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*A new occurrence of zunyite near Postmasburg,  
South Africa.*<sup>1</sup>

(With Plate IX.)

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With a note on the Crystallography by L. J. SPENCER, F.R.S.

[Communicated by permission of the Honourable the Minister for Mines and Industries; read January 14, 1930.]

WHILE I was engaged on the geological survey of the Postmasburg manganese fields during 1927 the rare mineral zunyite, a basic orthosilicate of aluminium, was discovered in some altered highly aluminous shales or flagstones. The only occurrence of zunyite so far known is in Colorado, where, according to Dana's 'System of Mineralogy',<sup>2</sup> it was found at the Zuñi mine, Anvil Mountain, San Juan Co., and near Red Mountain, Ouray Co.<sup>3</sup> At the former locality it is intimately mixed with the sulpharsenite of lead, gittermanite, and pyrite, and is also embedded in an earthy material

<sup>1</sup> This paper collects together the mineralogical details contained in the author's report on 'The geology of the Postmasburg manganese deposits and the surrounding country', Geological Survey of the Union of South Africa (Special Publication), Pretoria, 1929, 104 pp. [Min. Abstr., vol. 4, p. 232], with the addition of two new chemical analyses by Mr. H. G. Weall and some other new matter.

<sup>2</sup> J. D. Dana, System of Mineralogy, sixth edit., 1892, p. 436, and Appendix I, 1899, p. 75.

<sup>3</sup> These two localities are about five miles apart over the county boundary.

consisting in part of lead sulphate derived from the alteration of the associated ores. Near Red Mountain it occurs as minute tetrahedra in an altered porphyrite. Schlaepfer and Niggli<sup>1</sup> obtained tetrahedral crystals of a zunyite-like substance on heating  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  with water in simple molecular proportions in a bomb at  $470^\circ\text{C}$ .

In the Postmasburg area, situated in the northern part of the Cape Province, South Africa, zunyite has so far been found in two localities only; namely, on a low prominence or rise about 800 yards to the south-east of Lace's Goat on the farm Doornfontein (no. M. 82), and in a patch of altered shales occupying the valley at the back of the homestead on the farm Klipfontein (no. M. 24). During an early survey of this country in 1905 Dr. A. W. Rogers brought away with him some of the altered shales from the latter place, and in one of the thin sections he had cut he noticed the presence of a few small crystals of an isotropic mineral, but as no further occurrences of it could be found the mineral was not identified. This section is still available and a comparison of the isotropic mineral (the triangular crystals of which are about 0.4 mm. across) with the Doornfontein occurrence showed that it is undoubtedly zunyite. When in 1928 I was camped on Klipfontein, a search was made for this mineral in the valley but without success. Neither did any of the thin sections of several rock specimens collected reveal its presence.

The Doornfontein occurrence, on the other hand, is characterized by a fair abundance of zunyite in an altered shaly rock less than six feet thick and forming part of a small circular outlier of Gamagara beds hardly 150 yards across. This outlier gives rise to the low prominence referred to above.

*Associated Rocks.*—The Gamagara Series of the Waterberg System (probably of pre-Cambrian age), in which the zunyite occurs, embraces a succession of quartzites, highly aluminous flagstones and shales, and, along the base, lenticular bodies of a coarse ferruginous breccia or conglomerate. These beds, ranging in thickness from only a few feet to over 1,200 feet, occupy a linear-shaped tract about 38 miles long that corresponds to the trend of the Gamagara ridge of hills; they also occur in a number of isolated patches scattered over the country, outliers in an area now occupied by dolomitic limestones, banded ironstones, cherts, jaspers, shales, and andesitic lavas belonging to the Campbell Rand and Griquatown Series of the Transvaal System. These older rocks, which generally speaking form a broad

<sup>1</sup> M. Schlaepfer and P. Niggli, *Zeits. Anorg. Chem.*, 1914, vol. 87, p. 56.

anticline with its western limb complicated by faults and small flexures, are unconformably overlain by the Gamagara beds.

Usually the Gamagara Series dips towards the west with angles of about  $10^{\circ}$  to  $20^{\circ}$ , but now and again there are changes in the angle and direction of dip due to the disturbances or folding the beds have undergone as a result of thrust faulting on the west, or local subsidences of the basal portions into solution cavities in the underlying dolomitic limestones. These beds have attracted considerable attention because of the recent discovery along the base of the group of extensive and rich deposits of manganese ore.

The altered rock in which the zunyite was discovered belongs to a group of red, purplish, grey, and also pale-coloured shales and flagstones of varying width up to about 130 feet thick intercalated between the ferruginous, basal conglomerate, and the quartzites. Immediately above the conglomerate the shale is deep-red in colour and often also pisolitic. These rocks are soft and easily cut by a hack-saw and may lead one to suppose that they are of a talcose or steatitic composition, but chemical analyses disclosed a complete absence of magnesia with, instead, alumina and silica as the main constituents. This is illustrated in the following table of analyses of three samples of rock collected.

*Table I. Analyses of highly aluminous shales.*

	A.	B.	C.
Silica... ..	46.5	44.05	46.55
Titania ... ..	1.75	1.75	2.15
Alumina ... ..	42.2	41.35	42.6
Chromic oxide ... ..	0.05	0.05	0.05
Ferric oxide... ..	0.7	4.8	0.5
Ferrous oxide ... ..	0.2	0.3	0.15
Manganese oxide ... ..	trace	trace	trace
Magnesium oxide ... ..	nil	nil	nil
Calcium oxide ... ..	trace	trace	0.35
Alkalis (sodium and potassium oxides) ...	0.35	0.4	0.35
Phosphoric oxide ... ..	0.05	0.1	0.1
Loss on ignition ... ..	8.35	7.15	7.15
Moisture ... ..	0.1	0.1	0.1
	100.25	100.05	100.05

A, white or pale greyish shale. B, red shale. C, pale greyish shale.

Analyses by H. G. Weall, F.I.C., Government Chemical Laboratories, Johannesburg. (Previously published in the author's report, 1929, p. 35.)

From the above figures it is evident that there is not enough silica to combine with all the alumina to form one or more of the aluminio-

silicate minerals. This, as seen in thin sections, is due to a great number of minute diaspore crystals strewn in a dense scaly matrix composed of two minerals, one showing high and the other low double refraction. The red colour of sample B is due to finely divided red iron oxide disseminated through the rock, but especially noticeable along the margins of laminae. The titanium in the three samples is due to the presence of minute rutile crystals.

Diaspore apparently is always present in these shaly rocks, more especially in the pale or grey coloured varieties. Moreover, its dimensions are not always microscopic, but in places the mineral shows tabular crystals that are as much as a centimetre across. In some parts of the Postmasburg area an unusual variety of rocks has resulted from the alteration of the original aluminous shales and flagstones. In the most advanced stages of metamorphism the rock has lost all properties peculiar to shales or flagstones, and become granular. Near Lace's Goat, where the zunyite was found, coarse diaspore-rock, diaspore-granulite, diaspore-zunyite-rock, and diaspore-zunyite-granulite, depending on the characteristic or main constituents of the rock and the structure shown, are to be seen. In the diaspore-rock, for example, the characteristic mineral may or may not form the major portion of the rock, but it is always embedded in a whitish or greenish scaly matrix, whereas the diaspore-granulite consists practically of diaspore grains only and does not show any signs of foliation or schistosity. Similarly the diaspore-zunyite-rock is distinguished from the granular variety. Typical of the zunyite locality on Klipfontein again are diaspore-, kaolin-, diaspore-kaolin-, quartz-diaspore-, diaspore-leverrierite-<sup>1</sup> diaspore-leverrierite-quartz-, and ferruginous diaspore-rocks.

It is difficult to explain the alteration of these rocks. The presence of the diaspore and zunyite cannot be attributed to thermal metamorphism dependent on heat emanating from intrusive bodies. Acid or basic plutonic rocks are not present in the rock formations that appear on the surface in the Postmasburg area. The only igneous rocks are the Ongeluk lavas, much older than the altered rocks, some doleritic dikes, and a few kimberlite pipes, that have had no appreciable effect on the surrounding rocks.

The possibility of the alterations having been effected by dynamic metamorphism in the form of crustal movements was also considered,

<sup>1</sup> The mineral appears to be one of the leverrierite group, but its determination as such was unsatisfactory.

but here again the shales that are altered most do not occur in localities where the Gamagara beds indicate a greater degree of disturbance than usual. Moreover, the mineral arrangement is not suggestive of shearing stresses; foliation and schistosity, although seen occasionally, are not characteristic of these rocks. Apparently, then, the changes observed in the rocks have either been set up by circulating waters or some other process without the conditions of high temperature and great mechanical force.

The genesis of these highly aluminous rocks is also not clearly understood at present. They appear to me to have been derived from the clayey or lateritic residue left by the decomposition of some rock, and subsequently deposited as a sediment, because they show bedded structure and occasional detrital grains of quartz, chert, and ironstone. What appears to be more likely is that they represent the insoluble residual *slime*, probably a very small fraction, of a great mass of Campbell Rand limestones and dolomites removed by solution.

*Mode of Occurrence.*—On Doornfontein farm the zunyite occurs in two ways: either it forms curious patches in the coarse diaspore-rock (pl. IX, fig. 1), or its crystals are roughly arranged in layers or disseminated through a rock in which the diaspore is only of microscopic dimensions. The patches, frequently spherical or oval-shaped, range up to about half-an-inch or more in length; they are irregularly scattered through the rock, several of them now and again adjoining one another, while elsewhere only an isolated patch or two are seen. Their distribution in the coarse diaspore-rock appears to be confined to an indistinct layer only a few inches thick. These patches are really saccharoidal aggregates of glassy zunyite with very little impurity in the form of other minerals present. The crystals are beautiful little tetrahedra, hardly more than half a millimetre across.

In the second mode of occurrence, the zunyite crystals on the whole are larger, individuals of two and three millimetres across being quite common. The crystals are perfectly idiomorphic, and the solid corners of several tetrahedra are replaced by faces belonging to the negative tetrahedron. They are flesh to pinkish coloured, transparent to opaque, while in the centres of many are patches, often also tetrahedral shaped, of a dark red impalpable dusty matter. It seems to me that these patches consist of a fine haematite dust that got enclosed as the zunyite crystals developed.<sup>1</sup> Support is lent to this

<sup>1</sup> Similar dark red patches were noticed in several diaspore crystals.

supposition by the higher percentages of iron oxide indicated by analyses A and B in table IV, as compared with the analysis in table II of the glassy clear zunyite in the aggregate form. Haematite, moreover, occurs in great abundance in some of the associated rocks. The rock in which these zunyite crystals occur is very fine-grained, somewhat friable and, as seen under the microscope, largely made of a granular aggregate of diaspore with lesser amounts of scaly minerals such as kaolin and possibly pyrophyllite or leverrierite (pl. IX, figs. 2 and 3).

*Physical Characters.*—The mineral as noted above is cubic and occurs in the form of small perfect tetrahedra with the solid corners of some individuals replaced now and again by faces of the negative tetrahedron. Two measurements taken on a goniometer of the interfacial angle gave  $109^{\circ} 35'$  and  $109^{\circ} 50'$  respectively, the small difference from the theoretical angle ( $109^{\circ} 28'$ ) being accounted for by the multiple images given by the crystal faces. Occasionally one may find two crystals, usually of different magnitudes, interpenetrating so that the solid angles of one project through the triangular faces of the other. In some instances this appears to be the result of twinning about a triad axis. That twinning, however, is actually represented could not be satisfactorily confirmed by goniometric methods on account of the small size of the crystals and the multiple reflections obtained from faces. The mineral shows distinct octahedral cleavage; it has a vitreous to almost adamantine lustre; the hardness appears to be about 7, and the mineral is brittle. Two determinations of the specific gravity by the pycnometer method gave 2.884 at  $25.2^{\circ}$  C. and 2.891 at  $20.3^{\circ}$  C. respectively.<sup>1</sup> The refractive index from readings taken by the liquid immersion method at  $19.5^{\circ}$  C. and using sodium-light was found to be 1.600.

In thin rock sections under the microscope, zunyite always shows idiomorphic outlines, while there is a tendency for the crystals to collect into roundish-shaped clusters or aggregates (pl. IX, fig. 3). The mineral is perfectly isotropic, showing no signs of optical anomalies. Apart from the Klipfontein occurrence and those crystals on Doornfontein enclosing the fine haematite dust above referred to, the mineral is practically free of inclusions except for a few minute doubly refracting particles, some of which are rutile. As regards the manner in which zunyite and the other rock constituents are associated, the thin sections show that diaspore may either wrap round or enclose

<sup>1</sup> Corrected values  $D_4^{25.2} = 2.873$  and  $D_4^{20.3} = 2.884$ .

the zunyite; while a scaly or fibrous aggregate, composed partly of kaolin and partly of the other more strongly doubly refracting aluminous mineral, occupies the interstices between the diaspore and zunyite or forms the matrix in which they are set (pl. IX, figs. 4 and 5).

In the thin section cut from the rock sample collected by Dr. A. W. Rogers in 1905 on Klipfontein, diaspore and zunyite crystals are evenly scattered through a fine-grained groundmass composed of quartz, kaolin, and the other scaly mineral with the stronger birefringence, and give rise to a porphyroblastic texture. The diaspore is much more abundant than the zunyite. Both minerals are crowded with the constituents of the groundmass so much so that in the case of the zunyite it is practically impossible to distinguish the outlines of the crystals in ordinary light; only when the nicols are crossed do the isotropic triangular crystals stand out with great clearness.

*Chemical Characters.*—The zunyite when heated in a bulb-tube yields water that has a decided acid reaction. Before the blowpipe the mineral glows brilliantly, the sharp edges show not the slightest sign of fusion, and the whole becomes white, opaque and porcelain-like. It is insoluble in cold or hot acids. Material for quantitative analysis was carefully picked out from the glassy aggregates or clusters in the coarse diaspore-rock and submitted to the Government Chemical Laboratories. While great care was taken to get a pure product it is quite possible that fine cleavage-flakes of diaspore and minute specks of the scaly matrix escaped unnoticed. The amount of material available for analysis was only 3.9 grams. The following were the results obtained :

*Table II. Analysis of Zunyite from Doornfontein farm.*

Silica ... ..	29.1 %
Alumina ... ..	54.25
Ferric oxide ... ..	0.5
Magnesium oxide ... ..	trace
Calcium oxide ... ..	trace
Alkali oxides ... ..	trace
Phosphoric oxide ... ..	0.15
Chlorine ... ..	2.45
Fluorine ... ..	0.8
Loss on ignition ... ..	15.35
Moisture ... ..	0.9

To this Dr. J. McCrae adds the following:—<sup>1</sup>

Oxygen equivalent to chlorine and fluorine amounts to 0.9 per cent. Making a deduction of this amount the analysis accounts for 102.6 per cent. This excess over 100 per cent. makes it probable that none of the constituents has been under-estimated. The excess may in some way be connected with the loss on ignition which probably includes more than water of constitution: this suggestion is made because it was found that the ignited material contained no chlorine. If during the ignition the chlorine had been expelled (as was apparently the case) its place would, no doubt, be taken by oxygen: the loss due to this would be minus 2.45 plus 0.55 or 1.9 per cent. It is, therefore, possible that the water of constitution is approximately 15.35 (loss on ignition) minus 1.9, or 13.45 per cent. It is regretted that the amount of material available was not sufficient to permit of a direct determination of the water of constitution. If the water of constitution be taken as 13.45 per cent. then, making due allowance for oxygen equivalent to the determined quantities of chlorine and fluorine, the analysis accounts for 100.7 per cent. of material. The analysis as so readjusted is given under I in table III, where other analyses of zunyite are added for comparison.

Table III. Analyses of Zunyite.

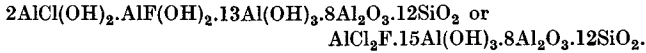
	I.	II.	III.	IV.
SiO <sub>2</sub> ... ..	29.1	24.33	24.11	24.15
Al <sub>2</sub> O <sub>3</sub> ... ..	54.25	57.88	57.20	57.68
Fe <sub>2</sub> O <sub>3</sub> ... ..	0.5	0.20	0.61	0.18
MgO ... ..	trace	—	—	—
CaO ... ..	trace	—	0.11	—
Na <sub>2</sub> O ... ..	trace	0.24	0.48	0.31
K <sub>2</sub> O ... ..	trace	0.10	—	0.18
Li <sub>2</sub> O ... ..	—	trace	—	—
Cl ... ..	2.45	2.91	2.62	2.90
F ... ..	0.8	5.61	5.81	5.19
P <sub>2</sub> O <sub>5</sub> ... ..	0.15	0.60	0.64	0.52
H <sub>2</sub> O+ ... ..	13.45	10.89	11.12	11.12
H <sub>2</sub> O— ... ..	0.9	—	—	—
	<u>101.60</u>	<u>102.76</u>	<u>102.70</u>	<u>102.23</u>
Less O for F and Cl ...	0.90	3.02	3.03	2.83
	<u>100.70</u>	<u>99.74</u>	<u>99.67</u>	<u>99.40</u>
Sp. gr. ... ..	—	2.875	2.876—2.904	2.878

- I. Doornfontein farm, Postmasburg, Cape Province, South Africa. J. McCrae in L. T. Nel, The geology of the Postmasburg manganese deposits, Geol. Survey S. Africa, Pretoria, 1929, p. 39.
- II. Zufi mine, Silverton, San Juan Co., Colorado. W. F. Hillebrand, Proc. Colorado Sci. Soc., 1885, vol. 1 (for 1883–4), p. 124; Bull. U.S. Geol. Survey, 1885, no. 20, p. 100.
- III. Charter Oak mine, Red Mountain, Ouray Co., Colorado. S. L. Penfield, Amer. J. Sci., 1893, ser. 3, vol. 45, p. 397.
- IV. Zufi mine, Colorado. B. Gossner and F. Musgnug, Centralblatt Min., Abt. A, 1926, p. 149; B. Gossner, Neues Jahrb. Min., Abt. A, 1926, vol. 55, p. 319 [Min. Abstr., vol. 3, p. 433].

<sup>1</sup> Reprinted, together with the above analysis (Table II), from the 1929 report (pp. 38–39).



The formula<sup>1</sup> assigned to zunyite is  $\text{Al}_3(\text{OH}, \text{F}, \text{Cl})_{12}(\text{SiO}_4)_3$ . The amount of chlorine in the specimens (say 2.5 per cent.), shows that whereas a halogen-free zunyite might be formulated as  $4\text{Al}(\text{OH})_3 \cdot 2\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$ , the specimens contain chlorine replacing hydroxyl approximately to the extent expressed in the (doubled) formula  $\text{AlCl}(\text{OH})_2 \cdot 7\text{Al}(\text{OH})_3 \cdot 4\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$ . The results quoted indicate that in the American specimens hydroxyl is replaced by fluorine to the extent expressed by the (doubled) formula  $\text{AlCl}(\text{OH})_2 \cdot 2\text{AlF}_2(\text{OH}) \cdot 5\text{Al}(\text{OH})_3 \cdot 4\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$ , but in the South African specimen hydroxyl has been replaced only to an extent approximately represented by the (quadrupled) formula



A compound of this last formula would give the following analytical values:

Silica	...	...	...	...	...	...	25.4 %
Alumina	...	...	...	...	...	...	57.6
Chlorine	...	...	...	...	...	...	2.5
Fluorine	...	...	...	...	...	...	0.7
Water of constitution	...	...	...	...	...	...	14.65
							<hr/> 100.85
Deduct oxygen equivalent to chlorine and fluorine...							0.85
							<hr/> 100.00

On another visit to the Doornfontein locality a year later further samples of zunyite-bearing rocks were collected. From these, samples were selected in which zunyite is scattered as single crystals or more closely gathered into streaks and bands. To separate the zunyite from the other constituents the rocks were crushed, and the material introduced into a bell-jar slightly moistened on the inside with alcohol. It was found that after rotating the jar a few turns, setting it down and tapping the sides with the hands many zunyite crystals adhered to the glass while the other minerals or rock particles dropped down. On repeating this a few times a product was eventually obtained practically free from foreign matter, and moreover, it was possible to get two or three grades of coarseness. Foreign particles that still remained were then carefully picked out under the binocular microscope. Two samples of zunyite crystals, a coarser and a finer product, were then submitted to the Government Chemical Laboratories for analyses. The average size of the crystals of the coarser

<sup>1</sup> W. F. Hillebrand's original (1885) empirical formula  $\text{H}_{18}\text{Al}_{18}\text{Si}_6(\text{O}, \text{F}, \text{Cl})_{45}$  was modified by P. Groth in 1889 (Tab. Übers. Min., 3rd edit., p. 104) as  $[\text{SiO}_4]_2\text{Al}_2[\text{Al}(\text{OH}, \text{F}, \text{Cl})_2]_6$ , representing a basic orthosilicate analogous to the garnet formula. B. Gossner and F. Mussgnug in 1926, insisting on a ratio  $\text{Si} : \text{Al} = 1 : 3$ , gave as alternative formulae  $\text{SiO}_2 \cdot \text{AlOF} \cdot 2\text{AlO}_2\text{H}$  or  $\text{SiO}_2 \cdot \text{AlF}(\text{OH})_2 \cdot 2\text{AlO}_2\text{H}$  and  $2\text{SiO}_2 \cdot 2\text{AlOF} \cdot 3\text{AlO}_2\text{H} \cdot \text{AlO}_3\text{H}_3$ ; while later, in order to conform with the results given by X-ray analysis, Gossner again readjusted the formula to  $3\text{SiO}_2 \cdot 3\text{AlO}(\text{F}, \text{Cl}) \cdot 4\text{AlO}_2\text{H} \cdot 2\text{AlO}_3\text{H}_3$ .

product would be about 1 mm. across. Many crystals in both samples had little red spots of haematite dust in the centre, which accounts for the presence of iron as shown in the analyses. The samples gave the following results: those under A for the finer grade, and those under B for the coarser grade. The values given under 'water of constitution' are the results of the determination of the amounts of combined water in the mineral and are not merely determined by loss on ignition. Lithium could not be detected.

*Table IV. New analyses of Zunyite from Doornfontein farm.*

(By H. G. Weall, F.I.C., Government Chemical Laboratories, Johannesburg.)

	A.	B.
Silica ... ..	24.25	24.1
Titania... ..	trace	trace
Alumina ... ..	56.75	56.85
Ferric oxide ... ..	1.3	1.45
Magnesium oxide ... ..	0.4	0.3
Calcium oxide... ..	0.35	0.2
Sodium oxide ... ..	1.65	1.45
Potassium oxide ... ..	trace	trace
Chlorine ... ..	3.5	4.8
Fluorine ... ..	0.5	0.4
Phosphoric oxide ... ..	0.25	0.25
Water of constitution ... ..	11.4	11.65
Moisture ... ..	0.4	0.35
	<hr/>	<hr/>
	100.75	101.80
Less O for F and Cl ... ..	1.0	1.3
	<hr/>	<hr/>
Total ... ..	99.75	100.50
Sp. gr. (corrected) ... ..	2.884	2.873

The composition of this mineral is thus very similar to that of the zunyite from Colorado, but the lower fluorine content with, apparently now and again, a higher chlorine percentage, serves to distinguish the South African mineral. The fluorine in the Postmasburg zunyite appears to be largely replaced by hydroxyl.

*Acknowledgements.*—In conclusion I should like to thank Mr. F. C. Partridge, of the Geological Survey, for his assistance in the determination of the physical and chemical properties, Prof. L. C. de Villiers and Mr. D. L. Scholtz of the Transvaal University College for their assistance in measuring the interfacial angle and refractive index of the zunyite. Dr. J. McCrae and Mr. H. G. Weall of the Government Chemical Laboratories also deserve my best thanks for the analyses of the highly aluminous rocks and zunyite, and to the former I am also indebted for the discussion of the results shown in Tables II and III.

*Note on the crystallography of zunyite.*

By L. J. SPENCER.

Specimens from the interesting new occurrence of zunyite in South Africa were generously sent in 1928 by the Director of the Geological Survey of the Union of South Africa for the mineral collection of the British Museum, and during my visit to Pretoria in 1929 Dr. L. T. Nel kindly handed over to me a further supply of material. A crystallographic study made on the two lots of crystals separated from the rock for analyses A and B (Table IV, p. 216) enables a few more points to be added to his paper. Twinning about a triad axis is suggested by Dr. Nel, and this I have been able to confirm. Rather than incorporating this extra matter in his paper without his knowledge and consent, I have taken the liberty of adding an appendix. His present paper, I may further explain, is the result of my suggestion that his account of this remarkable occurrence of a rare and interesting mineral should be given more prominence in mineralogical literature than would be obtained in a geological report on the manganese ore-deposits. In an abstract<sup>1</sup> of his report there is, for example, only the barest mention of the mineral in question.

The two lots, A and B, of separated crystals show certain differences. Those of lot A are smaller, varying only slightly from an average size of 1 mm. along the tetrahedral edge, and lighter in colour with smaller amounts of enclosed red iron oxide as central spots in the crystals. At first sight they appear to be simple tetrahedra, but under the microscope they all show small faces of the complementary tetrahedron. No twinned crystals were found in this lot. Crystals of lot B are rather larger ( $1\frac{1}{2}$ –2 mm. edge) and darker in colour with a larger nucleus of enclosed foreign material. On these crystals the complementary tetrahedron is more conspicuously developed, especially on the twinned crystals. About one per cent. of the crystals were found to be twins. One specimen of the rock with numerous embedded zunyite crystals yielded a higher percentage of twinned crystals.

The crystals are in all cases singly and sharply developed with brilliant faces on all sides. Only very rarely do they show broken corners or an irregular intergrowth of two or more crystals. The larger faces of the positive tetrahedron  $o(111)$  are brilliant and to all

<sup>1</sup> Min. Abstr., vol. 4, p. 232.

appearance quite smooth, but on the goniometer they give scattered reflected images. They show low pyramids of growth and lines parallel to the tetrahedral edges. The smaller faces of the negative tetrahedron  $o'$  ( $\bar{1}11$ ) are dull and pitted and give only blurred images. In their outer portions the crystals are colourless and transparent, and it is only the red nucleus that gives a pink tinge by reflection to the crystal as a whole.

Twinning, which has not previously been described for zunyite, is by rotation about a triad axis with interpenetration. Two tetra-

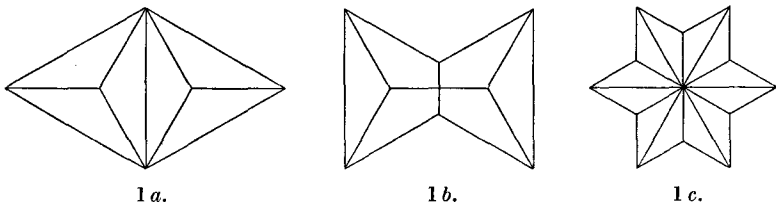


FIG. 1. Tetrahedra twinned by rotation of  $60^\circ$  or  $180^\circ$  about a triad axis. Plans viewed along the twin-axis.

hedra, in twinned position by a rotation of one of them through either  $60^\circ$  or  $180^\circ$  about a triad axis, may be joined together symmetrically in three different ways. Figs. 1a and b show the combination on one or other side of a plane parallel to the twin-axis, this composition-plane being a face of the icositetrahedron  $\{211\}$ . If the twin-axis is  $[111]$ , these faces may be  $(\bar{1}\bar{1}2)$ ,  $(1\bar{2}1)$ , or  $(\bar{2}11)$ , or their parallels. Fig. 1c shows the complete interpenetration of the two tetrahedra. In all three cases the tetrahedral faces  $(111)$  and  $(\bar{1}\bar{1}\bar{1})$  perpendicular to the twin-axis are common to the two individuals. Interpenetration-twins, as in fig. 1c, were figured for tetrahedrite by W. Haidinger<sup>1</sup> in 1824. Contact-twins of the (a) and (b) kinds have been described for tetrahedrite by A. Sadebeck.<sup>2</sup>

The zunyite twins may be described as interpenetration-twins, but no example was found in which the apices of the two crystals are coincident, as in fig. 1c. One individual is always smaller than the other. The twin represented in fig. 2a shows some resemblance to the contact-twin in fig. 1b with only a slight overlap or interpenetra-

<sup>1</sup> W. Haidinger, *Edinburgh Journ. Sci.*, 1824, vol. 1, p. 60, pl. 3.

<sup>2</sup> A. Sadebeck, *Zeits. Deutsch. Geol. Gesell.*, 1872, vol. 24, p. 427, pls. 16, 17; *Angewandte Krystallographie*, Berlin, 1876, pl. 3. See also W. J. Lewis, *Treatise on Crystallography*. Cambridge, 1899, p. 473.

tion. In fig. 2*b* the smaller crystal is pushed farther into the larger crystal, and in fig. 2*c* still farther. In the last figure the two separate portions of the smaller individual separately occupy positions relatively to the larger crystal as in fig. 1*a*; though taken together their

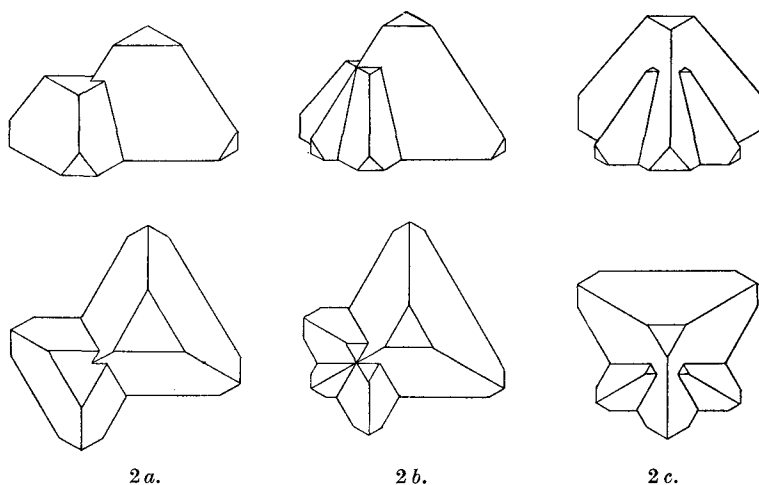


FIG. 2. Twinned crystals of zunyite from Postmasburg, South Africa.  
Clinographic drawings and plans.

relative position is as in fig. 1*b*. Often there are quite small projecting corners from two (never three) of the faces of an otherwise simple tetrahedron. The re-entrant angle between the faces of the two individuals was measured as  $56^{\circ} 17'$  (calculated  $56^{\circ} 15'$ ).

When a corner of the tetrahedron is chopped off, the fractured surface appears to be irregular, but in the goniometer it gives a poor reflected image in the position of the complementary tetrahedron. The crystals therefore have a poor octahedral cleavage.

The degree of hardness was determined by embedding a minute crystal in sealing-wax on a holder. The mineral scratched quartz, but only with difficulty. On the other hand, a crystal still embedded in the rock is more readily scratched by topaz. The hardness may then be placed at  $7\frac{1}{4}$ .

Being tetrahedral, the crystals would be expected to be pyroelectric. They were tested for this property by the simple method of dusting over the cooling crystals with a mixture of red-lead and

flowers of sulphur, a small tetrahedron of boracite being used for comparison, but with a negative result.

The refractive index for light of three wave-lengths was determined by the prism method through two tetrahedral faces, for which purpose the faces had to be artificially polished. The results obtained on two of the larger crystals (of 2 mm. edge) from the lot used for analysis B are :

Li.	Na.	Tl.	$n_{\text{Tl-Li}}$
1.5969	1.5996	1.6026	0.0057
1.5969	1.5997	1.6025	0.0056

Previous determinations of the refractive index of zunyite on material from the Zufi mine, Colorado, are :

E. S. Larsen (1921) <sup>1</sup> ... ..	$n = 1.589 \pm 0.003.$
M. Albis (1921) <sup>2</sup> ... ..	$n_D = 1.6022$ (and other wave-lengths).
B. Gossner and F. Mussgnug (1926) <sup>3</sup>	$n_{\text{Na}} = 1.595.$

The more accurate determinations of M. Albis by the prism method when compared with those for the South African mineral affords perhaps a correlation with the chemical composition. Judging from the analyses in Table III alone, it would seem that there is a slight decrease in the refractive index as fluorine is replaced by hydroxyl. This, however, is contrary to the result obtained by S. L. Penfield<sup>4</sup> in 1894 for topaz and herderite. Evidently this effect is counteracted by the larger percentage of chlorine shown in analysis B of Table IV.

<sup>1</sup> E. S. Larsen, Bull. U.S. Geol. Survey, 1921, no. 679, p. 160.

<sup>2</sup> Matilde Albis, Rend. R. Accad. Lincei, Cl. Sci. Fis., Roma, 1921, ser. 5, vol. 30, sem. 2, p. 472 [Min. Abstr., vol. 2, p. 43]. Determinations are given for six lines: B 1.5975, C 1.5991, D 1.6022, E 1.6048, F 1.6085, G 1.6124, with dispersion,  $n_{\text{G-B}} = 0.0149.$

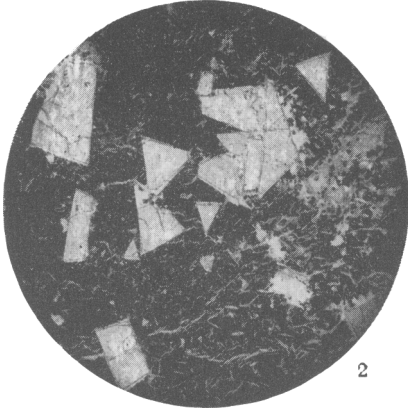
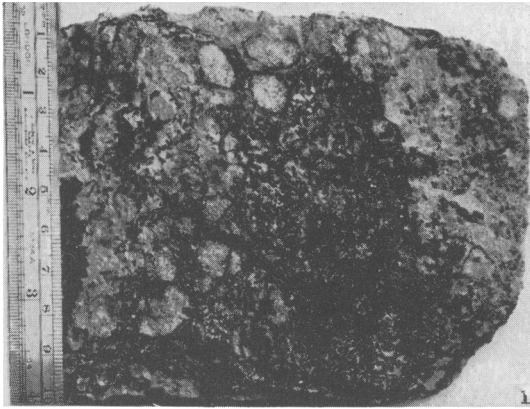
<sup>3</sup> B. Gossner and F. Mussgnug, Centralblatt Min., Abt. A, 1926, p. 149 [Min. Abstr., vol. 3, p. 433].

<sup>4</sup> S. L. Penfield, Abstract in Min. Mag., 1895, vol. 11, p. 42.

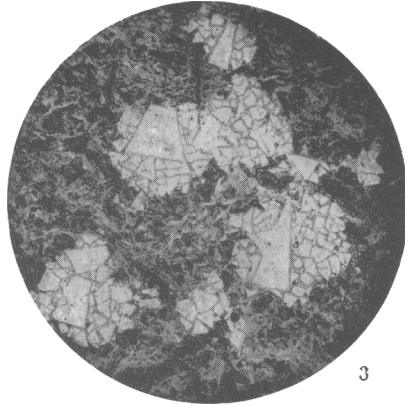
## EXPLANATION OF PLATE IX.

Zunyite from Doornfontein farm, Postmasburg, Cape Province, South Africa.  
(Figs. 2-5, Photomicrographs of rock sections.)

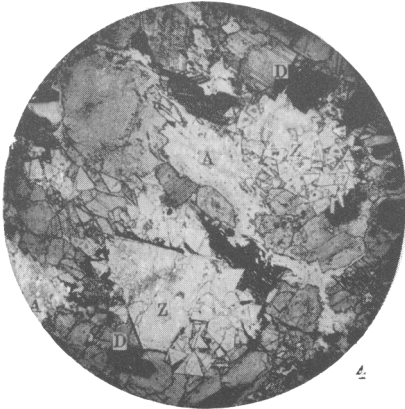
- FIG. 1. Rounded or oval-shaped white patches of zunyite crystals in a coarse diaspore-rock. The dark crystals of diaspore are set in a scaly aggregate of aluminous minerals such as kaolin.  $\times \frac{1}{2}$
- 2. Zunyite crystals in a granular aggregate of diaspore.  $\times 8.5$ .
- 3. Clusters of zunyite crystals in a groundmass composed of dark diaspore crystals and white scaly minerals such as kaolin and possibly pyrophyllite or leverrierite.  $\times 8.5$ .
- 4. Triangular zunyite crystals (Z) associated with diaspore (D) with a scaly aggregate (A) of kaolin and another aluminosilicate mineral with stronger birefringence.  $\times 8.5$ .
- 5. Illustrating diaspore (D) enclosing or wrapping round zunyite (Z) crystals. (A) is a scaly aggregate composed partly of kaolin and partly of another scaly mineral such as leverrierite or pyrophyllite.  $\times 21$ .



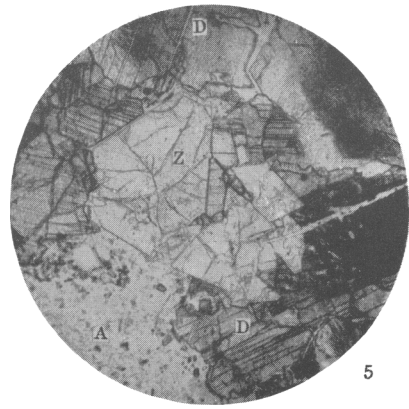
2



3



4



5

L. T. NEL: ZUNYITE FROM POSTMASBURG, SOUTH AFRICA.