assistance during the course of this study, and to George Switzer, Daniel Appleman and John S. White for suggestions for improvement of the manuscript. The spectrographic analysis was obtained from the Conservation Analytical Laboratory of the Smithsonian Institution.

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# MAGNESIOAXINITE, A NEW MINERAL FOUND AS A BLUE GEMSTONE FROM TANZANIA*

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A PALE BLUE circular mixed-cut gemstone, weighing 0·1577 grams (0·78 carats), was submitted for detailed examination by Mr R. K. Mitchell, who had received it from Mr C. R. Bridges, a mineral dealer operating in East Africa.   The rough

material had been obtained from a prospector in Tanzania, and there had been no distinct crystal faces or form. The stone did not identify with any of the usual gem minerals and was later shown to be a new member of the axinite group. It was acquired for the Institute collections (registered number MI 34610), and is now on display in the Geological Museum, London.

The cut stone is of brilliant appearance with a vitreous lustre; pale blue in daylight but pale violet under tungsten lighting. The refractive indices, obtained on a Rayner Dialdex refractometer using sodium light, are $\alpha$ 1·656, $\beta$ 1·660, $\gamma$ 1·668 (all ±0·001), giving a birefringence of 0·012. In contrast, a specimen of the well-known axinite from Bourg d'Oisans, Dauphiné, France gave values of $\alpha$ 1·672, $\beta$ 1·679, $\gamma$ 1·682 (all ±0·001). For a pale coloured stone the pleochroism is notable—from pale blue to pale violet to pale grey. The mineral is optically positive in contrast to most axinites which are biaxial negative; it has not yet been possible to determine 2V or the optical orientation.

The specific gravity of the gemstone is 3·178, whereas that of the Bourg d'Oisans axinite used for analysis and x-ray work is 3·288. The streak (powder) is white and the hardness is greater than 6 but less than 7. Under the binocular microscope very fine cleavage traces were seen in one plane, but no other inclusions were noted.

Under ultra-violet light the stone fluoresces a distinct orange-red by long-wave radiation (3650Å), but appears a duller red by short-wave radiation (2357Å); the Bourg d'Oisans material is inert. The stone appears pink through the Chelsea colour filter. Viewed between crossed filters (of copper sulphate solution and red glass) the stone fluoresces bright red. When viewed through the spectroscope, using the copper sulphate solution as a filter, it shows a faint, broad fluorescent band in the orange-red (5900-6500Å region) but no bright lines. These properties might be taken to indicate the presence of chromium, but possibly only in trace amounts since chromium is known to give similar fluorescent effects in concentrations as low as 100 parts per million. Examination of the absorption spectrum of the stone using white light, did not reveal any chromium lines in the red, but there was a faintly perceptible general absorption of the green, and of the deep violet.

369

## TABLE 1

OBSERVED AND CALCULATED X-RAY POWDER DIFFRACTION DATA FOR MAGNESIOAXINITE (1) AND FERROAXINITE FROM FRANCE (2).

| (1) | | | | (2) | | | |
|---|---|---|---|---|---|---|---|
| $I/I_1$ | $d_{obs}$ | $d_{calc}$ | $hkl$ | $I/I_1$ | $d_{obs}$ | $d_{calc}$ | $hkl$ |
| 15 | 8·95Å | 8·935Å | 010 | | | | |
| 25 | 6·29 | 6·290 | 110 | 20 | 6·30Å | 6·308Å | 110 |
| | | 6·278 | $1\bar{1}0$ | | | 6·305 | $1\bar{1}0$ |
| | | | | 1 | 5·85 | 5·851 | $10\bar{1}$ |
| | | | | 1 | 5·11 | 5·116 | 101 |
| 4 | 4·96 | 4·959 | 011 | 2 | 4·97 | 4·976 | 011 |
| 8 | 4·76 | 4·762 | $1\bar{1}1$ | 4 | 4·78 | 4·787 | $1\bar{1}1$ |
| 2 | 4·51 | 4·522 | $11\bar{1}$ | 6 | 4·54 | 4·535 | $11\bar{1}$ |
| 10 | 3·97 | 3·981 | $20\bar{1}$ | 4 | 3·99 | 3·987 | $20\bar{1}$ |
| 5 | 3·66 | 3·659 | $1\bar{2}1$ | 10 | 3·68 | 3·678 | $1\bar{2}1$ |
| 65 | 3·440 | 3·441 | 002 | 80 | 3·451 | 3·452 | 002 |
| 20 | 3·269 | 3·270 | $1\bar{2}\bar{1}$ | 20 | 3·277 | 3·281 | $1\bar{2}\bar{1}$ |
| 65 | 3·139 | 3·139 | $2\bar{2}0$ | 85 | 3·148 | 3·154 | 220 |
| | | | | | | 3·153 | $2\bar{2}0$ |
| 8 | 3·069 | 3·064 | $0\bar{2}2$ | 10 | 3·077 | 3·077 | $0\bar{2}2$ |
| | | 3·064 | 102 | | | 3·077 | 102 |
| 20VB | 2·985 | 3·001 | 012 | 20VB | 3·000 | 3·011 | 012 |
| | | 2·978 | 030 | | | 2·992 | 030 |
| | | 2·977 | $0\bar{3}1$ | | | 2·991 | $0\bar{3}1$ |
| | | | | 12 | 2·957 | 2·961 | $1\bar{1}\bar{2}$ |
| | | | | 4 | 2·923 | 2·925 | $20\bar{2}$ |
| 20 | 2·877 | 2·877 | $13\bar{1}$ | 18 | 2·886 | 2·887 | $13\bar{1}$ |
| | | | | 2 | 2·839 | 2·834 | $1\bar{3}0$ |
| | | | | | | 2·835 | 130 |
| 100 | 2·796 | 2·797 | $31\bar{1}$ | 100 | 2·799 | 2·801 | $31\bar{1}$ |
| 5B | 2·753 | 2·770 | $1\bar{3}1$ | 2 | 2·783 | 2·784 | $1\bar{3}1$ |
| | | 2·742 | 112 | 4 | 2·753 | 2·752 | 112 |
| 5 | 2·633 | 2·636 | $2\bar{1}\bar{2}$ | 6VB | 2·647 | 2·658 | $3\bar{1}\bar{1}$ |
| 25 | 2·556 | 2·559 | $2\bar{1}2$ | | | 2·642 | $2\bar{1}\bar{2}$ |
| | | | | 25B | 2·562 | 2·571 | $2\bar{1}2$ |
| | | | | | | 2·558 | 202 |
| | | | | 2 | 2·521 | 2·520 | $13\bar{2}$ |
| | | | | 1 | 2·477 | 2·480 | 230 |
| | | | | | | 2·479 | $2\bar{3}0$ |
| 18 | 2·429 | 2·429 | 311 | 20 | 2·440 | 2·437 | 311 |
| 18 | 2·415 | 2·411 | $30\bar{2}$ | 20 | 2·416 | 2·419 | 131 |
| | | 2·410 | 131 | | | 2·415 | $30\bar{2}$ |
| | | | | 1 | 2·391 | 2·393 | $2\bar{2}2$ |
| | | | | | | 2·387 | $1\bar{3}2$ |
| 8 | 2·352 | 2·354 | $11\bar{3}$ | 20 | 2·361 | 2·362 | 212 |
| | | 2·353 | 212 | | | 2·360 | $11\bar{3}$ |
| 1 | 2·305 | 2·309 | $23\bar{2}$ | 1 | 2·319 | 2·320 | $32\bar{1}$ |
| | | | | | | 2·315 | $23\bar{2}$ |
| 1 | 2·252 | 2·253 | $12\bar{3}$ | 3 | 2·261 | 2·261 | $2\bar{3}1$ |
| | | 2·252 | $2\bar{3}1$ | | | 2·260 | $12\bar{3}$ |
| 28 | 2·176 | 2·176 | $1\bar{4}1$ | 28 | 2.185 | 2·188 | $1\bar{4}1$ |
| 32 | 2·150 | 2·148 | 103 | 32 | 2.154 | 2·156 | 103 |
| 4 | 2·121 | 2·119 | $1\bar{1}3$ | 5 | 2.125 | 2·125 | $1\bar{1}3$ |
| 14 | 2·048 | 2·048 | $13\bar{3}$ | 20 | 2·055 | 2·055 | $13\bar{3}$ |
| 14 | 2·028 | 2·0285 | $1\bar{3}2$ | 14 | 2·035 | 2·0356 | $1\bar{3}2$ |

The intensities were estimated visually by comparison with an intensity scale.
B=broad, VB=very broad.

1. Magnesioaxinite, Tanzania (Registered No. M.I. 34610). CuKα radiation (λ=1·54178Å) *a* 8·933Å, *b* 9·155Å, *c* 7·121Å, α 102·59°, β 98·28°, γ 88·09° (cell volume 562·4Å³).

2. Ferroaxinite, Bourg d'Oisans, Dauphiné, France (Registered No. M.I. 34509), CoKα radiation (λ=1·79021Å). *a* 8·953Å, *b* 9·197Å, *c* 7·143Å, α 102·63°, β 98·10°, γ 88·21° (cell volume 568·2Å³).

Comparison of x-ray powder data (Table 1), obtained from films taken with an 11·46 cm camera, of the gem mineral and axinite from Bourg d'Oisans shows the gem to be an axinite. The powder data were provisionally indexed by comparison with published data and were refined using the least squares program (BA1·0) developed by Dr R. J. Davis, Department of Mineralogy, British Museum (Natural History), for the refinement of cell dimensions and enumeration of all possible d-spacings. This refinement gave cell dimensions *a* 8·933Å, *b* 9·155Å, *c* 7·121Å, α 102·59°, β 98·28°, γ88·09° (cell volume 562·4Å³) for the Tanzanian axinite and *a* 8·953Å, *b* 9·197Å, *c* 7·143Å, α 102·63°, β 98·10°, γ 88·21° (cell volume 568·2Å³) for the axinite from Bourg d'Oisans. The Tanzanian axinite gives slightly smaller d-spacings than the French material and gives an additional spacing at 8·95Å which is also given by the manganese-rich axinite known as tinzenite (Milton *et al.*, 1953).

In view of the unusual colour for an axinite and the low physical constants, it was decided to carry out a chemical analysis by electron microprobe (Geoscan microanalyser) despite its limitations on elements with an atomic number below 11 (sodium), and the consequent omission of boron and water from the results. A small fragment of axinite from Bourg d'Oisans was also analysed for comparison. Analyses were made of the various elements using appropriate silicates, oxides, sulphides and pure metals as standards. The analyses were made at an accelerating potential of 20kV and the results have been corrected for x-ray absorption, atomic number effect and secondary fluorescence using the computer program written by Mason, Frost and Reed.

371

TABLE 2

SHOWING ANALYSES OF MAGNESIOAXINITE (1) MAGNESIUM
RICH AXINITE FROM AUSTRALIA (2) AND FERROAXINITE FROM
FRANCE (3)

|  | (1) | (2) | (3) |
|---|---|---|---|
| $SiO_2$ | 44·0 | 42·39 | 42·2 |
| $TiO_2$ | 0·03 | — | 0·03 |
| $B_2O_3$ | * | 5·52 | * |
| $Al_2O_3$ | 17·9 | 17·10 | 17·5 |
| $Cr_2O_3$ | nt.fd. | — | nt.fd. |
| $V_2O_3$ | 0·13 | — | nt.fd. |
| $Fe_2O_3$ | nt.fd. | 1·68 | † |
| FeO | nt.fd. | 5·18 | 6·1† |
| MnO | 0·4 | 1·38 | 3·3 |
| MgO | 6·9 | 4·20 | 1·6 |
| CaO | 21·7 | 20·31 | 20·1 |
| ZnO | 0·06 | — | nt.fd. |
| NiO | nt.fd. | — | nt.fd. |
| CoO | nt.fd. | — | nt.fd. |
| $Na_2O$ | nt.fd. | 0·06 | 0·04 |
| $K_2O$ | 0·01 | 0·03 | 0·02 |
| $H_2O > 105°$ | n.d | 1·67 | n.d |
| $H_2O < 105°$ | n.d | 0·31 | n.d |
|  | 91·13 | 99·83 | 90·89 |

n.d. = not determined, nt.fd. = not found.   *The presence of boron was confirmed
by chemical tests.   †Assuming that all the iron is in the divalent state.

| | | | |
|---|---|---|---|
| α | 1·656 | 1·659 | 1·672 |
| β | 1·660 | 1·665 | 1·679 |
| γ | 1·668 | 1·668 | 1·682 |
| δ | 0·012 | 0·009 | 0·010 |
| D | 3·178 | 3·19 | 3·288 |

NUMBERS OF IONS ON THE BASIS OF 28(0) (COLUMNS 1, 2a, AND
3), ON THE BASIS OF 32 (O,OH) (COLUMN 2b).

| | (1) | (2a) | (2b) | (3) |
|---|---|---|---|---|
| B | — | 1·772 | 1·789 | — |
| Si | 8·012 | 7·885 }8·00 | 7·961 }8·00 | 8·025 |
| Al$^{iv}$ | — | 0·015 | 0·039 | — |
| Al$^{vi}$ | 3·842⎱ | 3·634 }3·87 | 3·746 }3·98 | 3·923⎱ |
| Fe$^{3+}$ | —⎰3·87 | 0·235 | 0·237 | —⎰3·93 |
| Ti | 0·004 | — | — | 0·004 |
| V | 0·019 | — | — | — |
| Mg | 1·872⎱ | 1·165⎱ | 1·176⎱ | 0·454⎱ |
| Fe$^{2+}$ | — | 0·806 | 0·814 | 0·970 |
| Mn | 0·061 | 0·217 | 0·220 | 0·531 |
| Zn | 0·008 ⎰6·18 | — ⎰6·27 | — ⎰6·33 | — ⎰6·07 |
| Ca | 4·234 | 4·049 | 4·088 | 4·095 |
| Na | — | 0·021 | 4·021 | 0·015 |
| K | 0·002 | 0·007 | 0·007 | 0·005 |
| OH | — | 2·072 | 2·092 | — |

The number of ions has been given to three places of decimals to avoid rounding
up errors.

1. Magnesioaxinite, Tanzania (Registered No. M.I. 34610). Microprobe anal. A. E. Tresham.
2. Magnesium-rich axinite associated with epidote, tremolite and calcite; London Bridge, near Queanbeyan, New South Wales, Australia. Anal. T. G. Vallance.
3. Ferroaxinite, Bourg d'Oisans, Dauphiné, France (Registered No. M.I. 34509). Microprobe anal. A. E. Tresham.

The results of these analyses and that of the magnesium-rich axinite described by Vallance (1966) are shown in Table 2. Since the microprobe analyses do not show $B_2O_3$ or $H_2O$ we have calculated the number of ions in the unit cell on the basis of 28 oxygens, but the full analysis of Vallance has been calculated on a 32 oxygen basis (column 2b). We also show the Vallance analysis calculated on a 28 (0) basis (column 2a) for direct comparison with the microprobe analyses.

Analyses for chromium using the microprobe are complicated by the overlap of the chromium $K\alpha$ peak by the vanadium $K\beta$ peak, and it was not possible to make a satisfactory count for chromium. It may be that traces of chromium are the cause of the red fluorescence, but one cannot exclude the possibility that the 0·13% $V_2O_3$ is responsible. A synthetic corundum simulating alexandrite and coloured by vanadium (probably > 1%V) showed the characteristic sharp line at 4750Å (not seen in the axinite gemstone) through the spectroscope using copper sulphate solution as a filter, but there was no fluoresence in the red part of the spectrum, although the fluorescent effects in UV light and between crossed filters are similar to the gemstone. However, the fluorescent effects of vanadium in axinite do not necessarily follow a precisely similar pattern to that when it is used as a colouring agent in synthetic corundum. The presence of manganese and vanadium interfere with some sensitive microchemical tests for chromium, and we were unable to confirm the presence of the element by this means. Accordingly, we record chromium as 'not found'.

Since boron and water cannot be detected with the microprobe used it was deemed desirable to confirm these constituents of the axinite by other tests. A scraping from the gemstone mixed with potassium bisulphate and fluorite was fused on a platinum

373

wire and the presence of boron was confirmed by the green coloration imparted to the flame. It was hoped to confirm the presence of water by heating in a dried tube and observing the condensation in the cooler part of the tube, but the results were not sufficiently conclusive and further material could not be spared from the gemstone.

The chemical formula of axinite has been given as 2 [(Ca, $Fe^{2+}$, Mn, Mg)$_3$Al$_2$BSi$_4$O$_{15}$OH] and there is considerable variation in the proportions of Fe and Mn, and also Ca, in different axinites. Sanero and Gottardi (1968) proposed the names ferroaxinite and manganaxinite for the calcium iron (Ca, Fe) and the calcium manganese (Ca, Mn) end members of the series. Vallance (1966) described an axinite from London Bridge, near Queanbeyan, New South Wales containing 4·2% MgO, 5·18% FeO, 1·68% $Fe_2O_3$ and 1·38% MnO (the only other axinite previously described with such a high Mg content seems to have been that of Steinwachs (1929), which had 4·13% MgO) and with this significant percentage of magnesium it appears that mutual substitution is possible between Fe, Mn and Mg. The refractive indices of the London Bridge material $\alpha$ 1·659 (1·656), $\beta$ 1·665 (1·660) and $\gamma$ 1·668 (1·668) approach those of the present gemstone (shown in brackets) and the specific gravity is also reduced 3·19 (3·178). It would seem that the increase in magnesium, at the expense of Fe and Mn, is responsible for the lowering of the physical constants (including the cell dimensions) compared with the Bourg d'Oisans and most other axinites. However, the physical constants of the present axinite (with 6·9% MgO) are not as low as might have been expected compared with those of the Australian material (4·2% MgO).

The composition of the gemstone now described closely approaches the theoretical calcium magnesium (CaMg) end member, with 6·9% MgO and only 0·4% MnO, and we now propose that the name *magnesioaxinite* should be applied to it. Fromme (1909) proposed the name magnesium-axinite for a theoretical end member of the series, but the mineral had not then been found in nature, nor was artificial material known. The name magnesio-axinite (following the style of Sanero and Gottardi) has been submitted for approval to the Commission on New Minerals and Mineral Names of the International Mineralogical Association.

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graphical Department of the Institute, and with friends at the Gem Testing Laboratory of the London Chamber of Commerce, Mr R. K. Mitchell and others—their assistance is gratefully acknowledged. We are especially indebted to Dr R. J. Davis and Mr J. G. Francis of the British Museum (Natural History) for their collaboration in making available the computer program for the refinement of the x-ray data. Prof. R. A. Howie kindly allowed us to see the revised typescript for the axinite section of Deer, Howie and Zussman, *Rock Forming Minerals*, 2nd edition.

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# INFRA-RED REFLECTION SPECTRA OF TURQUOISE (NATURAL AND SYNTHETIC) AND ITS SUBSTITUTES

*By M. ARNOULD and J.-P. POIROT*

*Abstract:* Studies are reported of the 800-1200 cm$^{-1}$ reflection spectra of natural and synthetic turquoise and some of its substitutes. Resulting curves permit an easy identification of the different stones.

Infra-red reflection spectroscopy is a non-destructive method of investigation, which can be applied to gemstones, even if they are