South African occurrences of willemite. Fluorescence of willemite and some other zinc minerals in ultra-violet rays.

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WILLEMITE is a mineral of comparatively rare occurrence, but it has long been mined in New Jersey as an important ore of zinc (Zn_2SiO_4, containing Zn 58·6 %), and it would seem also to be abundant in Rhodesia. In the standard mineralogies of Dana (1892) and Hintze (1889) it is mentioned from only four districts. As there is some confusion in the statement of these few localities, and further as several others have been discovered during recent years, a complete list of localities for this mineral has been compiled from the literature; and some others represented by specimens in the British Museum collection are added, including the African occurrences now to be described.

As a distinct mineral-species, willemite was first recognized in New Jersey in 1822, although it had evidently been mined there for many years before. It was then known as 'silicious oxide of zinc'. The name willemite was applied by A. Lévy in 1830 to what afterwards proved to be the same mineral. His material was found in the Netherlands, and was named after Willem (William) I (1772–1844), King of the Netherlands. It came from the small (less than 1,400 acres) neutral state of Moresnet situated between Prussia and Belgium (though the present kingdom of Belgium was not founded until that year—1830). Under the Treaty of Versailles (1919) it is now in Belgium. In this connexion it is interesting to recall that the name 'belgite' has been suggested for this mineral. R. Panebianco, writing in esperanto in 1916, objected to naming minerals after kings, preferring a name derived from the locality. He, however, overlooked the fact that the locality was not, at that time, in Belgium.

Localities of Willemite.

Mine Hill, Franklin Furnace,[1] Hardyston township, Sussex Co., New Jersey. Here are the Buckwheat (= Taylor), Parker, Trotter, and Franklin mines.

Stirling Hill,[2] Ogdensburg, Sparta township, Sussex Co., New Jersey. Two miles south of Franklin Furnace and on the same band of crystalline limestone. (L. Vanuxem and W. H. Keating, Journ. Acad. Nat. Sci. Philadelphia, 1822, vol. 2, p. 287; 1824, vol. 4, p. 8.)

Altenberg (= Vieille-Montagne),[3] Moresnet, Liége, Belgium. 8 km. SW. of Aachen. (A. Lévy, Jahrb. Min., 1830, p. 71; Ann. Mines, Paris, 1843, ser. 4, vol. 4, Mém. p. 513.)

Büsbacherberg (or Busbacher Berg), Stolberg, Aachen, Rheinland, Germany. 8 km. ESE. of Aachen, and on the same outcrop of Devono-Carboniferous rocks as Altenberg. (V. Monheim, Verh. naturhist. Ver. preuss. Rheinlande, 1848, vol. 5, p. 162. C. Hintze, Handb. Min., 1889, vol. 2, p. 35, mentions three other spots in the district between here and Altenberg, namely, Brockenberg on the German side, and Schmalgraf mine and Heggelsbrück mine on the Belgian side.)

Musartut, Tunugdliarfik fjord, Julianehaab district, Greenland. (A. Des Cloizeaux, Man. de Min., 1862, vol. 1, p. 554; O. B. Bøggild, Mineralogica Groenlandica, Meddel. om Grønland, 1905, vol. 32, p. 276.)

Merritt mine, Socorro Co., New Mexico, U.S.A. (F. A. Genth, Proc. Amer. Phil. Soc., 1887, vol. 24, p. 43; S. L. Penfield, Amer. Journ. Sci., 1894, ser. 3, vol. 47, p. 305.)

Sedalia mine, Salida, Chaffee Co., Colorado. (S. L. Penfield, 1894, loc. cit.)

Modoc Mountain, Morenci, Graham Co., Arizona. (W. Lindgren and W. F. Hillebrand, Amer. Journ. Sci., 1904, ser. 4, vol. 18, p. 451.)

Star district, Beaver Co., Utah. (R. W. Clark, Amer. Min., 1916, vol. 1, p. 89; Min. Abstr., vol. 1, p. 175.)

Konnerud, Drammen, Kristiania district, Norway. (V. M. Goldschmidt, Skrifter Videnskapssels. Kristiania, 1911, no. 1, p. 389.) Blue willemite previously described as apatite or thought to be lazulite.

Cho-Dan, near Bac-Kan, Tonkin, French Indo-China. (A. Lacroix, Min. de France, 1913, vol. 5, p. 84.)

Bou-Thaleb mine, SW. of Sétif, Constantine, Algeria. (A. Lacroix, Bull. Soc. Franç. Min., 1900, vol. 23, p. 255.)

[1] So named from the iron furnace where cannon were cast during the American war of independence (1775–1781). It is also known as Franklin, both names being in common use. At the time of my visit in 1924, the railway station was labelled 'Franklin Furnace' and the post office 'Franklin'. The name Franklin Furnace is here adopted, since Franklin is a very common place-name in the United States, there being, for instance, at least six other such places in New Jersey alone.

[2] Also spelt Sterling Hill, but evidently named after William Alexander (1726–1783), titular Earl of Stirling, a former owner of the land. He sent several tons of 'red ore' from there to England for the manufacture of brass about 1774; i.e. long before zincite was recognized as a mineral-species. 'Sparta', the name of the township, is sometimes quoted as the locality for willemite.

[3] Given in some of the old books as 'Old Mountain in Limburg'.

Jebel Reças (Ressas) mine, 25 km. SE. of Tunis, Tunisia. (A. Lacroix, Min. de France, 1910, vol. 4, p. 720.)

Mindouli (Minduli), Brazzaville, French Middle Congo. (A. Le Chatelier, Compt. Rend. Acad. Sci. Paris, 1893, vol. 116, p. 894. A. Lacroix, Min. de France, 1910, vol. 4, p. 720; 1913, vol. 5, p. 84, gives Tchicoumba mine, Djoué mine, and Pimbi in this region.)

Tshiniama river, tributary of the Lubi, Belgian Congo (lat. 6° S., long. 23° E.). (H. Buttgenbach, Mém. Soc. R. Sci. Liége, 1927, ser. 3, vol. 14, no. —, p. 9; Min. Abstr., vol. 3, p. 351.)

Broken Hill, Northern Rhodesia. (H. Buttgenbach, Ann. Soc. Géol. Belgique, 1919, vol. 42, Congo annexe, pp. c 8, c 12; Min. Abstr., vol. 1, p. 69. See also below.)

Near Sable Antelope mine, Mumbwa, Kafue district, Northern Rhodesia. (British Museum collection; see below, p. 393.)

Near Lusaka, Northern Rhodesia. (British Museum collection; see below, p. 393.)

Guchab, Otavi, South-West Africa. (British Museum collection; see below, p. 394.)

Peñoles, Mapimi, Durango, Mexico. (British Museum collection, 1925; from the collection of the late H. F. Collins; analysed by J. C. Hoal, 1905.)

Sinaloa, Mexico. (British Museum collection, 1922; bought of W. Maucher of Munich.)

Other localities considered as doubtful, and which could not be verified, include the following:

Wanlockhead, Dumfriesshire, Scotland. (D. C. Glen and J. Young, List of minerals and rock specimens, in J. Armstrong and others, Catalogue of western Scottish fossils, Brit. Assoc. handbook, Glasgow, 1876, p. 162.)

Raibl, Carinthia [now in Italy]. (G. Leonhard, Handwörterbuch der topographischen Mineralogie, 1843, p. 525.)

Upper Silesia. (C. F. Rammelsberg, Chem. Min., 3. Suppl., 1847, p. 65. 'Williamit. Ein oberschlesischer Galmei'.)

Kucsaina, Serbia. (Brooke and Miller, Min., 1852.)

Temora, New South Wales. (J. C. H. Mingaye, Ann. Rep. Dept. Mines, N.S.W., 1889, for 1888, p. 200; C. Anderson, Bibliography of Australian Mineralogy, Min. Res. Dept. Mines, N.S.W., 1916, no. 22, p. 75.)

Mont Albion (Montalbion), Walsh and Tinaroo mining district, Queensland. (J. S. Berge, J. H. Brownlee, and R. C. Ringrose, Proc. Roy. Soc. Queensland, 1900, vol. 15, p. 54.)

Ygnacio and Cerro Gordo mines, Inyo Co., California. (A. S. Eakle, Minerals of California, Bull. Calif. Mining Bur., 1914, no. 67, p. 124.)

Willemite from Broken Hill, Northern Rhodesia.

The occurrence of willemite at this locality was first recorded by Prof. H. Buttgenbach in 1919.[1] I had previously, in 1908, detected its presence in the 'yellow rock', specimens of which were received from

[1] H. Buttgenbach. La calamine des ossements fossiles de Broken-Hill (Rhodésie). Ann. Soc. Géol. Belgique, 1919, vol. 42, Congo annexe, pp. c 5–c 14 (Min. Abstr., vol. 1, p. 69). Microscopical crystals of willemite and some other

Mr. Percy S. Tarbutt after the publication of my paper on the minerals of Broken Hill.[1] *Other specimens representing another type of the* mineral were received in the British Museum collection in 1920 and 1923.

One of the 1908 specimens of more heterogeneous appearance than the others shows a small *cavity lined with minute reddish crystals of wille*mite. These were definitely determined by density, optical, and chemical tests. Other small cavities show minute crystals of quartz and velvety aggregates of goethite needles. The matrix contains small patches and veins of glassy quartz and of red earthy haematite (or hydrohaematite), while in one part of the specimen there are minute specks of fresh unaltered pyrite. A thin section of the compact dark-brown matrix examined under the microscope showed small interlocking grains of quartz and willemite. Both of these minerals are optically uniaxial and positive, but they differ widely in their birefringence (quartz 0·009, willemite 0·029). The crystals of both contain abundant yellow inclusions of limonite. Hemimorphite and smithsonite were not detected.

Other specimens more homogeneous and compact in appearance were lighter in colour, being ochre-yellow. Chemical tests showed the presence of silica, ferric oxide, zinc oxide, and water in this material. The specific gravity of small chips taken from one of these specimens ranged from 3·16 to 3·18.

This peculiar 'yellow rock' or 'yellow waste' is of considerable abundance (over 100,000 tons) at Broken Hill. It has been described by Mr. S. J. Speak[2] with special reference to its possible mode of origin. He states that it always occurs between the sulphide-ore and the dolomite walls of the ore-body, and that it frequently encloses brecciated blocks of dolomite.

Specimens of the 'yellow rock' sent to the British Museum in 1923

zinc minerals were recognized by their optical characters in the central cavity of limb bones. Appended is the following note (p. c 14):

'Enfin, je signale de jolis cristaux légèrement brunâtres, de willénite [*sic*] accompagnant de la descloizite : ces cristaux ont la forme habituelle du prisme hexagonal surmonté d'un rhomboèdre très obtus. La willémite n'a pas encore été signalée à Broken-Hill.'

[1] L. J. Spencer, On hopeite and other zinc phosphates and associated minerals from the Broken Hill mines, North-Western Rhodesia. Min. Mag., 1908, vol. 15, pp. 1–38.

[2] S. J. Speak, An occurrence of zinc silicate ore of supposed primary origin. Bull. Inst. Mining Metall. London, February 1926, no. 257, 5 pp., 2 pls.; Transactions, 1926, vol. 35 (for 1925–6), pp. 226–247, 2 pls.

by Mr. G. Chad Norris of the assay office at Broken Hill, were accompanied with the following analytical results (nos. 1–4). The analyses under nos. 5 and 6 are quoted from Mr. Speak's paper.

	SiO_2.	Fe_2O_3.	Al_2O_3.	ZnO.	PbO.	H_2O (loss on ign.).	Total.
1.	61·26	8·80	—	15·84	—	?	(85.90)
2.	27·26	60·42	—	0·49	—	?	(88·17)
3.	62·30	22·87	—	4·16	—	?	(89·33)
4.	1·60	39·91	—	33·14	—	?	(74·65)
5.	54·6	9·16	0·94	30·88	0·61	2·98	99·17
6.	44·8	23·3	0·10	19·3	4·6	3·6	99·75*

* Including in no. 6 also V_2O_5 0·42, P_2O_5 1·61, MgO 0·23, MnO 0·95, CaO 0·46, S 0·38.

These analyses show very wide variations, but (with the exception of no. 4) they can be explained as mixtures of willemite, quartz, and limonite. Mr. Norris's no. 4 is described as 'weathered', and Mr. Speak mentions that down to depths of over 50 feet the 'yellow rock' weathers to a hard clay. This specimen is duller and softer than the others, and when tested chemically was found to contain much carbonate, presumably as smithsonite. A thin section of no. 1 shows many small prisms and grains of willemite set in a matrix of minutely crystallized quartz, the whole being heavily charged with limonite inclusions.

Mr. Speak very kindly invited me to inspect the large series of specimens of 'yellow rock' and associated dolomite which he brought from Broken Hill in 1923. Those of the 'yellow rock' are all very compact and hard, ochre-yellow to brown in colour, and dull to vitreous or resinous in lustre on the fractured surfaces. To judge from their appearance alone they might very well be described as jasper or 'Eisenkiesel'. From a purely mineralogical point of view they were rather uninteresting. I was not able in a ton of material to find even a small crystal-lined cavity nor a single well-individualized mineral. Mr. Speak in his paper, says 'Microscopical examination reveals hemimorphite but no willemite'. This is clearly an error. Willemite is without doubt extremely abundant at Broken Hill, but so obscure mineralogically that it has hitherto been overlooked.

Two small specimens of well-crystallized willemite from Broken Hill came into the British Museum collection in 1920 and 1923, the first by exchange from the Museum of Practical Geology in London, and the second by donation from Mr. G. Chad Norris of Broken Hill. The crystals are prismatic with flat rhombohedral terminations, the forms being $a(10\bar{1}0)$ and $e(01\bar{1}2)$. Although small (2 mm. long) they are distinctly developed, and are colourless and transparent, though those on the first specimen are in part iron-stained and pearly on the surface. On the first specimen the crystals form a crust on a cellular matrix of altered blende, while on the second they rest on the surface of massive radiated willemite coloured red with iron oxide. Of later growth on the second specimen are some excellent crystals of smithsonite, with the form of the rhombohedron $f(02\bar{2}1) = (1\bar{1}\bar{1})$ measuring 8 mm. along the edges.[1]

Willemite from near the Sable Antelope mine, Mumbwa, Northern Rhodesia.

This material was collected in 1919 by Mr. R. Murray-Hughes from a small deposit of manganese and iron ore one mile north of the Sable Antelope mine (38 miles NNW. of Mumbwa) in the Kafue district. The earthy manganese and iron oxides formed a circular patch about 50 feet across in brown crystalline dolomite; and in this ore were two well-defined streaks of willemite, which gave out after 50 or 60 lb. had been collected, and no further trace of the mineral could be found. Granite outcrops at about 6 miles SW. of the Sable Antelope mine, and the sedimentary rocks into which it is intruded are correlated with the Transvaal System of the Union of South Africa and the Lomagundi System of Southern Rhodesia. These specimens of willemite consist of a friable aggregate of colourless prisms up to 2 cm. long and $\frac{1}{2}$ cm. thick. The prism faces $a\,(10\bar{1}0)$ are striated vertically. Most of the crystals are broken at the ends, but occasionally they show rough rounded terminations of the obtuse rhombohedron $e\,(01\bar{1}2)$. Associated is a powdery manganiferous haematite.

Willemite from near Lusaka, Northern Rhodesia.

Specimens presented by Mr. R. Murray-Hughes to the British Museum collection in 1927 were collected by him about 10 miles NW. of Lusaka (on the railway line 65 miles south of Broken Hill) in the Loangwa (Lungwa) district. The mineral occurs in crystalline dolomite, near a contact with granite, and blocks of willemite 'as large as a cottage' are lying about on the surface. The willemite forms compact masses of radial aggregates, with fibres 1–1$\frac{1}{2}$ cm. long from each centre. The colour is white to grey or yellowish, and the material has much the appearance of wavellite. In cavities small prismatic crystals are

[1] Similar to the crystals from Broken Hill, Rhodesia, on which E. D. Mountain has recently given accurately determined constants for smithsonite (Min. Mag., 1926, vol. 21, p. 51).

developed. Associated is earthy and fibrous haematite. Native silver[1] is found with the willemite at this locality, otherwise the mode of occurrence is very similar to that near the Sable Antelope mine (100 miles to the north-west); and it is probable that the mineral will be found at other places along the granite-dolomite contact between these two points. Mr. Murray-Hughes informs me that at both places the willemite occurs in necks or plugs of brecciated dolomite, and that copper-sulphide ores are found in similar necks (100 feet to 800 yards in diameter) nearer the granite, whilst at the actual contact and in xenoliths in the granite the dolomite has been completely replaced by haematite. The native silver occurs as an irregular intergrowth in the willemite, and nuggets weighing several ounces are found in the sub-soil near the deposit.

Willemite from Guchab, Otavi, South-West Africa.

This specimen, acquired by purchase in 1924 from Mr. W. Maucher of Munich, shows stout hexagonal prisms $\frac{1}{4}$ to $\frac{1}{2}$ cm. across with botryoidal malachite on massive chalcosine. The crystals are sulphur yellow on the exterior, and somewhat resemble the crystals of mimetite from this locality; but in the interior the material is white and grey in patches. The forms are $a\,(10\bar{1}0)$ and $e\,(01\bar{1}2)$. The occurrence here is similar to those in Rhodesia; the dolomites of the Nama system being intruded by granite.

Fluorescence of willemite and of some other zinc minerals in ultra-violet rays.

During a visit in 1924 to the famous mineral locality of Franklin Furnace, New Jersey, I was privileged to see over the works and laboratories of the New Jersey Zinc Company. Amongst the many points of interest that attracted my attention was a simple arrangement for the quick detection of willemite, which is an abundant mineral in the ores of the Franklin mine, but very variable in its aspect and superficial characters. In several of the laboratories and offices there was fixed to the wall in a dark corner a small apparatus giving a high-tension spark which could be switched on from the lighting circuit. A piece of ore held beneath the spark showed up any willemite present by a vivid green fluorescence. I have repeated this experiment by exposing specimens of willemite that I collected at Franklin Furnace to the sparks of a

[1] A similar occurrence of native silver with dioptase (and willemite) in limestone is known from Mindouli, French Congo (A. Lacroix, Min. de France, 1910, vol. 4, p. 841).

Ruhmkorff coil. The idea was to apply this test to the problematical 'yellow rock' from Broken Hill in Rhodesia. A far more effective source of ultra-violet rays is, however, given by a screened mercury-vapour lamp. A very convenient form is the 'analytic quartz lamp', made by the British Hanovia Quartz Lamp Co., Ltd., which was kindly placed at my disposal by Mr. W. D. McGillivray, the London manager of the company.

A specimen of willemite (a pale-green cleavage slab) from Franklin Furnace, placed in the dark chamber of this apparatus, glowed up with wonderful brilliancy, the colour being comparable with uranium-green, and it continued to glow when taken out of the apparatus. Another specimen from Franklin Furnace, with grains of pale-green willemite embedded in a cleavage-mass of white calcite, showed a very pretty effect—the calcite fluoresced with a dark flesh-red colour in which were spots of brilliant green due to the willemite. A specimen of willemite (crusts of small yellow-brown crystals) from Altenberg in Belgium, was tried, but it showed no trace of fluorescence. Other specimens of willemite which showed no indication of fluorescence, were the small colourless crystals from Broken Hill in Rhodesia, the aggregates of colourless crystals from near Sable Antelope mine in Rhodesia, yellow crystals from Guchab in South-West Africa, and colourless crystals from Peñoles, Durango, Mexico. The massive radiating willemite from near Lusaka in Rhodesia showed a dull dark-green fluorescence, and much the same colour was shown by the dark-coloured 'troostite' variety of willemite from Stirling Hill, New Jersey. The minute reddish crystals of willemite, found in 1908 in a cavity in the Rhodesian 'yellow rock', gave a bright yellow fluorescence, and scattered over the surface of the matrix were specks of yellow, white, and bluish-purple, and some very thin veins of bluish-purple. Four other specimens of the 'yellow rock' also showed minute specks of yellow, white, and bluish-purple. The red radiating willemite, forming the base of the colourless crystals from Broken Hill, also showed a bright yellow fluorescence, though only in patches.

Some other zinc minerals from Broken Hill, Rhodesia, were tested in ultra-violet rays for comparison. Smithsonite ($ZnCO_3$) showed differences in its behaviour: (1) white mamillated coarsely crystalline material showed a bright white fluorescence with a faint greenish tinge; (2) white botryoidal finely crystalline material gave no effect; (3) the rhombohedral (f) crystals, no effect. Hydrozincite (white mamillated; evidently pseudomorphous after smithsonite) showed a bright white fluorescence.

Hemimorphite (a pale-green crystalline crust) gave a dull white. Hopeite showed a pale straw-yellow with patchy distribution on the crystals. Parahopeite also showed a pale straw-yellow. Tarbuttite and descloizite gave no result.

The most striking fluorescent effect of all was that given by a massive granular black blende from Tsumeb, South-West Africa. This was tried because it shows a very pronounced triboluminescence: when lightly scratched with a knife-blade it gives streaks of yellow sparks. In ultra-violet rays it glows with a brilliant fiery yellow like a live coal. A crystal of zincite from New Jersey showed no effect.

A set of 23 small diamond crystals from the Mazaruni river district in British Guiana, selected to show the variation in colour, crystalline form, and inclusions, was also tested in ultra-violet rays. A yellow-green octahedron showed a brilliant fluorescence of the same colour, three colourless crystals showed up a good blue, and the rest gave no effect. Dr. G. F. Kunz in 1895 attributed the fluorescence and phosphorescence that is shown by some diamonds to the presence of a hypothetical hydrocarbon, for which he gave the name 'tiffanyite'.

It is evident from these few tests that fluorescence in ultra-violet rays is not a constant and essential character of a mineral-species, being shown by some specimens and not by others. It evidently depends on the presence of some admixed impurity in the material.

The action of ultra-violet rays on a large series of minerals of all kinds was tested by G. F. Kunz and C. Baskerville [1] in 1903, and by E. Engelhardt [2] in 1912. T. Liebisch [3] in 1912 determined spectroscopically the nature of the green fluorescence from willemite. W. S. Andrews [4] has pointed out that artificially prepared willemite is only active when it contains some manganese, the shade of the green fluorescence depending on the amount of manganese present.

[1] G. F. Kunz and C. Baskerville, The action of radium, Roentgen rays and ultra-violet light on minerals and gems. Science, New York, 1903, n. ser., vol. 18, pp. 769–783. (Willemite on p. 774.)

[2] Ernst Engelhardt, Lumineszenzerscheinungen der Mineralien im ultravioletten Licht. Inaugural-Dissertation, Univ. Jena, 1912, 42 pp.; Abstract in Neues Jahrb. Min., 1913, vol. ii, p. 358.

[3] T. Liebisch, Über die Fluoreszenz der Sodalith- and Willemitgruppe im ultravioletten Licht. Sitzungsber. Preuss. Akad. Wiss. Berlin, 1912, pp. 229–240.

[4] W. S. Andrews, Notes on the preparation of some fluorescent and phosphorescent compounds. Amer. Min., 1922, vol. 7, pp. 19–23. [Min. Abstr., vol. 2, p. 22.]