Papers

Part 5

Plate Boundary Evolution in the New Guinea Region

VOLCANIC AND PLATE TECTONIC EVOLUTION OF CENTRAL PAPUA NEW GUINEA

D.E. Mackenzie

Department of Geology, University of Melbourne, Vic.

Volcanic activity in central Papua New Guinea began in the Upper Triassic with submarine and terrestrial eruption of andesitic and dacitic lavas on and adjacent to the north-east corner of the Palaeozoic Australian continental crust. Minor basaltic to rhyolitic eruptions took place during the Jurassic in the same general area. During the Cretaceous, volcanic activity increased in intensity and distribution, spreading to the north and west (Fig.1), and produced mainly andesitic lavas, both subaerial and submarine. The increase in activity in the Cretaceous, may correlate with the beginning of spreading in the Pacific basin to the northeast (Packham, 1973), and could therefore have been a result of the first subduction in the area. There is no evidence to link the earlier volcanism with subduction, although it took place on or near a plate boundary.

A major shift in the focus of volcanic activity, correlating with the split of Australia from Antarctica about 55 m.y. ago (Weissel & Hayes, 1971), took place in the Palaeocene – early Eocene. Volcanism ceased in "mainland" Papua/New Guinea and commenced in the ancestral Torricelli-Finisterre-New Britain chain some distance to the northeast, where it continued until late Oligocene-early Miocene (Jaques, 1975). This volcanism was possibly related to a southward-dipping subduction zone (cf. Packham, 1973), and perhaps later also to a north-eastward-dipping zone (Jaques, 1975).

Volcanism recommenced on the mainland in the middle Miocene (12-15m.y.b.p.-Page & McDougall, 1971), with major activity occurring along a discontinuous 1000km-long belt stretching from near the present-day Irian Jaya border to the Port Moresby area. Most of the volcanism was calc-alkaline basaltic and andesitic, but at the northeastern corner of the Australian continental crust, adjacent to the ancestral Finisterre block (k-Fig.2), highly potassic under-saturated basalts were also erupted. Such volcanic rocks are at present restricted to island arc environments where they are generally accepted to be genetically linked to subduction zones (e.g. Nicholls, 1974). Geological evidence (e.g. Bain *et al.,*1975) indicates that subduction beneath central Papua New Guinea must have been from the northeast. It is postulated that the southwestern edge of a marginal sea floor between the Eocene-early Miocene arc and the Australia-New Guinea crustal block was underthrust to the southwest, beginning in the early Miocene. The beginning of this subduction would have coincided with the cessation of subduction and volcanism and the beginning of uplift in the Finisterre block (Jaques, 1975). If southwestward subduction began, say, 20m.y. ago, and assuming a very conservative convergence rate of 10cm/yr*, 200-500km of oceanic lithosphere could easily have been subducted before initiation of volcanism at 15m.y. before present. Collision between the mainland and Finisterre blocks could have occurred at the end of the lower Miocene, just **before** volcanism began on the mainland. This timing agrees well with the known geological data (Bain *et al.*, 1970; Page, 1975; Jaques, 1975).

After the middle Miocene volcanism there was a long break until volcanism began in the early Pleistocene and produced volcanoes scattered over a large area of the central mainland, but all in an area directly southwest of and adjacent to the Finisterre block (Fig.2). All except two of the volcanic centres, which show some hydrothermal and solfataric activity, are extinct, and the crust beneath them is almost aseismic. The seismicity is mainly in the form of small magnitude crustal events, with some deeper shocks indicating limited subduction beneath areas near either end of the Finisterre block (Denham, 1975). The crust beneath the volcanoes consists of about 25km of Palaeozoic granitic and metamorphic rocks overlain by about 10km of Mesozoic and Tertiary sediments. Northeast of the volcanoes the 35km thickness (St. John, 1970) is maintained, but is made up of tectonically thickened Mesozoic and Tertiary sedimentary, volcanic, and intrustive igneous rocks.

The Quaternary volcanoes are made up generally of porphyritic basalt (80 percent by volume) overlain by porphyritic andesite (about 20 percent). Chemical variation in the volcanoes from northeast to southwest can be summarized as follows:

1. Si (and Silica saturation), K, K/Na, Ba, and Pb decrease.
2. Rb,/Sr, La, and Ce generally decrease.
3. Ti, and to a less marked degree, Ca and Mg, increase.
4. Nb, Y, and Zr generally increase.
5. Sr isotope ratios increase.

The chemistry and chemical variations in the Quaternary volcanic rocks indicate an origin from above a subducted

* The actual rate was probably much higher, perhaps comparable to modern day rates, which have been estimated to be as high as 19cm/yr (Denham, 1975).

slab of oceanic lithosphere dipping to the southwest. The upper, northeasternmost parts of the slab which are in effect "fresh" will release greater amounts of water, K, Rb, Ba, and other incompatible elements into the mantle than the lower, more southwesterly parts that have already passed through higher parts of the mantle. This initial induced variation may produce one or both of two side effects: addition of increasing amounts of water to the mantle towards the northeast may progressively raise the top of low velocity zone (L.V.Z.) (Green, 1973), and the interstitial liquid may become more siliceous (Green, 1973; Nicholls, 1974), as well as being more enriched in K, etc.

FIGURE 1.

Distribution of volcanism in the Mesozoic. Heavy broken line is edge of Palaeozoic continental crust. Light broken lines are limits of sedimentation.

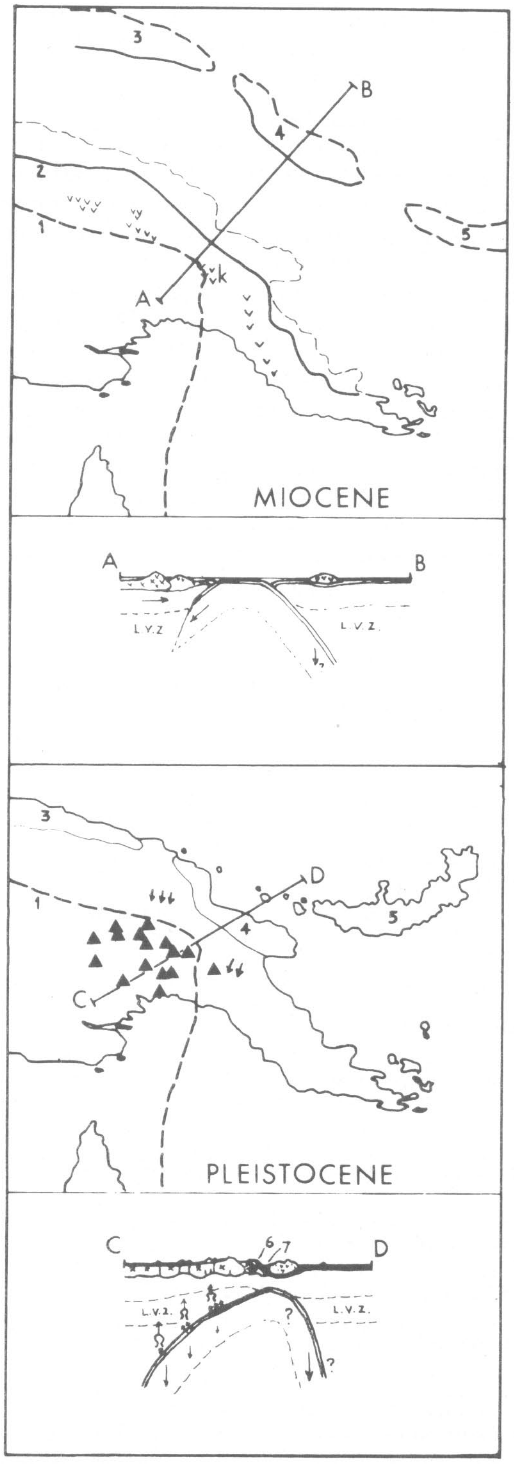

FIGURE 2.

Speculative early Miocene and Pleistocene reconstructions. 1 — edge of Palaeozoic crust. 2 — edge of Australia-New Guinea continental mass in Miocene. 3 — Torricelli volcanic block. 4 — Finisterre volcanic block. 5 — New Britain volcanic block. Miocene diagram: "V" pattern shows future (middle Miocene) volcanism; k — high-K rocks. Pleistocene diagram: triangles represent principle volcanic centres; arrows indicate areas of limited subduction; in section, 6—overthrust oceanic crust & mantle, 7—fault zone.

Addition of this volatile material to the mantle will cause instability and partial melting, with subsequent formation of rising diapirs(e.g . Green, 1972, 1973; Nicholls, 1974), the diapirs reflecting, and probably accentuating chemical variations in the parent mantle. Rise of the diapirs may be slowed by sinking of the slab, perhaps more so to the southwest where lower parts of the slab would sink more rapidly. This would be a delaying factor, and would also make the more southwesterly diapirs more likely to produce alkaline magmas by holding them at greater depths.

Large-scale crustal warping and uplift in the late Pliocene-earliest Pleistocene, centred on the northeastern part of the area of the volcanoes (Jenkins, 1974), could have triggered off large-scale adiabatic melting in the rising diapirs. If magma segregation occurred above the hornblende breakdown limit that is, the top of the top of the low velocity zone, the presence of hornblende in the residual phase could produce further enrichment in K relative to Na (Green, 1972). Magmas with the chemical variations inherited from the mantle below would then rise to the base of the crust, the thick, competent nature of which would resist their upward progress. Crystallization and crystal fractionation could then take place. Some basaltic magmas have escaped almost directly to the surface, probably **via** major fracture zones (Jenkins, 1974), while some remained to produce the andesites by removal of various amounts of phenocrystic olivine, pyroxene, probably amphibole (cf, Nicholls, 1974), and possibly biotite and plagioclase.

* The petrography, chemistry, and origin of the Quaternary volcanics will be discussed more fully by Mackenzie (in prep.).

References

BAIN, J.H.C., MACKENZIE, D.E., and RYBURN, R.J., 1970: Geology of the Kubor Anticline, central highlands of Papua New Guinea. *Aust. Bur. Mineral Resour. Rec.* 1970/79 (unpubl.); also 1975: *B.M.R. Aust. Bull.* (in press).

DENHAM, D., 1975: Distribution of underthrust lithospheric slabs and focal mechanisms – Papua New Guinea and Solomon Islands region. This volume.

GREEN, D.H., 1972: Magmatic activity as the major process in the chemical evolution of the Earth's crust and mantle. *Tectonophysics* 13: 47-71.

GREEN, D.H., 1973: Experimental melting studies on a model upper mantle composition at high pressure under water-saturated and water-undersaturated conditions. *Earth Planet. Sci. Letters* 19:37-53.

JAQUES, A.L., 1975: High-potash island arc volcanics of the Finisterre and Adelbert Ranges and their tectonic significance. This volume.

JENKINS, D.A.L., 1974: Detachment tectonics in western Papua New Guinea. *Bull. Geol. Soc. Amer.* 85: 533-48.

MACKENZIE, D.E., in prep: Origin of high-K and transitional alkaline volcanic rocks of central Papua New Guinea.

NICHOLLS, I.A., 1974: Liquids in equilibrium with peridotitic mineral assemblages at high water pressures. *Contr. Mineral. Petrol.* 45: 289-316.

PACKHAM, G.H. 1973: A speculative history of the southwest Pacific. *In* P.J. Coleman (Ed.) *The Western Pacific: Island Arcs; Marginal Seas; Geochemistry,* Univ. W. Australia Press, Perth:369-388.

PAGE, R.W., 1975: The geochronology of igneous and metamorphic rocks in the New Guinea region. *Aust. Bur. Mineral Resour. Bull.*

PAGE, R.W., and McDOUGALL, I., 1971: Potassium-argon dating of the Tertiary f_{1-2} stage in New Guinea and its bearing on the Geological time-scale. *Amer. J. Sci.* 269: 321-42.

ST. JOHN, V.P., 1970: The gravity field and structure of Papua and New Guinea. *J. Aust. Pet. Expl. Assoc.* 10:41-55.

WEISSEL, J.K., and HAYES, D.E., 1971: Assymetric sea-floor spreading south of Australia. *Nature* 231:517-521.

SOUTHEASTERN PAPUA – EVOLUTION OF VOLCANISM ON A PLATE BOUNDARY

I.E. Smith

Department of Geology, Australian National University, Canberra, A.C.T.

Eastern Papua straddles a minor plate boundary between the India plate to the south and the Solomon Sea plate to the north (Johnson & Molnar, 1972). This boundary is defined by a zone of weak, shallow, seismicity (Denham, 1969) and is clearly not particularly active at the present time. Nevertheless there is ample geological evidence for intense tectonic activity and volcanism at various times during the Cenozoic.

Three major tectonic events can be recognised in the area.
1) – rifting open of the Coral Sea basin; previously thought to have been a late Eocene event (Gardner, 1970; Davies & Smith, 1971), recent DSDP data (Burns & others, 1973) suggests that this took place during the early Eocene.
2) – overthrusting (obduction) of a segment of oceanic crust and upper mantle (the Papuan ultramafic belt, Davies (1971)) onto a dismembered sedimentary trough formerly adjacent to the Australian continental block. This event probably took place in late Eocene – early Oligocene times based on correlation with comparable tectonic events in northern New Guinea (Dow 1973) and evidence of folding in Eocene sediments in the Coral Sea basin (Burns & others, 1973).
3) – rapid uplift and block faulting; this was probably due at least in part to the bouyancy of sailic sediments thrust under the oceanic slab which were metamorphosed and rose isostatically to form the metamorphic core of the Papuan peninsula and some of the offshore islands. Uplift was accompanied in the late Tertiary and Quaternary by rifting and fragmentation of the emerging land mass. In southeastern Papua (east of about 148° 30′ E. longitude) and in the offshore islands, distinctive episodes of volcanic episodes are recognised.

The oldest volcanic rocks in southeastern Papua are slightly metamorphosed Upper Cretaceous submarine basalts of oceanic tholeiite type, which have been overthrust by the Papuan ultramafic belt and which apparently represent old sea floor on the India plate north of the Australian continental block prior to late Eocene – early Oligocene obduction. Similar, but unaltered, submarine basalts of mid-Eocene age make up the eastern tip of the Papuan peninsula. The exposed thickness of these basalts is of the order of 3 km and their chemical composition is clearly comparable to that of oceanic tholeiitic basalts. It has been suggested that these basalts represent new oceanic crust generated when the Coral Sea basin opened (eg Davies & Smith, 1971); however, unless the basin opened asymetrically these basalts are too young to have been erupted at that time and it seems likely that they were associated with a short-lived spreading episode along the northern margin of the newly formed Coral Sea basin.

Uplift of the volcanic basement in southeast Papua commenced during the late Oligocene. Volcanic and intrusive activity which occured during the early stages of uplift was high-potassium (shoshonitic) in character. This type of volcanism has generally been associated with the late stages in development of highly evolved island areas (eg Jakeš & White 1969);