Igneous Boulders from the Lake Wakatipu District

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DURING recent field-work in the Lake Wakatipu region, numerous boulders of various types of igneous rocks were collected from Pleistocene glacial moraines and sub-Recent river gravels. Many of these tally with descriptions published by Marshall (1903) and Park (1909), but additional types not previously described from this district are now placed on record.

LAMPROPHYRES.

Boulders of lamprophyre are fairly abundant in the gravels of the Shotover River (Park, 1906, 1909) and have probably been derived from dykes which are known to occur towards the headwaters of the Matukituki River (McKay, 1882; Turner, 1932). Three types not previously recorded from this locality are described below:

No. 2590 (Heterogeneous hornblende-camptonite).—This is a holocrystalline non-porphyritic rock with abundant ferromagnesian silicates, exhibiting panidiomorphic texture, and presenting the heterogeneous appearance, not uncommon in camptonites, as a result of local concentration of feldspar in widely scattered spots or " ocelli ". Unaltered barkevikitic hornblende is present in well-formed slender prismatic crystals (0·2 mm. to 0·3 mm. in length) and also as short stumpy crystals (0·1 mm. to 0·2 mm.); both types are frequently twinned parallel to 010. The maximum extinction angle (Z to c) is about 14°, and the birefringence is approximately 0·020. There is a strong pleochroism according to the scheme:—

$$\begin{aligned} X &= \text{light brown}, \\ Y &= \text{dark brown}, \\ Z &= \text{darker brown}, \\ Z &> Y > X. \end{aligned}$$

Titan-augite, often showing zonary and hour-glass structures occurs in two generations, viz., in idiomorphic prismatic phenocrysts usually about 0·15 mm. to 0·20 mm. in length, and also as small grains in the groundmass. The large crystals are frequently bordered with a reaction-rim of barkevikite, immediately adjacent to which a deeper purple tint is developed in the pyroxene. The leucocratic base is made up entirely of much-altered, twinned feldspar laths of indeterminate composition, averaging 0·6 mm. in length, usually with a radiate or sheaf-like arrangement, which is especially marked in the feldspar-rich spots. Fibres of a pale green pleochroic serpentinous material corresponding in its optical properties with bowlingite as defined by Winchell (1933, p. 437) build up aggregates which appear to be pseudomorphous after olivine. Magnetite, skeletal crystals of ilmenite, sphene, rare prismatic crystals of aegirine-augite

and a single cube of pyrites constitute the accessory minerals. A xenolithic group of quartz grains round which the ferromagnesian constituents are concentrated as a reaction-rim was noted in a duplicate section. The heterogeneous nature of the rock is exemplified by the various associations observed within the limits of a single section. These associations are closely similar to those mentioned by Turner (1933a, p. 318) for a similar camptonite from the Matukituki Valley.

No. 2591 (Olivine-camptonite).—In the hand-specimen large phenocrysts contrast sharply with the enclosing dense black, fine-grained base. In thin section there is an approach towards the heterogeneous appearance shown in No. 2590. The constituent minerals are leucocratic base 25%, augite 35%, hornblende 10%, olivine and pseudomorphs 20%, biotite 5%, aegirine 3%, and accessory apatite and magnetite. Purple titan-augite occurs in phenocrysts up to 1·5 mm., and as long, thin, partially altered prismatic crystals, 0·15 mm. in length, in the groundmass. It is sometimes rimmed with a thin reaction-border of deep green aegirine, but more often has partially or almost completely reacted with the magmatic liquid to give hornblende. The amphibole is always deep brown, strongly pleochroic, barkevikitic hornblende. Biotite occurs in flakes 0·2 mm. in length, with intense absorption, but frequently bleached centrally with accompanying lowering of birefringence. It is most abundant in the leucocratic patches. The occurrence of olivine is limited to large phenocrysts only (up to 2·0 mm.), which are partially or sometimes completely replaced by pseudomorphs of talc throughout which dense lines of magnetite granules are developed, giving rise to a type of mesh-structure. During the later stages of magmatic reaction the residual liquid enlarged the cracks of some of the olivine crystals, and there deposited minerals usually late in the crystallisation sequence, viz., biotite, aegirine, and indeterminate feldspar (cf. Turner, 1932, p. 219). The feldspar, medium labradorite, is zoned and much altered to calcite, the latter often occurring in good rhombohedra with secondary lamellar twinning. Some clear isotropic patches with a low refractive index probably represent analcite. Apatite occurs in idiomorphic crystals, often up to 0·4 mm., which show a tendency towards concentration in the leucocratic patches.

No. 2592 (Monchiquite).—The rock is holocrystalline and strongly porphyritic. The pyroxene, titan-augite, is the most abundant ferromagnesian silicate, and it occurs in idiomorphic to subidiomorphic phenocrysts, 0·25 mm. to 0·7 mm. in diameter; also as acicular crystals, 0·15 mm. in length in the groundmass. The amphibole, barkevikitic hornblende, occurs in the groundmass or as reaction-rims to the pyroxene. Pleochroic moderately birefringent serpentinous and chloritic minerals, sometimes associated with secondary sphene, are common, and may be in scaly irregular plates or fibrous masses with an outline similar to that often exhibited by olivine. The feldspar, in small amount is much too altered to enable determination of its composition. Analcite is abundant in the groundmass and may occur as clear patches 0·25 mm. to 0·4 mm. in diameter. Apatite, magnetite and calcite, the latter derived from

the feldspar, constitute the accessories. There is a single inclusion, approximately 8·0 mm. by 1·0 mm., consisting of altered plagioclase and abundant calcite, around which a double reaction-rim has developed. The outer layer consists of subidiomorphic grains of titan-augite (0·1 mm.–0·3 mm.) enclosing an inner zone of feldspar, prismatic aegirine-augite, almost isotropic feebly pleochroic chlorite, and perhaps some analcite.

PLUTONIC AND ALLIED ROCKS.

The plutonic rocks include olivine-gabbros, gabbros, hornblende-gabbros, tonalites, feldspar-porphyrites, granites and granite-gneiss, gneissic diorites and amphibolites.

No. 2593 (Olivine-gabbro).—Macroscopically this is a medium-grained greyish rock, with felsic and femic minerals in about equal amounts, and crystals of olivine visible to the unaided eye. The rock is holocrystalline with a finely gabbroidal texture and consists of feldspar 45%, olivine 20%, augite 15%, and brown hornblende 10%, together with green hornblende, biotite, magnetite and apatite totalling 10%. The feldspar (basic labradorite $Ab_{30}An_{70}$) occurs in allotriomorphic strained crystals (1·0 mm.–2·6 mm.), twinned according to the albite, Carlsbad and less commonly pericline laws. Allotriomorphic and often very highly irregular grains of olivine, averaging 0·5 mm., but sometimes reaching 2·6 mm., are usually much altered to fibrous mesh-serpentine having a very pale green colour, straight extinction and birefringence of approximately 0·009. Reaction-rims of pyroxenes and hornblende may partially enclose the olivines. The most abundant pyroxene is colourless, somewhat schillered diopsidic augite sometimes rimmed with primary hornblende. Occurring as a reaction-rim surrounding olivine is a poorly schillered pyroxene with pronounced pleochroism (from pale pink to pale green or colourless) corresponding closely in its optical properties to the "clinohypersthene" recorded by Service (1934) from the Bluff "norite," except that the sign is positive in the Wakatipu mineral. Recently, however, Bowen and Schairer (1935, p. 199) have determined the sign of artificially prepared clinohypersthene as positive, and a natural mineral of identical properties has been described from a meteorite by Henderson and Davis (1936, p. 222).† Deep brown strongly pleochroic hornblende occurs as reaction-rims to olivine and both pyroxenes; the pleochroism follows the scheme:—

$$\begin{aligned} X &= \text{pale brown,} \\ Y &= \text{pale brown,} \\ Z &= \text{darker brown.} \end{aligned}$$

$$X < Y < Z.$$

The extinction angle Z to c is 25° and the birefringence is approximately 0·015. Pale green hornblende occurs rarely as rims to augite. Strongly pleochroic biotite, rounded grains of apatite and magnetite constitute the accessories.

† E. P. Henderson and H. T. Davis, Moore County, North Carolina, Meteorite, A New Eucrite, *Amer. Min.*, vol. 21, pp. 215-229.

No. 2594 (Gabbro).—The rock consists of feldspar (very basic andesine) 70%, hornblende and augite 10%, olivine 15%, clinohypersthene, hypersthene and magnetite 5%. Olivine occurs in rounded crystals, somewhat serpentinised and frequently rimmed with colourless schillered augite and, rarely, brown hornblende. Occasionally magnetite may form vermicular intergrowths with the olivine. Hornblende is strongly pleochroic according to the scheme:—

X = very pale brown,
Y = deep brown,
Z = very deep brown,
X < Y < Z with Y nearly equal to Z.

This brown hornblende is frequently altered to secondary strongly pleochroic hornblende having an extinction angle (Z to c) of 25° and the following pleochroism:—

X = very pale green (sometimes colourless),
Y = green,
Z = green with a bluish tinge,
X < Y < Z.

The amphibole appears to have been precipitated in such a way that it has enclosed, partially or wholly, the pyroxene and adjacent grains of magnetite. This unusual relation is clearly shown by Harker (1923, p. 71, fig. 20A).

No. 2595 (Olivine-gabbro).—Megascopically this rock is heterogeneous with dark coarsely crystalline patches set in a medium-grained base in which about equal amounts of dark and light minerals are present. The feldspar, which is slightly granulated and epidotised, is a basic labradorite ($Ab_{38}An_{62}$–$Ab_{36}An_{64}$). The olivine encloses magnetite grains, the latter commonly rimmed with hornblende or rarely enstatite, while the olivine itself is almost invariably rimmed with a band of granular magnetite, on which follows a rim of hornblende. Alteration in the olivine is commonly to a deep brown platy mineral with fairly strong birefringence, low refractive index and distinct pleochroism (deep brown to yellowish brown), identified as iddingsite (cf. Ross and Shannon, 1925). The augite which is coloured and often schillered shows the same relation to the hornblende as in No. 2594. Occasionally iron ores form vermicular intergrowths with the pyroxene. Rare brown mica is also present.

No. 2596 (Pegmatitic secretion in gabbro).—This section represents one of the dark coarsely-crystalline patches in the parent rock, No. 2595. Megascopically it is coarsely crystalline, rich in dark minerals, and presents a remarkably heterogeneous appearance. The constituent minerals are feldspar 25%, chlorite 20%, actinolite 20%, augite 15%, talc 10%, iron ore 5%, biotite, tourmaline and hornblende 5%. The feldspar occurs in allotriomorphic grains much fissured and frequently granulated, with a composition of approximately $Ab_{47}An_{53}$; hence it is less basic than the plagioclase in the parent rock. The fissures in the feldspar are usually filled with pale green fibrous chlorites (both optically positive and negative varieties were noted) and short prisms of actinolite. The latter mineral also occurs in pale green to colourless parallel fibrous

aggregates, rarely showing replacement by talc, and sometimes enclosing relict augite; also as large sharply idiomorphic bright green crystals. Frequently idiomorphic colourless crystals of actinolite may be embedded in wide areas of chlorites, when the edges of the former are deep green and pleochroic, perhaps as a result of absorption of iron from the chlorite. These strongly coloured actinolite prisms may be arranged haphazardly, but frequently are grouped to form regular polygonal shapes which probably represent original ferromagnesian constituents. The dominant chlorite, a pale green negatively elongated variety, is associated with minor delessitic chlorite. Greenish-brown hornblende may occur as large prismatic crystals sometimes terminated by a bluish-green amphibole, or as reaction-rims to primary magnetite and colourless augite. The latter is usually in the form of ragged relicts embedded in a matrix of fine flaky talc, which is clearly developing at the expense of the pyroxene; sheaf-like bundles of prismatic crystals of tremolite and vermicular growths or grains of secondary magnetite are closely associated with this talc. Primary magnetite occurs in irregular grains which usually show a reaction relation to the hornblende. Sprays of strongly pleochroic biotite show slight chloritisation with separation of ilmenite along the cleavages, while rare grains of intensely dichroic tourmaline occur aggregated close to the biotite. It seems probable that both minerals have arisen by the action of residual fluids at a late stage in crystallisation.

No. 2597 (Soda-tonalite).—In the hand-specimen, this is a medium-grained rock with abundant dark minerals. In thin section it is holocrystalline, containing feldspar 30%, quartz 25%, hornblende 15%, micas 15%, epidote 10%, apatite 2%, and magnetite 3%. The feldspar, in round allotriomorphic grains, zoned and twinned, is about oligoclase-andesine, showing undulose extinction, bending of twin-lamellae, granulation and slight epidotisation as a result of shearing. Clear grains of quartz, not exceeding 1·3 mm. in diameter, also show strong undulose extinction, while biotite occurs in greenish-brown twisted plates with apatite inclusions. Chloritisation of the biotite has occurred, with concomitant separation of iron ore which may be leucoxenised. The biotite is usually idiomorphic towards, but sometimes appears to have simultaneously crystallised with, the hornblende. Muscovite occurs in rare plates 0·3 mm. in diameter. The hornblende often encloses granular epidote and is strongly pleochroic with—

$$\begin{aligned} X &= \text{yellow},\\ Y &= \text{greenish-yellow},\\ Z &= \text{dark bluish-green},\end{aligned}$$

$$X < Y < Z. \quad Z \wedge c = 20°.$$

It is usually zoned by a distinctive blue amphibole with the following pleochroism:—

$$\begin{aligned} X &= \text{yellowish-green},\\ Y &= \text{bluish-green to yellowish-green},\\ Z &= \text{deep blue},\end{aligned}$$

$$X < Y < Z. \quad Z \wedge c = 9° \text{ (maximum obtainable)}.$$

Occasional fibres of pale actinolite can be recognised in the blue amphibole. The blue amphibole is probably a product of shearing. The strong bluish tint for the Z vibration direction suggests the presence of the glaucophane molecule, but no pure glaucophane was recognised. However, the separation of the glaucophane constituent from the complex molecule in a manner similar to schiller inclusions found in hypersthene, is the mechanism believed by Stillwell (1918) to have produced mottled blue and green hornblendes. A similar reaction may possibly have occurred here. Whatever its mode of origin, the amphibole seems clearly referrable to the actinolite-glaucophane series of Kunitz (1930). Sphene occurs in wedge-shaped crystals, and irregular dusty grains. Apatite, in idiomorphic crystals, and magnetite in rounded grains constitute the accessories.

This rock does not clearly fall into any of the commoner families. On account of the sodic nature of the plagioclase, it cannot be referred to a tonalite or quartz-diorite, and because of the abundance of ferromagnesian silicates it does not fit in with the definitions of trondhjemites given by Goldschmidt (1916) or Vogt (1927). Again, on account of the lack of potash-feldspar, it cannot be termed a granodiorite. However, it agrees with Shand's specification (1927) for soda-tonalite where An>Or and Ab>An. Similar rocks which are common in the Preservation Inlet region of Fiordland have been classed as soda-tonalites by Benson and Bartrum (1935, pp. 136–139).

No. 2598 (Granite-gneiss).—Macroscopically this is a white moderately coarse-grained rock, which in thin section is seen to be holocrystalline, but with a dominantly cataclastic structure. The component minerals are quartz 30%, orthoclase (including microcline and perthite) 20%, albite 35%, biotite 5%, alteration products and sphene 10%. Orthoclase occurs in oval twinned crystals (2·0 mm. to 3·0 mm.) somewhat altered to sericite and minor clinozoisite. Microcline and microcline-perthite are only rare. The plagioclase is almost pure albite and is associated with clinozoisitic epidote and minor sericite. The sole ferromagnesian mineral is a chloritised biotite associated with secondary granular and idiomorphic sphene. Irregular crystals of quartz, averaging 0·1 mm. in diameter, show strong undulose extinction, while some of the larger crystals have been completely granulated. Magnetite is rare.

No. 2599 (Granite-gneiss).—A similar type to No. 2598. The potash-feldspar is usually perthitic, but not greatly altered, while the plagioclase, often in shattered crystals, is oligoclase ($Ab_{87}An_{13}$), much epidotised. Muscovite is a primary magmatic constituent while brown mica has been replaced by chlorite and secondary iron ore, sphene and epidote. Primary iron ores are rare.

The observed mineralogical changes accompanying cataclasis in Nos. 2598 and 2599 may be summed up as follows:—

Orthoclase	——→	microcline.
Orthoclase	——→	microcline-perthite.
Orthoclase	——→	sericite and minor clinozoisite.
Plagioclase	——→	albite, clinozoisite and sericite.
Biotite	——→	chlorite and sphene (or ilmenite).
Titanomagnetite (or ilmenite or rutile)	——→	leucoxene.

No. 2600 (Gneissic hornblende-diorite).—The hand-specimen is a banded gneiss, and in thin section the rock is seen to be holocrystalline with a granitoid texture. The component minerals are andesine 80%, hornblende 10%, biotite 5%, iron ores 3%, apatite and epidote 2%. The feldspar is medium andesine, much altered, except in the finer-grained bands, where the grains are waterclear, probably as a result of recrystallisation. Irregular and rounded grains of hornblende, often schillered, are strongly pleochroic and optically similar to the common type in No. 2597. In parts of the section, and especially in the finer-grained bands, the hornblende is sieved with waterclear xenoblastic grains of untwinned plagioclase, a structure suggesting recrystallisation of the two minerals concerned. In the recrystallised portions, the tint for the Z vibration-direction in the amphibole is a clear blue, while the schiller-inclusions so common in the non-recrystallised mineral are lacking. Strongly pleochroic biotite is often concentrated near iron-ores, to which it may show the normal reaction relation. Iron-ores (including magnetite, haematite and pyrite, all somewhat altered to limonite) and apatite are the accessories.

No. 2601 (Amphibolite).—Macroscopically this is a dense dark rock, cut by many yellowish-green veins. The section shows a gneissic structure and is composed of hornblende 80%, epidote 10%, sphene 5%, and serpentine 5%. The structure is dominantly gneissic. Xenoblastic grains of hornblende up to 2·5 mm. in length, are distinctly pleochroic according to the scheme:—

X = pale yellowish-green,
Y = yellowish-green,
Z = olive green,
$X < Y < Z$. $Z \wedge c = 22°$.

Alteration to chlorite, serpentine and xenoblastic epidote has taken place, the latter mineral being segregated in veins which appear to be located along shear-zones. The iron-content of the epidote mineral (as determined from birefringence) varies from 13% to 5% Fe_2O_3. Cutting the rock is a shear-zone composed of a very pale green flaky chrysotile serpentine (uniaxial, positive), almost microcrystalline in form, together with a little epidote. Sphene, in wedge-shaped or spindle-shaped crystals and calcite in irregular grains, make up the accessory minerals.

No. 2602 (Amphibolite).—In the hand-specimen, this is a dense dark green rock, cut by rare veinlets of calcite and quartz-pyrite. Microscopically hornblende is again dominant, in xenoblastic grains varying between 1·5 mm. and 5·0 mm. It is a more deeply coloured variety than that in No. 2601, the pleochroism being:—

X = yellowish-green,
Y = deep green,
Z = deep greenish-blue,
$X < Y < Z$. $Z \wedge c = 15°$.

The epidote is similar to that in No. 2601. Cutting the rock are two shear-bands containing large grains of yellowish ferruginous epidote, xenoblastic grains of clear granulated quartz, rare albite and pyrite, the latter in ragged grains. Enclosed in the hornblende are numerous

elongated reddish-brown grains with rounded ends, averaging 0·15–0·2 mm. in length. They are pleochroic (light brown to deep brown), usually with straight, though rarely oblique, extinction. Iron-ore granules often form rims to the grains. The refringence and birefringence are both very high, while the angle between the two cleavages is approximately 67°. With some doubt this mineral is referred to sphene, though a closely similar mineral, but without cleavage, has been identified by Marshall (1907) in sections G4 and G18 as rutile.

These last two rocks, Nos. 2601 and 2602, have been termed amphibolites on account of their total reconstitution, though closely similar rocks have been described by Turner (1933b, pp. 266–269) as hornblendites.

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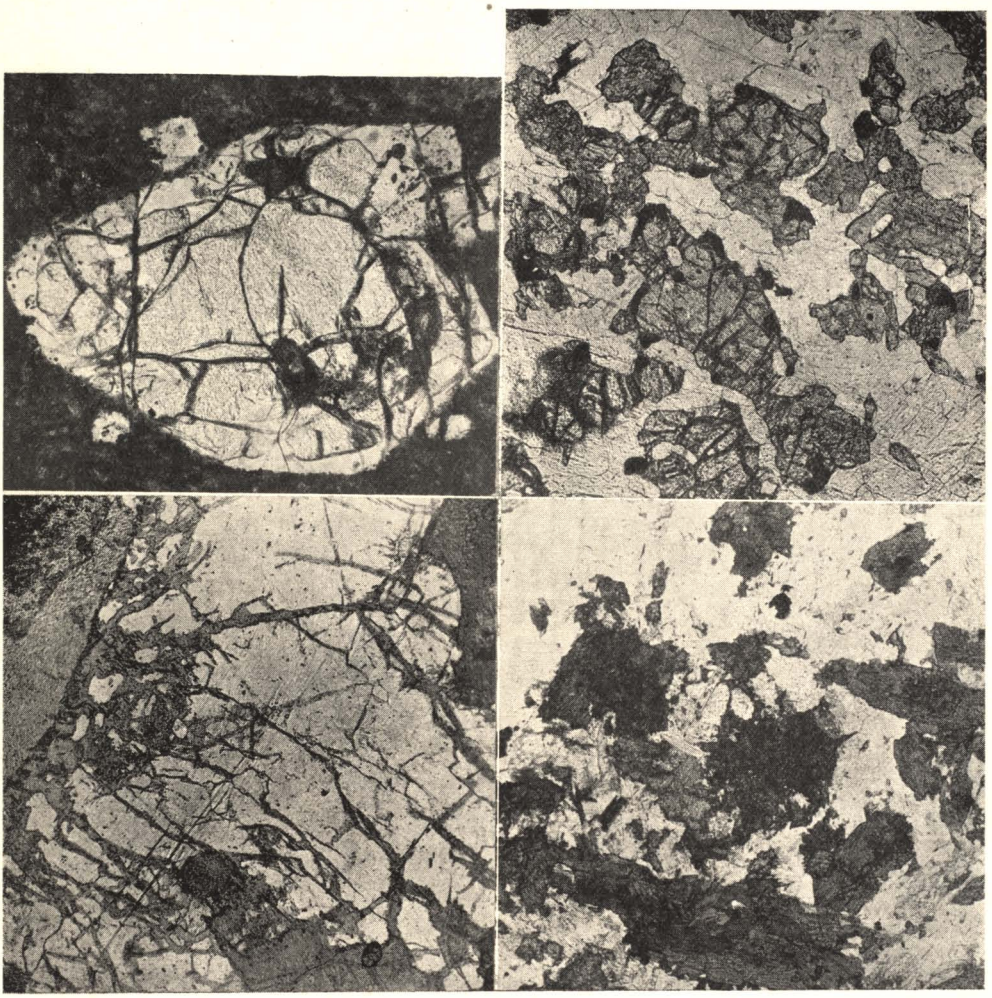

Top: FIG. 1.—Olivine-camptonite (No. 2591) with large phenocryst of olivine, showing replacement by talc.

Below: FIG. 3.—Fractured plagioclase with cracks filled with chlorite, in pegmatitic secretion in gabbro (No. 2596).

Top: FIG. 2.—Olivine-gabbro (No. 2593) with crystals of olivine slightly serpentinised along irregular cracks, set in a clear base of feldspar.

Below: FIG. 4.—Soda-tonalite (No. 2597) showing intergrowth of hornblende and biotite; coarse crystals of epidote are also shown.

(All magnifications 38 diameters.)

Face p. 36]