On the occurrence of petalite and pneumatolytic apatite in the Meldon aplite, Okehampton, Devonshire.[1]

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THE Meldon aplite is a small intrusion lying to the north-west of the Dartmoor granite about two miles south-west of Okehampton. Its microscopic characters were investigated by Sir Jethro Teall, whilst the geology of the district, with petrological accounts of the aplite and its associated rocks, has been fully dealt with by R. H. Worth,[2] who notes the presence of felspar, quartz, mica, tourmaline, topaz, apatite, fluor-spar, montmorillonite, and axinite.

My attention was first directed to this interesting occurrence by Dr. J. S. Flett who, some years ago, noted the presence in the aplite of veins of a peculiar pink material which we concluded to be petalite. The investigation was unfortunately interrupted at that time, but recently the matter was again taken up, and the results are embodied in the present communication. I take this opportunity of stating that Dr. Flett had already done a considerable amount of work on the subject, and he has most generously placed his notes at my disposal.

As noted by Worth, the Meldon aplite consists essentially of albite, orthoclase, quartz, and white mica, with tourmaline, topaz, and apatite as the more important accessory minerals.

The tourmaline rarely shows crystalline faces, but occurs as highly irregular grains spotted with inclusions of quartz and felspar. It is of very pale-yellow colour and weak pleochroism, ranging from colourless to pale-yellow. Its irregular form proves that it is a mineral that continued to crystallize till a late period in the history of the rock. The topaz occurs as irregular grains with a double refraction similar to that of quartz,

[1] Communicated by permission of the Director, H.M. Geological Survey.

[2] R. H. Worth, Quart. Journ. Geol. Soc., 1920, vol. 75 (for 1919), pp. 77–118.

but a much higher refractive index and a perfect cleavage. It tends to be more idiomorphic than the tourmaline, sections often having rectangular outlines; but irregular grains, which may contain inclusions of quartz and felspar, are also common.

Petalite.

This somewhat rare mineral has not previously been recorded from Britain, but in the Meldon aplite it is fairly common and occurs in two distinct ways:

(*a*) Occasionally in the somewhat coarser portions of the aplite it is present as irregular or roughly rectangular masses, usually pinkish to red in colour, which measure up to 5 cm. in length. Rarely these masses are so plentiful in the rock as to give it a suffused pink tinge. Microscopic sections of such material show the petalite as a colourless mineral, usually somewhat decomposed, filling up spaces between the other ingredients of the rock. It is never eumorphic, and is moulded on quartz and felspar besides enclosing crystals of these minerals. It shows good cleavage, a birefringence distinctly above that of quartz, and a characteristic decomposition into a clay-like substance which in section is pale-brown, but in hand-specimens has a pink or red colour and has been identified as montmorillonite by previous workers; this is dealt with in the sequel. The pink colour is due to decomposition, for when the petalite is fresh it has in hand-specimens a yellowish-grey colour, and all stages can be traced from such material to the characteristic pink clay.

The petalite may be readily identified by its optical properties. Tested by the immersion method, its mean refractive index is 1·51, whilst $\alpha = 1{\cdot}50(5)$ and $\gamma = 1{\cdot}51(5)$; the mineral is optically positive with a large axial angle. Before the blowpipe it fuses readily and gives the characteristic lithium flame; its specific gravity is 2·39.

(*b*) Petalite is more common in certain pegmatite-veins which occur in the aplite. These veins vary considerably in width, from mere strings up to those measuring 3–4 cm. across. They consist of quartz, felspar, mica, tourmaline, and petalite; topaz and apatite are also present. The petalite is never eumorphic and builds large, irregular plates moulded on quartz, felspar, and mica, and frequently encloses grains and crystals of these minerals. It may be quite fresh, but more often shows the characteristic weathering already described, whilst occasionally there are signs of an incipient alteration to mica. The alteration in both cases usually commences at the margin and spreads inwards along the well-developed

cleavage cracks giving the petalite a characteristic appearance in the sections.

It appears to be most plentifully developed in that part of the aplite intrusion which is crossed by the Redaven and in the exposure flanking the tramway on the south bank of that stream. Numerous pink veins, up to 5 cm. in width, can be seen in the aplite at that spot, but much

FIG. 1. FIG. 2.

FIG. 1.—Petalite in the Meldon aplite. The large, white patch in the centre of the field is petalite showing cleavage. It is moulded upon, and encloses, felspar. Crossed nicols, ×24. [Geol. Survey slide No. E. 9023.]

FIG. 2.—Large mass of petalite in a vein in Meldon aplite. It shows the characteristic cleavage and weathering. Ordinary light, ×24. [Geol. Survey slide No. E. 8346.]

of the material is very decomposed. In the quarry south of the Redaven it is not common, nor is it plentiful in the quarry to the north.

The presence of petalite at Meldon gives the aplite a character unique amongst British rocks and suggests that it has affinities with the soda-lithia pegmatites and aplites so admirably described by Lacroix.[1] The following analysis made in the Survey Laboratory by Mr. E. G. Radley

[1] A. Lacroix, Minéralogie de Madagascar, 1922, vol. 2, pp. 304–362.

confirms that view. For purposes of comparison an analysis of Dartmoor granite by Mr. Radley is also given :

	I.		II.
SiO_2	67·55	...	75·09
TiO_2	trace ?	...	0·25
Al_2O_3	17·22	...	13·46
Fe_2O_3	0·62	...	0·74
FeO	—	...	1·05
MnO	0·45	...	0·14
(Co, Ni)O	nil	...	nil
BaO	nil	...	nil
CaO	1·28	...	0·66
MgO	0·24	...	0·74
K_2O	4·38	...	3·78
Na_2O	6·41	...	3·10
Li_2O	0·42	...	nil
H_2O at 105° C.	0·08	...	0·14
H_2O above 105° C. ...	0·70	...	0·77
P_2O_5	0·35	...	0·19
CO_2	—	...	0·02
F	1·39	...	nil
	101·09		100·13
Less O for F	0·58		
	100·51		

I. Meldon Aplite (E. 8346). Anal. E. G. Radley.

II. Dartmoor (Haytor) Granite (E. 9138) Anal. E. G. Radley. Mem. Geol. Survey, Geology of Dartmoor (Sheet 338), 1912, p. 42.

The analysis emphasizes the fact noted by Lacroix[1] that in soda-lithia pegmatites and aplites, the soda preponderates over the potash, and this concentration of soda is accompanied by an increase in the percentage of lithia, present in the Meldon aplite not only in the petalite, but also in the mica which, as Worth has pointed out, is lithia-bearing. The fluorine is present not only as fluor-spar in the aplite but is a constituent of the mica and the apatite which is present in considerable quantity.

Montmorillonite.

The pink clay so prevalent in the petalite-rich portions of the aplite was first noted and referred to montmorillonite by Harford J. Lowe,[2] who remarks on its colour, waxy lustre, lack of crystalline form, and also on the fact that different specimens show the mineral in various stages of

[1] A. Lacroix, loc. cit., p. 315.

[2] H. J. Lowe, Rep. and Trans. Devonshire Assoc., 1901, vol. 33, p. 112.

formation. From its mode of occurrence it is clearly a decomposition product of the petalite. This is shown by nearly every microscopic section examined, and may be seen on careful examination of the hand-specimens. A particularly fine example, collected by Mr. F. N. Ashcroft, who kindly submitted it to me for examination, shows relatively large masses of the pink clay on two sides of a specimen of aplite. When these masses are examined closely with a lens they show greyish to white cores of cleavable petalite in their centres.

Under the microscope the clay has a fibrous structure, the fibres being weakly birefringent; the determination of the refractive index is difficult owing to the felted arrangement of the fibres, but it is usually about 1·49 for the vibration-direction parallel to the fibres and slightly greater for that across the fibres.

The species montmorillonite is an indefinite one,[1] but it is noteworthy that pink decomposition products have been recorded from the lithia-pegmatites of Branchville, Connecticut,[2] and from Harndon Hill, Stoneham, Maine.[3] A specimen of pink clay in the Ludlam Collection in the Museum of Practical Geology, labelled montmorillonite, from Poitiers, shows similar characters to those of the material under description. The refractive index is approximately the same, but the birefringence is higher.

Veins free from Petalite.

In addition to the pegmatite-veins carrying petalite there are others in which that mineral appears to be absent. Several types have been noted:

(*a*) In the quarry to the north of the Redaven the aplite is traversed by numerous pinkish coloured veins which, in hand-specimens, bear a deceptive resemblance to petalite. They vary in width but are usually $\frac{1}{2}$ to 1 cm. thick, and they tend to occur at the junction between the normal, fine-grained aplite and a coarser variety. Not infrequently the junction of the vein with the fine-grained aplite is marked by a thin, blue layer rich in apatite.

Under the microscope, these veins are seen to consist of quartz, which is rarely eumorphic, albite as lath-shaped crystals, large anhedral plates of orthoclase (microperthite), with abundant white mica as large, bladed crystals. The pink material fills up the spaces between these minerals.

[1] Cf. E. S. Larsen, The microscopic determination of the nonopaque minerals. Bull. U.S. Geol. Survey, 1921, no. 679, p. 113.

[2] G. J. Brush and E. S. Dana, Amer. Journ. Sci., 1880, ser. 3, vol. 20, p. 283.

[3] G. F. Kunz, ibid., 1884, ser. 3, vol. 27, p. 214.

It has a turbid appearance and consists, as described by Worth,[1] of a felted aggregate of mica, in which are enclosed grains and crystals of the above minerals with tourmaline and, occasionally, fluor-spar, apatite, and topaz which sometimes shows decomposition to a clay-like substance. In one or two slides there are plates of a highly refractive mineral with strong birefringence. It encloses the mica and is probably prehnite.

(*b*) A second type of vein approaches a greisen in character. It is pale-blue in colour and under the microscope is seen to consist of quartz, felspar, and large amounts of mica in tufted aggregates, with abundant fluor-spar. The mica is clearly replacing the felspar, especially the microperthite, whilst the fluor-spar occurs enclosed in and replacing the albite; good examples occur showing all stages from partial to total replacement.

This micasization of the felspars is not confined to the veins, for coarser specimens of the aplite sometimes have a delicate lilac tint which is due to extensive replacement of the orthoclase by mica, the plagioclase being comparatively unaffected;[2] topaz is especially plentiful in the slides.

(*c*) A third and much rarer type of vein characterized by the presence of prehnite is apparently a contact phenomenon. A specimen of aplite shows on one side a vein, 2 mm. in width, consisting essentially of purple fluor-spar with prehnite and axinite. A section shows turbid prehnite as large plates enclosing fluor-spar, quartz, which is occasionally idiomorphic, and small crystals of felspar, in association with large, transparent crystals of axinite. The prehnite is not confined to the vein but wanders into the aplite and replaces the felspar, which is very turbid; a large fragment of tourmaline is also riddled with prehnite, which appears to be replacing it. The other side of the specimen is coated with crystalline axinite. On a second specimen the veins are mere threads radiating from a xenolith into the aplite; they consist of prehnite with turbid felspar.

(*d*) Rarely there occurs at the junction of the aplite with the micaceous xenoliths mentioned below a thin, purplish-coloured layer which bears a superficial resemblance to fluor-spar. It proves to consist of cordierite of a peculiar type. Under the microscope, it shows as small grains and rectangular laths, sometimes with good cleavage, straight extinction, strong pleochroism and, for this mineral, an anomalously high birefringence; the mineral is biaxial and negative with a small axial angle. It is intimately associated with pale-blue apatite and often occurs enclosed

[1] R. H. Worth, loc. cit., p. 106.

[2] Mem. Geol. Survey, The Geology of the Country around Bodmin and St. Austell (Sheet 347), 1909, p. 68.

in and surrounding grains of that material. Its refractive indices as determined in oils are $\alpha = 1{\cdot}54$, $\beta = 1{\cdot}56$, $\gamma = 1{\cdot}57$; pleochroism α colourless to yellow, β deep-plum colour, γ pale-plum colour.

The junction of the aplite with the xenolith is marked by a layer of large felspar crystals radially disposed to the xenolith, and the spaces between are filled with an aggregate of cordierite, grains of felspar, and apatite; thin, thread-like veins consisting of fluor-spar and turbid felspar run from the aplite through the xenolith.

Pneumatolytic Apatite.

The apatite presents unusual features of special interest. A few small, clear prisms occur, as elements of early consolidation mostly included in felspar, in the manner which is usual for apatite in rocks of this class. The mineral, however, is far more common as large, irregular grains, pale-blue in colour, with weak pleochroism, which contain inclusions of the other components of the rock. Many of these apatites resemble ophitic plates filled with grains of quartz and felspar. They sometimes measure 2 mm. across and show no trace of hexagonal outlines. The refractive index, ω, is 1·630, thus showing that the mineral is a fluor-apatite.[1] The relations of the apatite to the other minerals are quite similar to those of the tourmaline, and leave no room for doubt that it is one of the final products of consolidation and must be added to the group of pneumatolytic minerals for which the granites of the West of England are so celebrated.

Dr. Flett[2] has pointed out that these minerals occur in three distinct ways:

(*a*) In the granites, tourmaline, muscovite, and topaz not only behave as pyrogenetic minerals and commence to crystallize at an early stage but, under the influence of the vapours in the magma, their crystallization continued to a late stage in the consolidation of the rock. Thus, whilst well-shaped crystals of tourmaline and muscovite are often enclosed in the primary felspar of granites and elvans, spongy masses of tourmaline may also be seen enclosing quartz and felspar; muscovite and topaz often show the same peculiarity.

(*b*) After the granites and elvans had solidified, a replacement of the original minerals by the pneumatolytic ones took place and, especially along lines of weakness, quartz with tourmaline, topaz, muscovite, and

[1] Cf. A. Lacroix, Minéralogie de Madagascar, 1922, vol. 1, p. 352.

[2] Mem. Geol. Survey, Geology of the Land's End district (Sheets 351 and 358), 1907, pp. 53-60.

kaolin are gradually substituted for felspar and biotite; thus arise the greisens, schorl-rocks, and kaolin-granites whose origin was closely connected with the production of the tin-veins.

(*c*) In the country-rocks around the granites the same process goes on, and inclusions of sediment in the granite are not only re-crystallized by contact action but are also permeated by mineralizing vapours, with the result that they become filled with tourmaline and other minerals indicating pneumatolytic agencies.

There now seems to be good evidence that apatite may behave as a pneumatolytic mineral. It is a characteristic associate of tin-ore in Cornwall,[1] and in the greisen veins of St. Michael's Mount not only is apatite found well-crystallized, but an analysis of the rock points to the conclusion that there has been an introduction of phosphoric acid.[2] It also occurs[3] as grains in quartz pseudomorphous after porphyritic felspar in the schorl-rock of Trevalgan, near St. Ives, whilst K. Busz has recorded it from the pegmatite veins of the granite in the Gready quarry[4] near Luxullian in Cornwall.

The occurrence in the Meldon aplite is perhaps the best instance, however, of the pneumatolytic formation of apatite, for not only is it a late consolidation product in the rock itself, but it is abundant in certain peculiar xenoliths which are not infrequently present. These xenoliths are of two types. Both of them are fine-grained, but white mica is abundant in one type and absent from the other. The micaceous inclusions have been described by Worth[5] and resemble in microscopic characters a fine-grained mica-schist. They contain, in addition to white mica, a little quartz and felspar, needles and grains of tourmaline, and numerous grains of apatite, small and of irregular form. These inclusions are undoubtedly altered sedimentary rocks.

The second type consists mainly of quartz and felspar as grains so small that their optical characters cannot be satisfactorily tested even with the highest powers of the microscope. At the margins of the slide, however, the refractive indices of a large part of the aggregate are seen to be below that of Canada-balsam, and consequently these inclusions are rich in felspar. They fuse easily before the blowpipe. The finely crystalline matrix has a distinct parallel banding that might be the

[1] F. W. Rudler, A Handbook to a Collection of Minerals of the British Islands, 1905, p. 24.

[2] Geology of the Land's End district, 1907, pp. 59–60.

[3] Ibid., p. 55.

[4] K. Busz, Rep. British Assoc. Adv. Sci., 1905, for 1904, p. 563.

[5] R. H. Worth, loc. cit., p. 86.

remains of bedding or foliation in a sediment, or of fluxion in an igneous rock. In this matrix there are larger crystals of felspar, nearly eumorphic, giving the rock a porphyritic structure. Although these inclusions simulate igneous rocks they bear a strong resemblance to the 'felspathic hornstones' which occur as bands alternating with the fine 'calc-flintas' so common in the aureoles of the West of England granites,[1] and more probably they are altered sediments perhaps felspathized by the aplite. Apatite is present as small, irregular grains, sometimes so numerous as to give a pale-blue colour to the whole mass; it often lies in bands parallel to the foliation of the rock. Brown tourmaline occurs with it, but its crystals may have perfect crystalline form. Around the inclusions there is usually a zone up to 2 mm. in width very rich in apatite, tourmaline, and topaz, and having sometimes a deep-blue colour. The presence of this zone suggests two explanations of the unusual occurrence of the apatite.

Firstly, the apatite might belong primarily to the inclusions of sedimentary rock, in which case they must have been phosphatic shales. This would explain the extraordinary abundance of apatite in the inclusions and their surrounding rims; but examination of a considerable number of specimens of the Meldon aplite shows that pale-blue apatite is almost universally present, and if derived from phosphatic sediments this would require that a very large amount of these rocks had been dissolved in the igneous magma, an hypothesis that is not easy to maintain.

Alternatively, the apatite may be, like its associate tourmaline, a constituent of the igneous rock. It occurs in precisely similar ways both in aplite and inclusions, and not infrequently is included in tourmaline or more rarely surrounds tourmaline in such a way as to suggest that these two minerals crystallized at about the same time and under similar conditions; in other words, the apatite is a pneumatolytic mineral.

The dark-blue ring around the inclusions is an illustration of the familiar fact that pneumatolytic minerals tend to be specially abundant in such situations, and in fact the apatite is accompanied by unusual amounts of topaz and tourmaline. The apatite that occurs in the inclusions and gives them a sky-blue colour is a pneumatolytic impregnation of the same kind as the tourmaline. Its presence indicates that the rock originally contained a small amount of lime, and this is in accordance with the view that these inclusions represent the felspathic hornstones of the calc-flinta series, for such rocks usually contain a little lime silicate.

[1] Cf. Mem. Geol. Survey, The Geology of the country around Bodmin and St. Austell (Sheet 347), 1909, pp. 98–99.

The occurrence of apatite in this connexion is a notable exception to the rule that calcareous rocks affected by the pneumatolytic action of the granites of the West of England contain axinite as their typical new mineral.

Crystallized Apatite.

In the aplite from the quarries at Meldon the apatite never occurs well-crystallized, but in a little stream about 50 yards north-east of the building erected for the manufacture of glass from the quarry rock there

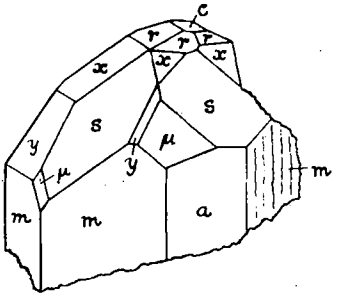

FIG. 3.—Crystal of Apatite from Meldon, Devonshire.

occur loose blocks of a coarse pegmatite which contains druses with well-crystallized apatite and tourmaline. The rock consists of the same constituents as the aplite, the felspar crystals being sometimes 2–3 cm. in length. Under the microscope, mortar structure is prominent, and many of the felspar crystals are bent, especially near the junction with the xenoliths. These are black in colour, and their junctions with the surrounding rock are sometimes marked by zones of blue apatite and pink tourmaline.

In the druses, crystals of apatite and tourmaline are associated with well-crystallized quartz, orthoclase, albite, and muscovite. The tourmaline occurs as well-developed prisms up to 2 cm. in length; it may be brown, pale-yellow, red, or green, and individual crystals often show variegation. The forms recognized are $a(11\bar{2}0)$, $m(1\bar{1}00)$, $r(10\bar{1}1)$, $t(21\bar{3}1)$, $c(0001)$.

The apatite varies in colour from deep-blue to pale-green and its crystals are rarely more than 2 mm. in length. They are seated on quartz or tourmaline, with which they are intimately associated. The forms recognized are $m(10\bar{1}0)$, $a(11\bar{2}0)$, $x(10\bar{1}1)$, $r(10\bar{1}2)$, $y(20\bar{2}1)$,

$s(11\bar{2}1)$, $\mu(21\bar{3}1)$, $c(0001)$. A drawing of a broken crystal showing such a combination is given (fig. 3).

Associated with the coarser rock there is also at this locality a fine-grained aplite, the junction between the two being usually marked by a layer of rose-coloured mica with pale-green or pink tourmaline. This aplite is remarkably rich in topaz, which shows square-shaped sections and large, irregular grains throughout the sections.

Summary.

(1) Certain portions of the aplite have developed a soda-lithia phase characterized by the presence of petalite, a mineral not previously recorded from the British Isles, and its product of decomposition, montmorillonite.

(2) The Meldon aplite affords a good example of the pneumatolytic phenomena so characteristic of the granites of the West of England.

(3) Evidence is brought forward to show that apatite occurs as a pneumatolytic mineral in the aplite.

I desire to express my most cordial thanks to Dr. E. H. Young of Okehampton, who placed his material and knowledge of the district entirely at my disposal for the purposes of this investigation.