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PAPUAN ULTRAMAFIC BELT

by

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SUMMARY

The Papuan Ultramafic Belt is one of a number of large bodies of gabbro and peridotite which occur in orogenic zones around the world and particularly on the Pacific margin. The Belt is 400 km long, up to 40 km wide, and consists of approximately equal proportions of mafic and ultramafic rocks. It is thought to be a segment of oceanic mantle and crust which has moved westward since the Cretaceous and has been forced upward by collision with the sialic core of Papua - New Guinea. Tilting of the Belt and erosion have exposed a section from peridotite at the base, through gabbroic rocks and minor diorite, to the basaltic lavas of the Cretaceous ocean floor.

INTRODUCTION

The Papuan Ultramafic Belt (Figure 1) is one of a number of large bodies of peridotite and gabbro which occur in orogenic zones around the Pacific margin. Other examples are found in New Caledonia, the Solomon Islands, Philippines, Celebes, Borneo, and the western United States. Similar bodies are found in orogenic areas elsewhere around the globe, for instance, Newfoundland, the Caribbean, and Cyprus. Characteristics of the orogenic mafic-ultramafic belts have been discussed by Thayer (1) and Green (2). They are typically composed of highly magnesian peridotite associated with gabbro and norite, are located on major structural breaks, are aligned parallel to major structural trends, and have faulted contacts. The idea that these bodies originate in the upper mantle has been put forward by de Roever (3), Hess (4) and others.

This paper was prepared for submission to XXIII Session of the International Geological Congress to be held in Prague in August 1968. It presents the results of surveys of the Papuan Ultramafic Belt by Bureau of Mineral Resources (B.M.R.) geologists; the surveys commenced in 1952 and continued intermittently (5-11) until 1965, when the writer commenced a three-year project to complete the field mapping and integrate the available data. Major contributions to the geological mapping have been made by J.E. Thompson (5), J.W. Smith (7), D.H. Green (7), and D.B. Dow (9); J.S. Milsom has contributed unpublished gravity data which incorporate previous work by J.E. Shirley and P.E. St John (University of Tasmania) (12).

In this paper the Papuan Ultramafic Belt is described first, followed by the rocks associated with the Belt, then the tectonic setting of the Belt, and finally conclusions about the origin of the Belt. Place names and topographic names have been avoided where possible and localities are mostly referred to by their approximate latitude and longitude. The three main divisions of the Belt, which are occasionally referred to, are the Bowutu Mountains in the north, the Ajura Kujara Range in the centre, and the Musa (River) area in the south-east.

Hypothesis of mantle origin

In order to provide a frame of reference for the description of the Belt a hypothesis of origin is given briefly here (see Figure 2); the hypothesis is based on ideas developed by J.E. Thompson in 1957 and published recently (13, 14).

The Ultramafic Belt is thought to be a segment of oceanic upper mantle and crust which has moved westward since the Cretaceous, and has been forced to the earth's surface by collision with the sialic core of Papua - New Guinea. As the mantle segment rode up over the sialic block, it was tilted and partly eroded. The result is an exposed section (from west to east, Figure 2) of (a) sialic core, separated by a thrust fault from (b) ultramafic rocks (upper mantle), (c) gabbroic rocks (lower oceanic crust), and (d) Cretaceous basaltic lavas (upper oceanic crust).

PAPUAN ULTRAMAFIC BELT

The Papuan Ultramafic Belt is 400 km long and up to 40 km wide, and lies on the north-eastern side of the Owen Stanley Range in eastern Papua - New Guinea between 7°S, 147°E and 10°S, 149°E. It forms a series of elongate mountain ranges with peaks between 2,000 and 3,000 metres above sea level.

The Belt contains mafic and ultramafic rocks in approximately equal proportions. The mafic rocks are gabbro and norite, and the ultramafic rocks are peridotite, dunite, and pyroxenite. The ultramafic rocks are generally restricted to the western and south-western side of the Belt, where they form elongate pods up to 80 km long and 18 km wide; they also occur as scattered inliers up to 10 km long within the mafic rocks. The mafic rocks generally intrude the ultramafic, but at a few localities the two are interlayered in accumulative sequences.

Ultramafic rocks (Upper Mantle?)

The ultramafic rocks are high magnesia peridotite, dunite, and pyroxenite which are thought to represent a part of the upper mantle. The most common rock type is pale green homogeneous enstatite olivinite (harzburgite) which consists of olivine Fo_{90-95} (60-80%) and enstatite En_{85-95} (40-20%) with accessory chromite; the olivine and enstatite typically form interlocking anhedra about 1 cm across. An analysis is given in Table 1.

Dunite masses interfinger irregularly with the olivinite; the intimate relationship of the two rock types suggests that they might be derived from an originally homogeneous dunite or olivinite by silica metasomatism according to the reversible reaction:

forsterite + silica = enstatite (15)

Enstatite pyroxenite (Table 1) occurs as ubiquitous veinlets, 1-3 cm wide, in olivinite and dunite. Coarse-grained pyroxenite is less common; it consists of enstatite crystals up to 10 cm long and forms veins and irregular bodies up to 5 metres across. In some areas it constitutes 20-30% of the exposed ultramafic rocks. The pyroxenite may have been injected as magma into solid olivinite, or have originated by silica metasomatism as explained above.

Clinopyroxene occurs only as ex-solution lamellae in enstatite except near the contact with mafic rocks. In the contact zone bright green chrome diopside occurs (a) with orthopyroxene in irregular bodies of coarse-grained pyroxenite, (b) with olivine in serpentinized peridotite, apparently as a metasomatic effect of gabbro intrusion, and (c) in rocks transitional from ultramafic to mafic (see below).

Serpentinization affects only about 20 percent of the ultramafic rocks and is generally restricted to shear and contact zones.

There is no evidence that the olivine-rich ultramafic rocks (peridotite, dunite) were ever fluid. No accumulative textures have been found and the only layering is a streaky layering which is present in about 30 percent of the ultramafics and which dips consistently over areas of up to 10 km^2. This layering is probably due to shear deformation of solid rock: pyroxene grains are stretched and granulated and parallel sets of joints are developed.

The ultramafic rocks may represent primary mantle material; rocks of this composition have the characteristic upper mantle seismic velocity of 8.2 km/sec and density of about 3.3 gm/cm^3 (16). Alternatively the ultramafic rocks may represent secondary mantle: the refractory peridotite produced when primary pyrolite mantle is partially melted to yield basalt magma (17: Pyrolite is a hypothetical mantle composition computed by adding one part of basalt to three parts of peridotite).

Transitional rocks

The contact between mafic and ultramafic rocks is typically intrusive, mafic intruding ultramafic. However, there are a few localities where the contact appears to be transitional through interlayered mafics and ultramafics (8, 18); some of these layered sequences have distinct accumulative textures, for instance graded beds 15 cm thick, grading from hypersthene - diopside pyroxenite at the base through gabbro to anorthosite at the top. The presence of these rocks proves that some minor amounts of ultramafics have formed by crystal settling from mafic magma. However the development of these layered sequences is not on such a scale as to suggest that all of the ultramafics might have formed in this way.

Mafic rocks (lower oceanic crust)

The common mafic rocks are gabbro and norite comprising brown hypersthene, green diopside, and calcic plagioclase (usually bytownite or anorthite); olivine is sometimes present. In some gabbro and norite the pyroxenes are stumpy and the rock has a granulitic texture. An analysis of a typical medium-grained granulitic norite is included in Table 1.

Pegmatitic gabbro occurs as irregular wisps and lenses in normal gabbro, and as dykes (with grains up to 15 cm) intruding ultramafic rocks near the mafic-ultramafic contact.

About 30 percent of the gabbro and norite has a streaky flow layering which has been produced by flow of part-solid magma under stress. Similar streaky layering in other mafic-ultramafic bodies is described by Thayer (19). Accumulative layering similar to that seen in the transitional rocks is preserved in 1-5 percent of the gabbro and norite (8, 18); this indicates crystallization from a highly fluid magma in quiet conditions and could hardly have developed in the same environment as the streaky layering.

The transitional rocks and mafic rocks with accumulative textures are thought to represent primitive lower oceanic crust. The homogeneous and streaky-layered mafic rocks, on the other hand, were probably generated as magma during movement of the Belt in Cretaceous-Eocene time; they may have originated by melting of primitive mafic crust or by partial melting of pyrolite (17) mantle. They intrude the ultramafics and the Cretaceous volcanics and are intruded by Eocene diorite.

Sulphide minerals containing copper and nickel are localized in joints or disseminated through hybrid gabbro in the roof zone of the intrusive gabbroic rocks.

Diorite and quartz diorite occur as stocks 10-20 km across at the contact between the mafic rocks and the overlying Cretaceous basalts, and intrude both. They are remarkably uniform in character, except where contaminated by inclusions, and consist of andesine, hornblende, and usually some quartz (up to 40 percent by volume). Diorite from Kui ($7^{\circ}30'$S) has been dated by A.W. Webb (B.M.R.), using the K-Ar method, at 55 ± 2 m.y. An analysis of this diorite is included in Table 1; it has a typical orogenic calc-alkali andesite composition.

Green and Ringwood have shown that andesitic magma may be produced by partial melting of (a) eclogite mantle at 100-150 km depth (20) or (b) basalt under hydrous conditions at depths of 30-40 km (21). The diorite of the Ultramafic Belt may have originated by either mechanism, or perhaps was generated in the sialic core and injected upward through the thrust plane into the oceanic rocks.

VOLCANICS ASSOCIATED WITH THE ULTRAMAFIC BELT

Cretaceous volcanics (basaltic oceanic crust)

Altered basalt lavas and pillow lavas are intimately associated with the Ultramafic Belt throughout its length. These lavas are mostly, or all, Cretaceous and are thought to be remnants of the oceanic crust which existed over the Ultramafic Belt before fault movement began.

The volcanics are best preserved in the Bowutu Mountains ($7^{\circ}30'$ to 8°S) where they comprise interbedded massive lavas and pillow lavas, flat-lying or dipping at $20-30^{\circ}$ to east and north-east, with a total exposed thickness of about 1500 metres. These are overlain by 500 metres or more of folded agglomerate and tuff. Almost all of the volcanics are uralitized, chloritized, and epidotized to some extent, and some are completely altered to epidote. Much of the alteration is localized on joints. Gabbro of the Ultramafic Belt and Eocene diorite intrude the volcanics in the Bowutu Mountains, and Miocene sediments overlie them unconformably.

In the Musa area ($9^{\circ}20'$ to 10°S) the volcanics are typically strongly jointed with joints spaced only a few centimetres apart. The major rock type is chloritized, epidotized, and locally sulphide-enriched basalt. Cretaceous foraminifera occur in associated red marl at 10°S, 149°E (D.J. Belford, B.M.R., pers. comm.).

South-east of Mount Suckling, at $9^{o}50'S$, $149^{o}10'E$, is a great mass of altered basalt with strong schistosity; the schistosity is folded into a broad anticline 3 km high and 25 km across. Limestone boulders shedding from the area contain Cretaceous foraminifera (D.J. Belford, pers. comm.). The Goropu Metamorphics, which form Mount Suckling, may be a slightly more metamorphosed equivalent of these rocks (see Sialic Core).

Miocene sediments and volcanics (Tertiary f_{1-2})

Miocene grit and volcanics unconformably overlie the Cretaceous volcanics at $8^{o}10'S$. The Miocene strata near the contact dip consistently at $15-20^{o}$ to north-east.

Miocene basalt and limestone (22) are faulted against the southern side of the Ultramafic Belt at $10^{o}S$. These rocks are similar to the Cretaceous volcanics and it is possible that some of the supposed Cretaceous volcanics may be Miocene.

Cainozoic Volcanics

Pliocene, Pleistocene, and Recent volcanics cover parts of the Ultramafic Belt south of $9^{o}S$; they range in composition from basalt to andesite, dacite, and rhyodacite (23). In the Musa area they are interbedded with gently folded terrestrial Pleistocene sediments. Three spectacular andesitic cones have been constructed north of the Musa area: Mounts Lamington, Victory, and Trafalgar. Lamington, Victory, and a small cone near Mount Suckling have erupted in historic time (24, 25).

SIALIC CORE

The sialic core of eastern Papua - New Guinea comprises low and moderate-grade metamorphics which are collectively known as the Owen Stanley Metamorphics. Common rock types are phyllites derived from siltstone and greywacke, chloritic mica schist, and quartz-mica schist. Conglomerate and marble beds and lenses are less common. Metamorphic grade is generally greenschist facies but garnet amphibolite is found between 8^{o} and $9^{o}S$. Acid intrusives occur throughout the metamorphics, especially around $7^{o}S$, where a granodiorite pluton of probably Miocene age crops out.

Cretaceous fossils have been found in the metamorphics north of $7^{o}30'S$ (26) at localities only a few kilometres west of the contact with the Ultramafic Belt. The metamorphics have not been mapped in detail and it is quite possible that they also include some pre-Cretaceous rocks.

The contact between the metamorphics and the Ultramafic Belt is marked by a major fracture, the Owen Stanley Fault; this is the thrust plane upon which the Ultramafic Belt has ridden up and over the sialic block. Smit (pers. comm.) notes that the grade of metamorphism in the sialic rocks decreases away from the fault and suggests that the metamorphism may have been caused by compression and shearing forces during the overthrusting. Schistosity within a few kilometres of the fault plane generally dips at $40-60^{o}$ to the east and north-east, as might be expected if Smit's theory is correct.

The Goropu Metamorphics which form Mount Suckling (9°40'S, 149°E), have been described by previous workers as a part of the sialic core which has been offset by faulting (7, 14). My scattered observations of the Goropu Metamorphics indicate that they are not sialic; the most common rock type is chloritic basic schist probably derived from basalt, and this is associated with minor marble. The association of altered basalt (?) and limestone suggests correlation with the Cretaceous volcanics.

Basic gneiss and amphibolite on Mount Suckling have not yet been mapped in detail, and have not been correlated with any of the other rock groups.

TECTONICS

The slab of oceanic mantle and crust, now represented in the Papuan Ultramafic Belt, is thought to have moved westward in late Cretaceous or early Tertiary time and to have ridden up over the sialic core of Papua - New Guinea. Movement took place along a sinuous major fracture, the Owen Stanley Fault (Figure 1); movement on the fault was partly low-angle thrust (where the fault trends north) and partly left-lateral strike-slip (where the fault trends north-west). The thrusting brought the oceanic slab westward over the sialic core, and the strike-slip faulting broke it into three pieces. (Bowutu Mountains, Ajura Kujara Range, and Musa area). Displacement on the two strike-slip faults is 90 km (Gira Fault) and 25 km (Mamama Fault).

The thrust plane of the Owen Stanley Fault probably dips eastward at 20-30°; this is the angle which best fits the surface mapping and gravity data (figure 2, Section AB). St John (12) and Milsom (pers. comm.) have defined positive Bouguer anomalies of about 200 milligals 15-20 km east of the ultramafic outcrop areas. These anomalies probably coincide with the maximum thickness of ultramafic rock; this might be expected to occur at and immediately west of the line along which the Owen Stanley Fault thrust plane intersects the Mohorovicic Discontinuity. If we assume that this intersection is at about 10 km depth then the plane connecting the intersection with the surface trace of the fault dips at 20-30°. The fault is seen to dip at this angle at 9°20'S but elsewhere appears to be near vertical; J.E. Thompson (pers. comm.) has suggested that the apparent steepness may be due to recent adjustments such as normal faulting accompanying isostatic uplift of the sialic core.

The Musa area differs from the other parts of the Belt in the irregular distribution of mafic and ultramafic rocks, and the occurrence of a gravity "low" over the main mafic-ultramafic outcrop area. These features are explained if we picture the oceanic slab as a thin subhorizontal thrust sheet, about 5 km thick, which has been broken into blocks by vigorous Quaternary vertical movements (Figure 2, Section CD).

CONCLUSIONS

The Papuan Ultramafic Belt and overlying basalts are a slab of oceanic mantle and crust which moved westward in Cretaceous or Eocene time and was forced upwards by collision with the sialic core of Papua - New Guinea. The slab consists (from top to bottom and east to west) of :

(a) Cretaceous basalt (upper oceanic crust)

(b) gabbro and norite (lower oceanic crust)

(c) peridotite (mantle)

The peridotite may be primary mantle or secondary refractory material formed from partial melting of primary pyrolite mantle. Some of the gabbro and norite has accumulative textures and is thought to be a remnant of primitive oceanic crust. However, most of the gabbro and norite was fluid during movement of the Belt and was probably generated by melting of primitive crust or partial melting of pyrolite mantle. Eocene diorite which intrudes at the gabbro-basalt interface may have originated in the sialic core, in eclogite mantle, or by partial melting of buried submarine basalts.

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TABLE 1

Analyses of typical rocks from the Papuan Ultramafic Belt

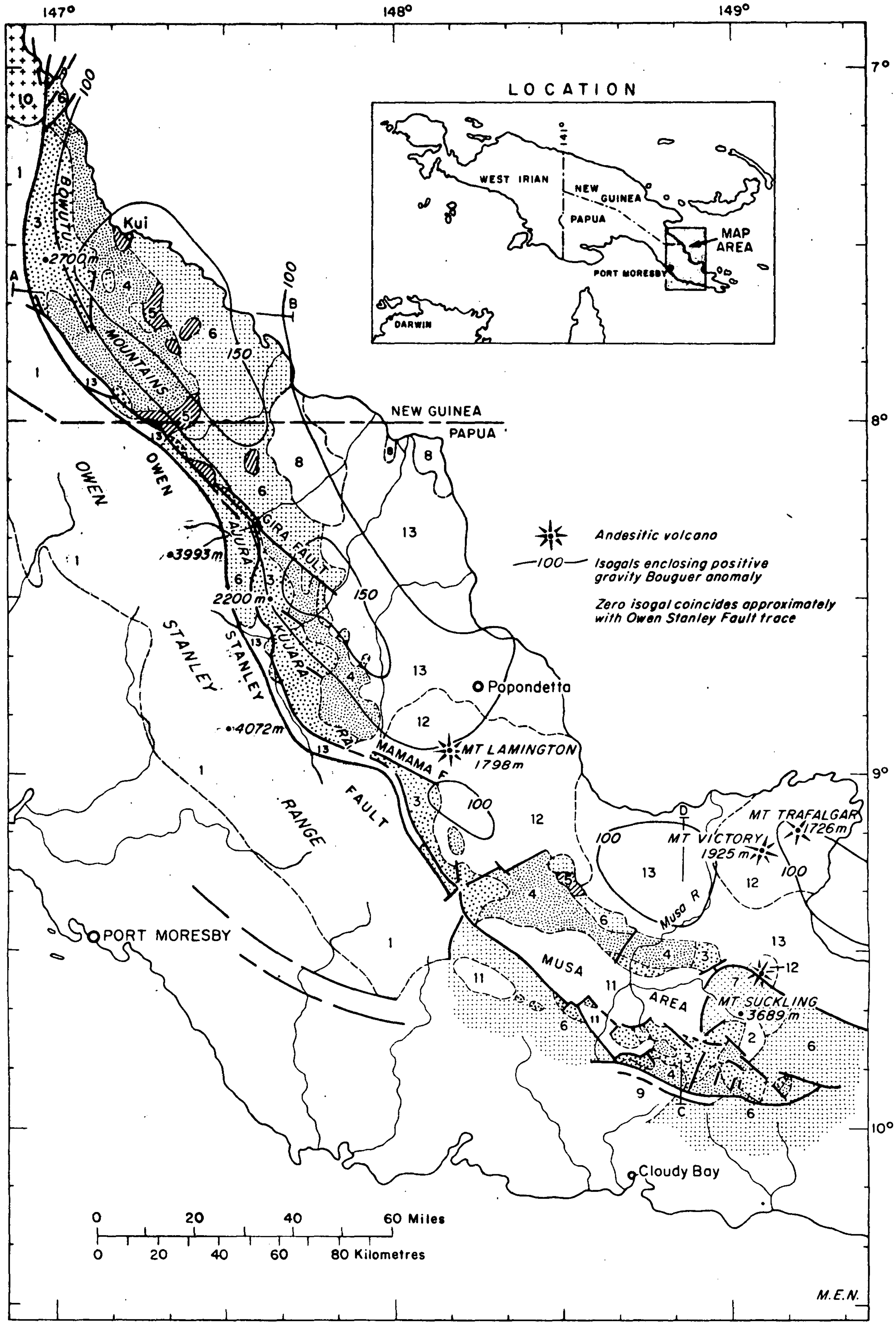
	Enstatite Olivinite (0046)	Enstatite Pyroxenite (0008)	Norite (6458)	Diorite (0021)
SiO_2	42.8	55.2	48.3	60.8
Al_2O_3	0.23	0.71	16.7	16.2
Fe_2O_3	0.99	3.00	1.45	1.50
FeO	6.45	3.90	3.25	5.40
MgO	48.0	34.1	11.1	3.35
CaO	0.55	1.96	17.6	7.65
Na_2O	0.07	0.05	0.66	2.90
K_2O	0.01	0.02	0.02	0.34
H_2O^+	0.24	1.04	0.45	0.82
H_2O^-	0.19	0.08	*	0.27
TiO_2	0.02	0.02	0.13	0.41
P_2O_5	nil	0.01	0.01	0.07
MnO	0.10	0.16	0.09	0.14
CO_2	0.05	0.06	0.03	0.12
Analysts	AJ & LC	AJ & LC	HK & AJ	AJ & LC

Analyses by Australian Mineral Development Laboratories

Chemists - A. Jorgensen, L. Castanelli, and H. Kresse

* not determined

Fig. 1.



PAPUAN ULTRAMAFIC BELT

1. Owen Stanley Metamorphics - Cretaceous (and older?)
2. Basic gneiss and amphibolite
3. Papuan Ultramafic Belt - Ultramafic rocks
4. " " " - Mafic rocks (gabbro etc.)
5. " " " - Diorite and quartz diorite - Eocene
6. Basaltic volcanics - Cretaceous
7. Goropu Metamorphics
8. Grit and basaltic volcanics - Miocene (Tertiary f_{1-2})
9. Basaltic volcanics with limestone - Miocene (Tertiary f_{1-2})
10. Morobe Granodiorite - Miocene? Pliocene?
11. Domara Beds : terrestrial sediments and minor andesitic volcanics - Pleistocene
12. Volcanics : Basalt, andesite, dacite - Pliocene, Pleistocene and Recent
13. Alluvium, swamp.

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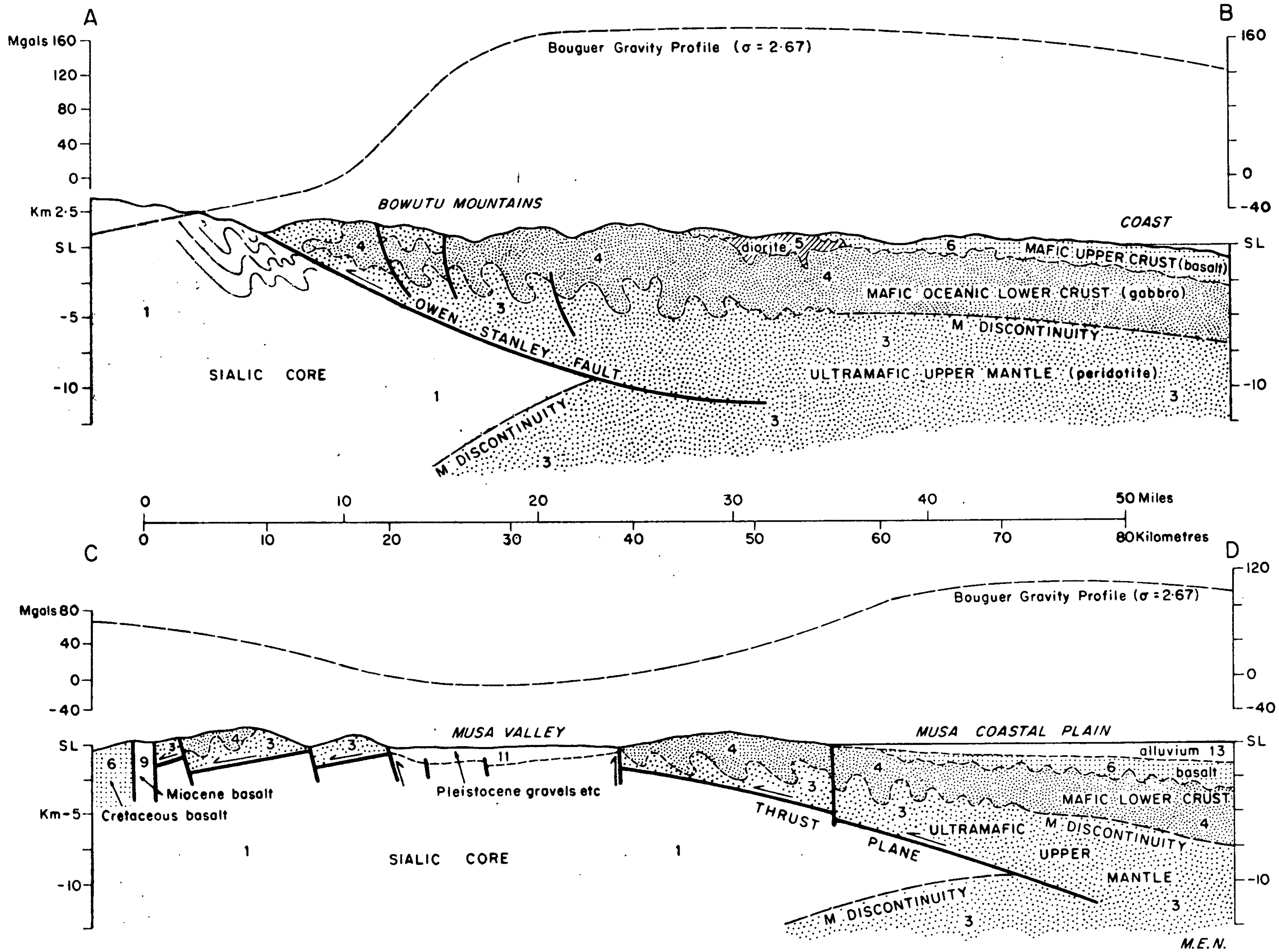
Fig. 2

PAPUAN ULTRAMAFIC BELT - SECTIONS



1. Owen Stanley Metamorphics
4. Mafic rocks (gabbro etc.)
6. Cretaceous basalt lavas
11. Domara Beds: Pleistocene gravels etc.

3. Ultramafic rocks
5. Diorite
9. Miocene basalt lavas
13. Alluvium