

## **Recent advances in the knowledge of geology, energy resources and metallogenesis of Papua New Guinea since 1981**

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### INTRODUCTION

Continuing world demand for petroleum sources outside the Middle East, maintenance of high precious metal prices (gold, silver particularly) coupled with State encouragement of private-sector exploration have led to an upsurge of petroleum and mineral exploration in PNG since 1981. During the last two years, the State has also supported an "in-house" review of its petroleum resource potential by securing a World Bank soft loan for up to \$US5 million which has allowed establishment of the Petroleum Resources Assessment Group (PRAG) within the Geological Survey. The work of this group will be described later. Furthermore, as a developing country situated astride the Pacific/Australia Plates' boundary, Papua New Guinea benefits from the results of marine scientific cruises, shore-based research and advice, sponsored and executed by aid organizations such as CCOP/SOPAC and by Government agencies and universities in Australia, New Zealand, Japan, West Germany and North America. All of the abovementioned groups have contributed towards the refinement of geological knowledge and concepts derived as a result of the now completed 1:250,000 geological mapping programme initiated by the Australian Bureau of Mineral Resources during the nineteen sixties and seventies.

### REGIONAL GEOLOGY

Falvey and his co-workers (Falvey & Pritchard, 1983) with the University of Sydney have virtually completed their palaeomagnetic studies on the New Guinea Islands and the Huon Peninsula.

Principal component analysis was used to determine primary declination variations between rocks of similar ages on New Guinea Islands situated on separate rotated microplates in a zone of active back-arc spreading. Results up to the beginning of 1983 (Falvey & Pritchard, 1983) suggest that the originally continuous Late Oligocene to Middle Miocene northwest-trending arc composed of the Solomon-New Ireland-New Britain-Huon arcs, was dismembered and rotated into its present configuration by a combination of arc reversal and back-arc spreading. Collision of the Huon Peninsula with New Guinea, and hence formation of the Ramu-Markham lineament, occurred during the Pleistocene. Figure 1 reproduces the model proposed by Falvey & Pritchard (1983).

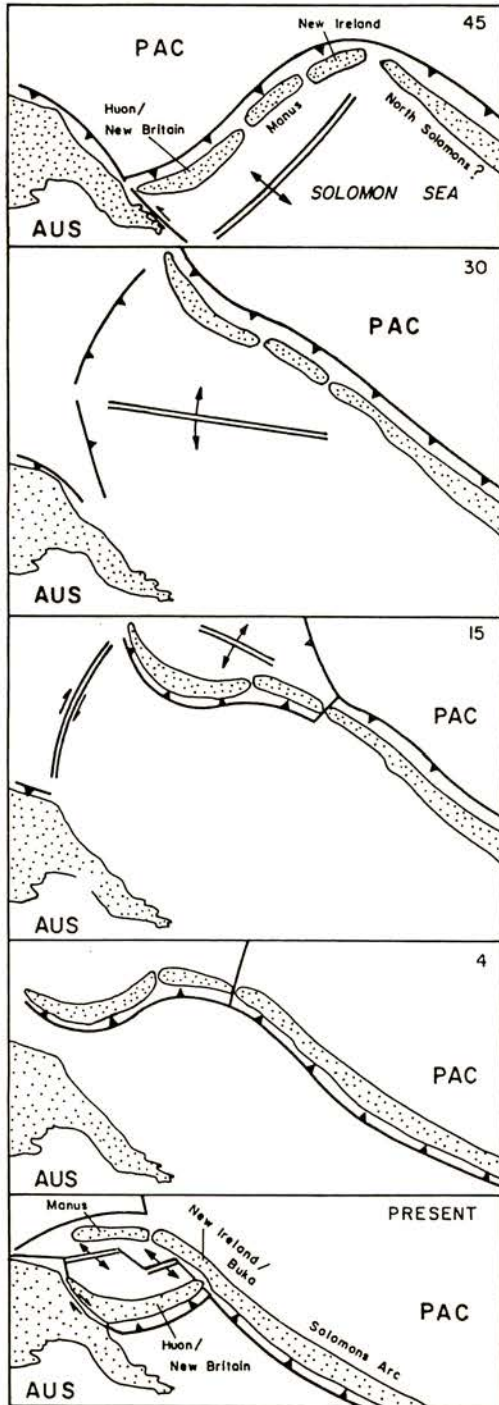


Fig. 1. Idealised tectonic development of the New Guinea islands region from 45 m.y. BP to the present (from Falvey and Pritchard, 1983).

Improved seismograph and accelerograph coverage of PNG initially installed by the Australian Bureau of Mineral Resources and now expanded by the Geological Survey of PNG, has allowed resolution of a seismically active zone named the Southern Highlands. It extends from Kerema on the Gulf of Papua through the Star Mountain region into Irian Jaya (Figure 2). The zone is coincident with the Papuan Fold Belt and is thought to represent the effects of continuing Pliocene-Quaternary thrust faulting in the crust and upper mantle of the Australian Plate, brought about by the collision of the Australian and Bismarck Plates over the sinking Solomon Sea Plate. Relief of collision stress is through progressive southward migration of continental plate margin splintering.

A second earthquake zone (Ripper & McCue, 1983), the Mount Hagen Seismic Zone, branches off the Southern Highlands Seismic Zone at about  $6.5^{\circ}\text{S}$ ,  $144^{\circ}\text{E}$ , to trend approximately north-northeast and plunges to intersect intermediate-depth seismicity beneath the Ramu and Sepik Valleys. Ripper & McCue (1983) believe that the Mount Hagen Zone could be associated with Quaternary Highlands volcanism as this plunging pipe-like zone provides a direct link between the subducted Solomon Sea Plate and the zone of Highlands volcanoes.

Large scale (1:50,000 or greater) geological mapping and regional synthesis sponsored by the Geological Survey and often done in conjunction with work by either

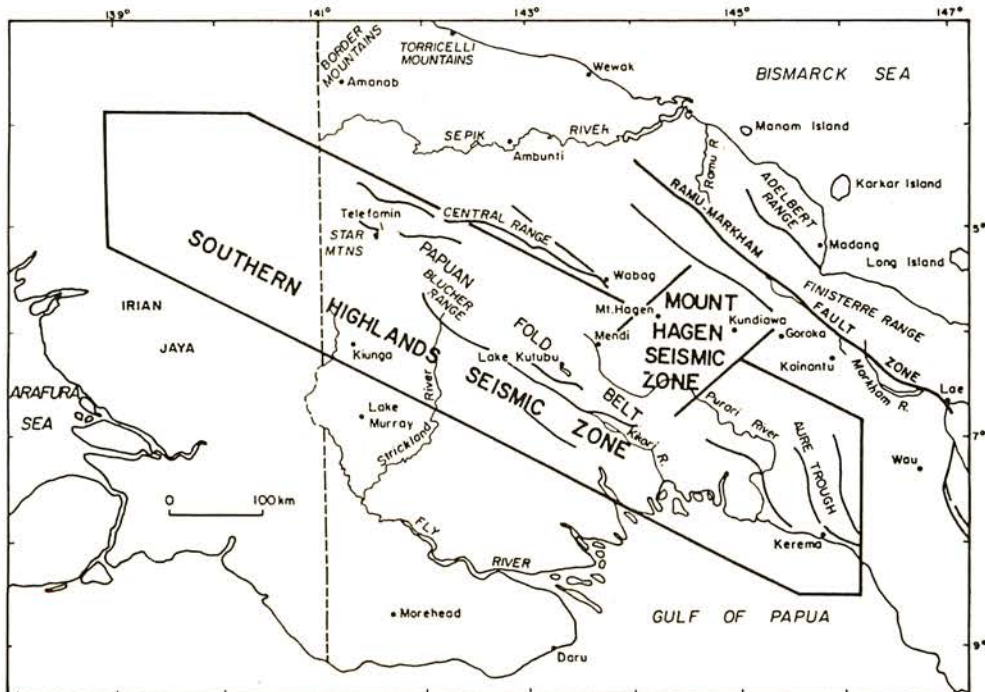


Fig. 2. Map of eastern Irian Jaya and western mainland of Papua New Guinea showing position of Southern Highlands and Mt Hagen Seismic Zones (after Ripper and McCue, 1983).

petroleum or mineral exploration companies has led to a greater geological understanding of areas thought to be prospective. Results of mapping and syntheses carried out on rocks in the Eastern Highlands (Rogerson *et al.*, 1982; 1:50,000 mapping) and the southeastern margin of the Papuan Fold Belt (Rogerson *et al.*, 1981; Francis *et al.*, 1982) forms the basis of two papers presented at this Conference (Rogerson and Williamson, 1984; Francis *et al.*, 1984).

Mapping and synthesis aimed at reviewing structure and stratigraphy of the Owen Stanley Metamorphic Complex was undertaken during 1982 and 1983 (Williamson & Rogerson, 1983; Rogerson & Francis, 1984). The Complex extends from near 7°S 146°E to 11°S 155°E including the Papuan Peninsula and Louisiade Archipelago. A small dismembered metamorphosed ophiolite has been recognized on Misima Island (approx. 10.5°S 152.5°E).

Davies (1980) had previously recognized two ophiolites on the Papuan Peninsula, one structurally overlying the other and both of which he believed were Cretaceous or older in age. Williamson & Rogerson (1983) believe that the metamorphosed structurally lower ophiolite (Goropu association) exposed in the Suckling-Dayman massif is Cretaceous in age, but that the overlying ophiolitic sequence (Lokanu association), which includes the Papuan Ophiolite Belt, may be in part Palaeogene in age, if the Kutu Volcanics (in part Eocene) correlate with the Lokanu Volcanics. Figure 3 shows a re-interpretation of stratigraphic and structural relationships in the S.E. Papuan Peninsula. Low and medium grade regional metamorphism affecting all pre-Miocene rocks of the Louisiade Archipelago and the D'Entrecasteaux Islands, suggest that the area formed part of an island arc during post-Paleogene to pre-Pliocene times. Since the Miocene, the arc has been dismembered by (?) largely transcurrent faulting.

Geological Mapping at 1:100,000 scale has recommenced in PNG after the State realised the importance of smaller scale mapping coupled with mineral prospecting for planning future development within underdeveloped areas of the country. The first area to be mapped is within the head-waters of the Sepik River north and northeast of Ok Tedi, and consists of three 1:100,000 sheets. A preliminary edition of one sheet which encompasses the Frieda prospect (Figure 6), was completed during 1984 and the synthesis presented below should be interpreted in the light of the small area mapped. Davies (1982) has previously summarized the geology and tectonics of the area based on reconnaissance geological mapping carried out by the Australian Bureau of Mineral Resources in the nineteen sixties and early nineteen seventies. That mapping discovered the Frieda prospect (Table 1).

The geology of the area is dominated by gently generally northerly dipping thrusts separating rocks of differing type, metamorphic grade, and in places, different metamorphic facies series. Rocks as old as Jurassic (Om beds) and at least as young as upper Te-lower Tf (late Early Miocene to Middle Miocene) are involved in the thrusting. In the south of the area Jurassic Om Beds lacking slaty cleavage are structurally overlain along a thrust by slates and phyllites which may represent in part metamorphosed Om beds. Green lithic and volcanolithic quartzites overlain by part Tb (Late Eocene) micrites appear in the slate/phyllite-dominated thrust sheet. It is not

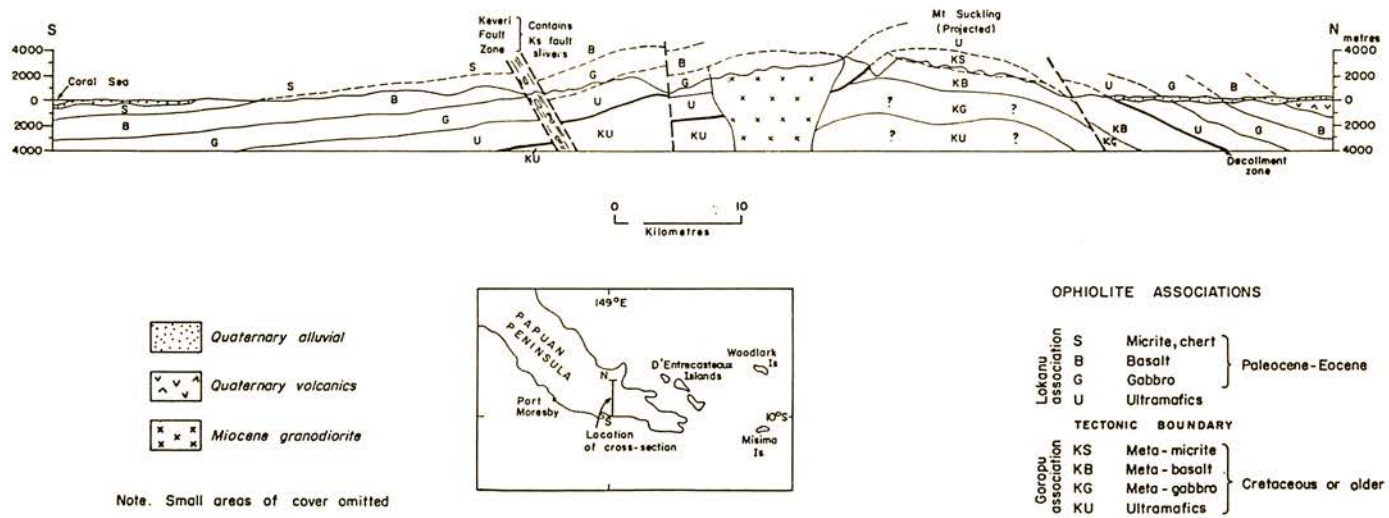


Fig. 3. Re-interpretation of the distribution of stratigraphic units in the south-east Papuan Peninsula.

TABLE 1

Published reserves from mines and major gold prospects in PNG

**Panguna mine**

Current reserves are about 760 Mt averaging 0.4% Cu and 0.4 g/t Au. (CRA Ann Rept, 1982)

**Ok Tedi mine**

Proven reserves of 410 Mt comprising 34 Mt at 2.87 g/t Au in a surficial cap, underlain by 351 Mt grading 0.7% Cu, 0.6 g/t Au and 0.011% Mo with a further 25 Mt averaging 1.17% Cu, below that again. (Min. Ann. Rev., 1983).

**Frieda prospect**

Estimates of the mineralisation are:

Horese-Ivaal area 500 mt at 0.5% Cu, 0.28 g/t Au

Koki area 260 mt at 0.4% Cu, 0.23 g/t Au

(MIM. Ann. Rept., 1981.)

**Yandera Cu prospect**

Reserves presented in the Financial Review (1977) were 540 Mt @ 0.65% Cu equivalent using a 0.4% Cu cut off.

**Porgera prospect**

Mining Monthly (April, 1983) reports reserves to be 59 Mt averaging 3.56 g/t Au, 14.4 g/t Ag using a 1.5 g/t cut off.

**Misima prospect**

Published reserves stand at 30 Mt averaging 1.3 g/t Au and 18.6 g/t Ag. (Placer Ann. Rept., 1982)

**Wau area**

Current reserves at Upper Ridges mine area 960,000t averaging 2.4 g/t Au and 7 g/t with probable reserves of 670,000 @ 2.3 g/t Au and 7 g/t Ag.

**Laloki prospect**

315,000 tonnes grading 4.3% Cu, 1.3% Zn, 6.4 g/t Ag, and 3.5 g/t Au.

**Arie prospect**

165 Mt grading 3.42% Cu. (Min. Jour. July 7, 1978).

**Ladolan prospect**

The deposit is estimated to contain about 20 Mt with oxidised mineralisation averaging around 3 g/t Au based on surface sampling, while sulphide mineralisation averages 2.1 g/t Au. (both using zero cut-off) (Rept. to shareholders, Niugini Mining Ltd., Feb., 1984).

known as yet whether it (the lithic sandstone unit) forms part of the Om beds or whether it forms part of a lithic sandstone cropping out in an adjacent area which Davies (1983) believed was Eocene in age. Schistose metasediments and amphibolites probably affected by a medium pressure facies series metamorphism structurally overlie the phyllites across a major thrust zone. They are in turn structurally overlain by high pressure facies series blue schists and rare eclogites originally named the Tau Blueschist. Upper Te-Lower Tf Wogamush formation

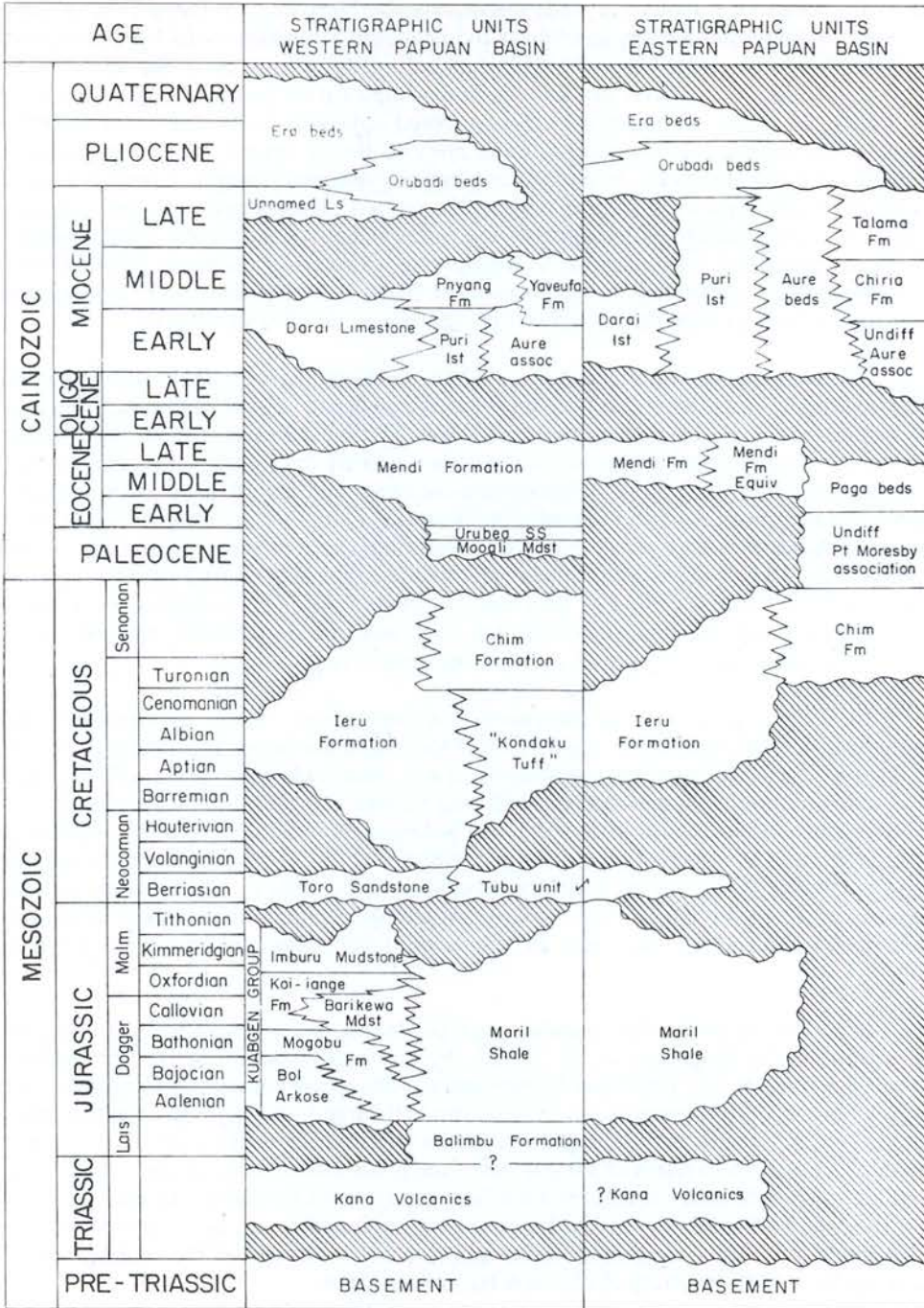
overlies schistose and phyllite grade metamorphics. The contact is faulted but in some areas conglomerates are apparent close to unexposed boundaries which suggests that the boundary may have been an angular unconformity prior to thrusting. How much decollement has occurred is not known. Some single thrust zones developed between metamorphic units are marked by dismembered ophiolitic units and/or serpentinite but several distinct thick ophiolite units are also thrust bound. Preliminary results suggest that the ultramafic, blueschist and higher grade metamorphics were emplaced over lower grade rocks. Intruding part of the area is a Miocene generally sub-volcanic dioritic suite associated with magmatic/hydrothermal porphyry Cu-Au mineralisation (Frieda prospect) and peripheral epithermal Au-Cu-As mineralisation (Nena prospect). The epithermal mineralisation at Nena is emplaced within Wogamush formation tuffs presumably produced by venting of the dioritic magma.

The origin of this imbricate zone is related to the collision of the South Bismarck Plate with the Australian Plate (Davies 1982), which began in Late Oligocene times and continued until at least post upper T<sub>e</sub>-lower T<sub>f</sub> times. Progressive south verging compressive deformation has vertically juxtaposed ophiolites and high pressure metamorphics from a north dipping pre-collision subduction zone with medium pressure metamorphics from the colliding Bismarck Plate fore-arc basin. These in turn have both been thrust over slate and phyllite grade rocks at the outer margin of the Australian Plate. Work is continuing in an attempt to simplify stratigraphic/tectogenic nomenclature employed by previous workers. Use of existing combined stratigraphic/metamorphic/structural unit nomenclature has clouded recognition of discrete stratigraphic, structural and metamorphic events.

In recent years considerable work has been done on the stratigraphy and geological evolution of the Papuan Basin (Figure 4), a Mesozoic and Cainozoic basin developed on Australasian continental crust. Although the Papuan Basin was originally a margin-sag basin developed on a passive margin of the Australian Plate, convergence between this plate and the Solomon and South Bismarck plates in Neogene times has given rise to a strongly deformed collision zone in which units of the Papuan Basin have been tectonically juxtaposed with units originally deposited on oceanic crust of the latter plates. Two main tectogenic units, the Papuan Fold Belt (Figure 2) and the less deformed Fly Platform, have developed within the Papuan Basin.

Recent work on this basin includes studies by the Geological Survey (Francis *et al.*, 1982; 1984; Rogerson *et al.*, 1982), by consultants working for the Survey (Robertson Research, 1984) and by petroleum exploration companies. Studies of the basin have been hampered by a proliferation of largely synonymous stratigraphic names which arose when geologists in earlier local surveys introduced new names without regard for what had been done in adjacent areas. Some progress has been made towards the establishment of a uniform stratigraphic nomenclature for the whole of the basin (Figure 4) but further work is necessary to achieve this objective. Descriptions of the stratigraphic units and a general account of the sedimentation history have been given by Robertson Research (1984).

One general problem which hampers stratigraphic correlation in the Jurassic and



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Fig. 4. Stratigraphy of the Papuan Basin.



Neocomian is that most of the formations were defined from outcrop type sections in the Papuan Fold Belt (Figure 2) which were dated mainly by macrofossils, whereas dating of these units in the subsurface has relied heavily on dinoflagellate analyses of well samples. Uncertainties in the correlations from the type sections to the wells have been difficult to achieve. However Davey (1984) has recently obtained precise dinoflagellate ages for samples from the type sections of the Imburu Mudstone, Toro Sandstone and Ieru Formation and is currently working on additional samples from these sections and several key wells. These studies when completed will provide a sound basis for biostratigraphic correlation of the Jurassic to Neocomian sequence throughout much of the basin.

Oligo-Miocene sediments in the eastern part of the Papuan Basin were in many cases deposited in deeper water than earlier workers realised. Units such as the Late Oligocene (P21–P22) "Dokuna Tuff" the latest Oligocene/earliest Miocene (P22/N4) "Boira Formation" and Early Miocene (NG/N7) "Fairfax Formation" of the Port Moresby region are now known to have been deposited under bathyal conditions (Rogerson *et al.*, 1981), as were the Middle Miocene (N9–N13) Chiria Formation of the Yule Island-Oroi region (Francis *et al.*, 1984) and the Late Oligocene to Early Miocene (P21–N5) Omaura Formation of the Kainantu region (Rogerson *et al.*, 1982). Earlier workers had considered these units to be inner to mid-neritic on the presence of calcareous algae, corals and shallow water benthic foraminiferids, without realising that these fossils were present in olistostromes, olistoliths and carbonate turbidites.

These bathyal units have close affinities with the Aure beds and thus are now included in an Aure association (Francis *et al.*, 1984) composed of Oligo-Miocene bathyal sediments. The Aure beds were generally considered to have been deposited in the "Aure Trough" (Figure 2), a major subsiding depocentre bounded on the west by a carbonate shelf (Darai Limestone) and on the east by an unstable shelf on which units such as the Omaura and Chiria formations were deposited. The new palaeobathymetric evidence from the latter formations indicates that general neritic conditions were not established in the Kainantu region until latest Early Miocene (N6) times when the deposition of the Omaura Formation was terminated by vulcanism associated with the development of the Maramuni Volcanic Arc (Rogerson *et al.*, 1982). Within the Yule Island-Oroi region bathyal sedimentation continued until latest Middle Miocene (N14) times (Francis *et al.*, 1984). These new data pose problems for the concept of an "Aure Trough", since they suggest that until latest Early Miocene or Middle Miocene times the "trough" was merely a continental slope on a passive margin and that the development of a bathymetric depression bounded on the northeast by a structural and bathymetric high was a later event.

## ENERGY RESOURCES

Four major sedimentary basins with petroleum potential occur within Papua New Guinea. The main focus of stratigraphic studies and petroleum exploration has been the Papuan Basin, though companies have also been active in the North New Guinea Basin (Figure 5). The Cape Vogel Basin was actively explored during the 1960's and early 1970's and a new petroleum prospecting licence (PPL41) within this basin has just

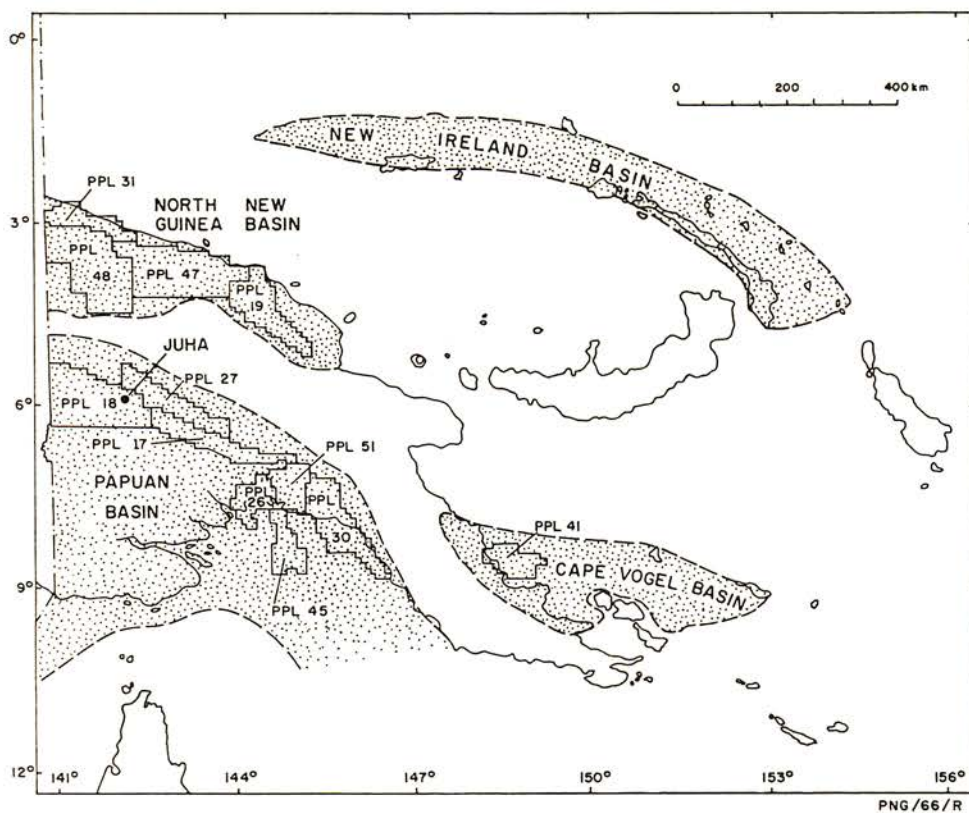


Fig. 5. Sedimentary basins and petroleum prospecting licences in Papua New Guinea.

been taken up. The New Ireland Basin is a frontier region which has not been explored for petroleum, though a recent interpretation of research cruise seismic data suggests that up to 5000m of sediments, including a 2000m carbonate platform sequence, is present (Exon and Tiffin, 1984).

Exploration within the onshore part of the Papuan Basin has concentrated mainly on possible reservoirs in the Late Jurassic and Early Cretaceous. In 1983 Niugini Gulf Oil discovered the Juha gas/condensate field in PPL 18 (Figure 5). The Juha 2X outstep well on this field recently flowed about 2700 BCPD of condensate from producing horizons within earliest Cretaceous strata of the Toro Sandstone. Further appraisal drilling on this discovery is required, but it seems possible that Juha may be the first commercial petroleum development in Papua New Guinea. Niugini Gulf Oil are also undertaking a slimhole stratigraphic test drilling programme in PPL's 17 and 18 to the southeast of Juha, to determine the regional extent and variations in reservoir properties of the Toro Sandstone.

Other companies such as Kina Oil and Gas and Western Resources are looking for plays within the Tertiary carbonate sequences in the eastern Gulf of Papua region

(PPL's 30 and 51). Kina have obtained good quality offshore seismic data over the fold-and-thrust zone of the Papuan Fold Belt in PPL 30, which provide an invaluable basis for elucidating the regional tectonic history, as well as defining potential drilling targets.

The seismically defined structures with limited well control suggest that folding commenced in the Late Miocene and culminated with folding and thrusting in the Early Pliocene (N18-N19). Although a few of the thrusts affect younger strata, subsequent deformation seems to have involved mainly local diapiric flowage of bentonitic Pliocene mudstones.

It is hoped that the recently completed seismic programme by Coastal P.N.G. Exploration in PPL 19 and the current programme by B.P.H. and Kina in PPL 31 will provide a better understanding of tectonic history and petroleum resources in the North New Guinea Basin.

One of the major problems facing petroleum explorationists in Papua New Guinea is the limited understanding of both macroscale and mesoscale facies variation within the sedimentary basins. Recent drilling results by Niugini Gulf Oil at Juha and sedimentological analyses of samples from older wells by Robertson Research (Aust), suggest that there is much greater local facies variation within Mesozoic sandstone than was previously realised. Furthermore, the regional distribution of potential reservoir units, such as the Cretaceous Toro Sandstone and the Miocene Puri Limestone is in many areas poorly controlled by existing wells and can only be reliably determined by further drilling.

The Geological Survey has recently commenced a major project involving a reassessment of existing petroleum data and the promotion of further petroleum exploration. The project is funded by a World Bank loan and is being done in conjunction with Robertson Research consultants. The project is also aimed at strengthening the Geological Survey through recruitment of additional professional staff and the acquisition of new petroleum data storage and retrieval facilities.

## METALLOGENESIS

The search for medium to high tonnage, low grade precious metal bearing mineral deposits amenable to bulk mining accounts for 94% of all exploration on the 116 mineral prospecting tenements currently held, or under application in PNG. The continuing collection and synthesis of company exploration data in conjunction with our own mapping programmes and prospect inspections has enabled the recognition and classification of several styles of precious metal mineralisation throughout PNG. Also, the distribution of known mineralisation is currently being reappraised as part of a recently initiated regional metallogenic mapping programme with the object of defining dominant controls of ore localisation in areas displaying similar geological features.

Precious metal deposits in PNG are being classified based on their geological attributes. The classification scheme is not rigid, with many deposits straddling certain

categories. The scheme is a modification of that proposed by Sillitoe (1983) for Au deposits in general.

Porphyry Au-Cu and related mineralisation has a widespread distribution throughout the main cordillera and the New Guinea Islands region. With the first stage of development at the Ok Tedi porphyry Au-Cu deposit almost complete (at an anticipated cost of 1 billion kina), gold production will commence shortly from the rich "gold cap". Numerous companies are exploring in the Star Mountains in an effort to locate similar style deposits. Similar attention has been devoted to assessing the gold potential of previously identified porphyry copper deposits eg Manus, Yandera. Production at the Panguna deposit in 1982 amounted to 170,000 tonnes Cu, 43 tonnes Ag and 17.5 tonnes Au (CRA Ann. Rept., 1982) and benefited from the high precious metal prices. Reserve estimates for major deposits are listed in Table 1.

A complex sequence of related mineralisation styles has been recognised at the Miocene age Frieda deposits. Skarns and fracture related Cu, Au and Mo mineralisation occur deeper in the system, while Pb, Zn, Au, and Ag veins and stockworks lie peripheral to the deposits and finally, pyrite-enargite-luzonite epithermal mineralisation removed from the intrusives represent a low temperature replacement body (Wall & Henry, in press).

A variation of the discrete porphyry copper style is the formation of Au-Cu veining related to several intrusive bodies. Vein and disseminated mineralisation may form within the intrusive or in the country rocks. Skarns may also develop in rocks of appropriate composition. Au-Cu occurrences at Kainantu related to Miocene Elandora Porphyry intrusives (Rogerson *et al*, 1982) typify this category.

Intrusive related epithermal deposits embody a wide range of mineralisation styles. Au-Ag mineralisation at the Porgera prospect falls into this category and is currently being appraised by a Placer-led Joint Venture. Fracture related Au-Ag mineralisation occurs in association with pyrite, sphalerite, galena, minor chalcopyrite with a quartz, calcite, dolomite, chlorite, hematite gangue. Several ore types have been identified in an effort to resolve the metallurgical complexities. The recently discovered Wafi prospect (CRA) may also fall into this class.

Breccia hosted epithermal deposits are typified by the Au-Ag mineralisation at the Upper Ridges mine at Wau (Lowenstein, 1982). Recent work by the Company has suggested that the Pliocene mineralisation is related to the venting of a hydrothermal diatreme. 1983 ore production amounted to 167kg Au and 116kg Au from the moderate sized open cut operation (Renison Goldfields Consolidated Ltd., RGC, Ann. Rept., 1983).

Vein type epithermal deposits are exemplified by the Umuna deposit on Misima Island, where Miocene Au-Ag mineralisation occurs within and east of a fault zone partly infilled by a massive quartz lode. Felsic intrusives and greenschist facies metasediments and metabasalt exhibiting propylitic alteration assemblages form the country rocks. Au-Ag mineralisation is accompanied by pyrite, galena, sphalerite, chalcopyrite with a calcite, quartz, chlorite gangue (Williamson & Rogerson, 1983). Woodlark Au-Ag mineralisation may also belong to this category.

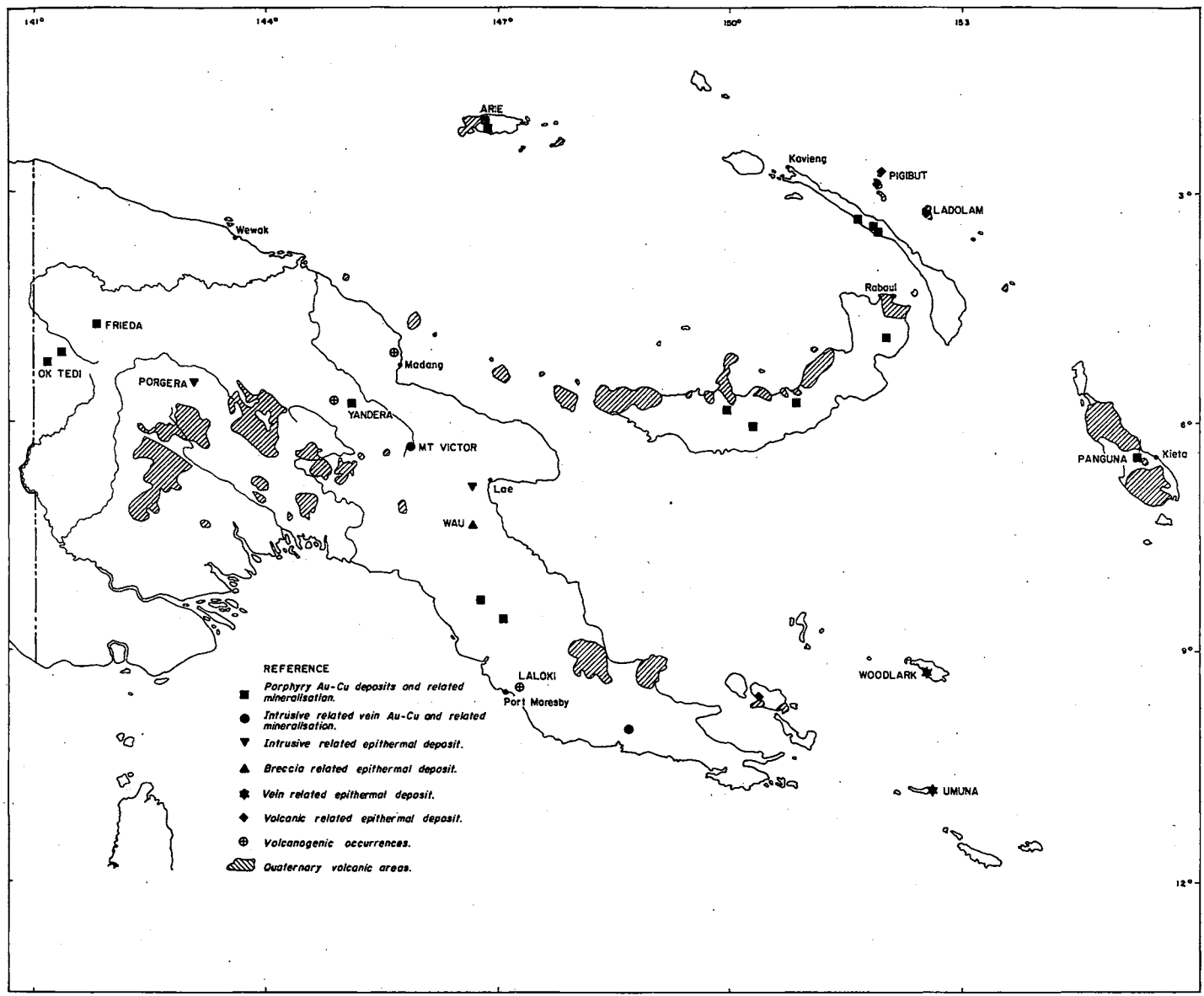


Fig. 6 Selected mineral distribution map (after Grainger & Grainger, 1974).

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The most significant advance in PNG exploration since 1981 has been the recognition of volcanic hosted epithermal deposits. Au-Ag deposits have been identified in active geothermal areas eg. Lihir Island, D'Entrecasteaux Group and in recently inactive volcanic piles eg. Pigibut prospect, Simberi Island. The deposits are invariably associated with argillic and sometimes advanced argillic alteration assemblages. The Ladolam prospect in Lihir Island occurs in a collapsed caldera of alkaline volcanics (Williamson, 1983b) and is currently being appraised by a Kennecott-led consortium.

As part of their overall precious metal search, numerous companies have been exploring for polymetallic volcanogenic massive sulphide deposits. Eastern Copper propose to mine the metallurgically complex Late Paleocene Laloki deposit (Williamson, 1983a) near Port Moresby employing the recently developed Siros melt process. Previously unreported auriferous massive sulphides in volcanic terrain in the Madang region and Jimi Valley area are being explored by several companies.

All of the above deposit classes (except the volcanogenic class) owe their origin, directly or indirectly, to the emplacement of felsic-intermediate intrusives. The majority of intrusives throughout the mainland cordillera are of Miocene age, as is the associated mineralisation. Widespread mineralisation is also associated with Pliocene intrusive activity and active (Quaternary) areas. The distribution of large mineral occurrences is shown in Figure 6.

Research involving fluid inclusion and isotope studies of the Panguna, Ok Tedi, Umuna and Ladolam deposits (Ayres *et al*, 1981; Eastoe, 1982; Williamson, in prep) is continuing in an effort to identify the sequence of mineralisation, prevailing physico-chemical parameters and, the nature and origin(s) of the hydrothermal fluids involved. Continuing collation and synthesis of exploration data, regional mapping together with consideration of relevant ore genesis research, should enable both the Geological Survey, mineral exploration companies and academics to further refine the geological understanding of mineralisation distribution in PNG.

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