AN OCCURRENCE OF NATROLITE, ANDRADITE, AND ALLANITE IN THE FRANKLIN FURNACE QUADRANGLE, NEW JERSEY*

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ABSTRACT

Masses of natrolite containing small crystals of green andradite and dark-brown allanite occur in the weathered debris of a nepheline syenite dike. Optical, chemical, and spectrographic data are given for these three minerals, with a brief discussion of paragenetic relationships. The nepheline syenite contains abundant brown melanite, but no andradite.

LOCATION AND GEOLOGICAL RELATIONS

Natrolite, andradite, allanite, and a little quartz occur together as a satellitic hydrothermal deposit in the heavily weathered portion of a dike of porphyritic nepheline syenite. They are found in a small area a hundred feet or so across at the western end of the dike, which extends eastward for more than a thousand feet, forming a pronounced topographic ridge. The exact locality, shown on the Franklin Furnace, N. J., Folio geologic map (1), is one mile slightly south of west from Wykertown. It is also shown on the more recent Army Map Service topographic map of the Branchville, N. J., quadrangle (2).

The dike is described briefly by J. E. Wolff (3) as consisting of: phenocrysts of biotite corroded and replaced by aegirite; crystals of augite, red in the center and green on the periphery; and apatite and melanite in a background of orthoclase and nepheline. In some specimens of the rock, collected by Charles Milton, there is also abundant cancrinite. The dike has been further studied as a possible source of feldspar by John M. Parker, III (4).

NATROLITE

The natrolite, with its associated minerals, is found in loose masses in a crumbly dark gravel resulting from the disintegration of the nepheline syenite. Only at the west end of this dike, and nowhere else in dikes of similar petrographic character in this region, was a similar state of disintegration noted; and this is the only locality where natrolite and the accompanying minerals were found. The abrupt ending of the nepheline syenite ridge at this place, with the other features mentioned, suggest that the dike has been faulted off and that here a zone of shearing has

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FIG. 1. View of natrolite-andradite-allanite locality, near Wykertown, New Jersey, from the south. This is the west end of the nepheline syenite dike, in an advanced state of disintegration. The natrolite, etc., fragments are strewn in the rubble.

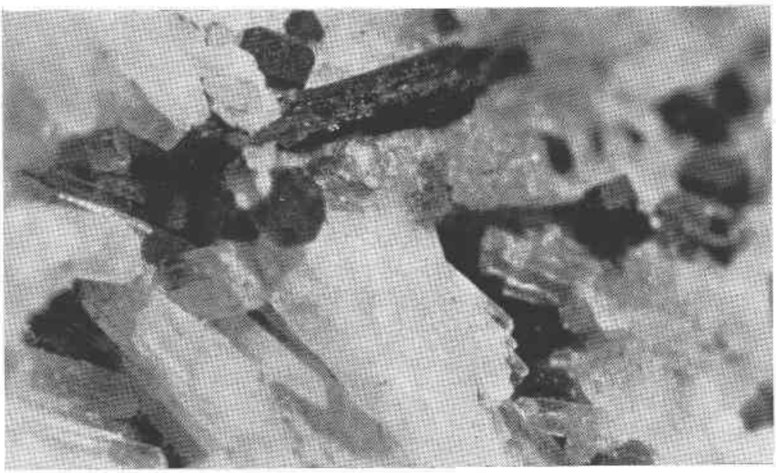

FIG. 2. x25. Glassy crystallized drusy natrolite, with rhombohedral andradite and prismatic allanite (upper center).

crumbled the dike and permitted the entry of the solutions from which these minerals were deposited. Figure 1 shows the appearance of the locality.

In the crumbly nepheline syenite, which looks much like a twenty-foot bank of pea-coal, the natrolite with its associated minerals is readily distinguished by its white color. It varies from almost clear glassy crystallized masses with individual crystals several inches long, to dull, almost opaque shapeless aggregates. Commonly well-crystallized aggregates of small crystals are found on such masses (Fig. 2).

Both the semi-opaque masses and the clear crystallized natrolite were analyzed, without finding any sensible difference in composition. The analyses are given below:

TABLE 1. ANALYSES OF NATROLITE, NEAR WYKERTOWN, N. J.
(Charles Milton, Analyst)

	1.	*Ratio*	2.	*Ratio*
SiO_2	47.64	3.01	47.33	2.97
Al_2O_3	26.90	1.00	27.13	1.00
Fe_2O_3	Trace			
CaO	.07		.10	
MgO	None			
Na_2O	15.51	.95	15.63	.96
K_2O	None			
H_2O-	9.59(ign)	2.02	.13	.03
H_2O+			9.54	1.99
	99.71		99.86	
Cs_2O	None			
Rb_2O	None			
Li_2O	.000x			

NOTES: Analysis 1 was made on white semi-opaque material. Alkalies were determined after removal of SiO_2, R_2O_3, and CaO, and of ammonium salts by volatilization, leaving only alkali chlorides. MgO was determined on separate sample. Rare alkalies were determined spectrographically by A. T. Myers, Spectrographer, U. S. Geological Survey.

Analysis 2. Made on clear crystallized material. Water by Penfield method. Alkalies by J. Lawrence Smith method.

Formula: $Na_2Al_2Si_3O_{10}\cdot 2H_2O$

Indices: $\alpha=1.477$, $\beta=1.480$, $\gamma=1.490$ (on clear material)

Optically positive.

ANDRADITE

The andradite garnet is well crystallized; many crystals show perfect dodecahedra, a few with suppressed faces simulate a rhombohedron (Fig. 3). It is sea green in color; in thin section colorless. This green andradite has been called demantoid. It shows optical anomalies; under crossed nicols each crystal is divided into numerous segments whose sides appear parallel to the dodecahedral planes. Each segment is biaxial with a moderate optic angle, estimated from 55° to 60°, positive character, and

$\alpha = 1.813$, $\gamma = 1.823$. Figure 4 shows the appearance of the segments under crossed nicols. The optics for the andradite were kindly determined by Miss J. J. Glass, mineralogist, of the Geological Survey.

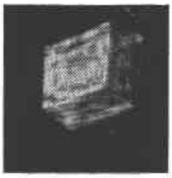

FIG. 3. ×35. Andradite garnet (single crystal). The shape is that of a rhombohedron, produced by suppression of a zone of six dodecahedral planes, parallel to an axis of trigonal symmetry.

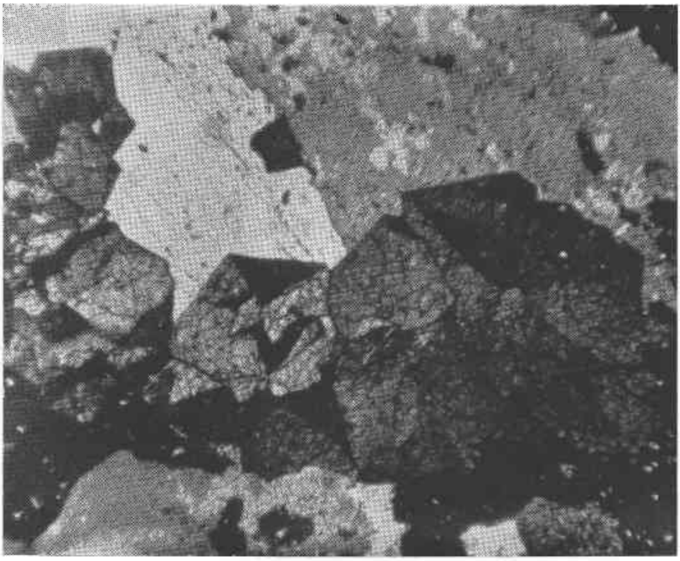

FIG. 4. This section ×100, crossed nicols. Andradite garnet and natrolite. Shows birefracting segments in andradite.

The optical anisotropy of garnets has been recognized for more than a century as anomalous in view of the isometric symmetry, Hintze (5) states, citing numerous instances: "Most macroscopic garnet crystals are not optically isotropic." The microscopic rock-forming garnets, on the other hand, are in general completely isotropic, or at most faintly anisotropic.

The analysis of the andradite garnet is given in Table 2.

Fleischer (6), in a discussion of the chemical composition and related physical properties of the garnet group, points out that deviations from

TABLE 2. ANALYSIS OF ANDRADITE, NEAR WYKERTOWN, N. J.
(Norman Davidson, analyst)

		Ratios
SiO_2	36.04	6.00
Al_2O_3	8.33	.82
Fe_2O_3	15.97	1.00
FeO	.92	.12
TiO_2	2.59 (Ti_2O_3 2.33)	.32 (.16)
CaO	35.20	6.28
MnO	.40	.06
MgO	.75	.19
H_2O-	.05	
	100.25	
Specific Gravity	3.69	

A. T. Myers further examined the andradite spectrographically. He found:

Major (>1%) Si, Al, Ca, Fe, Ti	
Minor (0.X%)	Mg, Mn
(0.0X–0.00X%)	Y, Yb, Be
Trace	Pb, Cu
Not found	Zn, Sr

Calculating titanium as TiO_2, with SiO_2, gives

SiO_2+TiO_2	632	3.47
$Al_2O_3+Fe_2O_3$	182	1.00
$FeO+CaO+MnO+MgO$	665	3.65

Calculating titanium as Ti_2O_3, with Al_2O_3 and Fe_2O_3 gives:

SiO_2	600	3.03
$Al_2O_3+Fe_2O_3+Ti_2O_3$	198	1.00
$FeO+CaO+MnO+MgO$	665	3.36

Calculation in terms of constituent molecules gives:

Grossularite	36.0%	with calculated refractive index 1.812
Pyrope	2.7	(as against measured 1.813–1.823)
Almandite	2.3	and density calculated 3.654
Spessartite	1.1	(as against measured 3.69)
Andradite	56.9	

the ideal $3RO \cdot R_2O_3 \cdot 3SiO_2$ formula occur most commonly in garnets with appreciable TiO_2, or much FeO. The deviation of the New Jersey andradite from the ideal formula, namely:

RO_2	R_2O_3	RO	
3.47	1.00	3.65	(Ti as TiO_2)
	or		
3.03	1.00	3.36	(Ti as Ti_2O_3)

is presumably to be referred to the titanium content of the garnet, 2.59% (as TiO_2), as the FeO is quite low (0.92%). Also, titaniferous garnets cited by Fleischer normally show high RO_2 and RO, and low R_2O_3, as does this. Calculating the titanium as Ti_2O_3, as suggested by Zedlitz (7), would give as shown above a more nearly ideal ratio. However, as trivalent titanium is a strong reducing agent, it would immediately reduce ferric iron to ferrous iron, and Ti_2O_3 would become TiO_2. Because there is only 0.92% FeO present, the most Ti_2O_3 that can be present is also 0.92%. Therefore, we cannot assume the titanium to be in the reduced form.

Examination of the literature with reference to andradite indicates that similar doubly refracting garnets have been described by Brögger (8) from Norway with generally similar paragenesis (i.e. in small veins of analcime and calcite, cutting augite porphyry; in calcite-albite veins, associated with a pitch-black or brownish-black isotropic mineral in small grains—(allanite?) and also leek-green garnet associated with natrolite). Weinschenk (9) has described similar garnets from the Alps, and mentions a high ferrous iron content (as opposed to high Fe_2O_3) as characteristic of "true-rock forming garnets" found in granites and schists. Stose and Glass (10) have described andradite crystals from Pennsylvania: deep reddish brown, almost black in color, which occur in cavities formed by solution of limestone pebbles in conglomerate adjacent to Triassic diabase. The garnets are doubly refracting, with refractive indices 1.85–1.87, considerably higher than those of the New Jersey garnets. No analysis is given.

Klein (11), after a study of several hundred thin sections of garnets, concluded that the optical structure is conditioned by the external form, and has no relation to chemical composition. Thus, with Hintze's observation cited above as to macroscopic garnets being characteristically anisotropic, it would appear that the anisotropy is of purely physical character, related to shape and size, and not to the elements composing the garnet.

Garnet having the composition of manganian andradite, called polyadelphite (12), has been found in the pegmatite cutting the ore body at Franklin Furnace, New Jersey. At the old Gooseberry iron mine in the same vicinity garnets essentially free from manganese were found, with magnetite. Both of these occurrences are evidently of altogether different paragenesis from the Wykertown garnet.

Allanite

The allanite is by far the least abundant of the minerals constituting the hydrothermal deposit. The ratio of abundance of natrolite-andradite-allanite may be the order of $10^6:10^2:1$.

The crystals were too small, and included too much of the surrounding natrolite to permit chemical analysis. The optical characters, together with an *x*-ray diffraction pattern obtained by Joseph M. Axelrod, and a spectrographic examination by A. T. Myers, satisfactorily establish its identity. Myers found:

Major (>1%) Si, Al, Ca, Fe, La, Nd, Ce
Minor (0.X%) Mn, Th, Sr
Trace Pb
Not found Be

The allanite is illustrated in Fig. 2.

Miss J. J. Glass has carefully investigated the optics of the allanite, a rather difficult matter in view of the intense absorption and variable indices of refraction of the mineral. No zoning is present. She found:

	Color
$\alpha=1.746$ to 1.765	colorless to pale reddish brown
$\beta=1.760$ to 1.779	reddish brown
$\gamma=1.771$ to 1.791	dark reddish brown, nearly opaque Large optic
$\Delta=$ .025 to .026	angle, distinct dispersion of the optic axes
$c\wedge X=38°$	$v>r$

These values are somewhat higher than those noted by Larsen (13) for allanite from Wyoming, namely $\alpha=1.727$; $\beta=1.739$; $\gamma=1.751$.

Larsen gives data for five allanites, including the one cited above and finds that they consist of "at least two and probably three distinct minerals." One of them is pale, sensibly isotropic, and has an index of refraction of about 1.68 to 1.70; another, possibly related to the one just mentioned, has a somewhat higher index of refraction, a weak birefringence, and is pleochroic in green and yellow; the third is clearly derived from the others and has the following optical properties: 2V rather large (−) sign, $r>v$ rather strong, $\beta=1.71-1.76$, $\Delta=0.01-0.02$, pleochroic in red-brown, with absorption Y and Z>X. Most of the Wykertown, New Jersey, allanite differs from the five studied by Larsen, in being optically a single substance, similar to the third type described by him.

Although nearly all of the allanite appears to be homogeneous, there are occasional crystals which do show a composite character, consisting of a few alternating zones or shells of the usual brown allanite, with others of a pale-yellow substance which may be the first of the three minerals noted by Larsen.

Allanite has been found in a pegmatite from the Franklin Furnace mine, described by Palache (14).

Acknowledgments

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References

1. Wolff, J. E., in Spencer, A. C., et. al., *U. S. Geol. Survey Atlas, Franklin Furnace Folio*, No, **161** (1908).
2. Brachville, N. J. *Sheet* **606611** *N. W. AMS Series V***822**, 2d Ed. (1946).
3. Reference 1, page 13.
4. Parker, John M. III, New Jersey's potential feldspar resources: *Bull.* **5**, Part 1, Rutgers University (1948), p. 56.
5. Hintze, Carl, Handbuch der Mineralogie, vol. **2**, 47 et seq. Leipzig (1897).
6. Fleischer, Michael, The relation between chemical composition and physical properties in the garnet group: *Am. Mineral.* **22**, 751–759 (1937).
7. Zedlitz, O., Ueber titanhaltige Kalkeisengranate: II. *Zentralblatt Min.* **(1935A)**, p. 68.
8. Brögger, W. C., Mineralien der sudnorwegischen Augitsyenit: *Z. Krist.*, **16**, page 160 et seq. (1890).
9. Weinschenk, Ernst, Ueber einige neue Mineralvorkommen des bayerischen Waldes; *Z. Krist.*, **25**, 36 (1896).
10. Stose, G. W., and Glass, J. J. Garnet crystals in cavities in metamorphosed Triassic conglomerate in York County, Penn.: *Am. Mineral.*, **23**, 430–435 (1938).
11. Klein, C., *N. Jahrb.*, **1**, 87 (1883).
12. Palache, C., The minerals of Franklin and Sterling Hill, Sussex County, New Jersey: *U. S. Geol. Surv.*, *Prof. Paper* **180**, 75 (1935).
13. Larsen, E. S., Jr., Microscopic determination of the non-opaque minerals: *U. S. Geol. Surv.* **679**, 37 (1921).
14. Palache, C., *loc. cit.*, pages 98–99.