Low-grade Regional Metamorphism in the Waipapa Group of the Whangarei Coastal Region, Northland

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Abstract

LOW-GRADE regional metamorphism of the geosynclinal rocks forming the Waipapa Group (probably of Permian age), in the Whangarei coastal region, has occurred in several stages which are thought to be related to separate periods of deformation.

The first stage involved the formation of platy prehnite in the clastic and pumpellyite in the volcanic rocks (spilitic); this is regarded as corresponding to the quartz-prehnite zone of the prehnite–pumpellyite metagreywacke facies. Stage two, seen only in the clastic rocks, is shown by the formation of zeolites, notably laumontite, and indicates a period of retrogressive metamorphism within the zeolite facies. In the third stage the zeolites were partially replaced by calcite and in addition veins were formed of quartz, calcite, and tabular and acicular prehnite. The fourth and final stage, resulting in the formation of epidote in the volcanic rocks and quartz–albite in the sedimentary rocks, occurred within the greenschist facies. The various stages of mineralisation are all incomplete, probably due to varying availability of water at the times of metamorphism, and this has resulted in a disequilibrium assemblage of minerals. Consequently the rocks cannot be assigned to any one facies.

In the writer's opinion the characteristic occurrence of pumpellyite and epidote in the volcanic rocks and of prehnite in the clastic rocks are related to bulk chemical compositions of the rocks.

INTRODUCTION

THE region studied lies along the coast east and north-east of Whangarei. The coast between Ocean Beach and Woolley's Bay was examined intensively, but specimens were also collected, and examined, from Helena Bay, Mokau and Pahii Bay, farther to the north (Fig. 1).

The rocks of the region belong almost entirely to the Waipapa Group, here probably Permian in age. Exceptions are small areas of Tertiary igneous and sedimentary rocks, viz. Parahaki Volcanics, Wairakau Andesites, and Motatau Group.

The Waipapa Group comprises greywacke-type sandstones, argillites, layered cherts, spilitic rocks, and minor amounts of volcanic argillite of the type described by Reed (1957). The rocks have been considerably deformed, and this is shown by their highly disrupted bedding, an abundance of shear joints, and an apparently complex structure. The deformation has resulted in low-grade regional metamorphism throughout the group and this is chiefly evident as veins along shear zones but also, to a lesser extent, as irregular pools of mineralisation throughout the rocks.

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In the clastic rocks veining is commoner in the sequences of alternating sandstone and argillite and is more rarely seen in the massive sandstone bodies. The argillites are often more intensively veined than accompanying sandstone beds, and the veins are both subparallel and oblique to bedding planes. In the sandstones veins usually cut the beds obliquely to bedding planes. The veins of the clastic rocks vary in width from several inches down to microscopic size, and frequently more than one generation of veins is present with the earlier ones showing complex folding.

In the volcanic rocks veins displaying all the features of those seen in the clastic rocks occur along shear zones, while other large masses of calcite, up to 3ft across, are present as irregular vein-like bodies but do not occupy well-defined zones of shearing.

The volcanic argillites exhibit a network of fine veins but not the large bodies of calcite seen in the spilitic rocks. Many of these veins are contorted, but due to their fine nature this is not always readily observed in hand specimen. In the cherts there are veins of quartz clearer than that of the chert layers. They cut the layers approximately normal to the layering but do not usually pass from one layer to another. In no instance do the veins contain cavities, and thus they do not appear to be the result of filling in open spaces.

MICROSCOPIC FEATURES

In hand specimen the only secondary mineralisation visible occurs in veins, but in thin sections it is seen that growth of new minerals has also occurred in the matrix and within constituent clastic fragments and mineral grains.

Plagioclase grains and volcanic-rock fragments are the most altered constituents of the clastic rocks. Within these grains fine flakes of pale yellow, non-pleochroic chlorite are ubiquitous, sericite is common in small fibrous masses, and small subhedral or euhedral crystals of epidote are occasionally seen. Frequently alteration, mainly chloritisation, of grains has proceeded so far that only the outlines remain.

In the matrix of the clastic rocks small pools of secondary minerals, consisting of quartz and fine albite, are often seen—e.g. 11266. (All specimen numbers refer to the petrology collection of the Geology Department, University of Auckland.) These pools are often larger in size than some of the finer clastic grains and are distinguished from them by their polycrystalline and unaltered appearance. Chlorite is ubiquitous in the matrix, both as fine blades and as masses of greenish, pleochroic fibres. Sericite and epidote are also present as secondary minerals in the matrix but are not as common as chlorite.

In the volcanic rocks alteration of the constituent grains is generally considerable, plagioclase being most affected and pyroxene least. Chlorite is the main alteration product, and frequently chloritisation has occurred to such an extent that original texture of the rock has been virtually obliterated. The volcanic argillites are extremely fine-grained and possess veins much smaller than those seen in the spilitic rocks. The secondary minerals comprise abundant chlorite together with pumpellyite, both in the mass of the rock and in the veins. Quartz is also present in the veins. No sharp distinction can be drawn between the secondary mineralisation in veins and that occurring as small pools and as alteration products of clastic grains; all gradations occur between these types. The vein mineralisation is next discussed.

Zeolites

These generally occur in small irregular veins and pools, with the host rocks considerably crushed and altered. In the less altered and crushed rocks zeolites were not seen, nor were they observed in any of the igneous rocks of the Waipapa Group.

Optical identification of these zeolites was difficult owing to their small grain sizes and often strained extinctions. However, the commonest zeolite (seen typically in 11241, 11254, 11276) has the following optical properties.

Length slow orientation: $\beta = 1.519 \pm 0.002$ (specimen 11254);
$2V\alpha = 24°$ to $45°$ (17 measurements, specimens 11241, 11254, 11276);
average $2V\alpha = 37°$

These properties are comparable with those given by Deer *et al.* (1963) for laumontite. The laumontite usually occurs in tiny, irregular, often monomineralic veins but is also present associated with quartz and can also be seen in small pools. The grains show a platy crystal habit and the extinction is often irregular or even blotchy. The writer considers that the blotchy appearance is due to the presence of some leonhardite. At one locality a large zeolite vein (11254) was seen occupying a zone of shearing approximately 4ft wide. This vein was nearly monomineralic, and a specimen showed an X-ray diffraction pattern very similar to that given by Deer *et al.* (1963) for laumontite.

From optical data obtained, *mordenite* was suspected in 11283, a sandstone from Helena Bay.

Analcime was observed in only one specimen, viz. 11278, from Pahii Bay. This rock has been considerably crushed and the analcime occurs in distorted veins and pools together with chlorite.

Prehnite

This mineral is common in the clastic rocks, chiefly in veins, but is seldom seen in the volcanic rocks. It occurs in two main forms: (1) as platy crystals which are generally anhedral but are occasionally subhedral (e.g. 11188, 11245, 11270). The anhedral plates occur in monomineralic veins which are often folded and considerably disrupted, with the prehnite showing severe straining and replacement by chlorite, calcite, or laumontite; (2) the second form of prehnite occurs as acicular and tabular crystals elongated parallel to *b* crystallographic axis (Y vibration direction). This form nearly always occurs in veins associated with quartz and the prehnite crystals frequently lie at right angles to the sides of the veins and cut the anhedral quartz grains (e.g. 11150, 11199). This second type of prehnite does not show strain extinction. It is usually associated with quartz, but some monomineralic veins do occur.

Over fifty measurements of optic axial angles of prehnite crystals were carried out; these were made on platy, tabular, and acicular crystals. Values obtained for $2V\gamma$ ranged from 56° to 84° with the majority in the range of 70° to 80°. It was not possible to relate any particular range of values for $2V\gamma$ to any one crystal type. Deer *et al.* (1962b) list the $2V\gamma$ range of prehnite as 65° to 69° and state that the mineral does not show any marked variation in composition. However, Brothers (1956) has recorded prehnite from Waipapa rocks with $2V\gamma$ ranging from 48° to 80° and other workers have also listed values not in accordance with those given by Deer *et al.* (1962b); e.g. Hall (1965) $2V\gamma$ 58° to 64°, Rusinov (1966) $2V\gamma$ 39° to 68°. The identification of prehnite in the Waipapa rocks examined by the writer was also established by X-ray diffraction patterns obtained from concentrates of the veins.

From the above evidence it would appear that the composition of prehnite may not be as invariable as Deer *et al.* maintain and that some isomorphous replacement may be possible. Evidence for this has been provided by Zolotukhin *et al.* (1965) who report iron-rich prehnites, although they do not record a wide range of optical properties. It seems likely that when formed under conditions of stress, as during metamorphism, prehnite composition may be more variable than when formed under magmatic conditions.

Pumpellyite

Pumpellyite has been seen only in volcanic rocks and volcanic argillites; in both types of rocks it is abundant in pools and veins as tiny stumpy crystals up to 0.2mm in length (e.g. 11160, 11164, 11217). The mineral is not as abundant in the volcanic argillites as in the volcanic rocks. It is frequently associated intimately with quartz, calcite, sericite, and chlorite (e.g. 11189) or quartz and chlorite (10522). No pumpellyite was seen in any clastic rocks, though Milligan (1961) has reported minor amounts of the mineral in Waipapa greywackes from elsewhere in Northland.

Epidote

Epidote occurs as stumpy crystals in veins, particularly in the volcanic rocks (e.g. 11158, 11235), but is not common as veins or pools in the clastic rocks, though, as already mentioned, it does occur as small grains in these latter and is seen to be formed chiefly from the alteration of feldspar grains.

Chlorite

The fine, bladed, non-pleochroic chlorite mentioned earlier is mainly restricted to secondary growth in the matrix and grains of the rocks, both clastic and volcanic. In the veins, however, the type of chlorite present is nearly always a fibrous, pleochroic green variety which occurs in both monomineralic veins and in asscociation with other secondary minerals, chiefly calcite and quartz, but seldom prehnite.

Calcite

Calcite is present in the matrix of a few clastic rocks, generally only in small amounts, but it quite common in veins in both clastic and volcanic rocks. In the latter the veins range in size from microscopic up to large monomineralic masses 3ft across; such large masses are rarely seen in the clastic rocks, though one such lump of calcite (11253) was found surrounded by laumontite (11254) along a zone of shearing in clastic rocks. Calcite usually occurs as monomineralic veins or associated with quartz, and only rarely is it replaced by any other mineral, though chlorite is seen replacing it in 11280.

Quartz

Quartz is widespread in veins and is found with all other vein minerals, but such associations do not always occur. The quartz is always anhedral with varying grain sizes and often shows strain extinction. Monomineralic veins of quartz are seen in many clastic rocks and are very common in the cherts. This secondary quartz seldom shows replacement by any other mineral, but occasionally chlorite replaces it to a minor extent (e.g. 11203).

Feldspar

The existence in the matrix of the clastic rocks of small pools of albite and quartz has already been mentioned and this association also occurs in small irregular veinlets in these rocks (e.g. 11174, 11269, 11276). The albite (An_{5-0}) was identified by its low refractive indices (lower than that of balsam) and by the presence of albite twinning, from which determinations by Michel-Levy's method were made. Mason (1962) states that such metamorphic albite seldom shows twinning, but in these rocks albite twinning was common, though not universal. The mineral is always associated with quartz and was not seen in monomineralic veins or pools.

In 11244 a mineral believed to be perthitic microcline was noted in several irregular pools.

Paragenesis of Vein Minerals

The paragenesis of the vein minerals appears complex and apparently has not been the same in every specimen. The sequences were determined from vein intersections and the development and corrosion of crystal faces; they were best observed in specimens obtained from shear zones. Examples of observed sequences of secondary mineralisation are given below, and are summarised in Table I.

Clastic Rocks

The earliest phase of mineralisation in the clastic rocks appears to have resulted in the formation of monomineralic veins of platy prehnite, as seen in 11188. In this thin section the early-formed prehnite has been complexly folded and is now ragged and strained and in places shows replacement by calcite or chlorite. Some of the calcite seen replacing prehnite in this thin section is also distorted and shows strain extinction. These veins of platy prehnite and calcite are cut by veins of quartz–calcite–chlorite, or quartz–chlorite, with minor amounts of tabular prehnite and calcite; such later veins show far less distortion than the earlier prehnite veins. Some of the later veins intersect one another and the most recent ones comprise quartz–calcite–chlorite. The paragenetic sequence in 11188 appears to be as follows. Prehnite veins formed initially and were greatly distorted by later movement; some calcite formed during this movement and as deformation progressed both the calcite and the prehnite were strained. At a later stage veins of quartz–tabular prehnite–calcite, and quartz–calcite, were formed. A somewhat similar sequence is seen in 11218, where veins of tabular, interlocking, relatively unstrained prehnite are cut by larger and coarser veins of quartz.

In 11242 platy prehnite, identical in appearance to that in 11188, occurs abundantly in small ragged pools which may represent the remnants of disrupted veins. The prehnite shows replacement by laumontite and calcite can be seen replacing both these minerals. Quartz is also common in veins cutting the prehnite.

Apparent replacement of prehnite by calcite and chlorite is seen in 11252, where also thin, broken veins of quartz cut the prehnite and *vice versa*. Prehnite veins also intersect other prehnite veins. In this specimen both prehnite and quartz have formed initially and the prehnite has later been replaced by chlorite and calcite, although some calcite may have formed at the same time as the prehnite. Similar replacement of prehnite is seen in 11268. In 11207 platy, ragged, and strained prehnite is cut by monomineralic veins of quartz, veins of quartz with tabular or acicular unstrained prehnite, or veins of quartz and calcite. Some ot the calcite in the later veins is pseudomorphous after tabular prehnite. In all these rocks the veins containing quartz appear to have formed as one of the last stages of mineralisation, but not before folding ceased, for many of them are deformed or disrupted, with the grains showing strain extinction in the folded portions (e.g. 11174, 11199, 11203). An even later phase of mineralisation involved the formation of small veinlets of albite and quartz, which cut the quartz–prehnite–calcite veins and can be seen replacing the earliest-formed platy prehnite (e.g. 11269).

The formation of the albite–quartz association appears to have succeeded laumontite in 11276, from Pahii Bay, and the zeolite is confined to irregular pools in the highly crushed rock, while the quartz–albite occurs in occasional small veins.

An intimate association of albite–quartz and analcime is seen in 11278, also from Pahii Bay. This rock has suffered considerable crushing and is cut by numerous discontinuous small veinlets and pools of albite–quartz; pools can be seen with ragged edges, while others possess sharp margins. Analcime, too, is present in numerous distorted lensoid pools and veinlets which also exhibit both ragged and sharp margins. The analcime is frequently margined with green chlorite and the whole association possesses a slight foliation. Analcime is sometimes entirely surrounded by, and elsewhere intimately associated with, albite and quartz. In other places the analcime is not associated with albite and quartz but may be cut by fine veinlets of chlorite growing along fractures. It is very difficult to tell which mineral phase is the later, albite–quartz or analcime. Probably the albite–quartz association formed after the analcime and this view is strengthened by the fact that albite and quartz are seen replacing laumontite in other thin sections.

Volcanic rocks

The most notable difference between the metamorphic minerals present in the volcanic rocks and those present in the clastic rocks is the presence of pumpellyite and epidote in the former and prehnite in the latter. Prehnite is only rarely seen in any of the volcanic rocks, or in zones of shearing that cut them (e.g. 11225, 11226, 11235), but it is abundant as a secondary mineral in the clastic rocks. Pumpellyite, however, is absent from the clastic rocks, but widespread in the volcanic rocks and volcanic argillites; similarly, epidote is much more common in the volcanic than in the clastic rocks.

Specimen 11158, collected from a shear zone cutting volcanic rock, contains abundant fine-grained pumpellyite scattered throughout the rock and occurring in occasional wisp-like veins. Much of the mineral is associated with, and appears to be replacing, an indeterminate, dirty-brown, non-pleochroic mineral with ragged edges and high refractive indices (about equal to those of the pumpellyite). The birefringence of this indeterminate mineral varies from very low to complete isotropism and it occurs in isolated pools and disrupted veinlets. It may be prehnite that has undergone considerable alteration and is being replaced by pumpellyite.

The pumpellyite in 11158 commonly shows replacement by euhedral and subhedral crystals of epidote, which are associated with quartz and calcite. Elsewhere, however, there is abundant epidote which shows no relationship to pumpellyite. The veining appears complex, but the last phase of secondary mineralisation has involved the formation of veins of quartz and calcite that occur together and in monomineralic veins. Similar relationships are seen in 11215, where pumpellyite is scattered throughout the rock as tiny ragged crystals and in small, irregular, and contorted veins; these veins are cut by quartz and quartz–epidote veins. In other thin sections containing pumpellyite epidote is not present, and in 11163 fine veins of pumpellyite–chlorite–calcite cut one another and are cut in turn by veins of quartz or quartz and calcite.

A complex sequence of mineralisation is evident in 11235, where platy prehnite has formed at an early stage throughout the volcanic rock and is now found as ragged plates. Later, veins of tabular prehnite, with quartz, have formed together with veins of fine-grained pumpellyite; both types of veins are somewhat distorted and form a crude foliation. At a still later stage there were formed veins of epidote, quartz, calcite, and combinations of these three minerals, and many of these later veins are contorted and cut across the crude foliation mentioned above. The quartz in the latest veins is strained, while the epidote is both strained and unstrained, even in the same vein. Veins of epidote both cut and are cut by calcite veins. The evidence suggests that epidote and calcite were the last minerals formed and that their formation continued after that of quartz had ceased.

DISCUSSION

The preceding descriptions indicate that the paragenesis of the metamorphic minerals has been quite complex and has varied in different rocks. However, the writer considers that a generalised paragenesis, occurring in several stages, may be deduced.

(1) Pumpellyite and platy prehnite were the first secondary minerals to form. Pumpellyite was formed only in the volcanic rocks, while prehnite, although present in both volcanic and clastic rocks, was more abundant in the latter. Some prehnite probably formed in the volcanic rocks before pumpellyite and then was replaced when the latter mineral was created.

(2) The second stage in the clastic rocks involved the formation of zeolites, which replaced much of the prehnite. In the volcanic rocks, however, this phase was either absent or has been obliterated.

(3) The zeolites were later partially replaced by calcite, and it is possible that at this time the veins of calcite, quartz, and tabular and acicular prehnite were formed.

(4) The last stage appears to have resulted in the formation of epidote in the volcanic rocks and quartz–albite in the sedimentary rocks.

The pumpellyite and platy prehnite have been considerably deformed, and they were probably formed during "burial metamorphism" (this term follows the usage of Coombs, 1961); a similar origin for pumpellyite and prehnite in other rocks has been postulated by Crook (1961). The zeolites, which are always present in the highly disrupted clastic rocks, were probably formed during a period of major orogenic deformation, and this is likely to have been the Rangitata Orogeny. The veins of quartz, calcite, and tabular and acicular prehnite may also have formed

during or towards the end of this orogeny. The last phase of mineralisation, which involved the formation of epidote and quartz–albite veins, possibly occurred during Upper Cretaceous–Lower Tertiary deformation for which some evidence exists in Northland (Brothers, 1956; Elliot, 1967). Some of the later, relatively undeformed veins of quartz and calcite probably formed during a period of Tertiary block faulting, as similar veins are seen in beds of the Motatau Group (Oligocene) in this region. Abundant evidence exists in Northland, including this region of study, for such a later period of block faulting (e.g. Brothers, 1956; Mayer, 1965; Leitch, 1966; Elliot, 1967). It is also possible that some of the laumontite, which is often found in crush zones, was also formed as a result of this Tertiary faulting.

1. Sandstone (10521), near Ocean Beach, (N20/065899)
2. Sandstone (10523), near Ngunguru, (N20/050080)
3. Sandstone (10528), near Matapouri Bay, (N20/035150)
4. Argillite (10524), near North Gable, (N20/044144)
5. Argillite (10527), near Matapouri Bay, (N20/035150)
6. Spilitic rock (10525), near Tutukaka, (N20/050085).
7. Spilitic rock (10526), near Tutukaka, (N20/050085).
8. Volcanic argillite, near Kauri Mt., (N20/062931)

The characteristic occurrences of pumpellyite and epidote in volcanic rocks and volcanic argillites is considered to be related to the bulk chemical compositions of the rocks. Both minerals require large amounts of iron and in addition pumpellyite contains Mn, Ti, Mg, and H_2O (Deer *et al.*, 1962a). Comparison of analyses of

clastic and volcanic rocks and volcanic argillites from the Waipapa Group (Table II) shows that iron and manganese are present in greater amounts in rocks of the volcanic association but that there are no marked differences in amounts of other constituents. The relative abundance of iron and manganese in rocks of the volcanic association, also noted in similar rocks elsewhere in the world (e.g., Bailey *et al.*, 1964; Vallance, 1965), may be sufficient to account for the restriction of epidote and pumpellyite to such rocks in this region. However, Bailey *et al.* (1964) state that pumpellyite is common throughout many of the Franciscan rocks, both clastic and volcanic, although from their descriptions the mineral seems to be more abundant in volcanic rocks.

The general absence of prehnite in the volcanic rocks is rather difficult to explain, because calcium, an important constituent of prehnite, is abundant in veins in these rocks. However, the occurrence of prehnite in 11235 and its suspected occurrence in 11158 indicate that it can form in such volcanic rocks, but some special conditions may apply. An alternative suggestion, already mentioned, is that any prehnite which did form has since been destroyed and replaced.

Inability to determine any stratigraphic sequence in the Waipapa Group renders it impossible to correlate mineralisation with depth of burial. However, the various types of mineralisation are widespread, and at the present level of exposure in the group there does not appear to be any regular change which could be correlated with varying depth.

The stages of mineralisation that have occurred are all incomplete, and there is no one rock that shows all stages of replacement and mineral growth. Similar incomplete mineral alterations have been recorded from Oregon by Dickinson (1962), who considers that the availability of water is important in determining the extent to which replacements will occur. The importance of water is attributed by Dickinson to three reasons. (1) It is an important constituent of minerals such as pumpellyite and prehnite; (2) gains and losses of chemical components will occur by aqueous transfer; (3) reactions are probably catalysed by water. Coombs (1954) has also noted the dependence of these reactions on the availability of abundant water. Thus it seems likely that water has had an important role in the growth of new minerals in the Waipapa rocks. The relative abundance of platy prehnite, considered by the writer to have formed during diagenesis, and the relative scarcity of later and more hydrated zeolites appear to confirm this view. During diagenesis abundant connate water would be available, but with increased lithification much less would be present. In the volcanic rocks, however, hydrated glass could continue to provide a source of water after connate water had been expelled from the adjacent clastic rocks. This may explain why pumpellyite is abundant and partially postdates the formation of prehnite in the volcanic rocks.

The Waipapa rocks cannot be assigned to any one metamorphic facies or subfacies but are clearly of low metamorphic grade. The early formation of prehnite and pumpellyite corresponds to the quartz–prehnite zone of the prehnite–pumpellyite metagreywacke facies (Coombs, 1960). Later formation of zeolites, notably laumontite, indicates a period of highly localised incomplete retrogressive metamorphism within the physical conditions of the zeolite facies of Coombs *et al.* (1959), with laumontite-bearing rocks as the most common grade within this facies, though in places retrogression proceeded to the lower analcime grade.

Coombs (1960) states that the critical assemblage for the onset of the greenschist facies is quartz–albite–muscovite–chlorite–epidote, without pumpellyite, lawsonite, or prehnite. Hence the latest metamorphic event affecting the Waipapa rocks resulted in the formation of greenschist mineral assemblages (viz. quartz–albite and epidote), although, as with the preceding period of zeolite formation, these did not completely replace previous mineralisation. Thus, seeing that the total metamorphic mineral association in the Waipapa Group appears to be a disequilibrium assemblage with multifacial aspects, it seems improper to assign the rocks to any one facies.

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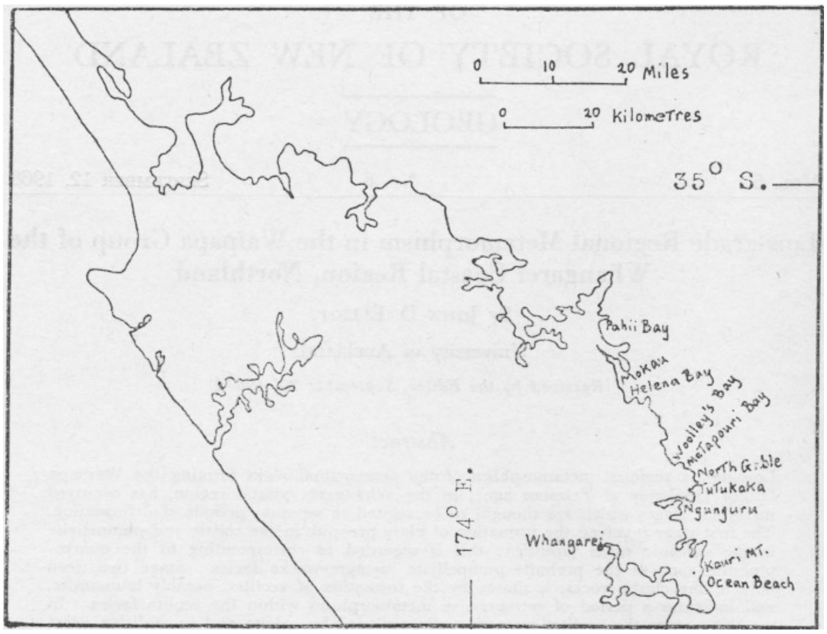
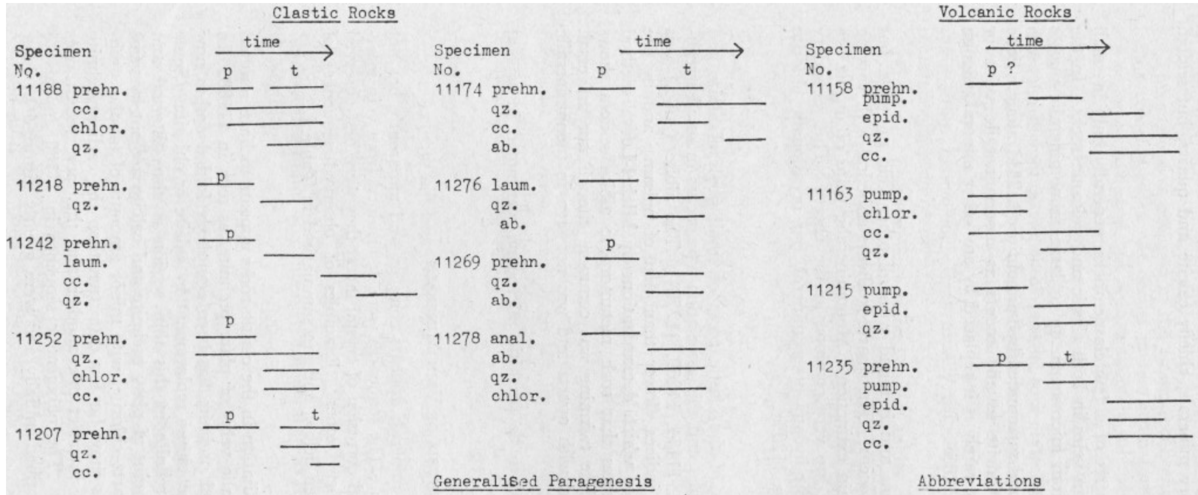
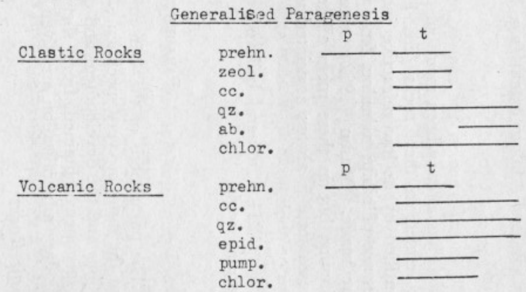


FIG. 1.—North Auckland Peninsula. Localities.





Abbreviations

prehn. : prehnite
qz. : quartz
cc. :calcite
chlor. : chlorite
laum. : laumontite
pump. : pumpellyite
ab. : albite
anal. : analcime
epid. : epidote
zeol. : zeolite
p : platy prehnite
t : tabular &/or acicular prehnite

Note : No vertical time correlation between specimens is implied (e.g. the laumontite in 11276 is not to be regarded as having formed at the same time as prehnite in 11269). However, such correlation is intended between clastic and volcanic rocks in the generalised paragenesis.

TABLE I.—Paragenesis of secondary minerals in some rocks of the Waipapa Group.

Sample No.	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	53.1	50.1	63.5	65.3	61.3	49.1	47.0	62.4
TiO_2	1.2	1.4	0.8	0.8	0.8	1.6	0.8	1.2
Al_2O_3	16.5	16.8	15.3	16.2	16.1	15.4	15.5	16.1
Fe_2O_3	3.8	3.1	2.3	3.1	2.1	4.0	8.5	2.6
FeO	4.9	6.1	5.0	2.8	4.9	5.6	5.8	3.2
MnO	0.3	0.2	0.1	-	-	0.4	0.5	0.4
MgO	4.1	5.9	3.0	0.9	2.8	5.3	4.9	2.0
CaO	5.1	7.9	2.8	1.4	3.0	10.3	5.0	4.2
Na_2O	2.4	3.0	3.4	2.6	2.6	3.9	3.9	2.6
K_2O	1.5	0.8	0.9	2.3	2.3	0.4	2.8	1.1
P_2O_5	0.4	0.9	0.4	Trace	0.7	0.8	0.6	0.5
H_2O-	1.6	1.4	0.2	1.2	0.6	0.9	1.4	0.5
H_2O+	3.6	2.1	1.8	3.0	2.4	2.6	2.9	2.7
CO_2	-	-	0.2	-	-	-	0.5	-
Totals	99.5	99.7	99.7	99.6	99.6	100.3	100.1	99.5

TABLE II.—Chemical analyses of rocks of the Waipapa Group