Southeastern Papua: Generation of thick crust in a tensional environment?

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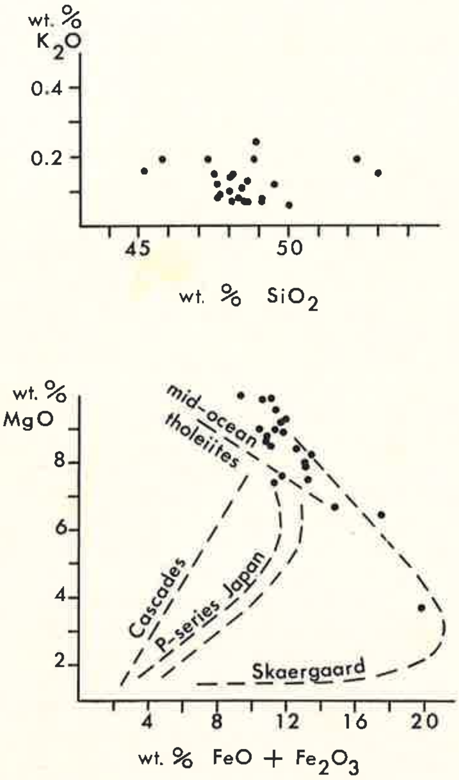

Figure 1. K_2O/SiO_2 and $MgO/(FeO+Fe_2O_3)$ plots for tholeiitic submarine basalt of southeastern Papua. On $MgO/(FeO+Fe_2O_3)$ plot, generalized relationships for Cascades (calc-alkalic), pigeonitic series of Japan ("island arc tholeiitic"), Skaergaard (tholeiitic), and mid-ocean tholeiite are shown (taken from Jakeš and Gill, 1971).

ABSTRACT

The extreme southeastern part of the Papuan peninsula is composed mainly of middle Eocene submarine basalt which resembles mid-ocean-ridge tholeiite. During middle Miocene time, the basaltic pile was intruded by potassic rocks, with which pronounced gravity and magnetic anomalies are associated. Although continental rocks have not been found in this area, geophysical data indicate that the crust is of near to normal continental thickness. The uplift of the basalt may be due to differentiation and expansion of the underlying mantle under a tensional regime, and the potassic rocks may be the surface expression of diapirs formed during that differentiation.

INTRODUCTION

The evolution of the extreme southeastern part of mainland Papua presents one of the more intriguing geologic problems of Papua New Guinea. Although the mountainous spine of most of the Papuan peninsula is made up of sialic rocks, and although sialic rocks reappear in the D'Entrecasteaux Islands to the north, outcrop on the mainland east of long. 149° E. is almost exclusively of Upper Cretaceous and middle Eocene tholeiitic basalt (less than 53 wt percent SiO_2) with minor contemporaneous intrusive masses of highly differentiated granophyre. In this paper we are concerned primarily with the Eocene rocks and younger intrusive rocks.

The distribution of the Upper Cretaceous basalt suggests that it formed the underthrust plate of the thrust zone in which the Papuan ultramafic belt (Davies, 1971) was emplaced. The basalt masses are variously metamorphosed from greenschist, with some development of high *P*/*T* mineral phases (glaucophane, aragonite, and rarely lawsonite) adjacent to the thrust zone, through prehnite-pumpellyite metabasalt to unmetamorphosed basalt in the southeast near their contact with Eocene basalt. Where it has been recognized in the field, the Cretaceous-Eocene contact is faulted (Smith and Davies, 1975).

The Eocene basaltic rocks are predominantly submarine lava flows with subordinate associated intrusive rocks and minor calcareous and tuffaceous sedimentary rocks; they have a present maximum exposed thickness of 2 to 3 km. In contrast to the Upper Cretaceous basalt, the Eocene rocks show no sign of metamorphism. The intercalated calcareous sedimentary rocks for the most part contain planktonic foraminifera; this fact and the lack of terrigenous or pyroclastic material in the associated sedimentary rocks suggest that the basalt was extruded on the deep-ocean floor. Evidence of a shallow-water environment has been found at only one locality, north of Milne Bay, where benthonic foraminifera occur in limestone interbedded with basalt. The microfaunas found in these rocks indicate late middle to early late Eocene age.

Although it has been implied that the tholeiitic basalt in southeastern Papua is "arc"-type tholeiite representing the initial stages of island-arc development (Jakeš and Gill, 1970), major- and trace-element data (Smith and Davies, 1975; Smith, unpub. data) show instead that the basalt masses in southeastern Papua are most closely comparable with the mid-ocean-ridge basalt and oceanic tholeiite of Engel and others (1965) and the abyssal tholeiitic series of Jakeš and Gill (1970). In particular, the trend of extreme iron enrichment, the very low K_2O content (Fig. 1), and the high values of Na_2O/K_2O (greater than 10) of the Papuan basalt masses are characteristic of the abyssal tholeiitic series but not of the island-arc tholeiitic series.

The Papuan ultramafic belt was probably emplaced by Eocene thrusting. Since that time, eastern Papua has been characterized by tensional tectonics involving rifting and block faulting and by strong vertical movements. Middle Miocene tension is suggested by the sediment-filled graben north of the D'Entrecasteaux Islands (Stoen and Garside, 1973) and by the probable opening of the Woodlark Basin through an angle of 5° about 20 m.y. ago (Luyendyk and others, 1973). Recent oceanographic work in the Coral Sea to the south of Papua (J. I. Ewing and others, 1970; M. Ewing and others, 1970; Gardner, 1970) has suggested that this basin was formed by early Cenozoic rifting. The deep-water Eocene tholeiitic basalt on the southeastern Papuan mainland presumably is related to the generation of new oceanic crust at the time of rifting of the Coral Sea Basin (see Davies and Smith, 1971).

The Eocene submarine basalt is intruded by potassic rocks comparable to rocks of Joplin's (1968) "Shoshonite Association" (Smith, 1972). Biotite-bearing pyroxenite, gabbro, monzonite, and syenite are associated in a number of small (4 to 36 km^2) stocks that crop out in the area southwest of Milne Bay. A dike swarm and other small intrusions crop out within an area of about 40 km^2 south of Goodenough Bay; the main rock types in this area are biotite gabbro, monzonite, syenite, and sanidine-melanite porphyry; biotite-pyroxenite inclusions are found in some of the more siliceous rocks. A small stock of monzonite crops out about 50 km to the west, on the southern flank of the ranges. Associated shoshonitic volcanic rocks have been mapped near the south coast of the peninsula.

Southeastern Papua emerged as a landmass during late Miocene time, and the subsequent history is one of autochthonous sedimentation accompanied by late Pliocene and Quaternary calc-alkalic volcanism (Davies and Smith, 1971).

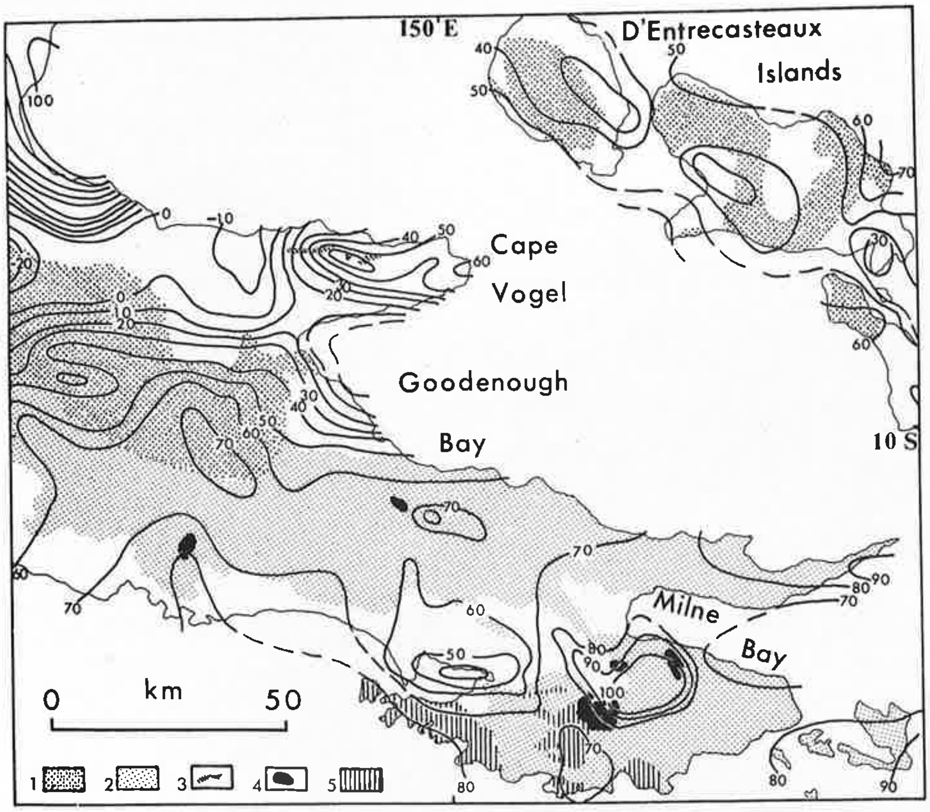

Figure 2. Southeastern Papua. Geology generalized from Davies and Smith (1971). Terrain-corrected Bouguer anomalies (contour interval 10 mgal) after Milsom (1973). 1, Cretaceous basalt and metabasalt; 2, Eocene basalt and related rocks; 3, Oligocene basalt; 4, middle Miocene intrusive rocks; 5, middle Miocene extrusive rocks; post-Miocene unshaded.

GEOPHYSICAL DATA

Information on crustal structure in southeastern Papua has been provided by gravity and magnetic surveys by the Australian Bureau of Mineral Resources. Gravity readings, taken at an average station spacing of about 10 km on all land areas, have been reduced to Bouguer anomalies and were corrected for variations in density of rocks above sea level and for the sometimes very large terrain effects (Fig. 2; Milsom, 1973). Aeromagnetic coverage (Fig. 3; Compagnie Générale de Géophysique, 1973) was obtained in two sections; coastal and offshore areas were flown at 2,440 m a.s.l. and mountainous regions at 4,570 m a.s.l. Terrain clearance was rarely less than 2,130 m. Line spacing varied but was generally 6.4 km east-west and 12.8 km north-south.

Steep gravity and magnetic slopes mark a major boundary trending westward at about 10° S. The elongate gravity low north of this gradient in the western part of the peninsula correlates well with surface exposures of sialic rocks (Milsom, 1973). Although sialic outcrops do not occur in the mainland area east of about long. 149° E., the eastern part of this gravity low, which terminates abruptly against a sharp local high on the Cape Vogel Peninsula, may indicate subsurface extension of the sialic belt. The abrupt termination and the existence of a complex gravity trough in the D'Entrecasteaux Islands to the north accord with the hypothesis (Davies and Ives, 1965) that the sialic crust has been displaced northward to these islands by strike-slip faulting. However, average Bouguer anomalies on the mainland south of the gradient are not suggestive of very thin (that is, oceanic) crust. Although a variety of crustal models can be postulated to fit the general field pattern, the data indicate the presence of crustal thicknesses of at least 25 km. Seismic refraction surveys showing the Moho deepening steadily northward from the center of the Coral Sea Basin (M. Ewing and others, 1970) support the hypothesis of relatively thick crust underlying the southeastern Papuan mainland.

In detail, gravity lows correlate with graben structures, and highs with middle Miocene intrusive rocks. The largest and most easterly high encompasses three distinct outcropping masses of these intrusive rocks near the southwest corner of the Milne Bay graben. Farther west, a smaller gravity anomaly is offset slightly from a small stock but is centered well within the surrounding zone of dike intrusion. A marked incursion in the gravity

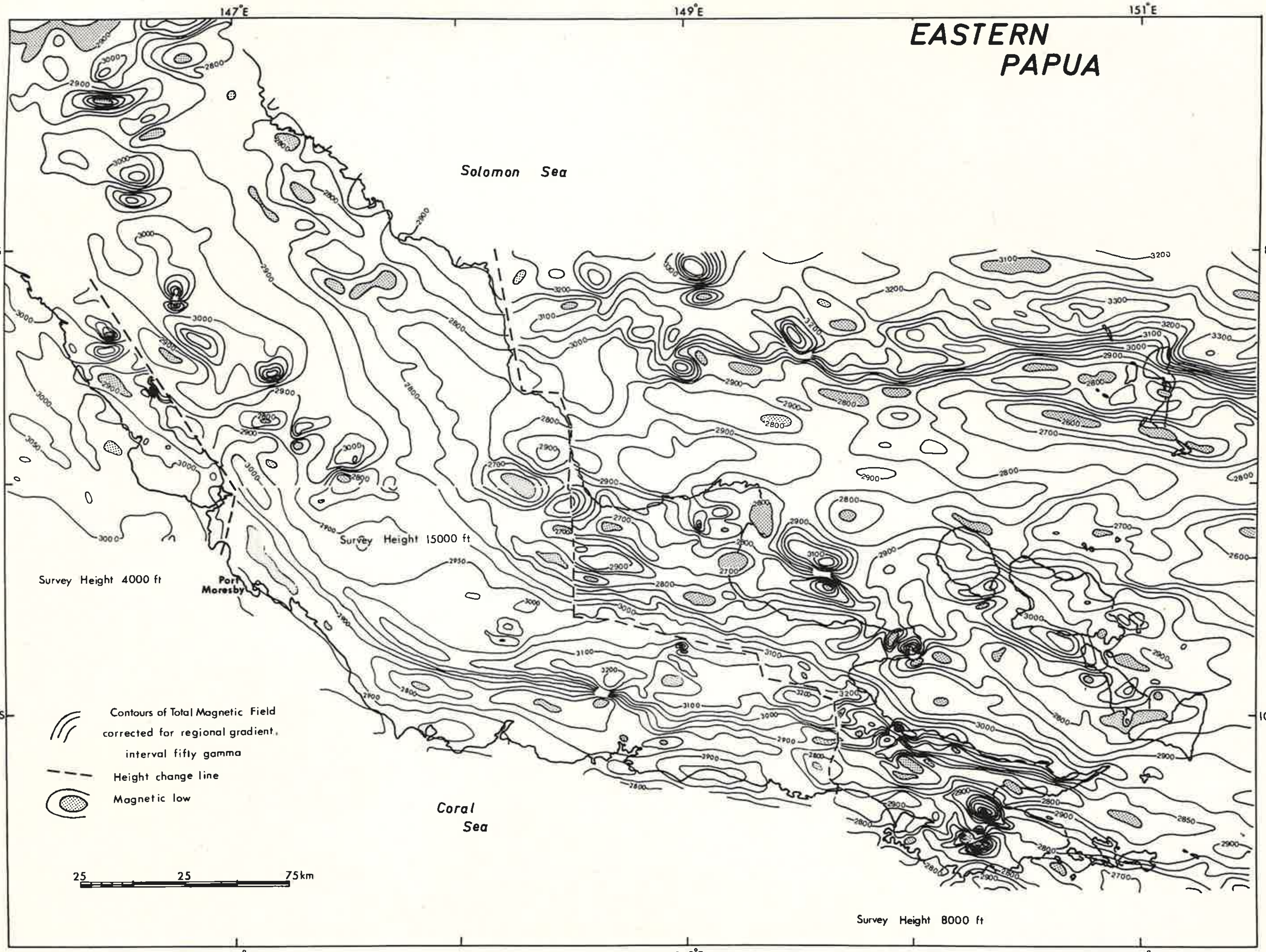

Figure 3. Aeromagnetic map of Papuan peninsula, from Compagnie Générale de Géophysique (1973).

contours near the south coast (which could, on the data available, be recontoured as a separate closure) corresponds to the isolated monzonite outcrop.

There are marked similarities between the gravity and magnetic maps. A strong magnetic gradient, with increasing intensity northward (which in the western part of the peninsula coincides with the southwestern margins of the exposed sialic rocks), approximately separates the Eocene basaltic terrane in the east from the rest of the peninsula. South of the gradient, anomalies are generally broad and of moderate amplitude, but complex, intense disturbances are associated with the intrusive rocks. This is true even of the most westerly of the shoshonitic outcrops (at about lat 10°10′ S., long 149°30′ E.), although the magnetic effects are not marked at the contour interval used in Figure 3. Because separation between detector and magnetic sources was always considerable, such intense anomalies imply very large rock masses with considerable extent in depth. The size and location of anomalies on the magnetic map thus indicates that the exposed intrusive rocks are the upper parts of large intrusive masses.

DISCUSSION

It is logical to associate the extrusion of the typically oceanic tholeiite with the opening of the Coral Sea during Eocene time. The apparent presence of thick crust beneath such rocks then requires explanation. Although they could have been extruded over a crustal block at the margins of the developing ocean, this is a pattern that has not been observed elsewhere (Falvey, 1974). Alternatively, the basalt could represent a fragment of oceanic crust that has been thrust into its present position. Despite recent criticism (Rod, 1974), geologic evidence for thrust emplacement of Cretaceous basalt, gabbro, and peridotite in the Papuan ultramafic belt farther west appears incontestable (for example, Davies, 1971; Smith and Davies, 1975). On the other hand, the Eocene basalt masses were extruded after the early Eocene thrusting, during which the Papuan ultramafic belt was emplaced; unless a second episode of thrusting (at a time of rifting associated with the opening of the Coral Sea Basin) is postulated, we must look for an alternative way of producing the thickened crust in southeastern Papua.

We suggest that crustal material may have been formed at least in part by mantle differentiation and diapirism in a middle Miocene tensional environment and that this has led to an effective thickening of the crust underlying the Eocene basalt masses. Although the outcrops of shoshonitic rocks are small in area, the associated geophysical anomalies suggest that they are merely the tips of much larger bodies that make up a significant proportion of the underlying crust. It is unlikely that these bodies are shoshonitic in overall composition, but the observed geophysical anomalies may represent diapirs of hydrated mantle that have undergone small amounts of adiabatic melting during ascent to produce shoshonitic magma.

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