Geology of Mayor Island

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INTRODUCTION.

MAYOR ISLAND lies to the north of Tauranga, twenty-three miles distant from the entrance to the harbour. Discovered by Captain Cook, it was for some time a secure stronghold for small parties of natives. It was first described by Goldsmith in 1884 (4, pp. 417-427); von Wolff in 1904 described some of the rocks that had been collected by Thilenius (10); Bell gave a short account of the island in *The Wilds of Maoriland* in 1914 (3). More recently Thomson (9) wrote a brief description of its field geology; while the rock specimens that he collected were described with great care by Bartrum (1). Sladden (7) described the surface features of the island as well as its fauna and flora. These three papers were published in 1925.

The island, which is three miles long from north to south and two miles wide, is the upper part of a volcano composed entirely of alkaline rhyolites, that are most properly classed as comendites. Bartrum (1) points out that some of them are almost pantellerites. The lower part of the volcano for a height of 500 feet above its surroundings is covered by the ocean waters. Its highest point, Opuahau on the west, rises to 1210 feet above sea-level, while Tutaretare on the south is 1162 feet high. In the portion now above sea-level the slopes rise gradually from the crest of the sea-cliffs, which average about 100 feet in height in the south, but in places in the northern portion of the island as much as 500 feet. There is always a steep drop internally to the floor of the crater. Except in the southern part of the island the sea has eroded away almost all of the exterior slopes of the volcano, and a mere ridge of varying width now separates the sea from the crater floor. On the eastern side at Taratimi this ridge is in one place no more than 100 feet high, and here the crater-wall is formed of coarse tuff. On the south side the exterior slopes are nearly a mile long, and the crater-wall 1000 feet high. The crater is about a mile and a-half in diameter, and within it there is a small cone 800 feet high which is densely covered with trees and lower vegetation. It has a low slope, and on the west its base reaches halfway up the inner slope of the main crater, but in both north and south directions the cone retreats slightly from the crater-wall, and in the east there is an interval of a quarter of a mile between it and the outer crater-ridge. Part of this space is now occupied by two small lakes. All the surface of the interior cone—the only part that is now visible—is formed of obsidian. The southern slopes of Mayor Island to a height of 600 feet at least are coated with a thick covering of pumice which completely conceals the real rocks of the island. The pumice is slightly greyish in colour and contains a considerable amount of hypersthene. It is evident that the pumice has floated over from the mainland, which is mainly formed of hypersthene-andesite and of rhyolites containing hypersthene.

The island is somewhat dissected by stream valleys, but it is only during the climax of the heaviest rainfall that any water flows in them, and then for a brief period only. In none of the four stream valleys that were examined could any solid formation of the rocks of the island be seen. On the sea-coast solid rocks are continuously exposed, and, except at Taratimi where tuffs only are found, the formations have an upper and lower selvage of obsidian. There are boulders of hard rock scattered promiscuously but somewhat sparsely on the pumice, and these have the characteristic mineral composition of the rocks of the island. Almost everywhere the descent to the crater-floor is extremely abrupt. In the south the surface descends in one unbroken precipice for a height of more than 1000 feet, but on the west it abuts against the slope of the interior cone, and on the east it is very low. The fact that no pumice has been found within the crater, though on the exterior slopes it has been found at far greater heights than that of the present lip of the crater, is an indication that at the time when the pumice fields floated over from the mainland the marine erosion of the crater-wall had not proceeded nearly so far as at present.

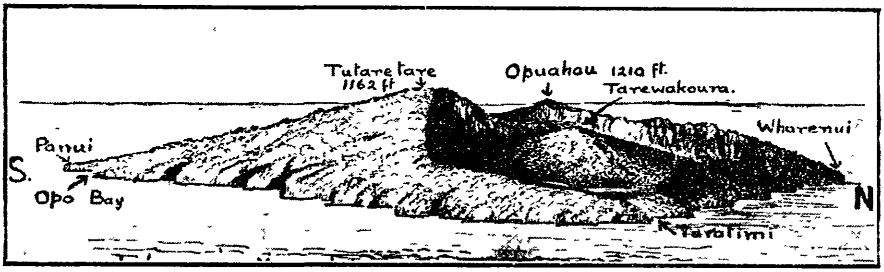

Fig. 1.—Imaginary bird's-eye view of Tuhua or Mayor Island, Bay of Plenty, New Zealand. 3 x 2 miles, 1210 ft. high. Rock: comendite and obsidian.

Many of the features of the land are picturesque and interesting. In places striking arches have been formed in the coast by wave-action. At the north end there is a dyke which has been worn back into some prominent stacks. Usually only a single formation is exposed on the sea-cliffs, but on the north and west where the cliffs are perhaps 50 feet high as many as three or four may be seen. Unfortunately on the occasions on which the island has been visited no landing was possible on these coasts.

Structure of the Comendites.

The most solid and compact rocks are found near the base of the cliffs forming the southern wall of the crater. Here the wall rises with extreme steepness almost to its maximum height of 1200 feet. The rock has a rough prismatic jointing and no flow structure can be seen in it. In hand-specimens it is dark brown in colour with irregular faintly bluish patches. On the sea-cliffs along what is probably the peripheral area of material that has been emitted from the crater the structure of the rock is far less massive, though rough prismatic jointing is still perceptible. Here there is often a banded appearance, which, especially near the eastern bay, may be extremely delicate and striking. Even when the rock is not well banded irregular streaks of lighter and darker colour can be distinctly seen. In these cliffs even in a single deposit the colour of the rock often varies considerably; there may be bands of black obsidian which is particularly glossy, perhaps because of the relatively high percentage of iron-oxides the rock contains. In the analyses of obsidian made by Washington the percentage of iron-oxides is recorded at 3·22, while in the ordinary rocks of the island von Wolff (9) found 7·10, mainly Fe_2O_3, while Seelye found 6·13, 5·93, and 5·87 per cent. in different samples. Its specific gravity is 2·40.

Occasionally the rocks are vesicular in a very irregular manner, some of the vesicles, and in the eastern bay some of the joint-planes, having a deposit of opal. In places there are minute patches of opal with a fine play of colour with scarlet fire. The occurrence of fire-opal in the rhyolites of Mexico is well known, and precious opal has been mentioned as occurring at Tairua, in the Coromandel Peninsula, New Zealand. In addition, these cavities, especially at Opo Bay and on the east side of Omapu Bay, contain splendent though small crystals of two kinds. The two species of mineral that are represented are aegirine and riebeckite. The former has the typical form of ordinary augite which apparently has not previously been recorded for aegirine. The crystals may reach a length of two millimeters with the prisms and two pinacoids as vertical faces and the minus pyramids as terminal faces. The vertical faces vary in relative length to a considerable extent. No twinned crystals have been seen. The cavities in the lightest green coloured rocks often contain aegirine only. In dark-grey rock on the south side of Opo Bay the cavities may contain riebeckite exclusively, or sometimes with aegirine as well. The riebeckite occurs in long bladed crystals which are occasionally one centimeter in length, though the breadth does not exceed one millimeter. The face 010 is narrow, but the prisms are relatively wide. The face 010 also has vertical striations. The extinction angle is 2·5 degrees. The pleochroism is from deep-blue to brownish-yellow, X dark-blue, Z brownish-yellow, Y pale-blue. The following are the best measurements that could be obtained:—110–$1\bar{1}0$ 57·3°, $1\bar{1}0$–$0\bar{1}0$ 62°, $0\bar{1}0$–$\bar{1}\bar{1}0$ 62·2°, $\bar{1}\bar{1}0$°$\bar{1}10$ 55°, $\bar{1}10$–010 62·3°, 010–110 62·3°. The terminal faces are clinodomes and plus orthodome. An observer accustomed to the use of the microscope goniometer would of course obtain quite accurate measurements. A large number of the crystals in some of the cavities are of capillary form. Crystals of riebeckite have been recorded by Sollas in glacial pebbles on the east coast of Ireland (8). The occurrence of these well-formed crystals in vapour cavities makes it obvious that they have been deposited from solution in volatiles. The occurrence of opal in some of the cavities, and lining perhaps half of them, indicates that silica was also present with the volatiles. Mr E. T. Seelye has determined the presence of 0·06 per cent. of fluorine in the rock, and that is probably a small residue only of the amount which was present in the magma. This suggests that the opal was deposited from the fluoride of silicon in the later stages of solidification of the rock. This may have favoured the occurrence of riebeckite and aegirine molecules in the vapour phase, though no evidence was obtained in support of this.

It is possible that the small peninsula of Panui on the south side of Opo Bay is the site of a separate eruption subsidiary to that of the main crater. Beds of tuff 100 feet thick occur between it and the slopes of the main cone. The south coast of this Panui Peninsula is accessible and displays the rock-structure well. As seen without any accessory aids to investigation the colour of the material as well as its structure is surprisingly variable. There are wide belts of light-grey rock in which riebeckite occurs almost to the exclusion of aegirine; in others that are light-green there is aegirine almost without any riebeckite; and in addition there are belts of black obsidian. Though all of these were emitted by this little vent probably in the fragmentary though viscous condition and accumulated quite close to the point of emission, they developed a slight massive flow outward; for it can be distinctly seen that the rocks have a circular outcrop and slope steeply outward.

It is in the massive rocks at the base of the main crater-wall that the main nature of the mineral structure when unaffected by volatile matter is best seen. So far as the species of mineral are concerned there is little to add to the description of von Wolff (10) and more particularly that of Bartrum (1), except that in practically all samples riebeckite is present and sometimes tuhualite also. It is remarkable that riebeckite was absent in all of the rocks that were examined by von Wolff and Bartrum (l.c.). The feldspar, quartz, aegirine and cossyrite in the rocks of the coastline have been so well described by Bartrum that there is little to add. The sections examined support his statement that quartz is very unusual among the phenocrysts and is almost restricted to the groundmass. The feldspar phenocrysts are as stated by him nearly all anorthoclase. In the groundmass there are frequent minute intergrowths of feldspar and quartz almost circular in cross-section, and, surrounded as they are by a zone of femic minerals, they give the rock a most distinct ocellar structure. In hand-specimens of the most compact type of rock, which is found at the base of the south inner crater-wall and as ejected blocks at Opo Bay, some of the feldspars have a deep-blue chatoyance. Aegirine is in the form of small idiomorphic crystals in such rocks and is intimately associated with aenigmatite, though this mineral is usually restricted to the groundmass as cossyrite. This form of it is very general and the litle crystals are almost equidimensional in cross-section. Crystals of aenigmatite occur also in the rocks on the south side of Opo Bay. In many sections the little grains of cossyrite have a red colour. The outline of some of the larger crystals of aenigmatite is a little wanting in sharpness. In the sections riebeckite is very general in rather mossy growths, but sharply bounded crystals are unusual in the rock. Aegirine and cossyrite also often have mossy growths in many of the rocks, which thus acquire a striking and unusual appearance, at once recalling some of the Central African rocks described by Prior and Campbell Smith. In the first specimens that the author described this mineral was in irregular grains only and was wrongly identified as arfvedsonite (Marshall, 5).

In the rocks at Opo Bay another hornblende in the form of small needles 0·1–0·001 mm. is often seen. It has brown to greenish-brown colour with moderate pleochroism. This has not been identified with certainty and it does not occur plentifully. A mineral with a brownish-yellow colour, which is undoubtedly a secondary product, often pervades much of the groundmass, and Col. Campbell Smith has been good enough to inform me that a substance similar to this is found in some of the rocks from South Africa.

The mineral tuhualite has a special interest because its occurrence in the rocks of Mayor Island appears at present to be unique. A description of this mineral is published in the present Part of these Transactions. Its bright violet colour allows it to be seen occasionally in the rocks, even in hand-specimens, when it is associated with transparent feldspar. Tuhualite occurs *in situ* in the rocks at or near the foot of the crater-wall on its south and south-east sides. It has, however, been found also in a number of ejected boulders on the slopes rising from Opo Bay.

MICRO-STRUCTURE OF THE COMENDITES.

So far as seen throughout the island there is a general tendency towards a development of spherulitic structure. When this structure is well developed the main mass of the spherulites is of course composed of radiating needles of feldspar which is probably anorthoclase. Associated with the feldspar are nearly always aegirine and riebeckite, sometimes cossyrite and occasionally tuhualite. In a few instances these four coloured minerals occur together in a single spherulite, though when this is the case each of the minerals is more or less restricted to a particular sector. This structure is best developed in rocks from the eastern side of the crater-wall. There is often a tendency towards a structure of an irregular nature when large areas of an indefinite shape have a light coloured central portion. This is often composed of quartz and feldspar, but not infrequently there are crystals of tuhualite, and associated with it the greenish substance mentioned above, which from its occurrence with the tuhualite apears to be an alteration product of that mineral. Around this central portion of these areas there is usually a border of needles of nearly colourless riebeckite with their long axes arranged radially. Occasionally tuhualite is associated with the riebeckite. Without this zone there is often a more or less indefinite ring of reddish cossyrite and finally a litle aegirine. In this type of the rock the feldspar alone is porphyritic. This structure is best developed in an ejected boulder that was found at Opo Bay. The same structure is, however, sometimes seen to a less degree in the rocks of the crater-wall.

Origin of the Banded Structure.

It is very generally the case that the comendites of Mayor Island are more or less distinctly banded. It can be said that the only materials which are quite free from this structure are the massive obsidians and also the rocks which are exposed on the face of the crater-wall. The banding is extremely pronounced and regular in some of the rocks, but it is perhaps less prominent in the rocks at Opo Bay than elsewhere. The darker bands are brown to black in colour and the lighter are grey. The rock splits readily along the bands of lighter colour, as would be expected, for they are actually far from compact and appear to have included much volatile matter. It has been previously shown that a banded or so-called flow-structure may result from a deposition of fragmentary matter laid down while still in a molten or viscous state by an eruptive action similar to that at Katmai which was so well described by Fenner. The particles of molten matter will then obviously be somewhat flattened out by their own weight and to a far greater extent by the weight of the material which rests on them, having been emitted subsequently to their origin. If such material comes to rest on a sloping surface some amount of mass flow-movement may well take place and accentuate the structure which was initiated by mere pressure. There will necessarily still be a certain amount of viscosity, but as cooling proceeds gaseous matter will be given off, though in insufficient amount to permit of bubbling through the viscous material of the overlying portion of the deposit. This evolved volatile matter may merely remain within the mass and tend to separate the layers of incompletely welded material that has accumulated. It is possible that surface material unaffected by a high overlying pressure may allow of the escape of gas and will thus become completely glassy. The exact nature of the material of the magma that consolidates into acid rocks, at any rate from a physical standpoint, may be regarded as still in doubt. The volatile matter may be physically and chemically more closely associated with the fluid and solid material than has generally been thought. In the present case the occurrence of riebeckite and aegirine crystals in cavities of the comendite at Opo Bay implies an intimate connection between volatiles and molecules of these minerals or of the radicals or even the atoms of which they are composed. Possibly the same statements may apply to the material of these minerals in the rock, which surrounds the vesicles, for whether in rock or vesicles they have precisely similar optical characters. In some instances it may be said that almost half of the total amount of riebeckite and aegirine in the rock has crystallised in the gas-pores.

TABLE OF ANALYSES OF COMENDITES AND RELATED ROCKS.

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	72.28	75.46	72.40	72.00	73.30	70.61	64.00	72.21
Al_2O_3	9.75	11.27	10.00	9.79	11.56	8.59	10.43	9.72
Fe_2O_3	4.44	1.17	6.17	4.95	1.68	2.52	6.30	3.26
FeO	1.43	2.05	0.93	0.97	2.41	5.96	3.86	1.07
MgO	0.28	0.27	0.00	0.24	0.24	0.07	0.34	0.29
CaO	0.44	0.53	0.22	0.37	0.78	0.61	1.45	0.82
Na_2O	4.96	3.45	5.43	4.53	4.84	6.77	7.59	4.42
K_2O	4.50	4.88	4.54	4.20	3.96	4.46	4.39	4.98
H_2O-	1.04	0.28	0.29	0.85	0.40	0.10	0.17	1.96
H_2O+	0.68	0.07		1.76	0.30			0.24
TiO_2	0.23	0.05		0.23	0.33	0.13	0.78	0.62
P_2O_5	0.04	0.00	0.02		0.03			0.10
S	0.02	trace						
B_2O_3	0.00							
MnO	0.14	trace		0.12				0.05
NiO	0.00							
BaO	0.00							
SrO	0.00							
ZrO_2	0.03							
Rare earths ..	0.10							
CO_2	0.00							
Cl	0.02	trace						
F	0.06							
Less	0.03 oxygen correction for Cl and F.							
Total	100.41	99.48	100.00	100.01	99.83	99.82	99.31	99.74

1. Comendite, Mayor Island, New Zealand, containing a little tuhualite. F. T. Seelye, analyst.
2. Obsidian, Mayor Island, New Zealand. H. S. Washington, Chemical Analyses of Igneous Rocks, *U.S. Geol. Surv. Prof. Pap.*, no. 99, p. 151.
3. Pantelleritic liparite, crater-rim, Mayor Island. Lindner, analyst. Von Wolff (10), 1904.
4. Comendite, Mayor Island, containing no tuhualite. F. T. Seelye, analyst.
5. Comendite, El Barta, Lake Naivasha. Campbell Smith, *Q.J.G.S.*, vol. 87, p. 219, 1931.
6. Lake Naivasha, pantellerite, Campbell Smith, *loc. cit.*
7. Lake Nakuru, pantellerite, Campbell Smith, *loc. cit.*
8. Cuddia Nera, Pantelleria comendite, lowest flow. Washington (11), 1914, p. 697.

These analyses, for two of which I am particularly indebted to Mr F. T. Seelye, of the Dominion Laboratory, New Zealand, with the permission of Mr W. Donovan, Director, show clearly that the rocks of Mayor Island are distinctly comendites as has been stated by Bartrum. The high percentage of Fe_2O_3 relative to that of ferrous iron probably accounts for the development of aegirine and riebeckite, especially when so little lime and magnesia are present. The amount of TiO_2 seems rather low for the quantity of cossyrite. The amount of rare earth is interesting, though no minerals especially related to this component were seen.

The Relation of Mayor Island to the Volcanic System of the North Island of New Zealand.

It is well known that andesite lavas, which often contain hypersthene among the femic constituents, constitute the main mass of rocks of the Coromandel Peninsula, which is situated close to the west of Mayor Island. In this area, and probably throughout the Rotorua-Taupo volcanic area also, the greater part of the rhyolite formation with its associated pumice débris was of later origin. At Ongaroto, which is near Atiamuri on the Waikato River and extending towards Rotorua, there is an occurrence of basalt which has pumice lying above and below it. This basalt has characters of a nature so similar to those found in the basalt of Auckland and of the Waikato basin and of the Bay of Islands that they cannot really be distinguished from one another even in microscopic preparations. All of the recent volcanoes of this district are of an andesitic nature, and in them hypersthene is the predominant femic mineral. The lava associated with the great explosion of Tarawera was an extremely basic type of andesite. The general succession of volcanic rocks in this district can thus be stated as follows:—Andesites of recent volcanoes, rhyolites which are actually associated with some emissions of basalt, andesites of Coromandel.

It is of course clear that the comendites of Mayor Island are alkaline representatives of the acid rocks or rhyolites, including under that term all the huge deposits of pumice and ignimbrites which cover so much of the Taupo-Rotorua district. These acid rocks, however, in the very many localities in which they have been studied contain none of the characteristic minerals found in the comendites of Mayor Island. At the present time no suggestion is offered as to the cause of the concentration of the alkaline features in the acid magma in this small localised area.

Suggested Geological History of Mayor Island.

1. The cone was built up in the early portion of the Pliocene period.

2. At a late stage a violent explosive effort enlarged the crater to its present extensive dimensions. Some blocks, notably a few that contained the mineral tuhualite, were scattered over the outer slopes of the cone.

3. Formation of the obsidian cone in the crater.

4. Formation of the small parasitic cone of Panui.

5. Depression of the island 600 feet below the present level. At this time its outer slopes were covered with pumice which drifted from the mainland.

6. Elevation to the present level with prolonged marine erosion, especially on the north and east sides.

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