THE MINERALOGICAL MAGAZINE
AND
JOURNAL OF
THE MINERALOGICAL SOCIETY

No. 161 June, 1938 Vol. XXV

Russellite, a new British mineral.

(With Plate II.)

By MAX H. HEY, M.A., D.Sc., and F. A. BANNISTER, M.A.
Assistant-Keepers in the Mineral Department of the British Museum.

With a note on the occurrence and the accompanying minerals.

By ARTHUR RUSSELL.

[Read November 4, 1937.]

IN May, 1936, a quantity of pale yellow, rounded fragments, averaging 7 mm. across, was submitted to us by Mr. Arthur Russell for examination, with the information that the material came from the Castle-an-Dinas wolfram mine, and contained bismuth and tungsten. Chemical and spectroscopic examination showed that, besides bismuth and tungsten, the mineral contained only traces of silicon, arsenic, and iron. A sample of the same material had also been given to the British Museum by Mr. E. H. Davison in 1934 and registered provisionally as bismuth tungstate. This, however, would not have provided sufficient of the yellow mineral for chemical analysis. We are also indebted to Mr. Davison for a further generous supply of yellow pellets picked from the wolfram concentrates received since the present work was begun. The mineral has all the attributes of an alteration product probably of native bismuth. It is fine-grained and compact, with hardness 3½, and on fracture it gives a clay-like odour. Some of the pellets show traces of a micaceous mineral and quite frequently enclose native bismuth, wolframite, and bismuthinite. Mr. Russell has picked out from the material he had collected a few green pellets and some showing both the yellow and the green mineral. Spectrographs of the two are identical, but an X-ray powder photograph of the green mineral is quite distinct from that of the yellow mineral. The former still awaits investigation.

An examination of the X-ray powder photograph of the mineral does not reveal the lines characteristic of any of the following compounds: bismuth oxide, cubic bismuth oxide,[1] tungstic oxide, and tungstic acid. Moreover, the photograph appears to be much simpler and to contain fewer lines. The most satisfactory proof that the material is really a single mineral and not a mixture rests upon comparison with the artificially prepared material.

We propose for the mineral the name russellite, in honour of Mr. Arthur Russell, who has contributed much to our knowledge of British mineralogy.

Zambonini has prepared and described two dimorphous forms of normal bismuth tungstate $Bi_2(WO_4)_3$.[2] He obtained a monoclinic form as grey-green to dark green lamellae isomorphous with raspite by direct fusion of the components. This green compound on fusion for three hours at 900–1000° C. with excess sodium chloride was partially converted into the tetragonal modification, as groups of white bipyramidal crystals ($a:c = 1:1{\cdot}566$) isomorphous with stolzite ($a:c = 1:1{\cdot}5667$), together with thin colourless flakes of bismuth oxychloride. The bismuth oxide content of both forms was determined and agreed very closely with the ideal figure for the normal tungstate.

We repeated these syntheses in the hope that one of the two artificial compounds of Zambonini would prove identical with russellite. No difficulty was experienced in duplicating Zambonini's first preparation. A pale olive-green platy material with a good cleavage resulted which yielded a powder photograph quite distinct from, and much more complex than, that of russellite. It is by no means certain, however, that we have been able to produce Zambonini's white bipyramidal compound. Three separate fusions of the green tungstate with excess sodium chloride at temperatures ranging from 700° to 900° C. all yielded abundantly a flocculent, pale yellow, flaky mass together with a few small grey-white crystal groups which proved to be cristobalite formed by attack on the crucible wall during fusion.

The yellow flaky material gave a powder photograph identical with that of russellite (pl. II, figs. 2 and 3). What is of more importance, the synthesis of this compound enabled us to proceed with the crystal-

---

[1] M. M. P. Muir and A. Hutchinson, Journ. Chem. Soc. London, 1889, vol. 55, p. 143. The X-ray photographs obtained from this substance indicate that it is a definite compound, quite distinct from ordinary Bi_2O_3.

[2] F. Zambonini, Gazzetta Chimica Italiana, 1920, vol. 50, pt. 2, pp. 129 and [illegible] [M.A. 2–245.]

lographic and optical studies of single crystals, for under the microscope the artificial compound is seen to consist of minute thin laths up to 0·25 mm. long (positive elongation) and thin plates yielding no optic picture. The refractive index of the crystals (obtained in sulphur-selenium melts) is 2·2. A few laths were mounted for X-ray work and rotation photographs were taken about the principal axes (pl. II, fig. 1). These showed that the mineral is tetragonal with unit cell edges, *a* 5·42±0·03 Å., *c* 11·3±0·3 Å. The laths are elongated along the *c*-axis and the plane of the lath is (100) or (110). Moreover, the single crystal photographs were exactly superposable upon powder photographs of russellite and of the artificial compound, so that there is good reason to suppose that the latter is a single mineral and not a mixture. The axial ratio of the yellow compound obtained from the unit cell measurements is $a : c = 1:2·084$, and is markedly lower than the value for stolzite $a : c = 1:2·208$. Dividing these values by $\sqrt{2}$, in order to compare them with the axial ratios adopted by Dana, yields 1·476 and 1·561 respectively. It is to be noted that the value 1·476 is well below the value observed by Zambonini for his crystals of tetragonal bismuth tungstate.

Since the natural and artificial compounds give identical X-ray photographs, they must have essentially the same structure and it was astonishing to find, on chemical analysis, that the natural mineral has a composition approximating to $Bi_2O_3.WO_3$, while the artificial approximates to $Bi_2O_3.2WO_3$ (in both cases, the departure from these formulae is outside the probable analytical error). Further, when the specific gravities were determined, it was found that that of the artificial mineral was greater than that of the natural, contrary to what would be expected from their compositions. The most natural assumption was that the specimens had somehow got interchanged, and therefore new analyses and specific gravity determinations were made on fresh material, and in duplicate; the first results were thus confirmed, and it was evident that we were dealing with a very remarkable substance. It was also found that the natural material varies somewhat in composition, while different batches of the artificial material also show considerable variations.

The chemical analyses, unit cell dimensions, densities, and atoms per unit-cell in natural and artificial russellite are given in table I. The analyses were made on a semi-micro scale, using 0·1 gm. of material, by the following method, while the densities were determined with the micro-pyknometer.[1]

---

[1] F. A. Bannister and M. H. Hey, Min. Mag., 1938, vol. 25, p. 30.

TABLE I. Chemical and physical data for russellite and artificial $(Bi_2,W)O_3$.

		Natural mineral.		Artificial product.		
Percentage composition	Bi_2O_3	68·26	62·3	48·15	50·3	42·3
	WO_3	25·50*	32·1	45·85	43·0	51·8
	As_2O_3†	0·26	0·29	—	—	—
	Fe_2O_3	trace	n.d.	—	—	—
	Al_2O_3	—	—	2·26	n.d.	n.d.
	Insoluble	1·60	1·6	1·78	1·8	n.d.
	Loss on ignition	4·86	n.d.	1·78	n.d.	n.d.
	Total	100·48	—	99·82	—	—
	Oxygen	13·13	13·9	15·37	15·1	16·0
Atoms per unit cell	Bi	4·60	4·2	3·56	3·75	3·1
	W	1·72	2·2	3·41	3·2	3·85
	As	0·04	0·04	—	—	—
	O	12·14	12·8	15·58	15·3	16·2

Specific gravities D_4^{21}, corrected to vacuum
Natural mineral: 7·26, 7·54, 7·18, 7·43; mean 7·35±0·2.
Artificial: 8·12, 8·01, 8·14, 7·97; mean 8·06±0·1.

Unit cell dimensions for both natural and artificial material: *a* 5·42±0·03 Å., *c* 11·3±0·3 Å.

The mineral powder was ignited just below a red heat, the loss on ignition being noted, then evaporated to dryness twice with strong hydrochloric acid, extracted with dilute acid, and filtered with an Emich filter-stick; the residue was extracted with ammonia and filtered; any residue after this was again extracted with hydrochloric acid and ammonia, then ignited and weighed. The united acid solutions were precipitated with H_2S after addition of a little tartaric acid and the precipitate collected on paper and dissolved in nitric acid, the paper being ignited and the small residue extracted with nitric acid; in the united nitric acid solutions, bismuth was precipitated as basic carbonate. The acid filtrate was boiled free from H_2S and a little tungstic acid recovered from it by precipitation with tannin and cinchonine, this precipitate being carefully ignited in a crucible, in which the ammoniacal extracts containing the bulk of the tungstic acid were then evaporated down and ignited. Iron (in the natural material) or aluminium (in the artificial) was recovered from the filtrate from the tannin-cinchonine precipitate by addition of ammonia. Arsenic in the natural material was determined on a separate portion of 0·1 gm. by distillation as $AsBr_3$, followed by precipitation and weighing as As_2S_3.

The insoluble material and alumina in the analyses of the artificial compound are evidently derived from the crucible, but it was not clear whether the very considerable water content in both the natural and artificial material should be included as an essential constituent of the compound, or excluded as adsorbed moisture. An X-ray powder photo-

---

* A third partial analysis of the natural mineral gave WO_3 23·44 per cent. All the analyses were made on separate specimens or preparations.

† Total arsenic as As_2O_3; the state of oxidation was not determined.

graph of material which had been gently ignited was found to be identical with that of the untreated material, and it is therefore probable that the water is adsorbed; in the following discussion it has been assumed that the water is wholly adsorbed.[1]

The chemical and physical data thus show that natural and artificial russellite have quite different numbers of oxygen atoms per unit cell; yet they give identical X-ray powder photographs. This is, of course, possible provided the metal atoms are similarly placed in the structures of the two substances, since the contribution of the oxygen atoms to the intensities of the diffractions is very small compared to that of the metal atoms. But it was clear that for a better understanding of the relation of the two compounds, a knowledge of their crystal-structures was desirable.

A rotation photograph of the artificial compound was readily indexed, and formed the basis for indexing the powder photographs. The observed diffractions clearly indicated that the heavy bismuth and tungsten atoms, considered alone, must satisfy the symmetry of the tetragonal space-group D_{4h}^{19}, at least to a very close approximation, but since the light oxygen atoms would contribute very little to the observed diffractions, the true symmetry might be lower. No indication could be found to suggest that the unit cell chosen was a submultiple of the true cell, as the atomic cell contents might suggest.

Moreover, the observed diffractions clearly showed that there was a very marked pseudo-cell *having half the height of the true cell*; this pseudo-cell has approximately cubic dimensions. After a careful consideration of a variety of possible arrangements, we concluded that the heavy atoms (bismuth and tungsten) must lie approximately on a face-centred pseudo-cubic lattice conforming strictly or very closely to the symmetry requirements of the space-group D_{4h}^{19}; and that it was impossible to find separate sets of equivalent lattice positions for the bismuth and tungsten atoms, which must be distributed over one eightfold set of equivalent positions, part of which will then be vacant.

The only possible position for the bismuth and tungsten atoms is thus the uniparametral eightfold position of D_{4h}^{19}, $\Sigma_8 00u$; a comparison of intensities in the first to fifth layer-lines of a rotation photograph of a crystal of the artificial material about the *c*-axis (table II) fixes

---

[1] This is not proved, at least for the natural mineral; a large part of the water might be present as 'zeolitic' water of crystallization in the vacant spaces of the structure, and its expulsion would not appreciably affect the X-ray photographs.

the parameter u at 0·23±0·005, and this result is confirmed by a comparison of observed and computed intensities in a powder photograph (fig. 1). This arrangement holds for both the natural and the artificial compound.

TABLE II. Observed and computed intensities of the diffractions on an X-ray rotation photograph of artificial $(Bi_2,W)O_3$ about the axis [001].

ξ.	Indices.	Intensities.	
		Obs.	Calc.
Equator:			
0·58	(200)	*vs*	10
0·82	(220)	*s*	8
1·16	(400)	*s*	4
1·29	(420)	*s*	6
1·63	(440)	*w*	3·4
1·73	(600)	*m*	3·6
1·82	(620)	*m*	10
First layer-line:			
0·29	(101)	*vw*	0·8
0·65	(211)	*vw*	0·4
0·87	(301)	*vvw*	0·2
1·04	(321)	*vvw*	0·2
1·19	(411)	*vvw*	0·2
1·45	{(431) (501)}	—	0·2
1·56	(521)	—	0·1
1·76	(611)	*	0·2
1·85	(541)	*	0·2
1·94	(631)	*	0·4
Second layer-line:			
0·40	(112)	*vs*	23
0·92	(312)	*s*	16
1·23	(332)	*m*	6
1·46	(512)	*s*	10
1·68	(532)	*s*	12
Third layer-line:			
0·29	(103)	*vvw*	1·5
0·65	(213)	*vvw*	1·5
0·86	(303)	*vvw*	0·5
1·04	(323)	*vvw*	0·9
1·19	(413)	*vvw*	0·7
1·45	{(433) (503)}	—	0·9
1·56	(523)	—	0·7
1·76	(613)	*	0·9
1·85	(543)	*	1·3
1·94	(633)	*	2
Fourth layer-line:			
0·58	(204)	*vs*	12
0·82	(224)	*m*	6
1·16	(404)	*m*	5
1·29	(424)	*m*	10
1·63	(444)	*m*	5
1·74	(604)	*m*	8
1·82	(624)	*s*	23
Fifth layer-line:			
0·29	(105)	*w*	3

ξ the longitudinal cylindrical co-ordinates of diffraction spots, see J. D. Bernal, Proc. Roy. Soc. London, Ser. A, 1926, vol. 113, p. 117. [M.A. 3–333.]

* General fog would probably prevent observation of this diffraction.

The oxygen atoms are unfortunately too light to fix by intensity considerations. In the artificial compound, they number sixteen, and if they are all equivalent (as seems most probable), they must occupy the positions[1] $\Sigma_{16} v\ \frac{1}{4}\ \frac{1}{8}$ of D^{19}_{4h} with v between 0·27 and 0·29. A value of 0·29 for v makes each oxygen equidistant from four bismuth or tungsten

---

[1] If it is assumed that the symmetry is lower than D_{4h}, the range of possible positions of the oxygen atoms is little affected. The more symmetrical assumption is made here as there is no evidence against it.

atoms at 2·40 Å., each bismuth or tungsten being surrounded by eight oxygen at the corners of a distorted cube. With a value[1] of 0·27 for v, each oxygen has as neighbours two bismuth atoms at 2·32 Å. (located at $00u$ and $0,\frac{1}{2},\frac{1}{4}-u$ for the oxygen at $v\,\frac{1}{4}\,\frac{1}{8}$) and two at 2·55 Å., and each bismuth atom has as its nearest neighbours four oxygen atoms distant 2·32 Å. and located at the corners of a rectangle in a plane parallel to (001), a structure which seems less probable than the more symmetrical one with $v = 0·29$.

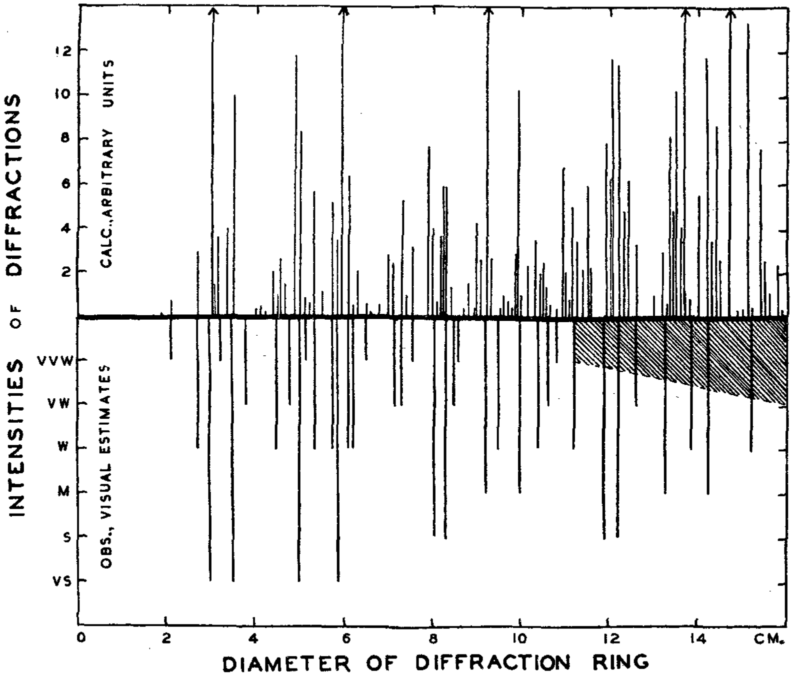


Fig. 1. Observed and calculated intensities of the diffractions in a powder photograph of russellite, taken with unfiltered Cu radiation λ 1·539 Å., in a cylindrical camera, diameter 6·04 cm. The film showed considerable background fog from 11 cm. outwards (represented by shading in the figure), which may obscure weak lines.

For the natural mineral, russellite, there are two structural possibilities. It may be strictly isomorphous with the artificial compound and

---

[1] Values of v less than 0·27 have been rejected since they would lead to bismuth-oxygen distances less than 2·32 Å., which is the distance found in the oxyhalides of bismuth (F. A. Bannister, Min. Mag., 1935, vol. 24, p. 53).

have an incompletely filled set of oxygen positions, or the structure may be different, the oxygen being divided between an eightfold and a fourfold lattice position. In the second case, it is not possible to find positions in accordance with the symmetry of the space-group D_{4h}^{19} which would give reasonable interatomic distances. But in the space-group D_{2d}^{12} (derivable from D_{4h}^{19} by a reduction of symmetry) an eightfold position $\Sigma_8 00u$ is available for the bismuth and tungsten atoms, while if the twelve oxygen atoms occupy the fourfold special position $\Sigma_4 000$ and the eightfold uniparametral position $\Sigma_8\,\frac{1}{4}\,v\,\frac{1}{8}$ with $v = 0{\cdot}345$, reasonable interatomic distances are obtained. Each bismuth or tungsten atom has as nearest neighbours three oxygen atoms, two at 2·29 Å. and one at 2·60 Å., while two more oxygens lie 2·68 Å. distant; the nearest approach between the oxygen atoms is 2·71 Å. (from the oxygen at 000 to that at $\frac{1}{4}\,v\,\frac{1}{8}$). The bismuth or tungsten atom and its three neighbouring oxygen atoms are coplanar. It is difficult to say which of these structures is the more probable.

Russellite and the related artificial compound have unit cells of the same size as those of the scheelite group, and the X-ray photographs of both groups are very similar, the most notable difference being that the odd layer-lines of a *c*-axis rotation photograph are relatively much stronger with russellite than with stolzite (which has atoms of comparable scattering powers). For russellite, which has only 12 oxygen atoms per unit cell, the scheelite type of structure would naturally be impossible.[1] It is possible that the artificial material might have a scheelite structure, the bismuth and tungsten occupying separate fourfold positions, which would not be wholly filled; but such a structure would contain a proportion of groups of four oxygen atoms without a central metal atom and does not, therefore, seem at all likely. It is unfortunate that owing to the low diffracting power of the oxygen atoms they cannot be directly located and the structure definitely fixed.

In the structures adopted, bismuth and tungsten are equivalent, and there is no sign of the WO_4 group of the tungstates; the natural assumption that russellite, being nearly $Bi_2O_3.WO_3$, must be basic bismuth tungstate $(BiO)_2WO_4$ is therefore quite incorrect, and so far from being a tungstate at all, russellite is an oxide, a mixed crystal of Bi_2O_3 and WO_3, crystallizing in a form quite different from that of either of the

---

[1] If 16 oxygen atoms per unit cell were asumed for russellite, the specific gravity should be 9·8, which differs from the experimental value by far more than the probable experimental error.

pure oxides,[1] and its empirical formula must be written $(Bi_2,W)O_3$. Whether the artificial material really represents the same species as russellite, or whether it is to be regarded as a compound of different (but closely allied) structure remains uncertain.

Summary

Russellite, a new species, occurs at the Castle-an-Dinas wolfram mine, St. Columb Major, Cornwall, as pale yellow fragments. It is tetragonal, space-group D_{2d}^{12} or possibly D_{4h}^{19}, a 5·42±0·03 Å., c 11·3±0·3 Å., repeat $(Bi,W)_{8-n}O_{12}$. Its composition is near $Bi_2O_3.WO_3$, but it is an isomorphous mixture of oxides, not a bismuth tungstate. The crystal-structure has been studied, and the bismuth and tungsten atoms located. The number and position of the oxygen atoms is discussed, and two possibilities described. An artificial compound with a composition near $Bi_2O_3.2WO_3$ and a repeat $(Bi,W)_{8-n}O_{16}$ is either a member of the same isomorphous series or has a structure very closely allied to that of russellite.

The occurrence and associations of russellite.

By Arthur Russell.

Towards the end of March, 1934, during one of my periodic visits to the Castle-an-Dinas wolfram mine, St. Columb Major, Cornwall (six-inch ordnance map, 33 SW.) my attention was called by Mr. J. Chynoweth (the manager) and Mr. W. A. Kessell (the underground agent) to a pale yellow, heavy mineral which had commenced to appear along with the wolframite in the jig concentrates in the mill. As the wolfram ore had, up to that time, been remarkably free from any other heavy minerals, with the exception of a little cassiterite, the mineral at once excited my interest, and having determined the presence of bismuth and tungsten, I again visited the mine and with Mr. Kessell made a careful search in the particular stope between no. 1 and no. 2 level in the sedimentary rock from which the wolfram ore containing the mineral was undoubtedly then coming. No trace of it, however, rewarded our search. Since then the mineral has only appeared in the concentrates at long intervals and in diminishing quantities, obviously owing to the fact that it occurs only in one limited section of the vein. Repeated and very careful searches by both Mr. Kessell and myself have up to now failed

---

[1] It was thought at first that cubic Bi_2O_3 might be an end-member of the series, but comparison of the X-ray photographs disproves this. It is not unknown for a mixed crystal to have a structure unstable in either of the pure components.

to detect a single specimen of the mineral, either in situ or in the crude ore. This, however, can be explained by the fact that it is probably present in small masses only, and owing to its inconspicuous colour and structure it would be exceedingly difficult to see underground, while the dirt-covered ore is tipped direct from the level mouth into the mill.

In the 'Mining Magazine' (London) for May, 1934, the Cornish correspondent referred to the mineral as being bismuth tungstate, and suggested that it might probably be a new mineral. This statement was apparently due to the fact that Mr. H. W. Hutchin, assayer of Tuckingmill, to whom a sample of the concentrate had been submitted, had detected bismuth and tungsten, and very naturally assumed the mineral to be a bismuth tungstate. Since that date Dr. M. H. Hey and Mr. F. A. Bannister, have, at my instigation, kindly undertaken the chemical analysis and the determination of its X-ray structure, with the result that the mineral proves to be undoubtedly a new species, and an interesting addition to the long list of minerals occurring in that most wonderful store-house—Cornwall.

The cream-coloured to greenish pellets of russellite show the following intimately associated minerals, all of which are sometimes embedded in their mass: native bismuth, wolframite, limonite, quartz, topaz, lithia-mica, and black prisms of tourmaline.

The main geological features of the mine have been described by Mr. E. H. Davison in 1920[1] and also by myself in 1924,[2] and are as follows. The hill of Castle-an-Dinas, crowned by an ancient camp, rises to a height of 702 feet, and is a small granite boss or outlier rising through banded sediments belonging to the Meadfoot series. The granite outcrops as a small rudely elliptical area on part of the summit and western side, the remainder of the hill consisting of the altered sediments. Small veins containing cassiterite have in the past been worked in the sediments near the north-east base of the hill, while on the south-west the original Castle-an-Dinas mine worked a stanniferous elvan by open quarries. In 1917, in consequence of somewhat rounded masses of wolframite having been found in trial pits sunk on the north side, mining operations on a small scale were commenced by the late Mr. W. E. Cox

---

[1] E. H. Davison, On the geology of Castle-an-Dinas and Belowda Beacon. Trans. Roy. Geol. Soc. Cornwall, 1919, vol. 15, pp. 269–285. On the geology of Castle-an-Dinas wolfram mine. Geol. Mag. London, 1920, vol. 57, pp. 347–351. [M.A. 1–387.]

[2] A. Russell, Topaz from Cornwall, with an account of its localities. Min. Mag., 1924, vol. 20, pp. 231–233.

of Newquay, the mine in 1918 being taken over by the South Crofty Company, by whom it has since been worked whenever the price of wolfram has justified it.

The wolfram lode has a direction of about 18° east of north, is nearly vertical, and varies in width from 2 to 6 feet. It is worked by means of four levels and a shaft, all on the north side of the hill, and traverses the sedimentary rock, entering the granite mass, or tongues connected with it, as the centre of the hill is approached. The sediment near the surface is a pinkish baked slate, in depth passing into a brownish, finely laminated gritty rock, showing marked zigzag puckering. The granite is white, fine-grained, and sometimes contains tourmaline, and near the lode is somewhat kaolinized and often passes into greisen. Quite recently, in no. 3 level, a soft gilbertite-bearing china-stone with deep-violet fluorite upon its joints has been driven through near the centre of the hill. The lode filling, while traversing the sediment, consists of quartz with limonite coatings, wolframite, topaz, brown lithia-mica, and some tourmaline, the rarer minerals present being cassiterite, native bismuth, bismuthinite, russellite, arsenopyrite, scorodite, wavellite, turquoise, and, very rarely, native copper and cuprite. Practically the whole of the wolfram so far produced has come from the sedimentary section of the lode. On entering the granite, arsenopyrite has, unfortunately, recently made its appearance in quantity; the concentrates from that particular section containing about half and half of the two minerals. Recently the lode in no. 3 level completely cut out against what appears to be the main granite core, but on driving 438 feet through the mass, it has again been found in the sediment, highly productive of wolfram on the south side of the hill. The lode has also been picked up by trenching on the south side of the hill, and new life has thus been given to the mine. The following minerals have been found in the lode.

Wolframite forms large, bright iron-black lamellar masses easily parting along the lamellae, which are often coated with a thin film of quartz, the outside of the masses being usually coated with limonite. The lamellae are elongated in the direction of the *c*-axis and are fluted from repeated oscillations of *a* (100) and *m* (110) and have a perfect *b* (010) cleavage. Terminated crystals, always rare in Cornwall, have so far not been observed. A curious development of this mineral, peculiar, I believe, to the locality, consists of masses built up of narrow alternating and rudely parallel strings of wolframite and quartz or quartz with topaz, between which are films of white pearly mica, twenty or so of these to an inch, giving the specimens a peculiar striped appearance.

These little wolframite strings often have a blue, green, or bronze iridescence and are formed of small parallel crystal lamellae with the *c*-axis usually at right angles to the string though sometimes set diagonally. Each individual is continuous throughout the mass though intersected and sometimes slightly faulted by the quartz strings, and when faulted all are slightly shifted in the same direction, the amount of displacement appearing to be dependent on the width of the quartz string. In one specimen the strings, instead of being straight, are distinctly folded. Associated with these masses are ordinary vein quartz, scales of rusty lithia-mica, and rarely a little turquoise. Some of the large lamellar masses of wolframite are the finest examples of the mineral which have been met with in Cornwall.

Cassiterite is rarely visible though at times the wolfram concentrates have contained up to 3% of the mineral. In 1936, a few specimens were found in the granite section of the mine which show numerous small, translucent, yellowish-brown, acute pyramidal crystals up to 6 mm. in length, embedded in quartz with needles of black tourmaline and interstices filled with white kaolin. A crystal was measured, the forms present being *m* (110), *e* (101), *s* (111), *z* (321) [Dana's letters].

Arsenopyrite, as already stated, has only recently (1937) made its appearance in the deeper granitic section of the mine. It occurs as large silver-white masses in quartz, and also in striped masses consisting of alternating parallel strings of arsenopyrite and quartz, exactly resembling the specimens described under wolframite.

Native copper and cuprite.—Both these minerals are of very rare occurrence. A specimen which I found on the dump derived from the upper part of the lode in the sediment shows small bright leaves and octahedra of native copper associated with minute bright octahedra of cuprite in quartz with topaz, wavellite, and scorodite. Small pellets up to 8 mm. of native copper have also occasionally been observed among the wolfram concentrates.

Native bismuth and bismuthinite.—Small quantities of native bismuth were found by myself in 1934 along with the russellite amongst the wolfram concentrates from the jigs. Like the russellite, all efforts have so far failed to detect a single specimen in situ or in the crude ore. It occurs in the sedimentary rock section of the mine and is of much rarer occurrence than the russellite with which it is associated. The fragments of native bismuth as they come from the jigs attain a maximum size of about 1 cm. and from the unbroken appearance of some of them it may be assumed that this is about the maximum size that they occurred in the vein stuff. Some of the fragments consist of native bismuth only with the characteristic reddish silver-white colour and coarse lamellar cleavages parallel to (0001) and $(02\bar{2}1)$; others are pellets of native bismuth externally covered with grey bismuthinite; others, again, consist of pellets of the yellow to greenish russellite with a core of native bismuth. Occasionally the native bismuth has a bluish iridescent film. The directly associated minerals are quartz, topaz, muscovite, and wolframite.

Bismuth minerals have been long ago recorded from four other localities in this neighbourhood:

Trethurgey, St. Columb Major.—The MS. catalogue of the Philip Rashleigh collection contains an entry under bismuth: 'No. 1 Native Bismuth from Tresurgy [later altered in Rashleigh's handwriting to Trethurgey] near St. Columb.' The name Trethurgey is no longer to be found on the six-inch ordnance map, but in the map appended to William Borlase's 'Natural History of Cornwall' (1758), and on Thomas Martyn's map of Cornwall (1784), a place Trethergy is shown in a position close to, and probably identical with Ennisworgey, one mile south-west of Castle-an-Dinas. The actual specimen to which the entry refers is probably in Truro Museum, but is inaccessible. William Phillips in his 'Mineralogy' (second edition, 1819, p. 205), says 'carbonate of bismuth is said to have occurred at Tregurthy and St. Columb'.

St. Wenn.—The collections belonging to the Royal Geological Society of Cornwall, Penzance, and the Royal Institution of Cornwall, Truro, both contain specimens consisting of small rolled pellets up to 1 cm. of bismuthinite (confirmed by myself) associated with quartz and a little gilbertite, labelled St. Wenn. It is almost certainly this occurrence which is referred to by Thomas Hogg in his 'Manual of Mineralogy' (Truro, 1825, p. 26), in which it is stated that 'sulphuret of bismuth ... occurs in a stream-work in the parish of St. Columb, of a dark lead grey colour, in the state of water worn pebbles'. The actual locality was very probably the alluvial valley directly north of Castle-an-Dinas, which divides the parishes of St. Columb Major and St. Wenn, and which has, in the past, been extensively streamed for tin, and which, in addition, contained wolframite, all three minerals having very likely come from the Castle-an-Dinas lode outcrops.

Trugo mine, St. Columb Major (six-inch ordnance map 40 NE.) situated on the road between White Cross and Trebudannon. According to Thomas Hogg ('Manual of Mineralogy', Truro, 1825, p. 24) native bismuth accompanied the smaltite which occurred in a small vein 4 to 6 inches wide crossing the copper lode in this mine, which is in greenstone. (See also W. Pryce, 'Mineralogia Cornubiensis', 1778, p. 50.) No specimens of native bismuth from this locality appear to have been preserved.

Cost All Lost tin mine, later known as *Roche Rock* or *Cornubia mine, Roche* (six-inch ordnance map, 41 NE.). Thomas Hogg ('Manual of Mineralogy', Truro, 1825, p. 25) describes under carbonate of bismuth, a greyish-green, brownish, and yellowish-grey mineral with small patches of included quartz which effervesces in nitric acid, as having been found by Mr. John Michell at this mine, which is in slate and granite. Unfortunately no specimens from this locality appear to have been preserved, for it would be interesting to know what this mineral really was.

Scorodite occurs as pale greenish-grey minutely botryoidal crusts on cellular masses of quartz with radiating spheres of wavellite which it also invests. On other specimens it occurs with wavellite as a greyish-green coating on the banded sediment. The mineral was evidently formed by the alteration of arsenopyrite and occurred in the upper part of the lode.

Wavellite occurs as flat, white to slightly greenish radiating disks up to 2 cm. in diameter, along with a greyish-green coating of scorodite on the joints of the laminated sediment traversed by quartz veins containing wolframite, topaz, &c., also more rarely as complete white spherical aggregates up to 1½ cm. in diameter in cavities in quartz lined with scorodite. Recently I have obtained a large mass which on being broken up is seen to consist almost entirely of small, radiating spheres and botryoidal crusts of wavellite externally varying in colour from white, green, yellow, or rusty brown, and internally from white to grey. In many of the cavities the spheres of wavellite are covered with minute crystalline botryoidal aggregates of bright green turquoise, a good deal of which is present throughout the mass. Some of the spheres are built up of concentric layers, others, which are very beautiful under the microscope, consist of bristling aggregates of minute acicular crystals, these sometimes studding botryoidal aggregates of turquoise. The wavellite crystals are elongated in the direction of the *c*-axis and show the forms *b* (010), *m* (110), *p* (101) [Dana's letters]. The (110) faces are deeply striated vertically and are not measurable. In the groundmass, included in the spheres of wavellite, are small black prisms of tourmaline; the other minerals present being quartz, rusty yellow ochre, and scales of lithia-mica; the whole forming a most curious assemblage of minerals. Wavellite has hitherto been found only at one other locality in Cornwall, namely, Stenna Gwyn mine, St. Stephen-in-Brannel.

Turquoise occurs as a bluish-green or leaf-green (Ridgway) minutely crystalline botryoidal and sometimes rippled crust on the banded sediment. Also as light bluish-green to rarely true turquoise-blue, minutely crystalline porous masses with wavellite, yellowish-brown lithia-mica, tourmaline, and limonite. A full description of the mineral will appear in a subsequent number of this Magazine.

Lithia-mica.—The surfaces of the masses of wolframite are frequently coated with rusty brown scales and rosettes of six-sided platy crystals of a lithia-mica almost certainly referable to zinnwaldite. A fine specimen, in which the crystals making up the rosettes attain a diameter of 8 mm., was recently (February, 1938) obtained by myself from the extreme south end of the mine where the lode re-enters the sediment.

Topaz, in places, forms an important constituent of the lode, and its occurrence has been fully described by myself in this Magazine in 1924. In the stope from which the russellite came, topaz formed a considerable portion of the lode filling. It occurred in a rusty yellowish friable coarsely crystalline form associated with quartz, wolframite, lithia-mica, tourmaline, and a little turquoise, and occasionally showed distinct crystals.

Psilomelane has recently been found in small quantity as a botryoidal crust on the quartzose vein-stuff.

Having eagerly watched with increasing interest the Castle-an-Dinas mine from its commencement some twenty-one years ago, I must here express my thanks to Mr. Clarence V. Paull for permission to visit the property, and my especial gratitude to Mr. J. Chynoweth and Mr. W. A. Kessell for their unfailing help and many acts of kindness.

EXPLANATION OF PLATE II.

X-ray and spectrographic photographs of russellite.

FIG. 1. Single crystal of artificial $(Bi_2,W)O_3$ rotated about c[001] axis.

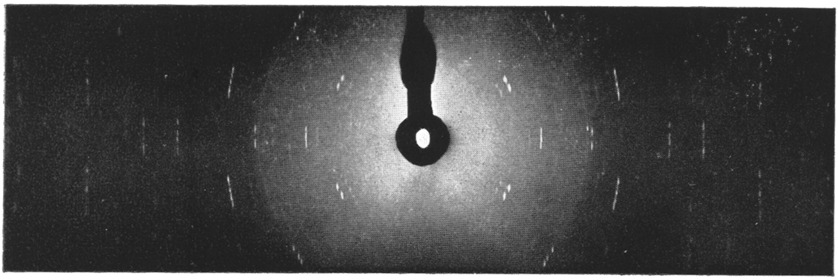
FIG. 2. Powder photograph of russellite.

FIG. 3. Powder photograph of artificial $(Bi_2,W)O_3$.

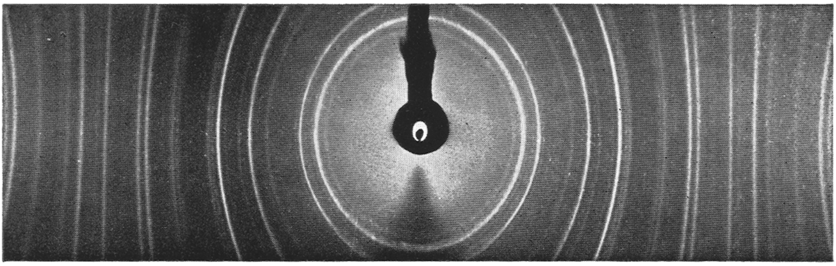
All three X-ray photographs were taken with unfiltered Cu radiation λ 1·539 Å. in a cylindrical camera, diameter 6·04 cm. A length of 10 cm. on the original films is equivalent to 9 cm. on the reproduced figures.

FIG. 4. Part of spectrographic record of (top) graphite electrodes, (centre) R.U. powder, (bottom) russellite.

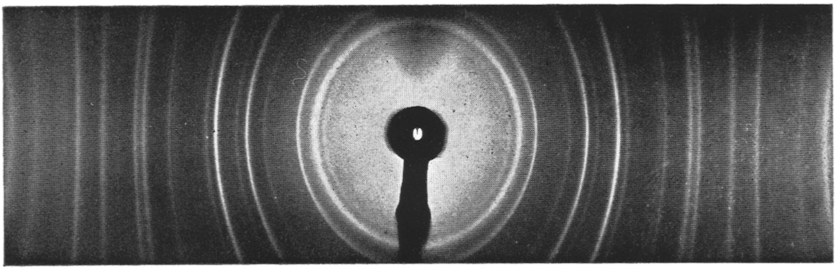
R.U. powder is composed of a base of Mg, Ca, and Zn oxides and small, varying amounts of 51 elements in such proportions that only a few of the most sensitive lines (raies ultimes) appear in the emission spectra. The wave-lengths of the marked lines are As 2790, As 2860, As 2898, Bi 2899, W 4009, W 4295.



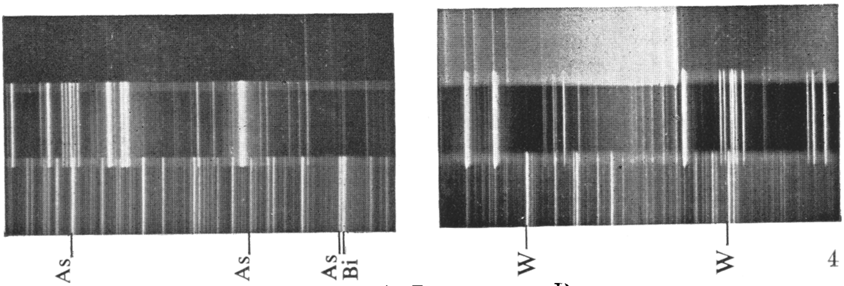
1



2



3



4

M. H. HEY and F. A. BANNISTER : RUSSELLITE