

MANGANPYROSMALITE, BUSTAMITE, AND FERROAN JOHANNSENITE FROM BROKEN HILL, NEW SOUTH WALES, AUSTRALIA

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SUMMARY

Manganpyrosmalite has been found in material from Broken Hill, New South Wales, where it occurs in association with ferroan johannsenite and calcium-poor bustamite. A partial analysis of manganpyrosmalite and a complete one for johannsenite have been made, and full optical properties for the three minerals are reported. X-ray powder data are recorded in addition to a Weissenberg study of the manganpyrosmalite. Transformation of the clinopyroxene into a manganese-iron wollastonite solid solution has been effected in the laboratory and the x-ray data for these materials are given.

INTRODUCTION

Before their discovery of a manganese analog of pyrosmalite at Sterling Hill, New Jersey, pyrosmalite had been described, according to Frondel and Bauer (1953, p. 755) from only two localities, *viz.* the magnetite deposits of Nordmark and Dannemora in Sweden. The writer has now recognized manganpyrosmalite in material from Broken Hill, New South Wales, and in view of its apparent rarity it would seem desirable to record the data determined for this mineral from this locality.

Before proceeding to its description it should be pointed out that the writer has been unable to find any record of the occurrence of pyrosmalite at Broken Hill in the literature available to him, other than its mere inclusion in a listing of mineral species reported from the main Broken Hill Lode, and the Pinnacles Mine, some 8-10 miles south-west from Broken Hill itself (Woodward, 1952, p. 63). Specific data as to physical properties, exact location, and occurrences were not given.¹

The specimen on which manganpyrosmalite was found was collected by Mr. Roy ("Floss") Campbell of Broken Hill in the South End of the 12th level of the Zinc Corporation workings, and it was given to the present author during a period spent collecting material with the kind permission and assistance of the Geological Staff of the Zinc Corporation.

¹ After this paper was written Dr. Austin Edwards very kindly gave the present writer the following information: "(1) Pyrosmalite, both manganese-rich and manganese-poor, was discovered in the Broken Hill lode by M. A. Mawby (now the President of Consolidated Zinc Pty. Ltd.) about fifteen years ago. He had both varieties analysed, and the identification confirmed by x-ray patterns, but the discovery was not published. (2) Dr. Stillwell rediscovered these two minerals independently about two years ago, in the course of the major investigation of the mineral composition of the Broken Hill lode. He separated them, and had them analysed, and I think, x-rayed."

It is a very great pleasure to be able to record one's thanks to the staff of the Zinc Corporation for their kindly assistance during the writer's visit to Broken Hill, and for their courtesy in shipping specimens collected at that time; and Mr. Campbell's generosity is deeply appreciated. The writer gratefully acknowledges the opportunities provided for research through the John Simon Guggenheim Memorial Foundation, and a welcome grant from the Shell Research Fund, Stanford, facilitated purchase of equipment.

MANGANPYROSMALITE

Manganpyrosmalite occurs in the form of hexagonal tablets up to 4 mm. in diameter, although they are usually very much smaller than this, attached to the outer surfaces of a long prismatic crystal of clear green ferroan johannsenite, in a manner that lacks any suggestion of epitaxial relationship between the two minerals. Crystals that are about 4 mm. in diameter are about 1 mm. thick, and this ratio of diameter to thickness is generally applicable to crystals of smaller dimensions. In one instance a perfect crystal of manganpyrosmalite, 1.5 mm. in diameter, was observed as a terminal cap to one extremity of a pale flesh-colored acicular crystal of bustamite, that in turn projected outwards at about 80° from a prism face of a crystal of ferroan johannsenite, 9 mm. long. The *c* axis of the manganpyrosmalite is almost parallel to the *b* axis of bustamite, but the angular relationship between bustamite and clinopyroxene does not appear to follow any simple crystallographic scheme.

Crystals 1 mm. thick are quite translucent and pale brown in color. Prism faces give good reflections but the basal plane does not, since the latter is distinctly but shallowly depressed without any suggestion of a spiral development.

Several crystals were carefully removed from the surface of the clinopyroxene and after being coarsely crushed, manganese stain was removed by treatment with SO₂ solution. This material was subsequently analyzed and it is to be regretted that in order to preserve sufficient material for reference purposes it was possible to make a partial analysis only; this is set out in Table 1 together with that of manganpyrosmalite described by Frondel and Bauer (1953, p. 757).

The Broken Hill material is decidedly more manganiferous than that from Sterling Hill, and accordingly, this points to the existence of a more continuous ionic substitution series that extends Frondel and Bauer's observed limits at the manganese end, *viz.* from Fe:Mn=1:3.2 to Fe:Mn=1:5.7.

The following physical properties have been determined:

$$\begin{aligned}\epsilon &= 1.631 \pm 0.001, \\ \omega &= 1.670 \pm 0.001, \\ \omega - \epsilon &= 0.039;\end{aligned}$$

Uniaxial and optically negative;
 Sp. Gr. at 21° C. = 3.12;
 A perfect (0001) cleavage.

Employing a camera of 114.59 mm. diameter and manganese-filtered iron-radiation a powder photograph was obtained for a sample of manganpyrosmalite prepared by rolling a thread of the mineral powder bonded with gum tragacanth. The *d*-spacings are listed in Table 2 together with those recorded by Frondel and Bauer (1953, p. 756), and it will be noted that a few weak reflections have been observed in the film of Broken Hill material that were not recorded by Frondel and Bauer, and *vice versa*. The extra lines present in the former are certainly not due to rhodonite, bustamite, nor johannsenite, and there is every reason to believe that the material used was quite pure. Beta lines for the strongest reflections were found on the film although filtered radiation was employed, but these are not listed.

The intensities [column *I* (2)] compare closely with those for Sterling Hill material but careful examination of the lines on the film reveals a lack of uniform density that points to preferred orientation of the particles in the spindle employed. Short arcs rather than uniform lines were present in a number of instances. A second preparation was formed into a sphere, 0.1 mm. in diameter, without formation of a thread or prelimi-

TABLE 1. ANALYSES OF MANGANPYROSMALITE

| | A | B |
|--------------------------------------|--------|--------|
| MnO | 39.09 | 43.44 |
| FeO | 12.43 | 7.65 |
| MgO | 0.74 | 0.89 |
| ZnO | 1.94 | * |
| CaO | nil | nil |
| (Al, Fe) ₂ O ₃ | nt.dt. | nil? |
| SiO ₂ | 34.13 | 34.29 |
| As ₂ O ₃ | 0.13 | nt.dt. |
| Cl | 3.80 | nt.dt. |
| H ₂ O | 8.18 | nt.dt. |
| | 100.44 | 86.27 |
| O = Cl | 0.86 | |
| | 99.58 | |

A. Manganpyrosmalite, Sterling Hill, New Jersey. Frondel and Bauer (1953, p. 757, Table 1).

B. Manganpyrosmalite, South End, 12th Level, Zinc Corporation Mine, Broken Hill, New South Wales, Australia. Anal. C. Osborne Hutton.

* Microchemical tests indicate that this constituent is present.

TABLE 2. X-RAY POWDER FILM DATA FOR MANGANPYROSMALITE
Manganese-Filtered Iron-Radiation, $\lambda = 1.9373 \text{ \AA}$. Intensities Determined Visually

| Broken Hill, N. S. W. | | | Sterling Hill, N. J. | | Broken Hill, N. S. W. | | | Sterling Hill, N. J. | |
|-----------------------|--------------|--------------|----------------------|----------|-----------------------|--------------|--------------|----------------------|----------|
| <i>d</i> . meas. | <i>I</i> (1) | <i>I</i> (2) | <i>d</i> meas. | <i>I</i> | <i>d</i> . meas. | <i>I</i> (1) | <i>I</i> (2) | <i>d</i> . meas. | <i>I</i> |
| 11.57 Å | 3 | 3 | 11.60 Å | 3 | 1.842 Å | 5 | 3 | 1.843 Å | 4 |
| 7.15 | 8 | 10 | 7.16 | 10 | — | — | — | 1.790 | 1* |
| 6.71 | 1 | 1 | 6.71 | 1 | 1.765 | <1 | 1* | 1.768 | 1 |
| 6.08 | 3 | 3 | 6.09 | 3 | — | — | — | 1.733 | 1* |
| 5.80 | 1 | 1 | 5.77 | 1 | 1.710 | <1 | 1* | — | — |
| 4.895 | 2 | 2 | 4.886 | 2 | 1.677 | 6 | 5 | 1.672 | 5 |
| 4.52 | 2 | 2 | 4.509 | 1 | 1.633 | 5 | 4 | 1.627 | 4 |
| 4.39 | 2 | 1 | 4.376 | 1 | 1.525 | 6 | 5 | 1.523 | 5 |
| 3.732 | 2 | 2 | 3.736 | 2 | 1.484 | <1 | 1* | — | — |
| 3.58 | 4 | 8 | 3.583 | 8 | 1.462 | <1 | 1* | — | — |
| 3.415 | 3 | 6 | 3.419 | 4 | 1.431 | 2 | 1* | 1.432 | 1 |
| 3.335 | 1 | 1 | 3.338 | 3 | 1.424 | 4 | 3 | 1.419 | 2 |
| 3.210 | 4 | 3 | — | — | 1.397 | 1 | 1 | 1.406 | 1* |
| 3.034 | 2 | 2 | 3.035 | 2 | 1.372 | 3 | 2 | 1.371 | 2 |
| 3.002 | 2 | 2 | — | — | 1.346 | 3 | 2 | 1.342 | 2 |
| 2.892 | 2 | 1 | 2.882 | 2 | 1.284 | 2 | 2 | 1.285 | 2 |
| 2.775 | 2 | 1 | 2.770 | 2 | 1.271 | 1 | 1* | 1.266 | 1 |
| 2.694 | 10 | 9 | 2.683 | 9 | 1.242 | 2* | 1* | 1.238 | 1 |
| 2.634 | <1 | 1* | — | — | — | — | — | 1.194 | 1 |
| — | — | — | 2.549 | 2 | 1.128 | 1* | 1* | 1.126 | 2* |
| 2.477 | <1 | 1* | — | — | 1.103 | 2* | 1* | 1.106 | 1* |
| 2.384 | 1 | 1 | 2.385 | 2 | 1.090 | 1* | 1* | 1.089 | 2* |
| 2.338 | <1 | 1* | 2.334 | 1 | — | — | — | 1.082 | 2* |
| 2.252 | 7 | 7 | 2.251 | 7 | — | — | — | 1.063 | 1* |
| 2.092 | 1 | 1* | 2.102 | 1* | 1.051 | 1* | 1* | — | — |
| — | — | — | — | — | — | — | — | 1.047 | 1* |
| — | — | — | — | — | 1.032 | 1* | 1* | — | — |
| — | — | — | — | — | 0.999 | 1* | 1* | — | — |

I (1) Intensities for film obtained from carefully prepared specimen that lacked any significant orientation of particles.

I (2) Intensities for film obtained from conventionally prepared specimen.

* Diffuse lines, often quite broad.

nary rolling, to prevent orientation of particles, and the x-ray film obtained therefrom exhibited powder lines devoid of uneven distribution of densities; the latter are recorded in column *I* (1), and it is felt that these figures are more acceptable than those in column *I* (2). Accordingly the three most prominent lines in order of decreasing intensities are those with *d*-spacings 2.694, 7.15, and 2.252. Examination of Table 2 will show other differences in intensities between the two patterns.

Rotation and Weissenberg films were secured for manganpyrosmalite and the latter were calibrated with quartz; appropriate measurements gave the following data:

$$a_0 = 13.38\text{\AA} \pm 0.03 \text{\AA}.$$

$$c_0 = 7.15 \text{\AA} \pm 0.03 \text{\AA}.$$

These values correspond closely to those obtained by Frondel and Bauer for Sterling Hill, New Jersey manganpyrosmalite, *viz.* $a_0 = 13.36 \text{\AA}$ and $c_0 = 7.16 \text{\AA}$.

It was noted earlier that in most instances the (0001) faces are shallowly depressed and exhibit at the same time an effect that closely resembles coarse mosaic structure. However, the amount of apparent disorientation of units within a single crystal that is so obvious megascopically is not especially evident in single crystal photographs, since only occasional reflections are slightly dispersed.

BUSTAMITE

Bustamite occurs as very pale, flesh-colored acicular crystals, slightly flattened parallel to the c axis, that project from plates of ferroan johannsenite and manganpyrosmalite. Most of the prisms do not exceed 3 mm. in length and none exceed 1 mm. in the direction of greatest breadth.

The following properties leave no doubt as to the identity of the mineral in question, which has been previously recognized at Broken Hill by a number of authors, among whom are Burrell (1942) and Gustafson *et al.* (1950): $\alpha = 1.686 \pm 0.002$, $\beta = 1.697$, $\gamma = 1.701$, $\gamma - \alpha = 0.015$; $2V = 46^\circ (-)$; this is an average of eight determinations with a range of 44° to 48° ; dispersion is faint with $r < v$. Two good cleavages intersect at 94° and α' makes an angle of 45° *ca.* with (100), assuming that the latter is the better developed of these cleavages. Crystals are flattened prismatic and elongated in the b direction. Specific gravity, determined by suspension in Clerici solution, is 3.42 at 22°C .

When these optical data are plotted on the curves developed by Sundius (1931, p. 513) they are found to correspond closely to moderately lime-poor bustamite with a composition equivalent to 40% (Mn, Fe)SiO₃ and 60% (Ca, Mg)SiO₃; thus it is comparable to a bustamite from Långban described by Otto (1936, p. 112, table 16, 3rd analysis), and very similar to Treburland bustamite described by Tilley (1946, pp. 237-238).

Employing manganese-filtered iron-radiation and a camera of diameter 114.59 mm., x-ray diffraction powder patterns have been obtained for carefully selected bustamite free from manganese oxide films. The d -spacings and estimated intensities are compared with those secured for carefully purified Franklin Furnace bustamite in Table 3, and these patterns are similar, although several lines of comparable d -spacings do

TABLE 3. DATA FROM X-RAY POWDER FILMS FOR BUSTAMITE
Manganese-Filtered Iron-Radiation. $K\alpha=1.9373 \text{ \AA}$. Intensities Estimated Visually

| Broken Hill, N. S. W. | | Franklin Furnace, N. J. | | Broken Hill, N. S. W. | | Franklin Furnace, N. J. | |
|--------------------------|----------|----------------------------|----------|--------------------------|----------|----------------------------|----------|
| <i>d.</i> meas. | <i>I</i> | <i>d.</i> meas. | <i>I</i> | <i>d.</i> meas. | <i>I</i> | <i>d.</i> meas. | <i>I</i> |
| 7.29 Å | 1 | 7.19 Å | <1 | 1.915 Å | 2 | 1.922 Å | 2 |
| 6.76 | <1 | — | — | 1.887 | <1 | 1.8845 | <1 |
| 4.78 | <1 | 4.78 | <1 | 1.852 | <1 | 1.8495 | <1 |
| 4.35 | 1 | 4.49 | <1 | 1.824 | <1 | 1.821 | <1 |
| 3.88 | <1? | — | — | 1.775 | 4 | 1.776 | 5 |
| 3.675 | 3 | 3.70 | 2 | 1.746 | 1 | 1.7395 | 1 |
| 3.56 | 1 | 3.56 | 1 | 1.706 | 5 | 1.706 | 2 |
| 3.39 | 3 | 3.41 | 2 | 1.6655 | 5 | 1.665 | 4 |
| 3.31 | 1 | 3.29 | 1 | 1.6555 | 2 | 1.6545 | 2 |
| 3.195 | 7 | 3.19 | 5 | 1.608 | <1 | 1.606 | 1 |
| 3.109 | <1 | 3.096 | 1 | 1.552 | 3* | 1.551 | 2 |
| 2.982 | 6 | 2.989 | 6 | 1.504 | 1 | 1.5025 | 1 |
| 2.872 | 10 | 2.880 | 10 | 1.4785 | 2* | 1.476 | 1* |
| 2.701 | 1 | 2.711 | 3 | 1.442 | 2 | 1.446 | 2 |
| 2.618 | 2 | 2.621 | 2 | 1.4325 | <1 | 1.436 | 3 |
| 2.551 | 1 | 2.556 | <1 | 1.4210 | 1 | 1.424 | 1 |
| 2.5035 | 1 | 2.509 | 2 | 1.407 | 2 | 1.4055 | 2 |
| 2.4545 | 4 | 2.462 | 1 | 1.3495 | 2 | 1.354 | 2 |
| 2.389 | 3 | 2.408 | 2 | 1.316 | 3 | 1.322 | 2 |
| 2.261 | 2 | 2.260 | 2 | 1.298 | 3 | 1.296 | 2 |
| 2.2235 | 5 | 2.227 | 4 | 1.264 | <1 | — | — |
| 2.1135 | 2 | 2.117 | 2 | 1.236 | 3 | 1.235 | 3 |
| 2.101 | 2 | 2.082 | 1 | | | | |
| 2.020 | 1 | 2.016 | <1 | | | | |
| 1.9535 | 2 | 1.956 | 1 | | | | |

* Broad and diffuse lines.

not exhibit identical intensities. Notable in this respect is the line at 1.706 Å. Further it should be noted that *ASTM* card 3-0693 for bustamite, also from Franklin Furnace, lists 1.78 Å and 1.67 Å as the second and third most intense lines, respectively, while it omits many apparently significant lines. The former situation does not apply with either of the bustamites reported upon here.

The diminution of intensities of lines corresponding to 1.78 Å and 1.67 Å in either case, would not appear to be the result of preferred orientation in the powdered preparations since several carefully prepared spheres of powder, 0.1 mm. in diameter, and not rolled threads or smeared fibers, were used. Diffraction patterns obtained with the latter, on the other hand, show that the intensity of the line at 1.78 Å is very

weak in both Broken Hill and Franklin Furnace material, whereas several other lines, sometimes unimportant in films secured from disoriented preparations, exhibit a considerable degree of intensity. Notable in this respect are reflections at 3.195 Å—the most intense lines in films secured from *rolled* spindles of Broken Hill and Franklin Furnace material.

FERROAN JOHANNSENITE

Clinopyroxene forms clear pale green bladed prismatic crystals that are strongly flattened parallel to the *b* axis, and coarsely striated parallel to the *c* axis; all crystals examined were devoid of terminal faces, but surfaces due to parting parallel to (001) are common. Ferroan johannsenite forms the base on which manganpyrosmalite and bustamite have crystallized, and in many instances the surfaces of the pyroxene crystals are obscured by films of deep red-brown sturtite.

The following physical properties have been determined: $\alpha = 1.716 \pm 0.001$, $\beta = 1.728$, $\gamma = 1.745$, $\gamma - \alpha = 0.029$; $2V = 64^\circ \pm 1^\circ (+)$, $Z \wedge c = 48^\circ$. The beta value lies within the narrow limits found for all Broken Hill clinopyroxenes by Burrell (1942) and quoted by Stillwell (1953). No dispersion was observed in suitably oriented interference figures and crystals lying on the dominant face (100) exhibit emergence of very nearly centered optic axis interference figures. The specific gravity at 16° C. is 3.55.

An analysis of the clinopyroxene is set out in Table 4; this shows that the mineral is richer in manganese than it is in iron and not greatly different from the composition of vogtite, a constituent of acid steel-furnace slags (*vide* Hallimond, 1919). However, on account of the higher manganese content it differs quite distinctly from the "green rhodonite" of the Broken Hill lode (Stillwell, 1922, p. 401), a mineral that was later shown to be manganhedenbergite (Hodge-Smith, 1926). If magnesia is distributed equally between theoretical hedenbergite and johannsenite molecules the composition is found to lie nearer that of johannsenite, and accordingly it would seem appropriate to use the term ferroan johannsenite for this pyroxene if one follows Schaller's (1930) nomenclatural recommendations, and the usage of Allen and Fahey (1953). It follows from this that the term manganoan hedenbergite ought to be employed for those pyroxenes in which the hedenbergite molecule is predominant, and the term manganhedenbergite—applied to an indefinite range of manganese-bearing clinopyroxenes—should be dropped.

It is interesting to note that johannsenite is much richer in iron than is bustamite, that is, if the composition of bustamite inferred from physical properties is correct. This suggests that a large excess of manganese would seem to have been available so that when the temperature of the

TABLE 4. FERROAN JOHANNSENITE FROM BROKEN HILL, NEW SOUTH WALES, AUSTRALIA

Anal. C. Osborne Hutton

| | | Metal atoms on basis of 6 oxygens | | mol per cent | |
|--------------------------------|-------|--------------------------------------|-------|--------------------|--------|
| SiO ₂ | 48.39 | 1.986 | } 2.0 | FeSiO ₃ | 23.05% |
| Al ₂ O ₃ | 0.58 | 0.028 | | MnSiO ₃ | 24.55 |
| TiO ₂ | nil | | | MgSiO ₃ | 6.70 |
| Fe ₂ O ₃ | nil? | | | CaSiO ₃ | 45.70 |
| FeO | 13.44 | 0.461 | } 2.0 | | |
| MnO | 14.14 | 0.491 | | | |
| MgO | 2.19 | 0.134 | | | |
| CaO | 20.79 | 0.914 | | | |
| K ₂ O | 0.05 | | | | |
| Na ₂ O | 0.09 | | | | |
| H ₂ O ⁺ | 0.08 | | | | |
| H ₂ O ⁻ | 0.12 | | | | |
| | | 99.87 | | | |

environment rose above that of the johannsenite-bustamite inversion point (*vide* Bowen, Schairer and Posnjak, 1933, pp. 271, 275), a manganese-rich bustamite was able to crystallize and at a lower temperature than would have obtained for inversion of manganese-poor hedenbergite. This inversion temperature would appear to have been above 830° C. (Schaller, 1938, p. 581), but below 965° C.

Broken Hill johannsenite was heated to 1070° C. for 15½ hours in a silica capillary tube that had been evacuated, filled with nitrogen and then re-evacuated, and the higher temperature was chosen in order that the inversion might proceed and be completed more rapidly. After heat treatment the pyroxene was white or very pale gray in color and the *x*-ray pattern (Table 5, column *B*) shows that the mineral had completely inverted to high-temperature manganese-iron wollastonite solid solution, or bustamite, as was to be expected from Bowen, Schairer and Posnjak's (1933, p. 271) study of the system CaO-FeO-SiO₂ (compare columns *B*, *C*, and *D* in Table 5). This experiment was undertaken primarily to check the *x*-ray powder data recorded by Schiavinato (1953) for bustamite or manganese-rich wollastonite artificially produced by inversion of johannsenite. Schiavinato's (1953, p. 8, Table 2) *x*-ray data for this inversion product are scarcely comparable to those obtained by the present study, and the smaller number of lines recorded by that investigator is puzzling, as also is the case for his johannsenite.

TABLE 5. X-RAY DATA FOR FERROAN JOHANNSENITE, INVERTED FERROAN JOHANNSENITE, (=BUSTAMITE), BUSTAMITE, AND WOLLASTONITE

Camera diameter=114.59 mm. A, B, and C: Mn-filtered Fe-radiation ($K\alpha=1.9373 \text{ \AA}$)
 D: Ni-filtered Cu-radiation ($K\alpha=1.54180 \text{ \AA}$).

| A | | B | | C | | D | |
|---------|-----|---------|-----|---------|-----|---------|-----|
| d meas. | I | d meas. | I | d meas. | I | d meas. | I |
| 9.18 A | <1 | 7.34 Å | 1 | 7.29 Å | 1 | 7.67 Å | 2 |
| 6.55 | 2 | 6.76 | <1* | 6.76 | <1 | 5.03 | 1 |
| 4.75 | 1 | 4.82 | <1 | 4.78 | <1 | 4.31 | 1 |
| 4.52 | 1 | 4.355 | 1 | 4.35 | 1 | 3.785 | 4 |
| 3.89 | 2* | 3.87 | 2* | 3.88 | <1? | 3.685 | 1 |
| 3.335 | 1} | 3.705 | 2 | 3.675 | 3 | 3.48 | 4 |
| 3.26 | 2} | 3.58 | <1 | 3.56 | 1 | 3.36 | <1? |
| 3.19 | <1? | 3.41 | 3 | 3.39 | 3 | 3.29 | 4 |
| 3.105 | <1 | 3.31 | 2 | 3.31 | 1 | 3.13 | 1 |
| 3.008 | 10 | 3.205 | 6 | 3.195 | 7 | 3.055 | 2 |
| 2.905 | 3 | 3.091 | <1 | 3.109 | <1 | 2.96 | 10 |
| 2.593 | 5 | 2.995 | 5 | 2.982 | 6 | 2.787 | 2 |
| 2.5435 | 8 | 2.889 | 10 | 2.872 | 10 | 2.7055 | 2 |
| 2.346 | 1 | 2.700 | 1 | 2.701 | 1 | 2.54 | 3 |
| 2.234 | 2 | 2.6315 | 2 | 2.618 | 2 | 2.46 | 5 |
| 2.187 | <1 | 2.560 | <1 | 2.551 | 1 | 2.335 | 4 |
| 2.156 | 3 | 2.5225 | 1 | 2.5035 | 1 | 2.281 | 3 |
| 2.1235 | 2 | 2.471 | 2 | 2.4545 | 4 | 2.170 | 6 |
| 2.070 | 2 | 2.407 | 3 | 2.389 | 3 | 2.083 | <1 |
| 2.034 | 2 | 2.276 | 2 | 2.261 | 2 | 2.009 | 2 |
| 2.014 | 2 | 2.2345 | 3 | 2.2235 | 5 | 1.970 | 1 |
| 1.9825 | 1 | 2.124 | 2* | 2.1135 | 2} | 1.9075 | 1 |
| 1.892 | <1 | — | — | 2.101 | 2} | 1.874 | 1 |
| 1.8615 | <1 | 2.0275 | <1 | 2.020 | 1 | 1.845 | <1? |
| 1.833 | <1 | 1.964 | 1 | 1.9535 | 2 | 1.824 | 5 |
| 1.8102 | <1 | 1.923 | 1 | 1.915 | 2 | 1.7845 | <1 |
| 1.7810 | 4 | 1.886 | <1 | 1.887 | <1 | 1.7465 | 4 |
| 1.6925 | 2 | 1.854 | <1 | 1.852 | <1 | 1.713 | 7 |
| 1.6435 | 4 | 1.8255 | <1 | 1.824 | <1 | 1.686 | <1? |
| 1.6280 | 4 | 1.7805 | 5 | 1.775 | 4 | 1.652 | <1? |
| 1.593 | <1 | 1.752 | <1 | 1.746 | 1 | 1.5985 | 6 |
| 1.5745 | <1 | 1.7115 | 3 | 1.706 | 5 | 1.527 | 1 |
| 1.5505 | <1 | 1.6715 | 5* | 1.6655 | 5} | 1.512 | <1 |
| 1.537 | <1 | — | — | 1.6555 | 2} | 1.4725 | 3 |
| 1.513 | 5 | 1.611 | <1 | 1.608 | <1 | 1.454 | 3 |
| 1.4515 | 6 | 1.560 | 2* | 1.552 | 3* | 1.4285 | 1 |
| 1.425 | 2 | 1.509 | 1 | 1.504 | 1 | 1.385 | 1 |
| 1.409 | 1 | 1.4815 | 1* | 1.4785 | 2* | 1.358 | 3 |
| 1.355 | <1 | 1.444 | 2 | 1.442 | 2 | 1.322 | 1 |
| 1.3405 | 1 | ? | — | 1.4325 | <1 | 1.298 | <1 |
| 1.3195 | <1 | ? | — | 1.4210 | 1 | 1.281 | <1 |
| 1.3000 | 2 | 1.415 | 1 | 1.407 | 2 | 1.265 | 2 |
| 1.2705 | 2 | 1.396 | 1 | ? | — | 1.2385 | 1 |
| | | 1.356 | 1 | 1.3495 | 2 | 1.210 | 2 |
| | | 1.3234 | 2 | 1.316 | 3 | 1.187 | 1* |
| | | 1.3024 | 1 | 1.298 | 3 | 1.1715 | 2* |
| | | 1.2672 | <1 | 1.264 | <1 | 1.1465 | 1 |
| | | 1.2375 | 1* | 1.236 | 3 | 1.1395 | 1 |
| | | 1.1807 | 2 | | | 1.1115 | 1 |
| | | | | | | 1.105 | 2 |
| | | | | | | 1.092 | 3 |

A. Ferroan johannsenite, Broken Hill, Australia.

B. Ferroan johannsenite inverted at 1070° C. to manganese-iron wollastonite solid solution (=bustamite).

C. Bustamite, Broken Hill, Australia.

D. Wollastonite, Harrisville, New York.

* Line wide and diffuse.

The d -spacings for inverted Broken Hill johannsenite tend to be very slightly greater than those for the associated bustamite yet the former contains less manganese than the latter. In view of the relative sizes of the ions concerned, *viz.* $\text{Fe}^{2+}=0.75 \text{ \AA}$ and $\text{Mn}^{2+}=0.80 \text{ \AA}$, one might have expected a reversal of this relationship. However, optical properties point to a calcium-poor bustamite, and since calcium is a relatively large ion ($\text{Ca}^{2+}=0.99 \text{ \AA}$) the diminution in d -spacings in the bustamite as compared to those for inverted johannsenite may thus be explained.

It might be pointed out at this stage that the d -spacings for wollastonite recorded by Clark (1946, p. 27) correspond in a general way to those listed in column *D* of Table 5 of this paper, but many significant lines would seem to have been omitted by him, or were not present in his x -ray film. Accordingly since the present author's d -spacings were obtained from a carefully purified powder, prepared for x -ray diffraction work so that preferred orientation of particles would be at a minimum, they are recorded here.

When ferroan johannsenite is heated to 1070° C. for $7\frac{1}{2}$ hours in air the resulting product is black in color and has a magnetic susceptibility that is less than that for the untreated pyroxene. The x -ray powder pattern

TABLE 6. X-RAY FOR FERROAN JOHANNSENITE HEATED TO 1070° C.
FOR $7\frac{1}{2}$ HOURS IN AIR

Manganese-Filtered Iron-Radiation ($K\alpha=1.9373 \text{ \AA}$)

| d . meas. \AA | I | d . meas. \AA | I |
|---------------------------|-----|---------------------------|-----|
| 7.50 | 1 | 2.306 | 3 |
| 5.20 | <1? | 2.251 | 3 |
| 4.89 | 2 | 2.149 | 3 |
| 4.48 | 1 | 2.116 | 3 |
| 4.24 | 1 | 1.980 | <1 |
| 4.055 | 7 | 1.9525 | 1 |
| 3.76 | 2 | 1.803 | 4 |
| 3.44 | 3 | 1.7295 | 3 |
| 3.33 | 2 | 1.686 | 4 |
| 3.25 | 5 | 1.632 | 3 |
| 3.044 | 3 | 1.603 | 2 |
| 2.989 | 1 | 1.579 | 3 |
| 2.922 | 10 | 1.522 | 1 |
| 2.751 | <1? | 1.500 | 4 |
| 2.6885 | 3 | 1.455 | 2 |
| 2.555 | 8 | 1.431 | 1 |
| 2.508 | 1 | 1.372 | 2* |
| 2.437 | 4 | 1.340 | 2* |

* Very diffuse line.

obtained for this material exhibits only the slightest resemblance to the spacings and intensities reported in column *B* of Table 5, presumably as a consequence of oxidation of both iron and manganese (Table 6).

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