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# Extensional and vertical tectonics in the New Guinea islands: implications for island arc evolution

I. DAVID LINDLEY

*Department of Earth and Marine Sciences, The Australian National University, Canberra, Australia*

The New Guinea islands region, Southwest Pacific, lies at the frontier of the Australian and Pacific plates and many morphotectonic features are typical of other Western Pacific island arcs. Field geological observations indicate current tectonic models are deficient in key aspects and, from a broader perspective, synthesis of these observations cautions the carte blanche application of plate tectonic theory in similar tectonic provinces. Models generally only account for the last 3.5 Myr (Bismarck Sea opening) of evolution of parts of the region and little is known of Early Tertiary tectonic evolution since the Upper Eocene. The present disposition of slabs of formerly extensive Miocene platform carbonate suggests that New Ireland and New Britain have undergone little more than gentle tilting and uniform uplift, despite location in tectonically dynamic areas, adjacent the New Britain Trench and/or separation by a plate boundary. Major structural corridors present throughout the region have gone unrecognized. They are oblique to existing morphotectonic features, have played a controlling role in localizing igneous activity and mineralization, and have documented long movement histories. Onshore extensional and strike-slip vertical structures in East New Britain show no spatial or genetic relationship to the Bismarck Sea Seismic Lineation (BSSL) and related transforms. High-angle structures predominate throughout the region and indicate major vertical movements of crustal blocks. The nature and timing of movements along many onshore structures indicate that some other major tectonic process has operated (and presently continues) in the New Guinea islands.

## 7.1. INTRODUCTION

This paper presents observations on the geology and tectonics of the New Guinea islands region, Papua New Guinea (PNG), made during the writer's many years (1981-1998) as a resident geologist. These observations indicate that current models for the tectonically complex region are deficient in many key aspects. The region is of interest because it lies at the rapidly and obliquely converging frontier of the Australian and Pacific plates (the Pacific Plate relative to the Australian Plate, is converging at the rate of 13 cm/yr toward the west-southwest) and many morphotectonic features are typical of other Western Pacific Island arcs.

The New Guinea islands encompasses the islands of the Bismarck Archipelago, namely New Britain, New Ireland (and offshore islands including the Feni, Tanga, Lihir and Tabar groups), New Hanover, the St. Matthias group, the Admiralty group (including Manus Island) and Bougainville Island (fig. 7.1). Data used by the writer in the formulation of ideas expressed in this paper has included a) high-quality total magnetic intensity and reduced to the pole aeromagnetics coverage over large tracts of New Ireland and New Britain, obtained by GeoMetrics using a helicopter-borne magnetometer with doppler navigation (1000 and 500 m line spacing; 150 m mean terrain clearance); b) false color Landsat imagery (1:250000 scale) of New Ireland and New Britain; c) USAF wartime and

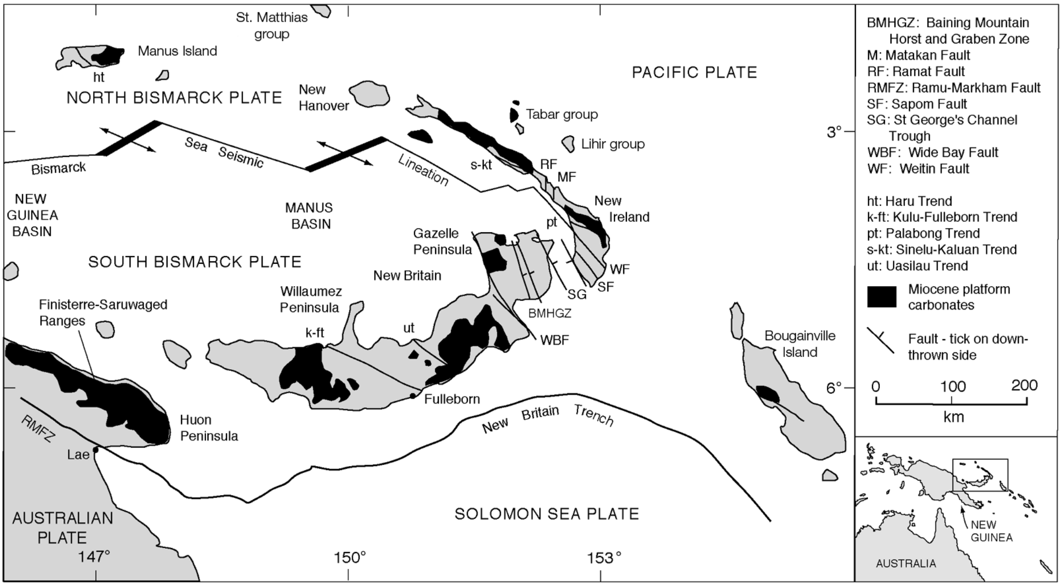


**Fig. 7.1.** Tectonic map of the New Guinea islands, Papua New Guinea, showing major plate boundaries, Tertiary structures and distribution of Miocene platform carbonate sequences.

1:100000 scale (Skaipiksa series) black and white vertical aerial photography of New Ireland, New Britain and Manus; d) field data from many spot helicopter landings (1300 remote sites on the Gazelle Peninsula, Lindley and Weightman, 1983) and 1-7 day field traverses throughout New Ireland and its island groups, New Britain and Manus Island; e) high and low level color vertical aerial photography (1:10000 and 1:26000 scales) of the Central Gazelle Peninsula, and f) detailed traverse geological map coverage of the Central Gazelle Peninsula (1:2500; 1:5000; 1:10000 scales) (Brook, 1983; Lindley, 1997-1998, among others).

## 7.2. Regional geological setting of the New Guinea Islands

Basement in the New Guinea islands is formed by Upper Eocene intermediate and basic pillow lavas, breccias and volcaniclastics with numerous lenses of coralline limestone, outcropping extensively throughout New Britain (Baining volcanics), Manus (Tinniwi volcanics), Bougainville (Atamo volcanics) and the Bewani Mountains (Bliri volcanics), in the Northern Sepik. These rocks are regarded by Madsen and Lindley (1994) as typical of an embryonic island arc, and are overlain by Upper Oligocene volcaniclastic formations and intruded by Upper Oligocene-Lower Miocene dioritic plutons. During the Lower to Middle Miocene thick carbonate sequences accumulated on a platform that extended across much of the region and beyond. The eastern, fault-bounded half of the Gazelle Peninsula was emergent at this time, and shoshonitic andesitic to rhyolitic ashflows sheets covering a 600 km$^2$ area (Nengmutka volcanics) were erupted from a caldera complex. Widespread deposition of fluvial and marine volcaniclastics occurred throughout the New Guinea islands during the Pliocene-Holocene. Raised Pleistocene-Holocene coral reefs fringe many of the islands of the region.

## 7.3. Tectonic setting of the New Guinea islands: an historical perspective

New Guinea and adjacent island arcs are the result of long-continued interaction between the Australian Plate to the southwest and the Pacific Plate to the northeast (Dow, 1977). Johnson and Molnar (1972), Curtis (1973b) and Krause (1973) provided the first comprehensive models for the tectonic evolution of PNG, using plate tectonic theory to document a long history of collision, compression and subduction. These broad tectonic concepts have essentially been adopted with little change by subsequent workers whose contributions have covered a wide range of topics and observations (Jaques and Robinson, 1977; Hamilton, 1979; Johnson, 1979; Taylor, 1979; Ripper and McCue, 1982; Davies *et al.,* 1984; Cooper and Taylor*,* 1987; Pigram and Davies, 1987; Silver *et al.,* 1991; Liu and Crook, 1991, 1993; Brierley *et al.,* 1993; Struckmeyer *et al.*, 1993; Abbott *et al.*, 1994a,b, 1997; Abers and McCaffrey, 1994; Abbott, 1995; Galewsky and Silver, 1997; Whitmore *et al.,* 1997, 1999, among others). To fully understand the reasons why PNG has proved to be fertile ground for applying the plate tectonic paradigm, one needs to appreciate the historical context of mapping activities in country. The first, and only, systematic nation-wide regional geological mapping was conducted between 1956 and 1973 by Australia's Bureau of Mineral Resources, Geology and Geophysics (BMR) and in the latter years, the Geological Survey of Papua New Guinea, and coincided with the emergence and general acceptance of plate tectonics. New Guinea with its numerous island arcs, deep ocean troughs and deformed spine running centrally along the main island, was an ideal place in which to apply the emerging theory.

The tectonic setting of the New Guinea islands is dominated by the Manus and New Guinea Basins, a composite back-arc basin to the New Britain Arc-Trench complex (Taylor, 1979; Taylor *et al.*, 1991a-c; Lisitzin *et al.*, 1992; Crook *et al.*, 1997). Opening of the Manus Basin commenced about 3.5 Myr (Middle Pliocene) by asymmetric sea-floor spreading along the Bismarck Sea Seismic Lineation (BSSL) (Denham 1969) at rates of 7.4 and 5.8 cm/yr to the northwest (North Bismarck Plate) and southeast (South Bismarck Plate), respectively (Taylor, 1979). Individual spreading segments in the basin are offset by a series of east-southeast transform faults. Two transform faults are projected across the «neck» and the northeastern tip of the Gazelle Peninsula, East New Britain (Hamilton, 1979; Taylor, 1979), and one onshore Southern New Ireland (Cooper and Taylor, 1987; Madsen and Lindley, 1994; Tregoning and McQueen, 2001), where it is known as the Weitin Fault.

The arcuate New Britain Arc-Trench complex is located at the presently converging boundary of the Solomon Sea and South Bismarck plates. The volcanoes on New Britain, which form part of the Bismarck Volcanic Arc, are distributed in three distinct groupings in the western, Willaumez Peninsula-Mt. Uluwan and Rabaul areas (Johnson, 1979). The Bismarck Volcanic Arc persists westward along the southern margin of the South Bismarck Plate, where it includes the active volcanoes on Ritter Island, Long Island, Karkar, Manam and Bam. This part of the South Bismarck Plate is in collisional contact with the Australian Plate along the Ramu-Markham Fault Zone (RMFZ). Tregoning *et al.* (1999) estimated that the South Bismarck Plate is rotating clockwise at a rate of $8.11°/10^6$ yr about an absolute pole near Finschhafen (fig. 7.2d). The relative pole for the South Bismarck Plate/Australian Plate lies northwest of Madang and, for the South Bismarck Plate/Solomon Sea Plate inland from the Gulf of Papua (Tregoning and McQueen, 2001) (fig. 7.2d). The predicted rates of convergence of the South Bismarck Plate with the Solomon Sea Plate vary from 8 cm/yr-15 cm/yr, west to east along the New Britain Trench (Tregoning *et al.*, 1998).

The placement of the northern boundary of the North Bismarck Plate and the Pacific Plate is less certain, so much so that Johnson (1979) questioned the existence of the former plate. There is no significant seismicity and arc-type volcanism, as would be expected of a zone of rapid convergence and subduction, to define a boundary, and closure of the eastern 'boundary' of the North Bismarck Plate is difficult to identify, defying a «tenet of the theory of plate tectonics [...] that plate bound-

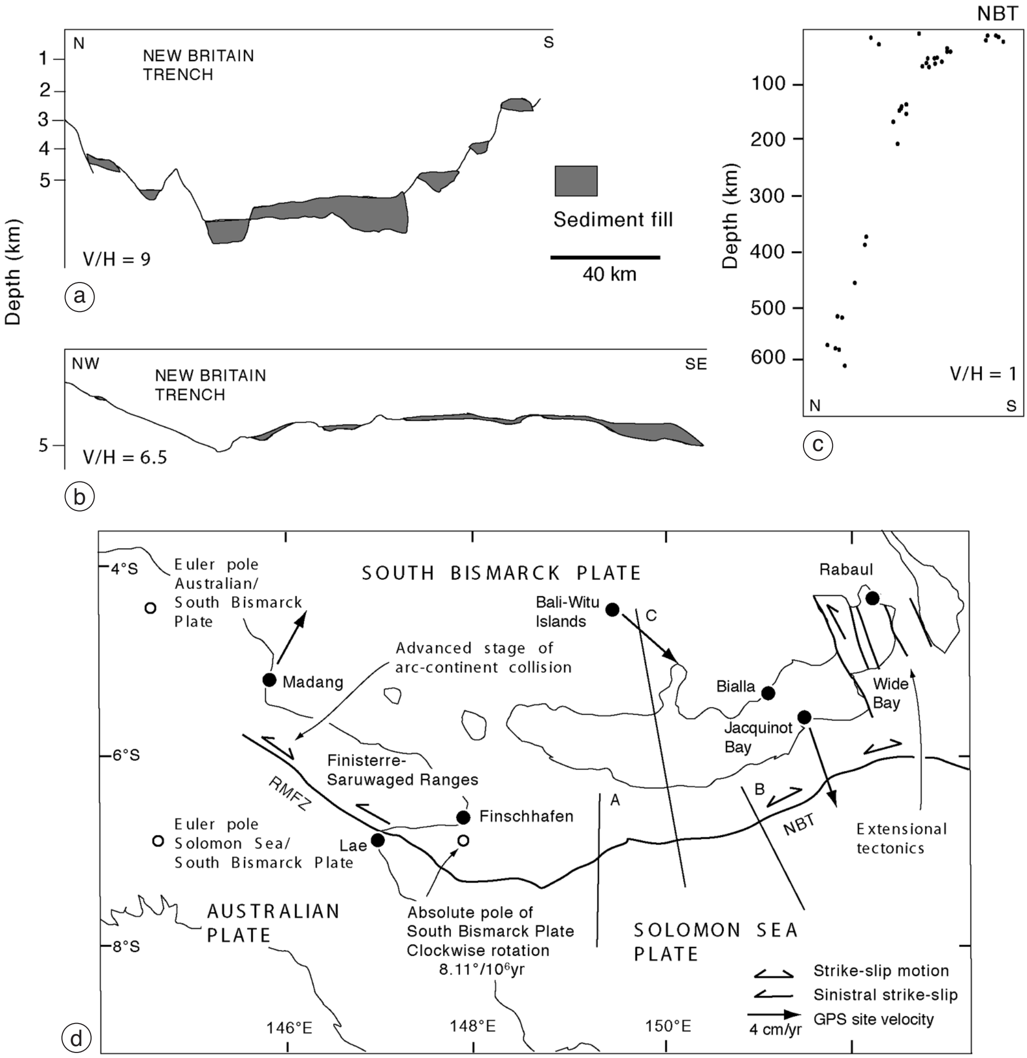


**Fig. 7.2a-d.** New Britain Trench-Ramu Markham Fault Zone. Seismic sparker profiles of the New Britain Trench, after a) Finlayson *et al.* (1976); b) Gulf Research and Development Company (1972), respectively. c) Seismic structure beneath New Britain, width of section ~100 km, after Cooper and Taylor (1987); d) tectonics of the southern margin of the South Bismarck Plate; GPS site velocities and Euler poles after Tregoning *et al.* (1999). NBT, New Britain Trench.

aries must connect with other boundaries» (Johnson, 1979). Although Tregoning (2002) used Global Positioning System (GPS) velocities from three sites (Kavieng, New Ireland; Manus Island; Wuvulu Island, west of Manus Island) to argue the existence of the North Bismarck Plate, he also noted that changing baseline lengths between these sites suggested that they may not lie on the same rigid plate.

## 7.4. Miocene platform carbonates of the New Guinea islands

During the Oligocene to Middle Miocene, extensive tropical to sub-tropical platform carbonate development occurred across a region stretching some 5600 km from southeast Asia through New Guinea to Fiji. During the Late Miocene, onset of tectonic activity along the edge of the Pacific Plate across much of this region resulted in uplift, and the establishment of a discontinuous volcanic arc with an influx of volcaniclastic sediments which may have caused the death of the reef complex. Due to subsequent tectonic dismemberment and dispersal of platform carbonate blocks, very little is known about the Miocene reef complex as an entity, despite its massive size. Only isolated remnants of limestone remain throughout much of the region. However, in the hinterland surrounding, and throughout the New Guinea islands, many large platform carbonate blocks have been preserved intact, and are relatively untectonised (fig. 7.1). Here, blocks of platform carbonate rest unconformably upon the onshore volcanics of New Britain, New Ireland, Manus Island, Bougainville Island and the Finisterre-Saruwaged Ranges. They present excellent markers for crustal movement associated with tectonism.

An examination of table 7.I reveals that the large intact carbonate slabs in the North Bainings, Kol Mountains and Nakanai and Whiteman Ranges of New Britain, and the Lelet Plateau and Hans Meyer Range of New Ireland, despite their location in tectonically dynamic areas adjacent the New Britain Trench and/or separation by a plate bounding transform fault, appear to have undergone little more than gentle tilting or arching and simple, regionally uniform uplift in the order of 1500-1800 m since the Upper Miocene. The present day disposition of Miocene carbonate slabs does not support the significant relative movements between New Ireland and New Britain proposed by Curtis (1973b), Taylor (1979) and Struckmeyer *et al.* (1993). The discrepancy in the height (ASL) of the youngest units in West New Britain, where the Yalam Limestone actually dips gently toward the nearby New Britain Trench (Ryburn *et al.*, 1973), may be explained by erosive removal of the formation (see discussion below).

**Table 7.I.** Stratigraphic and structural details of major slabs of Miocene platform carbonate in New Ireland and New Britain.

| Locality | Limestone unit and age | Height (ASL) of youngest beds | Average dip of unit | Reference |
|---|---|---|---|---|
| Central New Ireland | Lelet Limestone (Lower Miocene-Pliocene) | 1480 m (Lelet Plateau) | 5°NE | Hohnen (1978) |
| Southern New Ireland | Lelet Limestone (Lower-Middle Miocene) | 1871 m (Hans Meyer Range) | ~5°NE | Hohnen (1978); Stewart and Sandy (1988) |
| Gazelle Peninsula | Yalam Limestone (Middle-?Upper Miocene) | 1765 m (North Bainings) | 5°SE | Macnab (1970); Davies (1973); Lindley (1989) |
| Kol Mountains | Yalam Limestone (Lower-?Middle Miocene) | 1520 m | 3°NW | Ryburn (1974); Lindley (1988, 1989) |
| Central New Britain | Yalam Limestone (Lower Miocene--?Upper Miocene) | 1520 m (Nakanai Mountains) | 5°S | Ryburn (1975, p. 12) |
| West New Britain | Yalam Limestone (Lower Miocene--Lower Pliocene) | 640 m (Whiteman Ranges) | ~5°S | Ryburn *et al.* (1973); Ryburn (1976); Findlay and Haig (2002) |

## 7.5. Plate boundaries in the region

Records relating to the location of earthquakes in PNG are available from 1931, but it is only since 1964 that data has been available to permit earthquakes to be located accurately (Denham, 1969; Johnson and Molnar, 1972; Curtis, 1973a; Johnson, 1979). The distribution of earthquakes has been used to define most of the plate boundaries in the New Guinea region (Denham, 1969; Johnson and Molnar, 1972; Curtis, 1973a). More recently, GPS observations since 1990 have been used to constrain movements across these plate boundaries (Tregoning *et al.*, 1998, 1999, 2000; Tregoning and McQueen, 2001; Tregoning, 2002). These plate boundaries represent only those structures that are presently active (since 1964). Earthquake records restricted to such a limited period of observation cannot possibly define all structures associated with either the 3.5 Myr opening of the Manus Basin or the Early Tertiary evolution of the New Guinea islands region. Similarly, observed plate movements relate only to present motion. GPS observations of plate movement have not been reconciled with local geology in a region where high-angle faults are a dominant control on geology and topography. On the Gazelle Peninsula, for example, GPS observations of absolute velocities at several sites (Tregoning, 1999, pers. comm.; Tregoning *et al.*, 2000) are more likely to represent jostling amongst fault blocks of the Baining Mountain Horst and Graben Zone (Lindley, 1988; 1989) than movement of the South Bismarck Plate.

## 7.6. New Britain Trench-Ramu Markham Fault Zone

The New Britain Trench, widely accepted as a compressional feature and subduction zone, is an Upper Miocene-Quaternary structure which parallels the south coast of New Britain (Johnson, 1979; Cooper and Taylor, 1987) (fig. 7.1). Seismic sections indicate the New Britain Trench overlies a steeply-dipping, sub-crustal structure that is traceable to 600 km depth (fig. 7.2c; Denham, 1969; Curtis, 1973a; Cooper and Taylor, 1987). An abrupt 60° flexure in the New Britain Trench occurs at the eastern end of New Britain, between 152 and 154°E, and it passes offshore along the southern coast of Bougainville Island. Denham (1969), Ripper (1970), Coleman and Packham (1976) have all questioned the kinematic difficulties of thrusting one plate under another along such a tightly curved Benioff Zone. The Bougainville segment of the trench forms the convergent margin between the Solomon Sea and Pacific plates. There are no directly observed rates for subduction along the New Britain Trench (Tregoning and McQueen, 2001). The Solomon Sea Plate is being rapidly subducted under the Bismarck Sea and Pacific plates at predicted rates of 8-15 cm/yr and 10-11 cm/yr, respectively (Johnson, 1979; Tregoning *et al.*, 1998).

Wiebenga (1973) synthesized BMR seismic and gravity surveys in the New Britain-New Ireland region and rejected the concept of a compressional origin for the New Britain Trench. He modelled a tensional or rift origin probably beginning in the Early Tertiary. Seismic sparker sections across the New Britain Trench reveal a trough consisting of a series of sediment-filled rift blocks bordered by high-angle (normal) faults (fig. 7.2a,b). The profiles of these sparker sections show remarkable resemblance to several sections across the St. George's Channel-Bismarck Sea trough, separating the Gazelle Peninsula and Southern New Ireland (Brooks *et al.*, 1971). The southeastern-most sparker section (Brooks *et, al.* 1971, section G-H), indicates a feature that is an extensional graben (fig. 7.3).

The currently accepted plate tectonic paradigm for New Britain presents conflicting upper plate responses to subduction along the New Britain Trench. The present-day configuration of New Britain island, with raised Quaternary reef rimming the south coast and swampy alluvial plains along the north coast, suggests possible foundering to north, sympathetic with compressive uplift associated with trench subduction. However, as noted above, the platform carbonate slab in West New Britain dips toward the New Britain Trench, counter to the north foundering of the island. From the same area in West New Britain, Pain and Specht (1985) presented evidence from accurately dated cave de-

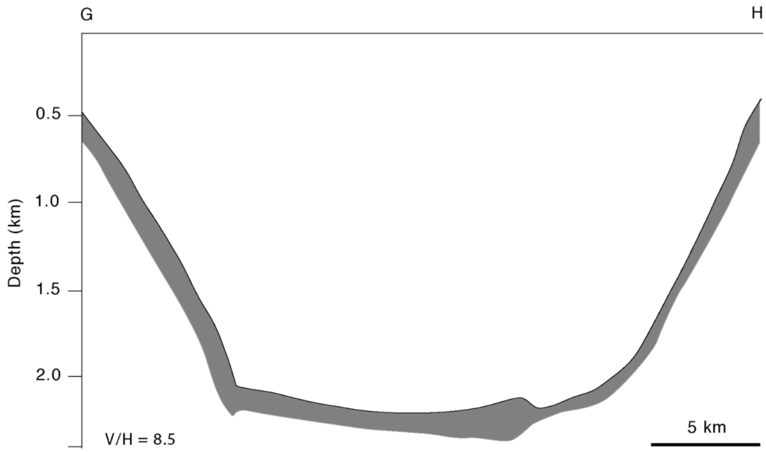


**Fig. 7.3.** St. Georges's Channel Trough, between New Ireland and New Britain. Sparker profile across the St. George's Channel showing graben-like structure. After Brooks *et al.* (1971). See fig. 7.5 for location of section.

posits in Missil Cave of very little, if any, tilting of the cave during the Late Pleistocene-Holocene (a 0.128 Myr period). Their results do not rule out the possibility of vertical tectonic movement during this period. This is a surprising result considering that during this period, at the current rapid rates of convergence along this segment, approximately 10-19 linear km of oceanic crust, with an estimated 10-15 km thickness (Wiebenga, 1973), have apparently been subducted under the island of New Britain.

The RMFZ is the western landward extension of the New Britain Trench (fig. 7.1). Convergence is presently occurring along the fault zone, which marks the collision between the Australian and South Bismarck plates (Cooper and Taylor, 1987; Silver *et al.*, 1991; Abers and McCaffrey, 1994; Whitmore *et al.*, 1997, 1999). Tregoning *et al.* (1998) calculated rates of convergence varying between ~2.9-5 cm/yr. In response to this arc-continent collision, the Australian Plate is presently being subducted, resulting in the uplift of the Finisterre-Saruwaged ranges, and forming a series of linear north-northeasterly tilted (45-50°) fault blocks of Miocene carbonate in a 200 km long by 20-30 km wide belt (Robinson, 1974, fig. 5; Dow, 1977). Robinson (1972, 1974) mapped abundant evidence of southeast-trending sinistral faults in the Rawlinson Range north of Lae and, like Dow (1977) and Hamilton (1979), regarded the RMFZ as a sinistral strike-slip fault. Abers and McCaffrey (1994) noted that strike-slip faulting within the Finisterre-Saruwaged Ranges is significant. Stevens *et al.* (1998) noted 20 cm of co-seismic slip across the RMFZ during a limited 6 month period of observation in 1993-1994.

While Tregoning and McQueen (2001) studied only earthquakes related to thrusting along the New Britain Trench-RMFZ, earthquake focal mechanism solutions reported by Ripper (1970), Denham (1973) and Curtis (1973b) have shown a mix of strike-slip and dip-slip solutions. Strike-slip movement was recorded by Denham (1973) and Curtis (1973b) from shallow earthquakes (58-65 km) along the New Britain Trench at Jacquinot Bay and Wide Bay (fig. 7.2d). Sinistral strike-slip motion and arc-normal tensional stresses were associated with the $M_s$ 7.1 Bialla, Central New Britain, earthquake of 1985 (Mori *et al.*, 1987). Along the RMFZ, Ripper (1970) determined strike-slip movements for both of two earthquakes studied (fig. 7.2d). Abers and McCaffrey (1994) provided solutions to all shallow (< 50-75 km) earthquakes between 1963-1992 on the Huon Peninsula, and noted that shallow and high-angle thrust and strike-slip faulting is associated with the RMFZ.

The foregoing discussion indicates that movement along the New Britain Trench-RMFZ structure documents a history of alternating regimes of compression and extension. Such alternating regimes are characteristic of major strike-slip systems (Reading, 1980). Clockwise rotation of the South Bismarck Plate, accommodated by thrust and strike-slip movements along the curvilinear RMFZ-New Britain Trench, adequately accounts for the observed structures along the southern edge of the plate. The generally younger arc-continent collision at the western end of the Finisterre-Saruwaged Ranges (Abers and McCaffrey, 1994) is occurring at the western, leading edge of the rotating South Bismarck Plate, while the extensional tectonics of the Gazelle Peninsula-Southern New Ireland is occurring at the eastern, trailing edge of the plate (fig. 7.2d). The concentration of thrust and strike-slip faults on the Huon Peninsula (Abers and McCaffrey, 1994) is readily explained by the area's situation at the absolute pole of the rotating South Bismarck Plate and the abrupt flexure of the New Britain Trench-RMFZ.

## 7.7. Weitin Fault, Southern New Ireland

The Weitin Fault is an example of a structure seen on the ground by few, but used by many as a key element of their tectonic models (figs. 7.1 and 7.5). The structure is widely accepted as a transform fault at the eastern end of the BSSL, separating the Pacific and South Bismarck Sea plates (Johnson, 1979; Taylor, 1979; Exon *et al.*, 1986; Cooper and Taylor, 1987; Stewart and Sandy, 1988; Madsen and Lindley, 1994; Tregoning *et al.*, 1998). The northwest-southeast trending fault has had a major impact on the topography of Southern New Ireland, with the deeply incised Weitin and Kamdaru Rivers forming flat-floored valleys up to 2 km wide. Shallow earthquake (0-49 km) distribution in the area since 1964 is widely scattered (Geological Survey of PNG, no date) and the fault cannot be followed with certainty beyond the southern coast of New Ireland (Taylor *et al.*, 1991a).

Despite the apparent importance of the Weitin Fault as a transform and plate boundary, there is no consensus on a sense of movement. French (1966) demonstrated sinistral movements on the fault using the displaced courses of small tributaries of the two rivers. However, Hohnen (1978) was not convinced by his argument, because the large volumes of gravel carried by the braided streams would quickly mask any movement (fig. 7.4). Johnson (1979) considered that earthquake focal-mechanism solutions and the overall trend of the earthquake zone were consistent with sinistral motion along the Weitin Fault. Stewart and Sandy (1988), by matching apparently similar geology at Kamdaru on the southwestern side of the fault, with that at Cape Siar, on the northeastern side, argued the case for dextral movement, indicating about 50 km of offset. Mori (1989) described several earthquakes from the area, and noted that fault plane solutions suggested a mix of sinistral and thrust movements along a rupture of ~50 km length. Tregoning *et al.* (1998) used several days of GPS observations in 1992 and 1996 on the remote (to the Weitin Fault) Nuguria and Carteret Islands to compute an expected relative motion for the block to the north of the fault of 13 cm/yr at a bearing of 316°, interpreted as sinistral movement.

The remarkably linear trace of the Kamdaru and Weitin valleys suggests the Weitin Fault is a vertical structure. Field observations by the writer in 1991 along both rivers indicates the geology of both the valley floors and along the lower reaches of tributaries consists of relatively soft, crushed rock developed on crystal tuff, porphyritic lava and bedded volcaniclastic sandstone of the Lower-Middle Oligocene Jaulu volcanics. There is a noticeable absence of slickensided surfaces in the crush rock, as well as extensional calcite ± quartz vein fillings and in-situ igneous dyking or float derived from igneous (dyke) sources. Extensive mass-wasting occurs on the steep slopes developed on this geology. The geology of the Great Glen Fault is a suitable analogue for the Weitin Fault, assuming the latter is a similar fundamental structure. Kennedy (1946) noted similar deeply incised valley systems developed on a broad (1.6 km wide) belt of crushed, sheared and mylonitized rock. He deduced that

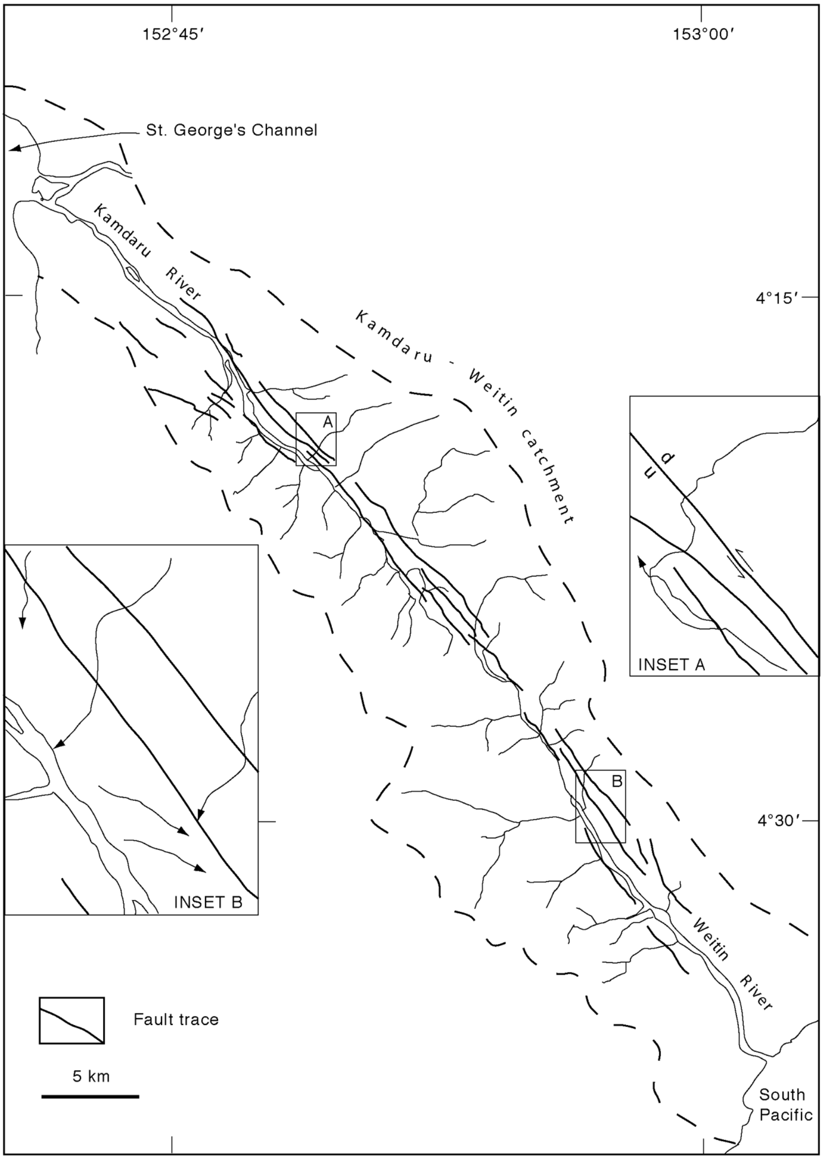


**Fig. 7.4.** Weitin Fault, Southern New Ireland, showing trace of fault, topography and evidence used by Hohnen (1978) to tentatively suggest sinistral fault movement (after Hohnen, 1978).

the structure was steeply inclined because of the rectilinear character of the fault trace and vertical subsidiary fractures. Although dyking was not observed within the crush-zone, the pattern of the distribution of dyke swarms found on both sides of the Great Glen Fault was interpreted by Kennedy (1946) to indicate a genetic link between igneous activity and faulting. Distinct differences between

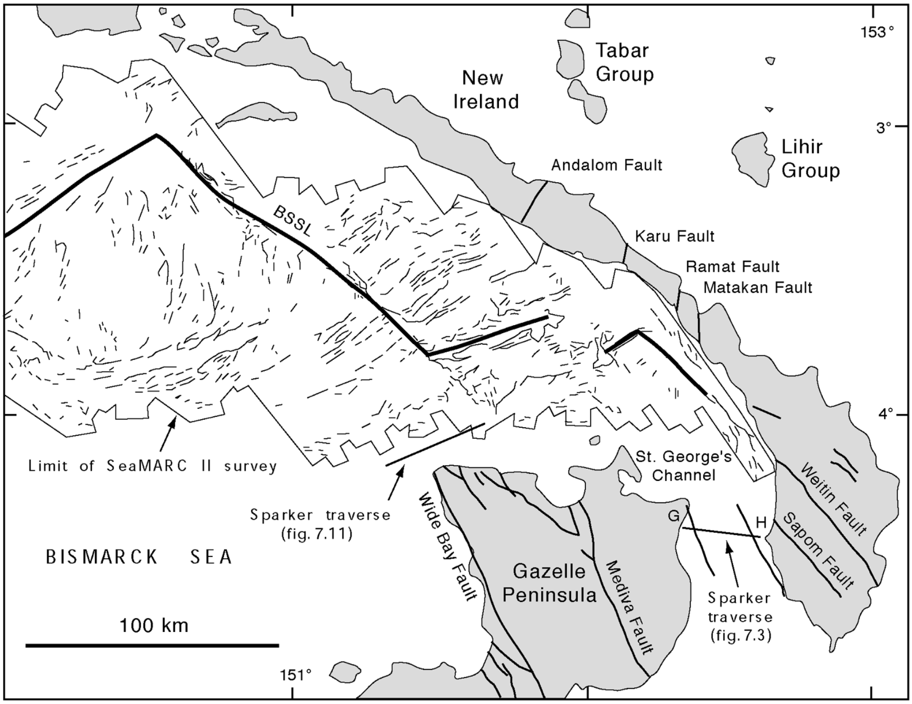


**Fig. 7.5.** Map showing onshore structures of the Gazelle Peninsula and New Ireland and those interpreted from SeaMARC II sidescan backscatter data in the Eastern Bismarck Sea. BSSL, Bismarck Sea Seismic Lineation (BSSL). SeaMARC II backscatter data from which lineations have been picked are from Taylor *et al.* (1991 a-c). Modified after Madsen and Lindley (1994).

the Great Glen and Weitin faults are the lack of slickensiding, mylonites and any clear relationship with igneous dyking in the latter.

There is little field evidence of prolonged strike-slip movement within the crush-zone of the Weitin Fault. Within major strike-slip fault systems, faults die out and motion may be taken-up by an adjacent, side-stepping, parallel fault (Reading, 1980). Mori (1989) deduced that the rupture along the Weitin Fault was about 50 km long. The fault cannot be traced offshore of Southern New Ireland (Taylor *et al.*, 1991a). The wide scattering of shallow (0-49 km) earthquakes in the vicinity of the Weitin Fault indicates that movement is being transferred across a number of faults, most notably the flanking Sapom Fault and faults along the eastern margin of the St. George's Channel trough.

## 7.8. Predominance of an intense vertical faulting in the New Guinea islands

The New Guinea islands is characterized by an intense steeply-dipping fracturing evident at all scales, from prospect to regional. North trending horst and graben structures predominate across a broad zone in the New Ireland-New Britain region (fig. 7.5). A graben (St. Georges's Channel-Bismarck Sea Trough; fig. 7.3) separates New Ireland from New Britain (Brooks *et al.* 1971) and the

Gazelle Peninsula is dissected by the Baining Mountain Horst and Graben Zone (BMHGZ), a wide zone of north-northwesterly trending horst and graben structures, indicative of an extensional tectonic regime since the Lower Miocene (Lindley, 1988, 1989; Madsen and Lindley, 1994). Madsen and Lindley (1994) have shown that some of these structures (Wide Bay Fault – WBF, and Mediva Fault) are deep-seated and continue through the crust. Between the WBF and the BMHGZ lies a block with an average depth to mantle of 18 km; to the east of the BMHGZ the average depth to mantle is greater than 30 km (Wiebenga, 1973). Clearly, the presence of such deep-seated vertical faults in the New Guinea islands is suggestive of great vertical and lateral movement of crustal blocks, a fact acknowledged by Coleman and Packham (1976).

Elsewhere in New Britain, Ryburn and Little (1971), Ryburn (1971) and Ryburn *et al.* (1973) have recorded normal faults of varying orientations throughout the Nakanai Range, Kol Mountains and Whiteman Range, respectively. The Ania River, on the south coast, is confined to a northwest trending, 10 km wide graben, with bounding faults having a maximum throw of 300 m (Ryburn, 1975).

At prospect (1:500 to 1:2500) and semi-regional (1:5000 to 1: 20000) scales on Manus Island, New Ireland and New Britain, the writer has mapped structure dominated by high-angle normal faults. Low-angle reverse faulting has not been observed. In the Central Gazelle Peninsula, well-developed north-northeasterly extensional joint sets of Upper Oligocene-Lower Miocene age, are traceable for a distance of some 26 km through the Nengmutka River region (fig. 7.10). These tensional gashes have been filled during multiple episodes of quartz veining, forming vein structures up to 40-50 m wide (Nengmutka vein system: Lindley, 1998).

## 7.9. Tabar, Lihir, Tanga and Feni Island groups

The Tabar, Lihir, Tanga and Feni Island groups consist largely of Plio-Pleistocene undersaturated alkaline volcanics. With no underlying Benioff Zone, no satisfactory explanation has been proposed for the origin of these rocks. Bathymetry shows that the Tabar, Lihir and Tanga groups lie atop elongate northward ridges (up to 170 km long; fig. 7.6) and there is little doubt that the northerly trending faults mapped onshore Central New Ireland by Hohnen (1978) are controlling structures in the development of these islands (Exon *et al.*, 1986; Shatwell, 1987; Lindley, 1988). Hohnen (1978) described a series of north-trending high-angle normal faults in Central New Ireland, *viz.* the Andalom, Lelet, Ramat and Matakan faults, with minor to considerable movements (fig. 7.6). The Andalom Fault appears to have been active since the Lower Miocene, and the Ramat Fault, with right-lateral strike slip of 6 km, is considered a Pleistocene-Holocene structure (Hohnen, 1978). The predominance of vertical structuring along the Tabar and Lihir ridges is evident in the seismic reflection profiles of Exon and Marlow (1990, fig. 7.7).

Highly undersaturated volcanic activity occurs when tectonic processes tap the low-velocity zone of the mantle (Green, 1972). It is likely that east-west extension in the offshore New Ireland region has allowed the high-level emplacement of undersaturated magmas along a series of active northerly structures. The documented Lower Miocene movement along the Andalom Fault suggests structuring was in place prior to the Middle Pliocene opening of the Bismarck Sea.

Volcanism has all but ceased on the islands, although very young, thick tephra deposits ($^{14}C$ dated eruption of 2300 year: Licence *et al.*, 1987) occur on the Feni group. The maintenance of deeply-sourced igneous activity, such as that which occurred during the Plio-Pleistocene, is difficult to reconcile with the region's present location at the rapidly (13 cm/yr: Tregoning *et al.* 1998) and obliquely converging edge of the northwest moving Pacific Plate. The northerly structurally controlled ridges underlying the Tabar, Lihir and Tanga groups suggests that a more likely scenario for the control of igneous activity is localization at a plate edge under the influence of east-west tensional stress.

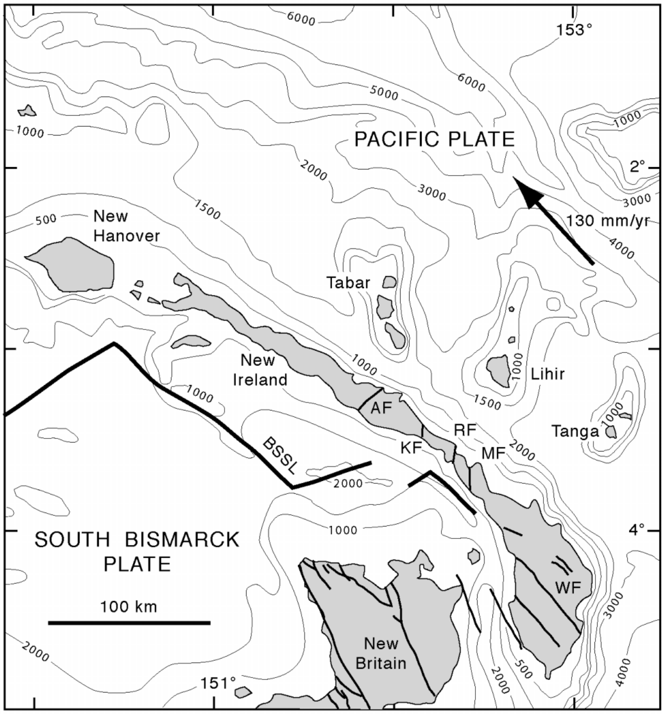


**Fig. 7.6.** Map showing the location of the Tabar, Lihir and Tanga Groups on northerly trending ridges at the advancing margin of the Pacific Plate, and their relationship to onshore structures of New Ireland. AF–Andalom Fault; KF–Karu Fault; RF–Ramat Fault; MF–Matakan Fault; WF–Weitin Fault; BSSL–Bismarck Sea Seismic Lineation. Absolute velocity vector after Tregoning *et al.* (1998). Modified after Exon and Marlow (1990). Isobath interval 500 m, isobaths in metres.

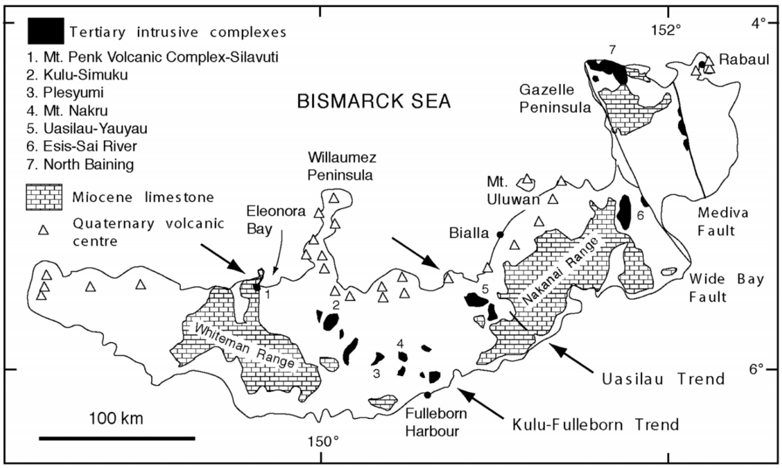


**Fig. 7.7.** Simplified geology map of New Britain showing the Kulu-Fulleborn and Uasilau trends and other structures, distribution of Miocene limestone and Quaternary volcanic centers.

## 7.10. Structural alignment of Tertiary intrusive complexes, New Britain, New Ireland, Manus Island

The structural alignment of Tertiary intrusives in New Britain, New Ireland and Manus Island has gone unrecognized. These fossil structural zones have clearly played a major role in the pre- , and in many cases post-, Bismarck Sea opening geological history of the New Guinea islands. All have localized the emplacement of copper ± gold mineralized intrusives, ranging in age from Oligocene-Pliocene, have long movement histories which may range through to the Holocene, and are oblique to existing major morphotectonic features, such as the New Britain Trench and structural elements associated with the Middle Pliocene-Recent opening of the Bismarck Sea. The well-exposed and clearly defined, long-lived Kulu-Fulleborn Trend forms a model for the interpretation of similar zones elsewhere in the New Guinea islands.

The arc-normal alignment of active and extinct Quaternary volcanoes over a distance of 75 km, to the south of and along the Willaumez Peninsula, West New Britain (Johnson, 1975; Ryburn, 1975), may represent a modern analogue for these fossil structural zones. Northerly trending extensional faults along the peninsula were interpreted by Ryburn (1975) to represent east-west crustal tension, and he concluded that the peninsula developed in a north-trending rift zone. The Willaumez structure intersects the Kulu-Fulleborn Trend at a 30° angle, and no comparable north-trending structures can be seen south of the intersection.

### 7.10.1. Kulu-Fulleborn Trend (new name), West New Britain (= Kulu-Metelin belt: Hine and Mason, 1978)

The Kulu-Fulleborn Trend is the name proposed for an alignment or corridor of Upper Oligocene-Pliocene intrusives and volcanics in West New Britain (fig. 7.7). The trend has a strike length of 150 km and a width of 25 km, and passes northwest-southeast (~300°M across West New Britain, from Eleonora Bay on the north coast to Fulleborn on the south coast. The orientation of the clearly defined trend is of particular interest, in that it is oblique to all major morphotectonic elements of the region, including the island of New Britain, the New Britain Trench and the BSSL. The trend has a documented long history of igneous activity with significant (~1000 m) vertical movement.

An interpretation of the free air gravity data and crustal depth studies of Wiebenga (1973) and Finlayson and Cull (1973) indicate the Kulu-Fulleborn Trend is a fundamental structural boundary of sub-crustal extent. An abrupt thickening of crust from 15-20 km to 40 km depth occurs in a southwestern direction across the structure (fig. 4 in Wiebenga, 1973) and the trend forms the western boundary of a large +200 mgal free air gravity anomaly (fig. 6 in Wiebenga, 1973; fig. 4 in Finlayson and Cull, 1973) which underlies Central New Britain. The eastern boundary of this gravity anomaly is the WBF, another sub-crustal structure with significant strike-slip and vertical movement (see later discussion). Wiebenga (1973) accounted for the Central New Britain anomaly as a major extensional fracture in the crust through which higher density material has risen toward the surface.

Many Upper Oligocene and Pliocene dioritic intrusives are localized in the Kulu-Fulleborn Trend and host porphyry copper, skarn and gold mineralization (Mackenzie, 1975; Titley, 1978; Macmin Silver Limited, unpublished data; Indo-Pacific, unpublished data). Significant zones of mineralization (and their ages) include, from the northwest, Kavola East Prospect (Pliocene; epithermal gold), Kulu-Simuku porhhyry copper system (Upper Oligocene; copper, gold), Plesyumi porphyry copper (Upper Oligocene; copper), Mt. Nakru Prospect (?Lower Miocene; gold, copper) (Mackenzie, 1975; Hine and Mason, 1978; Titley, 1978). The Upper Oligocene intrusives comprise large sub-batholithic bodies and smaller stocks, with the long axes of many of the bodies trending northeast, orthogonal to the main trend (Hine and Mason, 1978). Local structural controls, superimposed on the prominent northwest trend, have clearly controlled Upper Oligocene emplacement. There is a general decrease in age of igneous activity in a northwest direction along the trend. This corresponds with a shallowing in the depth of formation of mineralization, from the deeper porphyry coppers at Kulu-Simuku and Plesyumi, to relatively shallow epithermal mineralization at Kavola East.

The Kulu-Fulleborn Trend separates the Miocene carbonate slab of the Whiteman Range (to the immediate west) from that farther east in the Nakanai Range (fig. 7.1). Post Middle Miocene vertical movements along the structure readily account for the approximately 1000 m observed discrepancy in the topographic height of the youngest units (table 7.I) in these two areas. This estimate does not take into account erosive removal of much of the Whiteman Range sequence, where only 500 m thickness is preserved, compared with that in the Nakanai Range (1300 m thickness preserved) (Ryburn, 1975, 1976). The lack of any obvious displacements of the New Britain coastline suggests the Kulu-Fulleborn structure is not presently active.

## 7.10.2. Uasilau Trend (new name), Central New Britain

The Uasilau Trend lies to the east of the Kulu-Fulleborn Trend and strikes northwest-southeast (300°M) across New Britain. The southeasterly course of the Torlu River, on the southern fall of the Nakanai Mountains, is confined to the structure and a high-angle fault parallels much of the river's course (Ryburn, 1976). The fundamental sub-crustal nature of this structure is clearly reflected by regional Bouger anomalies (fig. 3 in Ryburn, 1975). The structure corresponds with high gradients at the northeastern boundary of a major +195 mgal anomaly. Ryburn (1975) concluded that such major anomalies were difficult to reconcile with surface geology and were probably related to deep crustal or upper mantle structure.

The Uasilau Trend has localised several large Oligocene dioritic intrusions. The controls on emplacement are reflected by the elongation of the largest intrusion, a sub-batholithic body with a long axis of 17 km, in the trace of the structure. This intrusion is host to porphyry copper mineralization at the Uasilau and Yauyau prospects. Several smaller stocks are associated with copper-bearing skarns (Pelapuna Prospect). Quaternary volcanism, localized at the northwestern extremity of the Uasilau Trend, is indicative of the the structure's longevity.

## 7.10.3. Mediva Fault, East New Britain

The Mediva Fault passes north-northwesterly across the Central Gazelle Peninsula, East New Britain (fig. 7.5). Detailed mapping by the writer (in Madsen and Lindley, 1994) has shown that almost all tonalite stocks of the Arabam Diorite abut against the fault, clearly indicating fault-controlled emplacement of the Middle Miocene intrusive. Reactivation of the fault after emplacement of the stocks has resulted in fault truncation and their eventual unroofing. Recent movements continue along the Mediva Fault, with Late Pleistocene beds ($^{14}C$ dated at 50000 year) tilted through 60° (Macnab, 1970) and the displacement of the recently erupted (1400 year) Rabaul Ignimbrite. Weak porphyry copper mineralization is known from some stocks of the Arabam Diorite. As noted above, the fault is an element of the BMHGZ, a deep-seated structure with sub-crustal extent. The long-lived currently active structure pre-dates the Middle Pliocene commencement of the opening of the Bismarck Sea, and is not obviously related to any structures associated with the BSSL (Madsen and Lindley, 1994).

## 7.10.4. Palabong Trend (new name), Southern New Ireland

The Palabong Trend is named for a zone of Lower-Middle Oligocene and Middle Miocene dioritic intrusives of the Lemau Intrusive Complex, which strikes northwest-southeast across the Hans

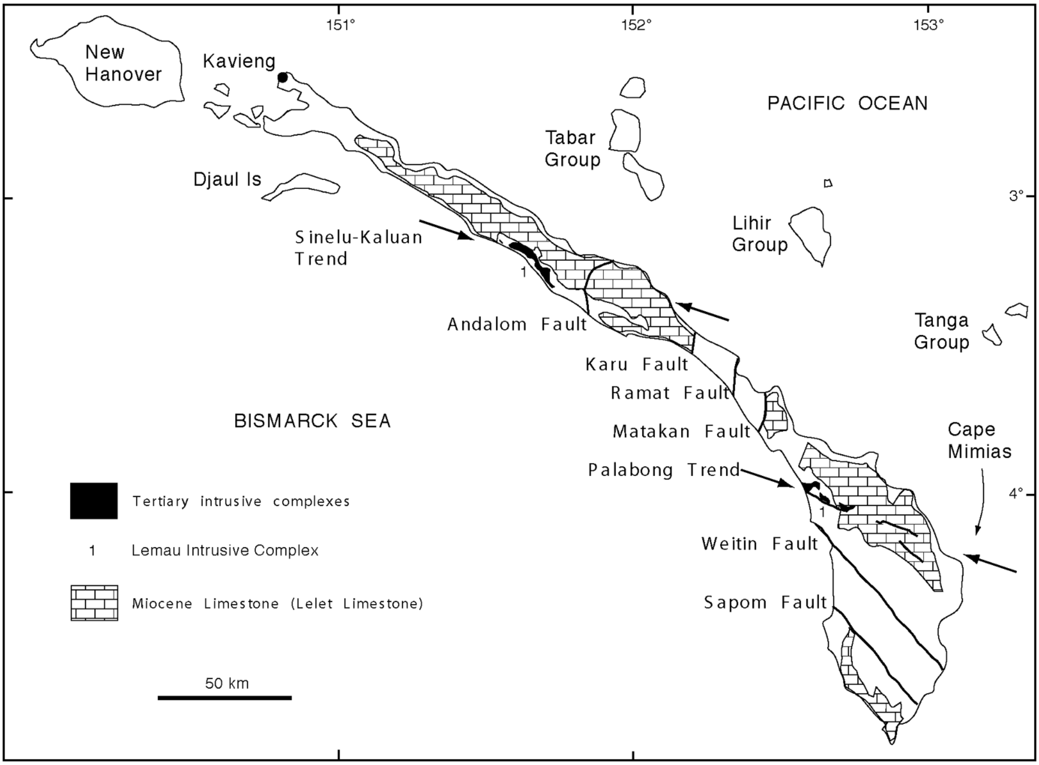


**Fig. 7.8.** Simplified geology map of New Ireland showing the Sinelu-Kaluan and Palabong trends and other structures and distribution of Miocene limestone.

Meyer Range of Southern New Ireland (fig. 7.8). The Palabong Trend has a strike length of 75 km and width of 8 km and extends southeasterly from Palabong village on the west coast of New Ireland, to near Cape Mimias on the east coast. The trend lies near the southern structural boundary of carbonates of the Lower to Middle Miocene Lelet Limestone, evidence for post-Miocene movement. Intrusive stocks are elongated in the direction of the trend, and Hohnen (1978) noted that norite from the headwaters of the Hirudan River has a weak foliation, developed during intrusion. Younger phases of the intrusive complex may have intruded the base of the limestones (Hohnen, 1978; Mitchell and Weiss, 1982). Weak porphyry copper-style mineralization occurs in stocks outcropping near Palabong. The trend is oblique to the nearby Weitin Fault, a transform at the eastern end of the BSSL, suggesting it to be a structure pre-dating and unrelated to the opening of the Bismarck Sea.

## 7.10.5. Sinelu-Kaluan Trend (new name), Central New Ireland

The Sinelu-Kaluan Trend is another obliquely trending, northwest-southeast structural zone, which has localized dioritic intrusives of the Lemau Intrusive Complex (fig. 7.8). The trend can be traced over a strike length of 75 km in Central New Ireland. The structural corridor, in part masked by Middle Miocene limestones of the Central New Ireland carbonate slab (table 7.I), is host to several stocks, the largest of which (partly obscured) measures 20×4 km. There are numerous other smaller stocks of 1-2 km size. By comparison with the Kulu-Fulleborn Trend, it is likely that the structural corridor has localized the emplacement of Lower-Middle Oligocene and Miocene intrusives. Porphyry copper mineralization has been investigated at the Legusulum, Kaluan and Sinelu porphyry prospects (Mitchell and Weiss, 1982). The timing of igneous events along the Sinelu-Kaluan trend indicates it is unrelated to elements associated with the BSSL. Much of the trend lies juxtaposed to the (offshore) flanks of the eastern-most spreading zone segment of the BSSL, but there is no obvious relationship between the two structures.

## 7.10.6. Haru River Trend (new name), Manus Island

The Haru River Trend is named for a zone of elongated intrusives and similarly trending faults which strike northwest-southeast from coast to coast, across Central-Western Manus Island (fig. 7.9). Prominent northwesterly faults and fractures flank the Haru River Trend (Jaques, 1975), and Jaques (1980) believed many of them to be transcurrent faults, although displacement could not be demonstrated. The northwest elongation of the multiphase, Late Lower-Middle Miocene, Yirri Intrusive Complex, measuring some 25×9 km, indicates Miocene fault activity influenced emplacement. The intrusive complex hosts several porphyry copper mineralized bodies, including the Mt. Kren, Arie and Aniwea porphyry prospects, and widespread low grade gold mineralization of the Metwarei Prospect. At Mt. Kren copper mineralization is mainly confined to vertical shear zones (Australian Anglo-American Ltd., 1975). The Haru River Trend is located about 100 km north of the western-most spreading segment of the BSSL (fig. 7.1). The localization of Miocene intrusive activity clearly indicates the structure predates the opening of the Bismarck Sea.

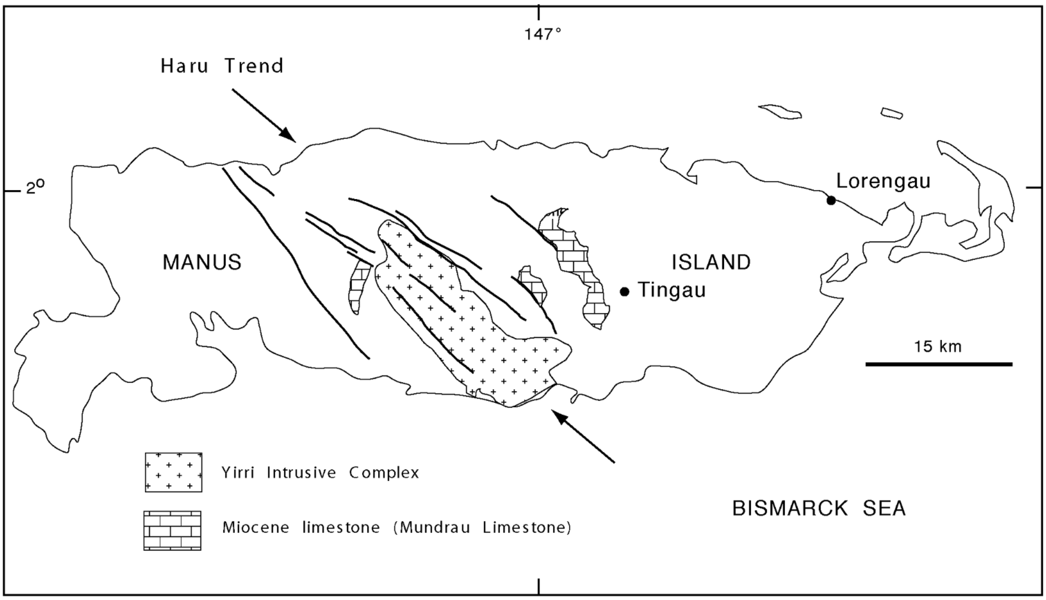


**Fig. 7.9.** Simplified geology map of Manus Island showing the Haru Trend and distribution of Miocene limestone.

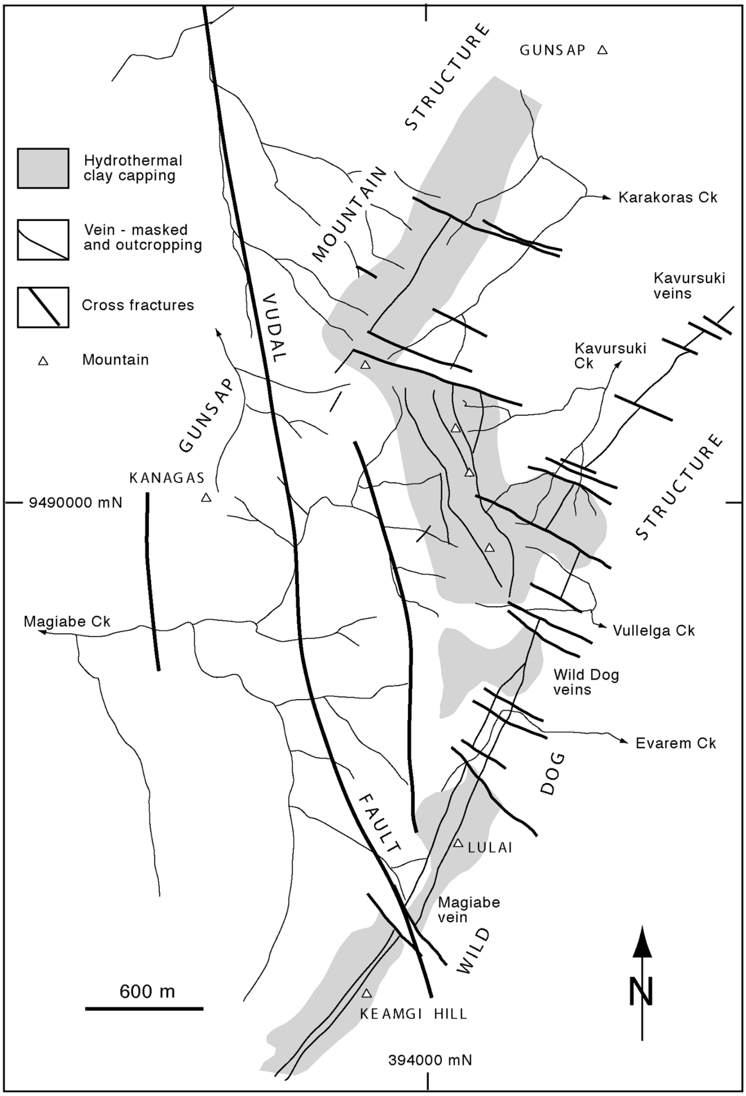


**Fig. 7.10.** Map showing the north-northeasterly trending Lower Miocene Nengmutka vein system, Gazelle Peninsula, East New Britain, and relationship to structures of the post Lower Miocene-Quaternary north-north-westerly trending Baining Mountain Horst and Graben Zone (Vudal Fault, etc.) (after Lindley, 1998).

## 7.11. Contrasting tectonic regimes

Detailed regional mapping and an understanding of the structural controls to long vein quartz mineralisation has resulted in the discrimination of two contrasting tectonic regimes on the Gazelle Peninsula, *viz.* an (at least) Lower Miocene period of north-northeasterly structuring, and a subsequent period of extensional tectonism which has persisted from the Lower Miocene to present (Lindley, 1998).

The structural pattern during the Lower Miocene is evident from the well-developed north-north-easterly extensional joint sets of the Nengmutka vein system (fig. 7.10). A cluster of radiometric dates on sericitic alteration associated with quartz veining indicates a 22-23 Myr age (Lower Miocene) for this structuring and hydrothermal activity. The presence of a north-trending dilational jog structure linking through-going structures of the Nengmutka vein system, indicates the operation of a sinistral shear duplex, in response to northeast-southwest directed extension (Wilcox *et al.*, 1973). The timing of the onset of this extensional regime is unknown.

The Gazelle Peninsula since the Lower Miocene has had a long history of extensional tectonism (Madsen and Lindley, 1994). The BMHGZ corresponds with a zone of crustal thinning, implying that the zone is a deep seated structure which penetrates the crust (Lindley, 1988; Madsen and Lindley, 1994). The horst and graben zone is traceable from coast to coast across the Gazelle Peninsula, a distance of 75 km. If the similarly trending WBF is included with the BMHGZ, the entire zone has a width in excess of 50 km. The WBF is a transcurrent fault with a documented long history of strike and dip-slip movements; sinistral strike-slip movement of 100 km since the Late Middle Miocene is indicated (Madsen and Lindley, 1994). The disruption of the recent Rabaul Ignimbrite in the Keravat district, west of Rabaul, by the Mediva and Vudal Faults, components of the BMHGZ, indicates active movement is still occurring (Madsen and Lindley, 1994). Neither of these throughgoing, sub-crustal structures has any clear relationship with structures associated with the spreading zones and transform faults in the Manus Basin (Madsen and Lindley, 1994).

## 7.12. Relationship of onshore structures to those of the Manus Basin

In the areas of the New Guinea islands where onshore geology is particularly well known, there are no clear spatial or genetic relationships between onshore structures and those associated with the BSSL. Geophysicist J.A. Madsen (in Madsen and Lindley, 1994) demonstrated that deep-seated structures on the Gazelle Peninsula, with documented major strike-slip and vertical movements, are oblique to lineations associated with the spreading zones and transform faults in the 3.5 Myr Manus Basin. By comparing the nature and trends of the structures observed in SeaMARC II backscatter data in the Eastern Manus Basin (Taylor *et al.*, 1991a,c) with detailed geological mapping on the Gazelle Peninsula, Madsen showed there was no obvious relationship between onshore and offshore structures

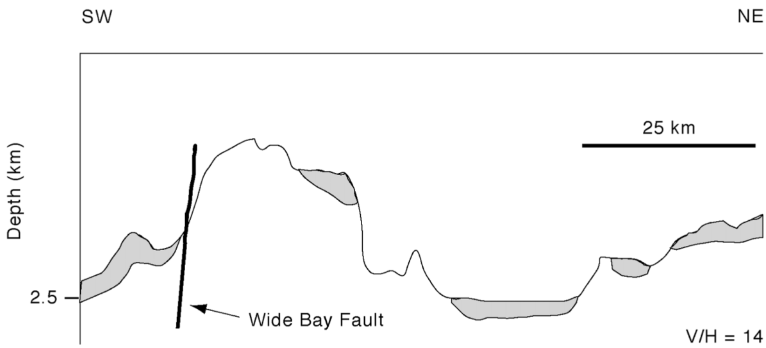


**Fig. 7.11.** Sparker profile showing the offshore extensions of the Wide Bay Fault, East Manus Basin. After Gulf Research and Development Company (1972). See fig. 7.5 for location of section.

(fig. 7.5). Furthermore, movement along onshore structures is long-lived (from at least the Upper Oligocene-Lower Miocene to the Recent), straddling the relatively short-lived opening history of the Manus Basin.

The Gazelle Peninsula structures are elements of a wide horst and graben zone straddling New Ireland and East New Britain. This zone is unequivocal evidence documenting a long regional history of extensional tectonism with large relative movements between crustal blocks (Brooks *et al.*, 1971; Wiebenga, 1973; Coleman and Packham, 1976; Lindley, 1988; Madsen and Lindley, 1994), counter to the generally accepted convergent tectonic models for this part of the New Britain Arc (Curtis, 1973b; Johnson, 1979, among others).

Extensive areas of oceanic crust at the margins of the Bismarck Sea lack seafloor magnetic anomalies, contrasting with the magnetically lineated crust on the flanks of the BSSL (K.A.W. Crook, 2003, pers. comm.). The formation of this crust is clearly unrelated to the opening of the Manus Basin. Evidence for this can be seen in the region offshore from Cape Lambert, at the northwest tip of the Gazelle Peninsula. Seismic sections across the strike projection of the WBF (Gulf Research and Development Company, 1972) (fig. 7.11), reveal the large vertical tensional displacements associated with this fundamental fault.

## 7.13. Conclusions

This paper has drawn together disparate observations from sources including unpublished mineral and petroleum company reports, government agencies and institutional researchers, along with the writer's own field observations in the New Guinea islands. Synthesis of these observations has found current models for the evolution of the tectonically complex region deficient in many key aspects and, from a broader perspective, cautions the carte blanche application of plate tectonic theory in other similar tectonic provinces. Results highlight the importance of reconciling geophysical, GPS and offshore observations with reliable onshore geology. Any amended model for the region's tectonics needs to account for all of the following:

1. There is compelling evidence for sea-floor spreading at the BSSL, but it accounts only for the last 3.5 Myr (Middle Pliocene) of evolution of parts of the New Guinea islands. Little is known of the Early Tertiary tectonic evolution of the region from the Upper Eocene.
2. Current tectonic models relating to the New Guinea islands rely heavily on 40 years of earthquake records and recent GPS observations and, as such, present tectonic histories of the region using structures that have only been active since 1964. The same conclusion applies to demonstrated plate movements.
3. The nature and timing of movements along most onshore structures indicate that some other major tectonic process has operated (and presently continues) in the New Guinea islands.
4. Current tectonic models of the region do not (and cannot) account for the contrasting extensional tectonic regimes evident on the Gazelle Peninsula. The transition between structural regimes is clearly unrelated to the Middle Pliocene opening of the Manus Basin, and the onshore structures of the Gazelle Peninsula show no spatial or genetic relationship to the BSSL and related transforms.
5. Major structural corridors present on New Britain, New Ireland and Manus Island have gone unrecognized. They are oblique to existing morphotectonic features, and many are sub-crustal in extent, have long movement histories, and have played a controlling role in the localization of igneous activity and associated Cu ± Au mineralization.
6. Current tectonic models do not (and cannot) account for the maintenance at regional scale, of the series of long-lived northerly extensional structures that have directly tapped the upper mantle and localized highly undersaturated Plio-Pleistocene alkaline volcanism on the Tabar, Lihir, Tanga and Feni Groups. It is difficult to reconcile the location of these deep-seated structures at the presently rapidly (13 cm/yr) and obliquely converging margin of the northwest moving Pacific Plate.

7. There is compelling geological and geophysical evidence that the Weitin Fault, widely accepted as a transform fault and the plate boundary between the Pacific and South Bismarck plates, is part of a complex strike-slip zone where movement is partitioned across several faults.

8. The present disposition of formerly extensive slabs of Miocene platform carbonates suggests that New Ireland and New Britain, since the Miocene, have undergone little more than gentle tilting or arching and simple, regionally uniform, uplift.

9. The New Britain Trench has not developed in response to convergence related compression. Geophysical and geological evidence indicates a structure with a mix of thrust and sinistral strike-slip movements and a history of alternating regimes of compression and extension, characteristic of a major strike-slip fault.

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