Hawk Crag Breccia (distinctive red-weathered fan-glomerate) about 130 m.y. old.

The main feature of the reconstruction is the angle between SMA and its parallel feature (the pre-upper Cretaceous rock belts) and A24 and its parallel features (the Hawk Crag Breccia, and the 100 m.y. old igneous rocks). The discovery of the same angle between the two sets of features in Lesser Antarctica would support the reconstruction.

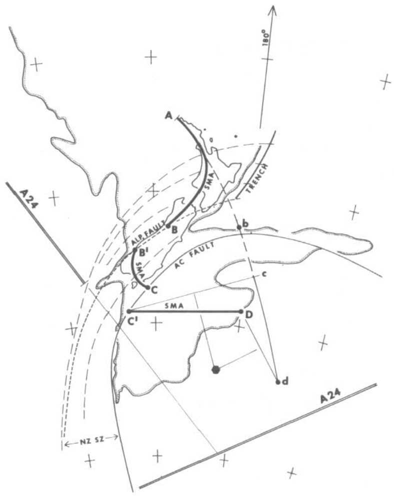

Figure 1
Map of NZ on conical projection with 10° grid, and standard parallels at 30° and 60°. A24 = Oceanic Magnetic Anomaly 24; SMA = Stokes Magnetic Anomaly; Abcd = inferred position of SMA 60 m.y.ago, north-west side assumed fixed; star = cumulative shiftpole for 60 m.y.; NZSZ = New Zealand Shear Zone India Pacific Plate Boundary.

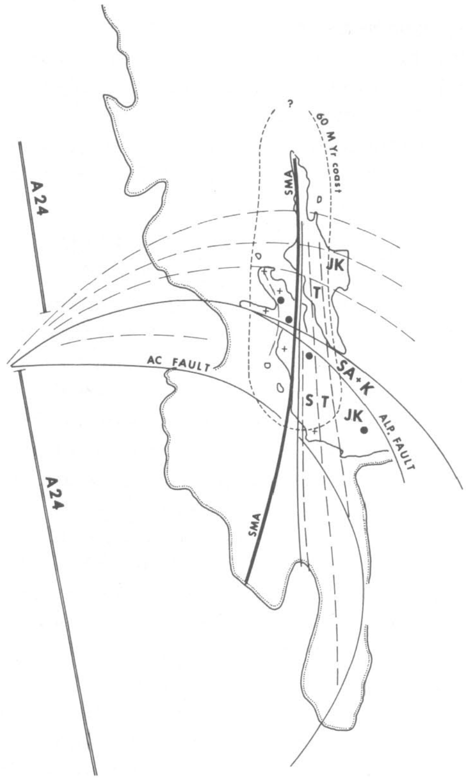

Figure 2
Map of NZ 60 m.y. ago based on Figure 1.
Rock belts left to right: O = Ordovician; SMA = Rotoroa igneous complex; Synclinal symbol = Marginal Syncline; S = schist; T = Triassic; JK = Jurassic and Cretaceous.
Other rocks; crosses = Hawk Crag Breccia; dots = 100 m.y. old basic igneous intrusives and volcanics.
SA + K = Gap to represent Southern Alps and Kaikoura Mountains.

MESOZOIC-MIDDLE TERTIARY TECTONIC DEVELOPMENT OF NORTHERN NEW ZEALAND

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Northland, that part of New Zealand north of the city of Auckland, is formed in large part from sedimentary rocks belonging to three successive sedimentary associations each of which is accompanied by distinctive igneous rocks. Deposition of the two earlier associations was terminated by brief but widespread periods of deformation at about 90 m.y. and 25 m.y. before present. Deposition in the youngest association ended some 15 m.y. ago, but no clear relationship between this event and deformation has been demonstrated. A brief outline of the rocks that formed during each depositional interval is outlined below and an attempt is made to construct a coherent tectonic history of Northland.

Interval 1 (prior to 90 m.y. before present)

A major break in the depositional record in Northland occurs between pre-Late Cretaceous rocks and younger strata. This break is a prominent metamorphic and structural discontinuity, a manifestation of the Rangitata Orogeny. South of 35°S latitude the older rocks are indurated sandstone and siltstone and accompanying limestone, chert and basalt, from which Permian and Jurassic fossils are known. Further north Jurassic and Early Cretaceous basalt and rhyolite contain intercalations of chert, siltstone, and sandstone, and are associated with a gabbro-periodotite mass, the Kerr Pluton (Leitch, 1970).

The close association of this pluton with the Jurassic Whangakea Volcanics is of special interest. Within the pluton serpentinised ultramafic rocks are overlain by interlayered gabbro and peridotite, and then gabbro which in its upper part is intruded by a swarm of basic dykes. Although the pluton is structurally disturbed the rock sequence is similar to that in many ophiolite complexes. Whangakea Volcanics are faulted against the pluton; they constitute massive and pillowed basaltic flows, dolerite dykes and sills together with minor breccia, chert and limestone. Close to the pluton the rocks are extensively altered and a 'spilitic' mineralogy is present, but further away alteration is less intense.

Interval 2 (90-25 m.y. b.p.)

Both the structure and depositional history of the Late Cretaceous – Late Oligocene sedimentary rocks of Northland are imperfectly understood. Two contrasting views have been promulgated; one suggests these rocks constitute a largely autochthonous dominantly shallow marine sequence laid down adjacent to a landmass of subdued topography, the other envisages that they are allochthonous and include

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much material initially deposited within or adjacent to an active trench.

Leaving aside for the moment the post-depositional history of the rocks the following points can be made:

(1) The Late Cretaceous stratigraphic sequence outlined by Hay (1966) is an upward fining, probably transgressive one, in which sandstone and conglomerate is followed by sandstone and then siltstone. In the latest Cretaceous coarse clastic debris again reached the depositional site and throughout the Early Tertiary shale, silty and crystalline limestone, shale, sandstone, greensand, coal and conglomerate accumulated.

(2) A prominent feature of all the sandstones is their micaceous nature. No source for this is exposed in Northland. Debris in conglomerates includes argillite, granite and altered igneous rock but overall the sequence contains very little volcanic detritus.

(3) Large basic volcanic masses grouped as the Tangihua Volcanics are closely associated with the sedimentary rocks. Their age has not been unequivocally established and all their external contacts are highly sheared. Geophysical measurements indicate many of the masses lack roots. These masses have been variously interpreted as later extrusions that have sunk into the surrounding strata, Cretaceous seamounts, and Jurassic oceanic crust. The rock suite is reportedly tholeiitic, although unusually enriched in alkalies (Brothers, 1974).

Brothers (1974) summarised the evidence for a deformational episode in the Waitakian Stage (lowermost Miocene) and considered many of the structural features produced at this time resulted from movement of a surface melange. Although there is unequivocal evidence that some gravity induced movement of older rocks over younger ones has occurred in Northland (Kear, 1959; Kear and Waterhouse, 1967), neither the timing of these slides nor their direction of movement has been agreed on. The extent of allochthonous strata remains unestablished.

Interval 3 (23-15 m.y. b.p.)

About the start of the Miocene calcalkaline volcanism commenced throughout Northland. Activity was dominantly andesitic but extrusive rocks range in composition from basalt to rhyolite. Much volcanic activity was marine and flows, pillow lava, and pyroclastic rock are intercalated with conglomerate and sandstone. Subsidence of depositional basins accompanied the outbreak of activity and there is evidence of at least two volcanic chains (Ballance, 1974). Potash/silica diagrams of well dated andesites at Whangerei Heads and Tokatoka indicate volcanic activity was related to a Benioff zone dipping west at a low angle. Although igneous material was a major sediment source all older rocks in Northland contributed detritus to the basin complex. Subsidence was rapid but irregular; Ballance (1974) recorded about 100 m of turbidite sandstone and siltstone around Auckland. In the extreme north the Waitakian-Altonian sedimentary sequence totals at least 3500 m and includes two major turbidite units separated by a 100 m thick conglomerate unit containing coal measures (Leitch, 1970).

Tectonic Development

The southern, dominantly sedimentary rocks of Interval 1, are similar to assumed ancient trench fill in many eugeosynclinal belts. They possibly accumulated about a trench associated with the subduction zone that dipped beneath the New Zealand Geosyncline from the Early Permian until the Early Cretaceous. The volcanic-rich sequence that accumulated during this interval may be a remnant of the volcanic chain associated with this subduction zone, subsequently displaced east by transcurrent movements, or it may be westward thrust oceanic lithosphere. The former interpretation better explains the presence of rhyolitic volcanic rocks in the sequence, but the latter is strongly supported by the presence of the Kerr Pluton.

Deformation at the end of the Early Cretaceous resulted from failure of the subduction zone and temporary coupling of the "India" and Pacific plates.

Until more is known concerning the nature of Late Cretaceous-Early Tertiary sedimentary rocks and the associated volcanic material, the tectonic setting of Northland during Interval 2 will remain speculative. Brothers (1974) has suggested that sediments of this interval accumulated in and adjacent to a subduction-related trench that lay well east of their present area of outcrop. He postulated that the subduction zone dipped east, and that deformation at the end of Interval 2 resulted from the blocking of the subduction zone by the sialic mass of Northland. Strong tilting of Northland, first east and then, after reversal of subduction polarity west, is considered to have caused westward gravity flow of allochthonous Upper Cretaceous and Lower Tertiary sedimentary rocks and tectonically incorporated oceanic crust (Tangihua Volcanics).

If the sedimentary rocks accumulated adjacent to an active subduction system it is remarkable that calcalkaline volcanic detritus is not widespread. The calcareous nature of many of the rocks suggests accumulation at depths less than those encountered in trenches, and the lack of high pressure metamorphism and extreme deformation contrasts with the expected results of a continent-arc collision.

I favour an alternative interpretation of conditions during Interval 2. At this time much of the eastern part of what is now the India plate was the site of active rifting with the opening of first the Tasman Sea (Hayes and Ringis, 1972), and then the South Fiji Basin (Packham and Terrill, in press). Incipient rifting of Northland induced an Upper Cretaceous marine transgression accompanied by effusive basaltic volcanism (Tangihua Volcanics) that seldom built up significant volcanic edifices. Sedimentation was epi-continental but surrounding relief was low. Significant detritus was derived from a western plutonic-metamorphic complex, the northern continuation of the Tasman Metamorphic Belt (Landis and Coombs, 1967), which subsequently foundered, or was perhaps removed by continued rifting and now forms part of the eastern Lord Howe Rise. This interpretation better accounts for the somewhat alkaline character of the Tangihua Volcanics, the character and provenance of the sedimentary rocks, and accords better with the known history of the oceanic regions surrounding Northland.

Deformation at the end of Interval 2 may have coincided with the end of sea floor formation in the South Fiji Basin, and possibly was an initial mechanism for stress release prior to inception of subduction further east (see below). Formation of the South Fiji Basin in Eocene and Oligocene times (Packham and Terrill, in press) indicates that the India-Pacific plate boundary was well removed from Northland by the end of Interval 2.

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.,