

## Tavistockite and bialite discredited

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**SUMMARY.** Specimens of tavistockite fall into two groups: true tavistockite from the George and Charlotte mine, Tavistock, Devon, and wavellite from the Stenna Gwyn mine, St. Austell, Cornwall. Both were sold as tavistockite by the discoverer, Richard Talling.

Tavistockite proper is a fluorapatite, as shown by optical and X-ray examination, and the alumina and water in the original analysis are certainly derived from kaolinite with which the apatite is intimately associated.

The published optical properties attributed to tavistockite were determined by E. S. Larsen on Stenna Gwyn material, and are those of wavellite.

Re-examination of a portion of Buttgenbach's type bialite, which he related to tavistockite on optical grounds, shows it to be wavellite.

**TAVISTOCKITE** has been a doubtful species from the time it was first described in 1865 by A. H. Church<sup>1</sup> as 'Hydrated Calcium-aluminic Phosphate (?)'. Its apparent validity has been established by successive appearances in all the standard works on systematic mineralogy, starting with J. D. Dana's renaming as tavistockite in 1868.<sup>2</sup> The present study is perhaps as much historical as mineralogical, since Church's original material cannot be traced and other specimens present a confused picture both in naming and in locality.

We have studied seventeen specimens (see table) that are or have at one time been labelled tavistockite, and find that they fall into two distinct groups that may readily be characterized by the mineral assemblages present. Specimens from Tavistock, Church's locality (more accurately the George and Charlotte mine),<sup>3</sup> consist mainly of groups of somewhat milky quartz crystals, sometimes showing patches of the chloritic country-rock, with pyrite, chalcopyrite, and partial encrustations of chalybite and childrenite. Using Church's words, tavistockite occurs in cavities and fissures as a light and soft white powder; when free from impurities it presents the appearance of a pearly powder of perfect whiteness, and under the microscope it is seen to consist of minute acicular crystals, transparent to translucent, and fragile; sometimes these crystals are sparsely scattered in irregular stellate groups upon the quartzose matrix. These specimens are the true tavistockite.

The other group of specimens consist of a granite- or greisen-quartz matrix bearing tufts and rounded aggregates of wavellite, with fluorite, cassiterite, chalcedony or opal, torbernite, and fluellite as possible but not invariable associates. These latter

<sup>1</sup> A. H. Church, *Journ. Chem. Soc.* (1865), **18** (N.S. 3), 263.

<sup>2</sup> Dana *Syst. Min.*, 5th edn (1868), p. 582.

<sup>3</sup> A. W. G. Kingsbury, *Trans. Roy. Geol. Soc. Cornwall* (1959 for 1955–6), **19**, 47.

specimens are from the Stenna Gwyn mine, St. Austell, Cornwall, and have been described in detail by A. W. G. Kingsbury.<sup>1</sup>

Church obtained his specimen from the mineral dealer Richard Talling (1820–83), well known for his evasiveness on the exact provenance of his material,<sup>2</sup> and it may be noted that his invoice dated 26 January 1866, for BM 39958 (Talling no. 3258) reads 'Hydrated phosphate of calcium and aluminium' without mention of the locality. This specimen, however, matches Church's description and the known paragenesis for the George and Charlotte mine, Tavistock, Devon. By contrast, two specimens of wavellite were bought from Talling in 1867, invoiced (24 October; BM 42098 and 42123, Talling nos. 3581 and 3582) as 'Hydrated phosphate of calcium and aluminium / from Stenna Gwyn mine'. This second supposed occurrence of tavistockite, at Stenna Gwyn, based only on Talling's guess or wishful thinking, gained printed circulation in 1871<sup>3</sup> and 1872,<sup>4</sup> and more recently in 1951.<sup>5</sup> It should be sufficient to say that wavellite, both botryoidal and as tufts of fibres, has been known since the beginning of the nineteenth century to occur at Stenna Gwyn,<sup>6</sup> and that all specimens of Stenna Gwyn 'tavistockite' that we have examined have proved to be wavellite although apatite is known from this locality.

Returning to authentic tavistockite, Church states that 'the specimen in the British Museum is placed with wavellite'. We cannot say with absolute certainty that this is BM 34285 (Talling no. 651) because the invoice and relevant correspondence (if any) have not been preserved, but it seems probable; bought in 1862 as an unknown species for investigation, the entry in the accessions register carries a contemporary pencilled note 'Wavellite?'. A second specimen, BM 39958, is referred to above and was invoiced only four months after Church's description was published. The first specimen is better, and matches the description more closely than the second with respect to the stellate groups of acicular crystals.

*X-ray examination.* X-ray powder photographs were taken of any material resembling Church's description on all the available specimens, and the results are summarized in table I. There is material on some specimens from the Stenna Gwyn mine with a close resemblance to Church's description, and the only material that could have been referred to tavistockite proves in all cases to be wavellite. Material on specimens from the George and Charlotte mine, with two exceptions, is apatite or kaolinite or a mixture of the two. One exception is a specimen in the Russell Collection (at the British Museum (Natural History)), tentatively labelled tavistockite by Russell, on which the chalybite and especially the chalcopyrite are unusually well crystallized. The white mineral on this specimen is a finely divided mica, and it seems probable that it comes from a different part of the mine from that where the other tavistockite

<sup>1</sup> Op. cit., p. 48.

<sup>2</sup> A. W. G. Kingsbury, *Min. Mag.* (1961), 32, 922–3. The date 1864 on p. 922, l. 8\*, relates to this same invoice and should read 1866.

<sup>3</sup> J. H. Collins, *A Handbook to the Mineralogy of Cornwall and Devon*, 1871, p. 100.

<sup>4</sup> *Descriptive Catalogue of Minerals, being the Collection of William Nevill, F.G.S., Godalming, Surrey* (London: printed by Taylor and Francis), 1872, p. 148, no. 3579. Much of Nevill's collection was acquired by Henry Ludlam, who bequeathed his collection to the Museum of Practical Geology (now the Museum of the Institute of Geological Sciences).

<sup>5</sup> *Dana Syst. Min.*, 7th edn, vol. 2 (1951), p. 125 (under fluellite).

<sup>6</sup> See p. 123, n. 3.

TABLE I. *Specimens of 'tavistockite' studied*

Accession number	Other numbers*	Locality	Associated minerals†	X-ray‡ identification
<i>British Museum (Natural History)</i>				
34285	T. 651 ms. (1861-2)	Tavistock	Q, Chl, Chal, Sid	{ FA FA + ? Wav.
39958	T. 3258 ms. (Jan. 1866)	Tavistock	Q, Chl, Chal	{ FA-FR FA-FR
1926, 1224	Trechmann (1906)	Tavistock	Q, Chl, Chal	Kaolinite (Apatite also. Opt.)
1957, 308	Kingsbury 1007, 1008	Tavistock	Q, Chal, Child	{ FA-FR Kaolinite
42098 §	T. 3581 ms. (Oct. 1867)	Stenna Gwyn	Quartz/Granite, Biotite	Wavellite
42123 §	T. 3582 ms. (Oct. 1867)	Stenna Gwyn	Quartz/Greisen	Wavellite
96897**	A.G. 42 (c. 1855)	Stenna Gwyn	Granite/Greisen, Gilb, Fluor	Wavellite
— (Russell)	T. (? no.) W. W. Smyth coll. 1856	Tavistock	Q, Chl, Chal, Pyr, Child, Sid	Kaolinite
— (Russell)	—	Tavistock	Q, Chal, Sid	Mica near lepidolite
<i>Institute of Geological Sciences</i>				
3579 (Nevill)	(pre 1872)	Stenna Gwyn	Quartz/Greisen	Wavellite
15889 (Ludlam)	T. 827 ms. (1861-2)	Stenna Gwyn	Greisen/Gilb, Fluor, Torb	Wavellite
15890 (Ludlam)	—	Tavistock	Q, Chlorite rock, Chal, Child	{ FA-FR -do + Kaol.
15891 (Ludlam)	T. 1184 ms. (? 1863)	Stenna Gwyn	Greisen, brown Opal	Wavellite
<i>Department of Mineralogy and Petrology, Cambridge University</i>				
1258	T. 428 pr. 1	Stenna Gwyn	Quartz/Greisen, brown Opal	Wavellite
<i>American Museum of Natural History</i>				
15392	T. 665 pr. 2 (Bement coll.)	Stenna Gwyn¶	Quartz/Greisen	Wavellite
<i>United States National Museum</i>				
R. 5409 (Roebling)	—	Tavistock	Q, Chal, Sid	Francolite
—	AMNH 15392	Stenna Gwyn¶	Quartz/Greisen	Wavellite

\* T. = Talling. He had three styles of numbers, a manuscript series (ms.) and two printed series (pr. 1 and pr. 2). A.G. = Allan-Greg, a collection bought by the British Museum in 1860. Dates in parentheses refer to original acquisition.

† Q = quartz, Chl = chlorite, Chal = chalcopyrite, Sid = chalybite (siderite), Child = chil-drenite, Gilb = gilbertite, Fluor = fluorite, Torb = torbernite.

‡ FA = fluorapatite; FA-FR = fluorapatite-francolite intermediate.

§ Invoiced by Talling as 'hydrated phosphate of calcium and aluminium'.

|| Labelled 'Tavistock' although the association is that of Stenna Gwyn.

¶ Labelled simply 'Cornwall'. The specimen examined optically by E. S. Larsen.

\*\* This specimen was changed in the records from wavellite to tavistockite and back again.

specimens were found. The other exception is a pattern from BM 34285 showing one or two additional lines that could belong to wavellite, but an optical examination failed to confirm this.

The apatite phase varies from fluorapatite to francolite on different specimens, and on the majority lies between the two. The powder patterns are closely similar, and differences may most easily be detected by direct film-to-film comparison and the study of line separations.

*Chemical analysis.* We have not considered it worth while to have a new analysis made on tavistockite, since the X-ray evidence backed up by optical examination shows conclusively that apatite and kaolinite are the major mineral phases present. It is, however, necessary to reinterpret Church's original analysis: 0·1875 g mineral gave CaO 36·27 %, Al<sub>2</sub>O<sub>3</sub> 22·40, P<sub>2</sub>O<sub>5</sub> 30·36, H<sub>2</sub>O 12·00, Total 101·03 % 'after deduction of insoluble gangue, etc.'. He notes that the mineral is 'rather difficultly soluble in acids', without saying which acid he used for the initial solution, and that the insoluble residue is 'chiefly silica, which I have assumed to be an intruding material, perhaps without sufficient reason'. He also states that 'while the lime, alumina, and phosphoric anhydride exhibit a definite and constant ratio, the silica does not', although he presents but a single analysis. He gives only the weight of material dissolved, not the total taken for analysis, so it is impossible to determine from his figures the weight of the insoluble residue.

It is clear that the water was determined by loss of weight on ignition before solution, and not by difference, since the total exceeds 100 % and so must include water lost by the insoluble residue. This also accounts for the presence of abundant alumina in the analysis, since although it is difficult to remove alumina from ordinary kaolinite it is well known that heating to about 800 °C renders the alumina almost 100 % leachable by dilute sulphuric acid.<sup>1</sup> The ratio alumina/water obtained by Church (22·40/12·00) is less than that required by kaolinite (22·4/8·2), so it is possible that heating was carried out at a lower temperature, resulting in less complete leaching. Bearing in mind that wavellite may be present, although not detected, a mixture of apatite, kaolinite, and wavellite in the rough proportion 4:2:1 could account for Church's analytical results. It is much more probable that wavellite is not a constituent of the mixture, and that the small deviation from the CaO/P<sub>2</sub>O<sub>5</sub> ratio required for apatite results from analytical error. It is unfortunate that Church gave too little detail of his analytical methods to permit a closer interpretation.

*Optical properties.* The optical properties attributed to tavistockite were determined by E. S. Larsen<sup>2</sup> on a specimen obtained from the American Museum of Natural History (AMNH 15392, Talling no. 665, from the Bement Collection). We have examined this specimen, and Larsen's fragment of it (now in the U.S. National Museum), and it is wavellite from the Stenna Gwyn mine. Larsen quoted the label correctly, giving the locality as Cornwall, England, but his results have been cited<sup>3,4</sup> as

<sup>1</sup> R. E. Grim, *Clay Mineralogy* (McGraw-Hill, 1953), p. 296 ff., gives several references.

<sup>2</sup> E. S. Larsen, The microscopic determination of the nonopaque minerals. *U.S.G.S. Bull.* (1921), **679**, 142.

<sup>3</sup> *Dana Syst. Min.*, 7th edn, vol. 2 (1951), p. 906.

<sup>4</sup> A. N. and H. Winchell, *Elements of Optical Mineralogy*, part 2 (4th edn), p. 229.

referring to Tavistock material. Clearly the misleading chemical formula attached to tavistockite has prevented the inference being drawn that its reputed optical properties are in fact those of wavellite. The published optical data for wavellite closest to Larsen's tavistockite results are those of Bingham, Utah material.<sup>1</sup> The low refractive indices suggest that Stenna Gwyn wavellite is low in ferric iron and has a high F/OH ratio.

*Bialite* was described as a new mineral from Mushishimano, Katanga, Congo, by H. Buttgenbach.<sup>2</sup> An X-ray powder photograph of part of the original material<sup>3</sup> shows it to be wavellite; it is of interest to note that apatite also occurs on the specimen we examined, but does not correspond to Buttgenbach's description.

Buttgenbach considered wavellite as the possible identity of his new mineral, but discarded the idea primarily because he considered that the refractive indices of his mineral differed too much from Larsen's values. Although low, the indices of bialite ( $\alpha/\beta$  1·525,  $\gamma$  1·541–1·546) fall in the wavellite range ( $\alpha$  1·520–1·535,  $\beta$  1·526–1·543,  $\gamma$  1·545–1·561) and have the correct orientation with respect to the crystals. Clearly more work is needed on the range of compositional variation in wavellite, but is outside the present investigation. We have shown above that the optical properties of tavistockite, with which Buttgenbach identified his bialite as a magnesian variety, were determined on wavellite.

The original chemical analysis of bialite was not quantitative. It contained  $P_2O_5$ ,  $Al_2O_3$ ,  $H_2O$ , and much more  $MgO$  than  $CaO$ ; the only figure given is that the ignition loss was greater than 27 %. The water content of fully hydroxylated wavellite is 28·42 %; most of this is lost at 200 °C, and the remainder at dull red heat.<sup>4</sup> Our tests on a few small crystals of bialite confirm Buttgenbach's observation that bialite is much more difficult to dissolve in hydrochloric acid than is usual for wavellite (we checked against Devonshire and Arkansas wavellite), and we can offer no explanation for this. The resulting solution gave a positive phosphate reaction, but an attempt to obtain microchemical confirmation of magnesium (by the production of crystals of struvite in presence of citrate and ammonia) failed. If magnesium is present its amount is less than 1–2 % of the sample tested (*c.* 30 µg).

*Conclusions.* Tavistockite is shown to be apatite, and the original analysis was made on a mixture of apatite and kaolinite. The optical properties of tavistockite were determined on a wrongly identified specimen of wavellite, causing bialite to be described as a magnesium analogue of tavistockite. Bialite is wavellite, and the presence of magnesium is not confirmed.

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<sup>1</sup> W. R. Anderson, B. Stringham, and J. A. Whelan, *Amer. Min.* (1962), **47**, 1305.

<sup>2</sup> H. Buttgenbach, *Ann. Soc. Géol. Belgique, Publ. Congo Belge* (1929), **51** (for 1927–8), C. 117.

<sup>3</sup> BM 1929, 85. Obtained by exchange from H. Buttgenbach.

<sup>4</sup> A. H. Church, *Journ. Chem. Soc.* (1873), **26** (n.s. **11**), 110.