ON THE TRICLINIC MANGANIFEROUS PYROXENES

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(Continued from page 429)

MINERAL DESCRIPTIONS

RHODONITES

The following rhodonites have been examined optically and chemically: rhodonite from Vittinge in Finland, rhodonite from Harstigen and three specimens of rhodonite from Långban. Also optical determinations have been made on three other specimens from Sweden, one from Långban and two from Dalsland. The specimens studied comprise mixtures of 70–95 mol. per cent of MnO.

RHODONITE FROM VITTINGE

A description of the mineral deposit at Vittinge was published by M. Saxén[29] several years ago. According to him the rhodonites of this occurrence show some variations as to color, some species being light red, while others are more brownish. This depends on the amount of iron, the FeO-content in three determinations varying from 0.27 to 3.70 per cent by weight. An analysis of the brownish-colored variety gave the following result (analysis by N. Sahlbom):

SiO_2	46.57	MnO	46.28
TiO_2	0.00	CaO	1.60
Al_2O_3	0.73	MgO	0.12
FeO	3.70	H_2O	0.72
			99.72

The refraction was shown to be raised by the presence of FeO as follows:

FeO%	0.27	1.58	3.70
β_{Na}	1.729	1.729	1.734

The determinations referred to in the following were made on a specimen from the collections of the State Museum (RM. No. 6296). The specimen is composed of a granular aggregate of rose-

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[29] *Fennia* **45** (No. 11), 1925, p. 15.

colored rhodonite and quartz As no other minerals are present and the rhodonite holds only a few inclusions of quartz, it was easy to obtain it in a pure state. The separation was made with the aid of Clerici's solution. On account of the granular character measurements of the refraction on a total refractometer were not possible. The values of α and γ obtained on the powder by means of the immersion method were 1.733 and 1.747. The double refraction is 0.014. A direct measurement of $\gamma-\alpha$ and $\beta-\alpha$ gave as a result 0.014 and 0.004. Thus β can be calculated as 1.737. The measurement of $2V_\gamma$ on a universal stage gave as an average reading 61°(±0.5°).[30] If we calculate $2V_\gamma$ from the indices, we get the value 64°44′. This implies an error of about 0.001 in the determinations of the indices and the double refraction.

The analysis made by Dr. A. Bygdén is given as No. 1 in Table 1. In slides the rhodonite shows thin twinning lamellae parallel to (010). The mineral is clear and free from traces of deformation. Readings were obtained on sections cut at suitable angles to the chief cleavages and the γ bisectrix. The resulting positions are shown in the stereographic diagram of Fig. 8, where all corresponding determinations on the minerals studied are collected. The average values obtained from five measurements are quoted below. As $\phi=0$, the cleavage plane $(\bar{1}10)$ is accepted.

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ	$(0\bar{1}0)$[a]
ϕ	92°44′	43.9° (±1.6°)	312.6° (±0.9°)	140.9° (±5.1°)	137.8° (±0.3°)
ρ	90°	86.3° (±1.1°)	65.3° (±0.9°)	25.2° (±1.2°)	90°

[a] According to measurements on twinning lamellae.

The cleavage angle was measured on a goniometer on cleavage prisms. On account of the small size of the prisms the value given above is only approximate, within the limit of about 20′. The spec. gravity, found by using the floating method and the Westphal balance is 3.70.

RHODONITE FROM HARSTIGEN

The sample received from Prof. Hamberg consisted of two transparent crystals of a maximum size of 8–10 mm. According to Ham-

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[30] The figures within parentheses indicate the greatest difference between the average values and the separate measurements.

berg the crystals belong to his type *a c* r k. The corresponding analysis, therefore, is No. 4 (anal. G. Paykull[31]). This analysis is quoted as No. 2 in Table 1. Moreover all analyses made on the Harstigen rhodonite are very similar, only the iron-content in some cases is a little higher than in the analysis quoted here. A polished artificial facet on one of the crystals gave distinct lines of total reflection. The following values were recorded: $\alpha=1.7208$, $\beta=1.7251$, $\gamma=1.7326$. The corresponding calculated angle for $2V_\gamma$ is 74.3°.

The preparation of slides from the crystals offered difficulties on account of the splitting up of the mineral along the cleavages. It was necessary to melt fragments in glass and cut the melt. But a close orientation of the slides was rendered impossible and on account of this difficulty no slide perpendicular to γ was obtained. The measurements of the axial angle, therefore, had to be made on the bisectrix α, only one of the optic axes being accessible. The average of six measurements gave as a result $V_\alpha=52.5° \pm 1°$, and from this $2V_\gamma$ becomes 75.8°.

As a control the refraction was determined on another crystal, taken from the collections of the State Museum (RM. No. 13360). The crystal belongs to the type *c k r* d of Hamberg and the corresponding analysis No. 2 of Hamberg's table is almost identical with that quoted by me. On this crystal a measurement of the dispersion also was made.

		α	β	γ	$2V_\gamma$ calc.
red	(656.3$\mu\mu$)	1.7183	1.7226	1.7302	74°22′
yellow	(Na light)	1.7206	1.7249	1.7324	74°34′
green	(485.15$\mu\mu$)	1.7337	1.7383	1.7458	75°58′

G. Flink, *loc. cit.*, determined the axial angle of the Harstigen rhodonite as 75°57′ for red (Li), 76°12′ for yellow (Na), and 76°22′ for green (Tl). The axial angle for yellow was found by Des Cloizeaux as 75°4′.

The cleavage angle is given by Flink as 92°29′, by Hamberg as 92°21′–92°23′. On fragments of the crystals I found angles of 92°13′–92°37′ and as an average 92°25′. The spec. gravity was determined by Dr. Bygdén by weighing in air and in water, and by the floating method. The resulting average was 3.616.

The following coordinates for the optical orientation are the averages from seven measurements on sections cut obliquely to the cleavages:

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[31] *Op. cit.*, p. 572, 1891.

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ
ϕ	92°25′[a]	40.2° (±2.6°)	303.7° (±3.7°)	143.3° (±2.9°)
ρ	90°	80.3° (±1.7°)	56.6° (±3.6°)	35.8° (±3°)

[a] According to goniometrical measurements.

A more complete examination of the Harstigen rhodonite has also been made by Hey. The values found by him on the whole agree well with those of the present writer. He found: $\alpha = 1.720$, $\beta = 1.725$, $\gamma = 1.733$, $2V_\gamma = 75°$, spec. gravity = 3.615.

RHODONITE FROM LÅNGBAN—SPECIMEN 1

The specimen examined (RM.13448) consisted of crystals of a thick tabular habit which had grown from a granular aggregate of rhodonite and small grains of a brownish mineral, which was not studied in detail. The size of the crystals varied from 3–10 mm. in the longest dimension. For the investigation only the tabular crystals were used. This rhodonite evidently was the first instance showing that the properties of rhodonites and those of bustamites do not vary according to the relations of an isomorphic mix-series. This was shown when an analysis had been made of the crystals. To exclude the possibility that a zonal structure or the presence of impurities might have influenced the positions of the corresponding points in the diagrams a second analysis was made by Dr. Bygdén. For this analysis the crystals were powdered and the powder was carefully treated with Clerici's solution. A few small grains of the brownish mineral were thereby removed. The spec. gravity determined on the powder by the floating method was 3.573. On the crystals first analyzed determinations by weighing in air and water, and by the floating method had given a similar result of 3.575. Both the analyses are quoted in Table 1 as Nos. 3 and 4, the former referring to the analysis first made, the latter to the second. As may be seen from the table, the purifying of the powder has exercised a sensible, though not great, effect on the values recorded. For the point in question whether rhodonites and bustamites belong to an isomorphous series or not, the differences in the two analyses are of no importance.

On polished facets on two of the crystals the following values of the refraction were recorded:

	α	β	γ	$2V_\gamma$ calc.
1.	1.7132	1.7171	1.7260	67.5°
2.	1.7130	1.7171	1.7259	69.2°

The average value of the axial angle becomes 68.4°. The average of six measurements of V_α in slides cut nearly perpendicular to α (only one axis was accessible) was 56°. From this $2V_\gamma$ becomes 68°(±0.7°). In this case also fragments of the crystals had to be melted in glass and no section with both axes accessible was obtained.

Besides isolated small inclusions of the brownish mineral (schefferite?) the rhodonite contains quite small lamellar inclusions of diopside arranged in the manner described in the general discussion. The number of the lamellae is somewhat variable, but in general they are not numerous and the inclusions would easily escape attention if they are not seen in sections parallel to (001).

The coordinates of the bisectrices resulting from four measurements on two sections are as follows:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ	$(0\bar{1}0)$[b]
ϕ	92°13′[a]	38.5° (±1.2°)	298.2° (±1.5°)	143.2° (±1.6°)	136.7°
ρ	90°	77.5° (±0.9°)	52.3° (±1.3°)	40.6° (±1.2°)	90°

[a] From goniometrical measurements.

[b] According to one measurement on twinning lamellae.

RHODONITE FROM LÅNGBAN—SPECIMEN 2

The appearance of this rhodonite is similar to that of the preceding one. A part of a larger crystal was used for the determinations. The specimen used belongs to the collections of the State Museum (RM. 13448). When studying slides of the crystal selected it was shown that this rhodonite was less homogeneous than Specimen 1, and that it contained a considerably larger number of "perthitic" inclusions of diopside. In addition to this there occur small grains of the same mineral which are not uniformly oriented, and not homoaxial intergrown with the rhodonite. On these grains $\gamma-\alpha$ was determined as 0.029 and the axial angle as about 55°. The refraction is somewhat lower than for the rhodonite. The same cleavages are seen as in the rhodonite. These properties agree with those of diopside. A conspicuous feature is that the perthitic inclusions are very richly distributed along irregular, fissure-like streams in the rhodonite. Also, on the whole, the amount of the perthitic diopside varies, some parts of the rhodonite being clearer and almost free fron inclusions, other parts being clouded by them. Figs. 5 and 6 show two reproductions from parts of the slides that are rich in diopside.

Besides diopside there are present several small grains of a colorless undeterminable mineral (amphibole?, optically neg., 2 V_α large).

Before making the analysis the powdered rhodonite was treated with Clerici's solution, the limits of the gravity of the solution being kept as near to that of the rhodonite as possible. In this way a homogeneous powder was obtained which would be practically free from the diopside grains but not free from all perthitic inclusions, the greater part of which may be included in the analysis. Their amount, on an average, is probably about 2–3 vol. per cent. The analysis made by Dr. Bygdén is quoted as No. 6 in Table 1.

The refraction measured on a polished plate, taken from the crystal analyzed, gave as a result: $\alpha = 1.7112, \beta = 1.7153, \gamma = 1.7239$. The corresponding calculated angle for 2 V_γ is 69.5°. Direct measurements on V_α (only one axis was accessible) had shown it to be 55.8°; $2V_\gamma$ calculated therefrom was 68.4°. The spec. gravity determined by the floating method was 3.563.

Measurements on the optical orientation showed it to be similar to that of specimen No. 1 from Långban. In the slides twinning lamellae parallel to (010) are visible.

RHODONITE FROM LÅNGBAN—SPECIMEN 3

This specimen was kindly sent, at the request of the present writer, from the Mineral Department of the British Museum by Dr. M. H. Hey. It is the same specimen (BM. 43473) which had been examined before by that writer, who had studied the bustamite associated with the rhodonite. The specimen consisted of a cleavage piece about 2 by 3 cm. in size. When examined in a slide, it was found to be rather nonhomogeneous. The dominant mineral is rhodonite, but included in it are the following minerals: bustamite, calcite, quartz, some micaceous pseudomorphous substance, and a small amount of the usual perthitic diopsodic inclusions. The bustamite is intergrown with the rhodonite, the different patches of the former present in the slide showing the same optical orientation, but this orientation does not agree with that of the rhodonite. The axes of the cleavage zone of both minerals form an angle of about 20° with each other. Furthermore, the obtuse cleavage angle of the bustamite runs in the same direction as the acute angle of the rhodonite. To judge from the description by Hey it is probable that the material of the bustamite, picked out by him from a crushed part of the specimen, may have come from some larger homogeneous masses of bustamite. In the material studied by me the quantity of bustamite was subordinate. At a preliminary separation of the minerals there was obtained 0.175 grams bustamite, 0.493 grams rhodonite and 0.078 grams quartz; calcite and micaceous pseudomorphs. These figures give an approximate idea of the relative amounts of the minerals contained in the specimen. From the powder the calcite was dissolved by hydrochloric acid and then the rhodonite was purified in the usual way. It could be obtained practically pure, the only impurities visible in the powder being small perthitic inclusions of diopside. The analysis made by Dr. Bygdén is quoted as No. 5 in Table 1. It corresponds to the highest Ca-bearing member of the rhodonite series found by me, and on account of the paragenesis with the bustamite it is not probable that varieties with any considerably greater amount of CaO exist, unless MgO should be completely replaced by CaO.

On a polished facet of the specimen the following values of the indices were recorded: $\alpha=1.7157$, $\beta=1.7203$, $\gamma=1.7281$. From this 2 V_γ becomes 75.7°. From direct measurements on V_α the value 74° is obtained for 2 V_γ. The spec. gravity of the powder was determined by the floating method as 3.581.

On grains melted in glass and cut obliquely to the cleavages, as on slides about perpendicular to α, the optical orientation was found to be about identical with that of the two preceding specimens from Långban. The angle of the cleavages, according to goniometrical measurements, is 92°24′.

Optical Determinations on Other Rhodonites

In connection with the researches summarized above, measurements of the refraction were made on rhodonite from Långban (RM. 13584), from Klapperud, Dalsland (RM. 13260) and from Kesebol, Fröskog, Dalsland (RM. 280181). The first-named specimen consisted of large anhedral rhodonite individuals occurring together with thaumasite and several other minerals, not determined; the second was a fairly large homogeneous cleavage mass; and the third consisted of crystals grown in a fissure, filled with quartz. The determinations were made on a total refractometer and the values recorded are the following:

	α	β	γ	$2V_\gamma$ calc.
Långban	1.7158	1.7199	1.7284	70.2°
Klapperud	1.7167	1.7215	1.7298	74.6°
Kesebol	1.7171	1.7221	1.7299	77.7°

All these values correspond to mixtures of from 22–25 mol. per cent of Ca (Mg) SiO_3 (see diagram in Fig. 10).

BUSTAMITES

The bustamites can be distinguished macroscopically from the rhodonites by a more intense pink color and by its fibrous and radiating structure, which is due to the better development in this mineral group of the cleavage parallel to (010). The material studied and reported in this paper comprises four specimens, three from Långban and one from Franklin Furnace. Also determinations of the axial angle was undertaken on a series of specimens from the same localities.

BUSTAMITE FROM LÅNGBAN—SPECIMEN 1

The analysis corresponding to this specimen was originally made for the State Museum by its chemist R. Blix and was kindly placed at the disposal of the present writer. It is quoted as No. 7 in Table 1. According to the analysis this bustamite is the richest Ca-bearing bustamite studied by me, the molecular ratios of CaO: Mn(Mg)O being nearly 1:1. In the specimen the bustamite is associated with a brownish mineral, showing the same cleavage as a pyroxene (probably schefferite). The bustamite forms a granular aggregate, but homogeneous individuals were obtained of a size sufficient to permit measurements on a total refractometer.

The following values were recorded:[32]

		α	β	γ	$2V_\alpha$ calc.
Red	(656.3$\mu\mu$)	1.66977	1.68280	1.68458	40°28′
Yellow	(Na-light)	1.67198	1.68493	1.68670	40°56′
Green	(485.15$\mu\mu$)	1.68342	1.69648	1.69856	43°12′

[32] In the case of axial angles of the small size occurring in the bustamites a change even in the fourth decimal place produces a considerable effect on the calculated angle. On this account the original values obtained through measurements are quoted unreduced.

Thus the dispersion is of about the same order as in the rhodonites. The axial angles resulting from direct measurements on a universal stage are as follows: red = 40.2°, yellow = 40.5°, green = 43°.

On a bustamite from Långban, Des Cloiseaux found the following axial angles: $2\ E$, red = 68°, green = 72°. When using the β-values quoted above, we get $2\ V_\alpha = 38°46'$ and $40°32'$. It remains undecided, however, whether the specimen used is of the same composition as specimen 1 or of one of the specimens to be described later.

In slides the ordinary cleavages are visible but the cleavage parallel to (010) is better developed than in the rhodonites. No twinning lamellae are seen parallel to the face named but parallel to (110) simple twinning is common. On the powder of the analyzed specimen I found the spec. gravity to be 3.317.

The average coordinates of the bisectrices according to six measurements on different grains are given below. The position of $(0\bar{1}0)$ is the result of two measurements on the universal stage, the angle of the cleavages was determined from measurements on a goniometer.

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ	$(0\bar{1}0)$
ϕ	94°35′	44.0° (±1.8°)	308.8° (±4°)	143.9° (±3.9°)	140.2° (±0.4°)
ρ	90°	82.2° (±3.2°)	53.8° (±3.2°)	36.8° (±3.8°)	90°

BUSTAMITE FROM LÅNGBAN—SPECIMEN 2

This specimen of bustamite had been analyzed previously by G. Lindström (RM. 13397).[33] His analysis is quoted as No. 8 in Table 1. According to the analysis this specimen is considerably richer in MnO and poorer in CaO than the preceding one. Otherwise the chemical differences are small. On a larger individual of the original specimen the following values were obtained on the refractometer: $\alpha = 1.68153$, $\beta = 1.69487$, $\gamma = 1.69691$. The axial angle calculated from the indices is 42°54′. On the powder of the bustamite the angle was measured as 43.3°. For the spec. gravity I obtained by the floatation method the value of 3.386. Lindström's value is 3.40.

The coordinates resulting from two measurements are given below. The cleavage angle is determined by goniometrical measure-

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[33] *Kungl. Vet. Akad. Övers,* **1880,** 53.

ments. On account of the somewhat deformed condition of the grains the value recorded is only approximate.

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ
ϕ	95°22′	43.7° (±0°)	311.8° (±0.2°)	142.5° (±4.7°)
ρ	90°	86.6° (±0°)	70.2° (±5.6°)	20° (±5.5°)

Bustamite from Långban—Specimen 3

The specimen is that from which the rhodonite from Långban, spec. 3, was separated (BM. 43473). Of the bustamite associated with the rhodonite only a small quantity (0.23 g) was obtained practically pure. The impurities present were a few small remnants of rhodonite adhering to the bustamite. The spec. gravity of the powder was 3.410. The corresponding analysis by Dr. Bygdén is No. 9 in Table 1.

An analysis of bustamite had been made previously by Hey. The values found by him are given below under column 2. They agree rather well with those of Bygdén, which are quoted under 1. The greatest difference is to be found in MgO, the amount of which is very small in the analysis by Hey. The difference between the values of this oxide in the two analyses corresponds approximately to the deficiency in the total sum of the analysis by Hey. Hence it seems probable that the value for MgO in his analysis is too low.

	1	2
SiO_2	48.31	47.69
Al_2O_3	tr.	0.43
Fe_2O_3		0.05
FeO	1.87[a]	1.93
MnO	33.04	32.93
MgO	1.90	0.02
CaO	14.93	15.24
Ign. loss		0.29
	100.05	98.65[b]

[a] Determined as Fe_2O_3.

[b] In the sum 0.07 ZnO is included.

The refraction of the bustamite could not be determined by the total reflection method. By immersion γ was found to be 1.7029. In a slide nearly perpendicular to β the double refraction $\gamma-\alpha$ was measured as 0.015–0.016. From this α becomes 1.6874 and from the measured axial angle β has been calculated as 1.7014. The axial angle $2V_\alpha$ recorded in the slides was 36.2°. On a fairly large inclusion in the rhodonite the angle of the cleavages was goniometrically measured as approximately 94°57′.

In order to obtain sections suitable for measurements of the optical orientation the powder was melted in glass and cut. The coordinates of the bisectrices resulting from three measurements are given below:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ
ϕ	94°57′	46.5° (±2.7°)	316.3° (±1.1°)	144.1° (±2.1°)
ρ	90°	87.9° (±0.1°)	76.8° (±3°)	13.1° (±2.8°)

The values of the optical properties recorded by Hey are the following: $\alpha=1.695$, $\beta=1.703$, $\gamma=1.710$; $2V_\alpha$ approximately $=84°$;[34] spec. gravity $=3.418$.

BUSTAMITE FROM FRANKLIN FURNACE

The specimen (RM. No. 24301) studied consisted of a coarse granular aggregate of bustamite, white or feebly yellowish-white willemite and franklinite. The bustamite was picked out by hand in ultraviolet light. Though great care was taken, small inclusions of willemite remained in the resulting powder. The small content of ZnO shown in the analysis may, therefore, at least be partly caused by them. The spec. gravity of the powder was found to be 3.324. The resulting analysis, made by Dr. G. Assarsson, is quoted as No. 10 in Table 1.

On the total refractometer the indices of refraction were measured as: $\alpha=1.67493$, $\beta=1.68766$, $\gamma=1.68973$. $2V_\alpha$ calc. from the indices is 43°32′. The angle directly measured is 44.6°(±0.3°). The average coordinates resulting from three measurements on different grains are:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ	$(0\bar{1}0)$
ϕ	95°11′[a]	44.1° (±1.8°)	310.1° (±1.5°)	143.3° (±2.9°)	140.2° (±0.8°)
ρ	90°	83.8° (±0.8°)	57.7° (±1.8°)	33.2° (±2. °)	90°

[a] According to goniometric measurements.

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[34] This angle was not measured directly, but it was obtained by construction. According to a personal letter from Dr. Hey a mistake with an angle was made in the construction. If the correct angle is used the result will agree with that of the present writer.

In the slides simple twinning is seen parallel to $(1\bar{1}0)$. Thus the twinning face is not the same as in the first described bustamite from Långban, but otherwise both the optical and the chemical properties are similar to those found on that specimen.

The bustamite from Franklin Furnace has been studied chemically and optically by E. S. Larsen and E. V. Shannon[35] and by M. H. Hey. The analyses indicate only small variations in the chemical composition. The content of ZnO in the analyses may, for the most part, arise from inclusions of willemite. The optical data given by the writers named show some departures from the values recorded by me. The figures given by the former and those found by me are compared below.

	Mol. per cent									
	$MnSiO_3$	$FeSiO_3$	$MgSiO_3$	$CaSiO_3$	Sp. gr.	α	β	γ	$2V_\gamma$	$m:M$
Larsen and Shannon	43.01	0.45	1.96	54.58	—	1.662	1.674	1.676	44° (±3°)	94°55
Hey	46.65	0.09	0.08	53.19	3.302	1.664	1.675	1.679	50–55°	95°13
Sundius	49.23	0.61	1.54	48.62	3.324	1.67493	1.68766	1.68973	44.1[a]	95°11

[a] The mean of the calculated and the measured angles.

The axial angles calculated from the indices, as determined by the two first named writers, are 43°38′ and 62°2′. In both cases the refraction seems to have been determined by the immersion method.

THE AXIAL ANGLES OF OTHER BUSTAMITES FROM LÅNGBAN AND FRANKLIN FURNACE

The survey of the axial angle of bustamites is rather easy to make on the powder of the mineral embedded in Canada balsam, because bustamites are negative with a small axial angle and α is directed nearly perpendicularly to the axis of the cleavages. Most of the specimens from Långban present in the collection of the State Museum were investigated in this way. Only in two cases were ordinary slides made. In all cases I obtained axial angles around 40°–44°. On one specimen from Franklin Furnace with an angle of 44.7° the orientation of the bisectrices was measured and found to be similar to that of the sample analyzed from this locality.

From this survey it appears that the axial angle of the bustamites

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[35] *Am. Mineralogist*, 1922, vol. 7, p. 95.

shows only small variations. Probably, therefore, the value 50°–55° found by one of the writers cited above may be due to some error.

IRON RHODONITES AND SOBRALITE

The rhodonites proper and the bustamites are characteristic minerals of the oxidized Mn-ores which are associated with oxidized iron-ores but are poor in ferrous iron. The Fe-rich varieties of the rhodonite group, here named iron rhodonite and sobralite, on the other hand, accompany eulysitic skarn ores, composed of minerals rich in ferrous silicates as knebelitic olivine, spessartite, and hedenbergitic pyroxene. Mineral occurrences of this kind containing triclinic pyroxenes of the species named are to be found at V. Silvberg, Tunaberg and Tuna Hästberg, all located in the central and southern parts of Sweden. A rhodonite with more moderate amounts of FeO is known from Gåsborn in central Sweden. The relations of the corresponding ore occurrences are more doubtful and not yet well understood. From South Carolina, North America, a triclinic mineral, chemically related to sobralite, has been described under the name of pyroxmangite,[36] but the information about it is still incomplete.

IRON RHODONITE FROM GÅSBORN

The mines of Gåsborn have recently been described briefly by N. H. Magnusson.[37] The rhodonite was known previously through a note by J. L. Igelström, who has published an analysis of a specimen from the Stålmalms mine.[38] As the amount of Fe_3O_4 present as included magnetite was not determined by him, a new analysis was necessary, and this was performed by G. Assarsson (No. 11 in Table 1). The specimen analyzed (RM. No. 171773) is made up of a very coarse aggregate of a black rhodonite, the individuals of which attain a size up to 5 cm. The black color is caused by numerous small inclusions of magnetite. A part of the magnetite was drawn out from the powdered material by a magnet, but the greater part could not be removed. The amount of Fe_3O_4 in the material analyzed is, calculated from the value of Fe_2O_3, 4.54 per cent by weight. Besides the rhodonite contains small inclusions of quartz, which calculated from the excess of SiO_2 is 1.74%. In addition

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[36] W. E. Ford and W. M. Bradley, *Amer. Journ. Sc.*, Ser. 4, Vol. **36**, p. 169, 1913.

[37] *S.G.U., Ser. Ca*, No. **23**, p. 98.

[38] *K.V.A. Övers.*, Bd. **40**, No. 7, p. 91, 1883.

to these impurities very small inclusions of a colorless or feebly green amphibole (tremolite?) are present. The amount of this material can not be calculated, but its quantity is small, and its influence must be inconsiderable. The iron content of the rhodonite is 5.2 per cent by weight (9.27 mol. per cent).

In slides the inclusions of magnetite are seen to be arranged in a peculiar manner along planes parallel to (010). The usual cleavages according to (110) and $(1\bar{1}0)$ are well developed. Thin twinning lamellae parallel to (010) occur locally. In addition a coarse intergrowth of lamellar individuals is developed in such a manner that the lamellae are turned 180° to each other around an axis perpendicular to (010), but the lamellae bound each other along planes parallel to (001). The twinning movement accordingly is the same as in the usual thin lamellae parallel to (010), but the planes of contact are different. Through the twinning movement β and γ of the one individual are brought to a nearly parallel position with γ and β of the other, whereas the directions of α of both individuals form a small angle with each other. The lamellae of this type are sometimes very broad (up to 2 cm.), and more irregular intergrowths of the individuals can also be seen along the contacts.

On a polished plate without visible twinning lamellae the refractive indices were determined as: $\alpha = 1.7205$, $\beta = 1.7251$, $\gamma = 1.7326$. $2V_\gamma$ from these values was found to be 76°. Direct measurements gave 76.8° (±0.3°). On account of the inclusions no reliable value of the spec. gravity could be obtained.

The coordinates of the bisectrices resulting from four measurements are as follows:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ	twinning lamellae $(0\bar{1}0)$
ϕ	92°24′[a]	41.5° (±4.3°)	296.2° (±4.8°)	145.7° (±1.7°)	137.0°[b]
ρ	90°	74.3° (±2.5°)	45.9° (±4.3°)	47.6° (±3.7°)	90°

[a] According to goniometrical measurements.

[b] One measurement.

IRON RHODONITE FROM TUNA HÄSTBERG

This rhodonite has recently been described by the present writer,[39] and only a summary of the results will be quoted here.

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[39] *Geol. Fören. Förhandl.*, Stockholm, Bd. **52**, p. 403.

The corresponding analysis is No. 12 in Table 1. It shows a content of FeO of 14.51 per cent by weight corresponding to 26.03 mol. per cent. Notwithstanding this the mineral has maintained the optical properties of a rhodonite with small modifications. The refractive indices resulting from measurements by the immersion method are: $\alpha=1.725$, $\beta=1.728$, $\gamma=1.737$. In slides the double refraction was found to be: $\gamma-\alpha=0.013$, $\gamma-\beta=0.0085$, $\beta-\alpha=0.0045$. $2V_\gamma$ according to measurements on a universal stage is 70.3°. On the powder, separated from the knebelitic skarn ore containing the rhodonite, the spec. gravity was determined as 3.653. The coordinates of the bisectrices resulting as the mean of five measurements are as follows:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ	$(0\bar{1}0)$
ϕ	92.6°	43.8° (±2.6°)	298.4° (±5.8°)	143.3° (±4.1°)	138.5°[a]
ρ	90°	78.2° (±2.3°)	40.8° (±3.8°)	52.3° (±4.7°)	90°

[a] From one measurement.

In the slides thin twinning lamellae after (010) are common.

The iron rhodonite occurs as microscopic grains in a knebelite-ore, composed chiefly of knebelite and some garnet. The content of the rhodonite in the ore does not exceed 5 vol. per cent.

SOBRALITE AND IRON RHODONITE FROM V. SILVBERG

M. Weibull in 1884 described a rhodonitic mineral characterized by a high content of iron,[40] and therefore he named it iron rhodonite. In his treatise on the sobralite from Tunaberg J. M. Sobral mentions a number of optical characters, determined by him on a specimen from V. Silvberg and emphasizes the differences in the optical properties of this mineral and the sobralite from Tunaberg. A similar distinction had been made previously by J. Palmgren.[41] As the true position of the mineral nevertheless remained in doubt, a study of it was undertaken by the present writer. For this purpose two slides of a specimen from the State Museum, collected by Weibull and designated by him as iron rhodonite, were examined. In the specimen considerable homogeneous aggregates of the mineral in question and of a dark green hedenbergite (called Mn-

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[40] *Kungl. Vet. Akad. Övers.*, **1884,** No. 9, p. 29.

[41] Compare below.

hedenbergite by Weibull), alternate with each other. In the slides the former mineral is shown to possess the same optical properties as the sobralite from Tunaberg. Hence the present writer drew the conclusion that the mineral analyzed by Weibull was in reality not an iron rhodonite but sobralite. However, the statements by Sobral and Palmgren were not in accordance with this view and for this reason a survey was made also on Weibull's original material, which is deposited in Lund. Of this material I received one specimen from Prof. A. Grönwall and a sample of crushed pieces of a mineral called iron rhodonite. In the former the mineral is distributed in a similar manner as in the specimen first described, though its amount is less. When examining slides of both specimens from Lund it appeared that in both cases the mineral associated with the hedenbergite is an iron rhodonite and not a sobralite. Thus in the same mineral occurrence both sobralite and iron rhodonite are associated with the monoclinic hedenbergite, which is the dominant mineral. Both the triclinic pyroxenes are similar in appearance, and it is not possible to distinguish them by megascopic properties. Both are colored yellowish red-brown and are developed as anhedral grains. But in determining the spec. gravities it was found that the sobralite was considerably heavier than the iron rhodonite (3.717 as compared with 3.657). Also the refraction showed a considerable difference.

The properties determined by Weibull are the following: the cleavage angle is 87°15′–87°49′. Sometimes also inferior cleavages occur, evidently parallel to (001) and forming an angle of about 70° with the former. Specific gravity was found to be 3.672 at 15°. In the slides the mineral is shown to be rather rich in inclusions, partly consisting of a feebly greenish mineral (Mn-hedenbergite), partly of small magnetite grains, more rarely also of calcite and silvbergite (Mn-bearing grünerite). In the slides studied by me no inclusions of hedenbergite were seen, but both the triclinic pyroxenes are rather rich in inclusions which may consist of grünerite, although the size is, for the most part, too small to permit definite determination. The triclinic character of the pyroxenic compounds was established by Weibull on sections parallel to (010) and (100). One complete and two incomplete analyses were made by him. After corrections on account of the inclusions present the values given in column 13 of Table 1 were obtained. According to the analysis the mol. proportions of $MnSiO_3$ and $FeSiO_3$ approach 1:1

(43.6:39.8). The amount of CaO at the same time is considerable (12.8 mol. per cent) and that of MgO is small (3.8).

From the description by Weibull it is not apparent if the mineral analyzed by him was an iron rhodonite or a sobralite. The extinction angles and the spec. gravity reported by him indicate rather the former than the latter, although the values recorded are intermediate in character. On account of this the sobralite obtained from the State Museum was separated from the Mn-hedenbergite. This was done with Clerici's solution. Though the solution was kept as near to the spec. gravity of the mineral as possible and the separation was repeated, small inclusions of grünerite could not be avoided, and their amount in the resulting powder was considerable, perhaps amounting to 8–10 per cent by volume. Any possible remnants of carbonate were removed by means of hydrochloric acid. The analysis was made by Dr. Bygdén and the result is quoted under No. 14 in Table 1. From the analysis it is evident that the material analyzed by Weibull was a sobralite, although the values obtained by him are somewhat different from those of Bygdén. This is due partly to the corrections made by Weibull, but also apart from them a considerable difference is found in the proportions of FeO and MnO. Probably the cause of the difference is partly to be sought in the purifying method used by me, but it is also possible that the specimen analyzed by Weibull contained some iron rhodonite. In any case the more correct composition of the sobralite is shown by Bygdén's analysis, though this also includes slight admixtures of grünerite.

On the other hand, it is probable that the material studied microscopically by Weibull, came from a specimen of iron rhodonite as the spec. gravity determined by him approximately agrees with this mineral.

In slides of the analyzed specimen the sobralite appears as anhedral grains of varying dimensions (up to 3 mm.). The different individuals are often intimately interwoven with each other and in some cases penetration twinning is seen. In these cases the grains are composed of several smaller parts belonging to two individuals. In the slides the boundaries of the parts show a tendency to assume the form of straight lines oriented parallel to the face (001), the one individual at the same time being turned 180° about an axis perpendicular to (010). Evidently the twinning phenomenon is the same as in the Gåsborn rhodonite, though the bounding faces in the sobralite are more irregularly developed. Locally also the general twinning lamellae parallel to (010) occur.

The optical properties of the sobralite were found as follows: $\alpha = 1.738$,[42] $\gamma - \alpha = 0.017$, $\beta - \alpha = 0.014$. From this we get $\beta = 1.752$, $\gamma = 1.755$, and from the indices $2V_\gamma = 42°48'$. The direct measurement gave as a result $2V_\gamma = 41.6°$. On the powder the spec. gravity was found to be 3.717.

The coordinates of the bisectrices, resulting from an average from three measurements, are:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ
ϕ	92°32′[a]	18.7° (±1°)	266° (±1.5°)	136.6° (±2.6°)
ρ	90°	60.9° (±0.9°)	53.7° (±2.0°)	48.5° (±1.4°)

[a] The value given by Weibull. The mean of the measurements on the universal stage is 92.2°.

On comparing the positions of the corresponding points on the stereographic projection of Fig. 8 with those of the rhodonites, and the iron rhodonites, the optical discontinuity between sobralite and the minerals named is clearly demonstrated. The same is shown by the size of the axial angle, which in the rhodonitic varieties varies but slightly and which for the members of similar CaO content is about 70°, whereas sobralite has an angle of about 42°.

For the iron rhodonite, associated with the Mn-hedenbergite from V. Silvberg, the following coordinates were obtained from three measurements:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ
ϕ	93.3°	44.4° (±2.7°)	294.3° (±5.6°)	143.3° (±2.4°)
ρ	90°	76.0° (±0.7°)	36.0° (±2°)	57.2° (±2.3°)

The measured axial angle $2V_\gamma$ is 76.9° and the spec. gravity was found to be 3.657.

SOBRALITE AND IRON RHODONITE FROM TUNABERG

The sobralite from this locality was found by J. Palmgren.[43] Ac-

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[42] Determined by the immersion method.

[43] *Bull. Geol. Inst. of Upsala*, Vol. **XIV**, p. 173, 1917.

cording to him the mineral forms "eine Aussonderung in Form einer einige dm. breiten Ader. Diese Aussonderung bestand aus einem Pyroxenmineral, welches im Handstück bräunlich mit einem Stich ins Lila ist sowie aus Manganfayalit und Spessartin." In the pure powder the grains of the triclinic pyroxene are slightly lilac-colored. Palmgren quoted an analysis made by R. Mauzelius, reported here as No. 15 in Table 1. The spec. gravity determined by Dr. Mauzelius was 3.60. Palmgren's report was accompanied by a preliminary determination of the optical orientation, made by J. M. Sobral. Later Sobral published a more exhaustive description of the mineral.[44]

Palmgren seems to have regarded the pyroxene contained in the specimen analyzed as homogeneous. In Sobral's description is mentioned the fact that the sobralite in the slides studied by him was associated with diopside, an asymmetrical pyroxene, olivine and spessartite. The other asymmetrical pyroxene present is compared by Sobral with the iron rhodonite from V. Silvberg. Sobral is of the opinion that this mineral forms a separate species and that it is not a rhodonite nor a sobralite though it optically stands nearer to sobralite than to rhodonite on account of its optically positive character. Evidently this assumption is due to the erroneous statement in the handbooks of the optical character of rhodonite, which is taken from the old investigations of G. Flink.

The writer studied the same specimen as that from which Sobral prepared his slides (RM. 172284). In agreement with him the writer found two asymmetrical pyroxenes, the one being sobralite, the other rhodonite with the optical properties of an iron rhodonite. Of the two pyroxenes the latter is present in greater quantity than the former. Mn-fayalite and garnet are present in rather large quantities and in addition the writer found small amounts of grünerite, some apatite and traces of a carbonate. The diopside recognized by Sobral occurs in subordinate amount. It is distinguished from the other pyroxenes by its high double refraction (about 0.030). The appearance of the pyroxenes and their mutual relations have already been described (see Fig. 2).

As it is not evident from Palmgren's paper whether the specimen on which the analysis was made is the same as that which was used for Sobral's slides, a new analysis was made on the specimen microscopically examined by Sobral and me. For this purpose the pyrox-

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[44] *Bull. Geol. Inst. of Upsala*, Vol. **XVIII,** p. 47, 1921.

enes were separated from the other minerals by Clerici's solution. The resulting powder had a spec. gravity of about 3.62. The analysis was made by Dr. Bygdén and is quoted as No. 16 in Table 1. It is in good agreement with Mauzelius' analysis and also the value of the spec. gravity is similar. Both the analyses thus correspond to a mixture of iron rhodonite and sobralite with a small admixture of diopside.

Sobral determined the following properties of the sobralitic pyroxene: $\gamma-\alpha=0.0200$, $\gamma-\beta=0.0175$, $\beta-\alpha=0.0025$, $2V_\gamma=41.1°$, $\rho>\nu$. From the first and the last values of the double refraction we get an axial angle of 41.4°. The cleavage angle was found to be 91.5°.

From the measurements quoted by Sobral the present writer has graphically deduced the following coordinates of the bisectrices:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ
ϕ	91.5°	15.7°	265.4°	135.4°
ρ	90°	62.4°	56.8°	47°

I have recorded the following values: $\gamma-\beta=0.0155$, $\beta-\alpha=0.0025$. From this $\gamma-\alpha$ is 0.0180, and $2V_\gamma=43.8°$. $2V_\gamma$ was measured as 41.2°(±0.6°).

The coordinates of the cleavages and the bisectrices resulting from five measurements are as follows:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ
ϕ	92°	14.2° (±5.4°)	264.7° (±4°)	136.9° (±5.1°)
ρ	90°	62.2° (±4°)	56.5° (±6.7°)	46.2° (±5.8°)

The values of the separate measurements vary a good deal on account of the somewhat deformed state of the mineral.

The values obtained by me are in good agreement with those of Sobral. Only the double refraction is somewhat lower in my measurements. No attempt to determine the refraction was made on account of the nonhomogeneous character of the powder.

On the iron rhodonite the following coordinates resulted from three measurements:

	$(\bar{1}10):(\bar{1}\bar{1}0)$	α	β	γ
ϕ	92.15°	40.6° (±0.9°)	296.2° (±1.4°)	141.0° (±2.5°)
ρ	90°	76.8° (±1.7°)	43.2° (±1.8°)	53.0° (±4.3°)

The axial angle $2V_\gamma$ was found to be 68.3°. Thin twinning lamellae parallel to (010) are seen locally.

PYROXMANGITE

This mineral has been described by W. E. Ford and W. M. Bradley from specimens coming from Iva, Anderson county, South Carolina. The mean of two analyses by Bradley is quoted as No. 17 in Table 1. According to the analysis the mineral represents a nearly pure Fe-Mn-silicate with subordinate admixtures of CaO and Al_2O_3. The amount of FeO is somewhat greater than that of MnO. The axial angle was determined as positive and approximately 30°. From the measurements quoted it appears that the mineral is triclinic and has a cleavage angle of 91°50′. In addition to the usual two main cleavages partings occur parallel to (010). Whether the optical orientation is in accordance with that of sobralite is not clear from the measurements given.

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THE OPTICAL ORIENTATION OF THE TRICLINIC PYROXENES

On the stereographic projection of Fig. 8 the positions of the bisectrices are plotted according to the coordinates given in the above. The positions of the bisectrices in relation to the cleavage faces are obtained at once when making the measurements on sections in which the two chief cleavages are accessible. The position of the face (001) and of the obtuse crystallographic angle β, on the other hand, can not be located in this way. This can only be accomplished in a section whose position is determined in relation to faces of known crystallographic indices. In order to accomplish this two crystals of rhodonite from Harstigen (RM. 13360) were selected and measured on a goniometer. The following faces and angles were recorded:

Crystal 1		Crystal 2	
$(\bar{2}21):(\bar{1}10)$	31°15′	$(\bar{2}21):(\bar{1}10)$	31°19′
$(1\bar{1}0):(001)$	86°28′	$(\bar{2}21):(110)$	76°54′
$(\bar{1}10):(\bar{1}\bar{1}0)$	92°23′	$(110):(1\bar{1}0)$	92°20′
$(110):(001)$	68°36′	$(\bar{1}00):(\bar{1}10)$	44° 9′
$(2\bar{2}\bar{1}):(00\bar{1})$	62°18′		

Crystal 1 was cemented with the face $(2\overline{21})$ on an object glass and cut down in this position. In the resulting slide the bisectrix β was observable. On crystal 2 an artificial face was cut at an angle of 4 degrees to $(\bar{1}00)$ and used for the preparation of the slide in a similar way as in the foregoing case. In this slide α was accessible. In both cases the orientation obtained was identical. The results of both measurements are brought together in Fig. 7. The orientation shown here is in agreement with that previously arrived at by Hey, but it does not agree with that of H. Buttgenbach and M. Melon,[45] whose results differ from that presented here by a rotation of the bisectrices of approx. 90° about the vertical *c*-axis.

The orientation shown in Fig. 7 is valid for the rhodonites. Concerning the crystallographic development of sobralite we do not

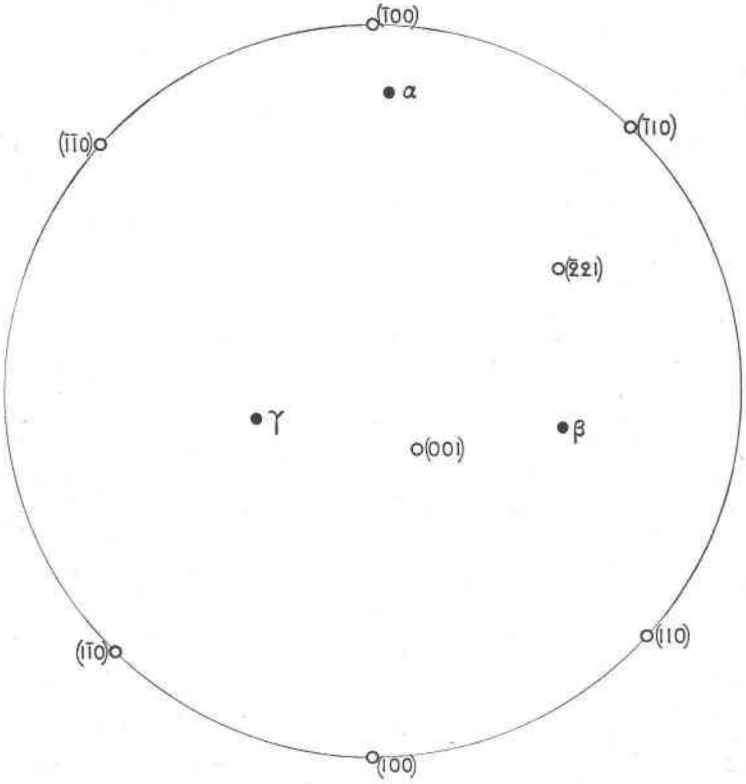

FIG. 7.

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[45] *Op. cit.*

twinning lamellae is not the same as in the monoclinic pyroxenes, the twinning face here being (100). In the iron rhodonite from Gåsborn and in the sobralite from V. Silvberg a modification of the twinning mentioned above is seen, the actual rotation of the individuals being the same, but the planes of contact are (001). Also more irregular intergrowths of the twinned individuals occur.

In the bustamites simple twinning parallel to the cleavage faces (110) or ($\bar{1}$10) are often developed.

SUMMARY OF THE OPTICAL PROPERTIES

The distribution of the points in the diagram of Fig. 8 offers several points of interest. If the different species of the triclinic pyroxenes were members of a related isomorphous series, this would appear in the arrangement of the points, the positions being changed continuously and in a regular manner according to the chemical variations. But this is not the case. From the diagram it is apparent that the rhodonites proper, as a result of the increase of CaO, change their positions in the diagram, though the movements occurring are not great, all points belonging to the same bisectrix being situated on a nearly straight line. The iron rhodonites lie approximately in the continuations of these lines or are only slightly displaced. The displacements may be due chiefly to the influence of the iron silicate; to some extent they can be caused by errors in the measurements. The bustamites, on the other hand, do not at all agree with the rhodonites, and the same is still more evident for the sobralites, whose orientation is very different from that of all the other triclinic pyroxenes.

The change shown in the diagram for the bustamites corresponds to an increase of the $CaSiO_3$-content from 33 to 49 mol. per cent. This change is considerable and is most conspicuous at β. Evidently, if we consider a continuous further enlargement of the Ca-content as possible, the change of the optical orientation would continue in the same direction as before. In a very Ca-rich composition we should get a position of β nearly or exactly coincident with the axis of the vertical zone (the *c*-axis in the present projection), the other bisectrices at the same time being displaced at the periphery of the projection. Thus we should get the picture of a monoclinic or nearly monoclinic mineral, projected on the crystallographic *b*-axis and the orientation obtained would be about identical with the relations in wollastonite. This is shown in Fig. 9 which contains an know more than the approximate angle of the cleavages. On the other hand, the orientation of the bustamites selected here is accidental and is only accepted for the sake of a better comparison. On account of the results obtained in this work it should more correctly be replaced by the orientation named elsewhere in this paper.

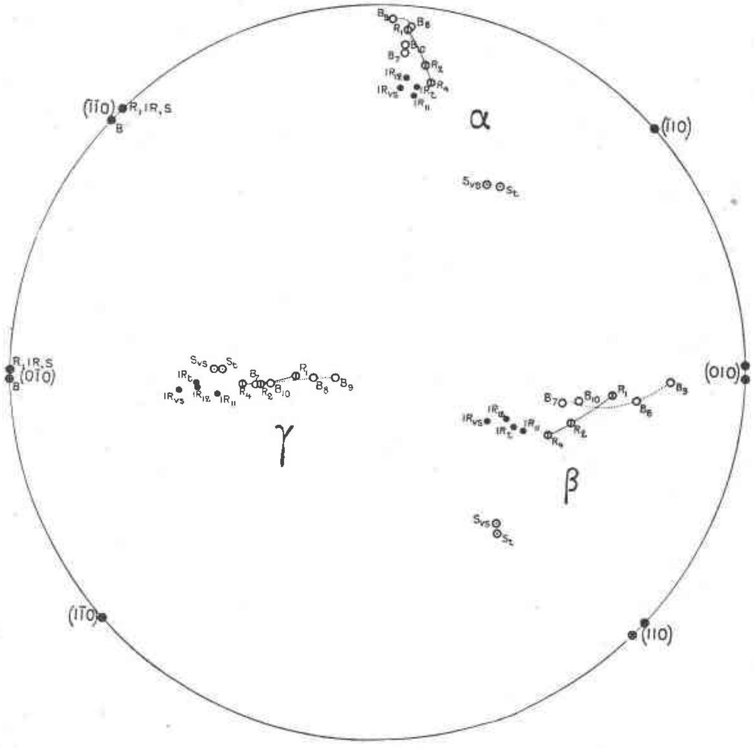

FIG. 8. Stereographic projection of the optical orientations of rhodonites (R), iron rhodonites (IR), sobralites (S) and bustamites (B). The figures of the letters refer to the figures in Table 2; *vs* = V. Silvberg, *t* = Tunaberg.

TWINNING PHENOMENA IN THE TRICLINIC PYROXENES

Twinning phenomena occur in most of the specimens examined. Most common is the appearance of thin twinning lamellae parallel to (010). Lamellae of this kind are seen both in the rhodonites and in the iron rhodonites, as well as in sobralite, but not in the bustamites. It deserves to be mentioned that according to the crystallographic orientation chosen for the rhodonite the position of the extrapolation from the bustamites in accordance with the change outlined above. Thus, in the figure the bisectrices of the most CaO-rich bustamites have been shifted so that there is coincidence of β with the axis of the cleavage zone. The resulting orientation, thereafter, is shown in a projection similar to that of wollastonite, projected with the crystallographic c-axis at the center. For this reason (110) in the ordinary orientation of the bustamite is made (100), and ($\bar{1}10$) as (001). As shown in the figure the differences occurring between wollastonite and the extrapolation from the bustamites are quite small and not greater than possible errors in the measurements on the universal stage, or to possible movements of the ellipsoid around β during the supposed change of its position. This is

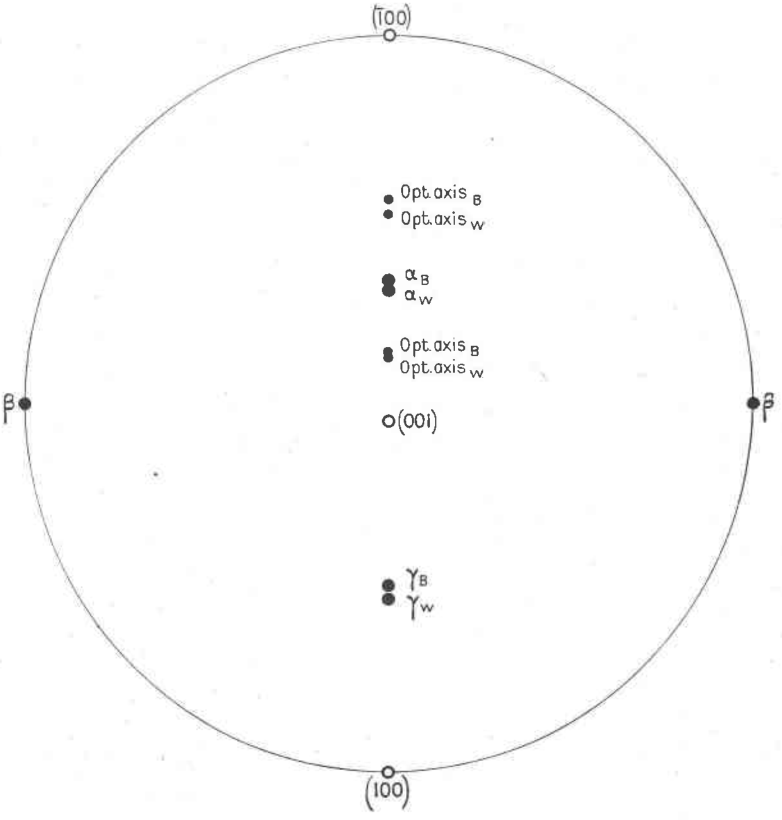

FIG. 9

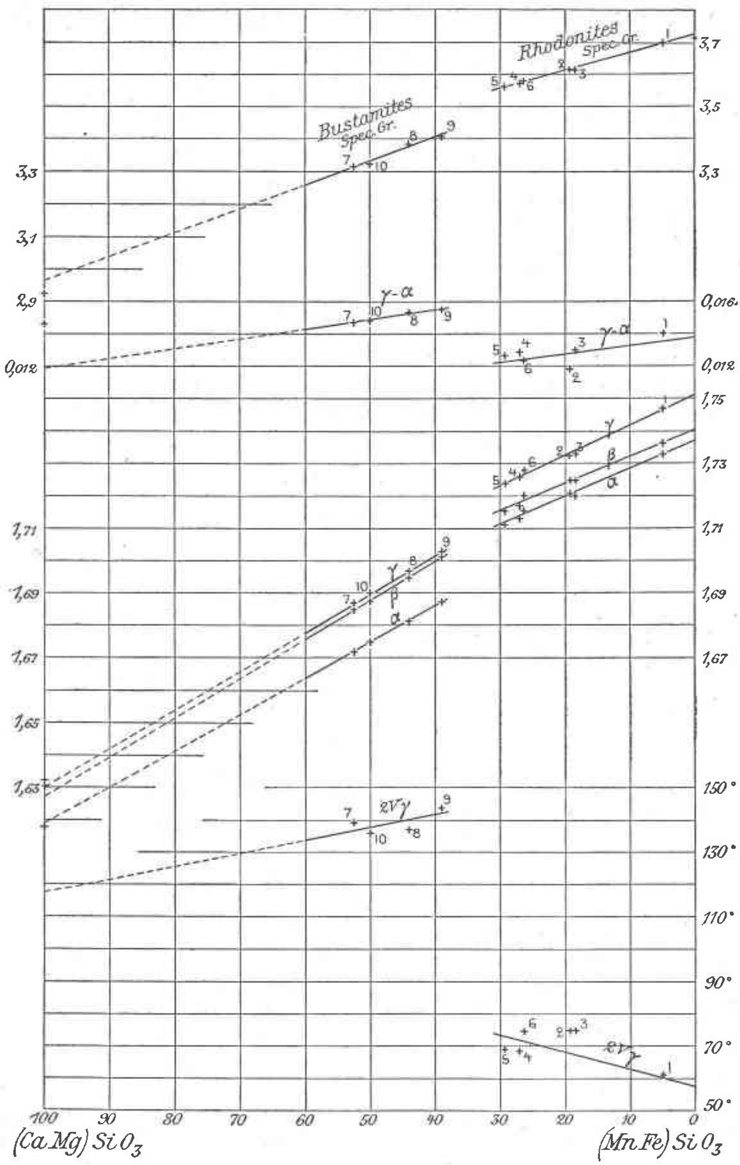

FIG. 10. The values reproduced in the diagram refer to the values in Table 2. The points on the Ca(Mg)SiO_3-side are the values of wollastonite from Pargas, determined by the writer.

one of the reasons why the bustamites in this work are considered as isomorphous with wollastonite.

In Table 2 the values of the refraction, the double refraction, the spec. gravity and of the axial angles obtained from the specimens examined are assembled.[46] For the rhodonite from Harstigen the values of Hey are added. The figures of the sobralite from Tunaberg represent the mean of the values of Sobral and those of the present writer. For the rest no older determinations have been quoted, partly because they are incomplete and partly because they may not be reliable.

In reproducing the values of the iron-poor rhodonites and those of the bustamites in a two-axial diagram we shall get the picture shown in Fig. 10. The reproduction is possible only if we unite $MgSiO_3$ with $CaSiO_3$, and $FeSiO_3$ with $MnSiO_3$. The amounts of FeO are generally small. The amounts of MgO, however, are in most cases larger and must have some influence on the positions of the points. The influence of this oxide is to reduce the refraction and the spec. gravity. On the axial angle some reduction of the angle around γ seems to be the result of a greater admixture of $MgSiO_3$. For these reasons the lines of the diagram only approximately refer to the relations in the pure Mn-Ca-series. On the other hand, the Fe-content of the specimens will, to some extent, counteract the influence caused by the Mg-component.

Of the lines shown in the diagram those of the refraction, the double refraction and of the spec. gravity are calculated as straight lines from the coordinates of the points. Only the determinations of the present writer have been used. The curves of the axial angles were deduced from the lines of the refraction. On account of the small variations in the axial angles the shape of the curves approaches that of straight lines. For pure rhodonite we obtain the following values:

$$\alpha = 1.7376, \beta = 1.7408, \gamma = 1.7514; 2V_\gamma = 57.5°; \text{spec. gravity} = 3.727.$$

On the diagram the value of the spec. gravity of the artificial rhodonite found by Jaeger and Van Klooster (3.716) has been marked.

From the relations in the diagram the non-isomorphous character of the two mineral series is apparent.

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[46] In the chemical formula the small amounts of Fe_2O_3 are included in FeO. BaO is joined with CaO. ZnO is not taken into consideration.

If we extend the lines originating from the coordinates of the bustamites they would have the course shown in the diagram. The end points on the $CaSiO_3$-side should be those quoted below. For comparison the values of wollastonite are recorded:[47]

	α	β	γ	$2V_\alpha$	Sp. Gr.
Extrapolated from the bustamites	1.6187	1.6270	1.6301	62°32′	2.961
Wollastonite	1.6177	1.6305	1.6323	39°	2.925

Owing to the short distance between the outermost points of the bustamites and the long extrapolation, the differences are small. Thus only a variation of 0.001 at most in the indices β and γ of one or two of the bustamites studied would be sufficient to render the extrapolated indices equal to those of wollastonite, and at the same time the axial angle would change correspondingly. At α the agreement is already sufficient. Owing to the method of measurement the size of the variation is too great to be due to errors of determinations on bustamites Nos. 7, 8 and 10, but in the case of No. 9 an error of the magnitude named is not excluded. On the other hand, variations of the size named may also be caused by admixtures of (Fe, Mg-) silicates. Even in the present state of our information the agreement on the $CaSiO_3$-side of the diagram is sufficient to make the isomorphic relations of the respective minerals probable.

The relations of the iron-rich compounds are more complicated owing to considerably greater admixtures of (Ca,Mg) SiO_3. The specimens known are also few in number. A two-axial diagram along the side $MnSiO_3$–$FeSiO_3$ of the triangular diagram is therefore impossible. In Fig. 11 a picture of the approximate relations in the area occupied by the stability field of the rhodonites-iron rhodonites is given, showing the variation of the refraction and the spec. gravity caused by the different silicates. As is seen here, the iron compound causes a marked influence on the properties named when compared with $MnSiO_3$. From the determinations of these properties an approximate statement of the proportions of these two silicates will be possible with the aid of the diagram.

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[47] The figures quoted have been determined by the present writer on a wollastonite specimen from Pargas (RM. 061282).

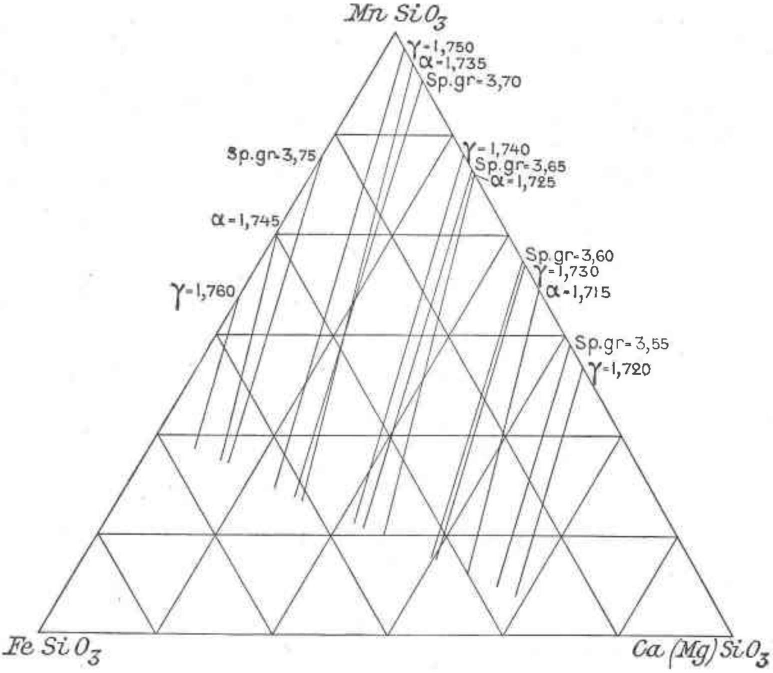
$MnSiO_3$
γ-1,750
α-1,735
Sp.gr-3,70
Sp.gr-3,75
γ-1,740
Sp.gr-3,65
α-1,725
α-1,745
Sp.gr-3,60
γ-1,730
α-1,715
γ-1,760
Sp.gr-3,55
γ-1,720
$FeSiO_3$
$Ca(Mg)SiO_3$

FIG. 11

TABLE I.[1]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO_2	46.13	45.86	47.46	47.51	47.42	48.16	47.78	47.66	48.31	48.27	46.56	47.78	45.12	46.53	47.92	46.91	47.14	48.29	49.84
Al_2O_3	—	—	—	—	tr	—	—	—	tr	—	—	0.08	1.38	0.21	0.16	0.22	2.38	—	0.78
Fe_2O_3					0.46		—			—	3.13	0.11		0.85	0.46	0.15	—		0.50
FeO	0.15[2]	0.36	0.07[2]	0.08[2]	1.77	0.04[2]	—	0.48	1.87[2]	0.25	6.23	14.51	22.44	24.69	13.78	14.29	28.34	24.01	19.85
MnO	51.55	45.92	41.01	41.37	39.42	40.16	27.69	31.65	33.04	28.30	34.12	29.20	24.25	20.50	27.96	28.58	20.63	6.47	3.66
MgO	0.61	1.65	3.23	3.16	1.97	4.55	1.06	1.18	1.90	0.50	1.55	1.93	1.20	1.39	3.58	3.46	—	2.83	6.90
CaO	1.31	6.40	7.89	7.61	8.98	6.71	22.62	18.16	14.93	22.04	7.70	6.55	5.62	5.46	6.20	5.99	1.88	17.69	18.42
BaO	0.07	n.d.	0.08	n.d.	0.06	0.16	n.d	0.19	n.d.	n.d.	n.d.	n.d.	n.d.	0.08	n.d.	n.d.	n.d.	n.d.	n.d.
ZnO	n.d.	n.d.	n.d.	n.d.	—	n.d.	n.d.	n.d.	n.d.	0.07	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
H_2O	0.23	n.d.	0.26	n.d.	0.20	0.31	0.21	n.d.	n.d.	0.12	0.42	0.09	n.d.	0.39	0.28	0.37	0.33	n.d.	0.35
	100.05	100.19	100.00	99.73	100.28	100.09	99.36	99.59[3]	100.05	99.55	99.71	100.25	100.01	100.10	100.34	99.97[4]	100.70	99.51[5]	100.30

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO_2	7688	7643	7910	7918	7903	8027	7963	7943	8052	8045	7760	7963	7520	7755	7987	7818	7857	8048	8307
Al_2O_3	—	—	—	—	—	—	—	—	—	—	—	8	135	21	16	22	233	—	76
Fe_2O_3	—	—	—	—	29	—	—	—	—	—	196	7	—	53	29	9	—	—	31
FeO	21	50	10	11	246	6	—	67	260	49	865	2015	3117	3429	1914	1985	3936	3335	2757
MnO	7260	6468	5776	5827	5552	5656	3900	4458	4654	3986	4806	4113	3415	2890	3938	4025	2906	909	516
MgO	152	412	807	790	492	1137	265	295	475	125	387	482	300	347	895	865	—	707	1725
CaO	234	1143	1409	1359	1604	1198	4039	3243	2666	3936	1375	1170	1004	975	1107	1070	336	3159	3289
BaO	—	—	5	—	4	11	—	13	—	—	—	—	—	5	—	—	—	—	—
ZnO	—	—	—	—	—	—	—	—	—	8	—	—	—	—	—	—	—	—	—
H_2O	128	—	144	144	111	172	117	—	—	67	—	50	—	217	156	206	183	—	194

1. Rhodonite, Vittinge (RM. 6296), analyst A. Bygdén.
2. Rhodonite, Harstigen, analyst G. Paykull.
3. Rhodonite, Långban, Nr 1 (RM. 13448), analyst A. Bygdén.
4. Rhodonite, Långban, Nr 1a (RM. 13448), analyst A. Bygdén.
5. Rhodonite, Långban, Nr 2 (BM. 43473), analyst A. Bygdén.
6. Rhodonite, Långban, Nr 3 (RM. 13448), analyst A. Bygdén.

7. Bustamite, Långban, No. 1 (RM. 27318), analyst R. Blix.
8. Bustamite, Långban, No. 2 (RM. 13397), analyst G. Lindström.
9. Bustamite, Långban, No. 3 (BM. 43473), analyst A. Bygdén.
10. Bustamite, Franklin Furnace, (RM. 24301), analyst G. Assarsson.

11. Iron rhodonite, Gåsborn (RM. 17173), analyst G. Assarsson.
12. Iron rhodonite, Tuna Hästberg, analyst A. Bygdén.

13. Sobralite, V. Silvberg, analyst M. Weibull.
14. Sobralite, V. Silvberg, analyst A. Bygdén.
15. Sobralite and iron rhodonite, Tunaberg (RM. 172284), analyst R. Mauzelius.
16. Sobralite and iron rhodonite, Tunaberg (RM. 172284), analyst A. Bygdén.
17. Pyroxmangite, South Carolina, analyst W. M. Bradley.

18. Mn-Hedenbergite, V. Silvberg, analyst M. Weibull.
19. "Diopside" (Hedenbergite), Gillinge, analyst R. Mauzelius.

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[1] All new analyses are calculated on basis of dried at 105°.
[2] Det. as Fe_2O_3.
[3] Incl. 0.27 alkalies.
[4] Hereto 0.007 TiO_2.
[5] Incl. 0.22 alk.

TABLE II.

	Mol. per cent										
	MnSiO$_3$	FeSiO$_3$	MgSiO$_3$	CaSiO$_3$	Sp. gr.	α	β	γ	$\gamma-\alpha$	2V$_\gamma$	(110):(1$\bar{1}$0)
1. Rhodonite, Vittinge (anal. 1)	94.69	0.27	1.98	3.05	3.70	1.733	1.737	1.747	0.014	61°	92°44′
2. Rhodonite, Harstigen (anal. 2)	80.12	0.62	5.10	14.16	3.616	1.7208	1.7251	1.7326	0.0118	75°	92°25′
3. Rhodonite, Harstigen, Hey	80.14	1.34	0.13	18.40	3.615	1.720	1.725	1.733	0.013	75°	
4. Rhodonite, Långban (anal. 4)	72.96	0.14	9.89	17.01	3.573	1.7131	1.7171	1.7260	0.0129	68.4°	92°13′
5. Rhodonite, Långban 2 (anal. 6)	70.63	0.07	14.20	15.10	3.563	1.7112	1.7153	1.7239	0.0127	69°	92°27′
6. Rhodonite, Långban 3 (anal. 5)	69.78	3.82	6.18	20.21	3.581	1.7157	1.7203	1.7281	0.0124	74.8°	92°24′
7. Bustamite, Långban 1 (anal. 7)	47.54	—	3.23	49.23	3.317	1.67198	1.68493	1.68670	0.01472	139.1°	94°35′
8. Bustamite, Långban 2 (anal. 8)	55.29	0.83	3.66	40.22	3.386	1.68153	1.69487	1.69691	0.01538	136.9°	95°22′
9. Bustamite, Långban 3 (anal. 9)	57.78	3.23	5.90	33.10	3.410	1.6874	1.7014	1.7029	0.0155	143.8°	94°57′
10. Bustamite, Franklin Furnace (anal. 10)	49.23	0.61	1.54	48.62	3.324	1.67493	1.68766	1.68973	0.01480	135.9°	95°11′
11. Iron rhodonite, Gåsborn (anal. 11)	66.38	9.27	5.36	18.99		1.7205	1.7251	1.7326	0.0121	76.4°	92°24′
12. Iron rhodonite, Tuna Hästberg (anal. 12)	52.77	26.03	6.19	15.01	3.653	1.725	1.728	1.737	0.013	70.3°	92°36′
13. Sobralite, V. Silvberg (anal. 14)	37.66	45.04	4.52	12.77	3.717	1.738	1.752	1.755	0.0165	41.6°	92°32′
14. Sobralite, Tunaberg									0.019	41.2°	91°46′
15. Pyroxmangite, Iva, S. Carolina (anal. 17)	40.48	54.84	—	4.68	3.80					30°	91°50′
16. Mn-Hedenbergite, V. Silvberg (anal. 18)	11.21	41.12	8.72	38.95	3.55						
17. Diopside (Hedenb.) Gillinge (anal. 19)	6.18	33.76	20.66	39.39	3.544				0.032	56.5°	