Note on the Occurrence of Clinohypersthene and Enstatite-Augite in the "Norite" from Bluff, New Zealand

By HAROLD SERVICE, Lubecki Research Scholar, Otago University.

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RECENT investigations upon the " norite " of Bluff Hill, Southland, have shown that in this rock most of the pyroxene hitherto recorded as hypersthene and augite (e.g., Wild, 1911) is actually either clinohypersthene or enstatite-augite. Since, as far as the writer is aware, the latter two have not been recognised as such in New Zealand rocks, their optical properties are here noted.

(1) Clinohypersthene. The following properties were obtained: Fine lamellar twinning on (100) frequently developed. Mean refractive index = 1·72. Birefringence = 0·023. Optic plane parallel to the traces upon (001) of the (100) twins, i.e., perpendicular to the clinopinacoid. X parallel to the b axis. Maximum extinction angle (Z to c) = 35°. Negative. 2V = 30° ± 3°. Pleochroism marked, with X = Y = pale rose pink, Z = pale apple green, and absorption Z > X = Y. The optic axial angle was measured by Becke's graphical method, and the refractive index by oil immersion.

These properties agree closely with those given for the rare species clinohypersthene by Winchell (1929, pp. 43, 157), who has here evidently modified his former statement that the mineral has positive optical character (1927, p. 181). Gotthard (1928) notes that the clinohypersthene of N.E. Bohemia is very similar to normal hypersthene, but has extinction angles (Z to c) up to 10°. Again, Tsuboi (1920, p. 83) records both hypersthene and clinohypersthene in basaltic rocks from Japan, and mentions that in these minerals the optic planes are parallel to and transverse to the c axis respectively; they are otherwise alike except for the inclined extinction of the monoclinic mineral. Presumably, then, the sign is negative in both of the above cases.

The negative sign, low optic axial angle, orientation of the optic plane at right angles to (010), frequent lamellar twinning, and pleochroism conclusively distinguish the mineral from other monoclinic pyroxenes.

(2) Enstatite-augite. Less common than the clinohypersthene is a pyroxene with inclined extinction, positive optical character, low optic axial angle, and pleochroism in shades of faint pinkish-green. Fine lamellar twinning parallel to (100) is universal, and schiller inclusions are seen in end section to be arranged in lines parallel to the traces of these twins. The optic axial angle is small (2V = 25°, assuming β = 1·7), and the plane of the optic axes

is the clinopinacoid—i.e., is transverse to the (100) twinning-plane. The extinction angle could not be determined accurately, but is not large.

Fermor (1925b) has summarised the literature dealing with the enstatite-augite series of monoclinic pyroxenes. They all have low optic axial angle and positive sign. The optic plane in clino-enstatite is perpendicular to (010), but as the diopside-hedenbergite content increases the optic axial angle decreases about Z in this plane until the mineral becomes uniaxial.* It then increases about Z in the (010) plane until the value of 59° is reached for pure diopside.

The mineral from Bluff may thus be identified as an enstatite-augite relatively rich in diopside-hedenbergite; the pleochroism suggests the presence of appreciable iron. Colour and pleochroism appear to vary in the enstatite-augite series (cf. Winchell, 1927, p. 182), though pale brownish tints with very faint pleochroism are characteristic (e.g., Thomas and Bailey, 1924, p. 284; Fermor, 1925a, p. 116). Pale pink distinctly pleochroic varieties have been recorded, however, by several writers (e.g., Tyrrell, 1909, p. 306; Dixey, 1922, p. 325).

This occurrence of pyroxenes of the pigeonite series as important constituents of the typically plutonic Bluff " norite " is of interest, as it bears upon the views advanced by Barth (1931) and Tsuboi (1932) as to the course of crystallisation of pyroxene from basic magmas. According to Barth, the first pyroxenes to crystallise normally are rich in diopside, but as crystallisation proceeds the pyroxene becomes gradually enriched in $(Mg,Fe)SiO_3$, and ultimately attains the composition of pigeonite.

Tsuboi, however, has criticised this view, and has reached the following general conclusions:—

1. In the intratelluric stage of crystallisation (designated as " condition A") either monoclinic or orthorhombic pyroxene commences to crystallise, according to whether the initial liquid lies in the field of monoclinic or orthorhombic pyroxene in the ternary system $CaSiO_3$ — $MgSiO_3$ — $FeSiO_3$. The liquid then changes in composition until the boundary curve between the two fields is reached, when the monoclinic and orthorhombic species crystallise together as separate phases. At the same time the two pyroxenes become progressively enriched in the $CaFe(SiO_3)_2$ and $FeSiO_3$ molecules respectively.

2. In the effusive stage of crystallisation, another condition (" condition B ") prevails, and with rare exceptions the pyroxenic components of the residual liquid crystallise in a single pigeonitic phase without separation into two pyroxenes.

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* Calculation from Hallimond's analysis of uniaxial enstatite-augite from Mull containing FeO = 27·77%, MgO = 12·69%, CaO = 3·80%, shows 10% of diopside in the pyroxene (Winchell, 1927, p. 181).

Thus " the pyroxenic components are only partially miscible in the intratelluric stage, while they are completely miscible in the effusive stage (with rare exceptions)."

The constant occurrence of " pigeonites " in the Bluff " norite " is thus in direct opposition both to the theory of Tsuboi and to the conclusion advanced by Barth. It should be noted, however, that Tsuboi himself thus recognises the possibility of exceptions to his generalisation:— ". . . it is not likely that the conditions A and B respectively correspond *always* to conditions in the intratelluric and in the effusive stages."

In a recent paper dealing with trends of differentiation in basaltic magmas, Kennedy (1933) has put forward an hypothesis which differs from the views of both Barth and Tsuboi. He recognises two independent fundamental basic magmas which he has termed respectively the " olivine-basalt " and the " tholeiitic " magma-types. In the former, early separation of olivine leaves the liquid enriched in lime so that a diopside-rich augite is the first pyroxene to crystallize. In the tholeiitic magma, however, no olivine, or in any case only a small amount, ever separates, so that the first pyroxene to crystallize belongs to the enstatite-augite series.

The clinohypersthene and enstatite-augite in the Bluff " norite " on this hypothesis would seem to be early products of crystallisation from a basic magma from which olivine had separated previously only in very small amount (seen from the rare occurrence of olivine in the Bluff rocks).

The occurrence of these two minerals in New Zealand rocks may be more widespread than has already been recognised, and in this respect it is interesting to note that Dr Marshall (1908, p. 363) records, in a mica-norite from the Darran Mountains, diallage with the " pleochroism and the schiller structure of hypersthene."

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