V.—CONTRIBUTIONS TO THE GEOLOGY OF CEYLON :

4. INTRUSIVE PYROXENITES, MICA-PYROXENITES, AND MICA-ROCKS IN THE CHARNOKITE SERIES OR GRANULITES IN CEYLON.

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(PLATE XX, IN TEXT.)

THE object of the present paper is to provide a short account of a group of rocks to which the general name of *pyroxenite* may be given, inasmuch as they are essentially non-felspathic plutonic rocks, free from olivine, and of igneous origin, and with a nearly colourless monoclinic pyroxene as the chief or only constituent of many of the most conspicuous varieties.¹ The exposures are widely distributed in the Central, Uva, and Sabaragamuwa provinces, and probably throughout Ceylon, but are individually of very small extent. The rocks are composed of the minerals diopside, amphibole, phlogopite (or biotite), scapolite, pyrite, sphene, and sometimes feldspar, calcite, and spinel; the dominant mineral is the pale green or grey granular diopside, colourless in thin sections: the rocks are often entirely, or almost entirely, composed of this mineral; next in importance are green amphibole (dark in hand-specimens, but very pale in thin sections), and a pale golden-brown phlogopite, which sometimes forms a large proportion of the rock, and in extreme cases the whole bulk of sills or dykes several feet in thickness.

The rocks occur in sills and dykes of all sizes, from a fraction of an inch to six feet or more in thickness, and their intrusive character is generally clear. Very similar or identical rocks occur also as nodular aggregates in crystalline limestones, and also near and along junctions of granulite and crystalline limestone²; but for the sake of brevity and clearness, only those occurrences which are less particularly associated with the crystalline limestones are described in the present paper. The pyroxenites are clearly intrusive in the charnockites or granulites; although often occurring in beds or sills following the foliation planes of the granulites, they occur equally or more often as typical dykes crossing these foliation planes, and sometimes occupying joints; the figures illustrate examples of both modes of occurrence, which, moreover, are frequently associated.

This occupation of joints shows that the pyroxenic material must have been introduced after the granulites had sufficiently consolidated to allow of the formation of joints. This fact, together with another, viz., the occurrence of what seems to be a very ordinary mica pyroxene dyke cutting the zircon granite (itself belonging to the Balangoda group,³ and forming an intrusive sill in

¹ For a discussion of the nomenclature of similar rocks, see C. H. Gordon "On the Pyroxenites of the Grenville Series in Ottawa County, Canada," *Journal of Geology*, vol. xii, No. 4, 1904, pp. 324, 325.

² For descriptions see A. K. Coomáraswámy, "The Crystalline Limestones of Ceylon," *Quart. Journ. Geol. Soc.*, 1902, vol. lviii, pp. 399-422.

³ A. K. Coomáraswámy, *Geol. Mag.*, No. 482 (1904), pp. 418-422.

the Charnockite Series or granulites) of Massena estate, Balangoda, appears to indicate that the date of the pyroxenite intrusions was long posterior to that of the intrusion and consolidation of the granulites. Nevertheless, careful examination of the junctions shows that there is never any sign of a chilled edge, but the pyroxenic rock passes, rapidly indeed, but never abruptly, into the granulitic rock next to it, and this even where the intrusive character is otherwise most distinct. There is, in fact, a rapid transition from one rock to the other. Inasmuch as the pyroxenites are intrusive in rocks which had cooled sufficiently to allow of the formation of joints, these facts seem to show that re-melting must have taken place to some extent.

A zoned structure is very characteristic of the rocks, the zoning being marked by the distribution of mica in bands parallel to the edges of the dyke or sill, the individual crystals of mica being disposed in planes perpendicular to the edges of the dyke or sill, which is often symmetrical in structure about a median line, after the manner of mineral veins. The zoned structure is not always produced by mica; in Fig. III, Pl. XX, p. 366, for example, the central darker zone is distinguished by its content of hornblende, and mica is not present.

The pyroxenites seem to be in some way connected both in mineral composition and in actual distribution with the occurrence of crystalline limestones, though the exact relation is not perfectly clear. One curious feature is the presence of carbonates in parts of the dykes, especially at Ella (Uva) and Kadawat Oya (Sab.); when it becomes abundant, the central zone is sometimes indistinguishable from an ordinary crystalline limestone with abundant accessory minerals.

A more detailed account of various exposures (especially those illustrated) will now be given; the localities described have been visited at various times during the last two years.

1. At Ella (Uva) are interesting exposures (Fig. I, Pl. XX, p. 366) in the bed of the Kitul Ela, just below the point at which it is joined by the small stream from near the Rest House. The main part of the intrusive rock consists almost entirely of granular greyish-green diopside (1152);¹ in parts scapolite and a little granular sphene are also present, and more locally hornblende or mica. A section (1153) through the junction with granulite at the point X in the figure shows granulite (a rock composed of quartz and orthoclase with a little pale-green diopside) passing very rapidly but with no loss of continuity into a granular rock consisting of colourless diopside with scapolite and a few rounded grains of sphene. At one point in the exposure a large crystal of diopside projects from the pyroxenite into the granulite, merely an exaggeration of the usual interlocking of minerals at the junction. The inner portion of the pyroxenite (at *h*) becomes rich in carbonates, and the relation to the rather impure granulites at *g*¹

¹ The numbers in brackets refer to thin sections in the author's collection.

is not quite clear. The bands of intrusive pyroxenite following the granulite foliation planes tend to pass into lenticles, as if by a process of pinching, the lenticular forms being exactly followed by the granulite foliation planes; this fact, and the junction phenomena, makes it seem likely that the granulites were not in a completely consolidated state when the pyroxenitic material was introduced. Similar 'pinching' is shown in Fig. II, Pl. XX, p. 366, at X.

2. In the bed of the Talatu Oya at Uduwela, near Kandy, there are several exposures of pyroxenitic rock. Fig. II shows sills of pyroxenite (nearly pinched out at X) combined with dykes along joint planes. A section (1067) of the junction at X shows the intrusive rock to consist internally of an aggregate of colourless diopside with a peripheral hornblende zone passing into the granulite, in which plagioclase and diopside are the dominant minerals, and pyrite is also common. A section (1069) of the pyroxene further from the edge shows only colourless diopside with a trace of plagioclase and green spinel. A junction section (1068) at ϕ (Fig. II) showed orthoclase diopside rock (granulite) passing into a diopside plagioclase rock (pyroxenite) with accessory pyrite, sphene, and apatite. The (subordinate) plagioclase has an ophitic habit, enclosing more than one individual of diopside, which is also intergrown with it in radiating root-like fashion. In the central part of the dyke mica becomes abundant, and is arranged in planes perpendicular to the edges of the dyke, as indicated in Fig. IIa, Pl. XX, p. 366. One other slide (1066) from the place marked XX shows an aggregate of diopside and amphibole with a little accessory pyrite.

Some smaller dykes at Uduwela are very micaceous; a section (1149) of one about an inch wide shows granulite (quartz-orthoclase-plagioclase rock with a little diopside) passing successively into diopside rock with a little plagioclase, diopside rock, and diopside-mica rock. The mica is in hand-specimens the most conspicuous mineral, and is arranged in planes perpendicular to the edges of the dykes.

3. Fig. III shows a zoned pyroxenite dyke cutting the foliation of the Charnockite Series, exposed in the bed of a stream entering the Badulla Oya from its right bank, about $8\frac{1}{2}$ miles from Badulla and near Nanla. The outermost zone (about 3 inches wide) shows under the microscope (1147) a compact intergrowth of colourless diopside (partly also in granular forms) with subordinate plagioclase. The diopside intergrown with plagioclase exhibits root-like forms, and the intergrowth is on a very fine scale, so that the plagioclase is not easily recognizable. The central one or two inches of the dyke are clearly marked by the presence of dark hornblende, which in the hand-specimen can be seen moulded on idiomorphic grey-green diopside in ophitic wire. In the thin section (1148) the hornblende appears pale bluish green, with pleochroism a pale straw, b bluish-green with a brown tinge, and c bluish-green. This is the usual amphibole characteristics of the rocks now described.

Intrusive Pyroxenites in the Ceylon Granulites.

4. There are good exposures of pyroxenites at Kadawat Oya bridge, between Belihul Oya and Halpe (near the 99½ mile-post), Sabaragamuwa. A number of pyroxenic sills and dykes occur, and very heavy hornblende and pyritic types are characteristic. The dykes vary from mere threads up to 1½ yards in width. Some show very clearly penetration of the pyroxenic material along joints (Fig. IV). Several dykes have quite narrow central zones, consisting mainly of pyrite; in one case large individuals of pyrite occurred at intervals along this line. Some of the larger dykes have central portions composed largely of carbonates with abundant accessory minerals (amphibole, phlogopite, spinel).

A section (1122) from the point marked X in Fig. IV shows a rock consisting almost entirely of pale sea-green diopside with a very little pyrite, apatite, and phlogopite; the diopside has a very curious structure, the cavities being occupied by semi-ophitic plagioclase. The whole dyke is about 6" wide. A section (1123) of another dyke, 6"-8" wide, proves it to consist mainly of very pale sea-green diopside, with some strongly pleochroic phlogopite, yellowish-green amphibole, green spinel, pyrite, apatite, and calcite. The diopside tends to granular forms, moulded by the mica and spinel, the latter being apparently almost the last formed mineral, occupying interstices amongst the grains of pyroxene. As the junction with granulite is approached the mica dies out, and some felspar and pink garnet come in. One other dyke, very dark in colour, consisted mainly of hornblende (especially in the central zone), pale bluish green in thin section (1150), and diopside with a trace of plagioclase occupying interstices; the hornblende has a strong tendency to crystalline form, even when in contact with diopside (a reverse relation is found in the central zone of the dyke shown in Fig. III, Pl. XX, p. 366, see description above).

5. 'Thread dykes' and others slightly wider. These very narrow dykes appear as dark lines crossing foliation on the surface of rock exposures (Fig. V). Under the microscope there appears nothing more than a rapid concentration of hornblende along a zone perhaps ¼ inch wide (1103). These very narrow dykes are often in more or less parallel groups of two or three (Fig. V); sometimes they intersect at acute angles. Occasionally they widen out into dykes an inch or more wide, clearly visible in the field, but with such indefinite margins as to be hardly recognizable in hand-specimens.

A few additional examples may be briefly referred to.

6. A sill of grey-green pyroxenic rock 6-8 feet thick is exposed in the river bed below the road, about 10½ miles from Badulla on the Bandarawela road. The rock (1109) is a coarse aggregate of diopside and scapolite with scattered idiomorphic sphenes; other varieties consist practically entirely of diopside, individuals of which reach ¾ inch in width. The rock is very tough. Somewhat similar rocks are found, not quite *in situ*, on the slope below the 69th mile-post on the Badulla Nuwara Eliya road, and some of these are very handsome coarse aggregates of diopside, amphibole, and scapolite, with calcite and idiomorphic sphene (often over ½ inch

long). The magnesian silicates and scapolite are idiomorphic towards the calcite and present a handsome appearance in weathered specimens.

In the Uma Oya below there are numerous exposures, both of 'thread dykes' and of intrusive pyroxenic and micaceous rocks, as well as of coarse felspathic pegmatites, with which their relations are somewhat confused.

7. Of pure mica rocks or veins there may be instanced those described in the (first) "Administration Report of the Mineralogical Survey," Colombo, 1904. Analyses of mica will be found in Professor W. R. Dunstan's "Reports on the Results of the Mineral Survey [of Ceylon] in 1903-4," London, 1905.

One example of a mica rock or vein may be quoted from the (second) "Administration Report of the Mineralogical Survey," Colombo, 1905, p. 20. A large vein of brown phlogopite is exposed in the Mineran Oya, just within the boundary of Sherwood estate (about nine miles north of Balangoda), in the south-west corner. The vein is about 5 feet wide, and strikes 20° N. of E. and has 70° S.S.E., and crosses the foliation of the granulites, which are inclined at low angles. The Oya has for some distance cut its way along the mica vein, which is exposed in the bed of the stream. The largest crystals are 18 inches in diameter, but somewhat flawed.

8. A fairly typical zoned mica pyroxene dyke, from 2 inches to 1 foot wide, is found cutting the zircon granite (Balangoda group) of Massena estate, Balangoda. As the zircon granulites are themselves intrusive in the granulites,¹ the pyroxenic intrusions would thus appear to be removed from the date of intrusion of the material composing the Charnockite Series, by the period required for the intrusion of the Balangoda group.

Canadian analogies. The rocks described closely resemble the pyroxenic rocks associated with the apatite deposits of Canada, described by A. Osann ("Notes on certain Archean Rocks of the Ottawa Valley," Geol. Surv. Canada, part O, Ann. Rep., vol. xii, 1902), and by C. H. Gordon ("Pyroxenites of the Grenville Series in Ottawa County, Canada," Journal of Geology, vol. xii, No. 4, 1903, pp. 316-325), who states that the evidence there too "clearly warrants the conclusion that the pyroxenic rock is intrusive." Detailed descriptions and further references will be found in the papers mentioned.

Summary. A group of pyroxenites, in which the minerals diopside, phlogopite, hornblende, and scapolite predominate, while sphene, plagioclase, pyrite, apatite, and spinel are often accessory, occurs in small sills and dykes intrusive in the Charnockite Series or granulites, and in one case apparently also in a zircon granite of the Balangoda group. The pyroxenic intrusions have usually a zoned or laterally symmetrical structure analogous to that of mineral veins. The intrusive material never shows a chilled edge,

¹ A. K. Coomáraswámy, "The Balangoda Group": GEOL. MAG., 1904, pp. 418-422.

but there is a rapid transition from the pyroxenite to the granulite. The course of the small sills and dykes of intrusive pyroxenitic material is usually determined by the foliation planes and joints of the granulites or Charnockite Series.

EXPLANATION OF PAGE-ILLUSTRATION, PLATE XX (p. 366).

INTRUSIVE PYROXENITES IN THE CEYLON GRANULITES.

- FIG. 1.—Intrusive pyroxenite at Ella (Uva); area shown about 6×4 yards. P, pyroxenite; G, granulite; F, fault.
 „ 2.—Pyroxenite sills and dykes, Uduwela (Central Prov.); length shown about 8 yards. P, pyroxenite; G, granulite.
 „ 3.—Pyroxenite dyke with well-marked symmetrical structure, exposed in feeder of Badulla Oya, near Naula; average thickness, 6 inches. P, pyroxenite; G, granulite.
 „ 4.—Intrusive pyroxenite following foliation planes and joints in granulites (also in Figs. 1 and 2), Kadawat Oya bridge (Sab.); thickness, 6 inches. P, pyroxenite; G, granulite; J J, joints.
 „ 5.—Thread dykes, exposed in feeder of Badulla Oya, near Naula; average thickness, $\frac{1}{2}$ inch.

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VI.—GOLD AT KNYSNA AND PRINCE ALBERT, CAPE COLONY.

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IN 1895 the author visited the Prince Albert Goldfields, and later the Millwood Goldfields in Knysna, and has had the subject constantly before him till quite recently, when, in reviewing the whole question in connection with the geology of the region, which he has now worked out under the auspices of the Geological Commission of the Colony of the Cape of Good Hope, he was able to come to some definite conclusions. The gradual building up of convictions on a subject like this, as facts became clearer with increased knowledge derived from the reports of prospectors, the progress of the Survey, and the access to literature bearing on kindred questions, led to the acceptance of certain general principles, which the author has thought worth while to state in definite form for criticism. The peculiar points in the occurrence of the precious metal in these localities cause them to rank high as fields for research, if not for general enrichment of the inhabitants of the Cape Colony.

The Millwood fields lie in the Outeniqua Mountains, shut off on the north by high grass-covered ridges with many picturesque peaks, rising to heights of about 4,000 feet, on the south by lower hills covered with dense forest. The Outeniqua Mountains form the first of a series of parallel chains that screen the Karroo from the coast, and on the seaward side there is but a narrow coastal ledge separating the foot-hills from the shore of the Southern or Indian Ocean. The rainfall is abundant, but subjected to periods of drought lasting from three to four months; on the whole, however, one can say that there is a heavy shower once a week. The ground about the goldfields is all on a steep slope, and storm-water