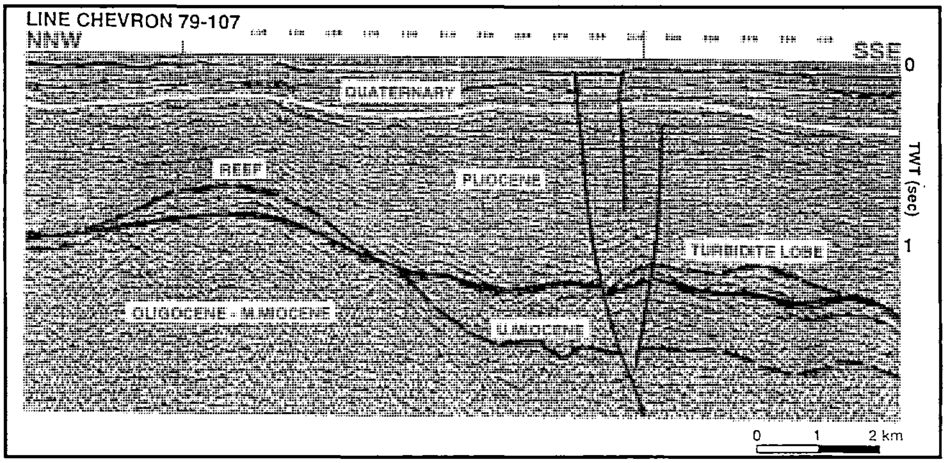

Figure 20. Seismic line Chevron FJ79-107, southwest Bligh Water Basin. See Figure 17 for location.

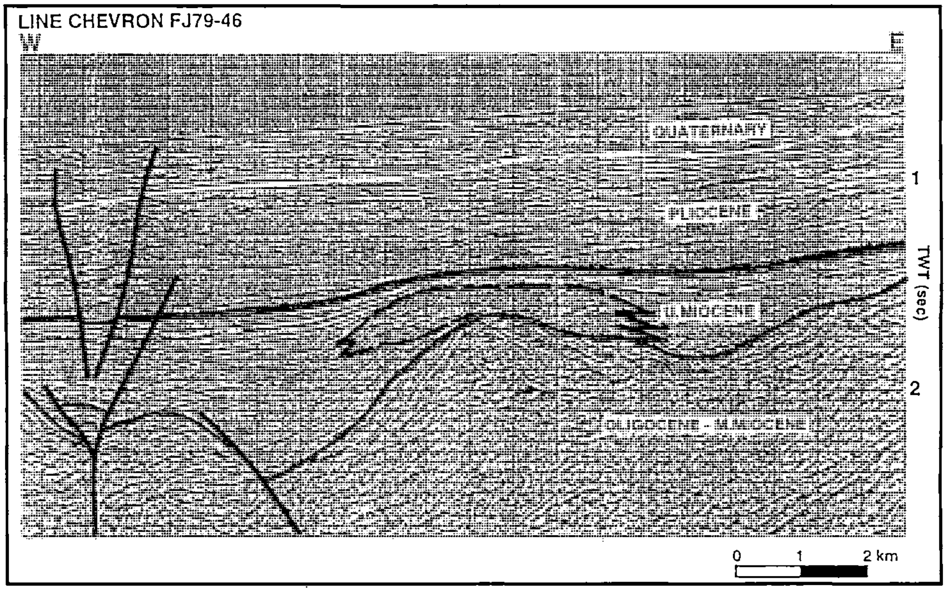

Figure 21. Seismic line Chevron FJ79-46, east Bligh Water Basin. See Figure 17 for location.

provinces worldwide, including Abu Dhabi and Oman in the Middle East, the UK North Sea and the Philippines. In Fiji there are good examples of deep-water limestone turbidites exposed onshore (see Reservoirs). Three limestone turbidite leads have been identified in western Bligh Water Basin (Fig. 17). They form elongate mounds situated down-slope of a palaeo-shelf edge (Figs. 19 and 20). These are thought to be turbidite lobes derived from erosion of reefal mounds situated on the palaeo-shelf edge, an interpretation which is supported by the coincidence of the lobes with a sea-level lowstand at 3.8 Ma (Fig. 13). Such lowstands are known to favour deposition of reef derived turbidite lobes (Sarg, 1988).

The turbidite leads have estimated unrisked recoverable reserves of about 100 million barrels of oil per structure. This could be increased to over 200 million barrels of oil if combined structural-stratigraphic trapping occurs (Table 2). As with the reefal leads, the clustering of structures may result in ultimate cost economies at the development/production stage.

For both the reef play and the turbidite play, key factors of hydrocarbon charge and timing are favourable. In central and eastern Bligh Water Basin, the Late Miocene to Pliocene reef and turbidite leads could have been charged from Oligocene and Miocene source rocks (Fig. 9 and Table 1). In western Bligh Water Basin and in Bau Waters Basin, the Pliocene sequence is buried to depths in excess of 2,000 m, sufficient for Pliocene source rocks to provide oil and gas charge in addition to the Oligocene and Miocene intervals. The timing factor is favourable, since both the reefal and turbidite traps formed in the Late Miocene to Pliocene and could have been subsequently charged by oil and gas from the Late Miocene to present (Figs. 10 and 11).

LEGISLATION

This summary of the Petroleum Legislation of Fiji provides an overview of some of the principal features of the legislation and should not be considered a comprehensive account. Full details of the legislation are available through the Fiji Government Printing and Stationary Department.

The petroleum legislation consists of:

- Petroleum (Exploration and Exploitation) Act, 1978
- Petroleum (Exploration and Exploitation) (Forms and Fees) Regulations, 1979
- Notice of Directions

Revisions to the existing legislation and a new Model Petroleum Agreement are being considered by Government.

The existing legislation covers licences in onshore and offshore areas. The Act sets out definitions, financial provisions, keeping of records and accounts, data provision and confidentiality, rights reserved by Government and various obligations of the company. Ownership and control of petroleum in Fiji are vested in the State. Petroleum exploration and exploitation rights may be granted only by the Government. The basis of all licence agreements is an agreed work program in a specified licence area. The area available for licensing includes the entire Exclusive Economic Zone (EEZ) of Fiji, some 1.3 million km^2. The main prospective offshore areas have been divided into blocks each of which is 6 minutes of latitude by 6 minutes of longitude, or about 117 km^2 per block (Fig. 24). The maximum area permitted for any one licence is 70 blocks or about 8,200 km^2, though more than one license may be held by any one company.

Exploration licences are valid for an initial term of five years after which 50% of the licence area must be relinquished. The company may carry out agreed geological and geophysical surveys, and may drill wells with the consent of the Minister of Lands and Mineral Resources. The licence may then be extended for a further three years after which the remaining licence area must be relinquished.

Following a commercial discovery, a production licence may be granted for a specified number of blocks. Production licences are valid for an initial term of 21 years, with an extension for a further 21-year period. Pipeline licences may be granted for onshore and offshore areas according to agreed technical specifications. These licences are awarded for an initial period of 21 years and may be renewed. All data are held confidential by the government until the licence is relinquished, though summary data of discovery wells may be released after two years.

Government revenue is recovered with Royalty and Corporation Tax. Royalty is 10 to 12.5% depending on the number of blocks in the production licence. Corporation Tax is typically 37.5% for a Fiji Company and 47.5% for a foreign company. In order to encourage development of small fields, proposed revisions to the legislation include a variable royalty, which is determined by the field size.

The fiscal terms are open to negotiation. The Government of Fiji recognises that Fiji is a frontier area and as such is prepared to offer favourable conditions in order to encourage exploration investment.

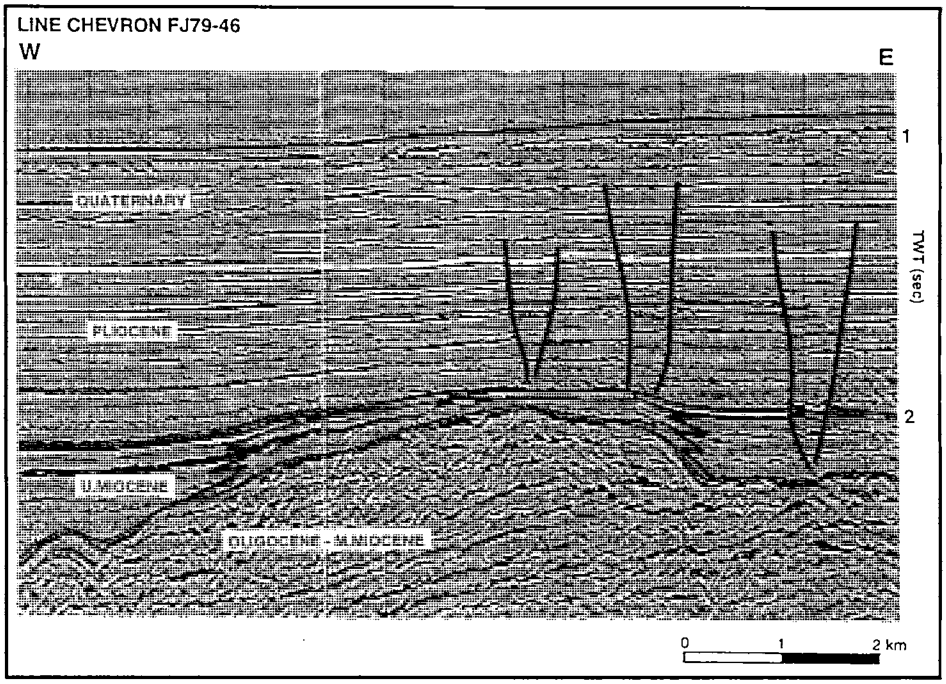

Figure 22. Seismic line Chevron FJ79-46, central Bligh Water Basin. See Figure 17 for location.

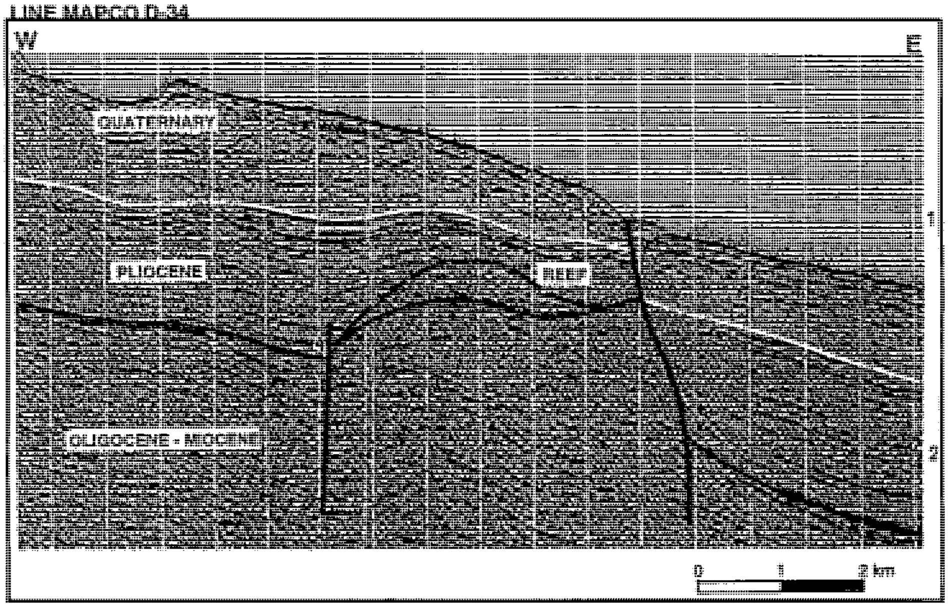

Figure 23. Seismic line Mapco D-34, Bau Waters Basin. See Figure 18 for location.

CONCLUSIONS

1. The same Tertiary reefal carbonates that produce oil and gas in arc-related basins of Southeast Asia are present in Fiji. The reefs form part of a continuous play trend which includes the oil fields of Irian Jaya, Indonesia and the gas/condensate fields of Papua New Guinea. This play has not been tested by drilling in Fiji.
2. The most prospective areas are offshore Bligh Water Basin and Bau Waters Basin, which have shallow water depths (50-500 m) and sediment thicknesses in excess of 5 km.
3. Source rocks of Oligocene, Miocene and Pliocene age occur on the main island of Viti Levu and have been drilled in the offshore basins. An offshore oil seep, together with oil and gas shows encountered in offshore wells, provide conclusive evidence that hydrocarbon generation has occurred.
4. Over twenty reefal leads have been identified on seismic data in Late Miocene and Pliocene intervals in Bligh Water and Bau Waters

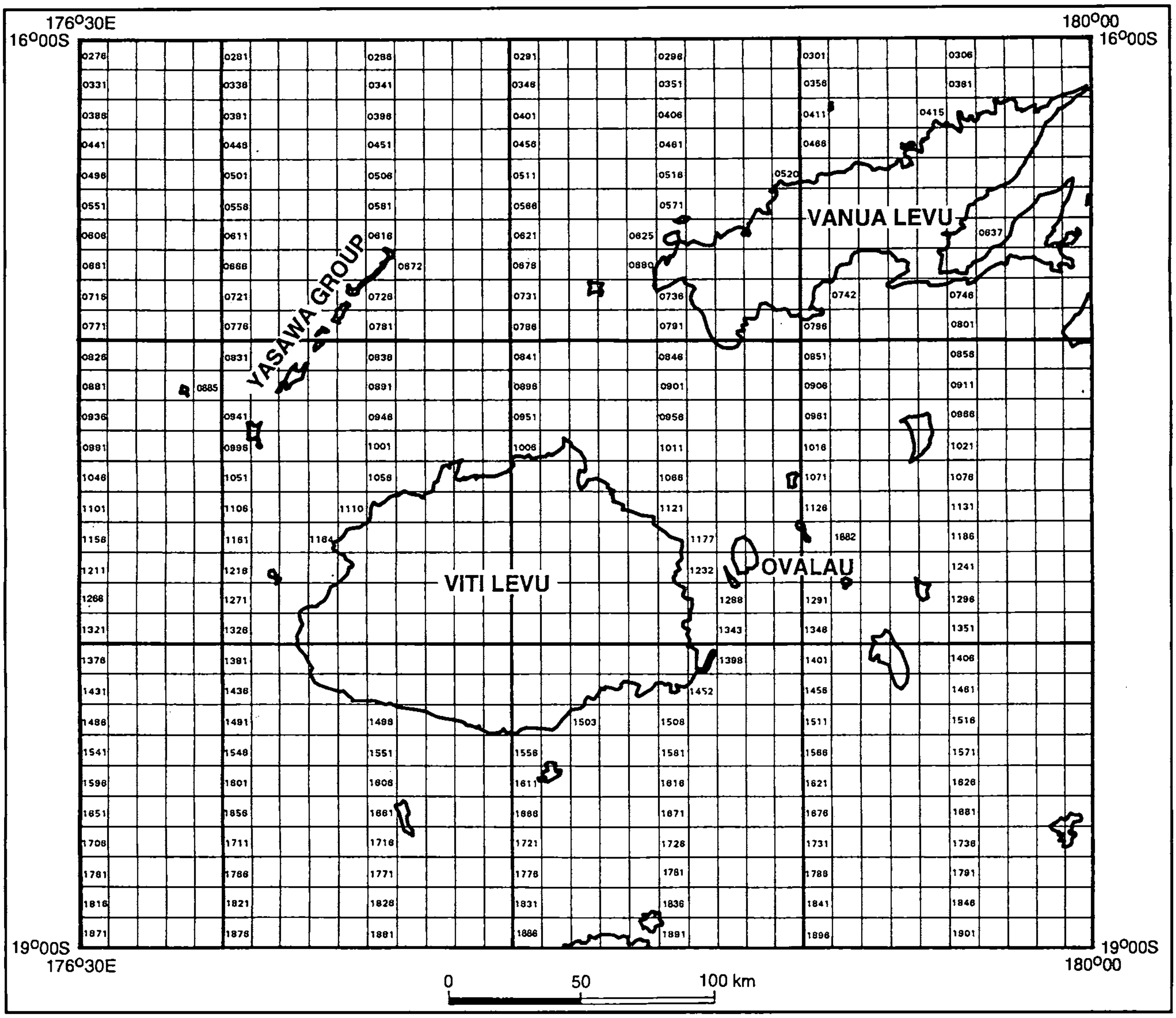

Figure 24. Map of available licence blocks in Fiji. Note only the most prospective part of the area designated for petroleum licencing is shown.

Basins. Limestone turbidite mounds occurring downslope of the reefal mounds constitute a secondary prospective play.

5. There is considerable scope for more reefal and turbidite targets in the deeper Oligocene-Middle Miocene section, which cannot be resolved with the existing seismic data, and in areas where existing seismic coverage is sparse.
6. Estimated potential recoverable reserves for the leads, based on structural closures, are typically 270 million barrels of oil per structure. If lateral seals give rise to combined structural-stratigraphic trapping, recoverable reserves could be more than 1 billion barrels of oil per structure.

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