Art. XXXVII.—*On the Igneous Intrusions of Mount Tapuaenuka, Marlborough.*

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(By permission of the Director of the Geological Survey.)

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INTRODUCTION.

Mount Tapuaenuka,* the highest point of the Inward Kaikoura Range, has long been known to be intersected by numerous igneous intrusions. The aim of this paper is to give a preliminary petrographical account of some of these. The material studied consists of a series of rock-specimens obtained from boulders in the gorge of the River Dee, Middle Clarence Valley, by Mr. C. A. Cotton and the writer in the early part of 1912. The Dee is a mountain-torrent rising in enormous screes on the abrupt slopes of Tapuaenuka, from which it carries in flood-time boulders of very large size. In its bed there is little to be found but crystalline rocks of varying textures and colours, and there is no reason to doubt that these rocks come from within the watershed of the torrent. Care was taken to confine the collection to the upper part of the gorge, above the intersection of the "Post-Miocene conglomerate," in order that possible exotic rocks should be excluded.

Our knowledge of the structure of the Inward Kaikouras is due almost entirely to the labours of A. McKay, who traversed the Middle Clarence Valley in 1884–85, and the Awatere Valley in 1888–89. The three lengthy reports in which he embodied his results are full of details of stratigraphical and structural geology of the highest interest, and will probably long remain the chief source of information on the geology of Marlborough.† Only those parts which relate to the intrusions need be noticed here.

The Inward Kaikoura Range is composed of sandstones, grits, greywackes, argillites, and jasperoid slates of uncertain age, but Jurassic or Lower Cretaceous at the latest. McKay placed them in the Maitai series, of Carboniferous age, with a saving clause that the only evidence obtained indicates a Secondary age. On each side the range is bounded by Upper Cretaceous and Tertiary rocks, let down along tremendous faults. On the Clarence Valley side the Lower Tertiary rocks are covered uncomformably by the "Post-Miocene conglomerate," which is interposed between them and the fault-plane.

Volcanic rocks of Cretaceous age occur in the Clarence Valley, opposite the Bluff River and in the Gore River, but below Tapuaenuka they are absent, and dykes through the Cretaceous and Tertiary rocks are rare. A greater development of Cretaceous volcanic rocks is found in the Awatere Valley, and these are seamed by dense dykes, which pass uninterruptedly into the greywacke series, and run almost to the top of the range.

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* Also spelt Tapuaenuku.

† "On the Geology of the Eastern Part of Marlborough Provincial District," Rep. Geol. Expl., vol. 17, pp. 27–136; 1886.

"On the Geology of Marlborough and the Amuri District of Nelson," Rep. Geol. Expl., vol. 20, pp. 85–185; 1890.

"On the Geology of Marlborough and South-east Nelson, Part II," Rep. Geol. Expl., vol. 21, pp. 1–28; 1892.

Innumerable dykes, forming a perfect network, traverse the older rocks in the upper part of the watersheds of the Branch, Dart, and Muzzle Rivers, Clarence Valley, and trend north to the top of the Inward Kaikoura Range into the watersheds of the Dee and Mead Rivers. The rocks are described as green porphyritic rock, light-grey elvan rock, hornblende rock, fine-grained basaltic rock, &c. It is, doubtless, from these dykes that the specimens studied were derived. There is a great development of similar

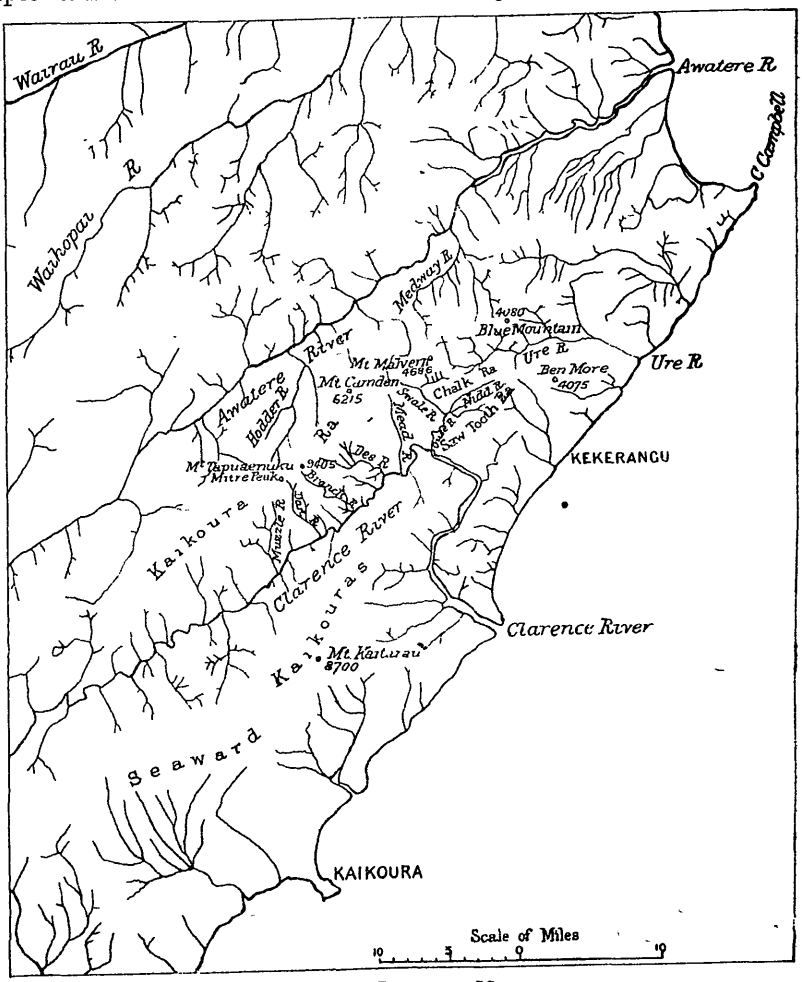

Fig. 1.—Locality Map.

dykes on the Awatere side of the range. McKay considers that these dykes belong to a series older than those intersecting the Cretaceous rocks, since the basal Cretaceous conglomerates contain pebbles of similar character. The pre-Cretaceous dykes he again divides into two series, relying on the fact that the darker and denser dykes usually intersect the lighter syenitic intrusions.

The rocks described in this paper consist apparently of the pre-Cretaceous series of McKay. There is such an *air de famille* about the whole collection as to suggest that they all belong to one series of intrusions. Naturally, if this is the case, a considerable amount of intersection is to be expected, and the district is evidently a favourable one for determining the sequence of intrusions. As to their absolute age, nothing may be certainly stated; until the boulders in the Cretaceous conglomerates are examined and shown to be similar, it is unsafe to affirm that the dykes are pre-Cretaceous. The petrographical character of the Cretaceous volcanics in the Awatere and Clarence Valleys is as yet unknown, and it seems possible that the coarser rocks that form dykes in Tapuaenuka are intrusions from the same magma that poured out the lavas and the dense dykes intersecting them. In this connection it must be remembered that considerable differential elevation has taken place since Cretaceous times, and that in all probability there was then a continuous sea from the Clarence to the Awatere Valley, over the present site of Mount Tapuaenuka.

DESCRIPTION OF THE SPECIMENS.

MINERALS.

As the nature of the minerals is similar in many of the specimens, it will be convenient to notice them first.

The *olivine* is a clear variety, with an axial angle approaching 90°. It is penetrated by the usual cracks, along which opaque iron-ores have segregated, and shows in addition a fairly well-developed schiller structure, due

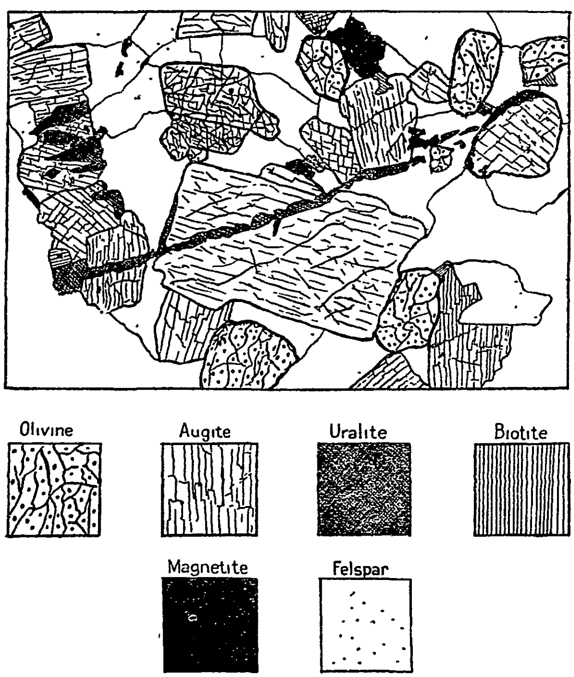

FIG. 2.—Olivine-biotite-dolerite crossed by a shear-zone along which uralite has developed from the augite. Magnified 5 diameters.

to the enclosure of arborescent crystallites of opaque material along vertical planes of the crystals. The commonest alteration is into a tangled mass of talc scales, with occasional prisms of tremolite. This may be termed pilite, in accordance with current practice, although the original pilite of Becke was a mixture of chlorite and tremolite after olivine. Another mode of alteration is into iddingsite, which can be easily distinguished from the biotite present in the rocks by its greener colours, poorer pleochroism and cleavage, and less-regular birefringence. It frequently retains the schiller structure of the olivine. Serpentinous alteration has not been observed in any of the rocks.

The *augite* is a pale lilac-brown titaniferous variety, and frequently exhibits zoning characterized by varying intensity of colour. It has a dispersion so strong that many sections do not yield complete extinction. The axial angle is moderate, the mineral being optically positive. The commonest alteration is to a bright-green uralite both around the edges and along shear-zones (see fig. 2). In many of the rocks the former presence of augite is inferred from the inclusion of greenish or colourless amphibole within brown hornblende.

Amphiboles of various colours and habits are present in most of the rocks. Original common brown hornblende is very common. In the basic dolerites it occurs in subordinate quantity, mostly on the exteriors of augite crystals, and is generally in parallel crystallographic position to them. Sometimes it is intergrown marginally with the augite; at other times it appears to result from a partial magmatic resorption of that mineral. In the rocks with lamprophyric affinities it forms independent crystals or encloses only relatively small cores of augite, and in the spessartites forms also elongate prisms of a second generation. In the acid rocks the original hornblende is a green variety with brown tones. Green hornblende, more or less fibrous, is common as uralite. In many cases the original crystals of brown hornblende contain outgrowths of massive green hornblende which must be interpreted as migrated uralitic material from the augites undergoing that change. As before mentioned, tremolite is found along with talc in pseudomorphs after olivine.

A strongly pleochroic *biotite* is common in most of the rocks, but is sometimes absent. In the dolerites it is usually subordinate to the olivine and augite, and is clustered around these minerals and the iron-ores. Very beautiful intergrowths with augite occur, and in one case a triple intergrowth of augite, biotite, and brown hornblende was observed. The relative abundance of biotite in the basic rocks points to a higher potash-percentage than in normal dolerites.

The *iron-ores* appear to belong to magnetite in all the rock types, and may often be seen by their decomposition-products to be titaniferous. In the doleritic rocks they form large allotriomorphic masses, being moulded on the other minerals; they are seldom decomposed, and show no traces of the rhombohedral structure of ilmenite in reflected light. In the lamprophyric rocks they form small idiomorphic octohedra, and are often altered in part to a white leucoxenic product. Alteration to limonite is also not uncommon. Pyrite is very abundant in all the rocks, and is generally present as a replacement of the magnetite.

The *feldspars* consist of plagioclase in the basic and subbasic rocks, and of potash-feldspars and plagioclase in the acid rocks. The species of plagioclase ranges from bytownite in the most basic dolerites to albite in some of the rocks with lamprophyric affinities. The basic feldspars are generally clear, but the more acid plagioclase and potash-feldspar are extensively sericitized, so that identification is sometimes impossible. In the granites a microperthite forms the dominant feldspar, but owing to its state of alteration the nature of its components has not been determined.

In the identification of the species of plagioclase the methods advocated by Flett and Dewey* have been used for the determination of albite, and extended for the determination of bytownite. These writers point out that the use of extinction angles is not always satisfactory, but that a feldspar with indices less than that of balsam, and with optically positive sign, must be albite or oligoclase-albite. Similarly a feldspar showing symmetrical extinction angles as high as 34° in albite lamellae (and therefore as basic as labradorite), if it is also optically negative, must be as basic as bytownite. The optical sign is determined by the Becke method (observation of the effect obtained by introducing a gypsum plate at 45° to the nicols when studying the interference figure).

The use of the Becke effect (displacement of the halo into the medium of lesser refractive index when focussing downwards) is considerably minimized by the method of preparation commonly used in New Zealand—viz., the use of an adhesive made of a mixture of Canada balsam and shellac, and of liquid Canada balsam for the cover-glass. The drying-off of the covering balsam is seldom carried so far as is the custom in slides made purely with Canada balsam, and consequently the usual data for the refractive index of the dried balsam cannot be used in the few cases where, owing to breaks in the cement, the balsam touches the minerals at the side as well as above. The index of the cement is equally unknown, and must be variable, unless the proportions of shellac and balsam and the period of heating are constant. The advantages of the cement seem thus to be outweighed by its disadvantages, for the use of pure balsam furnishes one of the most delicate methods of distinguishing certain species of plagioclase. The chief advantage of the cement is the ease of mounting, or, rather, the obviation of the necessity of learning by repeated failures the exact amount of cooking necessary to produce the best result with balsam. A good lapidary, however, will work just as quickly with the pure balsam as with a cement.

In the slides used in writing this paper the index of the cement was always appreciably greater than that of the (partially baked) balsam, and less, in all cases where it could be observed, than those of quartz.

The *secondary minerals*, other than those mentioned above, call for little mention. Epidote forms conspicuous nests in some of the hand-specimens of the lamprophyric rocks, but is not markedly abundant in the slides. Chlorite and carbonates are both widespread.

Rock Types.

Certain clearly marked rock types may be distinguished, but there are no sharp lines separating the basic and intermediate biotitic and hornblendic rocks. Any classification must therefore be more or less arbitrary, and this would be probably still more the case if a larger series of specimens were studied. The so-called dolerites are coarse-grained rocks, but nevertheless they must be regarded as hypabyssal and not plutonic.

Olivine-biotite-dolerites.

These are the most basic rocks collected, and are very abundant in the gravels. They are dark-coloured coarse rocks, sometimes resembling gabbro-pegmatites. Olivine, augite, and a basic plagioclase (labradorite or bytownite) are the main constituents; biotite, iron-ore, and occasionally brown hornblende occur in subsidiary amount; while apatite is the most common accessory. The structure is simple, both olivine and augite showing

* Geol. Mag., dec. 5, vol. 8, pp. 203–4; 1911.

idiomorphic outlines to the feldspar, which generally surrounds them as tabular prisms of smaller size, but at times is moulded on them in large crystals. The iron-ores are clearly moulded on olivine and augite, but appear to be anterior to the feldspar. Biotite and hornblende are of late crystallization, and clustered around the iron-ores, olivine, and augite. An interesting feature of the rocks is the presence, in some cases, of a reaction-rim between olivine and feldspar.

Biotite-dolerites.

This type, also fairly abundant in the Dee gravels, differs from the former not only in the absence of olivine, but also in the greater amount of feldspar compared to the augite, and the richer development of biotite. The feldspar is more often zoned, and, on the whole, more acid (andesine to labradorite). Apatite and iron-ores are more abundant, and zircon makes its appearance as an accessory. Brown hornblende is only an occasional constituent, but green uralite is very common.

Structurally these rocks differ from the former in an inversion of the relative order of the feldspar and augite. This is most marked in the more feldspathic types. The feldspars are quite idiomorphic, and are frequently enclosed by the augite, which occurs for the most part interstitially, without forming large ophitic plates. The iron-ores are moulded both on feldspar and augite, but are anterior to the biotite. In some cases, however, the latter must have commenced crystallization at an earlier stage, since it is found intergrown with the augite.

One rock, somewhat similar in composition to the biotite-dolerites, differs from them in the greater abundance of allotriomorphic magnetite, and in the structure. Large crystals of augite are fairly common, but for the most part this mineral occurs in quite small grains, of similar size to the magnetite, and forms with it and basic plagioclase a fine-grained groundmass. There are a few larger feldspars which might be considered as phenocrysts did they not enclose numerous small grains of augite and magnetite. Biotite occurs in large honeycombed plates, and pilite pseudomorphs of olivine are occasionally seen. Although at first sight the rock seems porphyritic, a more careful inspection suggests that this appearance is deceptive, and that crystallization has been uninterrupted.

Biotite-quartz-dolerite.

Only one of the specimens collected is to be placed in this category. Its augite is completely uralitized, but otherwise it differs mineralogically from the biotite-dolerites only in the presence of a moderate amount of primary interstitial quartz. Structurally an ophitic structure is better exhibited, and the iron-ore is anterior both to the feldspar and the pseudomorphs of augite. The biotite has the same relationships as before, and appears to have been intergrown with the original augite.

So far as the writer is aware, this is the first recorded instance of a quartz-dolerite (or quartz-gabbro) in New Zealand.

Doleritic Rocks with Lamprophyric Affinity.

Two rocks agree qualitatively in mineral composition with the olivine-dolerites, but are distinguished by a very different structure. There are a few large plates of augite, but this mineral occurs mostly in quite small and often long prisms. The other minerals—olivine (represented by pilite pseudomorphs), brown hornblende, biotite, and magnetite—all occur in small idiomorphic crystals of characteristic shapes. Large crystals of labradorite enclose all these minerals and abundant prisms of apatite in poecilitic fashion. The chief mineralogical difference from the olivine-dolerites lies in the greater relative abundance of hornblende and apatite and the lesser amount of olivine. The resemblance to the lamprophyres lies in the small size and elongate prismatic habit of the ferro-magnesians.

Two rocks are of a very unusual type. Augite (partially uralitized), brown hornblende, iron-ore, and an acid plagioclase are the principal constituents. Apatite and sphene occur in lesser amount. Chlorite, epidote, calcite, leucoxene, pyrite, and sericite are abundant as secondary products. The order of consolidation appears to have been apatite, sphene, iron-ore, augite, hornblende, and feldspar. The most marked feature of the structure is the perfect idiomorphism of the brown hornblende towards the feldspar, although it encloses augite, iron-ore, and apatite abundantly. The texture is coarse, like that of the average dolerites.

The feldspars are seldom twinned, and are very sericitic. Since, however, they have indices less than both balsam and cement, and are optically positive, they must be referred to albite or oligoclase-albite. The rocks show some superficial resemblances to the Cornish minverites, but differ in the absence of basic plagioclase in addition to the albite. A re-examination, based on fresher material, is necessary before they can be correctly named.

The Spessartites.

The spessartites, according to Rosenbusch, bear the same relationship to vogesites as kersantites bear to minettes—*i.e.*, they contain plagioclase instead of, or in addition to, orthoclase. Camptonites are distinguished by containing barkevicitic hornblende and aegerine borders to the augite. Moreover, the olivine of camptonites is never pilitized.

A considerable number of the rocks from the Dee Gorge are hornblende lamprophyres. Like most rocks of this class, they are considerably altered, and in consequence the determination of the feldspars presents considerable difficulty. Orthoclase has not been certainly determined, while the plagioclase ranges from albite to a semibasic species. Owing to the lack of the distinctively camptonitic characters, and the presence of pilite in some of the rocks with lamprophyric affinities, it is safer to class the hornblende lamprophyres with the spessartites.

No two of the rocks examined agree in all respects, and the degree of variation is considerable. The presence of phenocrysts and needles of brown hornblende is the most constant character. Feldspar occasionally occurs as phenocrysts, more or less sericitized, and is abundant as small prisms or microlites in the groundmass. Titano-magnetite also occurs in two generations, and often shows a marginal alteration into sphene. Augite is not always present, but is sometimes abundant in large and small crystals. Biotite occurs only in the groundmass. Apatite is fairly abundant, sometimes in prisms of sufficient size to justify the name of phenocrysts. Calcite, chlorite, and epidote are abundant.

There are considerable variations in grain-size, but the groundmass is always holocrystalline, the feldspars being sometimes in short prisms and sometimes in radial aggregates. Some of the rocks vary rapidly in texture from place to place, and appear to consist of dark parts veined by clearer material.

Acid Rocks.

Only three specimens of the acid rocks have been studied, and of these one is too near the junction of an argillite inclusion to show its normal characters. The other two rocks are granitic in texture and structure, but in each case the amount of quartz is rather low for a granite. One of the two consists predominatingly of microperthite, with smaller amounts of plagioclase, hornblende, biotite, and accessory zircon, and might be termed a quartz-syenite. The other contains augite in addition to the above minerals, and in it the microperthite does not predominate so much over the plagioclase; it is a hornblende-granite or a quartz-diorite.

Affinities of the Rocks.

It cannot be definitely asserted that the acid rocks belong to the same rock-series as the more basic rocks, but it is probable that they do. The dolerites are not normal lime-alkali rocks, differing in the presence of titaniferous augite and in the abundance of biotite. At the same time, they are not definitely of alkaline affinity. Chemical analyses are necessary before the true position of the rocks can be made out, and it was not considered advisable to undertake these on river-gravels, the more particularly as a much better series of rocks could probably be collected from the dykes *in situ*.

A very similar series of rocks has been described by Bell and Fraser from the Hokitika Sheet, North Westland Quadrangle.* They are described as "pyroxene-camptonite, hornblende-camptonite, hornblende-porphyrite, pyroxene-porphyrite, diabase, augite-diorite, and olivine-basalt." A re-examination of their microscopical sections suggests that the "camptonites" are better termed spessartites. The "augite-diorite" is very similar to the hornblende-albite rock described above from the Dee gravels, but is more easily deciphered; it is an albitized hornblende-dolerite, passing in places into a hornblendite. Bell and Fraser believe the dykes to be of early or middle Tertiary age, because of the lithological similarity to the olivine-basalt of Koiterangi Hill, which rests on a denuded surface of the (Tertiary) coal-measures. This lithological similarity is not brought out in their petrographical description, and, as they admit that the dykes have been found only in pre-Tertiary rocks, considerable doubt must attach to their conclusion as to the age.

Dr. J. Henderson has kindly shown me sections of many similar rocks, found for the most part as boulders in river-gravels near Reefton. They include pilite-spessartites, and some of them approach the odinites in the structure of the groundmass (Dr. Henderson had already identified the rocks as spessartites and odinites). It is perfectly possible, however, that true camptonites also occur in Westland and west Nelson, since alkaline plutonic rocks (ditroite) are known.

The closest analogies with British rocks lie with the pilite-spessartites of the central Highlands, which are associated with vogesites.†

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* Bull. No. 1 (n.s.), Geol. Surv. N.Z., pp. 82–84; 1906.
† Flett, J. S.: The Geology of Sheet 55, Mem. Geol. Surv. Scotl.; 1905.