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THE GRAVITY FIELD OF THE PAPUAN PENINSULA

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ABSTRACT

Large gravity anomalies on the Papuan Peninsula (the eastern part of the island of New Guinea) are associated with the Papuan Ultramafic Belt, an overthrust ophiolitic complex which may once have formed the frontal zone of an island arc. Very low fields occur over outcrop of the underthrust sialic metamorphics. The extreme east of the peninsula is built up of basaltic lava over which moderately high gravity fields are observed; the structure of this latter area is most simply explained in terms of Recent extensional movements.

INTRODUCTION

Eastern Papua consists of the curved tapering Papuan Peninsula, which extends south-east from the central New Guinea block, and a large number of offshore islands (fig. 1). Geologically it forms a link or transition zone between the Australian continent, of which New Guinea is the active northern margin, and the island arcs of Melanesia; its greatest affinities are with the large islands of New Caledonia and New Zealand, with which it may once have been linked by a now fractured and fragmented rise in the sea floor (Coleman, 1967). The peninsula is notable for the presence of large masses of ultramafic rock which form the base of a layered ophiolitic complex; the entire ophiolite sequence, through gabbro and diabase to pillow basalt with intercalated limestone and chert, is exposed in some of the mountain ranges. The discovery during reconnaissance work of large gravity anomalies associated with the ultramafic rocks (St John, 1967; St John and Green, 1967) led the Australian Bureau of Mineral Resources to give priority to more detailed gravity surveys in eastern Papua. This paper presents the results of the work on the peninsula and the islands west of 151°30'E, and incorporates some of the earlier data. The gravity measurements on the islands east of this line can only be satisfactorily interpreted in conjunction with marine data, and are not discussed here.

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All gravity differences were measured with LaCoste--Romberg geodetic meter G20, and absolute fields obtained via ties to stations of the Australian Isogal Network (Barlow, 1972). Additional sub-bases were established as required for control and checking. Station positions were plotted on one inch to one mile maps or uncontrolled photo mosaics and subsequently transferred to 1:250,000 base maps by reference to identifiable topographic feature.

Because of the sparsity of conventional communications systems in New Guinea, the surveys were carried out almost entirely by helicopter; a limited amount of work was done on foot in areas of particular interest and some river traverses were made using jet-boats. Even with helicopters it proved impossible to obtain a uniform coverage with the desired station spacing of 10 km. since much of the area is covered by thick rain forest or sago swamp where usable landing sites are rare.

Height measurements were made by microbarometer, using a single base technique, or by direct reference to sea level, and constitute one of the principal sources of error in the Bouguer anomaly map. Terrain corrections have been applied, and estimates at some stations exceed 40 milligals; because of inaccuracies in the available topographic maps large errors may have been introduced at this stage also. Calculations were extended out to the Hayford Zone 0 (166.7 km.) and the International Association of Geodesy topographic-isostatic maps (Kärki et al., 1961) were used to allow for the effects of topography beyond this distance. In calculating Bouguer anomalies, rock densities appropriate to the geological setting of each gravity station were used. Details of survey procedure and the application of correction terms are given in Milsom (1971), where the probable error in Bouguer anomaly is estimated at ± 5 milligals.

GEOLOGY

The geology of eastern Papua (fig. 2) has been described by Davies and Smith (1971). The Papuan Peninsula consists of a core of sialic metamorphic rock of Mesozoic

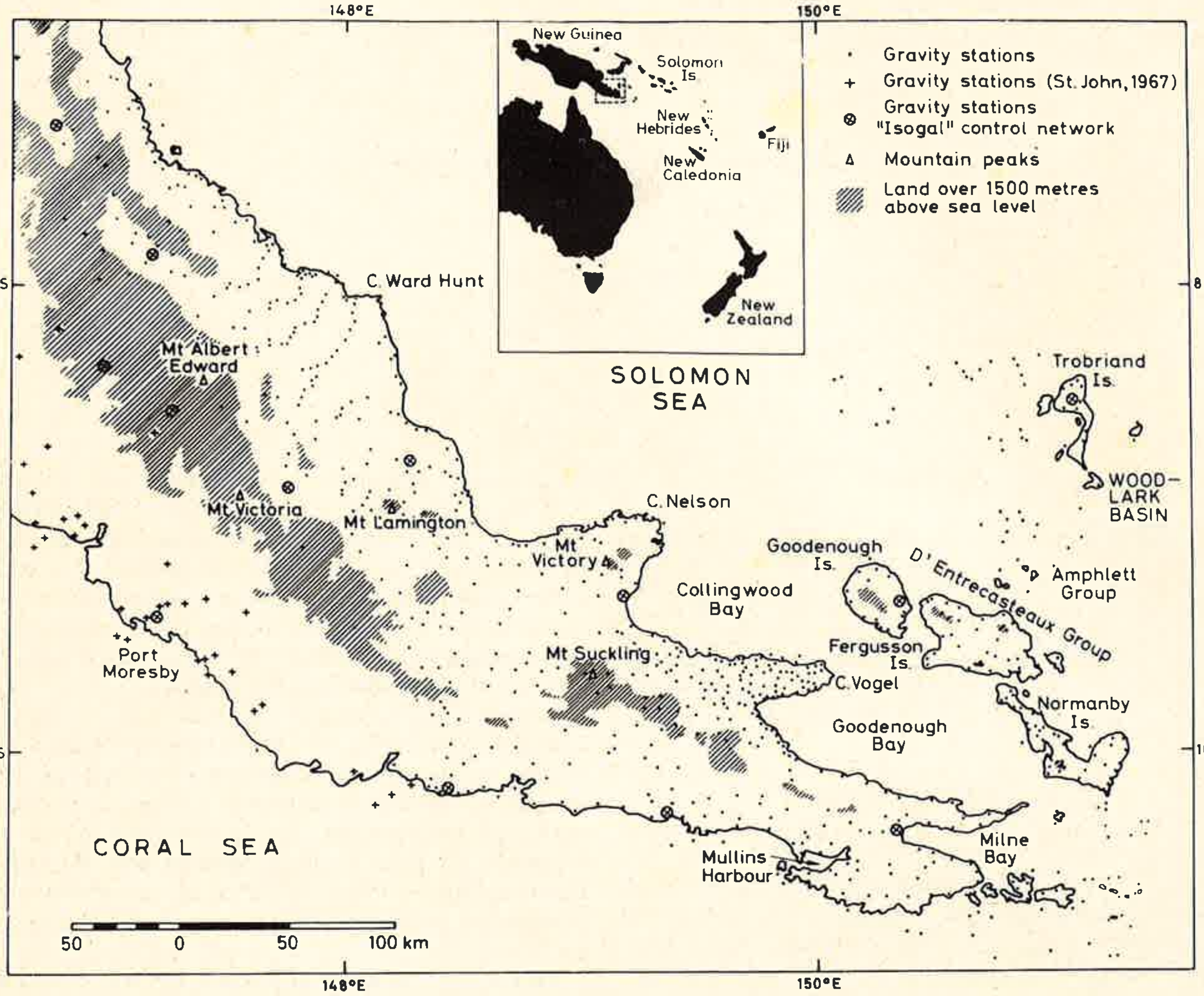

Fig. 1
Papuan Peninsula, locality map showing gravity stations used in preparing fig. 3.
Inset: the south-west Pacific.

age, surrounded by, and in the east probably underlying, rocks of oceanic affinity. Recent surveys (Furumoto et al., 1970, Ewing et al., 1970) have shown that the Coral and Solomon Seas, which flank the peninsula, and the Woodlark Basin to the east, are all oceanic, at least in their central areas.

The sialic core of the Papuan Peninsula, consisting of low to medium grade metamorphics of Mesozoic age, is exposed in the Owen Stanley Ranges as far east as 148°15′E. These mountains form the backbone of the peninsula, with peaks up to 4000 metres in height. Further east they are built up of a monotonous pile of basaltic lava, partly Eocene and partly Upper Cretaceous, but sialic rocks reappear offshore in the D'Entrecasteaux Group. From 147°E to 149°E Owen Stanley metamorphics and basalts are overthrust by the Papuan Ultramafic Belt, in which basal ultramafics are overlain by several kilometres of Cretaceous gabbro and submarine basalts, intruded by Eocene tonalites. Intermediate volcanics, also of Eocene age, are known, supporting the hypothesis (Davies and Smith, 1971) that the belt represents the frontal section of an island arc which collided with the thick crust of the peninsula in the lower Tertiary.

Basic intrusive and extrusive rocks also crop out along the southern flank of the main sialic zone. Late Tertiary uplift has been extreme (Smith, 1970) and has led to high rates of denudation and sedimentation, the coast of the peninsula being backed in many places by extensive alluvial plains and swamps. The sunken barrier reef off the south coast and the drowned coast line at the north-west end of the ultramafic belt testify to Recent negative movements, but it seems probable that large segments of the area are still rising. There has been considerable post-Pliocene volcanic activity, both on the peninsula and in the D'Entrecasteaux Islands, and the products of volcanism have contributed to the development of the coastal plains.

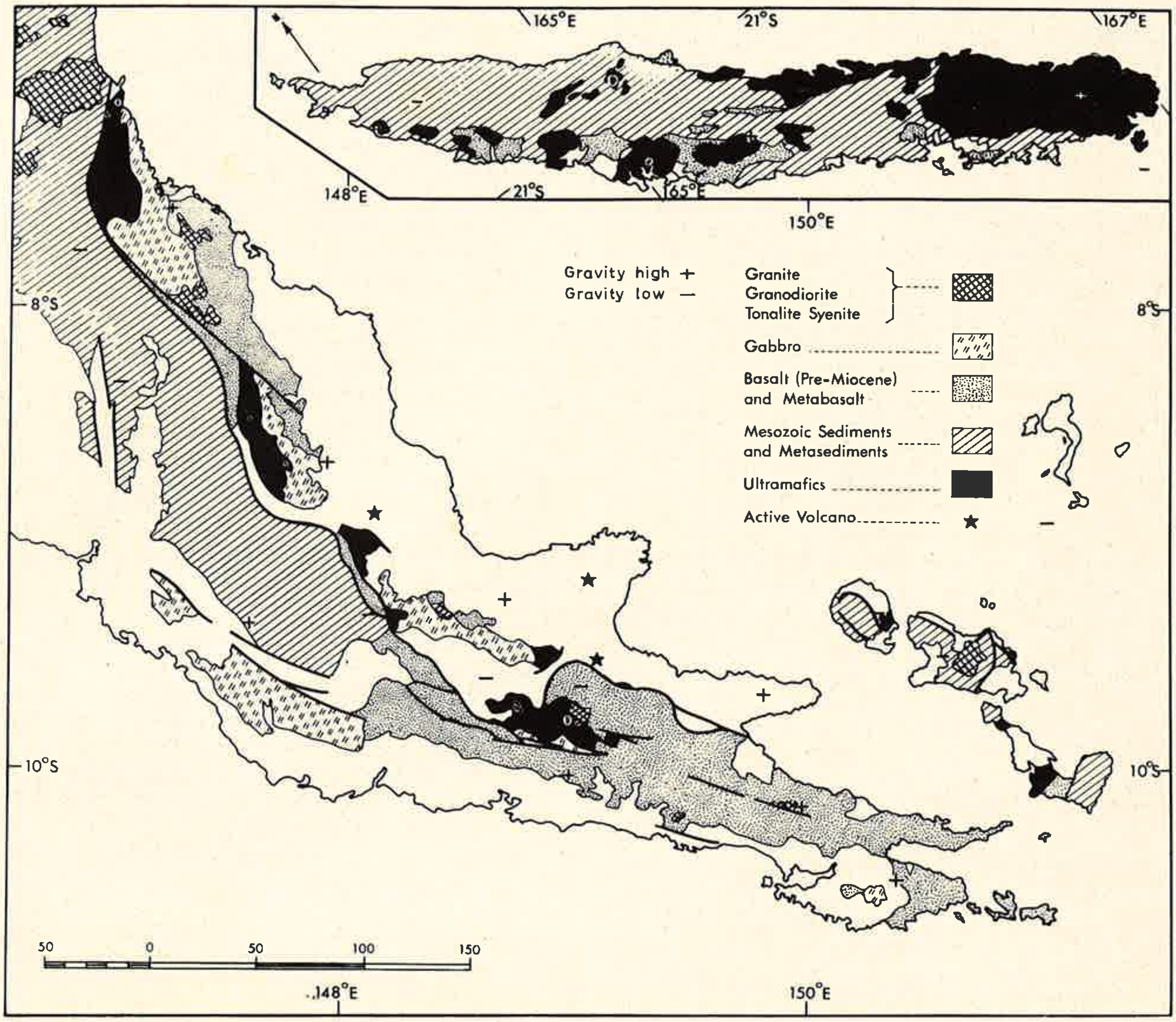

Fig. 2
Simplified geology of the Papuan Peninsula, after Davies and Smith (1971).
Inset: simplified geology of New Caledonia, after Lillie and Brothers (1970).

Reef corals are commonly developed in shallow waters, and the Trobriand Islands, which cap a major east-west trending bathymetric rise north of the D'Entrecasteaux, are entirely coralline. A few isolated volcanic plugs are known along this rise both east and west of the main islands.

THE GRAVITY FIELD

The Bouguer anomaly map (fig. 3) is dominated by the region of high fields and steep gradients associated with the Papuan Ultramafic Belt. The peaks of the positive anomalies are offset seawards with respect to the main ultramafic outcrops, and the degree of offset increase steadily to the east. At the eastern end of the belt partially serpentinized peridotites crop out in a region of low gravity field thirty to seventy kilometres south of the corresponding gravity high, which is centred in the coastal swamps. This pattern is immediately suggestive of thrusting of ultramafic slabs from root zones out to sea.

Variations in gravity along the line of the belt are of considerable importance. The ultramafics outcrop in large irregular masses and the gravity pattern also suggests a "lumpy", although essentially continuous body. Peak anomaly values decrease eastward and the saddles separating the peaks become both broader and deeper. This evidence for a thinner and more fragmented ultramafic belt in the east-cen-

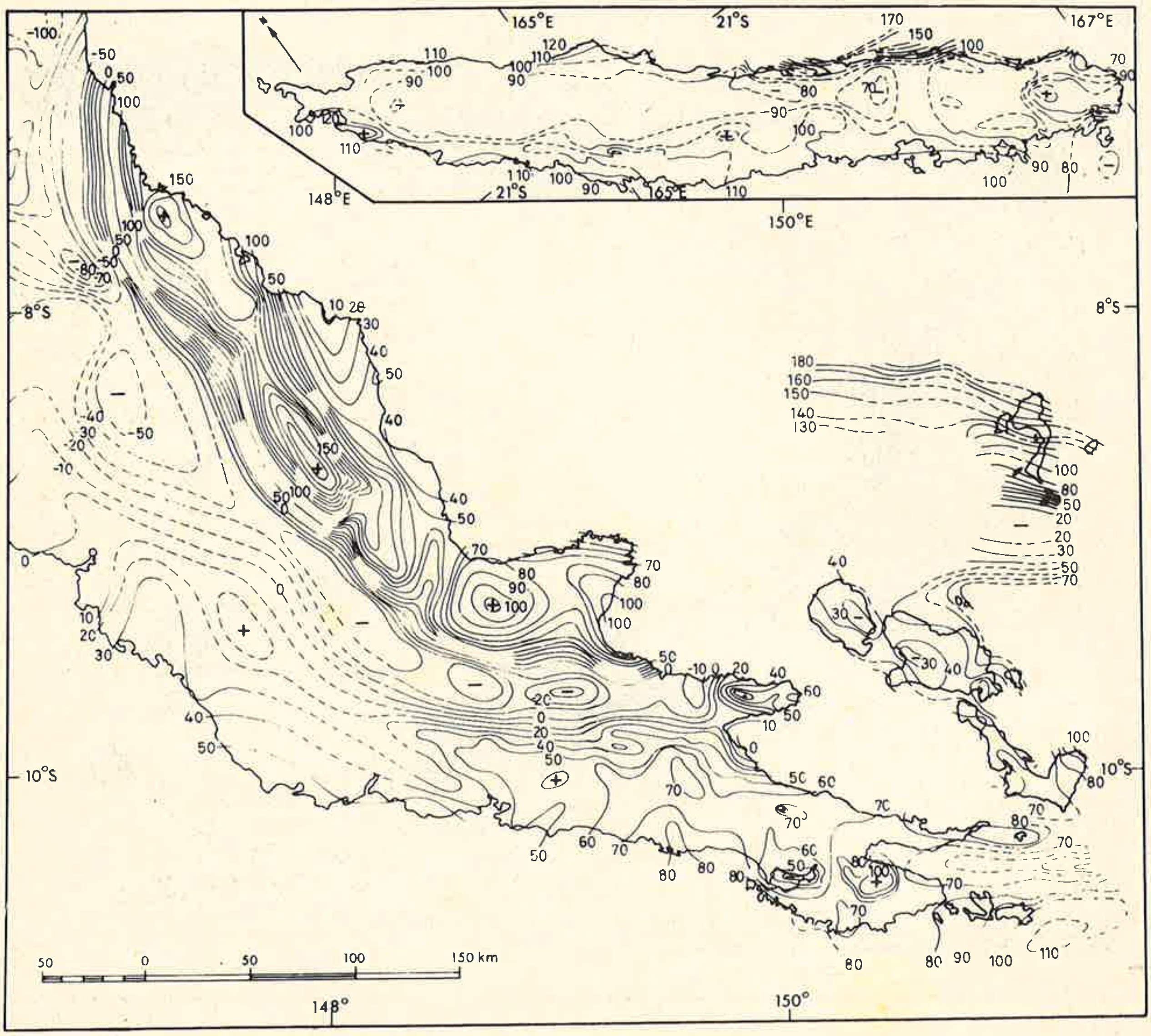

Fig. 3
Bouguer Anomaly map of the Papuan Peninsula; full topographic corrections applied using density based on local geology.
Inset: Bouguer anomaly map of New Caledonia, after Crenn (1953).

tral part of the peninsula is in agreement with the outcrop pattern.

In the north-western part of the peninsula a minor gravity trough tapers south from the coast in an area of outcrop of Miocene basalts and Recent alluvium. The gravity contours, since they do not extend offshore, may here be somewhat misleading, and the truly anomalous feature may be the north-east trending gravity high which marks the eastern margin of the trough. The most probable source of this feature would be a subsurface basement ridge, defining a basin which could contain over 1500 metres of marine and paralic sediments in the onshore section, and deepen offshore.

The majority of saddles and indentations in the belt anomaly are associated with Quaternary volcanism. The major break at 148°25′E coincides with the now dormant Hydrographer's Range complex (R u x t o n, 1966) and the marked flexure a little to the west with the recently active Mt. Lamington (T a y l o r, 1958). The saddle at 149°E also lies close to an active area, although the major vents lie east of the saddle axis. It seems unlikely that pressure developed within lower crustal magma chambers could have caused fracturing of a coherent ultramafic sheet, and more probable that the breaks in the belt are primary features which have allowed magma to rise.

The gravity pattern south of the volcanoes closely resembles that in New Caledonia (Crenn, 1953) (fig. 3, inset), where large masses of partially serpentinized peridotite overlie a Mesozoic geosynclinal sequence (Lillie and Brothers, 1970) (fig. 2, inset). On this island there are only minor positive anomalies coincident with the ultramafic outcrops, but the Bouguer anomaly increases towards the north coast, and extremely high gradients are observed in the coastal region, suggesting an ultramafic root zone offshore. In Papua extensive coastal plains have been built up by volcanic activity, and the peak anomaly associated with what may be a very similar root has been defined by land measurements.

A Bouguer anomaly low associated with the metamorphic rocks of the Owen Stanley Ranges lies south and west of the ultramafic belt along its entire length; only the eastern part of this feature was delineated by the author's surveys but in the west it is reasonably well controlled by previous reconnaissance (St John 1967). Crustal thicknesses in excess of those required for strict isostatic compensation are suggested by the magnitude of the low, in agreement with the geological evidence that the mountains are still rising. The indentation in the low at 8°S is probably due to Upper Tertiary volcanic rocks which give rise to intense magnetic anomalies in this area (Compagnie General de Geophysique, 1969), but its extent may be exaggerated on the present map; the gravity stations are located on volcanic plugs which may be expected to cause local highs.

East of 148°15′E, beyond which the metamorphic rocks are dominantly of basic composition, the axis of the anomaly tracks rather to the north of the main mountain ranges, passing beneath Mt. Suckling and ending abruptly at the base of the Cape Vogel Peninsula. The trend of the gravity low is somewhat unexpected; although Mt. Suckling, at over 3700 metres, is the highest point in the region, it is relatively isolated, and the mass of rock projecting above the sea level datum is probably less than in the mountainous zone of uniformly high Bouguer anomaly to the south. Even in the immediate vicinity of the Suckling massif the axes of the gravity low and the mountain block are not coincident, or even parallel, and simple isostatic compensation of existing surface features clearly does not account for the pattern observed. The most probable explanation is that the sialic rocks seen in outcrop further west persist at depth in this area, and that the gravity low follows the axis of the sialic belt; the presence of small outcrops of granite on Mt. Suckling gives some support to this idea.

The gravity high associated with the ultramafic belt passes out to sea east of Cape Nelson, and none of the anomalies further east can be clearly related to a continuation of the belt. In the absence of marine data three possibilities must be considered.

(1) The belt may continue across Collingwood Bay in fragmented form, giving rise to the small but very sharp gravity high on the Cape Vogel Peninsula and the ultramafic outcrops and associated small gravity anomalies in the D'Entrecasteaux Islands.

(2) A major transcurrent fault may exist in Collingwood Bay offsetting all the structures of the Papuan Peninsula northwards, a possibility first suggested by Davies and Ives (1965) on purely geological grounds. If this is correct the D'Entrecasteaux Group represents displaced Owen Stanley sialic core, and an ultramafic root zone might be expected north of the islands.

(3) The belt may end in Collingwood Bay and the ultramafics of the islands may not be directly related to those of the Papuan Peninsula. A completely independent mode of origin seems unlikely, and the fact that these bodies cannot be easily fitted into the simple pattern of a crust-upper mantle overthrust may be an indication that the mode of emplacement of the entire belt was rather more complex than this.

The abrupt termination of the gravity trough at the base of the Cape Vogel Peninsula can be regarded as evidence in favour of the second alternative. Goodenough Bay, south and east of Cape Vogel, is a remarkably deep, steep sided and flat bottomed depression, with a southern shore formed by an impressive line of normal faults in Plio-Pleistocene sediments; similar faults may also define the northern margin, on Cape Vogel and the D'Entrecasteaux Islands. If the hypothesis (Milsom, 1970) that the Woodlark Basin east of the Papuan Peninsula is a zone of current crustal formation is correct, a fault in Collingwood Bay could be of transform type, with north-south extension to the east only. This would explain the displacement of the sialic rocks, the extrusion of the Cape Vogel lavas (Dallwitz et al., 1966) via a tensional crack in the crust and the subsidence of Goodenough Bay, and of Milne Bay to the south-east. Even if this offset is real, however, the presence of an ultramafic root zone north of the D'Entrecasteaux Islands seems unlikely, though not impossible. The gravity high outlined by readings on the scattered volcanic and coralline islands of the Amphlett Group seems to be an extension of a broader high in the central Woodlark Basin to the east, and to diminish in intensity westwards, while the amplitude of about sixty milligals is also not suggestive of the very large density contrasts between ultramafics and more normal crustal rock. It seems that the ultramafic belt must at least undergo extensive fragmentation in Collingwood Bay.

The sharply defined low north of the Amphletts indicates a small basin with sediment thicknesses probably in excess of 3000 metres. The presence of such a feature, which has been confirmed by recent aeromagnetic work (Compagnie Generale de Geophysique 1971), is further evidence of a tensional environment. From the almost complete sediment fill it can be deduced that the basin formed in pre-Quaternary times, and at present extension is presumably taking place in Goodenough Bay.

The gravity patterns on Goodenough and Fergusson Islands are relatively simple. Gravity minima are associated with the cores of the islands, although not directly with granodiorite outcrop, and are due in part to the presence of low density intrusives and in part to isostatic crustal thickening. However, local isostatic compensation can play no part in the elongate low paralleling the north-east coast of Normanby Island and while the more obvious source of this anomaly would be an offshore sedimentary basin, the alignment with the lows on the other two islands suggests the possible presence of a further intrusive body; if this latter hypothesis is correct, Normanby is structurally more similar to Fergusson and Goodenough Islands than at first sight appears, consisting, as they do, of ultramafic and metamorphic rocks marginal to a major sialic intrusion.

The high general level of Bouguer anomaly in the D'Entrecasteaux Group is an inevitable consequence of the rise in Moho level beneath the adjacent Solomon Sea, and does not necessarily imply thinner than normal crust beneath the islands themselves. Morphologically Goodenough and Fergusson Islands resemble the Suckling massif of the mainland in their markedly domal structure, a resemblance that must have been still greater if, as proposed by Davies and Ives (1965), the islands originally formed a single elongate dome now disrupted by transcurrent faulting. It is even possible, as noted above, that this composite dome was once continuous with the mainland massif, although since parts of the Suckling block were certainly submerged until well into the Pleistocene, it seems unlikely that there was significant uplift prior to displacement. The pattern of uplift in the absence of evidence for lateral compression indicates current, or at least recent, overcompensation of both Mt. Suckling and the islands.

The Papuan Peninsula south of the islands is built up of a monotonous sequence of pillow lavas ranging in age from late Mesozoic to mid-Tertiary, with scattered syenite and gabbro intrusions and minor limestone intercalations. Gravity values rise steeply from the "sialic" negative anomaly along the north boundary of this province. The age relationships in the volcanic pile are not, of course, susceptible to gravity analysis, and south of the gradient and as far east as 150°E the Bouguer anomaly map is relatively featureless. Local highs, some based only on a single gravity reading, can be correlated with syenites (Smith, 1972). South of Milne Bay a much larger positive anomaly is associated with a more complex intrusion, dominantly gabbroic but with syenite also present. The high gravity fields extend east of the Peninsula to 150°30′E; small islands in this area (the Engineer Group) were stated by Davies and Smith (1971) to be entirely coralline, but some are volcanic. A minor, poorly defined high north of Milne Bay is also associated with gabbro, while a gravity low, defined only at its edges, coincides with the bay and extends east as far as 150°15′E.

West of Milne Bay and centred along the north shore of Mullins Harbor is another extensive region of relatively low gravity. A narrow trough, now infilled with light unconsolidated material, is indicated by the steep gravity gradients near the centre of the anomaly, which suggests that the northern margin of the inlet was originally controlled by normal faulting accompanying a major downwarp. The remainder of the low is roughly coextensive with outcrop of Lower Miocene limestone and volcanogenic sediments. Milne Bay and Mullins Harbour would both appear to be zones of subsidence, bounded by steep normal faults, and as such are fully compatible with theories involving Recent or continuing north-south extension.

With the exception of the syenites the rocks of the basaltic province are characteristic of the ocean floor, and it has been suggested that they are in fact exposed oceanic crust (Thompson and Fisher, 1965). StJohn (1967) pointed out that the position of the basalts relative to the D'Entrecasteaux sialic suite made overthrusting of such crust from the north unlikely, and that overthrusting from the south raised difficulties in adjacent areas; he noted that the observed elevation and positive Bouguer anomalies could be explained either by assuming the basalts to have been extruded over continental crust, or to represent oceanic crust in situ overlying low density mantle. In neither case does the net positive anomaly over the basalt necessarily imply isostatic disequilibrium, since the effect of the light rocks at depth would be of smaller amplitude and longer wavelength than that of the near surface mass excesses. Recent seismic refraction work in the Coral Sea (Ewing et al., 1970) has shown that thrusting from the south is improbable and that the crust thickens to near normal continental values as the Papuan Peninsula is approached, indicating StJohn's first solution to be correct. However the presence of great thicknesses of pillow lavas of different ages does indicate a long history of submergence, and the present elevation and gravity fields are most simply explained by accepting that there has been some expansion of the mantle beneath the peninsula.

Bouguer anomaly values increase northwards across the Trobriands and towards the south coast of the peninsula, in a pattern characteristic of the transition from continental to oceanic crust.

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