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SERENDIBITE FROM WARREN COUNTY, NEW YORK, AND ITS PARAGENESIS

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ABSTRACT

Serendibite has been found in considerable abundance a few miles west of Johnsburg in Warren County, New York, the second known occurrence of this boro-silicate. It occurs in Grenville limestone near its contact with an intrusive granite and is of hydrothermal-contact-metamorphic origin. It is associated most closely with abundant colorless diopside and pale phlogopite. Other associated minerals are spinel, scapolite, orthoclase, plagioclase, calcite, tremolite, sericite, and two undetermined minerals.

The serendibite is massive, showing no crystal faces, and is optically triclinic with an axial angle near 90° and is in part optically + and in part optically −. Its indices of refraction and pleochroism are:

$\alpha = 1.701$, very pale yellowish green.
$\beta = 1.703$, nearly colorless.
$\gamma = 1.706$, Prussian blue.

It has prominent polysynthetic twinning resembling that of the plagioclase feldspars. The optical orientation is shown in Figure 2.

Two analyses of the serendibite from New York are given yielding the formula $3Al_2O_3 \cdot 4MgO \cdot 2CaO \cdot B_2O_3 \cdot 4SiO_2$.

OCCURRENCE AND ASSOCIATION

Serendibite, a boro-silicate of alumina, lime, and magnesia, has been previously reported only from the type locality in Ceylon. It occurs in considerable abundance in New York State where it was found by Mr. John Puring of New York City, on the farm of Mr. J. Noble Armstrong, about half way between Johnsburg and Garnet Lake, in Warren County, New York. The occurrence was later examined and studied by Larsen, the chemical analyses were made by Schaller, and the present paper is a report of these investigations.

The grayish blue-green serendibite (analysis given in Table 1) occurs just above the alluvium about half a mile northwest of Mr. Armstrong's house in a small gulch in the Grenville limestone near its contact with gneissoid granite. The Grenville beds dip about

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45° south in the same direction as the slope of the hill but more steeply, and the section of the beds here, from the top down, is:

Limestone—about 100 feet.
Mica gneiss—about 40 feet.
Limestone, with many silicates including serendibite, and aggregates of quartz—about 60 feet
Mica gneiss.

The mica gneiss is well banded and is made up chiefly of andesine, with some microcline, dark biotite, diopside, magnetite, and apatite. It was probably derived from a marl.

The limestone on the lower slopes of the hill, at the serendibite outcrop, is a rather coarse-grained marble which carries several per cent of diopside grains more or less altered to pale green serpentine, and locally a little nearly colorless phlogopite, and rarely scapolite or graphite. In many places the marble contains nodules up to several feet across which are made up chiefly of white diopside, some calcite, rarely phlogopite, tremolite, graphite, albite, and secondary serpentine and talc. Some of these nodules are bordered by pale phlogopite which seems to be later than the diopside. Many of the nodules are altered to serpentine along their borders with a fairly sharp contact between the unaltered and the serpentinized parts. The limestone is cut by several vein-like bodies, up to several feet across, of nearly pure white diopside rock with borders rich in phlogopite.

Near the top of a low hill, just east of the main serendibite occurrence, there are some small bodies of a white granular rock made up chiefly of feldspar, mostly albite in one specimen and microcline-perthite in another, and showing smaller quantities of grass-green diopside and colorless phlogopite. Much of the rock lacks quartz but one specimen collected contains large quantities. Diopside makes up from 5 to 10 per cent of the rock and phlogopite from 1 to 5 per cent. Brown titanite is abundant in two specimens and rutile in another. Calcite is present in small quantity and scapolite is present in one specimen. The rock is banded and the grains are interlocked or intimately intergrown. This rock is believed to be a metamorphosed limestone though it has some resemblance to granite.

Two other types of metamorphosed limestone were noted just above the serendibite and near a small body of granite. They contain much iron and in that respect differ appreciably from the other lime silicate rocks. One of these types consists of about equal quantities of red garnet and green diopside, with a little andesine, brown hornblende, sericite, apatite, and magnetite. It is similar to the garnet rock mined in this part of the Adirondacks. The other type consists chiefly of brown hornblende, with considerable andesine and a very little diopside.

The serendibite is associated with the diopside-phlogopite bodies. The best exposure, about six feet long, is just east of the small gulch and near the covered granite-marble contact. The mineral relations are shown diagrammatically in Figure 1. The lowest outcrop is a

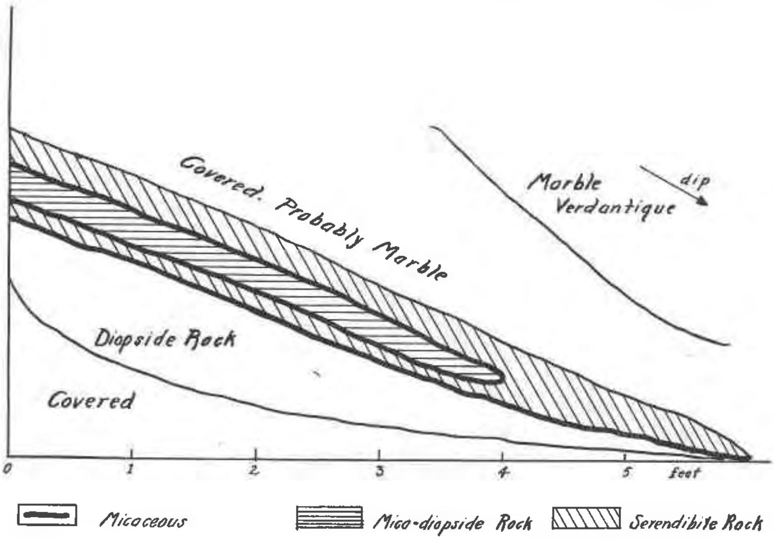

FIG. 1. Sketch of serendibite-bearing contact zone.

white diopside rock about a foot thick, over which is a thin discontinuous layer of phlogopite, above this are a few inches of rock containing serendibite, then another narrow layer of phlogopite, followed by six inches of rock with diopside and phlogopite, another narrow layer of phlogopite, six inches of serendibite rock, a foot with no exposures, and then marble with serpentinized diopside.

The serendibite layer is itself zoned microscopically, the zones from one to a few millimeters wide grading into each other. A characteristic section across 15 millimeters of this zone is:

(a) Serendibite with diopside and phlogopite.
(b) Diopside with phlogopite.

(c) Diopside and scapolite, intimately intergrown.
(d) Scapolite and phlogopite.
(e) Scapolite and andesine.
(f) Andesine.

The scapolite ($Ma_{40}Me_{60}$) borders and replaces the serendibite and is clearly younger. It is probably also younger than the diopside and feldspar. A little pale green tourmaline is locally associated with the serendibite.

Another specimen shows the following zoning for about 50 millimeters:

(a) Chiefly diopside, phlogopite, and serendibite with some altered scapolite	15 mm.
(b) Scapolite and diopside with a little phlogopite	4 mm.
(c) Orthoclase and scapolite, intergrown	3 mm
(d) Orthoclase with a little calcite and some scapolite	8 mm.
(e) Scapolite with some diopside	2 mm.
(f) Pure diopside, rather sharply separated from (e), but fingering into (g)	½ mm.
(g) Phlogopite in blades across the layer with a very little spinel and calcite	20 mm.

Smaller streaks of serendibite rock are present in the limestone about 150 feet up the hill east of the main body. Here the serendibite is confined to a band a few millimeters across. It forms large irregular anhedral crystals, many of which surround pale green spinel and is associated with much phlogopite, some diopside, tremolite, andesine, and calcite. Beyond the serendibite-bearing band is a layer a few millimeters across made up chiefly of andesine and phlogopite with a little diopside. Scapolite is present in the outer part of this layer and increases in quantity for another millimeter. Then comes a narrow zone of scapolite and diopside and finally fifteen centimeters of nearly pure diopside. In some specimens there is an outer narrow zone made up of colorless phlogopite and diopside. The phlogopite includes the diopside poikolitically.

The minerals closely associated with the serendibite are, in their approximate order of abundance: colorless diopside, nearly colorless phlogopite, plagioclase (andesine and labradorite), scapolite (wernerite), orthoclase, tremolite, pale green spinel with $n=1.720$ (analysis given in Table 3), magnesia tourmaline (dravite), chlorite, serpentine, sericite, talc, and several undetermined minerals.

Two of these (A and B) were studied optically and one (B) was partially analyzed.

The undetermined mineral (A) is optically negative, 2V small, $\rho<v$ strong, $\alpha=1.575$, $\beta=1.613$, $\gamma=1.614$. Density about 2.78. Its composition is unknown.

The second undetermined mineral (B) is closely associated with serendibite in the specimen that yielded the serendibite for analysis but was not found in other specimens. It is colorless. nonmagnetic even to a strong electromagnet, has a density greater than 3.20, is optically negative, with 2V rather large, slight dispersion, $\alpha=1.665$, $\beta=1.692$, $\gamma=1.705$. Partial analyses of this mineral are shown in Columns 2 and 3, Table 3, but material for a complete analysis was not available.

The serendibite and associated minerals are of hydrothermal contact metamorphic origin. The solutions brought in chiefly magnesia, silica, alumina, soda and potash, with some boron and chlorine. They were notably poor in iron.

The order of deposition of the minerals associated with the serendibite was only partly determined. The phlogopite appears to be in part later than the diopside. The serendibite appears to be later than the spinel and older than the diopside. It is partly replaced by the scapolite. The scapolite is probably younger than the albite and diopside. The tremolite is later than the diopside. The serendibite is in part replaced by sericite and the scapolite is more or less replaced by a cloudy, clay-like mineral and some sericite. The serpentine is late. The temperature of the main metamorphism must have been high as indicated by the presence of abundant diopside, spinel, and lime-soda feldspar.

The serendibite of the moonstone pits of Gangapitija, Ceylon, has a similar association and occurrence, and probably a similar origin.[2] Impure limestone beds are separated from granulite by successive layers of diopside alone, next the marble, and of diopside, serendibite, and spinel with some scapolite and plagioclase. The diopside next to the granulite layer is from 2 1/2 to 3 cm. across; the serendibite layer is from 1/4 to 2 1/2 cm. across.

Optical Properties of Serendibite

The serendibite from New York is in part optically + with 2V near 90° (measured 83°). In part the mineral is also optically −. The indices of refraction and pleochroism are:

[2] Coomáraswámy, A. K., The crystalline limestones of Ceylon: *Quart. Jour. Geol. Soc., London,* vol. **58,** pp. 420–22, 1902.

$\alpha = 1.701$, very pale yellowish green.
$\beta = 1.703$, nearly colorless.
$\gamma = 1.706$, Prussian blue.

It shows prominent polysynthetic twinning, resembling that of plagioclase feldspars. The optical orientation with respect to the twinning is shown in Figure 2 which was kindly furnished by Dr. Tom. Barth. The optical orientation of the two individuals is sym-

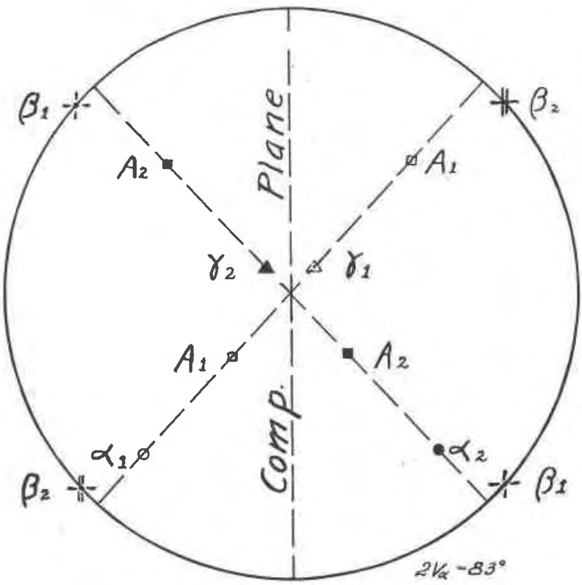

FIG. 2. Stereographic projection of the optical orientation of serendibite.

metrical with respect to the composition plane of the twins and hence the twinning axis is normal to the composition plane. The mineral is triclinic, judging from the optical relations. No crystal faces were observed, all of the material being massive.

ANALYSIS AND COMPOSITION OF SERENDIBITE AND SOME OF ITS ASSOCIATED MINERALS

The analyses were made on two separate lots, carefully selected and purified, with the following results:

TABLE 1. ANALYSES OF SERENDIBITE

	New York				Ceylon
	1	2	Average	Ratios	Prior's analysis
SiO_2	26.37	26.23	26.30	3.95 or 4×0.99	25.33
Al_2O_3	33.96	34.13	34.05	3.01 or 3×1.00	34.96
FeO	2.76	[a]	2.76	3.81 or 4×0.95 (FeO + MgO)	4.17
MgO	15.44	[a]	15.44		14.91
CaO	13.17	13.43	13.30	2.14 or 2×1.07	14.56
B_2O_3	8.12	8.61	8.37	1.09 or 1×1.09	[4.17]
Etc.	.....	.....	.....		1.90[b]
			100.22		100.00

[a] Not determined.
[b] Na_2O, 0.51; K_2O, 0.22; P_2O_5, 0.48; Loss on ignition, 0.69.

Alkalies and water are practically absent; fluorine was not detected in a qualitative test. The analysis of serendibite from New York agrees well with that from Ceylon except for a higher B_2O_3 content, which was not determined directly on the Ceylonese material,[3] the value given being obtained by difference. The formula derived from the calculated ratios of the mineral from New York is $3Al_2O_3 \cdot 4MgO \cdot 2CaO \cdot B_2O_3 \cdot 4SiO_2$.

Ratios calculated from the analysis of the serendibite from Ceylon agree fairly well with those determined from the analysis of the New York serendibite, except for the B_2O_3, as is shown below in Table 2. Enough CaO is alloted to the P_2O_5 in Prior's analysis to form apatite and the alkalies are combined with the lime.

TABLE 2. RATIOS OF PRIOR'S ANALYSIS OF SERENDIBITE FROM CEYLON

SiO_2	0.4215 = 3.77 or 4×0.94
Al_2O_3	0.3427 = 3.07 or 3×1.02
(Mg, Fe)O	0.4281 = 3.83 or 4×0.96
CaO	0.2595 = 2.32 or 2×1.16
B_2O_3	0.0599 = 0.54 or $\frac{1}{2}$×1.00

If the 34.96 percent of Al_2O_3 in Prior's analysis be assumed to include 2.77 per cent of retained B_2O_3, reducing the percentage

[3] Prior, G. T., and Coomáraswámy, A. K., Serendibite, a new borosilicate from Ceylon: *Mineral. Mag.*, vol. **13**, pp. 224–227, 1903.

of Al_2O_3 to 32.19, then the ratios of $SiO_2:Al_2O_3:CaO:(Mg, Fe)O$ become 3.97:2.98:2.46:4.05, agreeing very closely except for the CaO to the ratios 4:3:2:4, deduced from the analysis of the serendibite from New York. The ratio of B_2O_3 then is correspondingly raised somewhat. Even if the reported figure for Al_2O_3 is correct and contains no B_2O_3, the ratios of Prior's analysis are close to the simpler formula derived from the analysis of the New York serendibite, except for the B_2O_3.

Prior gives as a provisional formula: $10(Fe,Ca,Mg)O.5Al_2O_3 \cdot 6SiO_2 \cdot B_2O_3$ writing it, in an expanded form, as $6(Fe, Ca, Mg)SiO_3 \cdot 4MgAl_2O_4 \cdot 2AlBO_3$, "suggestive of a combination of aluminum borate with molecules having the composition of diopside and spinel, the two minerals with which serendibite is so intimately associated." The formula derived from the analysis of the New York serendibite, namely $3Al_2O_3 \cdot 4MgO \cdot 2CaO \cdot B_2O_3 \cdot 4SiO_2$, which is somewhat simpler than Prior's formula, can be similarly expressed, namely $2[CaO \cdot MgO \cdot 2SiO_2]+2[MgO \cdot Al_2O_3]+1[Al_2O_3 \cdot B_2O_3]$ or 2 diopside+2 spinel+1 jeremejevite.

Ferrous iron replaces a small part of the magnesia. The serendibite from New York contains 90 per cent of the iron-free magnesia compound and that from Ceylon contains 85 per cent.

Spinel and Unknown Mineral B

The analyses of the blue spinel and the white unknown mineral B, associated with the serendibite from New York, are shown below, two analyses on different samples of the unknown white mineral being given. The silica present is due to admixed diopside.

Table 3. Analysis of Blue Spinel and of White Unknown Mineral (B) Associated with Serendibite from New York

	Spinel	Unknown mineral (B)	
Insoluble residue	0.86	0.81	0.41
SiO_2	4.23	2.22	7.15
Al_2O_3	60.63	24.51	26.73
FeO	4.57	[a]	Not det.
CaO	0.29	[b]	3.73
MgO	24.24	29.82	27.84
	94.82		

[a] Several per cent.

[b] Determination lost.

Deducting diopside (based on the silica content) from the two analyses of the unknown white mineral, the following results are obtained:

		Ratios		Ratios
Al_2O_3	24.51	0.24	26.73	0.26
CaO	.....		0.36	
MgO	29.07	0.72	25.43	0.63

These figures suggest that in the unknown mineral, the ratio of Al_2O_3 to MgO is about 1:3 or 2:5. Other elements (such as boron) were not tested for and at present no suggestion can be made as to the identity of the mineral. It is definitely not a silicate.