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The geology of the Kikori 1:250 000 Sheet area, PNG

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CONTENTS

ABSTRACT

This report attempts to compile all relevant geological and geophysical information on the Kikori Sheet and Gulf Sheet areas and to present it in an easily manageable format. The regional geological history of the area is re-interpreted in the context of interaction between the Australian and Pacific lithospheric plates.

The western two-thirds of the Kikori Sheet and Gulf Sheet areas is underlain by Palaeozoic metamorphic and granitic basement which forms the northeast extension of the Australian continent; the eastern boundary may approximately coincide with the position of the concealed Pasca Ridge and Erave-Wana Swell. In the Triassic the basement platform was locally covered by terrestrial sediments, and shelf marine sediments were deposited along the eastern margin and in block-faulted embayments. In the Middle and Late Jurassic, shallow seas transgressed over the platform and resulted in widespread deposition of mudstone and minor sandstone. These sediments represent the inner, shallow part of a Mesozoic to lower Tertiary geosyncline which developed over and along the margin of the Australian continent. Mudstone and sandstone sedimentation continues in the Cretaceous, until in the Late Cretaceous the northeast part of the platform was uplifted and eroded. Farther to the north and east, sedimentation persisted in the deeper part of the geosyncline until some time in the Eocene. Middle and late Eocene sediments transgressed from east to west over the eroded Mesozoic rocks.

In the Eocene and/or Oligocene, interaction between the Australian and Pacific plates resulted in strong deformation and metamorphism of the trough sediments in the outer zone of the Mesozoic to lower Tertiary geosyncline, but over the platform and platform margin the interaction only caused widespread regression and little erosion during the Oligocene.

A new Cainozoic geosyncline developed after the partial emergence of the tectonised sediments in Southeast Papua and the central ranges of Papua New Guinea. The axis of this geosyncline roughly coincides with the Aure Trough and probably extends to the southeast into the Coral Sea Basin. In the late Oligocene and Miocene turbiditic sediments derived from the new landmasses accumulated in the Aure Trough, which was bordered to the west by a carbonate-mudstone shelf that developed over the stable continental platform. From late Miocene to Pleistocene rapid sedimentation, folding and thrusting, and intermittent uplift accompanied by volcanic activity characterised the Aure Trough. Shelf sedimentation continued on the platform until the late Pliocene when uplift to the north (Kubor "basement high") initiated detachment tectonics. In the Pleistocene, continuous uplift of the Aure Trough and the northern and eastern parts of the platform were accompanied by widespread subaerial volcanism.

Numerous oil and gas seepages have encouraged petroleum exploration throughout the area since 1911. Considerable flows of gas were met at the onshore wells Barikewa 1, Iehi 1, Kuru 1 and Bwata 1, and of oil and gas at Puri 1. Gas and condensate were also discovered in the offshore wells Uramu 1 and Pasca C1. The possibilities of economic reserves in the Tertiary section are discouraging, but Barikewa 1, Iehi 1, and Omati 1 wells indicate considerable potential for petroleum production from the Mesozoic. Since the 1960s petroleum prospecting has attempted to delineate structural and stratigraphic traps where Mesozoic source, reservoir, and cap rocks occur in close association.

INTRODUCTION

The Kikori 1:250 000 Sheet (SB/55-13) overlaps the south coast of Papua New Guinea at the northern culmination of the Gulf of Papua; it extends from 7^{o}-8^{o} south and 144-$145^{o}30'$ east. The Sheet area covers part of the Gulf Province; it includes most of the Kikori District and a small portion of the Kerema District approximately east of the Purari River. Administrative centres include the District Office at Kikori and the Patrol Posts at Baimuru and Ihu (Fig. 1). This report also includes geological information obtained from petroleum wells in the Gulf 1:250 000 Sheet area which covers the Gulf of Papua south of the Kikori Sheet.

Population is about 22 500, most of whom live along the coast or in the delta area. Concentrations of villages occur around Orokolo Bay to the southeast and to a lesser extent around Kikori. Except for hamlets along the Purari and Kikori Rivers the foothills and central ranges are almost uninhabited.

Communications in the delta area are mainly by sea, tidal inlets, and rivers. Village people move around in double or single canoes which increasingly are being equipped with outboard motors. The Government and some business enterprises operate shallow-draught coastal vessels. The three major ports are Kikori (with watering facilities), Baimuru, and Ihu, each of which receive regular calls from coastal vessels from Port Moresby. These three centres are also served by airstrips which can accommodate aircraft up to Twin Otter standard. There are landing grounds near Kogiki in the delta of the Purari River and higher upstream along the Purari River, immediately east of Wabo damsite at the southern edge of the Karimui Sheet (Fig. 1).

There is no major road development in the Kikori Sheet area and motor transport is restricted to tracks around the administrative centres. Because of the difficult access, geological field work is best carried out by helicopter except along the major rivers and the lower reaches of their tributaries where outcrops can be visited by shallow-draught dinghy.

The climate is wet tropical with higher rainfall during the period from May to October, when the southeast trade wind is blowing (Fig. 1). The average annual rainfall for Kikori is 5761 mm, and for Ihu 3212 mm; at Kikori 500 mm may be expected each month during the wet season. The southeast trade wind sometimes causes choppy conditions in the bays, making coastal navigation hazardous. The remainder of the year, including the time of the northwest monsoon between December and March, is characterised by still, oppressive weather with very high humidity (relative humidity up to 100). At Kikori the mean annual temperature is 27^{o}C and the mean annual range is 4^{o}C.

Most of the foothills, the central ranges, and the well-drained parts of the delta are covered by tall lowland and locally montane rainforest; secondary forest and grassland are rare. The estuarine coast is fringed with mangrove forest, and extensive areas of nipa palms occur where brackish conditions predominate. The permanent freshwater swamps support sago palms, herbaceous and grass vegetation, and low forest, gradually giving place to mid-height and tall forest on better drained ground.

Village people practise family-based shifting cultivation, fishing, and a little cash cropping. Around Orokolo Bay beach ridges and plains support coconut groves, breadfruit trees, and gardens with bananas, yams, taro, and sweet potatoes. These supplement the staple food,

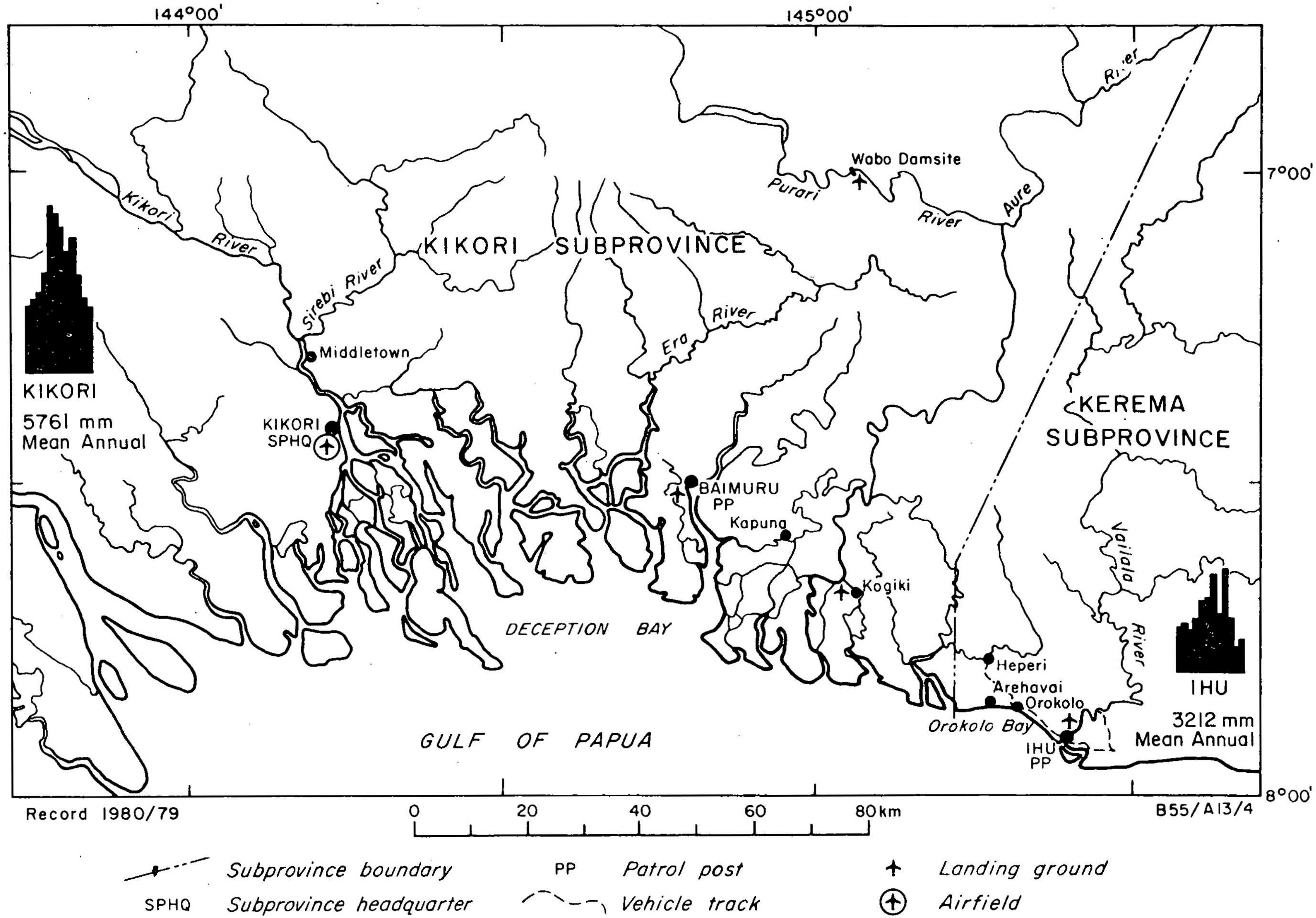

Fig. 1 General information

sago, which is collected from the intervening swampy swales. In the swamp area along the remainder of the coast, land available for gardening is extremely limited and sago collecting and fishing are of great importance. The village people move quite frequently, spending much time living in small sago-making settlements. Minor cultivation is on levees and terraces.

Cash cropping, which is of very minor importance in the area, is concentrated near Kikori. There are several small settlement schemes of 15 to 20 acre blocks which are planted with coconut palms or rubber trees.

Fish is a potentially economic resource of the Gulf of Papua. Prawns and barramundi are fished by overseas fish companies; local fishing groups are handicapped by the lack of easily accessible urban markets.

Timber is logged at several places in the area, and sawmills, all of which are expatriate business ventures, are situated at Baimuru, Era, and Ihu.

Limestone, as aggregate for local use, is quarried from along the Kikori River, 2.6 km south of Middletown.

Under study is a potentially large-scale hydro-electric scheme in the Purari River, several hundred metres upstream from its junction with Wabo Creek, 2½ km north of the northern edge of the Kikori Sheet. The Papua New Guinea Electricity Commission holds the Investigation Permit over this area and investigations being carried out are in conjunction with the Commission. The initial study by Nippon Koei Inc. of Japan indicated that the Wabo site could provide over 1000 megawatts of power. This would make it the largest contributor of the Purari Basin hydro-electric development scheme which has a total output possibly exceeding 10 000 megawatts. A more detailed study is currently being undertaken by Nippon Koei Inc. and the Snowy Mountains Engineering Corporation (SMEC). This involves the technical and economic aspects as well as aspects such as a market for the power, the infrastructure, and environmental changes. The realisation of this project would give an enormous boost to the development of the Gulf Province and surrounding area, and lift it out of its socio-economic isolation, which is the main cause of the migration of about 30 percent of its population to other areas of Papua New Guinea.

The topographic base used for the Kikoria geological sheet was compiled from 1:100 000 scale topographic maps prepared in 1977 by the Royal Australian Survey Corps. A less accurate 1:250 000 topographic map was compiled in 1963 by the US Army Map Survey and revised and reprinted by the Royal Australian Survey Corps in 1965. Both maps are available from National Mapping Bureau, Waigani, Port Moresby, Papua New Guinea, and from the Division of National Mapping, Canberra, A.C.T., Australia.

Airphotos, flown by Adastra Airways and Qasco Air Surveys between 1953 and 1968, are on 1:40 000 to 1:50 000 scale and give almost complete coverage of the Sheet area. In 1973-1974 the area was flown again by the RAAF as part of the 'Sky Piksa' survey with the aim of complete 1:100 000 scale airphoto coverage of Papua New Guinea. The Australasian Petroleum Company Pty Ltd and Island Exploration Company Pty Ltd obtained airphotos of part of the Sheet area in 1939 in support of their petroleum exploration program. A few runs of trimetrogon photos flown in 1947 by the US Air Force extend onto the Sheet area.

A Westinghouse Electric Corporation (1970) side-looking-radar east-west strip covers the most northern part of the Sheet area.

PREVIOUS INVESTIGATIONS

Coal was discovered in the Gulf Province in 1892, and on the upper Purari River by the Mackay-Little Expedition of 1909. In 1912 a Government geologist, J.E. Carne, investigated coal seams in Samia Creek, a tributary of the Purari River (Carne, 1913). In the course of petroleum exploration several other coal discoveries were made, mainly in the area drained by the Era River and Purari River. The coal occurrences of Papua New Guinea have been reported on by D.J. Grainger (1969). In 1974 C.R.A. Exploration Pty Ltd investigated the coal potential of the foothills between the Era River and Purari River.

The discovery of oil seepages near the mouth of the Vailala River in 1911 instigated intensive petroleum exploration work in western and central Papua which still continues. From 1920 to 1929 Anglo-Persian Oil Company undertook petroleum prospecting as an agent for the Commonwealth Government of Australia (Wyllie, 1930). Shell was active in western Papua between 1936 and 1939 through its subsidiary the Papuan Oil Development Company (information not used for compilation of map). In 1938 Australasian Petroleum Company Pty Ltd (APC) and Island Exploration Company Pty Ltd (IEC) commenced a program of regional mapping supplemented by seismic, gravity, and magnetometer surveys, and selection of prospects for drilling. Operations were temporarily suspended in 1942 because of the war; they were resumed in 1946 and continue to the present day. The unpublished APC and IEC geological reports relevant to the compilation of the map are listed in the References under the heading 'APC/IEC Reports'. A comprehensive summary of the petroleum exploration activities of APC and IEC in western Papua was published by the Geological Society of Australia in 1961 (Australasian Petroleum Co., 1961). A detailed compilation of information accumulated by oil companies was attempted by G.A.V. Stanley on behalf of Papuan Apinaipi Petroleum Company (Stanley, 1960).

Phillips Australian Oil Company has conducted offshore petroleum exploration in the Gulf of Papua since 1965. Marine seismic surveys by Western Geophysical Company of America on behalf of Phillips have defined several structures which were subsequently drilled. Unpublished reports on geophysical work by Phillips are listed in the general References and drilling operations by APC, IEC and Phillips are listed under the heading 'Well Completion Reports'.

The regional gravity pattern of the area was described by St John (1967).

An aerial magnetometer survey was conducted over the Sheet area in 1967 by Compagnie Generale de Geophysique (CGG) on behalf of BMR (Compagnie General de Geophysique (1969)).

In 1970, CGG carried out a marine geophysical survey in the Gulf of Papua on behalf of BMR (Mutter, 1972a, b; Willcox, 1973). Continuous gravity, magnetic, and seismic reflection profiles were run along lines oriented east-west and spaced at intervals of 18.5 km (10 nautical miles).

Systematic geological mapping of the Sheet area was carried out in 1974 by P.E. Pieters, G.P. Robinson, C.M. Brown, and C.J. Pigram of the Geological Survey of Papua New Guinea.

The broad geology of the Kikori Sheet area is described in papers on structural development and stratigraphy in western and central Papua by Jenkins (1974), Findlay (1974), and Brown, Pieters & Robinson (1975). The Quaternary volcanic deposits are described in detail by Mackenzie (1977).

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GEOMORPHOLOGY

In the Kikori Sheet area the strongly embayed south coast of Papua is backed by the Purari-Kikori delta. Farther north and northeast this low, flat terrain gives way to foothills and at places the southern extensions of the central ranges (Fig. 2).

The confluent cones of the extinct volcanoes Mount Duau and Mount Favenc rise to approximately 1850 m above sea level; the highest peak on the Aure Scarp along the east and south banks of the Purari and Aure Rivers is about 1580 m above sea level.

The Sheet area is drained, from east to west, by the southerly flowing Vailala, Purari, Era, and Kikori River systems. Downstream from Hather Gorge in the Karimui Sheet area where the Purari River debouches from the central ranges, the river is braided, and still farther downstream, meandering. It follows roughly the west-northwest structural grain until it is forced by the Aure Scarp to flow south with a slightly winding channel and few alluvial flats. On the delta the river resumes a meandering course, but towards the coast it splits up in an intricate network of channels which pass gradually into tidal inlets. The Kikori River also has a rather straight course until it bifurcates on the delta. The river is bordered by levees and back plains. The Vailala and Era Rivers are both meandering; they have a relatively larger and coarser sediment load than the Purari and Kikori Rivers and are fringed by meander plains.

Rare, small (up to 15 m high) terrace remnants of possible Holocene age occur along the Kikori River and its tributary Pinini Creek, and along the Vailala River and the south flank of the Hohoro Range. The local terrace development on the delta and the estuarine character of the coast suggest stable tectonic conditions during the Holocene, and that the drowning of the shore was the result of the post-glacial rise in sea level.

The Sheet area is subdivided in eleven main landform types (terminology adopted from Löffler, 1976; Fig. 2).

The seaward part of the delta is mainly made up of (1) swamps and estuaries. The drainage is tidal with a maze of channels. Mudbanks along the channels support mangrove vegetation.

Orokolo Bay is backed by (2) beach ridges and beach plains. The beach ridges may be as long as 10 km and are separated by swampy swales.

More landwards the delta is formed of (3) meander and back plains and (4) levee and back plains, respectively east and west of the Era River. Meander and back plains also occur along the Vailala River. The meander plains (mostly associated with the lower Purari, Era, and Vailala Rivers) include oxbow lakes, swamps, discontinuous levees, point bars, and scroll complexes. The levee plains mostly border the Kikori River; the back plains are subject to frequent flooding during high water level, and where drainage is impeded by levees or meander plains they are permanently swampy.

(5) Relict alluvial plains, probably of Pleistocene age, occur near Kikori and locally between the Purari and Vailala Rivers.

The landform types in the foothills and central ranges are predominantly determined by lithology. In the limestone country (6) karst plains occur along the Kikori River and between the Kikori and Omati Rivers. These plains are flat to gently undulating and occur where the baselevel of karst erosion - the sea level or the level of Kikori and Omati Rivers -

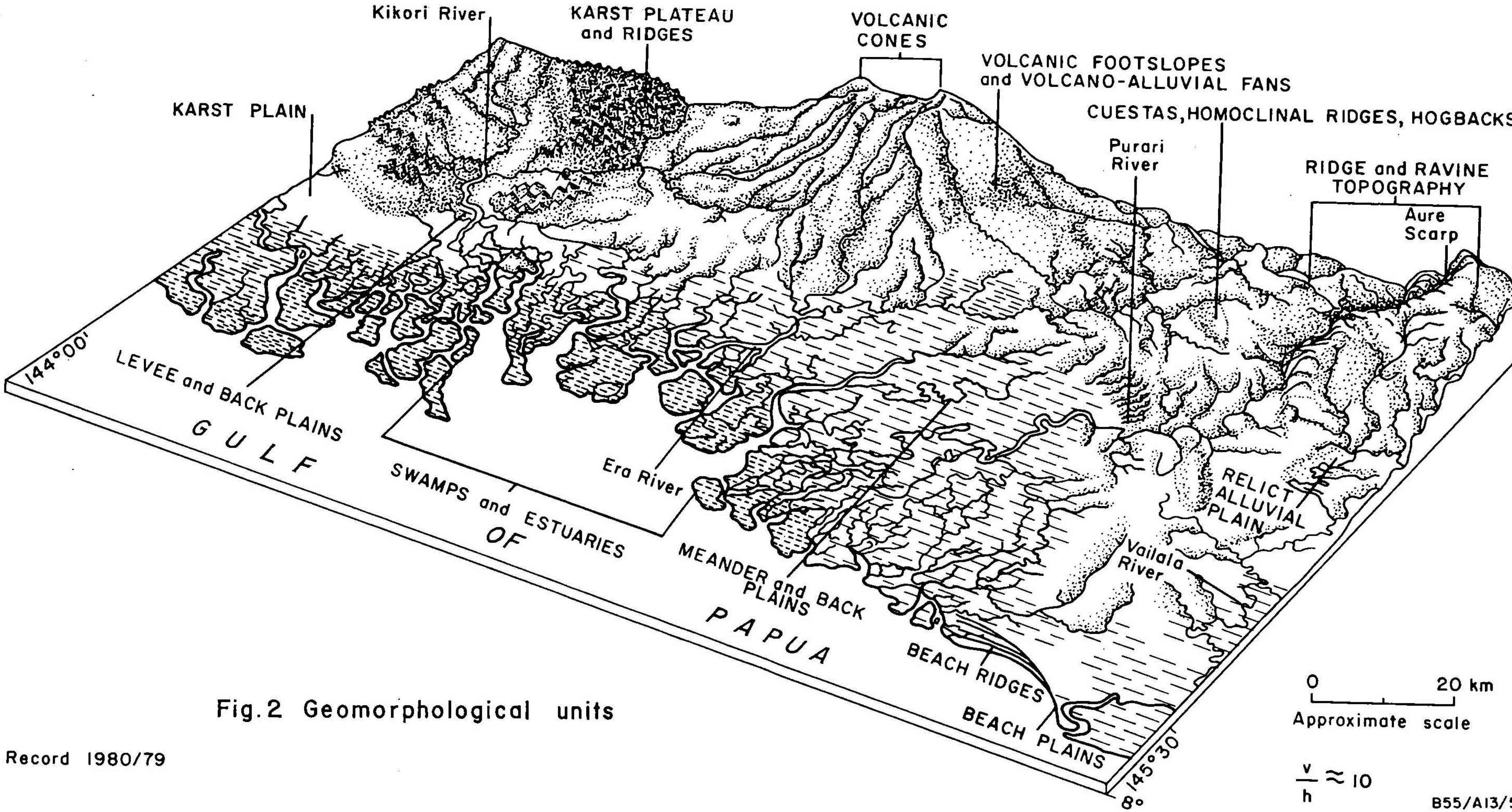


Fig. 2 Geomorphological units

Record 1980/79

has been reached. A veneer of alluvium generally covers the plains and seals off the limestone surface.

(7) Karst plateaux and ridges are widespread in the western half of the Sheet area and in the Kereru Range. The karst types are differentiated in: (a) conical karst (CK), (b) honeycomb karst (HK), (c) karst crevices (JK), (d) doline karst (DK), (e) poorly developed karst (pdK). As the climate does not vary greatly over the Sheet area the different karst types may be attributed to variations in limestone lithology and structure. Karst types (a), (b), and (c) appear to dominate on plateaux underlain by flat-lying or shallowly dipping shelf facies Darai Limestone, karst type (d) is developed on the folded basinal facies Darai Limestone in the Kereru Range, and karst type (e) is developed on the Susuworo Beds.

Mount Duau and Mount Favenc are moderately dissected (8) volcanic cones. Both have strongly enlarged and breached craters.

The volcanic cones (including Mount Murray in the Karimui Sheet area) are flanked by (9) volcanic footslopes and volcano-alluvial fans, which are locally developed as small, low, isolated plateaux. The deposits include volcanic sediment, lahar, fanglomerate and ash, and are dissected by widely spaced radial drainage systems. The valleys are steep sided, and bottom in sedimentary rocks in the lower parts of the fans and locally in the footslopes (e.g. Abede River). Micro-relief of the volcanic aprons is controlled by lithology and Quaternary tectonics. Smooth and flat terrain is underlain by volcanic sediment and lahar, and finely textured hummocky terrain by ash. Local steepening of the apron is caused by flexures or faults.

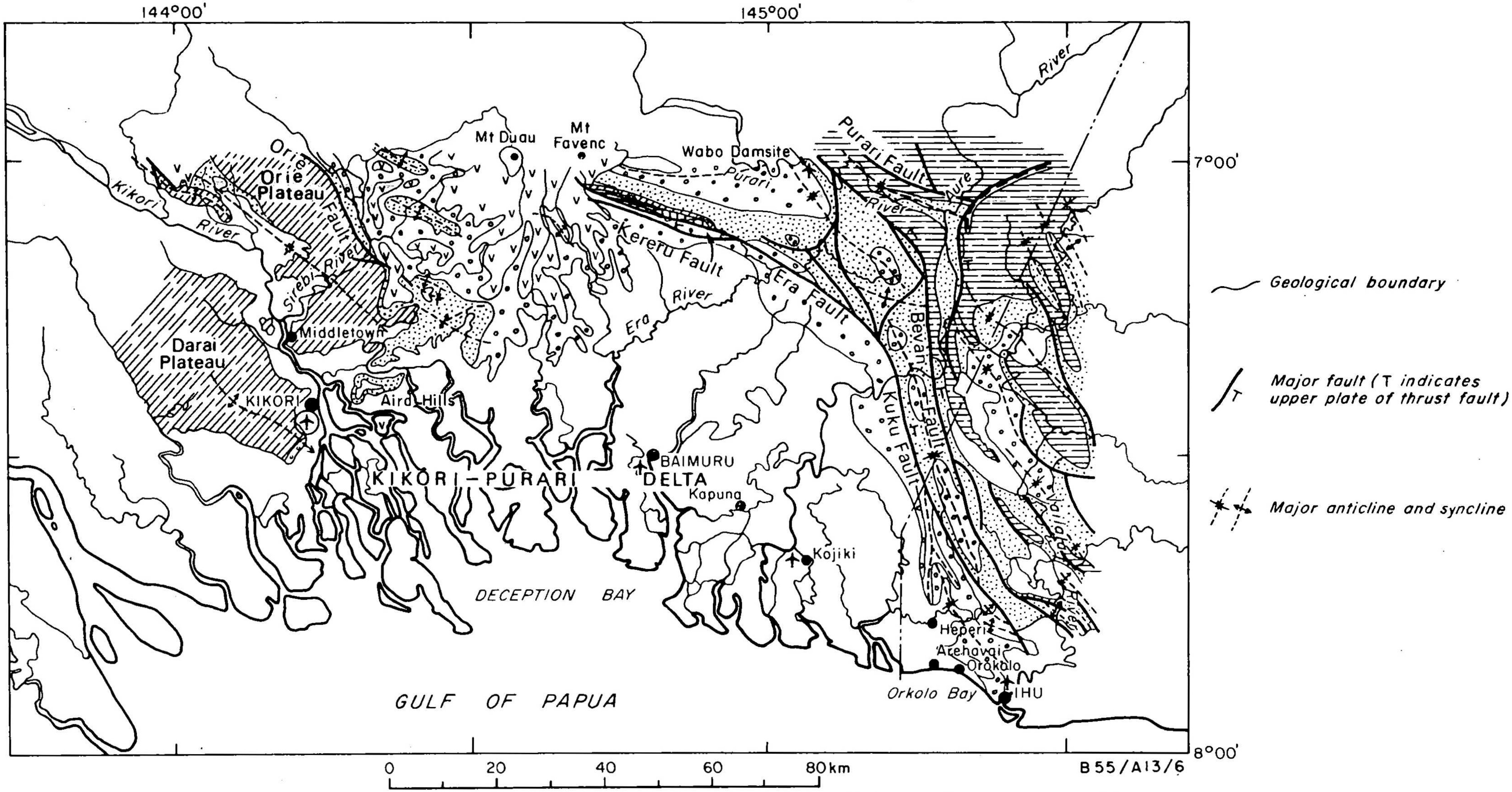
Where the foothills and central ranges are developed on interbedded mudstone and sandstone the country is dominated by (10) cuestas, homoclinal ridges, and hogbacks; where formed on uniform terrigenous clastic sediments, by (11) ridge-and-ravine topography. A succession of six cuestas or basin structures follow the regional strike, changing from west-northwest at the Mena River to north-northwest near the Heperi River. Low-relief (10-50 m) ridge-and-ravine country is typical of the soft mudstone between the Era and Purari Rivers. Local 'mudpugs' give rise to completely chaotic and deranged finely spaced drainage. The high-relief (100-400 m) ridge-and-ravine landform is underlain by thickly bedded to massive greywacke in the northeast corner of the Sheet area, where the Aure Scarp, with cliffs up to 300 m high, forms the dominant topographic feature. Both landform types are scarred by numerous slumps and landslides, and by gullying; an old slump 2.8 km long by 1.7 km wide was photo-interpreted in the headwaters of Iova Creek. Scree covers the foot of the Aure Scarp.

Several faults and fractures are clearly expressed in the topography by linear scarps (e.g. Kereru Fault Scarp and Aure Fault Scarp).

GENERAL GEOLOGY

The simplified geology of the Kikori Sheet is shown in Figure 3; the well sections of Figure 4 are based on data from 24 petroleum wells and on geophysical information.

The sedimentation history of the Sheet area is largely controlled by the development of an arcuate Mesozoic to Eocene geosynclinal basin around the northeastern margin of the Australian continent. Early Cainozoic interaction of the Australian and Pacific Plates resulted in deformation of the outer zone of this geosyncline and in the partial



Pleistocene to Holocene	*Unconsolidated or weakly consolidated sediments, mostly mud and silt, minor sand and gravel; deltaic, shallow marine, alluvial, beach deposits* (Qph, Qp, Qpo, Qa, Qs)
Pleistocene	*Andesite and basalt volcanics, and volcanic sediment* (Qva, Qvm, Qvd)
Piocene to Pleistocene	*Lithic sandstone, siltstone, mudstone, minor conglomerate; regressive sequence from shallow marine to continental; coal seams in middle part* (TQe)
Upper Miocene to Pliocene	*Mudstone, siltstone, minor sandstone, rare conglomerate, calcarenite; carbonaceous; open and shallow marine deposits* (Tmup)
Upper Oligocene to Lower Miocene	*Limestone, shelf, basinal and reef deposits* (Darai Limestone; Tmds, Tmdp, Tmdr, Tmdo)
Lower to Upper Miocene	*Greywacke sandstone, siltstone, mudstone, minor conglomerate, locally limestone; turbiditic deposits* (Tma)
Middle to Upper Eocene	*Limestone, rare chert, glauconitic sandstone; shallow shelf deposit* (Te)
Lower Cretaceous	*Mudstone, minor siltstone, rare sandstone; micacaous, glauconitic, carbonaceous, pyritic; open marine deposits* (Klt)

Record 1980/79

Fig. 3 Generalised Geology

emergence of mainland Papua New Guinea. Erosion of this landmass and volcanic activity provided the main source of sediment for a Cainozoic geosynclinal basin.

The western two-thirds of the Sheet area is occupied by the Papuan Basin which refers to the unmetamorphosed Mesozoic to Tertiary sedimentary sequence of western and central Papua (Jenkins, 1974). The Papuan Basin is underlain by continental crust, and, over the platform, forms the stable inner part of the Mesozoic to Eocene as well as Cainozoic geosyncline. The outer, orogenically deformed, part of the older geosyncline is represented by the New Guinea Highlands and the Owen Stanley Range. The Aure Trough of the eastern part of the Sheet area is considered as the axis of sedimentation of the Cainozoic geosyncline (Pitt, 1966; Dow, 1973; Brown et al., 1975). It was bordered to the west by a carbonate shelf over the stable continental platform and to the east by a narrow unstable shelf peripheral to the emergent Owen Stanley orogen. It has been suggested that the north-trending Aure Trough developed over a zone of crustal thinning (St John, 1967, 1970; Mutter, 1972) which may have resulted from the opening of the Coral Sea.

Rapid sedimentation, contemporaneous folding, and intermittent uplift accompanied by volcanic activity are characteristic of the Aure Trough through to the present day. Sedimentation on the western stable shelf continued until the late Pliocene when uplift of the Kubor "basement high" in the New Guinea Highlands initiated detachment tectonics and resulted in the formation of the Papuan Fold Belt (Jenkins, 1974; Findlay, 1974).

The oldest known rocks of the Sheet area were penetrated by petroleum wells: mainly feldspathic sandstone and conglomerate in Barikewa 1, and quartzite in Pasca 1. Exact ages are not known, but the sediments of Barikewa 1 may be early Jurassic or Triassic, forming part of the basal section of the Papuan Basin. The quartzite of Pasca 1 is probably pre-Mesozoic and belongs to the basement.

The oldest units are overlain with an angular unconformity by middle and late Jurassic sediments, which are encountered only in petroleum wells (Fig. 4). The sediments are mostly shaly mudstone with minor siltstone and sandstone and rare oolitic limestone; they represent an open marine, basinal depositional environment. Rates of deposition over the platform were controlled by tectonism. The north to north-north-west Kutubu Trough was a zone of thick sediment accumulation (slightly less than 2000 m at Barikewa 1); farther east the parallel trending Erave-Wana Swell (Fig. 3) received much less sediment and may have been intermittently emergent.

The Jurassic pattern and nature of sedimentation persisted into the early Cretaceous. From Wana 1 and the Kereru Range (Tubu Shale) in the east, to Omati 1 and Barikewa 1 to the west, siltstone and sandstone beds became progressively more numerous. Coarse sediments including lithic sandstone, shelly greywacke, and gastropod limestone in the central southern part of the Karimui Sheet area may have been formed along the temporarily emergent flanks of the Erave-Wana Swell. The late Early Cretaceous (Albian) is missing at Kuru 1, Puri 1, and Iviri 1, as a result of either non-deposition or erosion, and many intercalations of Albian marine sandstone at Barikewa 1, Omati 1, and Iehi 1 suggest a nearby coastline. Late Cretaceous sediments are absent in the Sheet area because of widespread emergence. Differential uplift locally caused higher rates of erosion resulting in the removal of the early Cretaceous and part of the late Jurassic over the crest of the Erave-Wana Swell. Seismic data also indicate extensive truncation of the Mesozoic eastward across the Swell.

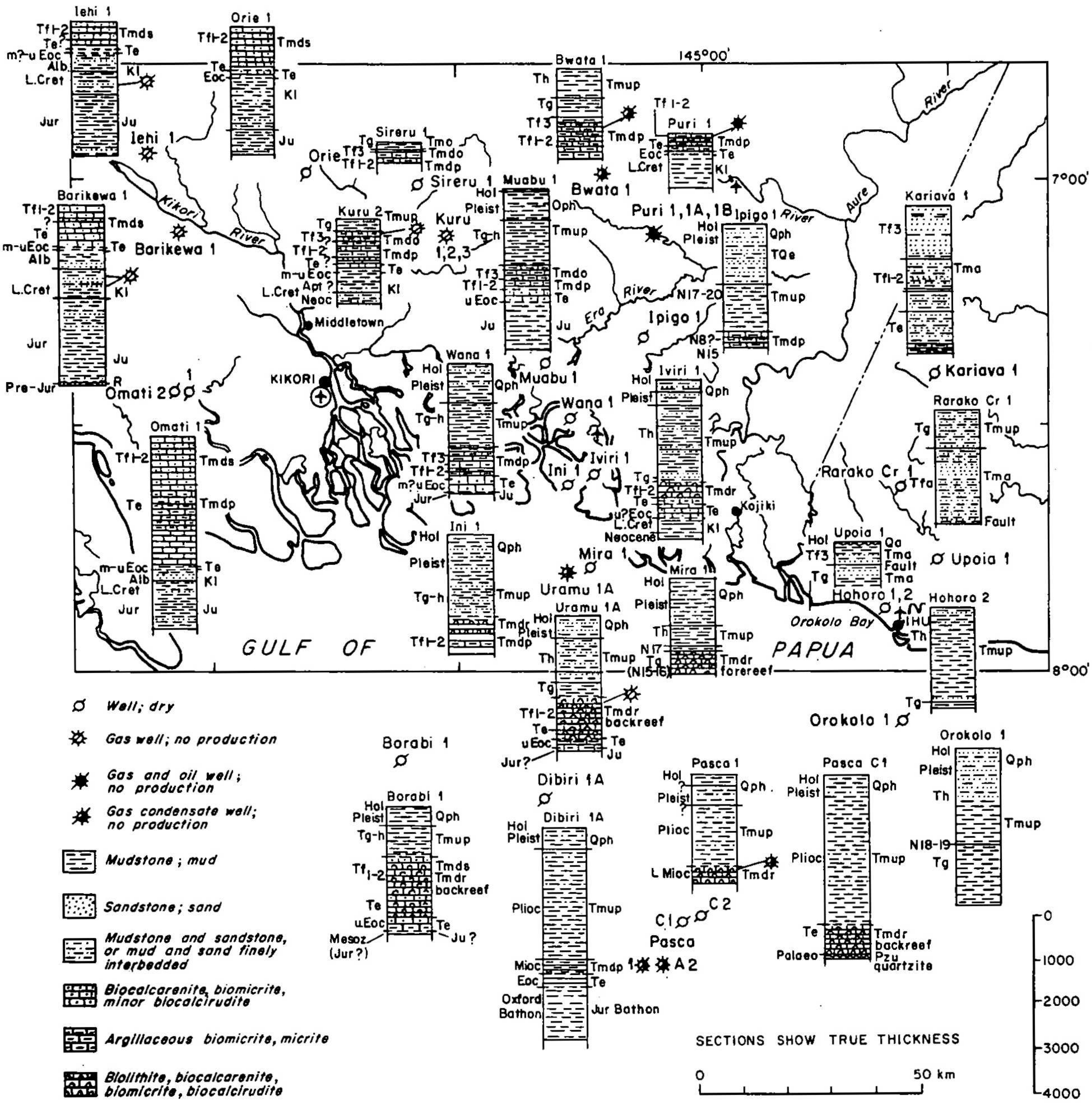


Fig. 4 Localities and sections Petroleum Wells

Report 1980/79

B55/A13/7

Paleocene and early Eocene sediments are also unknown from the Sheet area, but the middle and late Eocene are represented by a thin sequence of shallow shelf and nearshore clastic and argillaceous limestone. The sediments transgressed from east to west, and they progressively thin westward to extinction west of Borabi 1.

The next cycle of sedimentation started in the late Oligocene-early Miocene with limestone on the platform, and in the early Miocene with turbidites in the Aure Trough. The hiatus between Eocene and late Oligocene may be attributed to regression followed by minor erosion (APC, 1961; Thompson, 1967), submergence (Davies & Smith, 1971), submarine erosion, or lack of palaeontological control.

On the stable platform of the Papuan Basin up to 1600 m of limestone (Darai Limestone) was deposited during the late Oligocene and Miocene (Te and Tf). The unit is composed of the uppermost Susuwora Limestone underlain by three interfingering limestone facies types, viz. shallow shelf, basinal, and reef. The shallow shelf limestone comprises biocalcarenite, biocalcirudite, and biomicrite; it is exposed and penetrated by petroleum wells in the northwest part of the Sheet area. The basinal limestone consists of micrite and is argillaceous in places; it crops out in the Kereru Range and was encountered in petroleum wells Kuru 1, Sireru 1, and Dibiri 1A. The reef limestone is known only from petroleum wells. The reef structures were drilled after being located by detailed seismic work. Their lithology is porous to vuggy biolithite, biocalcarenite, and biomicrite. This facies type includes reef core as well as forereef and backreef deposits. It probably developed as atoll or patch reefs along the margin of the carbonate shelf (Fig. 7) and on tectonic 'highs' of the basement farther east (e.g. Pasca Ridge, Erave-Wana Swell). The biomicrite of the Susuwora Limestone becomes progressively more argillaceous to the east, and, because of its transitional character, it is not always easily distinguishable from the underlying limestone subunits and overlying Orubadi beds. For this reason the unit is locally defined by microfaunal contents rather than lithology.

Limestone deposition was interrupted or limestone was eroded during middle and early Late Miocene on parts of the Erave-Wana Swell and Pasca Ridge (Pasca 1 and C1, Uramu 1A) as the result of uplift. On the other hand the build-up of reef limestone continued until late Miocene (N17) at Mira 1.

Regional limestone deposition and reef growth ceased with the influx of fine-grained terrigenous sediments from the north represented by the Orubadi beds. This unit is up to 2000 m thick and consists of carbonaceous mudstone and minor siltstone and fine-grained sandstone; the sediments were laid down in an open marine environment. Although conformably overlain by coarse clastics of late Pliocene age (Era beds) in the northern part of the Sheet area, deposition continued at least until the Pliocene in the delta area and in the Gulf of Papua. The Orubadi beds are a diachronous unit ranging in age from late Late Miocene to Pliocene.

The Era beds consist of up to 2000 m of coarse, thick fluviatile, lacustrine, deltaic, and shallow marine clastic sediments, associated with renewed emergence of the orogen to the north. Continued uplift of this landmass (central ranges) in the Quaternary was accompanied by subaerial andesite to basaltic volcanism (Duau, Aird Hill, and Mount Murray Volcanics) and renewed deposition of proximal coarse clastic terrestrial sediments (Qph, Qp, Okani Beds, and Qa) and distal deltaic and fine-grained shallow marine sediments (Qph).

In the Sheet area the oldest rocks in the Aure Trough are of early Miocene age (Aure beds) and deposition continued into the early Late Miocene. The monotonous sequence of turbiditic sediments approximately 7000 m thick consists of lithic greywacke with increasing mudstone and minor argillaceous micrite beds towards the west. The sediments are largely volcanically derived with variable amounts of metamorphic and sedimentary clasts from the emergent orogen to the east and northeast (Owen Stanley Range).

The Aure beds are conformably and unconformably overlain by the Orubadi beds which have a sandier character than where they occur over the platform. The calcareous Susuwora Limestone of the platform pinches out to extinction over the Aure Trough. The pattern of deposition of the Orubadi beds is controlled by uplift and folding of the Aure beds in the late Miocene, which resulted in local shallowing or emergence. During the late Miocene the north-south axis of sedimentation in the Aure Trough shifted from the Wau Sheet area westward to about the Vailala River. Turbiditic sediments probably still accumulate in the offshore Aure Trough.

The Orubadi beds are overlain by the Era beds which have a similar facies as seen on the platform to the west; the sedimentation pattern was strongly controlled by contemporaneous folding and uplift of the Aure beds. Flat-lying coarse clastic terrestrial Pleistocene sediments (Qp) fill te c tonically controlled depressions.

STRUCTURE

The structural pattern is largely controlled by the configuration of the rigid platform, the unstable Aure Trough and the intervening zone forming the continental slope. The platform is made up of two major structural divisions: the southern part of the Papuan Fold Belt (Bain, 1973) and the broadly warped and tilted, or flat-lying sediments underlying the delta area and Gulf of Papua. In both divisions basement and sediments were at intervals deformed by block-faulting. The Aure Trough sediments are characterised by tight to open folds and associated thrust faults. From Mount Favenc to Orokolo Bay the structural grain in the foothills follows a reversed sigmoidal curve. This zone approximately coincides with the transition from the Aure Trough to the platform across the continental slope, and is strongly deformed by a series of closely spaced, parallel, curved faults and at places by cross-folding.

Broad warping and tilting strongly controlled the pattern and nature of sedimentation on the platform from Mesozoic to Quaternary time. The Erave-Wana Swell (Fig. 7) which possibly links with the Kubor Anticline to the north and the Pasca Ridge to the south, was an important positive tectonic feature and became at places intermittently emergent. It is overlain by a thinner Mesozoic sequence than in the Kutubu Trough to the west, which was a rapidly subsiding downwarp. During late Cretaceous and Eocene time widespread block-faulting and mild regional tilting and warping of the platform were followed by the emergence and erosion of the area.

During the Tertiary the Erave-Wana Swell was a barrier between basinal limestone deposition over the continental slope to the east and northeast, and shoal limestone deposition to the west. The Swell itself and other 'tectonic highs' supported patch and atoll reefs.

Fault structures in the basement such as the Pasca Ridge have been detected by seismic work and drilling (see 1:250 000 scale map). The broadly warped limestone structures of the Darai and Orie Plateaux may have formed over fundamental high-angle basement faults, possibly intermittently active during, as well as after, sedimentation. The limestone of the Darai Plateau is warped to form the shallow symmetrical Barikewa Anticline to the north, the asymmetrical Darai Anticline to the south, and the intervening broad and shallow Omati Syncline. The Orie Plateau is developed on an asymmetrical anticlinal structure with dips of 40° along the east-northeast to northeast flank, and a broad, flat, shallowly dipping southwest flank, which is interrupted along the margin by a monocline with dips up to 15°. To the southeast the monoclinal fold dies out into the southwest flank of the main fold. The asymmetrical Kuru Anticline with its steeper flank to the northeast is also thought to have developed over a basement fault.

Structures of the Papuan Fold Belt occupy the northern part of the foothills of the Sheet area where they include overthrust anticlines (e.g. Puri Anticline), asymmetrical anticlines with north-dipping axial planes (e.g. Bwata Anticline), monoclines and associated thrust faults (e.g. western extension of Era Fault), and intervening broad synclines (e.g. Pide Syncline). The deformation was caused by gravity sliding from the north associated with the uplift of the Kubor Anticline during the late Pliocene. The detachment planes occur predominantly in early Cretaceous shale (Tubu Shale), but thrust planes also reach the surface through Tertiary units as young as Pliocene (e.g. Era Fault). Early Cretaceous shale is exposed only along the Puri Fault south of the Puri Anticline.

Along the eastern edge of the Sheet area the Aure Trough sediments are deformed into north-trending narrow anticlines separated by broad synclines. The axial planes dip steeply to east or west and thrust-faulting from the east is associated with some of the more asymmetrical faults.

Farther west the turbiditic rocks are less competent owing to increasing mudstone content, and in places they are overlain by a thick sequence of Orubadi beds (Tmup). Here, discontinuous north-northwest trending anticlines and synclines are of much the same width. Thrust-faulting from the east, though present, is not obviously associated with anticlinal axes. The fold style and thrusting suggest that detachment planes may have developed at several stratigraphic levels within the greywacke/mudstone sequence and that the Aure Trough sediments may have 'gravity glided' to the west and southwest in response to uplift of the Owen Stanley Orogen (Brown et al., 1975). Fold structures mapped at the surface may be relatively shallow features and are possibly underlain by thrust planes.

The Aure Fault stands out as a conspicuous geomorphological and geological feature. It differs from most of the faults farther east: it is not related to fold structures, it is exposed over a relatively long distance of almost 100 km, its northern extension bends from a north-south to an east-northeast strike, perpendicular to the structural grain of the Aure beds, and it abruptly separates east-trending structures to the west from north-trending structures to the east. Its southeastern continuation passes into the steeply folded southeast-plunging Horbu Anticline. The Aure Fault is interpreted as a major thrust fault with strong steepening of the fault plane along the leading edge transport was from the east and active during the latest Pliocene and possibly into the Pleistocene, after the major phase of folding.

In the extreme west of the onshore Aure Trough, where the turbiditic sediments wedge out and interfinger with a thinner sequence of contemporaneous shelf sediments, the north-northwest trending folds give way to a succession of major curved faults, and a complicated system of cross-folds. The Era, Kuku, Bevan and partly the Purari and Kereru Faults change in trend from west-northwest near Mount Favenc to north where they approach the Purari River. Shear zones and zones with strongly disturbed sediment locally accompany the faults. The Bevan Fault is marked by a zone up to 100 m wide of intense disturbance, anomalous dips, and shattered, slickensided, and calcite-veined rocks. Evidence of large displacement is given by the manner in which it truncates the Uheedi Anticline and in which the axes of the Horbu Anticline and Kuku Syncline converge near the Purari River. The faults are cnsidered to be thrusts; the Aure Beds are thrust against the Orubadi beds along the Bevan Fault, and the Orubadi beds are thrust against the Era beds along the Kuku and Era Faults. The Kereru Anticline and Fault system is a low-angle overthrust with the south flank of the anticline overturned and truncated by the thrust plane.

The cross-folds formed as a result of interference of the north-trending structures in the Aure Trough and the east-trending structures of the Papuan Fold Belt.

GEOPHYSICS

Aeromagnetic results

The simplified map of the total magnetic field (Fig. 5) is based on an airborne magnetic survey of part of the Papuan Basin and Basic Belt carried out in 1967 by Compagnie Generale de Geophysique (CGG) under contract to the BMR (CGG, 1969). Over the offshore and coastal areas the survey was flown at 1200 m above sea level along north-south lines spaced at roughly 10 km intervals and east-west lines at roughly 5 km intervals; the mountainous northeast corner of the Sheet area was flown at 4500 m above sea level on north-south and east-west lines at double spacings.

Anomalies of roughly circular paired highs and lows with sharp gradients are associated with the Quaternary volcanics of Mount Duau and Mount Favenc and Aird Hills. For the remainder the total magnetic intensity is very even without regional trends; the anomalies have low values and gentle gradients. The magnetic contours roughly parallel the northwest to west-northwest structural trend over the platform west of $145^{\circ}18'$, and the north to north-northwest structural trend over the Aure Trough east of $145^{\circ}18'$. The magnetic anomalies have a slightly stronger relief over the Aure Trough than over the platform, which may be explained by the large amount of basic to intermediate volcanic detritus, and therefore iron, in the Aure beds (Tma).

The spot depths to basement on the Kikori 1:250 000 Sheet were determined from magnetometer profiles of the CGG airborne magnetic survey.

Gravity results

Land gravity surveys by APC, IEC, Papuan Apinaipi Petroleum, and Union Oil between 1937 and 1963, and by the University of Tasmania from 1963 to 1965 have been compiled by St John (1967, 1970).

The first marine gravity data in the Gulf of Papua were collected by Williams in 1958 and 1959 with short traverses perpendicular to the shoreline in Redscar and Kerema Bays. He found that the anomalies generally decrease towards the coast.

A regional marine geophysical survey carried out in the Gulf of Papua by CGG for BMR provides gravity coverage over most of the offshore part of the Kikori Sheet area. Traverses were directed along east-west lines spaced at intervals of about 20 km, and currently available contour maps compiled by Mutter (1972a, b) are based on hourly values, i.e. on point readings taken along traverses at intervals of about 15 km.

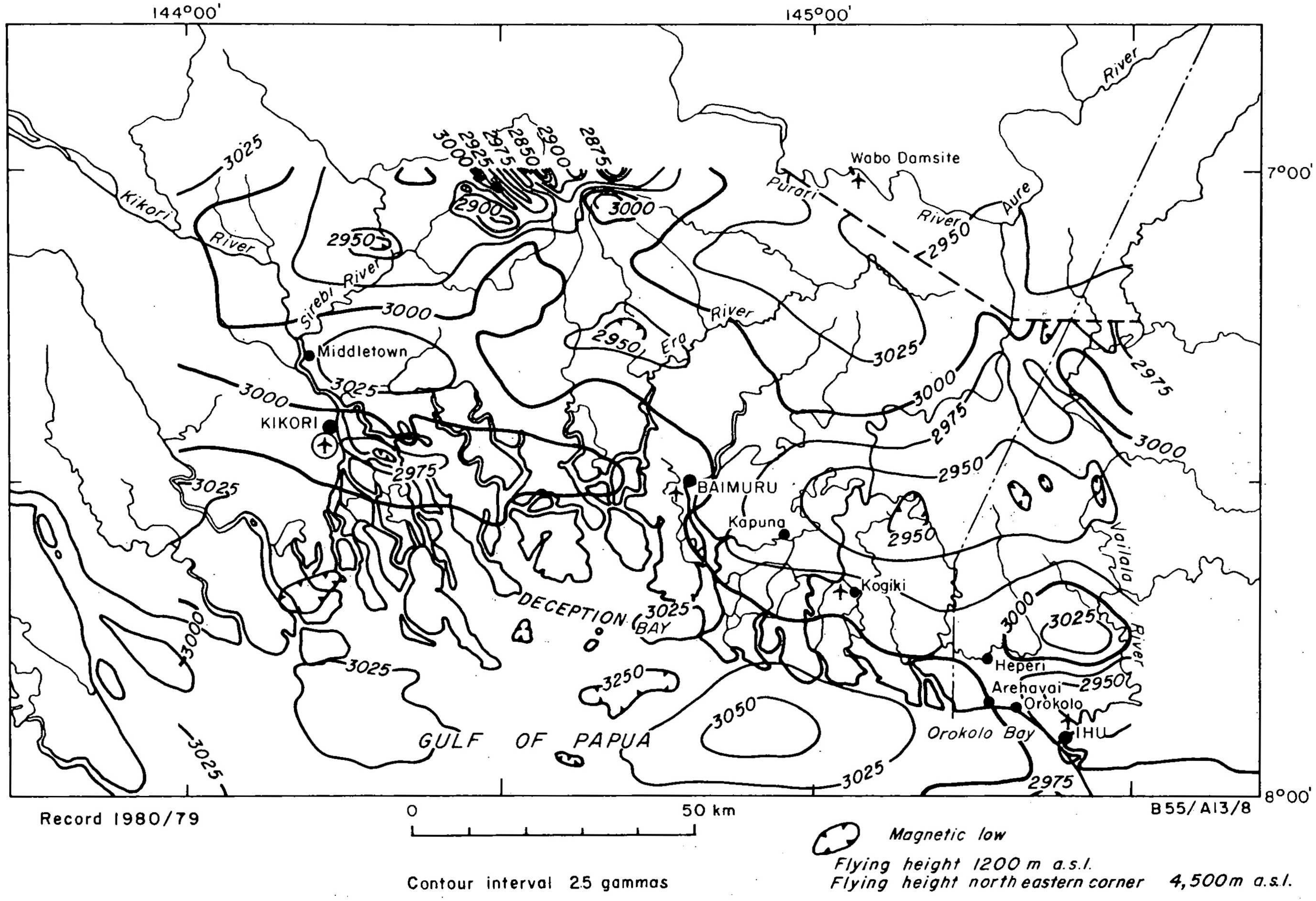


Fig. 5 Total magnetic intensity

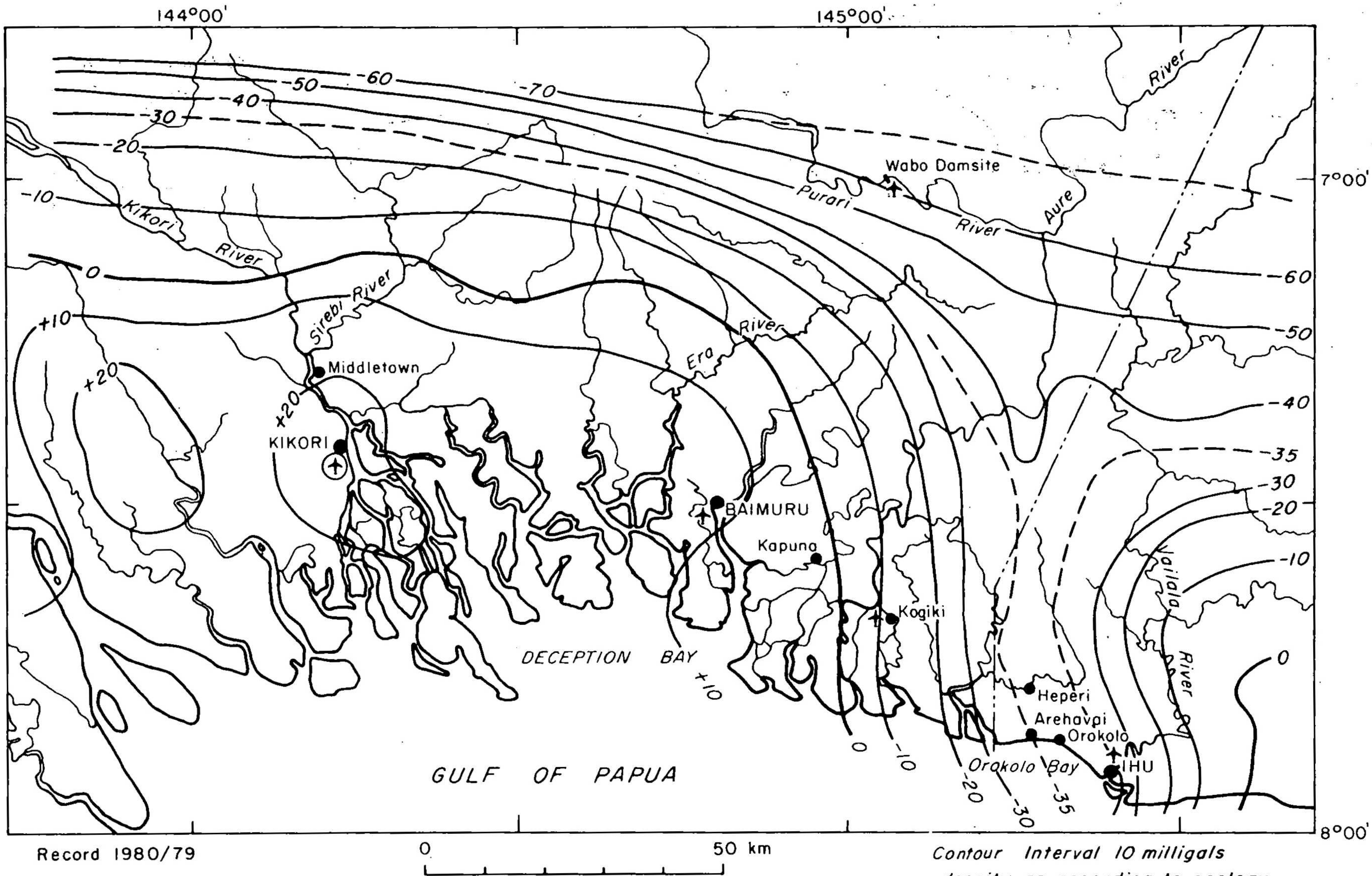


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Fig. 6 A Bouguer anomalies Kikori Sheet area

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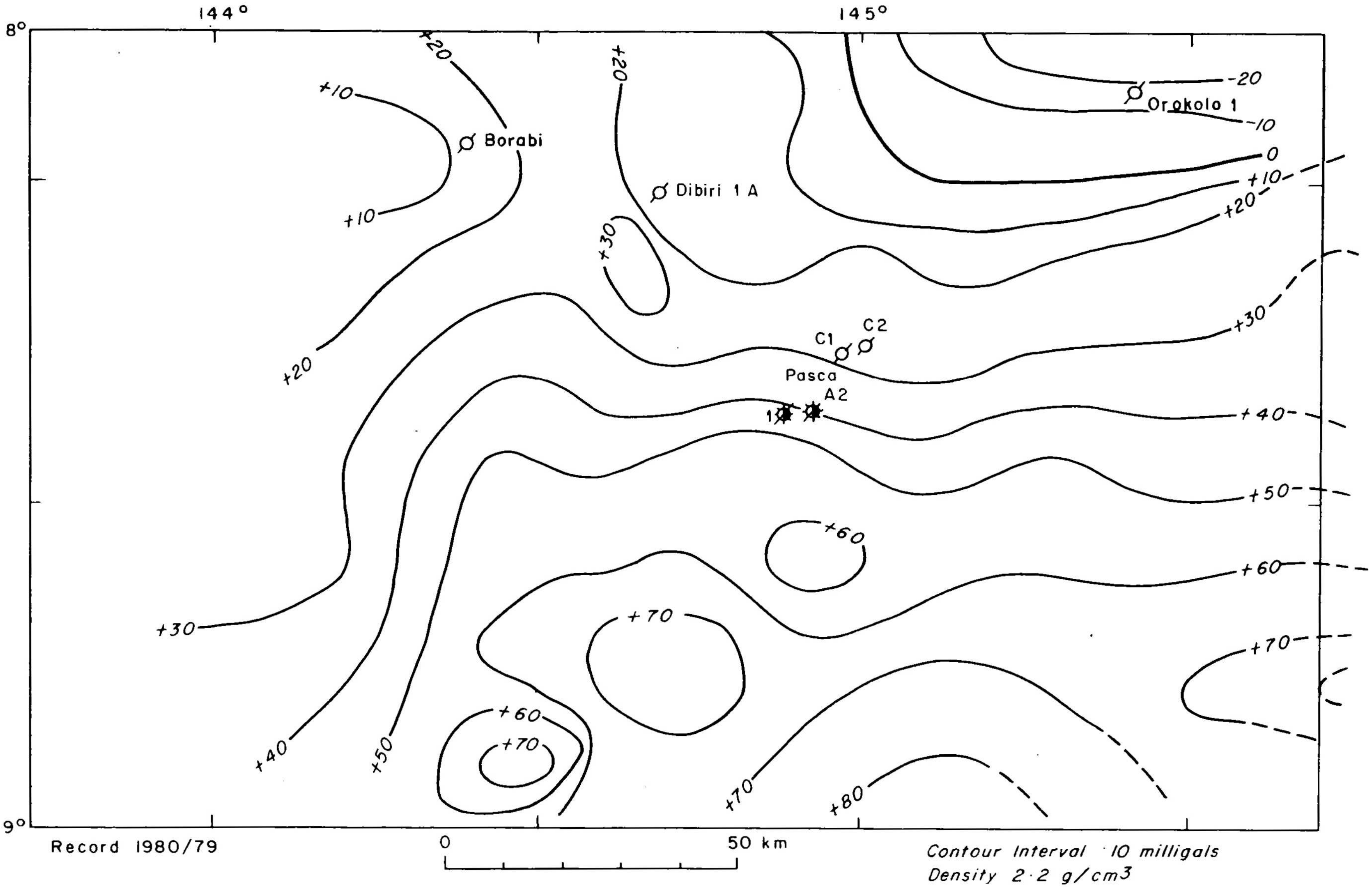

Fig. 6 B Bouguer anomalies Gulf Sheet area

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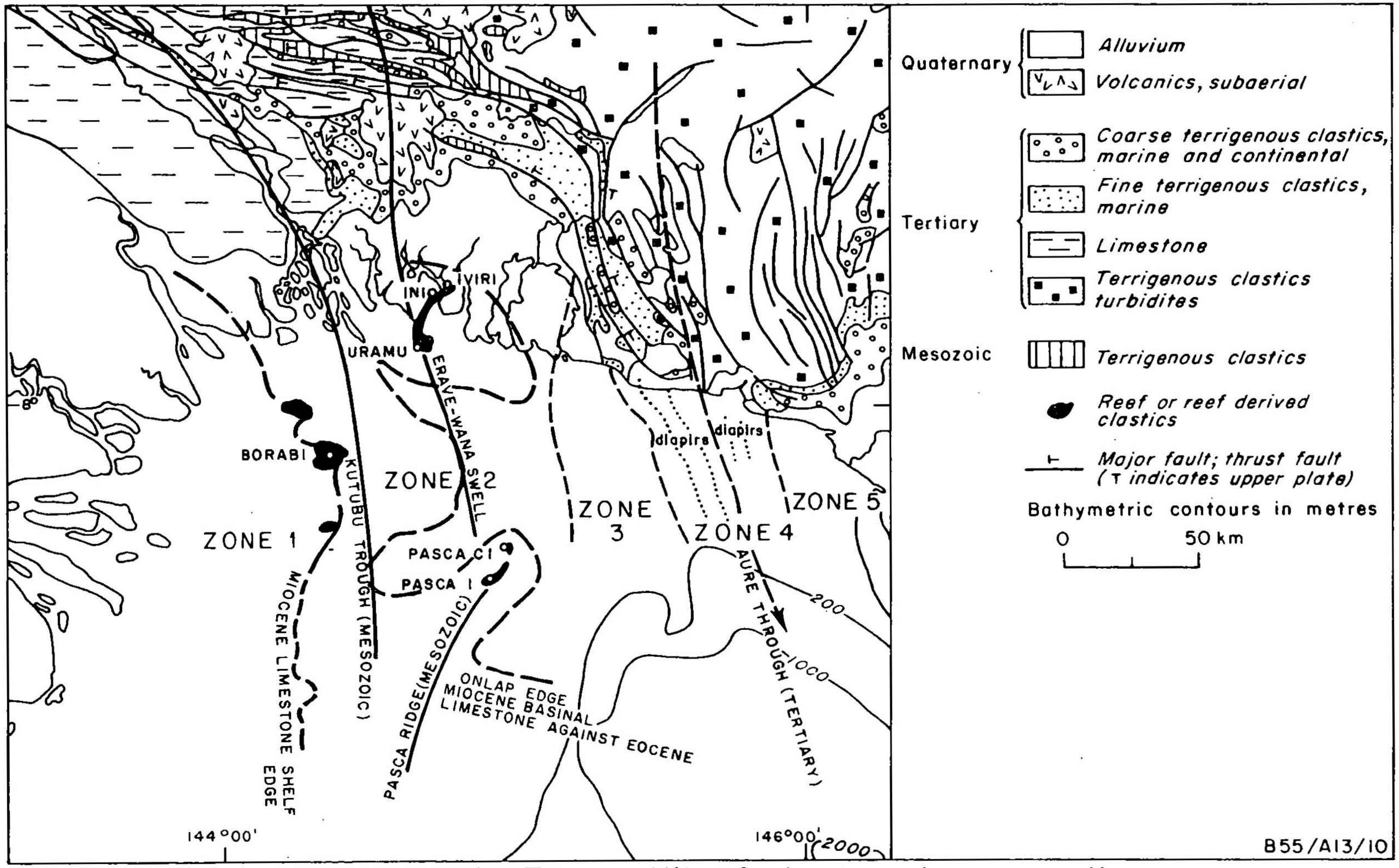

Fig. 7 Tectono-Stratigraphic Zones: Kikori sheet and surrounding area

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The Bouguer Anomaly maps of Figures 6A and 6B are based on the work of St John and Mutter.

On the easternmost part of the Sheet area the regional northwest to west-northwest trend of the Bouguer anomalies changes to north-south following a similar break in the structural trend from the platform to the Aure Trough. The anomalous high gravity values across the Aure Trough were explained by St John as the result of crustal thinning beneath the Aure Trough. St John (1967) deduced a crustal thickness of 28 km at Cape Cupola in the Wau Sheet area to neutralise the negative anomaly caused by the thick pile of the sediments in the Aure Trough. A prominent north-trending low occurs over the Aure Trough between the Purari and Vailala Rivers; it covers the axis of maximum late Miocene and Pliocene (Tg-Th) sedimentation of rocks with slightly less density than the rocks of the Aure beds.

North of the Sirebi River, the negative gravity gradient to values of minus 130 mGal on the Karimui Sheet area is attributed partly to considerable thickening of Mesozoic sediments to the northeast of the Kikori and Sirebi Rivers and partly to isostatic compensation (St John, 1967 and 1970).

The 20 mGal closure about 20 km east of Kikori is correlated with a hypothetical intermediate intrusive body associated with the Aird Hill Volcanics (St John, 1967).

Seismic results

The onshore seismic work carried out by APC and IEC between 1937 and 1966 is of restricted value for this report: much of the work was shallow refraction shooting confined to small areas, and complicated superficial geological structures made interpretation difficult. The subsurface continuation of the asymmetrical Orie Anticline was traced by seismic refraction methods for about 45 km to the Pie River, its southeast-trending axis passing slightly north of Wana 1.

Marine seismic surveys in the Gulf of Papua were carried out for Burmah Oil Company in 1960/61, for Phillips Australian Oil Company from 1964 to 1966, for Esso Exploration and Production Australia Inc. in 1967/68, and for Marathon Petroleum Australia Ltd in 1966/67. The seismic work for Phillips was done under contract by Western Geophysical Company of America, and three of the four seismic surveys are relevant to the geology of the Kikori Sheet and immediately surrounding area.

The Papuan Marine Seismic Survey, Gulf of Papua, Permit 39 (Phillips, 1968) covered an extensive area at reconnaissance scale and from the acquired information Phillips subdivided the Gulf of Papua into five structural zones (Fig. 7):

Zone 1: Western stable shelf with relatively thin Tertiary section dipping eastwards. Structurally disturbed. Miocene reef development is suggested on the basinward edge (platform).

Zone 1A: A Miocene limestone shelf area in Deception Bay. Eocene block uplift and a Miocene reef development are indicated (platform).

Zone 2: West slope of the basin in which the Tertiary dips more steeply, and rapidly thickens, towards the east. Tertiary/Mesozoic unconformity is evident and the Mesozoic is locally folded and faulted (platform passing eastward into continental slope).

Zone 3: An undeformed belt occupying the western part of the mobile Tertiary basin. Sediments dip steeply to the east. Local faulted structures are recognised in the older rocks on the eastern edge of this zone. Gentle folding is present in strata tentatively identified as upper Miocene and Pliocene (continental slope).

Zone 4: Seaward extension of the Aure Trough, a complex fold belt characterised by gentle synclines separated by tight anticlines. Crests of the anticlines tend to be thrust-faulted, and diapirs have developed in the anticlinal cores by flowage of incompetent mudstones. Regional dip is to the west.

Zone 5: A mobile eastern shelf and slope province where there is good evidence of thrust-faulting associated with the eastern shelf of the Aure Trough.

In the shelf and western slope areas (Zones 1 and 2) three seismic horizons were mapped:

(i) Top of the Miocene limestone horizon - a composite of the middle Miocene in the west and the lower Miocene in the east. The middle Miocene horizon is a strong reflector showing a gentle easterly dip and terminating abruptly eastwards from the edge of the shelf. The lower Miocene horizon is of outstanding character and is tied to the lower Miocene limestone in Iviri No. 1.

(ii) Cretaceous/Tertiary unconformity is marked by a seismic energy band correlated with the base of the Eocene limestone. Wide variation in the thickness of the overlying limestones gives the mapped two-way times little structural value. Reflections below this horizon are weak and are thought to represent a predominantly shale section.

(iii) Horizon near the base of the Mesozoic shows as a strong reflection in the Deception Bay area but deteriorates to the west and south. Faulted Mesozoic basement can be inferred from this event.

In the Orokolo Bay area (Zone 3) two horizons were mapped:

(i) Pliocene horizon. A low-energy band in the lower part of the Pliocene section. Phillips interprets small closed structures as obscured flowage or thrusting in Miocene mudstones.

(ii) Top of lower Miocene limestone and possibly Eocene limestone. A strong reflection near the base of a large interval of weak energy is ascribed to the Eocene limestone, estimated to be 6000 metres below sea level. This horizon is equivalent to the lower Miocene reflection as mapped in the Deception Bay area.

In the eastern portion of the Gulf, in the shelf and slope province (Zone 5) reflection quality is poor, and only one horizon was mapped.

The Marine Seismic Survey, Gulf of Papua, 1968 was made in Permit 42 in the central area of the Gulf of Papua, in an attempt to locate reef structures and to provide connecting control into Permit 39. The principal feature in the survey area is interpreted as a broad pre-Miocene arch extending across the entire length of the Permit in a southwest direction; it is considered to be the Tertiary expression of the Erave-Wana Swell. Biohermal reefs appear to be developed on a structural high on the northeast tip of the arch. The reef varies in thickness from 1000 to 3000 m and is covered by 2000 to 3000 m of late middle Miocene to Recent fine-grained terrigenous sediments.

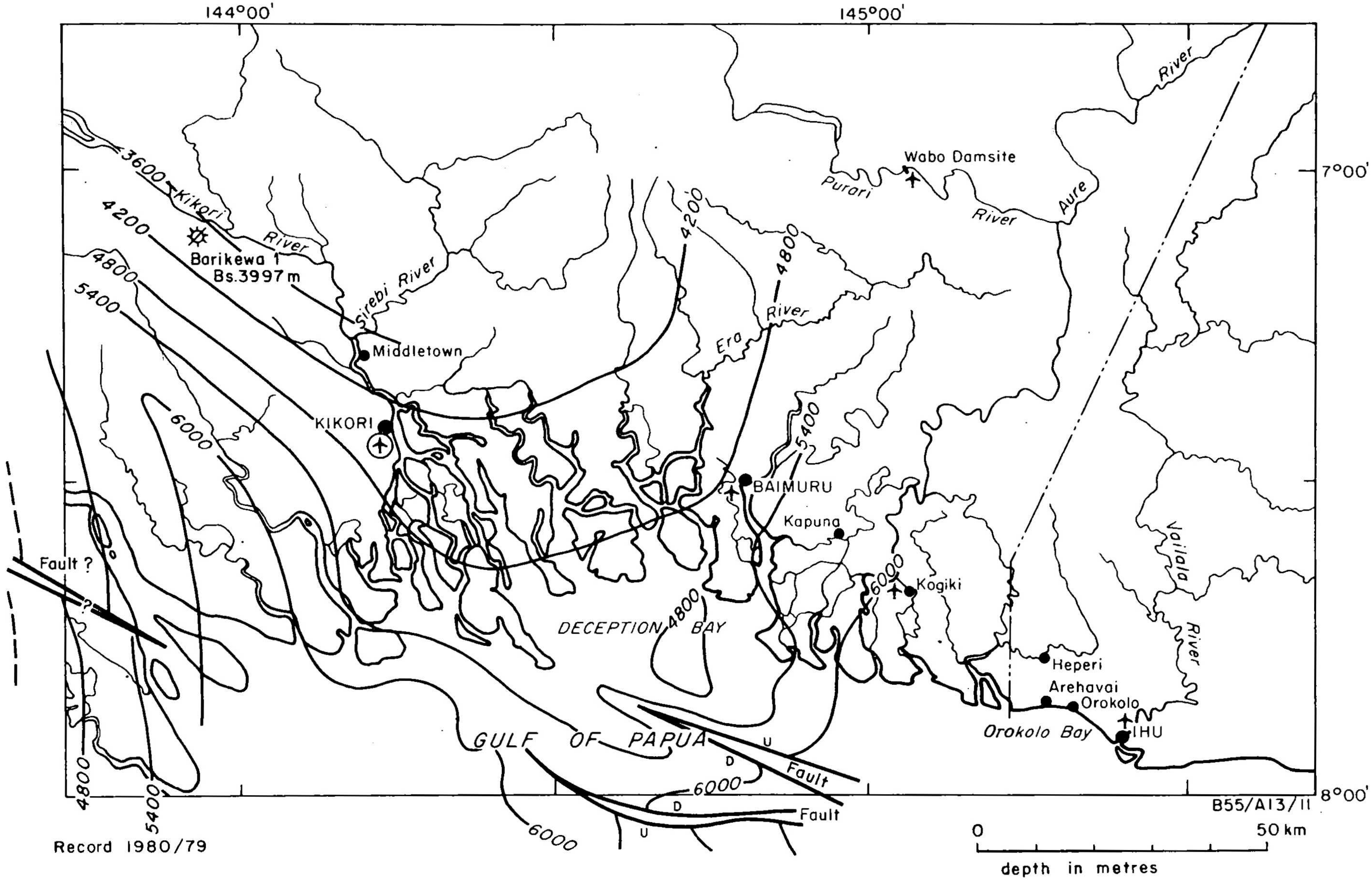

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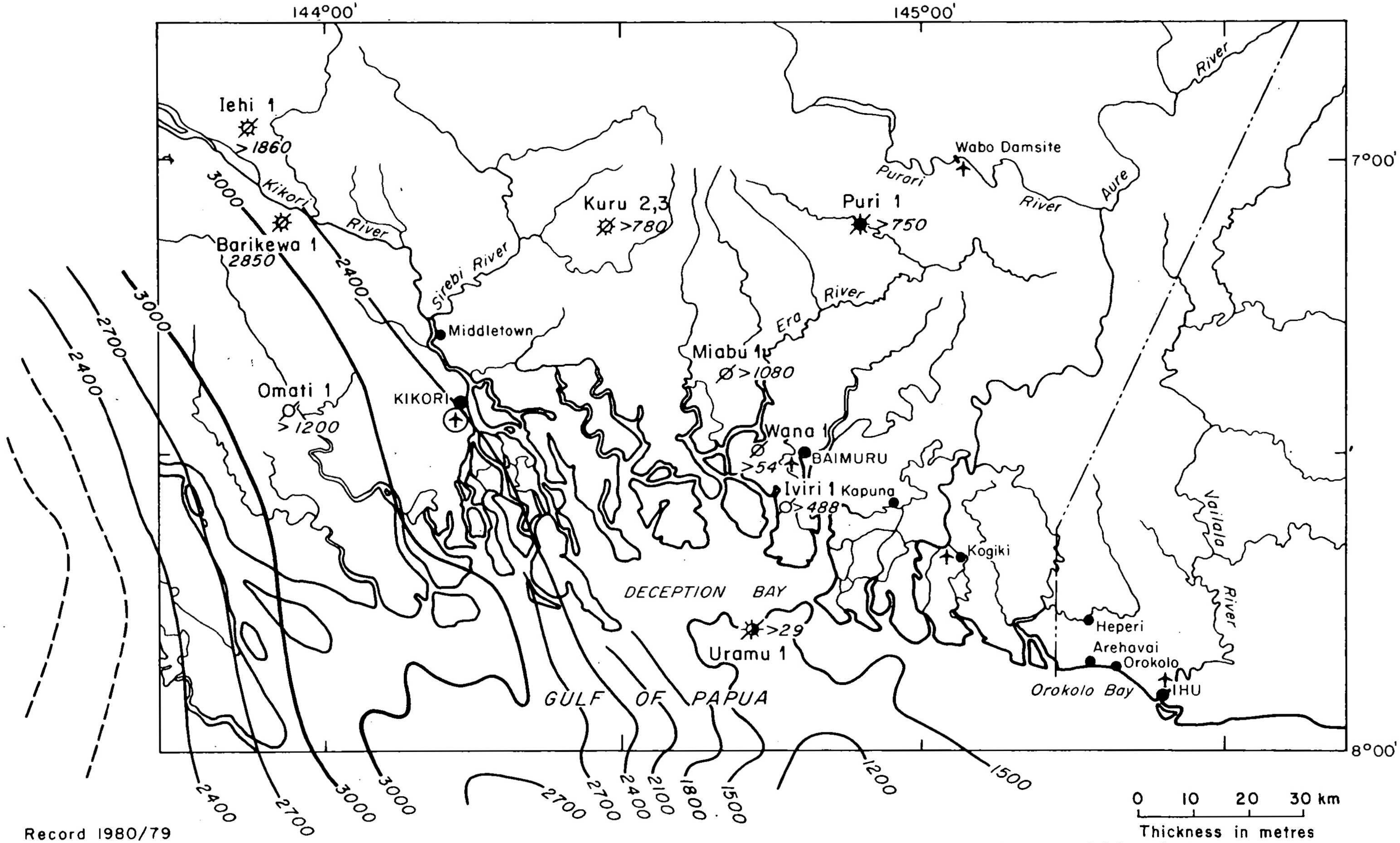
Fig. 8 Basement depth map (using rough estimate of average seismic velocities)

After Philips Australian Oil Co., 1973



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(from limited well control and available seismic information; used average velocity of 3000 m/sec

Fig. 9 Isopachous map of Total Mesozoic

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The Bligh Entrance Marine Seismic Survey (Phillips, 1969) was made in the northwest Gulf of Papua. The survey was designed to provide further details over anomalies outlined in the previous work and to extend reconnaissance surveying farther to the west and southwest. The following seismic horizons were mapped:

A horizon within the Pliocene

Top of the lower Miocene limestone

Possible top of the Eocene

Possible top of the Mesozoic

Two horizons from within the Mesozoic

The pliocene horizon can be traced to Orokolo 1 to the north. It illustrates the folding attributable to flow in the late Tertiary to Recent mudstone/silt section. The lower Miocene limestone reflection shows a northeast-dipping fold plunging from the broad arch that underlies the Pasca area. North and east of Pasca the reflection time configuration is affected by the low-velocity overburden. The unidentified top of Eocene horizon is persistent and covers the entire area to the south of Pasca. The possible top of Mesozoic reflector dips from 1.5 seconds in the southwest, on the continental shelf, to below 6.5 seconds in the basin, northeast of Pasca. It is the only horizon that could be traced across the entire area. The upper of the two Mesozoic horizons shows thinning of the Mesozoic section to the north of the structural arch, and eventual truncation at the Mesozoic/Tertiary unconformity.

The basement depth map (Fig. 8) and isopach map of the total Mesozoic (Fig. 9) are based on seismic information from Phillips using a rough estimate of average velocities and with some control from petroleum wells. The depth-to-basement contours on the Kikori 1:250 000 Sheet are derived from seismic time contoured maps of Phillips and spot depths to basement obtained from the CGG airborne magnetic survey (1969). Phillips has not converted the time contours to depth contours because accurate depths are very dependent on good velocity control through the variable carbonate thickness (Darai Limestone). There is however some agreement between magnetic depths and estimated seismic depths shown on Figures 8 and 9.

ECONOMIC GEOLOGY

Petroleum

The discovery of oil seepages in 1911 at Upoia, near the mouth of the Vailala River, initiated an extensive search for petroleum which is still continuing. In the course of surface exploration in the Gulf Province by APC and IEC many additional seepages of oil and gas were found. Onshore deep drilling began after World War II, and some considerable flows of gas were met at Barikewa 1, Iehi 1, Kuru 1, and Bwata 1, and of oil and gas at Puri 1. During the 1960s the emphasis on petroleum exploration was transferred to the Gulf of Papua, where several offshore wells were drilled by Phillips. Gas and condensate were discovered in Uramu 1 and Pasca C1. Oil and gas seepages are shown on the Kikori 1:250 000 Sheet and hydrocarbon resources are summarised in Table 1. The localities of all petroleum wells are plotted on the Kikori 1:250 000 Sheet and in Figure 4.

Initially the search for oil and gas was directed to the finding of traps in reservoir rocks of Tertiary age. At Kuru 1, Bwata 1, and Puri 1 petroleum was derived from argillaceous limestone which acted as both source and reservoir rocks. The reservoir characteristics came from fracture porosity; the sealing rock at Kuru 1 and Bwata 1 is late Miocene and Pliocene calcareous mudstone overlying the argillaceous limestone, and at Puri 1 Early Cretaceous mudstone which was thrust over the argillaceous limestone. The traps were caused by folding at Kuru 1 and Bwata 1, and by a combination of folding and thrust-faulting at Puri 1. Most of the oil and gas seepages appear to be located along faults through Pliocene sediments and it is thought the oil and gas has migrated directly from the source rocks rather than from reservoirs. The early petroleum exploration indicated that large reservoirs of oil and gas are absent in the Miocene shelf and basinal limestone and younger terrigenous sediments of the Gulf Province, and from 1960 onwards exploration was directed at other targets.

Large flows of gas were tested from Miocene reef limestone reservoirs at Uramu 1A and Pasca C1. The reefs are blanketed by late Miocene and Pliocene mudstone; the source rock is probably Miocene argillaceous limestone and/or late Miocene to Pliocene mudstone. Detailed and sophisticated seismic techniques must be applied to pinpoint small diameter pinnacle reef structures. Facies analyses, seismic work, and drilling by Phillips (Tallis, 1975) outlined a potential reef belt along the eastern margin of the carbonate shelf in a line with Uramu 1A and Pasca C1, but other occurrences may be associated with scattered 'tectonic highs' on the carbonate shelf.

Barikewa 1, Iehi 1, and Omati 1 indicate considerable potential for petroleum production from the Mesozoic. Closely associated reservoir, source, and cap rocks probably extend from these wells westward to Magobu Island (mouth of Fly River) and northwestward to the south of Wok Feney (Blucher Range Sheet area). East and northward of the wells the Mesozoic sequence is predominantly clayey, and sandy beds with reservoir potential are rare or absent. The Mesozoic mudstone has generally good source-rock characteristics. However, in Dibiri 1A there are indications of organic metamorphism at depths below 4350 m. Since the 1960s petroleum prospecting has attempted to delineate structural and stratigraphic traps where Mesozoic source, reservoir, and cap rocks occur in close association.

Coal

Coal was discovered in the Gulf Province in 1892 and seams were found on the upper Purari River by the Mackay-Little Expedition of 1909. In 1912 a Government geologist, J.E. Carne, investigated coal deposits in the Samia Creek, a tributary of the Purari River (Carne, 1912). In the course of systematic oil prospecting from 1950 onwards, by APC and IEC, more coal was discovered in the Pide River, in tributaries of the Era River, in the Oroli Creek, and near the mouth of the Vailala River. Coal-bearing strata were intersected in the APC Iviri 1 well, Esso Ini 1 well, and Phillips Uramu 1A well. An inventory of coal deposits in the Purari River and Era River area was made by CRA Exploration Pty Ltd in 1974 (CRA Exploration, 1975).

In the Gulf Province seams of lignite and sub-bituminous coal are associated with the middle part of the Pliocene Era beds (TQe). The Pliocene sedimentary sequence indicates widespread regression which began in late Miocene time in response to regional uplift in eastern Papua and the New Guinea Highlands.

The main coal occurrences are plotted on the Kikori 1:250 000 Geological Sheet.

The small size, remote locality, attitude, and low grade of the coal deposits in the Gulf Province have precluded exploitation. The low grade of the coal necessitates cheap water transport if extraction for more than local use is to be economically feasible. For this reason the Orloli Creek locality near the navigable Purari River, the Hohoro and Kuku areas near the mouth of the Vailala River, and the Era River localities near the limit of wet-season navigation may be of potential interest. The Gulf Province lignite and sub-bituminous coal have been suggested as fuel for a local cement industry, and with increasing industrialisation of Papua New Guinea the coal could be used as a raw material for the chemical industry.

Iron

Beach sands with titaniferous iron have been reported from the shores of Goaribari Island, Cape Blackwood, and Deception Bay; their localities are shown on the Kikori 1:250 000 Geological Sheet.

Construction materials

Demand for construction materials in the Kikori Sheet area is at present limited to paving aggregate for maintenance and upgrading of road and airfield surfaces. A limestone quarry on the eastern bank of the Kikori River 2.6 km south of Middletown satisfies the local need within the Kikori area. Sand from beach ridges around Orokolo Bay may be used for fine aggregate.

Groundwater

A village water supply survey in the Gulf Province (Braybrooke, 1967) found that surface water supplies were generally inadequate and commonly open to pollution. Fibreglass or concrete tanks connected to roof top catchment areas were recommended for most coastal villages. On the beach ridges and plains around Orokolo Bay groundwater is expected to be found at depths of less than 7 m; for domestic use it can be recovered by simple shallow dug wells. Prolonged droughts in the July to November period may cause these wells to dry up. Wells 25 to 35 m deep would be required to supply schools and hospitals.

GEOLOGICAL HISTORY

Mesozoic and early Tertiary geosyncline

Triassic (Fig. 10A)

Minor arkosic terrestrial sediments ('Red Beds') and marginal marine sediments were deposited along the eastern margin and in block-faulted embayments and depressions of the platform of the Papuan Basin, which was continuous with continental Australia to the south. The basement of the platform consists of Palaeozoic acidic igneous and metamorphic rocks forming the northernmost part of the tectonised north-trending Tasman Geosyncline. The edge of the platform possibly runs from near Pasca Ridge to the Kubor High, where its north-south trend changes to west-northwest and continues to the basement high underlying the Muller Anticline.

Quartzite of the basement was penetrated at Pasca C1 and Barikewa 1 bottomed in arkosic terrestrial deposits of Triassic or Early Jurassic age.

Jurassic (Fig. 10B)

The Triassic tectono-sedimentary framework persisted during the Early Jurassic. In the Middle and Late Jurassic shallow seas transgressed westward over the platform and inundated the 'tectonic highs'. With progressive transgression the marginal marine and terrestrial sediments became overlapped by marine fine clastics. The Kutubu Trough, a north-west to north-trending downwarp was an area of rapid deposition with a thick pile of mudstone and intercalations of quartzose sandstone reflecting minor regressions. Provenance was to the west and sedimentation in the Kutubu Trough was in a prodelta environment; Pasca Ridge was not a source of detritus, but the Kubor High may have been intermittently emergent. Deposition of mudstone and greywacke continued along the margins of the platform in eugeosynclinal conditions. The continental slope and Kutubu Trough probably were separated by a broad submarine rise (precursor of the Erave-Wana Swell) with slightly less accumulation of sediment than in the adjacent basins.

Cretaceous (Fig. 10B & C)

The Early Cretaceous (Tithonian-Neocomian) began with a period of regional marine regression, with deposition of reworked clean quartz sandstone advancing east and northeastward. Uplift and basin shallowing also occurred in the Kutubu Trough, where mudstone is intercalated with minor sandstone beds; farther east the regression is not noticeable and Jurassic mudstone deposition persisted into the Early Cretaceous. If present, the broad submarine rise, between the Kutubu Trough and the eugeosyncline along the margin of the platform, had no significant influence on the sedimentation pattern, but the Kubor High was at least intermittently emergent.

In the late Neocomian fine clastics transgressed over the marginal marine sediments and continued to accumulate until the early Cenomanian.

Later in the Cenomanian and continuing to early Eocene, epeirogenic tilting and warping accompanied by faulting resulted in a new widespread regression. Uplift and warping is most pronounced in the northeastern and eastern part of the platform, from the Erave-Wana Swell to Pasca Ridge where offshore seismic and exploration wells indicate that faulting and erosion exposed the Late Jurassic. Farther south and west over the platform the erosion surface cuts less deeply into the Mesozoic section and Early Cretaceous rocks are generally preserved.

The emergent platform (Kubor High, Erave-Wana Swell, Pasca Ridge) provided detritus for the oceanward mio- and eugeosynclinal trough where sedimentation was accompanied by some submarine volcanism.

Eocene (Fig. 10C & D)

Middle and late Eocene sediments transgressed from east to west over the tilted, faulted, and eroded Mesozoic rocks. The shallow shelf and near-shore limestone progressively thin westward to extinction west of Borabi 1 and Barikewa 1. The actual depositional limit may have been more widespread, but is probably modified by erosion which followed late Eocene regression.

Early middle Oligocene (Fig. 10E)

There is no record of sedimentation during the early and middle Oligocene. As a result of orogenesis of the eugeosynclinal Mesozoic and Eocene sediments most of the area probably was low emergent, although sedimentation in the Aure Trough may have commenced during this time. The lack of diagnostic micro-fauna is another possible reason why early and middle Oligocene sediments have not been recognised.

Cainozoic geosyncline

Late Oligocene to middle Miocene (Fig. 10F)

The Cainozoic Papuan Geosyncline took shape during the Oligocene concomitant with and following the tectogenesis and early phases of uplift of the eugeosynclinal Mesozoic and Eocene sediments (Brown et al., 1975). By the late Oligocene, deposition of turbidites had started in the Aure Trough; the sediments were derived from the emerging landmasses and volcanic complexes to the east and north by-passing an unstable shelf. To the west the Trough shallowed over a broad continental slope with

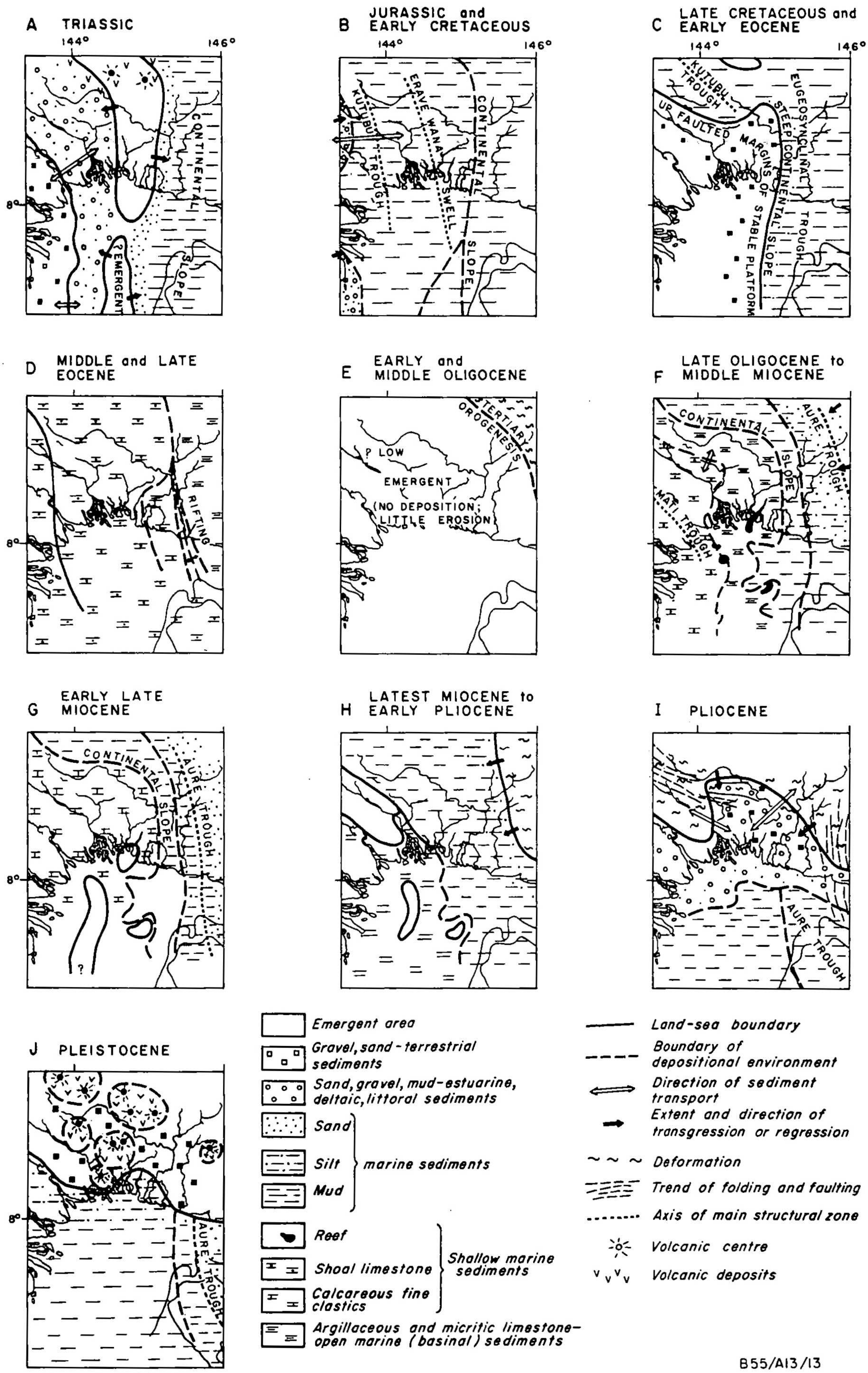

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Fig. 10 Geological History

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sedimentation of fine clastics. The slope passed into the eastern flanks of the Erave-Wana Swell and Pasca Ridge which formed 'basement highs' along the eastern edge of the platform during the Cainozoic. A miogeosynclinal deepwater carbonate shelf with deposition of argillaceous limestone developed around the margins of the platform, and graded to the west into a shallow stable shelf environment with a blanket of bioclastic limestone. The maximum rate of argillaceous limestone deposition was in the Omati Trough. The stable shallow shelf was an environment suitable for the growth of patch reefs which provided the detritus for the shoal limestone. Reef structures also developed over the Erave-Wana Swell and Pasca Ridge 'basement highs', which possibly shielded the shelf area over the platform from inundation by fine clastics from the east and north. Folding of sediments in the Aure Trough started in the early Miocene.

Late Miocene to early Pliocene (Fig. 10G & H)

During the early Late Miocene, folding and partial emergence of the Aure Trough was accompanied by marine regression over the miogeosynclinal and stable shallow shelf of the platform. Over the eastern marginal part of the miogeosynclinal shelf the introduction of terrigenous clastics derived from landmasses to the east and north result in the deposition of calcareous mudstone. Turbiditic sedimentation in the Aure Trough continued but the eugeosynclinal axis shifted westward as Trough sediments were uplifted and became emergent in the northeast.

The latest Miocene to early Pliocene was a period of subsidence and marine transgression accompanied by the deposition of a thick sequence of open marine mudstone.

Pliocene (Fig. 101)

Renewed uplift of the orogen in East Papua and the New Guinea Highlands was accompanied by widespread volcanism, and caused folding and faulting in the adjacent parts of the Cainozoic Papuan Geosyncline. On the margin of the emerging Aure Trough and over the northern part of the miogeosynclinal shelf a regressive sequence of coarse terrigenous sediments was draped around rising landmasses (anticlines) and formed thick deposits in adjoining basins (synclines). Fine clastics were deposited south and west of the tectonically unstable area in an open marine environment; in the Gulf of Papua, mudstone sedimentation continues to the present day.

The Aure Trough sediments are folded and thrust-faulted. The uplift of the orogen in East Papua may have caused westward tilting of the Aure Trough sediments. As a result detachment planes may have developed at several stratigraphic levels within the turbidite sequence and the sediments may have 'glided' to the west and southwest in response to gravity. In the late Pliocene, following uplift of the Kubor 'basement high', the northern part of the miogeosynclinal shelf was subjected to southwest 'gliding', and sediments were folded and thrust faulted. The southern part of the miogeosynclinal shelf and the stable shallow shelf remain tectonically inactive except for minor normal faulting. In the extreme western part of the Aure Trough the north-northwest trending folds give way to a complicated system of cross-folds, formed as the result of interference with the east-trending overthrust folds that are related to the uplift of the Kubor 'basement high'.

Pleistocene to Recent (Fig. 10J)

Continuous uplift of the Aure Trough and the northern and eastern parts of the platform was accompanied by widespread subaerial volcanism. The extent of the land area approached the present-day coastline. Coarse lahar and terrestrial sediments fringed the volcanoes; offshore in the Gulf of Papua, sedimentation of mud and silt continues.

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APPENDIX 1

STRATIGRAPHY

Age - UPPER PALAEOZOIC or possibly LOWER MESOZOIC.

Unit or Formation - Pzu.

Rock type - quartzite; probably widespread pelitic and psammitic metamorphics intruded by granite.

Estimated thickness - unknown.

Distribution - not exposed; in Pasca C1.

Remarks - with angular unconformity under Darai Limestone (Tmdr) in Pasca C1. Probably basement rock of Papuan Basin uplifted along Pasca Ridge during Upper Cretaceous. If Upper Palaeozoic, probably correlative with Permian Omung Metamorphics of Kubor Range (Karimui Sheet); if Lower Mesozoic possibly remnants of Triassic sediments overlying basement.

Age - TRIASSIC or possibly LOWER JURASSIC.

Unit or Formation - R.

Rock type - sandstone, minor conglomerate and thin beds of silty mudstone. The sandstone is feldspathic, fine to coarse-grained, calcareous, friable and slightly pyritic; the conglomerate is arkosic.

Estimated thickness - unknown.

Distribution - not exposed; in Barikewa 1.

Remarks - with angular unconformity under Upper, possibly Middle Jurassic in Barikewa 1. Terrestrial 'red bed' depositional environment. Age based on stratigraphic position, and tentative correlation with Upper Triassic fluviatile and marginal marine sediments (Rux) in Kanau 1 (Lake Kutubu Sheet) or possibly with Lower and Middle Jurassic Bol Arkose (Blucher Range Sheet).

Age - UPPER, possibly MIDDLE JURASSIC.

Unit or Formation - Ju.

Rock type - mostly mudstone with beds and laminae of siltstone, sandstone and rare oolithic limestone. Mudstone is dark grey to brown or black, hard, locally shaly, slightly micaceous, variably silty, and contains rare pyrite, carbonaceous matter, and glauconite. Sandstone is white to light grey, mostly very fine-grained to medium-grained, slightly calcareous, normally well-cemented. Composed predominantly of quartz and feldspar with some glauconite and rare pyrite. Fossils include bivalves, echinoid fragments, ostracods, forams, spores, and microplankton.

Estimated thickness - 1890 m in Barikewa 1.

Distribution - not exposed; in Iehi 1, Barikewa 1, Omati 1, Orie 1, Wana 1, ?Borabi 1, Muabu 1, Dibiri 1A, ?Uramu 1A; with apparently complete section in Barikewa 1, although boundary with Lower Cretaceous is not sharply defined.

Remarks - With angular unconformity over feldspathic sandstone and arkosic conglomerate (Ru) in Barikewa 1. Conformable under similar sediments of Lower Cretaceous (Kl) and unconformable (usually disconformable) under middle and upper Eocene limestone (Te) in Muabu 1, Wana 1, ?Uramu 1A, Dibiri 1A. Open marine, basinal, transgressive depositional pro-delta environment; provenance to west or southwest. Age from spores, microplankton, and bivalves (Inoceramus); floral assemblages assign the 1176 m thick section in Dibiti 1A to Oxfordian and Bathonian. Possibly lateral equivalent of the marginal marine and continental sediments of the Kuabgen Group in Blucher Range Sheet area, and open marine, dark pyritic shale and siltstone of the Maril Shale in Lake Kutubu Sheet area, and Om Beds of the Blucher Range Sheet area. Uplifted and at places block-faulted and slightly tilted to east and northeast during Upper Cretaceous and lower Eocene (e.g. Erave-Wana Swell), and between upper Eocene and lower Miocene (e.g. Pasca Ridge). Potential source rock for petroleum, although there are indications of organic metamorphism at great depths in wells (e.g. below 4350 m in Dibiri 1A); no good reservoir sandstones detected as yet, but should be present farther to the west where they are closer to the sediment source.

Age - LOWER CRETACEOUS (NEOCOMIAN, ALBIAN, APTIAN)

Unit or Formation - Kl; Tubu Shale in Kereru Range, Klt.

Rock type - Mostly mudstone with beds and laminae or streaks of siltstone and sandstone and rare beds or concretions of argillaceous limestone. Mudstone is grey to black or greenish grey, massively bedded to finely interbedded with siltstone or fine-grained sandstone, variably shaly, glauconitic and micaceous. Siltstone and sandstone are light grey, greenish grey to dark green, slightly micaceous, typically glauconitic, variably sorted, friable to well-compacted, in places calcareous and speckled with pyrite or iron oxide, and occur in beds ranging in thickness from a few millimetres to 120 m. Sand content increases progressively from east to west and from bottom to top of the Lower Cretaceous. Fossils include ammonites (up to 50 cm diameter), belemnites, bivalves, spores, forams, radiolaria, and microplankton.

Estimated thickness - at least 480 m in Kereru Range; approximately 1070 m in Barikewa 1.

Landform and airphoto pattern - Almost continuous, up to 750 m wide belt of smooth, subdued hills along foot of limestone scarp of Kereru Range.

Distribution - Exposed along southern flank of Kereru Range; in Iehi 1, Orie 1, Barikewa 1, Omati 1, Kuru 2, Iviri 1, Puri 1.

Remarks - Conformable over similar Upper Jurassic sediments (Ju); overlain by middle and upper Eocene with disconformity or slight angular unconformity (e.g. Barikewa 1). Subdivision in Neocomian, Albian and Aptian in Barikewa 1 based on spores (Burger, 1969); Lower Cretaceous age based on microplankton, forams (planktic and benthic), ammonites, bivalves, and belemnites. Open marine, basinal, pro-delta depositional environment; provenance to west or southwest. Possibly lateral equivalent of shallow and open marine sediments of Feing Group in Blucher Range Sheet area, open marine sediments of the Kerabi Formation in Lake Kutubu Sheet area, and volcanolithic sediments and volcanics of the Kodaku Tuff in the Karimui Sheet area. Emergent and slightly tilted to east and northeast during Upper Cretaceous and lower Eocene (e.g. Erave-Wana Swell), and between upper Eocene and lower Miocene (e.g. Pasca Ridge). In Kereru Range folded and thrusted. Potential source rock for petroleum; generally no good reservoir rock, although fine to coarse-grained, quartzose, friable, slightly argillaceous sandstone units in Barikewa 1 and Iehi 1 produced dry gas; thicker sandstone units could be expected farther west, closer to sediment source.

Age - EOCENE (MIDDLE AND UPPER)

Unit or Formation - Te

Rock type - Calcarenite, minor micrite and calcareous mudstone, and rare chert, glauconitic sandstone, claystone, and shelly calcirudite; locally dolomitised, recrystallised and stylolitically veined. Calcarenite is light grey, cream to buff and predominantly bioclastic with minor detrital quartz and glauconite. Micrite and calcareous mudstone are light grey to cream, at places cherty, and may contain pyrite and very fine-grained quartz grains. Fossils include algae, larger benthic forams, echinoids and bryozoan fragments in coarser lithologies and planktic forams in micrite and calcareous mudstone.

Estimated thickness - maximum 330 m.

Landform and airphoto pattern - not diagnostic.

Distribution - Thin discontinuous outcrops along the foot of the limestone scarp of Kereru Range; along Aure Scarp as far south as 7 km downstream of junction of Purari and Aure Rivers; in many petroleum wells (Fig. 5).

<u>Remarks</u> - With low angular unconformity or disconformity over Jurassic (Ju) or Lower Cretaceous (Kl; Tubu Shale, Klt) and disconformable under Darai Limestone (Tmdr, Tmds, Tmdp) and Aure Beds (Tm). Wide lateral distribution; Eocene transgression advancing from east and possibly north as far west as longitude 143°30'. Essentially only upper Eocene is known but some middle Eocene rocks may be present in Dibiri 1A, Omati 1, Barikewa 1, Kuru 2. Deposition over stable shelf under shallow water marine conditions; depositional limit was subsequently modified by erosion following block faulting and partly emergence between upper Eocene and upper Oligocene. Age based on larger benthic, and planktic forams. In Kereru Range folding and thrusting during Pliocene. Minor gas and brine produced by Wana 1; the rocks may have some potential as reservoir rocks when formed in suitable trap conditions.

<u>Age</u> - Lower Miocene to uppermost Miocene, upper Te-upper Tf.
<u>Unit or Formation</u> - Aure Beds, Tma.
<u>Rock type</u> - Greywacke sandstone, siltstone, mudstone, minor conglomerate, argillaceous micrite; well and thin bedded to massive, usually grey to dark grey, and grey to brownish grey on weathered surfaces; graded bedding and related cross-lamination, intra-formational conglomerate, slumping and solemarks. Composition conglomerate pebbles: mostly andesite to basalt volcanics, minor diorite, milky quartz, metamorphic and sedimentary fragments, and rare Eocene limestone; composition greywacke: feldspar, hornblende, igneous fragments (mostly andesite), metamorphic and sedimentary fragments, pyroxene, milky quartz and quartzite in a clayey matrix. The rocks are uniformly low in SiO_2, high in MgO, and low in K_2O (Edwards, 1947) and approach the average chemical composition of andesite (Nockolds, 1954). Fossils and planktic forams, rare benthic forams, fragments of echinoids, corals and molluscs, and plant remains and carbonised wood fragments.

Sediments become progressively richer in mudstone (partly calcareous) westward from the Purari River.

Estimated thickness - 4500 m between Tauri and Vailala Rivers (Wau Sheet area) gradually thinning westward and grading into Darai Limestone over continental slope and platform.

Landform and airphoto pattern - Rugged terrain, moderate to strong relief (50-400 m), homoclinal ridges, hogbacks, ridge-and-ravine topography, moderately dense, structurally controlled to dendritic drainage.

Distribution - Aure Trough.

Remarks - Synonym is the informal name Aure Group (e.g. Rickwood, 1948). In certain areas (e.g. Keka-Pemani) the Aure Beds were subdivided by APC geologists, but the absence of distinctive lithological marker beds (monotonous succession of alternating greywacke and mudstone), structural complexity and paucity of guide fossils make it impossible to apply the subdivision on regional scale. Disconformable over upper Eocene limestone (Te); possibly unconformable over oceanic volcanic crust or quasi-continental crust (Brown et al., 1975). Conformable and unconformable under Orubadi Beds (Tmup); unconformable under Pleistocene sediments (Qph, Qp); lateral equivalent and interfingering with basinal facies Darai Limestone (Tmdp). Deposited in deep, unstable marine, linear trough with continuous sedimentation of fine detritus and intermittent supply of coarse sediment by turbidity currents; the nearby source area of intermediate to basic volcanic rocks and minor metamorphic and sedimentary rocks was to the north and east. Age from planktic forams. Synsedimentary deformation (broad folding) possibly commenced in lower Miocene resulting in local emergence during uppermost Miocene (Tg). Intense folding, and thrusting in Pliocene and possibly Pleistocene with axial fold and thrust planes dipping east and east-northeast. The young topographic feature of the Aure Scarp is probably underlain by a late

Pliocene or Pleistocene thrust fault. A few oil seepages and numerous gas blows have been reported from outcrops of the Aure Beds; small oil shows were encountered at Upoia 1, dry gas and saline water in Kariava 1. The Aure Beds are not considered to be potential reservoir rocks for petroleum.

Age - Upper Oligocene to lower Miocene; Te-lower Tf.

Unit or Formation - Darai Limestone; shelf facies, Tmds.

Rock type - Biocalcarenite, biomicrite and calcirudite, and rare argillaceous limestone and horizons with chert nodules; white, cream, light grey, yellow to brown; thinly bedded to massive, at places cross-bedded; slightly dolomitised; towards top biomicrite becomes more common and locally is lithologically indistinguishable from overlying Tmdo. Fossils are mostly fragmentary and include algae, bryozoa, corals, bivalves, gastropods, echinoids, crinoids and forams. Sequences of interbedded algal and non-algal (bryozoan-rich) limestone reflect fluctuations in depth of seawater.

Estimated thickness - maximum of at least 1080 m at Omati 1.

Landform and airphoto pattern - Limestone plateaux and ridges with conical and honeycomb karst, karst crevices and doline karst, or poorly developed karst; flat to gently undulating karst plains with widespread veneer of alluvium, sealing off the limestone surface.

Distribution - Southeast extension of Darai Plateau; Orie Plateau.

Remarks - Disconformable over Eocene limestone (Te; derived Eocene fauna) and Lower Cretaceous (Kl, Klt), interfingering wihth and lateral equivalent of basinal and reef facies Darai Limestone (Tmdp, Tmdr), conformable under but locally lithologically indistinguishable from Susuwora Limestone (Tmdo). Shallow marine, shelf environment with nearby atoll or patch reefs on main sources of detritus. Age from larger benthic and planktic forams.

Mostly (sub)horizontal; Pliocene deformation into broad gentle anticlinal structures and monoclines supposedly developed over basement faults. Upper Oligocene and Miocene basement faulting probably controlled partly the distribution of limestone facies types. Potential source rock for aggregate and building stone; a small quarry along Kikori River 2.6 km south of Middletown satisfies local need.

Age - Upper Oligocene to lower Miocene; Te-lower Tf.

Unit or Formation - Darai Limestone; basinal facies (Puri Limestone Member), Tmdp.

Rock type - Argillaceous biomicrite and micrite, rare thin beds of calcareous mudstone and calcarenite. Micrite is thinly bedded to massive, light to dark grey, hard, dense, locally dolomitic, partly recrystallised and slightly pyritic, and contains variable amounts of planktic forams (globigerinids), rare chert nodules and carbonaceous streaks. Calcarenite is cream, grey to white and contains larger benthic forams (orbitoids), planktic forams, fragments of bryozoa, echinoids, algae and rarely grains of quartz and glauconite.

Estimated thickness - maximum at Omati 1, 1800 m.

Landform and airphoto pattern - Linear east-trending belt of smooth hilly terrain with local dolines and broad north-facing dip slopes; to south bounded by a cliff.

Distribution - Kereru Range and north of junction of Purari and Aure Rivers; in petroleum wells on the delta and offshore.

Remarks - Disconformable over Eocene limestone (Te), conformable under and locally lithologically indistinguishable from Susuwora Limestone (Tmdo), lateral equivalent of and interfingering with shelf and reef facies Darai Limestone (Tmds, Tmdr), over stable continental slope interfingering with lower and middle Miocene part of Aure Beds (e.g. northwest of junction of Purari and Aure Rivers). Deep marine to shelf margin environment.

Age from larger benthic and planktic forams. (Sub)horizontal to folded and thrust; Pliocene deformation and uplift decreasing in intensity from north to south.

Reservoir and source rock of oil and gas in Puri 1 and of gas condensate in Bwata 1; accumulation of petroleum associated with structural traps. Low porosity and permeability indicate that the unit is not a potential reservoir rock. Potential source of aggregate and building stone.

Age - Upper Oligocene to Miocene, Te-lower Tf, very locally upper Tf.
Unit or Formation - Darai Limestone; reef facies, Tmdr.
Rock type - Biolithite, massive, white to light brown, skeletal with strongly variable amounts of framework organisms as solitary and colonial corals, red and green algae, bryozoa, but also molluscs, echinoids, brachiopods and forams; vuggy and cavernous, slightly to moderately dolomitic. White to grey or brown biocalcarenite, biomicrite and biocalcirudite are more prominent in forereef and backreef facies and contain detritus of above fossils.
Estimated thickness - maximum at Borabi 1, 1230 m.
Distribution - Not exposed, but penetrated by Borabi 1 along the edge of the carbonate shelf, and by Uramu 1A, Iviri 1, Mira 1, Ini 1, and Pasca 1 and C1 over the Erave-Wana Swell and Pasca Ridge 'basement highs'.
Remarks - Disconformable over Eocene limestone (Te); in Pasca C1 unconformable over basement quartzite (Pzu). Disconformable under upper Miocene Orubadi Beds (Tmup) except at Mira 1 where reef growth kept pace with subsidence until uppermost Miocene (N17) when it was buried conformably by Orubadi Beds. The absence of the upper Tf Susuwora Limestone does not necessarily indicate a hiatus, but the paucity of diagnostic fossils makes it difficult to prove that reef growth continued during that time. Age

from larger benthic and planktic forams. Differential uplift, and slight tilting caused by post middle Miocene blockfaulting. The Miocene limestone reefs are prospective reservoir rocks for oil and gas; they are blanketed by upper Miocene to Pliocene mudstone. At Uramu 1A gas was tested at 22.4 million cubic feet (2.08 million cubic metres) per day, and at Pasca 1 at 6.85 million cubic feet (0.64 million cubic metres) per day together with 100 barrels of condensate per million cubic feet of gas.

Age - Upper Miocene, upper Tf.

Unit or Formation - Darai Limestone; Susuwora Limestone Member, Tmdo.

Rock type - Argillaceous biomicrite and micrite, minor calcareous mudstone, rare calcarenite. Cream to light brown, light to dark grey, mostly thin bedded or laminated but locally medium to coarse bedded or massive, soft (chalky) to moderately hard, often friable, rare carbonaceous streaks, generally abundant planktic forams (predominantly Orbulina and Globigerina) in places concentrated in thin beds; other fossils include nannoplankton ooze and fragments of molluscs.

Estimated thickness - maximum at Bwata 1, 175 m.

Landform and airphoto pattern - Rolling to flat terrain dissected by widely spaced crevices, usually oriented in one dominant direction.

Distribution - Southeastern extension of Darai Plateau, Orie Plateau, and in many petroleum wells over the platform.

Remarks - Synonyms are the informal names Orbulina Marl (e.g. Llewellyn & Turner, 1960), Susuwora Marl Formation (e.g. Sykes, 1954), and Susuwora Marl (e.g. Crichton, 1955). Conformable over shelf and basinal facies Darai Limestone (Tmds, Tmdp) at places with gradational contact; missing over reef facies Darai Limestone (Tmdr). Conformable under Tg-state part of Orubadi Beds (Tmup) with either sharp break or gradual transition; where Tg-stage is missing, disconformable under Th-stage (Tiviri River and

Orie Plateau area). Defined by microfaunal content where lithological contacts with underlying and overlying units are unrecognisable. Probably lateral equivalent of upper Tf stage Aure Beds (Tma) with zone of transition across continental slope (between Bwata 1 and Puri 1, and Purari River). Source and reservoir rock of dry gas in Kuru 1 with estimated maximum flow of 50-100 million cubic feet (4.6-9.3 million cubic metres) per day; the accumulation is in a structural trap. No potentially economic reservoir rock because of widespread low porosity and permeability.

Age - Uppermost Miocene to Pliocene, Tg-Th.

Unit or Formation - Orubadi Beds, Tmup.

Rock type - Platform: Mudstone, siltstone, minor sandstone; generally calcareous and carbonaceous, blue grey to mid and dark grey, moderately indurated except for hard calcareous sandstone beds, commonly fine to medium well bedded or laminated, at places small-scale cross-bedding, locally pyritic (nodules); mudstone in places bentonitic; fossils include planktic (*Globigerina*) and Benthic forams, molluscs either sparsely distributed or concentrated in beds or lenses as fragmentary detritus, flecks and streaks of plant material; the unit tends to become sandier towards the top.

Aure Trough: Mudstone, sandy mudstone, siltstone, sandstone, minor conglomerate, rare calcarenite and limestone breccia; in part calcareous, generally carbonaceous with occasionally thin coal seams; locally pyritic (nodules), and calcareous concretions; blue grey to medium and dark grey, brownish where more calcareous; well, fine to medium bedded, also coarse bedded and massive, moderately to well indurated. Sandstone is generally immature, fine to coarse grained or pebbly and consists of strongly variable amounts of feldspar, Fe-Mg minerals, quartz, carbonate, and metamorphic and sedimentary fragments with much detritus derived from the Aure Beds; at places tuffaceous mudstone has locally a flowing or plastic nature as the result of a bentonitic component and in these zones (e.g. Hohoro Anticline) occur major gas blows, mud volcanoes, oil smelling mudstone and mudstone pugs.

Estimated thickness - Platform: maximum - 1700 m N of Kereru Range.

Aure Trough: maximum - 2400 m at Hohoro Anticline.

Landform and airphoto pattern - Platform: subdued hilly with dense dendritic and at places irregular and poorly integrated drainage, some homoclinal ridges and hogbacks formed on resistant sandy beds; much land instability.

Aure Trough: generally low hilly with dense dendritic drainage at many places modified by homoclinal ridges and hogbacks.

Distribution - Widely exposed over Kikori Sheet area; also penetrated by most petroleum wells in delta area and offshore.

Remarks - Synonyms are the informal names Toa Mudstone (Zehnder & de Caen, 1956), Murua Group (e.g. Rickwood, 1948), Orubadi Mudstone (e.g. Llewellyn & Turner, 1960) and Orubadi Formation (e.g. Stanley, 1954). Where Tg-stage is complete, conformable over Susuwora Limestone (Tmdo) and Aure Beds (Tma); where Tg-stage is incomplete or missing the contact is unconformable or disconformable. Conformable, but locally unconformable under Era Beds (TQe); at places mantled by Duau and Mount Murray Volcanics (Qva, Qvm). In Aure Trough Orubadi Beds have been locally subdivided by APC geologists (e.g. de Verteuil & Rickwood, 1947), but the restricted lateral extension of these subunits and the structural complexity make it impracticable to apply the subdivision on regional scale. Diachronous unit with upper age of Th-stage; upper age limit becomes progressively younger to the south, and under delta and Gulf of Papua the unit is partly lateral equivalent of Era Beds (TQe). In Aure Trough sediments were rapidly deposited in an unstable shallow to moderately deep marine environment with nearby source

areas; on the platform the moderately deep marine environment was more stable and source areas were more remote or very low. Age from planktic and larger benthic forams. Synsedimentary folding and uplift at the later stages of Aure Beds (Tma) deposition became more pronounced during Tg-stage and parts of the Aure Beds (Tma) deposition became more pronounced during Tg-stage and parts of the Aure Trough became emergent in anticlinal structures which supplied detritus for the intervening basins. Most of the platform also became emergent during Tg-stage but discontinuous sedimentation of fine terrigenous detritus occurred along the northern and eastern margins. During Th-stage a marine transgression had begun, resulting in more widespread sedimentation. In the northern part of the platform the unit is folded and thrust along an east-west trend line with axial planes and fault planes dipping north. In the Aure Trough, folded and thrust along a north-northwest trend line with axial and fault planes dipping east. In the intervening area, complicated deformation with cross-folding and a series of closely spaced, roughly parallel major fault zones (Kuku, Beban, Purari and Aure Faults). Where only mudstone is exposed the structure is generally extremely confused, with chaotic dips; at places the mudstone behaved plastically forming zones of mudstone pug. The plastic behaviour is explained by the high content of bentonite material; the tendency of this mudstone to expand or flow into a borehole has caused serious and sometimes insuperable drilling difficulties. In southern part of platform, horizontal or slightly tilted. On the platform small gas seepages occur on the crest and eastern pitching end of the Kuru Anticline, on the Toi Anticline, the Me'epo Nose, and the Bwata Anticline; surface occurrences of oil and gas have been found within the area of closure on the Purari Anticline and in the saddle between it and the southeast pitching end of the Kereru structure.
Kuru 1 encountered gas on striking the top of the Darai Limestone, and gas

shows were noted in mudstone at Wana 1. In the Aure Trough oil impregnation occurs 20 km south of Kariava 1 near the west bank of the Vailala River; a number of springs of saline water accompanied in some cases by gas or small quantities of pale yellow to light brown oil were reported from the Upoia area; a number of gas blows and oil smelling mudstone occur at the Hohoro Anticline, but only brackish water and small quantities of dry gas were struck in Hohoro 1 and 2. The unit is a possible target for further drilling if potential reservoirs can be located. Bentonitic mudstone of Hohoro Anticline has been quarried as a source for drilling mud.

Age - Pliocene to Pleistocene.

Unit or Formation - Era Beds, TQe.

Rock type - Lower part: Sandstone, minor siltstone and mudstone and locally basal conglomerate. Sandstone is fine to medium grained, lithic, blue grey, brown weathered, generally cemented by carbonate, well compacted, well bedded, rarely massive, locally cross-bedded, and has moderate porosity, moderate grain roundness, and good sorting. Siltstone and mudstone are dark grey and commonly carbonaceous; some beds contain subspheroidal hard calcareous concretions. Basal conglomerate has pebbles up to 8 cm in diameter composed of quartz, chert, and acid plutonic and metamorphic rocks. Abundant lamellibranchs, gastropods, and forams.

Middle part: Mudstone, sandstone and siltstone with lenticular coal seams. Sandstone is fine to coarse grained, lithic, grey to bluish grey, moderately compacted, well and fine to coarse bedded, cross-bedded, locally massive, and contains sporadically clay pellets. Mudstone and siltstone are grey to bluish grey and generally finely interbedded. Coal seams are mostly associated with siltstone beds and vary in thickness from 4 cm to 7 m with most common thickness between 50 cm and 100 cm; the maximum observed lateral extension is 1500 m; the coal is black to dark brown, lignitic to sub-bituminous, generally brittle and closely cleated; coaly wisps, carbonaceous partings and plant debris are common. Rare beds with marine lamellibranchs and gastropods.

Upper part: Mostly sandstone, minor siltstone and mudstone, rare coal seams. Sandstone is commonly massive, cross-bedded, fine to coarse grained, ferruginous, moderately compacted. Mudstone and siltstone are usually finely intercalated, blue grey to grey, and contain frequent carbonaceous streaks and plant debris. Rare bands with molluscs are associated with basal sandstone beds. Massive sandstone beds at top contain locally large proportions of tuffaceous debris.

Estimated thickness - strongly variable due to syn-sedimentary tectonic movements; maximum about 2000 m.

Landform and airphoto pattern - Moderate to steep relief, homoclinal ridges, hogbacks and flatirons developed on sandstone beds, structurally controlled oval to circular, scarp-bounded basinlike structures and cuestas aligned along northwest to north-northwest trend. Dense to moderately dense dendritic drainage.

Distribution - Widely distributed east of Sirebi and Kikori Rivers, in particular in southern foothills.

Remarks - Conformable, locally unconformable (e.g. Orie and Kuru areas) over, and towards south (under delta area) grading laterally into, Orubadi Beds (Tmup); conformably and unconformably overlain by Pleistocene sediments (Qph, Qpo, Qp) and Duau Volcanics (Qvd); uppermost part grades laterally into Duau Volcanics (Qvd). The shallow marine and littoral sediments of the lower part, the paralic sediments of the middle part, and the continental sediments of the upper part represent a regressive sequence. Sediment derived from landmass to the north. Age from larger benthic forams. Tectonism during Pliocene sedimentation caused incomplete sequences over crests of rising folds, thicker sequences in adjacent troughs, and unconformities within the unit. Moderately to weakly tilted and deformed into oval to circular shallow synclinal structures along northwest to west-northwest trend west of Bevan Fault; moderately to steeply tilted and warped in long narrow anticlinal structures east of Bevan Fault. The coal deposits have not been exploited because of the small size, low grade, and remoteness. Some deposits may have potential as local fuel source.

Age - Pleistocene; probably similar age as New Guinea Highlands volcanics, i.e. approximately 200 000 years B.P.

Unit or Formation - Aird Hill Volcanics, Qva.

Rock type - Aphyric to porphyritic plagioclase-rich, leucocratic andesite or dacite lava and volcanic breccia. White to pink feldspathic groundmass; phenocrysts of plagioclase and hornblende range up to 2 cm long; massive layering. Colour-banded andesitic tuff and andesite agglomerate reported by APC.

Landform and airphoto pattern - Group of four low, rounded hills rising abruptly from the delta plain, occupying an area of about 4.5 by 3.5 km in a roughly square configuration with the highest peak to about 370 m above sea level. The hills are separated by moderately deep, short valleys and gullies.

Distribution - Isolated outcrop on island, 13 km east-southeast of Kikori.

Remarks - In valleys overlain by highly disturbed ?Era beds (TQe) (mudstone, siltstone and minor sandstone). Remanent exogenous cumulodomes as suggested by morphology and lithology. Age uncertain; only by correlation with Quaternary volcanic centres in New Guinea Highlands (Mackenzie, 1977). The volcanics consist of phenocrysts of plagioclase and hornblende in a fine to very fine-grained groundmass of plagioclase, hypersthene, tridymite, magnetite, a little augite and potash feldspar, and accessory apatite. Three silcrete and trace element analysis of Aird Hill Volcanics are given in Table 2. All rocks are weathered to various degrees with up to 5% weathering products.

Age - Pleistocene, probably similar age to New Guinea Highlands volcanoes, i.e. approximately 200 000 yrs B.P.

Unit or Formation - Duau Volcanics, Qvd.

Rock type - Agglomerate, tuff and minor lava near central parts of cones; distal deposits of volcanic sandstone, conglomerate, subaerial and water-laid tuffs. Volcanics range in composition from olivine-rich shoshonite and absarokite through olivine-bearing intermediate types containing hypersthene with or without hornblende to olivine-bearing and olivine-free hornblende, two-pyroxene andesite.

Estimated thickness - Outwash deposits up to 400 m.

Landform and airphoto pattern - Mount Duau and Mount Favenc are twin volcanoes with confluent cones rising to a height of about 1850 m. Central parts of the cones are moderately dissected and eroded but lower slopes form mesa-type flat to hummocky outwash aprons cut by a medium spaced radial system of steep V-shaped valleys. The summit of Mount Duau is formed by a steeply scarped old crater or caldera, greatly enlarged and breached to the southwest by erosion. A younger small volcanic core with an almost concentric summit crater lies within the old crater. This cone and the associated apron lying to the south and southwest are slightly more dissected than the older centre, presumably because of a higher proportion of pyroclastics. At Mount Favenc the crater remnants are much less well preserved and the arcuate scarp extending east and south from the summit is probably a retreated crater wall. A deep gorge has been cut by the Abede River through the southern wall of the main crater, exposing the underlying sedimentary rocks. Slight irregularities in the lower southern slopes of Mount Duau and Mount Favenc are caused by gentle monoclinal flexures and fractures.

Distribution - Mount Duau and Mount Favenc.

Remarks - Overlies with angular unconformity Darai Limestone (Tmds, Tmdp, Tmdu), Orubadi beds (Tmup) and Era beds (TQe). Age from correlation with Quaternary volcanic centres in New Guinea Highlands and degree of erosion. The two volcanic centres are extinct. Six silicate and trace element analyses of Duau Volcanics (Qvd) are presented in Table 2.

Age - Pleistocene, probably similar in age to New Guinea Highlands volcanoes, i.e. approximately 200 000 years B.P.

Unit or Formation - Mount Murray Volcanics, Qvm.

Rock type - Mostly distal deposits of volcanic sandstone, conglomerate, subaerial and waterlaid tuffs, and minor agglomerate; chemical and mineral composition similar to Duau Volcanics.

Estimated thickness - Outwash deposits up to 150 m.

Landform and airphoto pattern - The southern and southeastern volcanic apron of Mount Murray is strongly dissected and broken up into smoothly or hummocky surfaced mesa-type outliers; the break-up is partly controlled by fracturing.

Distribution - Mount Murray.

Remarks - Overlies with angular unconformity Darai Limestone (Tmds, Tmdo) and Orubadi beds (Tmup). Age from correlation with Quaternary volcanic centres in New Guinea Highlands and degree of erosion. The volcanic centre is extinct.

Age - Pleistocene, Holocene.

Unit or Formation - Qph.

Rock type - Mud, silt, sand and gravel; locally abundant decomposed plant material.

Estimated thickness - up to 1000 m in delta area and Gulf of Papua (e.g. Mira 1).

Landform and airphoto pattern - Along coast mudbanks and mudflats colonised by mangrove and nipa palm and cut by a maze of meandering channels; farther inland meander and back plains associated with the Era, Purari, and Vailala Rivers and levee and back plains bordering the Kikori River. The meander plains comprise oxbow lakes, swamps, discontinuous levees, point bars, and scroll complexes. Beach ridges and intervening swampy swales, and beach plains border Orokolo Bay. Extensive intermontane plains lie between the lower reaches of Purari and Vailala Rivers. Lower parts of karst plains are covered with thin veneer of alluvium sealing off the limestone surface.

Distribution - Along downstream parts of major rivers, on delta and in Gulf of Papua.

Remarks - In hilly country with angular unconformity over Aure beds (Tma). Darai Limestone, Orubadi beds (Tmup), and Era beds (TQe); in delta area and offshore, conformable or disconformable over Orubadi beds (Tmup) and possibly Era beds (TQe). Provenance mostly Aure beds (Tma), Orubadi beds (Tmup), Era beds (TQe), and Duau and Mount Murray Volcanics (Qvd, Qvm). Age from low degree of dissection, stratigraphic relations unconsolidated character of sediments. The intermontane plains are possibly formed on lake and alluvial sediments; on the delta and offshore, deposition was in a paralic, estuarine, and shallow marine environment. Sand of beach ridges along Orokolo Bay is potential source of fine aggregate.

Age - Pleistocene, possibly partly Holocene.

Unit or Formation - Okani beds, Qpo.

Rock type - Conglomerate, sandstone, minor siltstone, and mudstone. Weakly compacted, dark to red-brown, friable, ferruginous, predominantly volcanically derived, abundant decomposed plant material, poorly bedded, locally basal conglomerate, rare lignite seams.

Distribution - Scattered outcrops along Kikori River.

Remarks - Overlies with angular unconformity Darai Limestone (Tmds), Orubadi beds (Tmup) and Era beds (TQe); locally disconformable over Era beds (TQe). Lateral equivalent of outwash (lahar) deposits of Duau and Mount Murray Volcanics (Qvd, Qvm). Fluviatile, lacustrine and brackish water deposits; main provenance is Quaternary volcanics, but locally Darai Limestone. Age from correlation with Quaternary volcanics. Flat-lying terrace remnants.

Age - Pleistocene, possibly partly Holocene.

Unit or Formation - Qp.

Rock type - Conglomerate, sandstone, siltstone and mudstone. Abundant decomposed plant material, soft brown lignite, massively lenticular bedding, locally cross-bedding, unconsolidated or weakly consolidated.

Estimated thickness - Up to 100 m in Aure Trough in easternmost part of Sheet area.

Landform and airphoto pattern - Flat, smoothly surfaced inliers with widely spaced drainage; remnants of terraces.

Distribution - Easternmost part of Sheet area in Aure Trough; lower reaches of Purari River near Pawaia 1 Village, in Koriki Basin.

Remarks - With angular unconformity over Aure beds (Tma), Orubadi beds (Tmup) and Era beds (TQe). Fluviatile (floodplain and point bar) and lacustrine deposits in intermontane basin (e.g. Koriki Basin) and valleys. Provenance mostly nearby Aure beds (Tma), Orubadi beds (Tmup) and Era beds (TQe). Age from low degree of dissection and stratigraphic relations. Uplifted to 50 to 100 m above depositional level; flat lying.

Age - Holocene, possibly some Pleistocene.

Unit or Formation - Qa (alluvium).

Rock type - Sand, silt, gravel, and mud along rivers.

Estimated thickness - Up to 10 m.

<u>Landform and airphoto pattern</u> - Low, alluvial flats along major rivers.

<u>Distribution</u> - Along major rivers.

<u>Age</u> - Holocene.

<u>Unit or Formation</u> - Qs (scree).

<u>Rock type</u> - Chaotic deposits of angular rock fragments (from rubble to blocks), sand and mud.

<u>Landform and airphoto pattern</u> - Old and recent landslide aprons; scree apron with slump blocks along foot of Aure Scarp.

<u>Distribution</u> - Landslides common in foothills, particularly formed on interbedded terrigenous sediments; along foot of Aure Scarp.

APPENDIX 2

MICROPALAEONTOLOGY, KIKORI 1;250 000 SHEET

Micropalaeontological data have been obtained from D.J. Belford. Locality Numbers refer to the geological map. 'Epoch or Stage' refers to the stages in the East Indies letter classification of the Tertiary.

Locality No.	Specimen No.	Epoch or Stage	Float or outcrop	Lithology
1	7441-0641	N18-19	outcrop	calcareous mudstone
2	7441-0656	N16-21	outcrop	calcareous mudstone
3	7441-0053	N17-18	outcrop	calcareous siltstone
4	7441-0055	N17-18	outcrop	calcareous siltstone
5	7441-0057	N5-23	outcrop	calcareous siltstone
6	7441-1091	N9-21	outcrop	biomicrite
7	7441-1095	N9-21	outcrop	micrite
8	7441-1167	N16-18	outcrop	mudstone & shell fragments
	7441-1170	N18	outcrop	mudstone
9	7441-0015	N17-18	outcrop	calcareous mudstone
	7441-0117	N16-18	outcrop	argillaceous micrite
10	7441-2015	N19	outcrop	mudstone & shell fragments
11	7441-0066	N16-18	outcrop	calcareous sandstone
12	7441-1160	N5-23	outcrop	calcareous mudstone
13	7441-0105	N16-18	outcrop	calcareous siltstone
14	7441-0103	N19	outcrop	calcareous micaceous carbonaceous siltstone
15	7441-0101	N18-19	outcrop	calcareous mudstone
16	7441-0132	N19	outcrop	calcareous siltstone
17	7441-0128	N17-18	outcrop	calcareous siltstone
18	7441-0130	N19	outcrop	calcareous mudstone
19	7441-0134	N16-18	outcrop	calcareous carbonaceous micaceous siltstone

Locality No.	Specimen No.	Epoch or Stage	Float or outcrop	Lithology
20	7441-0136	N17-18	outcrop	calcareous siltstone
21	7441-0095	N16-18	outcrop	siltstone
22	7441-2036	N16-18	outcrop	carbonaceous mudstone
23	7441-2034	N16-18	outcrop	mudstone
24	7441-2013	N17-18	outcrop	calcareous mudstone
25	7441-0020	u. Mioc.-Rec.	outcrop	calcareous siltstone & shell fragments
26	7441-0004	u. Mioc.-Rec.	outcrop	calcareous sandstone & shell fragments
27	7441-0709	N17-18	outcrop	siltstone
	7441-0708G	N9-23	float	micrite
	7441-0708H	N9-21	float	micrite
28	7441-0086	Te-Tf	outcrop	biocalcarenite
29	7441-1124	N16-18	float	micrite
	7441-1125	Te-Tf	float	calcarenite
30	7441-1126	N16-18	outcrop	mudstone
31	7441-0697	N18	outcrop	calcareous mudstone
32	7441-0698	N17-18	float	calcareous mudstone
33	7441-1127	Te-Tf	outcrop	mudstone
34	7441-0578	N11 or younger	outcrop	mudstone
35	7441-0614	N17-20	outcrop	carbonaceous mudstone
36	7441-0559	N17-18	outcrop	mudstone
37	7441-0562	N17-18	outcrop	shale
38	7441-1014	N18-20 possibly N18	outcrop	calcareous, carbonaceous mudstone
39	7441-0589	N17-20	outcrop	mudstone
40	7441-0592	N11 or younger	outcrop	mudstone
41	7441-1050	N17-18	outcrop	calcareous mudstone
42	7441-1047	N11 or younger	outcrop	mudstone

Locality No.	Specimen No.	Epoch or Stage	Float or outcrop	Lithology
43	7441-1100	Mioc.-Rec.	outcrop	biocalcarenite
44	7441-0650	N9-21	outcrop	biomicrite
45	7441-1115	N16-18	outcrop	biomicrite
46	7441-1111	N16-18	outcrop	biocalcarenite
47	7441-1076	N16-18	outcrop	biocalcarenite
48	7441-1077	N19	outcrop	calcareous mudstone
49	7441-1070	N20-22	outcrop	calcareous mudstone
50	7441-1075	N20-22	outcrop	calcareous mudstone
51	7441-0542	Mioc. or younger	float	calcareous mudstone
52	7441-1020	Mioc. or younger	float	calcareous mudstone
53	7441-0573	N11 or younger	outcrop	calcareous mudstone
54	7441-0041	N16-18	outcrop	calcareous mudstone
55	7441-0501	Plioc. or younger	outcrop	mudstone
56	7441-0507	N18-20	outcrop	calcareous mudstone
57	7441-0531	N11 or younger	outcrop	calcareous siltstone
58	7441-0526	N18-20	outcrop	mudstone
59	7441-0051	l. Mioc.-Rec.	outcrop	calcareous sandstone & shell fragments
60	7441-1062	Plioc. or younger	outcrop	sandstone
61	7441-1008	Plioc. or younger	outcrop	calcareous, carbonaceous mudstone

Table 1. Hydrocarbon Resources (data source Beddoes, 1973)

Field	Gas	Liquids (NGL)
Barikewa	31 to 300 billion c.f. (0.88 to 8.5 billion m^3)	-
Bwata	206 billion c.f. (5.83 billion m^3)	1.4 million bbls (0.22 million kl)
Iehi	10 to 126 billion c.f. (0.28 to 3.57 billion m^3)	
Kuru	not estimated	
Pasca	1.0 $\pm$ trillion c.f. (28 $\pm$ billion m^3)	150 $\pm$ million bbls (24 $\pm$ million kl)
Puri	not estimated	
Uramu	200 $\pm$ billion c.f. (5.7 $\pm$ billion m^3)	600,000 bbls (95 $\pm$ thousand kl)

Table 2

Chemical Analyses of Duau Volcanics (Qvd); from Mackenzie, 1977

Sample No.	0037E	Mt Duau 0124	0038C	0038B	Mt Favenc 1020	0140
SiO_2	53.2	53.6	54.6	56.5	57.6	58.6
TiO_2	1.14	1.08	0.71	0.88	1.07	0.68
Al_2O_3	17.1	18.7	18.1	17.4	17.8	18.0
Fe_2O_3	3.05	4.10	3.40	2.60	2.72	2.55
FeO	5.25	4.36	4.45	4.16	3.80	3.43
MnO	0.17	0.18	0.16	0.14	0.15	0.14
MgO	5.10	3.03	3.80	4.05	2.80	3.15
Cao	8.60	8.45	7.80	6.90	6.85	6.15
Na_2O	3.18	3.40	3.50	3.47	3.30	3.90
K_2O	1.65	1.65	1.65	2.30	2.27	2.18
P_2O_5	0.59	0.67	0.64	0.65	0.53	0.64
H_2O^+	0.58	0.60	1.00	0.72	0.87	0.65
CO_2	0.01	-	-	-	0.04	0.03
S	0.05	0.04	0.03	0.03	0.03	0.04
Total	99.67	99.82	99.84	99.80	99.83	100.13
Rb	41.1	-	43.8	65.7	-	65.5
Ba	292	-	350	462	-	544
Pb	16.0	-	13.0	16.0	-	17.0
Sr	895	-	790	944	-	1145
La	19	-	18	22	-	27
Ce	34	-	29	45	-	28
Y	26	25	26	21	21	18
Th	2.7	-	4.3	7.0	-	6.5
U	0.7	-	1.2	1.5	-	1.8
Zr	130	130	140	180	160	190
Cu	60	24	50	48	29	62
Ni	30	<10	14	30	17	20
Sc	24	16	20	19	14	12
V	242	140	190	171	115	105
Cr	50	<10	20	43	46	29

Table 3

Chemical analyses of Aird Hill Volcanics (Qva); from Mackenzie, 1977

Sample	0128	0126	0040
SiO_2	60.7	61.1	63.4
TiO_2	0.56	0.51	0.44
Al_2O_3	18.3	18.7	18.4
Fe_2O_3	4.20	3.45	2.35
FeO	0.60	0.88	1.09
MnO	0.10	0.08	0.08
MgO	1.30	1.45	1.35
CaO	5.15	5.43	4.45
Na_2O	4.39	4.70	5.34
K_2O	1.80	1.80	1.90
P_2O_5	0.38	0.38	0.40
H_2O^+	1.99	1.18	0.77
CO_2	0.11	0.12	0.07
S	0.03	0.03	0.04
Total	99.61	99.81	100.08

Rb	49.1	~48.5	47.7
Sr	1275	~1550	1682
Y	15	~17	10.8
Zr	~190	~190	228
Nb			18.5
Pb	16.5	~18	19.0
Ba	993	~1200	13.60
La	28		52.0
Ce	35		62.5
Cu	17	17	15
CO	21	23	19
Ni	21	~20	17
Sc	9	8	4
V	85	70	41.5
Cr	16	~20	21.5
Th	6.7		
U	2.2		