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Sepik River Helicopter Gravity Survey, TPNG 1968

by

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SUMMARY

A helicopter gravity survey of the Sepik-Ramu area of New Guinea carried out by the Bureau of Mineral Resources during the last four months of 1968 established 1300 gravity stations on a 4-mile grid. Amongst the more important features delineated were: a major Bouguer anomaly low defining the Tertiary Ramu River Basin; a smaller feature, termed the Timbunke Gravity Low, which may indicate thick sediments near the Sepik River; and a gravity high corresponding closely to a basic intrusion on the west side of the Ramu River. A coastwards gradient related to the thinning of the continental crust reaches a value of 4 mgal/mile in the BOGIA 1:250,000 sheet area and may obscure other features.

Although most readings were obtained by the conventional helicopter gravity technique, the hover-site method was tested in the Sepik swamp, using a remote-reading gravity meter lowered from a hovering Jet Ranger helicopter; this showed that the new technique had promise but required further development.

1. INTRODUCTION

During the last four months of 1968 a helicopter gravity survey of part of the Territory of New Guinea was made by the Bureau of Mineral Resources (BMR). The survey area is shown in Plate 1, and consisted of the Sepik-Ramu valleys and the adjacent mountain areas - the Torricelli, Prince Alexander, Adelbert, Bismarck, and Central Ranges.

A study of Plate 5 will show that this is an area of unusual tectonic complexity, and an early decision was taken to make gravity readings at the corners of a four-mile grid, rather than the seven-mile grid employed on the systematic coverage of Australia. Airphotos and information supplied by the Geological Branch of BMR showed that this coverage would be difficult to attain unless special techniques were used; this led to the testing of the hover-site technique (Eckhardt, 1966; Flavelle et al., in prep.).

A Bell Jet Ranger helicopter was used throughout the survey to transport initially a conventional La Coste gravity meter and subsequently a remote-reading meter lowered from the helicopter. Chartered aircraft, ranging in size from small Cessnas to DC.3s, were used to position fuel at airstrips within the area. On the Sepik River, jet boats and double canoes were also used for this purpose. Full details of the logistical organisation of the survey are contained in Appendix 2.

During the ten weeks of helicopter usage, nearly 1300 new gravity stations were occupied, ranging in elevation from sea level to 12,500 feet. Concurrently 300 stations were occupied on the Sepik-Ramu river systems using jet boats as transport. The average density of helicopter stations was one per 15 square miles, exceeding the planned coverage of one per 16 square miles. Further survey statistics are contained in Appendix 3.

2. GEOGRAPHY

Three major physiographic units (Plate 2) can be recognised within the survey area:

1. The Sepik-Ramu Plains.
2. The Central Highlands.
3. The coastal ranges.

The Sepik-Ramu Plains The Sepik-Ramu Plains here include both the actual swamp-lands and the low hills that rise irregularly from them. They are drained by many highly convolute channels, the larger of which run between levees slightly above the general swamp level. The mean elevation of the swamp is only about 50 feet; at Pagui, 200 river miles from the sea, the elevation of the Sepik River is only 40 feet. Low hills, the remnants of a drowned topography, together with the river levees form the only dry ground in the swamp region and so are the normal sites for villages. At some places - south of Angoram, for instance - large villages have been erected on stilts in the swamp. Vegetation within the swamp consists largely of sago forest, normally marshy underfoot and forming a dense cover broken only by streams. In the more inundated areas tall grasses predominate. The drier areas above the general swamp level are clothed in dense rain forest, although hills lying between the Sepik and Ramu mouths have a cover of kunai grass. Rainfall in the district is low - 98 inches per annum at Ambunti and 82 at Angoram - with a dry season between June and August. Ground mist frequently occurs in the early morning, but usually clears by 9 a.m.; it delayed helicopter operations only on three or four occasions.

Access within this area is by boat or helicopter only. There are no roads or airstrips, so rivers and minor waterways are the only practicable routes. On the Sepik and the larger tributaries jet boats can be used, whilst coastal vessels of about 200 tons can reach Ambunti. Native traffic, including outboard-powered double canoes, is restricted to the slow-moving waters of the Sepik and the lakes. An outboard-powered barge operating up to Aiome is the only craft on the Ramu River.

The Central Highlands

The Central Highlands include a number of mountain ranges - the Bismarck, Schrader, and Central Ranges - within the survey area, and high-altitude inter-montane valleys, notably the Lai (near Wabag), and the Wahgi (Mount Hagen). Relief is extreme, with a maximum elevation of 15,400 feet at Mount Wilhelm, although the highest elevation attained on this survey was a point on Mount Hagen (sensu stricto) at 12,500 feet. Rivers typically are fast flowing and so run in deeply incised gorges; the Jimi River is an extreme example, and has a gorge up to 2500 feet deep. The high stream velocities restrict the formation of sand and gravel banks and so eliminate many possible helicopter landing grounds.

Vegetation varies both with locale and altitude. Most of the mountain ranges are covered in dense rain forest, only rarely broken by villages. At high altitudes - above about 10,000 feet - the forest gives way to a tundra-like vegetation of mosses and short grass. In the Jimi and Lai valleys there are extensive plains of kunai grass growing on Quaternary volcanic detritus which filled earlier valleys (C.f. Dow et al., 1968, fig. 34).

In the flatter Wahgi and upper Lai valleys, the natural vegetation is probably again kunai or a similar type of grass. However, the very dense population has cultivated the area extensively. Both native-style gardens (growing taro etc.) and larger, often European-owned, plantations of tea and coffee are present. Cattle raising has also commenced in the Baiyer River valley near Mount Hagen.

The climate, although pleasantly cool to work in, is frustrating from the surveying aspect. Rainfall is between 130 inches per annum at Kompian and about 300 inches per annum in the appropriately-named Rain Mountains. Cloud usually fills the valleys until about 10 a.m., and rarely leaves the mountain peaks. Frequently one valley can be free of cloud while all the surrounding country is obscured.

Access is excellent. A good road network exists along the axis of the Highlands, and is sufficiently complex to allow a reasonable distribution of fuel. Airstrips of various standards serve the rest of the populated area, and all have regular services provided by the major airlines or the mission services.

<u>The Coastal Ranges</u>

The term "Coastal Ranges" is an envelope term designed to cover the area north of the Sepik, including the Torricelli-Prince Alexander Mountains, and the area east of the Ramu, including the Adelbert Mountains.

The mountain ranges are fairly low - less than 4000 feet elevation - but can be exceedingly rugged, consisting in many places of apparently randomly oriented razor-backed ridges so narrow that a helicopter can only balance with power on at their apex.

To the south of the Torricellis, extensive kunai plains stretch to the Sepik River and provide survey conditions similar to those found in Australia. A narrow coastal fringe consists largely of uplifted coral reefs, although alluvial flats occur near the mouths of the larger rivers, e.g. the Gogol River south of Madang.

Although the dominant vegetation type is again rain forest, appreciable inroads on it have been made by the native population, both in the construction of village sites and gardens and in the establishment of extensive coconut plantations on the coast. Near Bogia, and to a lesser extent elsewhere, many small kunai patches occur; most of these are probably restricted to a soil type too poor to support other vegetation, but others are burned occasionally by natives during hunting.

Some of these vegetation types are illustrated in Plate 14; this shows locations where a conventional helicopter could land (kunai patches and a creek bed), but also small clearings where the hover-site technique would be suitable, especially for a detailed survey. Within this coastal range area, a near-perfect 4-mile gravity station spacing was achieved without recourse to the hover-site technique for the following reasons:

1. The rivers have low gradients and many sandbanks.
2. There are frequent kunai patches.
3. There are many villages, including abandoned ones, conveniently sited on ridges and with large clear central spaces.

Access is again excellent; an important road runs from Wewak through Maprik to the Sepik at Pagui, and a level traverse was run along it by the Army surveyor attached to the gravity party. Other roads run along the coast from Wewak west to Suain and north from Madang to the Gil-gil River. All were used for positioning fuel. Airstrips are conveniently spaced, and all have regular services. Bulk fuel supplies were shipped to Angoram and Ambunti from Madang by the regular Pimco (a 100-ton coastal vessel) service.

3. GEOLOGY

The area of this survey falls entirely within the New Guinea Mobile Belt (Dow et al., 1968), a tectonic zone bounded on the south by the Australian Continental Block (Plate 4). It was the site of heavy geosynclinal sedimentation throughout the Tertiary period, accompanied probably by massive contemporaneous transcurrent faulting, leaving the continental block a stable region of shelf sedimentation (Plate 5). Rod (1966) follows Carey (1958) in postulating an earlier (? Mesozoic) phase of activity along these fault lines, during which New Guinea moved from a position parallel to the Queensland coast to its present site.

Thompson (1965) following Osborne (1956) has described this zone of thick Tertiary sediments as the Northern New Guinea Basin (Plate 6). He suggests that the principal axis of deposition lies offshore, but the abrupt near-shore bathymetry, including a plunge to 1000 fathoms 16 miles off Wewak (Krause, 1965, Plate 1, incorporated in Plate 3 of this report), does not support this hypothesis. Carey (1965) comments that the ranges north of the Sepik-Ramu zone have a basement core representing "the 'basaltic' ocean floor on which the northern sediments were directly deposited beyond the continental shelf of the time, and which has now been thrust up to form the cores of fault slices". Both of these hypotheses may be tested by the gravity technique, and it will be shown in Chapter 6 that neither is probable. It is also of interest to note that Visser and Hermes (1962, reproduced in Marchant, 1968, Plate 26) show the continental margin diverging from the continental shelf near the West Irian-New Guinea border to include the Bismarck Sea within the continental area. Whilst this of course supports (or rather does not refute) the axial position for the Northern New Guinea Basin suggested by Thompson (op. cit.) it does not agree with gravity data collected on the present survey.

In detail, the stratigraphy is made complex by rapid lithologic variations and considerable faulting (Plate 3). It will be described here in two areas, separated by the Ramu-Markham Fault, a major fault running north-west from near Lae (Plate 8). The zone to the east of this structure may be significantly different from the remainder, and has been termed the Ramu River Basin by Continental Oil Company geologists.

Area to the west of the Ramu-Markham Fault

The swamp-covered Sepik Plains separate the Torricelli-Prince Alexander Mountains from the Central Range to the south. The presence of the swamp prevents any accurate stratigraphic correlation between the two areas, but a synthesis based on the photogeologic interpretation of Marchant (1968) and detailed mapping by Dow et al. (1968) will be attempted.

North of the Sepik River, Marchant has recognised six photogeologic units, most of which may be diachronous. A thick sedimentary section is present (Table 1), in which the maximum geosynclinal development was reached in the Miocene. This sequence rests on a basement complex exposed in the core of the Torricelli and Prince Alexander Mountains.

The south-western edge of the survey area is crossed by the Lagaip Fault (Plates 3,8) and according to Dow et al., (1968) this represents the boundary between the stable Australian continental block to the south and the oceanic crust to the north. The tectonic differences were reflected in the region's sedimentation, shelf-type sediments being laid down on the craton whilst geosynclinal deposition was occurring to the north. A detailed summary of the stratigraphy and history is given in Table 2 and Plate 9; however, the correlation with the North Sepik data is tenuous and the author assumes responsibility for this attempted correlation.

Basement south of the Sepik consists mainly of the Ambunti Metamorphics, which are largely metasedimentary in nature - slate and schist, etc - although some complex intrusive bodies, now amphibolite and orthogneiss, are present. The oldest unaltered sedimentary rocks are shelf deposits of Triassic age, the Yuat Shale and Kana Volcanics, which are exposed between the Yuat and Maramuni rivers. The Basement Complex described by Marchant (1968) in the Torricelli Mountains appears to be lithologically similar to the Ambunti Metamorphics but with a higher proportion of acid plutonics.

TABLE 1

Photogeologic unit (Marchant, 1968)	Age (approx.)	Lithology	Thickness (approx.)
VI	Pleistocene	Sand, gravel.	?
III-V	Plio-Pleistocene	Sandstone.	?
II	Pliocene	Silt, marl, limestone, volcanic agglomerate.	2000m +
I	Paleocene-Miocene	Greywacke, limestone, basalt, spilite, tuff.	5000m
Basement complex	?	Amphibolites to phylliles; diorite.	

TABLE 2

South of Lagaip Fault | North of Lagaip Fault

UNIT	AGE	FACIES	LITHOLOGY	UNIT	AGE	FACIES	LITHOLOGY
Quaternary Mount Hagen Volcanics							
				METAMORPHISM OF SALUMEI BEDS TO SLATES			
				Wogamush Beds/ Karawari Conglomerate/ Burgers Formation	Miocene	'island arc'	sandstone, tuff volcanics, cobble conglomerate
				Maramuni Diorite	upper Lower Miocene		
				April Ultramafics	Lower Miocene		
Yangi Beds	Lower Miocene	reef+shelf	marls, limestone	Pundugum Beds	Lower Miocene		basic tuff
PERIOD OF UPLIFT AND EROSION							
Lagaip Beds	Middle Jurassic to Cretaceous	euxinic: Kutubu Trench shallow marine	black shale, siltstone, quartz sandstone	Salumei Formation	Cretaceous to Eocene	eugeosyncline	siltstone, greywacke, basic volcanics
				Maril/Sitifa shale	Upper Jurassic	shallow marine	grey shale
				Mongum volcanics	Middle Jurassic	eugeosyncline	basic volcanics
				Ambunti metamorphics	deformed in previous orogeny?		metasediments; slates to amphibolites
PERIOD OF FOLDING, FAULTING AND EROSION							
				Kana volcanics	Middle Triassic		dacite volcanics
				Yuat shale	Middle Triassic	shelf	black shale

To the south of the Sepik, sedimentation recommenced in the Jurassic after an orogeny that deformed the Triassic deposits. A thick sequence (over 8000 ft) of basic volcanics was followed in the Upper Jurassic by deposition of shallow marine shales, termed the Maril and Sitipa shales. These and the lower part of the succeeding Salumei Formation have no counterpart in the North Sepik area.

Full development of the geosyncline was reached in the Cretaceous and Eocene periods when the Salumei Formation, consisting of siltstone, greywacke, and limestone, was laid down. The upper part of this unit is equivalent to the lower part of Marchant's Photogeologic Unit I, which has a similar lithology.

Uplift and erosion took place during the Oligocene in the South Sepik region, but deposition of Unit I continued apparently without break in the north.

During the Miocene, tuffaceous sediments were deposited over a wide area, being represented by the Pundugum Beds and the upper part of Photogeologic Unit I. At the same time emplacement of the Maramuni Diorite and the April Ultramafics occurred. After this, the only rocks deposited south of the Sepik were Plio-Pleistocene volcanics, but shallow marine sedimentation continued with Units II to V in the Toricelli area.

Immediately west of the Ramu-Markham Fault is a possible equivalent of the April Ultramafics, termed the Marum Basic Belt, an extensive zone of basic (gabbro) and ultrabasic (dunite, pyroxenite, serpentinite) rocks which give rise to a major Bouguer anomaly feature.

<u>Area to the east of the Ramu-Markham Fault</u>

At the south-east end of the Northern New Guinea Basin, inland from Madang, a thick sequence of Tertiary rocks lies on a basement of Upper Cretaceous and Lower Tertiary sediments intruded by batholiths, dykes, and sills (Continental, 1968). The so-called Ramu River Basin is fault bounded on the south-west by the Ramu-Markham Fault and may be bounded on the north-east by faulting along the Adelbert Range.

Corbett (1962) described a very thick (18,000 ft) sequence of Lower Miocene to Pliocene sediments, but the only systematic mapping of this sub-basin has been by Continental Oil Company geologists. The following paragraph is taken from Continental (1968):

"On the eroded basement surface, rest Lower Miocene reefs, shales, sandstones and conglomerates which were folded and faulted in, probably Middle Miocene. Upper Miocene sandstones and mudstones rest unconformably on, mainly Lower Miocene although some Middle Miocene sedimentation did take place. Thick Pliocene sediments begin with basal sandstones and conglomerates and pass upward into mudstones and fine sandstones. The relationship of the

Pliocene to Upper Miocene varies; in some areas deposition was continuous and in others there is probably onlap of Pliocene on Upper Miocene. Thick Pleistocene mudstone and sandstone with occasional reef limestones are the youngest fairly consolidated sediments. The total thickness of sediments is not known, but over 13,000 feet have been measured on the south flank of the Adelbert Range, the bulk of this being marine".

In that a thick Plio-Pleistocene succession is present, this area seems to have a greater affinity with the North Sepik region than with the geographically closer South Sepik.

Tectonics

There is little doubt that the structure of the New Guinea Mobile Belt is dominated by faulting, but opinions differ widely as to its nature. Dow et al. (1968) have considerable evidence in favour of a complex system of faults, many of a transcurrent nature. Marchant, on the other hand, in an interpretation which he warns may be subjective, maintains that high-angled thrusting, trending 300° to 310°, is the principal structural feature. This would require a tectonic regime of quite different character from that suggested by Dow's hypotheses.

Both authors infer the presence of a major fault - the Sepik Fault - near the southern margin of the Sepik Plains. On the basis of a straight contact between the high-grade Ambunti Metamorphics and the unaltered Salumei Formation, Dow et al. propose a fault downthrown to the south by many thousand feet (Plates 8, 13).

Marchant, on the other hand, postulates a fault upthrown to the south, (Plate 13) running along the southern side of the Sepik Plains. The main evidence in this case is the "improbability of completely disposing of 15,000+ feet of Mio-Pliocene sediments by simple thinning and overlap on to the basement in a distance of 30 km between their southerly outcrops in the Bongos and Yellow River areas and the appearance of basement near Ambunti".

Other geologists (e.g. Krause, 1965) have shown major faults running along the Sepik River itself, but offer no substantial support for their hypotheses.

Dow et al. also postulate north-west extensions of major faults mapped in the Highlands (Plate 8),

On a preliminary analysis of the available gravity data, none of the faults mentioned have a major effect on the Bouguer anomaly pattern. However, the Ramu-Markham Fault has an appreciable expression caused by the contrast between ultrabasic rocks of the Marum Basic Belt and Tertiary sediments of the Ramu River Basin, It is probably one of the most important faults in New Guinea but is geologically poorly known, since its topographic expression as a valley has resulted in its being covered with alluvium. Two theories on its extent exist: Rod (1966, Fig. 3) shows it turning west near Annanberg to join a supposed Sepik Fault, whilst Dow et al. (1968) show it continuing in a north-west direction to the Bismarck Sea (Plate 8).

4. PREVIOUS GEOPHYSICS

Aeromagnetic surveys

Young (1963) records the results of a few widely-spaced traverses across the Northern New Guinea Basin. Only one group of three traverses crosses the survey area, and these are duplicated by a more recent survey for Australian Aquitaine. The interpretations of the two surveys agree in general terms, although the Aquitaine data are considered to be over-interpreted. The Australian Aquitaine (1967) survey covered the area between the Sepik River and the coast, as shown in Plate 10. The results "apparently dependably predict a good interior basin with 6500m of section and suggest the possibility of a coastal basin with more than 3000 m in the Arnold River area". The interior basin is in an area largely covered by Pleistocene drift and Pliocene sediments, possibly concealing an older basin.

A survey for Continental covering the Ramu River Basin is in progress; results so far indicate a thick sedimentary section (about 14,000 ft) which is not, however, coincident with the main gravity feature.

Gravity surveys

Between 1963 and 1967, scattered gravity observations were made throughout Papua-New Guinea by J.E. Shirley and V.P. St John (St John, 1967). The data indicated in general terms the main features defined by the present survey, but otherwise presented a regional picture only.

Extensive cruises were carried out by the U.S.S. Shoup in 1963-64 in the New Guinea region. Surface gravity meter readings are available in the form of free-air anomalies, but positioning was by dead reckoning only. Apparently the vessel's depth-sounder was inoperative for the duration of the cruise, and so Bouguer anomalies are obtainable only by scaling depths off Admiralty charts - an unreliable method. Nearer to shore (at depths less than 1000 fathoms) better bathymetry is provided by Krause (1965), and this has been used to compute the Bouguer anomalies shown offshore in Plate 11.

5. OBJECTIVES AND PROGRAMME

Originally the survey was proposed by the Geological Branch of BMR in order to determine the structure of the Sepik Plains, including delineation of the inferred Sepik Fault. A study of the area showed that conventional helicopter gravity techniques were unlikely to suceed in the extensive swamp zones, and the survey objective was broadened to include an evaluation of the hover-site method (Eckhardt, 1966). It was recognised that some such method might be necessary in order to obtain complete coverage of Papua-New Guinea on future surveys. Thus the specific objectives of the survey may be listed as:

1. Development and evaluation of the hover-site technique (this evaluation is not the subject of the present report).

2. To test whether the inferred Sepik Fault exists; if it does, to establish its delineation.

3. Assessment of the existence of sediments and basin structure beneath the Sepik-Ramu swamps.

Minor objectives suggested by the geological review of the area included:

4. Evaluation of the Northern New Guinea Basin concept of Thompson (1965), which would require a relative gravity low corresponding to the thickest sedimentary section - i.e. Bouguer anomaly values decreasing northwards from the Toricelli-Prince Alexander Ranges.

5. Approximate delineation of other faults (see Plate 8)

6. To test Carey's (1965) hypothesis in relation to the origin of the coastal mountain ranges. This hypothesis would require positive residual Bouguer anomaly features of high amplitude to coincide with the coastal ranges' axes.

Of these six objectives, significant contributions have been made to all except the second, which remains untested owing to inadequate coverage of the AMBUNTI 1:250,000 sheet area. A report on the hover-site technique is being given by Flavelle et al. (in prep.) but it may be mentioned here that while the method produced some usable results in the swamps a more powerful helicopter and better hover position control are required wherever vegetation demands a relatively high hovering position above ground level.

The survey was carried out as a two-phase operation: during the first six weeks (2 September - 13 October 1969) conventional helicopter gravity survey techniques were used on the MADANG, RAMU, KAR-KAR, BOGIA, and WEWAK 1:250,000 sheet areas. The winch and controls for the hover-meter were then fitted, allowing hover-site operations to commence at Angoram on 20 November and to terminate on 17 December.

During the whole of the survey period jet boats were used to make readings along the Sepik, Karawari, Yuat, Keram, and Ramu Rivers.

The delay caused by the extended fitting-out period reduced the area surveyed considerably, so that most of the gravity stations on the AMBUNTI sheet area are river stations. Thus insufficient control was obtained to allow delineation of the inferred Sepik Fault or to permit the sub-Sepik plain structure to be determined. However, complete coverage of the Ramu River Basin has been obtained by the combined use of conventional and hover-site techniques.

6. DESCRIPTION AND INTERPRETATION OF BOUGUER ANOMALY FEATURES

Eight Bouguer anomaly features have been recognised, but no attempt has been made to divide the region into gravity provinces as the area covered is too small to permit this. The features described are listed below and indicated in Plate 11:

A New Guinea Coastal Gradient
B Madang Gravity Low
C Torricelli Gravity High
D Adelbert Gravity High
E Ramu Gravity Low
F Potter Gravity Low
G Marum Gravity High
H Timbunke Gravity Low

It is recognised that these names are provisional only, as future work may re-define or extend the features considerably.

A. New Guinea Coastal Gradient

The dominant feature of the Bouguer anomaly map is the high coastal gradient, shown by Bouguer anomaly values ranging from about -80 mgal in the highlands to +130 mgal on Kairiru Island, near Wewak. Almost certainly its cause is the thinning of the continental crust towards the continental shelf, with the denser oceanic crust coming closer to the surface. Marine data from the U.S.S. Shoup show that the gradient flattens out and the Bouguer anomalies reach a value of about +180 mgal in the central part of the Bismarck Sea; thus there is evidence to show that this sea is underlain by typical oceanic crust, in contrast to the hypothesis of Visser and Hermes (1962). Refraction seismic data from the eastern part of the Bismarck Sea (BMR, 1969), indicate velocities of 7.7-8.9 km/s at the comparatively shallow depth of 12-15 km; this is interpreted as a sub-Moho section, showing that the area is underlain by oceanic crust.

Similarly, the high Bouguer anomaly values show that the geographic edge of New Guinea approximates closely to the present edge of the continent, casting doubt on the location of the North New Guinea Basin described by Thompson (1965). There is no gravity evidence to show that the major part of the basin lies offshore.

B. Madang Gravity Low

Near Madang, Bouguer anomaly values decrease rapidly towards the sea, the -140 mgal contour running through the coral islands at the top of the continental slope. Surface marine gravity data from the U.S.S. Shoup show this feature to be a closed, roughly circular, relative Bouguer anomaly low of about 30 mgal amplitude and 7-8 miles half-width. The gradients associated with it imply that the maximum depth to the anomalous body's upper surface is of the order of 7 km; i.e. it lies well above the Moho.

In a paper delivered at the APEA Conference in March 1969, J. Harrison of Continental Oil Company described a small Pliocene basin, containing at least 16,000 feet of sediments, north of the Finisterres. It seems highly likely that the Madang Gravity Low represents the marine extension of this basin.

C. Torricelli Gravity High

A residual Bouguer anomaly high with a maximum amplitude of 30 mgal is present over the Torricelli-Prince Alexander Mountains. In part is corresponds closely to the antiformal axis where the basement complex crops out (Plates 3, 12, 13), but to the south of Wewak it is offset to the south of the mapped outcrop by about 10 miles. This substantially corresponds with the aeromagnetic interpretation of shallowest basement by Australian Aquitaine (1967), and suggests that the Plio-Pleistocene forms a thin veneer above the basement in this locality.

D. Adelbert Gravity High

A residual high of 10-15 mgal amplitude correlates with the basement outcrop sketched by Continental (1968) to the north-west of Madang.

Carey (1965) has suggested that the Adelbert and Torricelli Mountains are upfaulted segments of oceanic (basaltic) crust. However, the low amplitudes of the associated Bouguer anomalies indicate that crustal thicknesses under both these mountain ranges are near normal. The situation is comparable with the South-Eastern Papua Gravity High (Milsom, in prep.), which coincides with an area of basaltic rocks which have also been considered (Thompson & Fisher, 1965) to be uplifted ocean floor. The gravity high in this case is much more pronounced - over 80 milligals - but is still smaller than that required by the uplift hypothesis.

E. Ramu Gravity Low

This feature has a close areal correspondence to the Tertiary Ramu River Basin. It has an amplitude of 70-90 mgal and a half-width of 30 miles; the axis has a north-west trend, parallel to that of the basin, and can be traced for about 100 miles. A very steep gradient to the south-west separates the Ramu Low from the Marum High and markes the trace of the Ramu-Markham Fault. Examination of residual Bouguer anomaly profiles suggests that a fault may also bound the basin on the north-east, separating it from the Adelbert Range.

F. Potter Gravity Low

The Potter Gravity Low is a north-south trending low of about 25 mgal amplitude; this minor feature may represent an offshoot or extension of the main Ramu River Basin. It occurs in the POTTER 1-mile sheet area, from which it derives its name.

G. Marum Gravity High

This is a negative Bouguer anomaly high of about 90 mgal amplitude; it corresponds closely to the gabbroic phase of the Marum Basic Belt but not to the ultrabasic part of the mapped outcrop. The maximum gradient attained is 14 mgal/mile on the north-east flank, but that to the south-west is appreciably less as would be expected from the lower density contrast between gabbro and the lightly metamorphosed Tertiary sediments and volcanics.

H. Timbunke Gravity Low

This feature has been defined only by river stations along the Sepik and Karawari Rivers. It has an amplitude of about 35 mgal and corresponds closely to a magnetic basement low postulated by Australian Aquitaine (1967); however, the 16,000 ft depth-to-basement suggested is not in total accord with the amplitude of the gravity feature. Assuming a density contrast of 0.3 g/cm^3 between the sediments and the basement, the plane parallel slab formula gives a first-order approximation to the sediment thickness of about 10,000 feet. An abrupt gradient, poorly defined along the Karawari River only, suggests that this section may be fault-bounded on the south-west.

7. CONCLUSIONS

Throughout the survey area there appears to be a direct correlation between geological features and the Bouguer anomaly field: sedimentary basins are reflected by relative Bouguer anomaly lows whilst basement areas and basic intrusions correlate with relative Bouguer anomaly highs.

On a regional scale, the Bouguer anomaly values suggest rapid thinning of the continental crust towards the coast and offer little support for hypotheses that consider the Bismarck Sea to be continental.

During the final part of the survey, a remote-reading gravity meter lowered from a hovering helicopter was used to obtain readings in the Sepik-Ramu swamp. The technique was fairly successful in the swamp area but required further development for application in more difficult terrain where it is necessary to hover at a greater height.

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APPENDIX 1

SURVEY PROCEDURE

The method of cell-flying outlined by Vale (1962) and Hastie and Walker (1962) was used with no modification other than the adoption of a four-mile station interval. Navigation was carried out on airphotos, although mosaics were used where long transit flights between base and cell centre were involved. The very rugged nature of the terrain introduced considerable photo distortion, resulting in appreciable mis-planning; apparently flat clearings in rain forest would turn out to be on the sides of ridges with slopes frequently reaching 45°; the Jet Ranger is restricted to landing grounds with a slope of less than 7°.

Conventional instruments were used in most of the survey area. In the Highlands modified Mechanism microbarometers, reading about 200 mB lower than normal, were used between 7000 and 12,000 feet. These suffered from erratic drift rates and sometimes extended reading points: that is, the instrument could be balanced over an extended counter range at a fixed elevation point. A high-altitude Wallace and Tiernan micro-altimeter was also used late in the survey, and it functioned correctly over a range of 5000 to 11,000 feet; it appeared more reliable than the modified Mechanism instrument. Barometric (instrumental) drift was high on many occasions, reaching 40 ft; this is believed to be due to rapid elevation changes and to stresses in the pressure capsule, caused by helicopter vibration. Use of the remote-reading gravity meter is described in a record by Flavelle et al. (in prep.).

Cell centres were distributed between the following types of location:

45% in rivers; 15% in kunai patches; 40% on beaches, airstrips, and roads. Usually, adequate shade was available except in the kunai patches, where an umbrella was used to shield the instruments. Occasionally natives built a banana-leaf shelter for the observer (as well as finding him coconuts, bananas, and pineapples). An automatic base barometer was used but was unsatisfactory.

The cell centre was marked by a five-foot orange-painted steel stake, but these were noticeably impermanent as natives found them attractive. At villages, however, Polaroid photographs or trade tobacco were used as inducement for the kuskus (clerk) to guard the stake. All cell centres were photographed from two directions on the ground, using a Polaroid camera, in order to facilitate future identification. Where possible, more permanent features were used, such as trig points and airstrip wind-socks, especially at the edge of the survey area, where a number of years could elapse before reoccupation.

All gravity stations were pinpricked on aerial photographs on landing. The station positions were subsequently transferred to 1:250,000 compilation sheets by comparison with the available topographic maps. In places such as the Jimi Valley where the terrain has been sketched in from foot patrols only, positions were plotted by referring the photos to an identifiable point such as a trig. point or major river intersection. Latitudes scaled off these compilation sheets probably have a relative accuracy of ± 0.5', although the absolute position may be in error by as much as ± 4.0'.

Computing was carried out by hand in Madang using an abbreviated procedure: elevations were calculated from tables prepared by Whitworth (1968) which assumed a constant 22°C atmospheric temperature (probably an accurate estimate for the highlands, but low elsewhere), but no corrections for temperature or humidity were applied. All elevations were referred to sea level either by direct measurement or via trig. points established by the TPNG Department of Lands, Surveys & Mines or by the Army Survey Corps. Gravity measurements were all calculated with reference to the Isogal base stations established by Milsom (in prep.). No corrections were made for the terrain effect, which St John (1967, p. 41) computed to be up to +70 mgal in the highlands. However, most of this correction would have a wavelength corresponding to the areal extent of the highlands and so would cause only a small regional component in the lowland Bouguer anomalies.

The error in the Bouguer anomaly values has a standard deviation of 0.72 mgal constructed thus:

S.D. of heights = 11.08 ft = 0.66 mgal

S.D. of gravity = 0.20 mgal

S.D. of latitude = $\frac{1}{2}$ (absolute error) = 0.2'
= 0.2 mgal

S.D. of errors = $0.66^2 + 0.20^2 + 0.20^2 = 0.72$ mgal

Re-computation of Bouguer anomalies is at present being carried out using BMR - developed programmes and will be completed by May 1969.

APPENDIX 2

SURVEY LOGISTICS, STAFF, AND EQUIPMENT

The lack of roads in New Guinea tended to simplify rather than complicate the logistics of the survey operation. Transport was largely restricted to aircraft, and so the only possible camp sites were at airstrips; because the airstrips were constructed to serve settlements of some size, there was generally accommodation available at missions, hauses-kiap, or rented houses.

Fuel was available for the helicopter from bowsers at Wewak, Madang, Goroka, and Mount Hagen, but elsewhere the Mobil Jet A-1 had to be positioned by BMR. Drums of fuel cannot be carried by single-engined aircraft to airstrips where a twin-engined plane can land. Table 3 lists the aircraft used, their cargo loads, and charter rates.

Passengers cannot be carried in an aircraft loaded with drums of fuel; thus for shifting personnel around the survey area, separate charters were required. For camp shifts a twin-engined Cessna 402 (charter rate $100/hr) was found the most useful aircraft, although the smaller Beechcraft Baron was also used. Although the field party which operated during the conventional phase of the operation consisted of only four people - helicopter pilot, engineer, observer, and field hand - the amount of ancillary gear such as generators, batteries and so on was such that the large aircraft was required; it should be pointed out that no camping gear was included in the operating party's equipment.

In the first phase of the operation, bases of about four days' duration were established at the following localities: Bundi, Aiome, Josephstaal, Awar, Maprik, and Wewak. Of those, only the last two had any roads from which fuel could be usefully positioned. At the others, all fuel was deposited at the airstrip, requiring frequent returns by the helicopter for refuelling. DCA requires the helicopter to have a 45-minute fuel reserve; thus with four 5-gallon jerrycans of fuel aboard, duration was about 210 minutes. This enabled a transit flight of 15-20 miles and only three loops to be flown before refuelling, and thus limited production rates considerably. Although a shorter inter-station distance was used than in conventional Australian helicopter gravity work, flying time per loop was greater because of the time spent searching for landing points, the amount of climbing often necessary, and the manoeuvring required on landing and takeoff.

TABLE 3

	Load: No. of 44-gall. drums of Avtur fuel	Cost per hour
D.H. Twin Otter	7 ex Mount Hagen	$174
	12 ex Madang	
Douglas DC.3	18-20	$175
Piaggio P166	4	$115
Cessna 336 (push-pull)	2	$ 85
Cessna 185 (single-engine)	2	$ 50

NOTES:

(1) The DC. 3 was used at the following strips only: Madang, Wewak, Mount Hagen, Wabag, Aiome.

(2) The Twin Otter landed at those in (1) plus Angoram.

(3) The Piaggio lands at Ambunti and Awar in addition to the above strips.

(4) The Cessnas will land at any strip except Wanuma.

(5) Some highlands strips, such as Lumusa, are so marginal that only mission pilots are willing to land there.

(6) Many airstrips are not shown on maps and post-date the aerial photography; thus for adequate pre-survey planning the local knowledge of mission pilots is required.

Party Organisation

BMR Staff

A.J. Flavelle	Party Leader, Geophysicist
M.D. Watts	Geophysicist
A.R. Fraser	Geophysicist
D.A. Coutts	Chief Observer, Technical Officer
A.W. Waldron	Observer, Technical Assistant
I.G. Cravino	Draughtsman
G. Strathearn	Field Hand
K. Cozens	Field Hand
S. Broomham	Mechanic

Army Surveyor

P. Davis	Corporal

Helicopter Transport Pty Ltd Staff

B. Evans	Pilot
J. Arthurson	"
L. Hindley	"
D. Binnie	"
R. Hamilton	"
N. Phillips	Engineer
B. Mansell	"

Equipment and Vehicles

LaCoste & Romberg gravity meter	101-L	27/8/68 to 16/12/68
LaCoste & Romberg gravity meter	G 20	15/10/68 to 11/12/68
Worden gravity meter	W169	27/8/68 to 15/12/68

Mechanism microbarometers Nos. 751, 962, 1170, 1171, 1173, 294/62, 317/62, 318/62, 529/63, 574/63, 583/64, 581/64.

Automatic microbarometer

3 Theis hair hygnometers

3 Traeger TM3 transceivers

1 Holden HD Station Sedan (Avis)

1 Toyota 4 x 4 one-ton truck(TPNG Administration)

2 Pride Jet boats

1 Bell 206A Jet Ranger (VH-FJR, Helicopter Transport Pty Ltd)

APPENDIX 3

SURVEY STATISTICS

Stage One (using conventional LaCoste & Romberg meter)

Commenced survey (Madang)		1 September
Completed survey (Angoram)		9 November
Total days available		61
- on survey		38
- in transit		2½
- pilot rest days		3
- helicopter unserviceable		2½
- search and rescue		8½
- inclement weather		6½
Total helicopter days		43
Percentage helicopter unserviceability		5.8
Total loops completed		131
Ties (not included in above)		9
Loops per day (excluding ties)		3.0
Average loop time (minutes)		80
Individual averages (minutes)	P.D. (3 loops)	122
	A.J.F. (4 loops)	96
	A.R.F. (5 loops)	113
	M.D.W. (28 loops)	86
	D.A.C. (191 loops)	74
Helicopter hours		200
New stations read		949

Stage Two (using LaCoste & Romberg underwater meter)

Commenced survey (Madang)	18 November
Completed survey (Angoram)	16 December
Total days available	29
- in training	3½
- on survey	13
- in transit	2
- helicopter unserviceable	4½
- meter unserviceable	2

- search and rescue	3
- inclement weather	1
Total helicopter days	23
Percentage helicopter unserviceability	19.6
Total loops completed	31
(includes 2 with conventional meter)	
Ties (not included in above)	4
Loops per day (excluding ties)	~~115~~ 1.4
Individual averages (minutes) A.W.W. (15 loops)	132
D.A.C. (14 loops)	97
Helicopter hours	80
New stations read	214

Road and River Surveys

New stations read	567

APPENDIX 4

TERRAIN OBSERVATIONS

by D.A. Coutts

General

The type of terrain utilised as landing points in the survey area using a conventional gravity meter can be broadly defined as being of four types, some of which are illustrated in Plate 14.

(a) River beds
(b) Kunai patches
(c) Villages
(d) Beaches

After an initial settling-in period, the general pattern of operations resolved itself into the following:

Having set up base and taken the initial readings, the base observer would be left to note readings at fifteen-minute intervals while the helicopter departed to work a planned loop. On reaching each selected landing point and effecting a landing, the helicopter motor would be shut down to an idle while the observer took readings at a suitable position about twenty yards away. Such a position was always chosen ahead of or to the side of the helicopter, partly to minimise the risk of contact with the tail rotor and partly to enable the observer to be in view of the pilot at all times in case of emergency. After the readings had been taken the pilot would begin to apply power, so that by the time the observer was back in the cockpit the helicopter would be able to take off immediately to minimise lost time. In general the time spent on the ground was $1\frac{1}{2}$-2 minutes, but this time was of necessity increased if there was a large local anomaly present or if a large height increment was involved relative to the previous station - both of these conditions required much winding to null the gravity meter.

Types of Terrain

(a) River beds

Approximately 40% of all landings were made in river beds since these consistently proved to be the only clear spaces available in mountain regions away from populated areas.

Access to most river stations in the mountain regions was complicated by steep gorges, with narrow creeks at the bottom and dense foliage overhanging the banks. The excellent manoeuvrability of the Bell 206A Jet Ranger plus its ability to ascend and descend vertically was a big factor in overcoming such obstacles. Most rivers had rocky beds, so that it was possible at these landing points to actually have the skids of the helicopter under water whilst taking readings on a larger rock jutting out of the water.

Smaller creeks were strewn with large boulders which presented difficult conditions for landing. Having effected a landing, a further difficulty presented itself in that the skids of the helicopter maintained only point contact with two or three boulders; these boulders were inclined to shift suddenly, which threatened to tilt the helicopter beyond the angle permitted for safe operation. In such cases it was necessary for the pilot to maintain full power whilst the helicopter was on the ground, in order to have full control immediately available should the need arise. This necessitated the observer moving farther away from the helicopter to take the readings, in order to avoid the turbulence set up by the rotor blades.

In general, rivers in the mountain regions were shallow but flowed rapidly, and were subject to rapid fluctuations in level. The larger river systems away from the mountains, e.g. in the Ramu Valley, were deeper and slower running and were dotted with sandbars which provided excellent landing points, although the occasional mudflat had to be avoided.

(b) Kunai patches

Kunai patches were utilised in about 40% of all landings and were found sprinkled liberally throughout the Ramu Valley and North Sepik areas. Access proved to be easy as most patches were large and gently undulating with uncluttered approaches, but an occasional patch was swampy and usually could not be identified as such until a landing had been made.

Care was needed on the part of the observer when working in kunai patches as the sword grass which is often present can inflict deep cuts with the risk of subsequent infection. Where cell centres were sited in kunai it was essential that the base observer be provided with a bush knife to cut a clearing and an umbrella to shade both himself and the instruments.

In most patches the grass was less than five feet high and of a flexible nature so that the wash from the rotor blades flattended it sufficiently to clear the tail rotor on landing. The optional high skid gear fitted to this helicopter proved most effective in this respect, since the low skid normally fitted would have caused the tail rotor to become fouled in many cases. Some patches were overgrown with a much taller and stouter grass similar to pit-pit; although this was usually thinly distributed, considerable manoeuvring was required before the pilot could land in it, and the observer had to keep a constant watch through the open door to ensure that the tail rotor did not become fouled.

(c) Villages

In densely jungled areas devoid of suitable rivers and kunai patches, as exist in parts of the Adelbert and Schrader Ranges, the only potential landing points were village clearings and gardens.

Most villages, even those on sharp ridges, consisted of a ring of huts around a central clearing and there was usually sufficient room in such a clearing to land a helicopter without inflicting too much damage to huts due to the rotor blast. The main hazards encountered in these situations were the many coconut palms usually to be found growing in and around villages, and care was taken to ensure that both helicopter and observer were clear from overhanging palms in the event of coconuts being dislodged by the rotor blast.

In the absence of suitable villages it was often possible to land in native gardens, although most of these appeared to be built on steep slopes. Care had to be exercised when landing amongst leafy crops about two feet high because the foliage often concealed sharp stakes used to support the crop, or old tree stumps. Where it was not possible to land in a garden for this reason it was necessary for the helicopter to hover while the observer got out, and then to return when the readings had been taken. Many gardens, however, were dotted with dead trees about ten feet high and this latter technique was not possible in such cases.

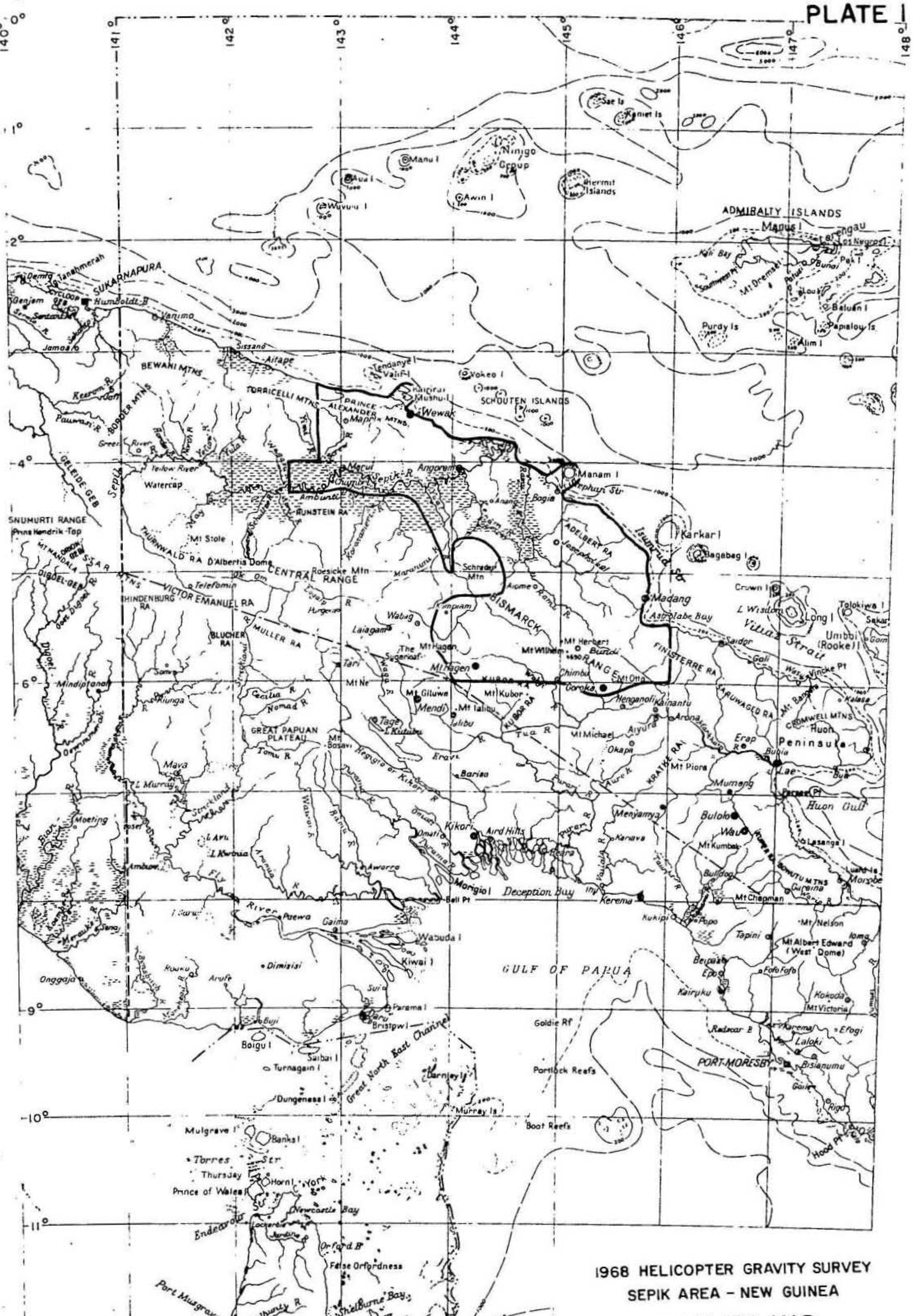
A few landings were made on roads, but blind corners and hills had to be avoided for obvious reasons.

(d) Beaches

Beaches in general proved to be very acceptable landing points, although some were shelved to such an extent as to make landing difficult.

When the beach was narrow it was advisable for the observer to face the sea whilst taking readings to guard against freak waves inundating the meters, as almost happened on one occasion. Where possible the meters were read at or near the high water mark thus providing a useful height check.

PLATE I



1968 HELICOPTER GRAVITY SURVEY
SEPIK AREA - NEW GUINEA

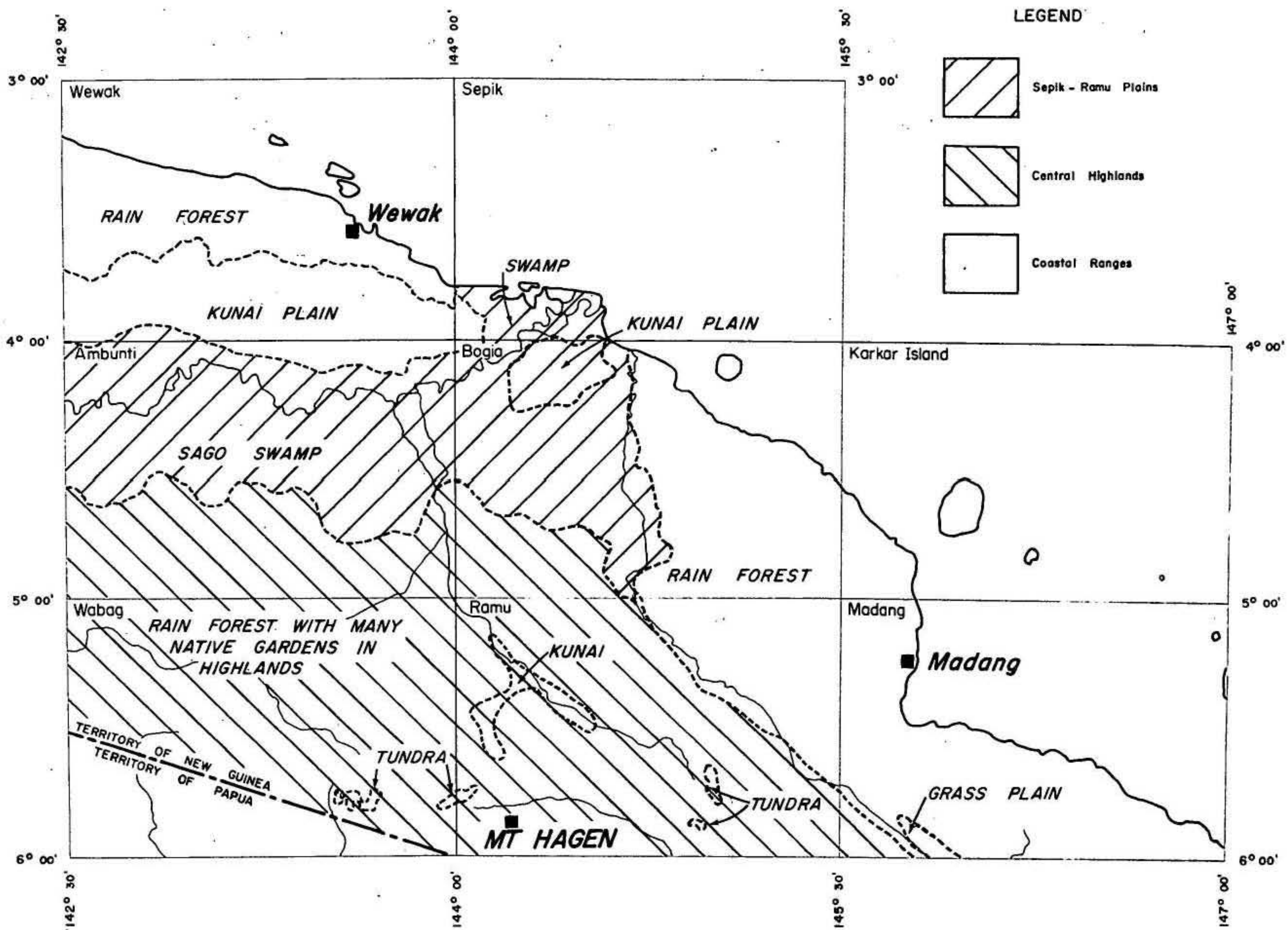
LOCALITY MAP

100 50 0 50 100 150 MILES

BOUNDARY OF SURVEY AREA

TO ACCOMPANY RECORD NO. 1969/124 PNG/B2-18

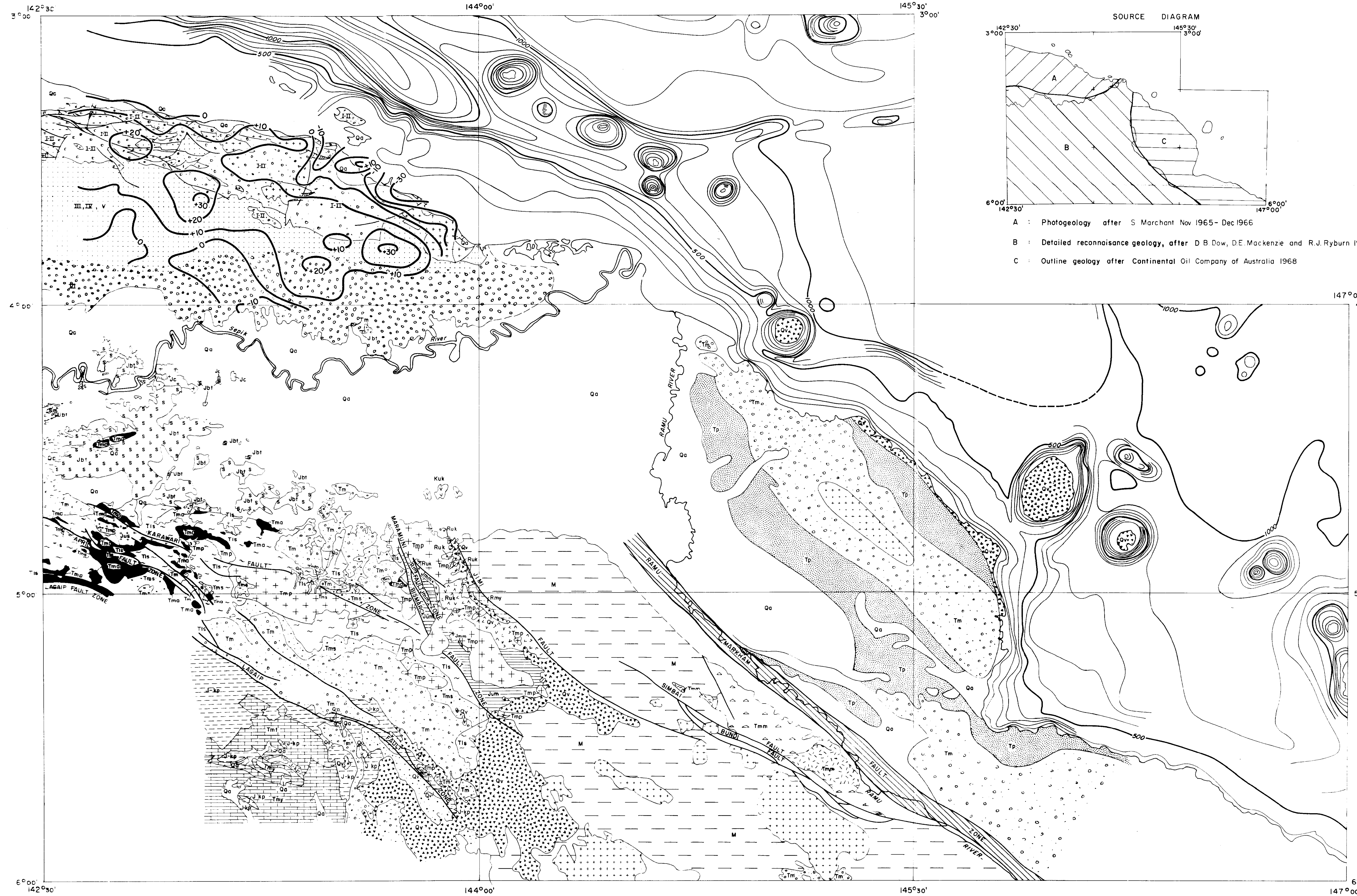
PLATE 2



VEGETATION TYPES

TO ACCOMPANY RECORD NO. 1969/124

PNG/B2-21



CAINOZOIC	QUATERNARY	RECENT		Qa
		PLEISTOCENE	Photogeological Unit VI	VI
			Hagen Volcanics	Qv
	TERTIARY	PLIOCENE	Photogeological Units III, IV & V	III-IV-V
				Tp
		MIOCENE	Photogeological Units I & II	I. II / Tm
		LOWER MIOCENE	Maramuni Diorite	Tmp
			April Ultramafics	Tma
			Marum Basic Belt	Tmm
			ultrabasic phase	Tmm
		LOWER MIOCENE (TERTIARY g STAGE)	Yangi Beds	Tmy
			Tibinini Limestone Member	Tmt
			Pundugum Formation	Tms
MESOZOIC	CRETACEOUS	CRETACEOUS TO EOCENE	Salumei Formation	Tls
		UPPER CRETACEOUS	Kumbruf Volcanics	Kuk
	JURASSIC	MIDDLE JURASSIC TO PALAEOCENE	Lagaip Beds	J-kp
		JURASSIC ?	Chambri Diorite	Jc
			Ambunti Metamorphics	Jbt
		UPPER	Sitipa Shale	Jus
			Maril Shale	Jum
		MIDDLE	Mongum Volcanics	Jmm
				M
	TRIASSIC	UPPER	Kana Volcanics	Ruk
		MIDDLE	Yuat Formation	Rmy

Undifferenciated plutonics

Bathymetric contours after D.C. Krause (1965), contour interval 100 fathom

0 / +10 Residual Isogals (10 milligal interval)

GEOLOGY OF THE SEPIK-RAMU AREA TERRITORY OF NEW GUINEA

MILES

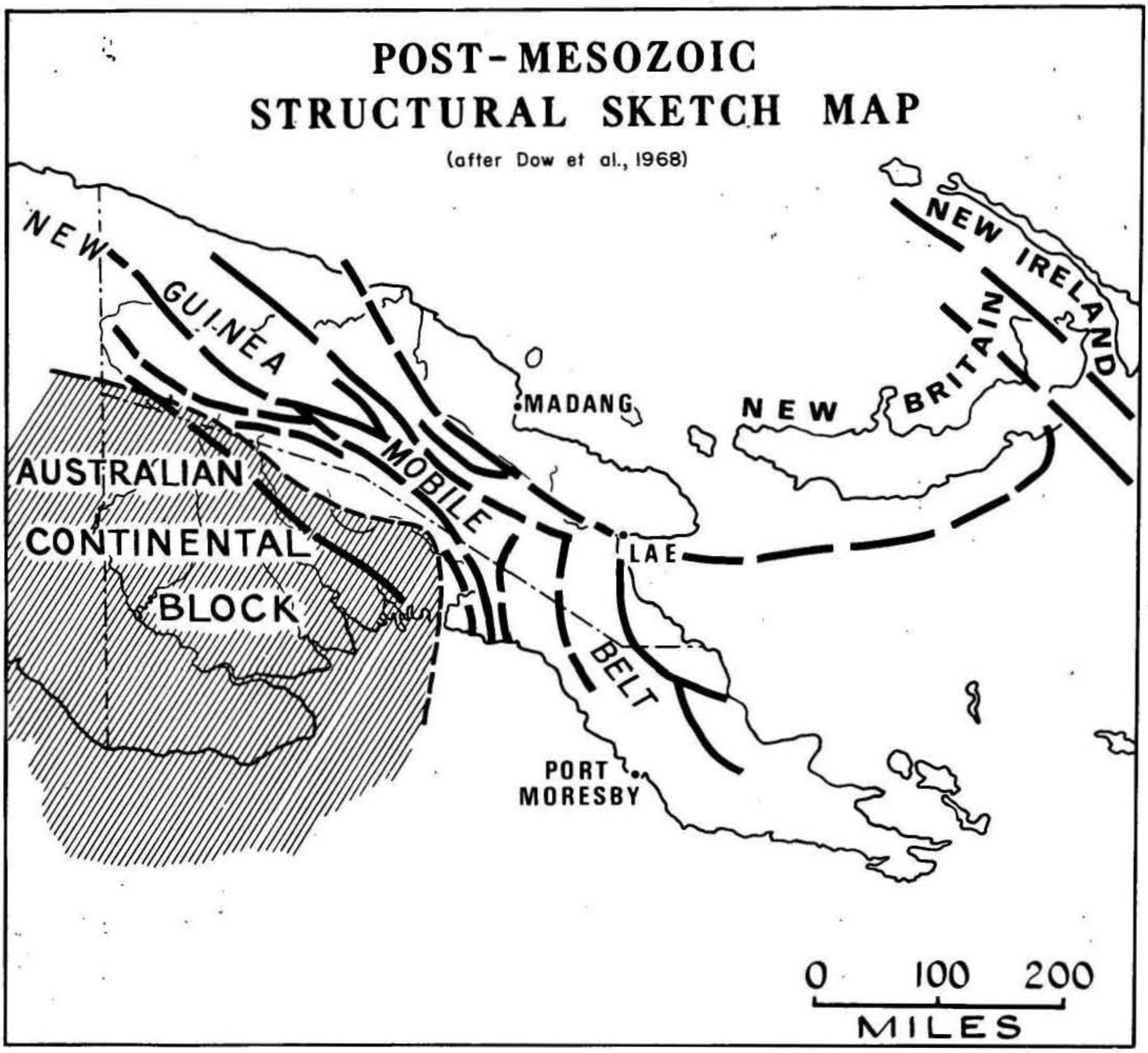
10 0 10 20 30 40 50 60 70 80

Projection : Lambert Conformal Conic

Base Map : World Aeronautical Charts nos 2974, 2987, 2988, 2973

TO ACCOMPANY RECORD NO. 1969/124 PNG/B2-19

PLATE 4



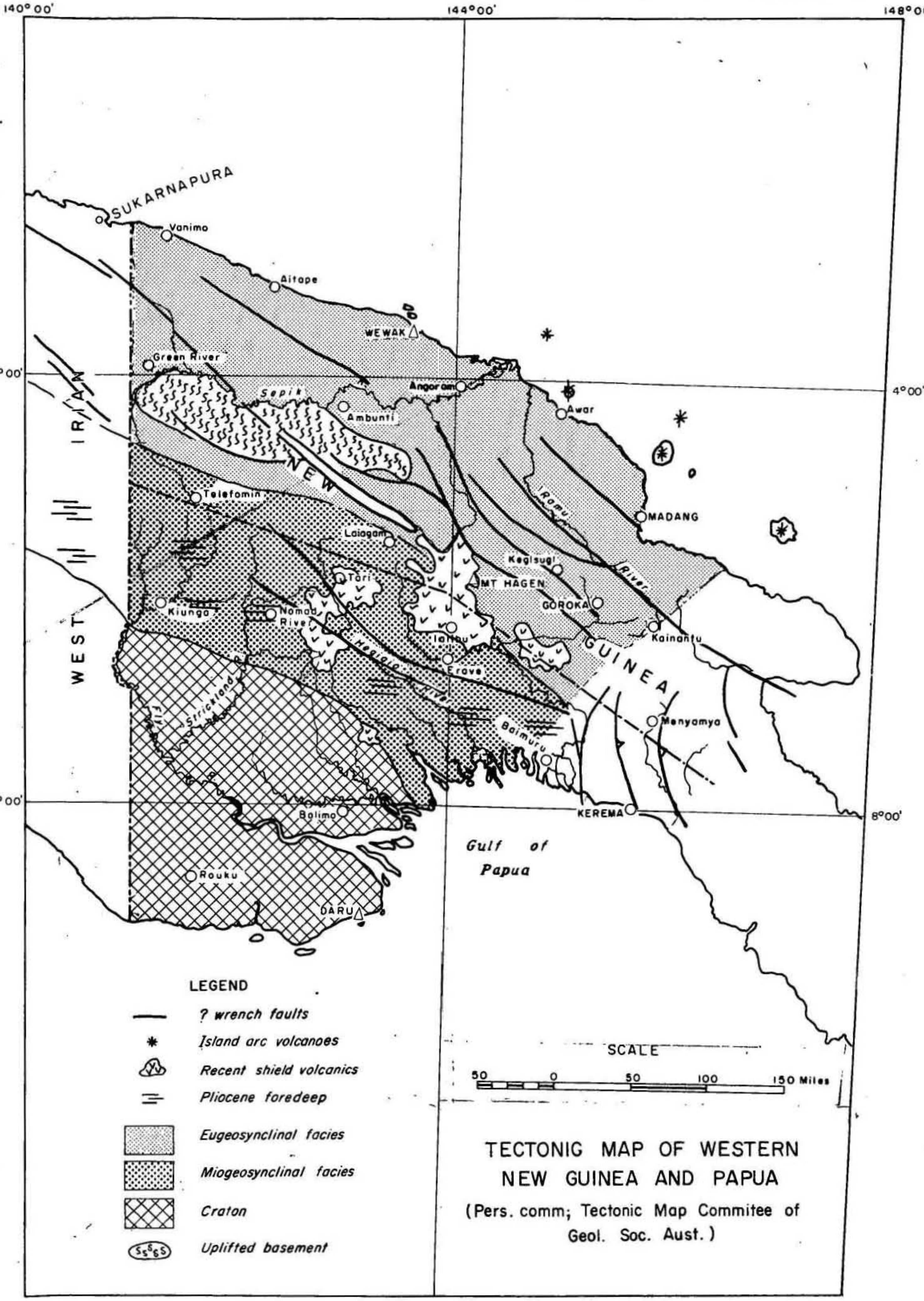
POST-MESOZOIC STRUCTURAL SKETCH MAP

(after Dow et al., 1968)

TO ACCOMPANY RECORD NO. 1969/124 PNG/B2-17

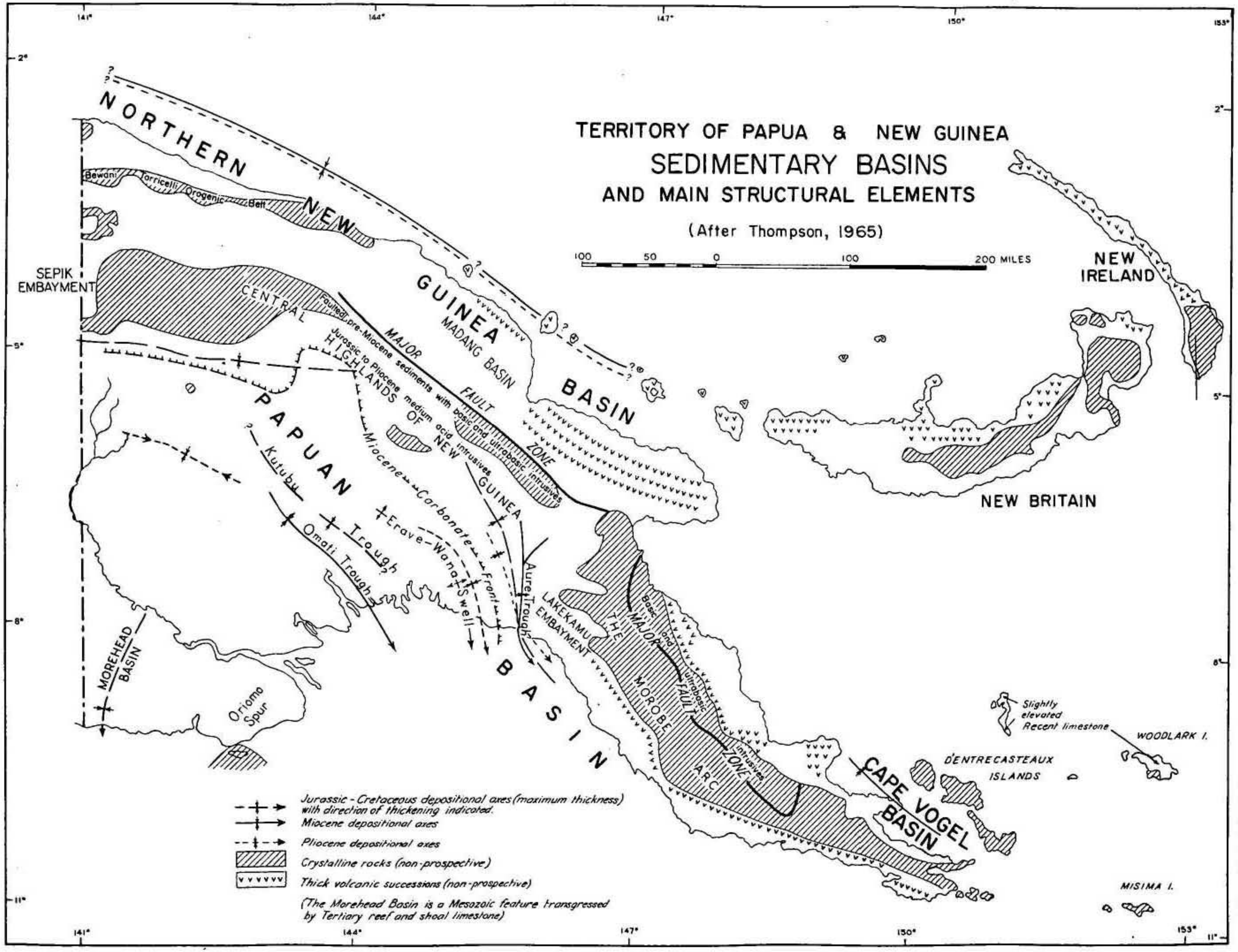
print with vertical image

PLATE 5



TECTONIC MAP OF WESTERN NEW GUINEA AND PAPUA

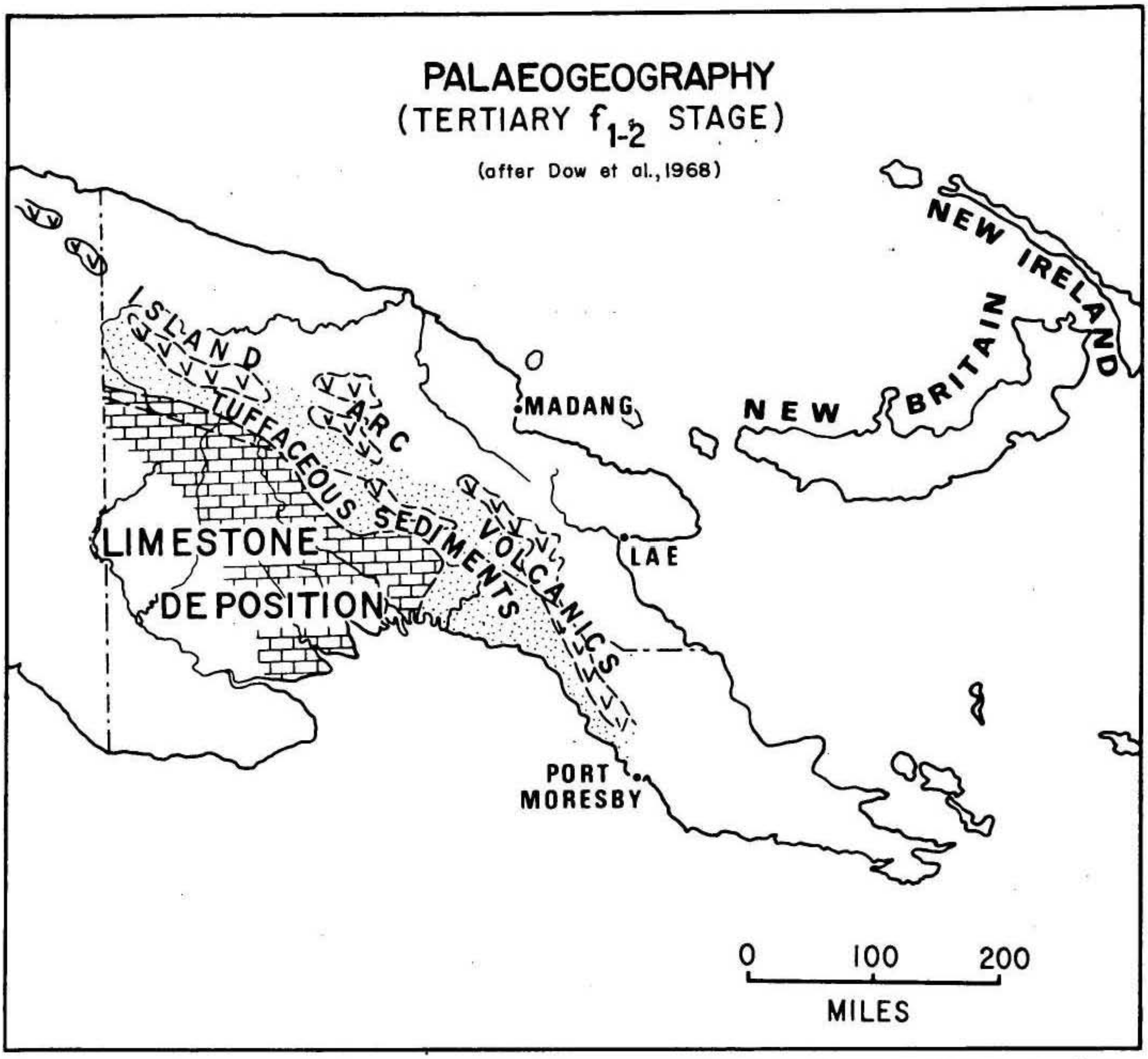
(Pers. comm; Tectonic Map Commitee of Geol. Soc. Aust.)



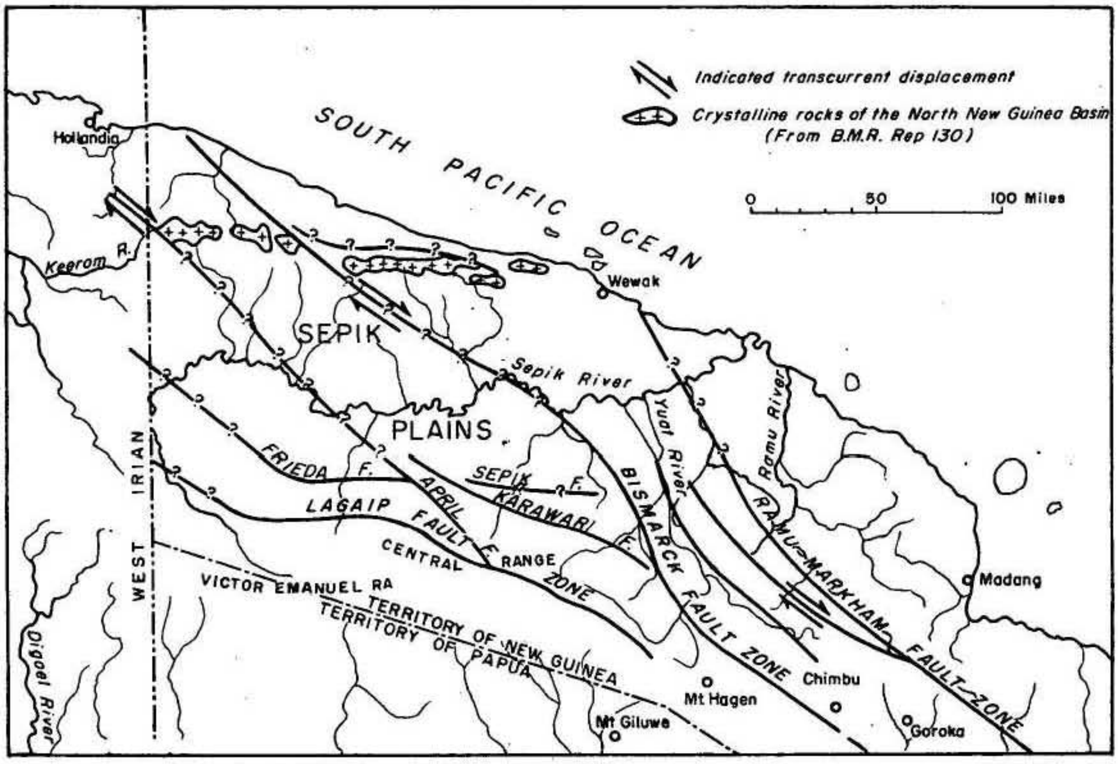
TO ACCOMPANY RECORD NO. 1969/124

PNG/B2-24

PLATE 6



TO ACCOMPANY RECORD NO. 1969/124 PNG/B2-15

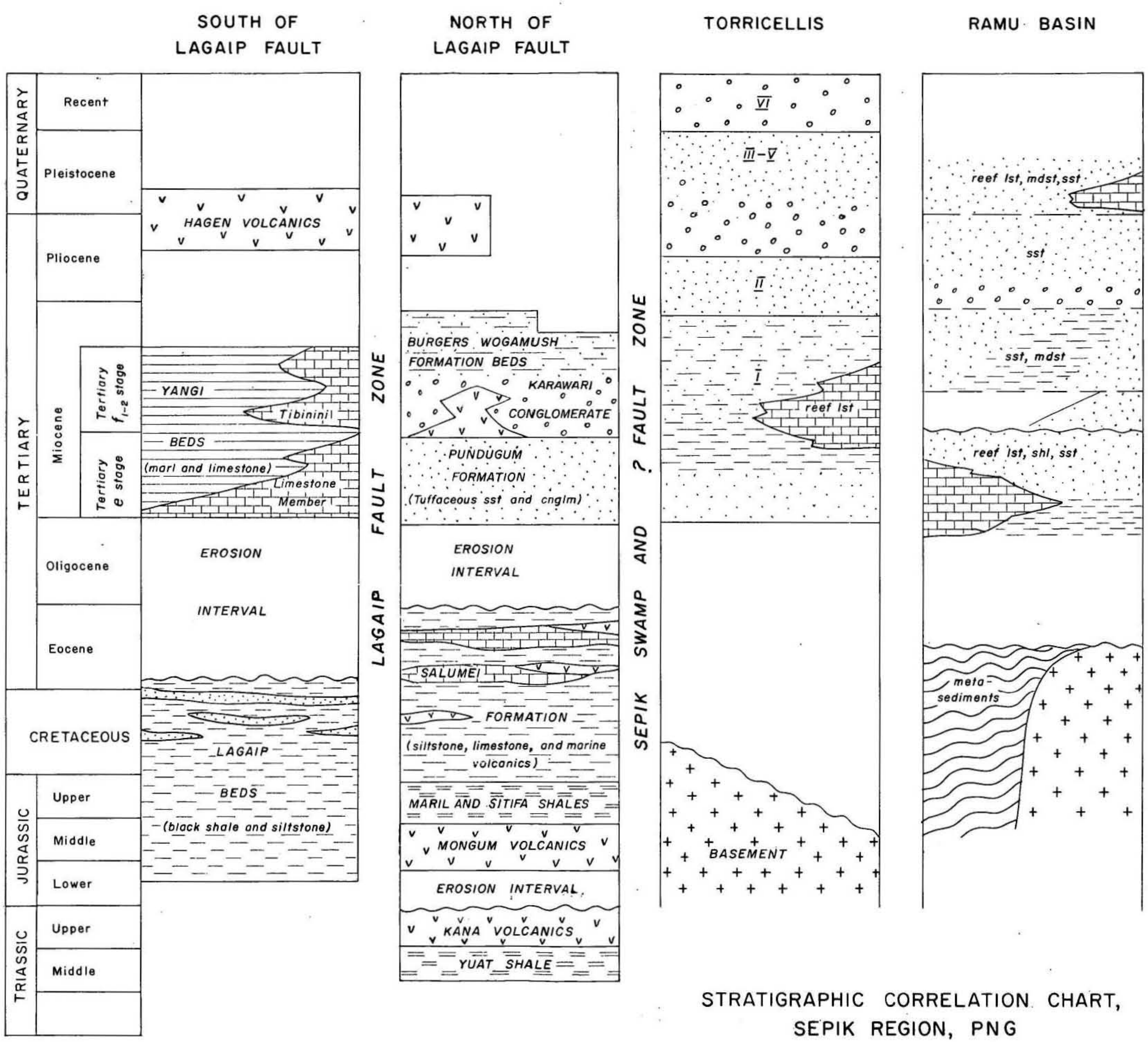


MAJOR FAULTS - SEPIK REGION

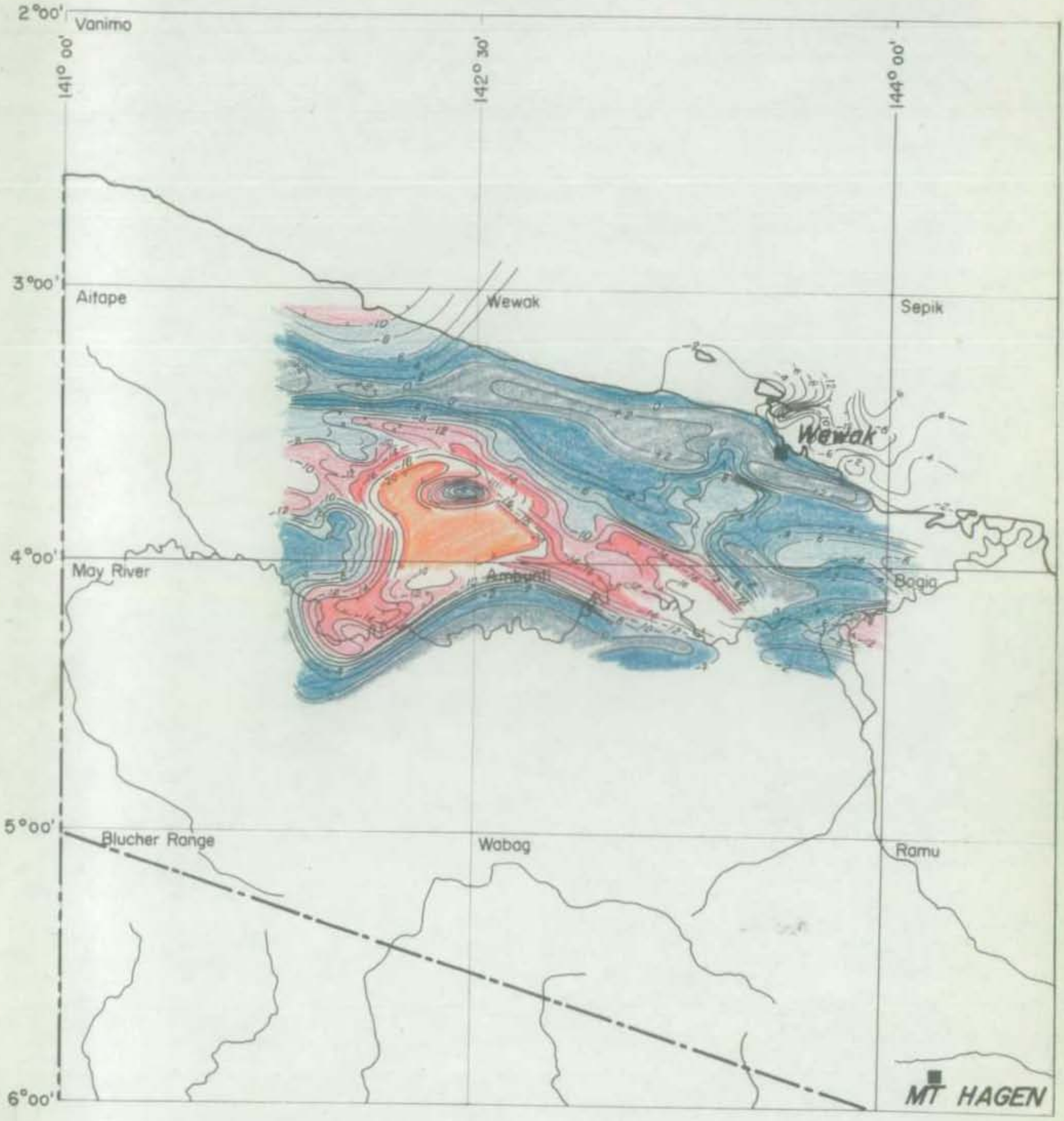
Showing postulated trends across the Sepik Plains
(modified from Dow et al., 1968)

PNG/B2-16

TO ACCOMPANY
RECORD NO. 1969/124



STRATIGRAPHIC CORRELATION CHART, SEPIK REGION, PNG



MAGNETIC BASEMENT CONTOURS

AFTER AUSTRALIAN AQUITAINE, 1967

CONTOUR INTERVAL 2000 feet

SCALE

0 50 100 MILES

PLATE II

LEGEND

A Bouguer anomaly feature

Preliminary Bouguer Anomalies Sepik-Ramu area computed using a rock density of 2·67 g/cm³. Marine data from U.S.S. Shoup, 1963-1964, reduced to Bouguer anomalies using bathymetry from Krause (1965)

Projection: Lambert conformal conic

PRELIMINARY BOUGUER ANOMALIES
SEPIK-RAMU AREA

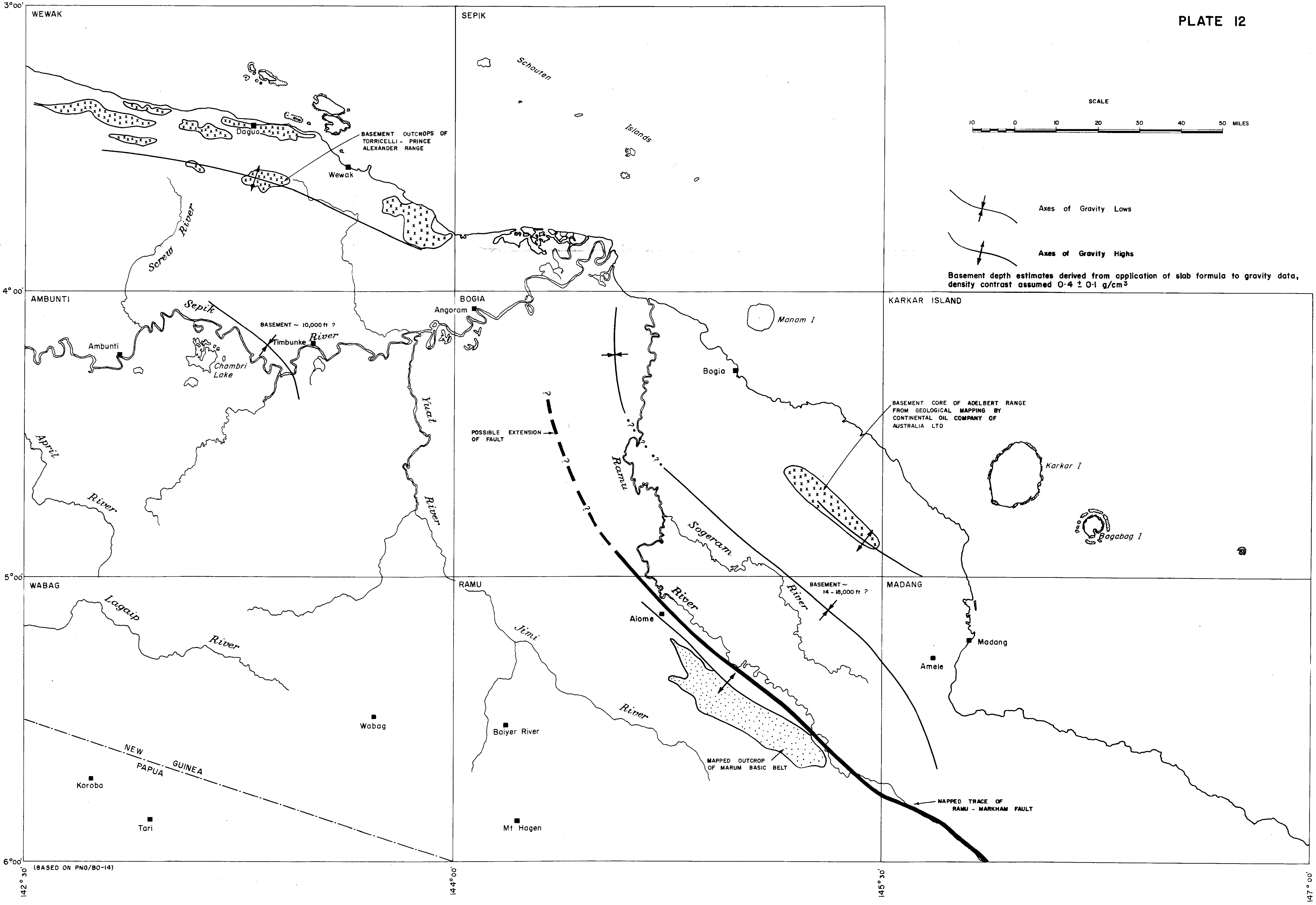
SCALE

10 0 10 20 30 40 50 MILES

Contour interval 10 milligals

TO ACCOMPANY. RECORD NO. 1969/124 PNG/B2-26-1

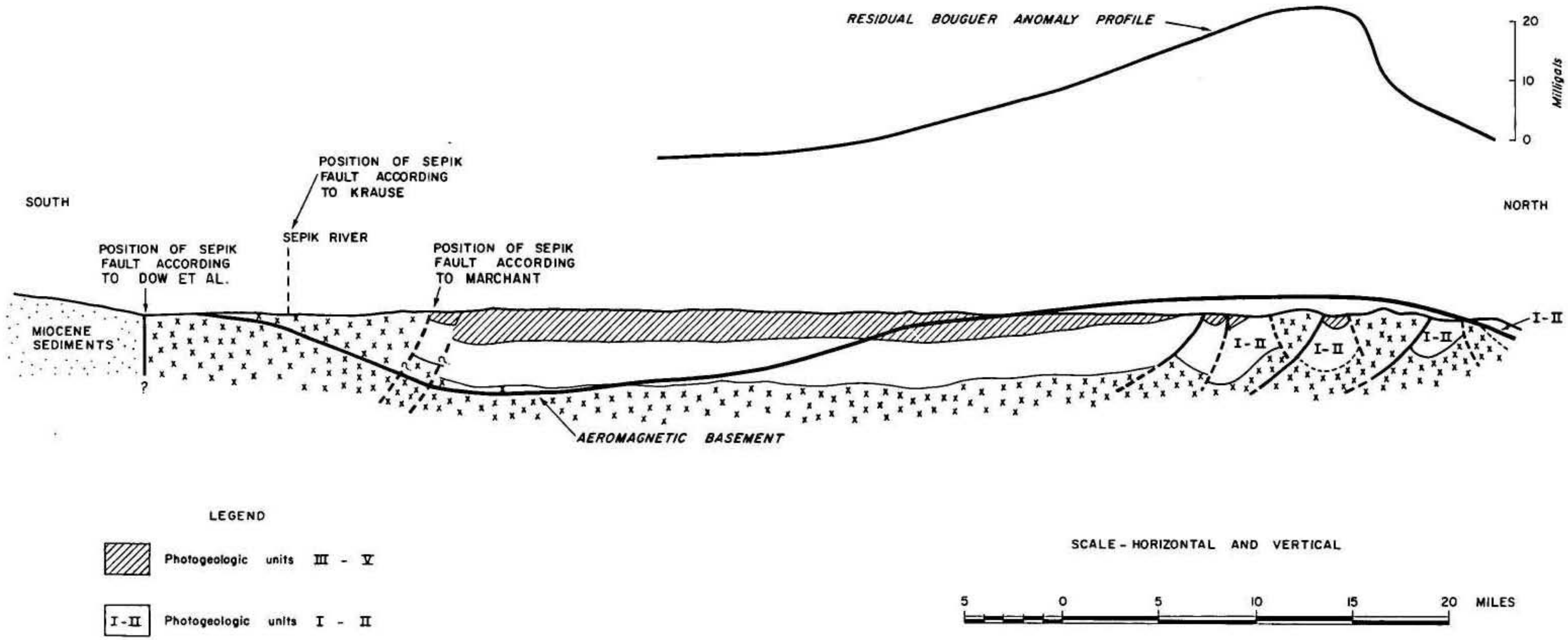
PLATE 12



MAIN BOUGUER ANOMALY FEATURES IN RELATION TO SURFACE GEOLOGY

SEPIK REGION

GRAVITY PROFILE AND GEOLOGICAL CROSS-SECTION THROUGH SEPIK AREA

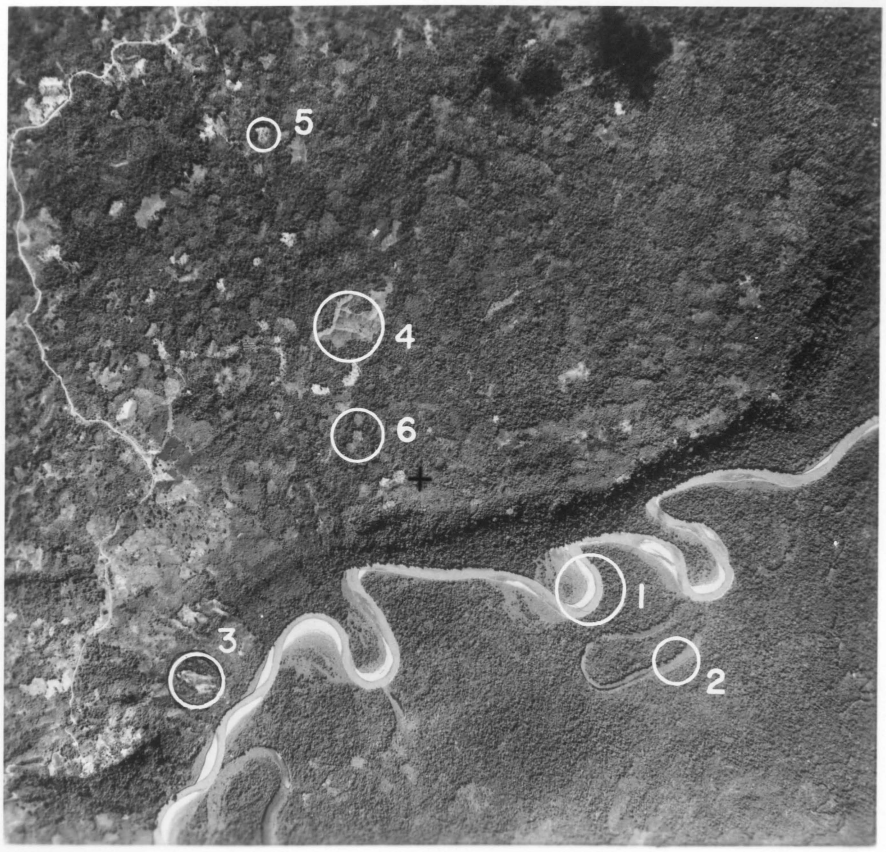


Geology to north of Sepik River after Marchant (1968, pl. 24); to south of Sepik, after Dow et al., (1968)

TO ACCOMPANY RECORD NO 1969/124

PLATE 13

A55/B2-18



Airphotograph CAJ 29-5068 Bogadjim W/K. Flown 24/7/55, 152·28 mm. lens altitude 25,000 ft. Scale approx. 1:50,000.

This photograph illustrates some of the main types of location which appear usable as helicopter landing grounds.

1. Point bar in river.
2. Oxbow, infilled with mud and usually with pit-pit growing to 20 ft, and thus not usable.
3. Apparently clear stretch of ground, but in fact a rock-slide sloping at 45° down to the river.
4. Kunai patch with ridge, making an ideal helicopter landing ground.
5. Clearing, but with some trees remaining, and a 10° slope — may be usable with the hover-site technique.
6. Clearings with native gardens – a marginal landing ground for the Jet Ranger in conventional mode.