Papers

Part 6

Present Plate Boundary Seismic, Volcanic and Kinematic Processes

THE VOLCANIC ROCKS ASSOCIATED WITH A COMPLEX PLATE BOUNDARY

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Given that the plate tectonic model (Le Pichon *et al.,* 1973) is a valid working hypothesis that has operated during the Phanerozoic; then one should be able to use the data that are available on the abundance, composition and distribution of volcanic rocks as pointers to the various tectonophysical regimes that have operated in this segment of time. At present most of the major tectonic events that are observed at the surface of our planet are considered to be related to a relatively simple world-wide kinematic pattern; and it is claimed that along most major plate boundaries there is a relatively simple relationship between volcanism and tectonism. While this is true of most major plate boundaries some boundaries are complex. As most of these complex boundaries leave a relatively permanent record of their former existence in the geologic history of the continents, it is important to attempt to explain their origin and evolution. New Zealand lies astride a complex plate boundary and the tectonic diversity and complexity of the New Zealand crustal unit is regarded as a response of the continental crustal rocks of this area to the significant changes that are taking place in the kinematic character of this plate boundary.

In order to examine the present day relationship between tectonism and volcanism in North Island the chemical nature of the Quaternary volcanic rocks (i.e. Challis, 1971) from four active volcanic domains has been determined (Middlemost, 1972). The volcanic rocks of the Auckland domain were found to consist of sodic alkalic basalts, sodic transitional basalts and nephelinites. In the Taupo domain the volcanic rocks were mainly rhyolites with lesser volumes of dacites and high-Al basalts, and minor volumes of andesites, icelandites and tholeiitic basalts. Most of the volcanic rocks in the Tongariro domain were icelandites and andesites; while the volcanic rocks of the Egmont domain were mainly andesites with lesser volumes of benmoreites, tristanites, hawaiites and trachybasalts. It is thus found that the compositions and the relative proportions of the various materials that have erupted onto North Island during the Quaternary exhibit a complex pattern that is not similar to that found along simple major plate boundaries at the present time. It is, however, believed that similar patterns of volcanic rocks existed in the past. An example of such an area is the Palaeozoic Lachlan Fold Belt of Eastern Australia.

An attempt will now be made to construct a simple model that contains the major tectonic features found within and around North Island. Three major geomorphic features lie to the northeast of North Island. They are (1) the Kermadec Trench which is regarded as the surface expression of a westward dipping subduction zone that is terminated by a transcurrent fault, or series of faults, off the central-east coast of North Island; (2) the Kermadec Ridge which is considered to terminate to the north of North Island, and (3) the Havre Trough which is regarded as an active zone of spreading that continues onto the land in the Taupo Volcanic Domain. The latter zone of crustal extension considered to terminate in the Tongariro Volcanic Domain.

It is proposed that the Kermadec subduction zone is at present subducting old oceanic crustal materials that contain more serpentine than normal younger oceanic crust. Most of the magma from which the volcanic rocks of the Kermadec Ridge were derived, is considered to have formed above the Benioff seismic zone, mainly as the result of the release of water during the transformation of subducted amphibolite into eclogite. At greater depths along the Benioff seismic zone the serpentine, and the high-pressure derivatives of this mineral, continue to release significant quantities of water. This water assists in the generation of an incipient magma which is able to mobilize a huge volume of quasi-liquid mantle material. This material rises as a thermal diapir. At depths of the order of 7 km a sub-alkalic basaltic magma separates from the thermal diapir and it is emplaced into the growing inter-arc basin (i.e. Havre Trough). When a series of similar thermal diapirs welled up beneath the Taupo continental block, the upper part of the block broke up into a complex graben structure, while in the lower part of the block there was extensive partial melting that resulted in the generation rhyolitic magmas. These magmas were able to burst rapidly through to the surface where they were erupted as a solid-liquid gas system. Magmas that were more mafic than rhyolite in composition were able to reach the surface in those parts of the Taupo Volcanic Domain that were not underlain by extensive zones of crustal melting.

It is also proposed that subduction initiated the processes of magma generation in both the Auckland and Egmont domains. In both these domains the process operated beneath the lithosphere, and as the Australian-Indian plate drifted north-

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westwards relative to Antarctica the volcanic foci remained relatively stationary. It is proposed that the line traced by the volcanic foci that are at present operating in the Auckland area lie to the east of the line traced by the volcanic focus that lies beneath the Egmont area. The relatively small volumes of nephelinitic magma from which the volcanic rocks of the Auckland domain were derived is considered to have been generated at a depth of the order of 75km beneath a relatively thick plate of lithosphere. The magma responsible for the generation of the volcanic rocks of the Egmont domain is believed to have initially formed at even greater depths than the Auckland volcanic focus. This magma was initially silica and potash rich but after reacting with the phases present in the overlying upper-mantle this initial magma changed in composition; and this process has resulted in the evolution of a suite of magmas that consist mainly of andesites, benmoreites and tristanites.

References

CHALLIS, G.A., 1971: Chemical analyses of New Zealand rocks and minerals with C.I.P.W. norms and petrographic descriptions. *New Zealand Geol. Surv. Bull.* 84: 178p.

LE PICHON, Z., FRANCHETEAU, J., and BONNIN, J., 1973: *Plate Tectonics.* Elsevier Sci. Pub. Co., 300p.

MIDDLEMOST, E.A.K., 1972: A simple classification of volcanic rocks. *Bull. Volcanologique* 36 (2): 382-397.

THE ORIGIN OF MAGMAS AT CONVERGENT PLATE BOUNDARIES

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The dominant lava types produced by volcanism in young island arcs are basalts close to silica-saturation, basaltic andesites and andesites. These lavas are often referred to two associations — the island arc tholeiitic association, found in volcanoes ~80 - 150 km above the Benioff Zone, and the calc-alkaline association, in volcanoes ~ 100 - 250 km above the Benioff Zone. The major possible source materials for primary magmas of the two associations are former oceanic crust (in the form of eclogite) in the subducted lithosphere slab, and the overlying wedge of peridotitic mantle (Figs. 1 and 2).

Complementary experimental studies of the crystallization of tholeiitic basalts (Nicholls and Ringwood, 1973) and the partial melting of the pyrolite model mantle composition (Green, 1973), both under high water pressures, have indicated that basaltic to basaltic andesite magmas of the island arc tholeiitic association may be produced by partial melting of hydrous peridotitic mantle to depths of ~ 80 km.

Both the nature and origin of primary magmas of the calc-alkaline association are under debate. Studies of the crystallization of andesites at high pressures (T.H. Green, 1972; Stern, 1974) have indicated that andesitic magmas (~60% SiO_2) may be produced by partial melting of eclogite in the former oceanic crust at depths of ~ 100 km.

Liquids with 55-60% SiO_2 have also been produced by experimental melting of hydrous peridotitic assemblages, the estimated maximum depths for the corresponding equilibrium partial melting process in the mantle ranging from ~ 40 km. (Nicholls, 1974) to $>$ 60 km. (Mysen and Boettcher, 1975). These results show that, if partial melting of peridotitic mantle is the major process in the formation of andesites, then partial melting and magma separation must take place in the shallow portions of the mantle wedge beneath volcanoes of the calc-alkaline association, rather than immediately above the Benioff Zone. However, experimental liquids with 55-60% SiO_2 are much more magnesian than natural andesite lavas, suggesting that the latter have a more complex history, almost certainly involving processes of crystal fractionation.

Further consideration of geochemical data and experimental phase relationships for island-arc magma types has allowed the formulation of a model which attempts to explain spatial variation in the geochemistry of island-arc volcanic rocks (Ringwood, 1974; Nicholls and Ringwood, 1973). At shallow Benioff Zone depths (80-100 km) dehydration of the basaltic crustal component of downgoing oceanic lithosphere causes the introduction of water into the overlying mantle wedge

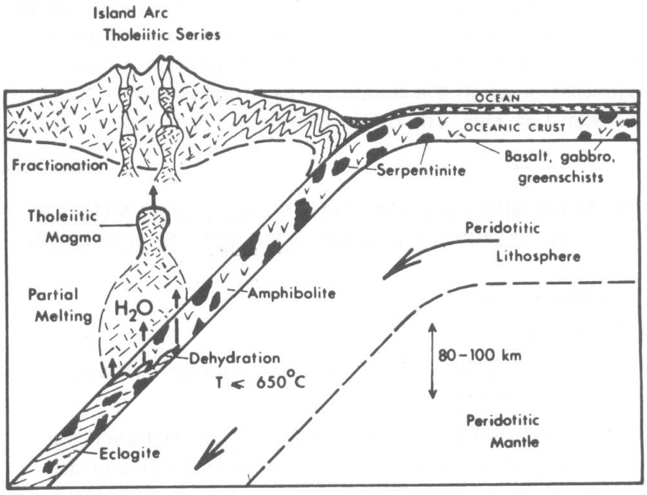

Figure 1
Petrogenetic model of tholeiitic volcanism in island arcs (modified from Ringwood, 1974).

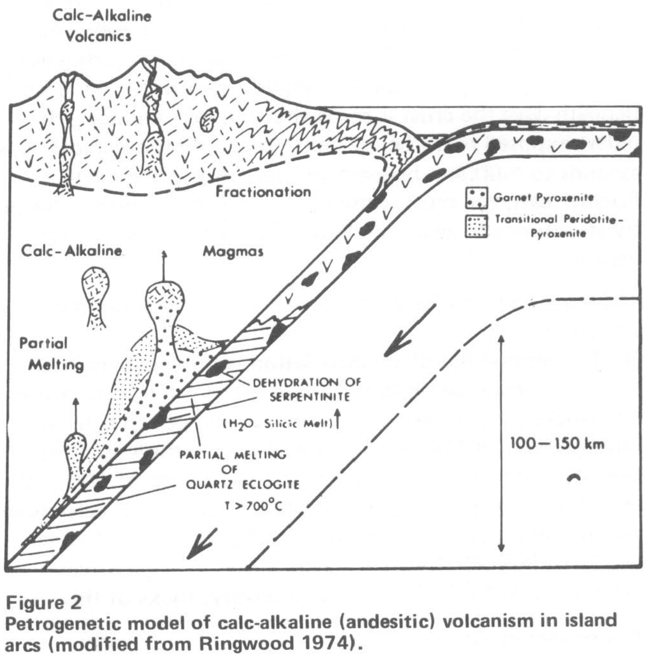

Figure 2
Petrogenetic model of calc-alkaline (andesitic) volcanism in island arcs (modified from Ringwood 1974).

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