The varied calcalkaline volcanic suite of Lower Miocene age argues strongly for subduction of oceanic lithosphere east of the Northland coast at this time. Although Packham and Terrill (in press) in their study of the South Fiji Basin, failed to find evidence of underthrusting in this region perhaps the deformed sediments of the Northland Marginal Plateau are younger than they anticipated and the remains of the subduction zone lie buried beneath these. The origin of this plateau might be related to isostatic uplift of sediment carried into the inferred trench complex; the comparative modest uplift resulting from the small volume of material that accumulated in this short-lived subduction zone.

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EVOLUTION OF THE INDIA-PACIFIC PLATE BOUNDARY IN NORTH ISLAND, NEW ZEALAND

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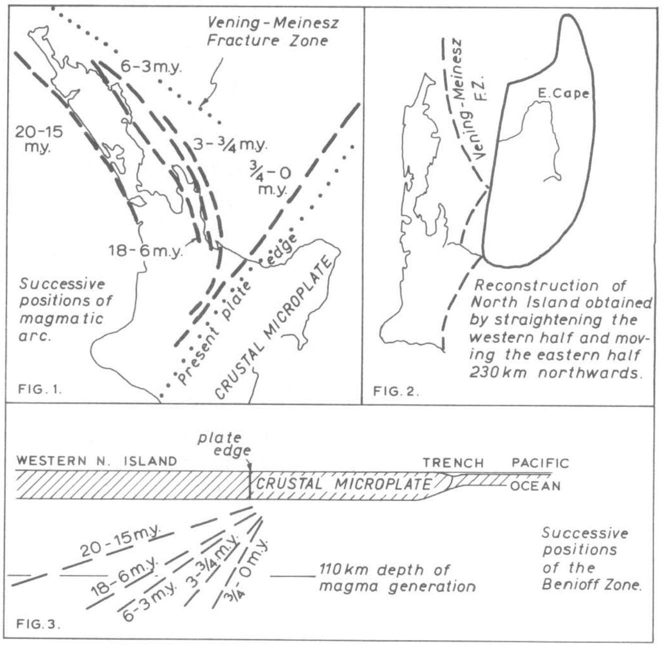
The plate boundary is first clearly identifiable on land in New Zealand from tectonic activity and arc magmatism, at about 20 m.y.b.p. (this date is poorly controlled, and lies in the interval 24 to 19 m.y.). Subsequent evolution of the plate boundary is inferred from the history of the New Zealand magmatic arc, which migrated eastwards to yield a succession of five geographically separated volcanic arcs (Fig. 1). Volcanism began with an initial 'oceanic' phase of basic/intermediate activity erupting through a substantial graben (20-15 m.y.). It then evolved to 'continental' phases erupting through basement horst; these eruptions were initially andesitic/dacitic (18 to 6 m.y.) and later rhyolitic/ignimbritic/dacitic/andesitic/basaltic (6 m.y. to 0). The last phase has been accompanied by abundant mineralization. Sporadic, behind-arc volcanic activity, from 16 m.y.b.p., has been of two types: high-K andesites in the south, and basalts in the north.

Evolution of the plate boundary is deduced from the history of the magmatic arc using the following assumptions: 1) Configuration of the Benioff zone may be deduced by analysis of the K_2O versus distance relationship (Hatherton and Dickinson, 1969). 2) The magmatic arc in the North Island has always been at the southern limit of a South-west Pacific arc, as at present. 3) The 70° angle between the active Tonga-Kermadec-Taupo volcanic arc and the older North Island magmatic arcs (Fig. 1) therefore resulted from anticlockwise bending of the western half of North Island. 4) The 'effective' plate boundary has been an Alpine-Wairau type transform fault which extended from the South Island through the centre of the North Island. 5) The apparent southerly migration of volcanism (Fig. 1) resulted from dextral transform movement between eastern and western halves of the North Island.

North Island east of the active magmatic arc is at present being deformed by dextral shearing; it lies above Pacific Plate lithosphere, which passes beneath it before turning down a steep Benioff zone beneath the arc. Reconstruction of the North Island, by removing the anticlockwise bending and reversing the dextral displacement of the wester half (Fig. 2), indicates that the eastern half has been similarly placed with respect to the Benioff (subduction) zone throughout the Upper Cenozoic. The eastern half of North Island is accordingly interpreted as a crustal micro-plate which has been poised over a descending lithospheric slab and deformed by dextral shearing since about 20 m.y.b.p. A possible measure of the transform displacement between eastern and western halves of North Island may be given by the southerly migration of volcanism, assuming the southern limit of volcanism to have been determined by the same factors in the past as at present; this gives the following increments of movement totalling approximately 230 km; a) 20 to 6 m.y.,



30 km b) 6 to 4 m.y., 30 km c) 4 to 2 m.y. (taking into account unpublished dates of J.J. Stipp), 130 km d) 2 to 0 m.y., 40 km. The maximum phase of transform movement inferred between 4 and 2 m.y. does not coincide with the anticlockwise bending of western North Island, which is inferred from Fig. 1 to have taken place later than 1 m.y.b.p.

When the anticlockwise bending and dextral displacement of western North Island are reversed, a residue of eastwards m migration of the magmatic arc remains unexplained. This is ascribed to progressive steepening of the Benioff zone, from an initial 18° to 20° at 20 m.y. to the present 55° to 60° (Fig. 3). Twin active arcs between 18 and 15 m.y. can be explained by fracturing of the descending lithospheric slab to give two parallel zones of magma generation.

Prior to 20 m.y. there is little evidence of the plate boundary on land. Some Cretaceous/Lower Tertiary sediments in eastern North Island can be regarded as 'trench' sediments, but they are tectonically complex and there is no evidence of contemporaneous magmatic arc. It is suggested that prior to 20 m.y. the active plate boundary may have been confined to the north of New Zealand; that at about 20 m.y. it propagated through New Zealand and south along the Macquarie Ridge (as reported by the Deep Sea Drilling Project Leg 29, Kennett, Houtz, *et al.*, 1974); and that the Hikurangi Trench may have propagated southwards in parallel with the magmatic arc at about this time.

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DETAILED STRUCTURE OF NORTH ISLAND SEISMIC ZONE

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Fifty four North Island N.Z. intermediate depth earthquakes which had high precision P arrivals at each of the North Island Seismograph stations CNZ, ECZ, GNZ, KRP, MNG, TNZ, WEL*, and whose epicentres lay inside the convex hull of these stations, were relocated using only this P data by the usual least squares method. By restricting the data in this way, the error in location of earthquakes in a small enough geographical group due to errors in the velocity model used should be a constant. Examination of the time residuals of the earthquakes in a group will reveal whether the group is small enough: if at each station the standard deviation of the residuals about the mean residual for that station is very much smaller than the average standard deviation for the group without station means removed, the assumption is valid.

When the 54 earthquakes were divided into eight rather arbitrary geographical groups not larger than about 40 km radius, a pooled estimate of the standard deviation of residuals about the group means was 0.39 seconds compared with typical standard errors for individual earthquakes of 0.8-1.4 seconds. Reading errors would have a standard deviation of the order of 0.2 seconds.

It was thus anticipated that the locations of these earthquakes would define the relative spatial distribution of North Island mantle earthquakes more tightly than any previous study and so it proved. A least squares plane fitted the hypocentres with a standard deviation of 5.6 km. A previous study in which Hamilton and Gale (1969) fitted median curves to hypocentres in sections through the zone found standard deviations greater than 13 km.

Using the plane of best fit as a reference plane a quadratic surface was fitted to the 49 earthquakes which were placed at depths greater than 118 km. The earthquakes above 118 km were omitted because of their obvious failure to fit the plane model. Examination of the distribution of hypocentres about the quadratic surface showed that these fell into two groups: a group of 39 to which a second quadratic surface was fitted with standard deviation perpendicular to the surface of 3.4 km, and the remaining ten which lay at a mean distance of 8.8 km from this second surface with a standard deviation of only 1.5 km. The standard deviation of 3.4 km of the main group agrees with a standard deviation of 3.5 km predicted by confidence ellipses using the time standard deviation of 0.39 seconds.

A model of the North Island intermediate zone emerges: hypocentres below about 118 km can be thought of as being distributed about two parallel slightly curved surfaces 9 km apart which become steeper with depth. Above 118 km the zone dips much less steeply. Although systematic errors in location may mean that for example the depth at which this flattening of the zone occurs is shallower than 118 km, the evidence for the thickness of the zone being about 9 km is very strong. Focal mechanism studies show no clear differences between earthquakes originating on either surface (Harris, 1974).

Engdahl (1973) has concluded that the thickness of the intermediate zone in the Aleutians is about 10 km. It has been suggested that these zones are the top and bottom of the oceanic crustal section of the down-going lithosphere (Oliver and Isacks, 1967; Wyss, 1973) or some colder region within the lithosphere (Engdahl, 1973).

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