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SEISMICITY AND LATE CENOZOIC VOLCANISM IN PARTS OF PAPUA–NEW GUINEA*

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ABSTRACT

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Late Cenozoic volcanoes in the New Guinea Highlands and eastern Papua are of calc-alkaline and shoshonitic compositions, and those along the north coast of New Britain and islands to the west consist of tholeiitic basalt, andesite, dacite, and rhyolite. From an examination of the distribution of earthquake foci for the period 1958 to 1970, we are unable to relate the composition and distribution of the volcanoes to the presence of a southward-dipping Benioff zone, as proposed by Jakeš and White (1969). A well-defined Benioff zone dips northwards beneath New Britain island, but seismicity in the New Guinea Highlands and eastern Papua is restricted to relatively few events, mostly less than 70 km deep, which do not define any dipping seismic zones.

INTRODUCTION

Using the seismic data of Brooks (1965) and preliminary petrological results, Jakeš and White (1969) proposed that the compositions of Late Cenozoic lavas in Papua-New Guinea (excluding Bougainville Island and islands north and east of the Bismarck Sea; Fig. 1) could be related to the depth to an underlying seismic or Benioff zone. Jakeš and White believed that a Benioff zone dips southwards beneath New Britain and the north New Guinea mainland, and that tholeiitic, calc-alkaline, and shoshonitic rocks, which overlie the Benioff zone, occupy successive zones to the south. They compared this magmatic zonation to that found in other circum-Pacific island arc areas, in which the more alkaline rocks overlie the deeper parts of the Benioff zones (see for example, Kuno, 1966, and Dickinson and Hatherton, 1967). Jakeš and White also proposed that successive eruption of tholeiitic, calc-alkaline, and shoshonitic lavas takes place in island-arc environments (this sequence of eruption has since been demonstrated on Viti Levu Island, Fiji; Gill, 1970).

We are currently involved in geological and petrological investigations of three areas of Quaternary volcanism in Papua–New Guinea (Fig. 1). These are, the volcanic arc along

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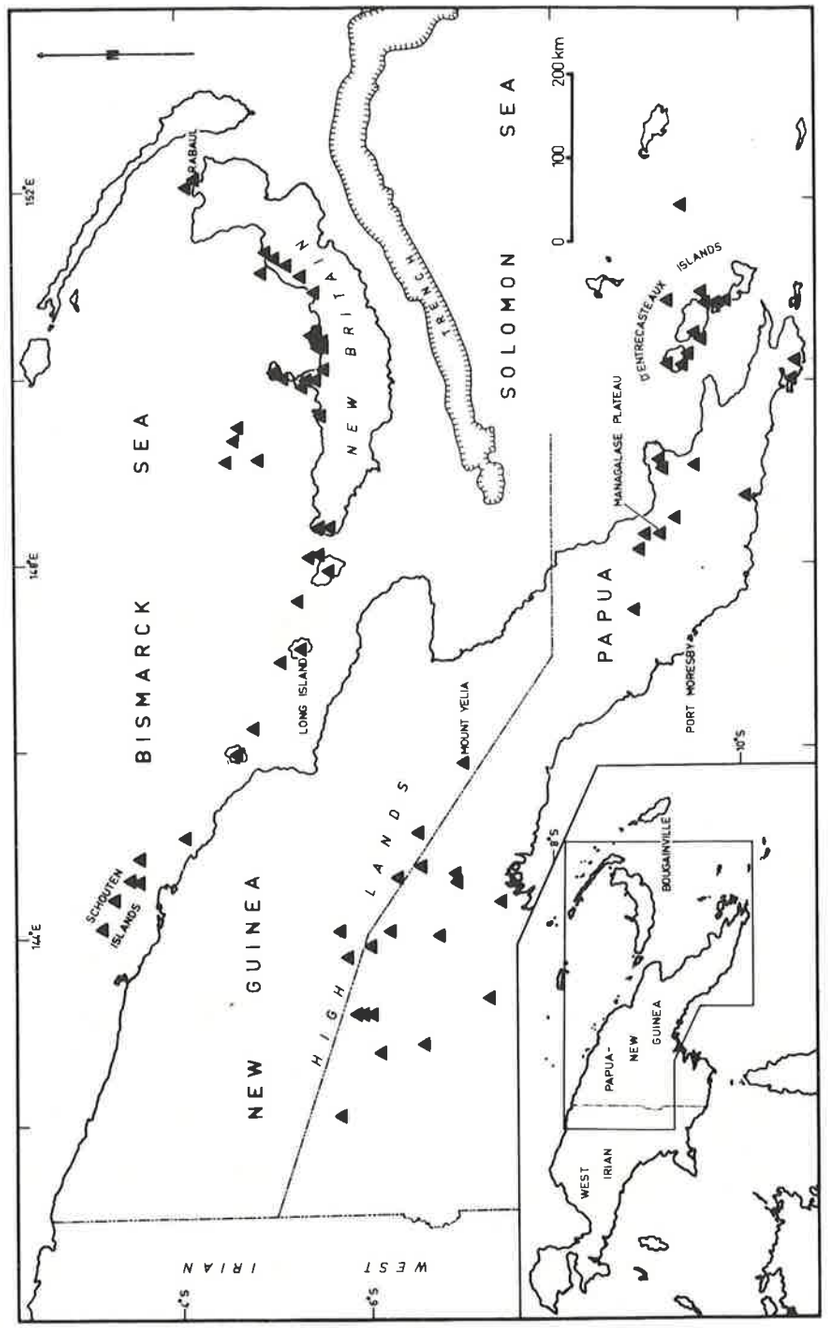


Fig. 1. Distribution of principal Late Cenozoic volcanoes (triangles) discussed in this paper.

the north coast of New Britain and islands off the north coast of mainland New Guinea (R.W. Johnson), and the volcanoes of the New Guinea Highlands (D.E. Mackenzie) and eastern Papua (I.E. Smith). Our petrological data, and examination of the distribution of recent earthquake foci in the region, lead us to present some amendments to the conclusions of Jakeš and White.

PETROLOGY

The Quaternary volcanic arc off the north coast of New Guinea and in New Britain extends for about 1,000 km from the Schouten Islands in the west to Rabaul in the east (Fig. 1). Lavas include tholeiitic basalt (with high alumina contents), large volumes of andesite (with moderate ion-enrichment), dacite, and rare rhyolite. These silica-saturated rocks are chemically similar to those found in other island arc areas in the western and southwestern Pacific (for example, the "hypersthenic series" of Japan; Kuno, 1950, 1966).

Pliocene to Recent rocks of shoshonitic and calc-alkaline compositions are found in both eastern Papua and the New Guinea Highlands. The volcanoes of eastern Papua and the Highlands form two separate groups (Fig. 1), but there are known to be scattered occurrences of Late Cenozoic volcanic rocks between the two.

In eastern Papua, calc-alkaline rocks form a zone of volcanoes extending eastward along the north coast (Taylor, 1958; Ruxton, 1966; Jakeš and Smith, 1970) to the D'Entrecasteaux Islands (Fig. 1). Shoshonitic lavas interfinger with calc-alkaline lavas on the Managalase Plateau, and they are also present in two areas on the south coast of Papua (Smith et al., in preparation). Thus, in eastern Papua, both volcanic suites are the same age, but there is a broad zonation with calc-alkaline lavas to the north and shoshonite lavas to the south. The available data for the New Guinea Highlands volcanoes do not indicate any separation of calc-alkaline and shoshonite lava types in space or time.

SEISMICITY

In a recent study of seismicity in the New Guinea–Solomon Islands region, Denham (1969) plotted the epicentres of earthquakes of magnitude 5 or greater, and recorded by more than 15 stations, for the period 1958–1966. He showed a concentration of epicentres along the northern part of West Irian and New Guinea and in New Britain, and a deficiency of epicentres in the New Guinea Highlands and eastern Papua. Denham also presented seismic cross-sections across the north New Guinea coast and New Britain; these showed a northward-dipping zone of earthquake foci beneath New Britain, but no well-defined seismic zone beneath mainland New Guinea.

One of us (R.W.J.) has re-examined in detail the distribution of earthquake epicentres associated with the volcanic arc along the north coast of New Guinea and in New Britain. Fig. 2 is a map of these epicentres, which are of earthquakes of magnitude 4.5 or greater, and recorded by 10 or more stations for the period 1958–1969. Fig. 3 shows seismic cross-sections through five segments of the volcanic arc. These data illustrate in greater detail the general seismic features identified by Denham (1969). Furthermore, they show that the volcanic arc can be divided into two sections, each with a distinctive seismic regime:

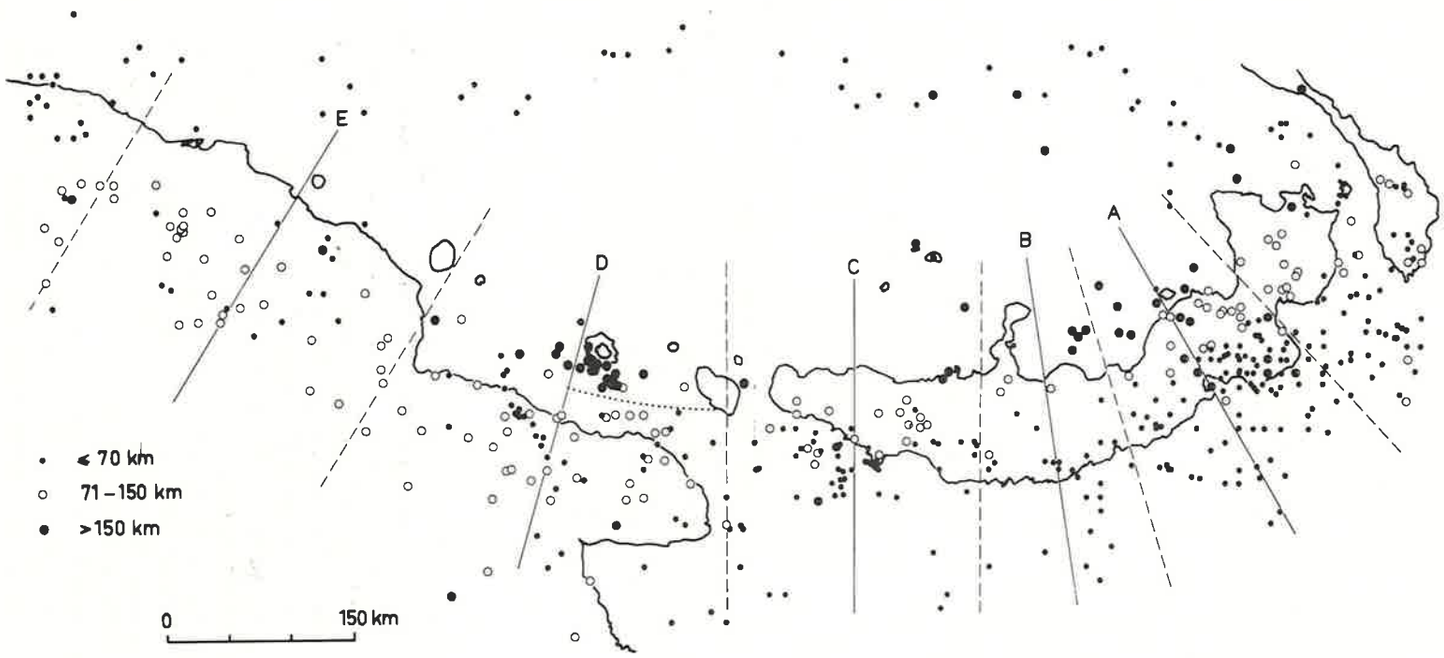
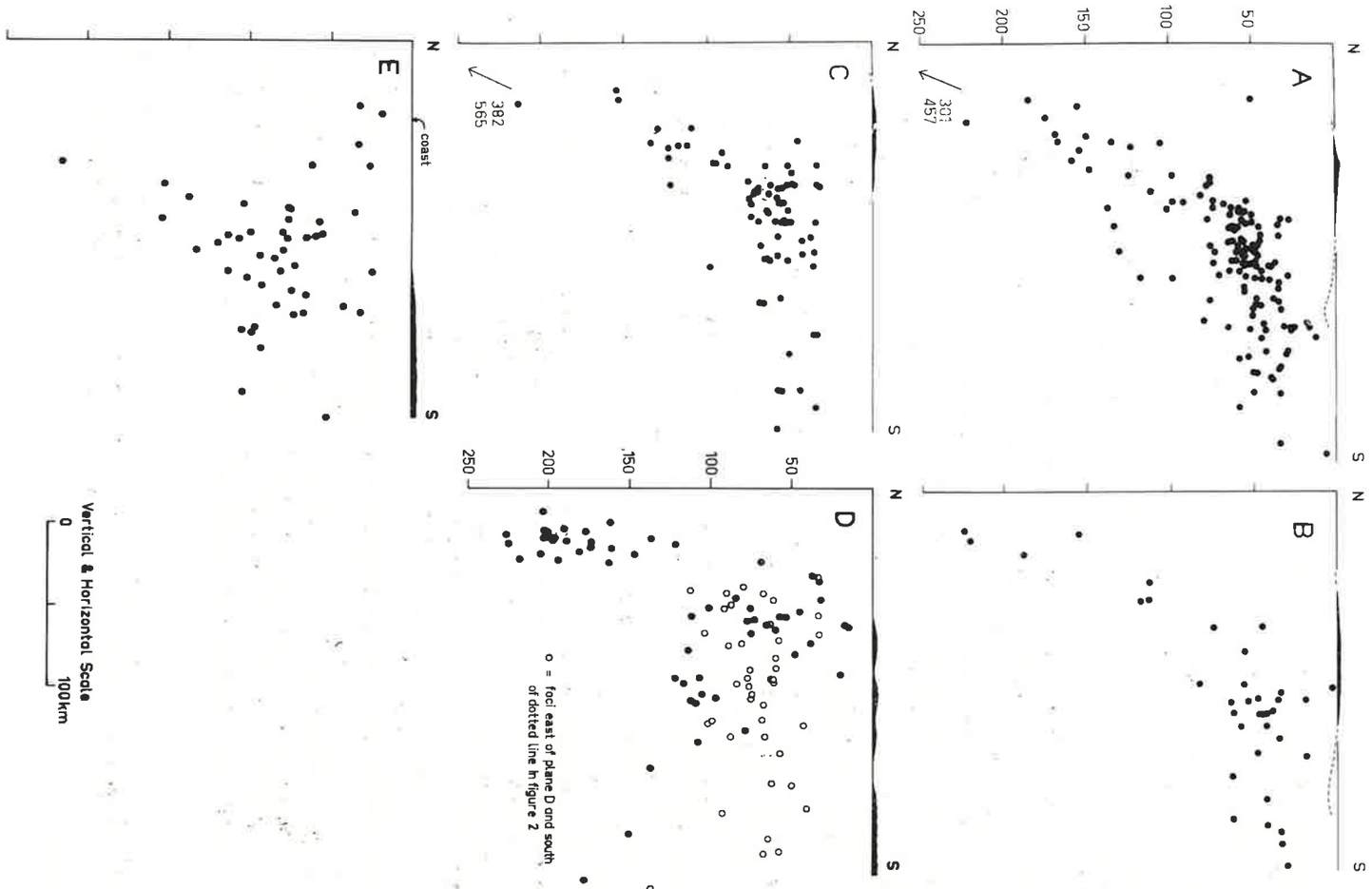


Fig. 2. Epicentres for earthquakes of magnitude 4.5 and over, and recorded by 10 or more stations, during the period April, 1958, to June, 1969. The volcanic arc north of mainland New Guinea and in New Britain is divided into five sectors whose limits are shown by the dashed lines. The solid lines, A to E, are traces of vertical planes onto which foci for each sector were projected to give the seismic cross-sections in Fig. 3 and 4. Note also the seismic lineament across the Bismarck Sea identified by Denham (1969).



these are, New Britain island, and the section between the western end of New Britain and the Schouten Islands.

Each of the three seismic cross-sections beneath New Britain (Fig. 3A, B and C) shows a well-defined Benioff zone that dips northwards at about 70° beneath the island, and underlies the volcanoes of the north coast at depths between 100 and 250 km. Earthquake foci down to 70 km define a horizontal zone south of New Britain, and where this zone intersects the northward-dipping zone there is a concentration of earthquake foci. A submarine trench of the type commonly associated with Benioff zones is present on the south side of New Britain.

Fig. 2 shows that, in contrast to New Britain, shallow earthquakes (70 km deep or less) beneath the northern part of mainland New Guinea are much less common than those of intermediate depth (71–150 km deep). Moreover, they do not concentrate in any obvious planar seismic zone, but appear instead to have a more or less scattered distribution (Fig. 3D and E). In cross-section D there is a tendency for deeper earthquakes beneath mainland New Guinea to be more common in the south, and for foci east of plane D to be shallower than those to the west (Fig. 2, 3D and E), but as in cross-section E, no Benioff zone is defined. There is no submarine trench associated with the volcanic arc along the north coast of mainland New Guinea.

Cross-section D also reveals a zone of deep-focus earthquakes beneath Long Island (Fig. 1, 3D and E). These foci appear to be contained in a vertical "seismic cylinder", separated from both the intermediate-focus earthquakes of the mainland and the deep-focus earthquakes of the New Britain Benioff zone. It is possible, however, that this "separation" is only an apparent feature, due merely to a lack of recorded deep-focus seismic events in this area during the 1958–1969 period. If this is so, then the deep foci beneath Long Island could be interpreted as a steeper, western extension of the deep part of the New Britain Benioff zone.

The most recent seismic data available to us show there have been only ten earthquakes of magnitude 4 and over in the area of the New Guinea Highlands volcanoes during the period 1958–1970. Of these events, only two, in the vicinity of Mount Yelia (a calc alkaline volcano at the eastern end of the group; Fig. 1), were deeper than 42 km. These data, combined with those from the north coast of New Guinea (Fig. 2, 3D and E) indicate that no dipping seismic zone is present below the Highlands volcanoes.

Seismicity in eastern Papua between 1958 and 1970 has also been confined to relatively few, shallow, low to moderate magnitude earthquakes (mostly less than 70 km deep, and less than magnitude 6). Epicentres fall mainly within the western part of the easterly-trending seismic zone across the southern Solomon Sea noted by Denham (1969). The data indicate that no seismic zone dips beneath eastern Papua.

Although a Benioff zone does not appear to be present beneath either the New Guinea Highlands or eastern Papua, it should be emphasized that the earthquake foci considered

Fig. 3. A, B and C are seismic cross-sections for New Britain island (compare with Fig. 2). In A and B the submarine trench south of the island is shown by the dotted lines. The depths in kilometers of four foci deeper than 250 km are shown in A, and C. D and E are seismic cross-sections for the New Guinea coast section.

here are restricted to the 1958–1970 period, and that we cannot eliminate the possibility of Benioff zones having been present in these areas during the earlier part of the Late Cenozoic.

CONCLUSIONS

(1) Based on the distribution of earthquakes between 1958 and 1970, we conclude that: (a) a Benioff zone dips northwards at 70° beneath New Britain (see also Denham, 1969); (b) earthquake foci beneath the north part of mainland New Guinea are mostly 71 to 150 km deep; they show a scattered distribution and define no obvious southward-dipping seismic zone; (c) seismicity in the New Guinea Highlands and eastern Papua is restricted to relatively few events, mainly less than 70 km deep; there is no evidence of any dipping seismic zones.

(2) We are unable to recognise separate zones of calc-alkaline and shoshonite rocks in the New Guinea Highlands, but in eastern Papua shoshonites are present south of calc-alkaline lavas.

(3) In Papua–New Guinea, each of the various lava suites in the areas with which we are concerned ranges at least throughout the Quaternary. We are therefore unable to demonstrate any simple evolutionary scheme (cf. Gill, 1970) for this part of Papua–New Guinea involving the successive eruption of different lava suites.

(4) In some circum-Pacific volcanic arcs, correlations have been made between the composition of lavas and the depth to the Benioff zone beneath the volcanoes. In mainland Papua-New Guinea and New Britain there appears to be no simple relationship between the distribution and composition of the volcanoes, and the distribution of earthquake foci. However, the volcanic arc off the north coast of New Guinea and in New Britain can be divided into two parts with contrasting seismic regimes, and it is possible that petrological work still in progress may establish significant compositional differences between lavas in the western part of the arc, and those in the eastern part.

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