REEDMERGNERITE, NaBSi$_3$O$_8$, THE BORON ANALOGUE OF ALBITE, FROM THE GREEN RIVER FORMATION, UTAH*

Charles Milton, E. C. T. Chao, Joseph M. Axelrod,† and Frank S. Grimaldi, *U. S. Geological Survey, Washington 25, D. C.*

Abstract

Reedmergnerite, NaBSi$_3$O$_8$, is a boron analogue of albite, occurring with eitelite, shortite, nahcolite, searlesite, leucosphenite, acmite, analcite, and magnesioriebeckite in unmetamorphosed dolomitic oil shales of the Green River formation in several oil wells in Duchesne County, Utah. It is triclinic, colorless, in stubby prisms with characteristic wedge-shaped ends; biaxial, negative, 2V = 80°, indices of refraction α 1.554, β 1.565, γ 1.573, all ±0.001. X-ray diffraction and crystallographic data are given.

Introduction—Name—Acknowledgments

The discovery of leucosphenite in 1953 (Milton, Axelrod, and Grimaldi, 1954) in brown dolomitic core from the Sinclair Company Senior Mortenson No. 1 wildcat oil well near Duchesne, Duchesne County, Utah (Fig. 1) led to a careful search for other unusual minerals. A thin section of leucosphenite-bearing rock (Figs. 2 and 3) showed crystals evidently different; these were isolated (Fig. 4) and from them an x-ray diffraction pattern was obtained which could not be identified with that of any known mineral. Further investigation showed that the crystals were NaBSi$_3$O$_8$, isostructural with albite, NaAlSi$_3$O$_8$, and were a new species which was then named reedmergnerite.

The name was given to honor two outstanding technicians of the U. S. Geological Survey, Frank S. Reed (1894–   ) and John L. Mergner (1894–   ) who for almost half a century have prepared thin and polished sections for several generations of Survey geologists. Through their skill, and willingness to use it generously, they have made possible much of the petrological and mineralogical research of their better-known colleagues.

For most of the core and cutting material on which this study is based, we are indebted to the generous co-operation of Mr. J. C. McCulloch and Mr. Verne E. Farmer, Jr., geologists of the Carter Oil Company.

Occurrence and Localization

Following the initial discovery in the Sinclair Mortenson well, the mineral was found in relative abundance in cores and cuttings from five other wells within an area of 20 miles west and 10 miles south. The wells
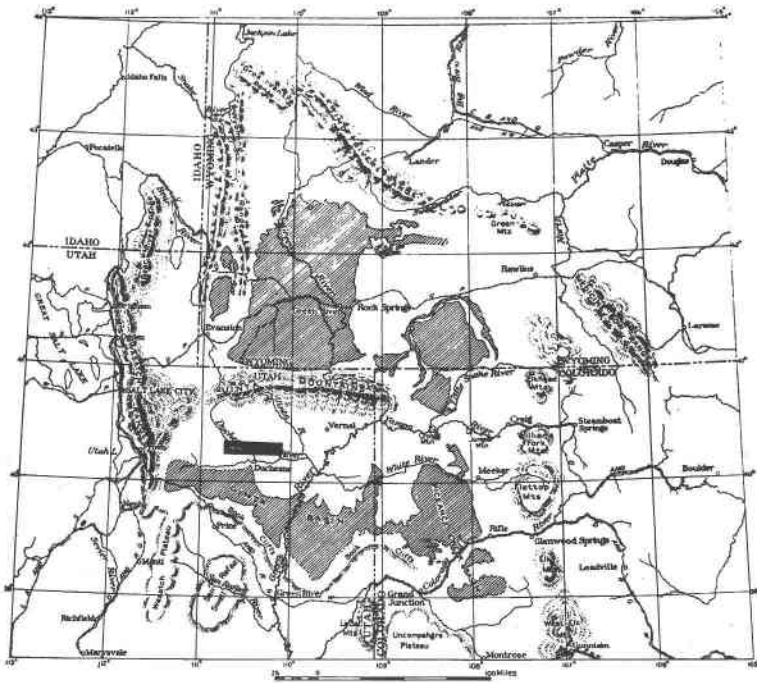
FIG. 1 (From Bradley, 1931). Map showing outcrop (shaded) of Green River formation in Utah, Colorado, and Wyoming. In Utah the Green River formation continues northward underground from the shaded area to the Uinta Mountains, and reedmergnerite occurs at depths of two thousand or more feet. The six wells in which reedmergnerite was found are in the rectangle just north of Duchesne, Utah.
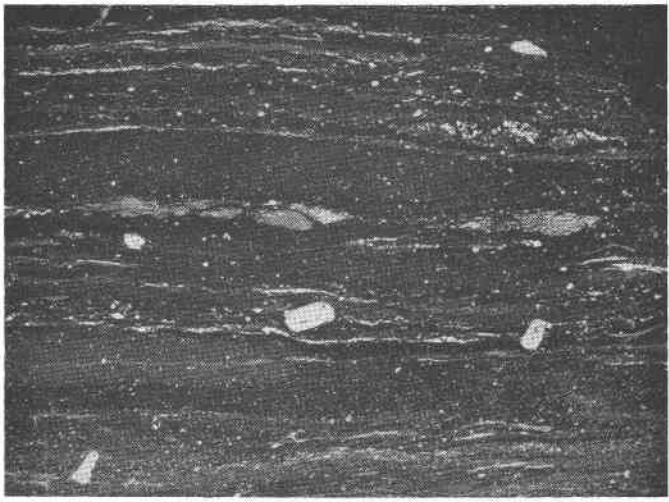

FIG. 2. Reedmergnerite crystals with band of lenticular aggregates of blue magnesiorie-beckite (across middle, gray), in black oil shale. Thin section, ordinary light. ×7.5
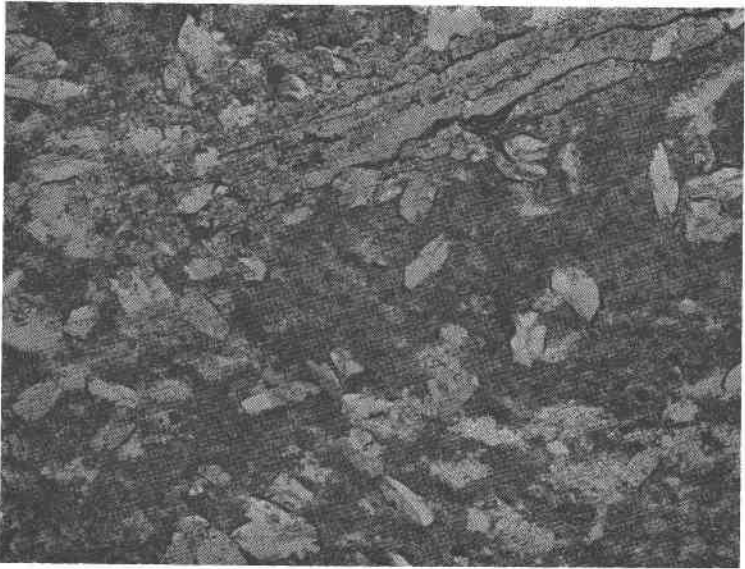
Fɪɢ. 3. Reedmergnerite in black oil shale. The diagonal wide band across the upper right is nahcolite. The oriented inclusions almost invariably present are shown in many crystals. Thin section, ordinary light. ×20.

in which reedmergnerite has been found are:

Sinclair Senior Mortenson No. 1	Sec. 7, T. 3 S., R. 2 W.
Carter Oil Co.	
Willis Moon No. 1	Sec. 13, T. 4 S., R. 4 W.
Elmer Moon No. 1	Sec. 8, T. 4 S., R. 3 W.
Duchesne County No. 1	T. 3 S., R. 5 W.
Joseph Smith No. 1	Sec. 16, T. 3 S., R. 5 W.
Kermit Poulson No. 1	Sec. 31, T. 3 S., R. 4 W.

The general area in which these wells were drilled is shown in Fig. 1.

The mineral occurs as mentioned in a brown dolomitic rock, and also, especially in the Joseph Smith, in black oil shale. In addition to leucosphenite, nahcolite, $NaHCO_3$, and shortite, $Na_2Ca_2(CO_3)_3$, are abundantly present; also eitelite, $Na_2Mg(CO_3)_2$, searlesite, $NaBSi_2O_6 \cdot H_2O$, acmite, $NaFeSi_2O_6$, analcite, $NaAlSi_2O_6 \cdot H_2O$, and magnesioriebeckite, $Na_2(Mg,Fe)_3Fe_2^3Si_8O_{22}(OH)_2$; all of which are likewise authigenic, not detrital.

Later papers will describe leucosphenite, eitelite, acmite, and magnesioriebeckite in the Green River formation.

Reedmergnerite seems to be restricted in the Green River to the single Utah area of the six wells indicated in Fig. 1, and albite is similarly restricted, having been found only in the oil shale mine near Rifle, Colorado.
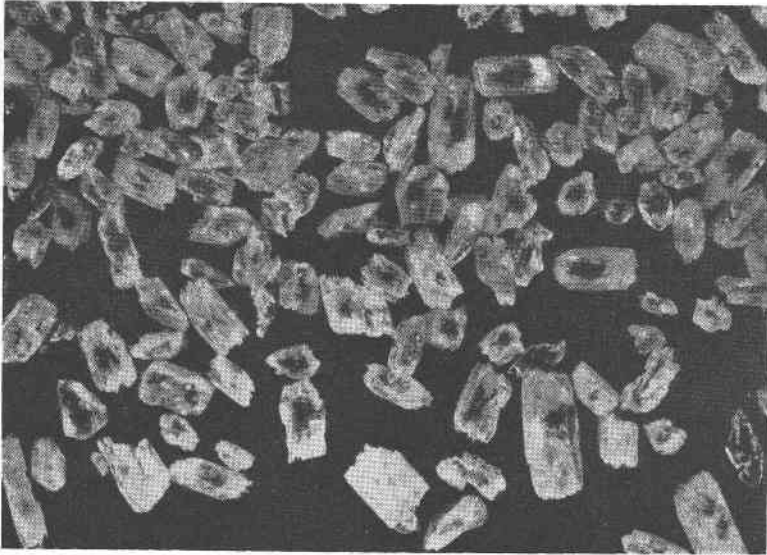
FIG. 4. Reedmergnerite crystals, isolated from oil shale. ×10.

Yet searlesite and analcite are almost ubiquitous in the Utah-Wyoming areas of the Green River so far studied. (Note—recently authigenic albite has been found fairly widely in the Wyoming Green River.)

CRYSTALLOGRAPHY

Optical and physical data

Reedmergnerite is colorless with a vitreous luster. It is easily fusible, insoluble in nitric or hydrochloric acid, but decomposed by hydrofluoric acid. The hardness is about 6 to 6.5. The specific gravity is 2.69 (observed), 2.77 (calculated). Crystals are usually microscopic; the largest being about 0.2 cm.

The indices of refraction, optic sign, and optical orientation were determined on the Federov universal stage. Indices were determined using white light at 28° and corrected to 25° C. Immersion liquids in 0.002 steps were checked by refractometer at time of use. The data are:

$$\alpha \ 1.554 \pm 0.001 \qquad 2V \ (\text{measured}) \ 80°$$
$$\beta \ 1.565 \pm 0.001 \qquad \text{optic sign} \ (-)$$
$$\gamma \ 1.573 \pm 0.001 \qquad \Delta 0.019$$

Reedmergnerite has a perfect {001} cleavage. Crushed fragments therefore tend to lie on this cleavage; indices of such flat lying grains will be

$$\alpha' = 1.558 \quad \text{and} \quad \gamma' = 1.567 \text{ at } 25° \text{ C.}$$
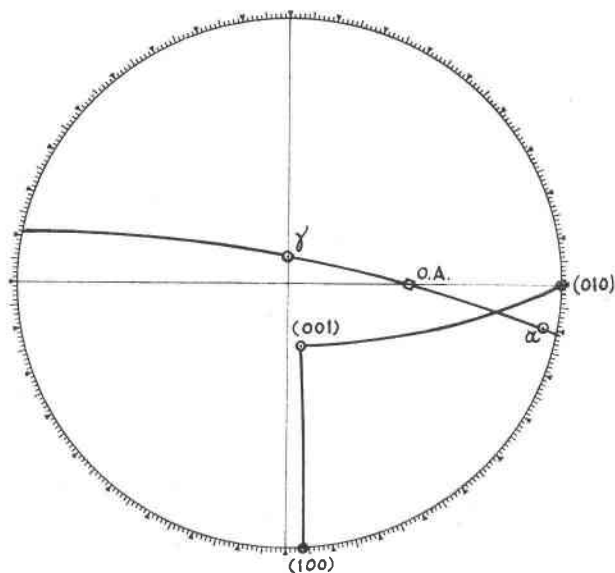
FIG. 5. Stereographic projection of reedmergnerite crystal, showing optic orientation.

Figure 5 is a stereographic projection, showing the relations of optics to morphology, based on the feldspar orientation.

X-ray single crystal data

Precession photographs of the $h0l$ and $0kl$ nets of reedmergnerite, taken with Mo/Zr radiation (λ MoKα = 0.7107 Å), were used to measure the cell dimensions. Reedmergnerite is triclinic and the presence of a center of symmetry is assumed from sudy of the morphology. Two descriptions of the direct cell of reedmergnerite are given in Table 1, one for a primitive cell, and one for the conventional feldspar orientation. The transformation matrix from primitive to feldspar-type cell is $\overline{1}10/1\overline{1}0/00\overline{1}$. Crystallographic data for albite are given for comparison.

The observed density of reedmergnerite 2.69 (determined on a portion of the sample chemically analyzed) is appreciably lower than the calculated 2.77. The discrepancy can probably be explained by the numerous fluid inclusions characteristically present in these crystals (Fig. 3). The formula, $NaBSi_3O_8$, suggests the possible analogy with albite. Although the powder patterns are complex and not notably similar, comparison of precession photographs reveals an isostructural relationship. Crystal structure studies of reedmergnerite are now in progress by Joan R. Clark and D. E. Appleman of the U. S. Geological Survey.

TABLE 1. CRYSTALLOGRAPHIC ELEMENTS OF REEDMERGNERITE AND ALBITE

	Reedmergnerite		Albite	
	Primitive cell[1]	Feldspar orientation[1,2]	Present study[1,3]	Cole, Sörum, and Taylor (1951)[4]
a	7.21 Å	7.85 Å	8.14 Å	8.1353 Å
b	7.44	12.38	12.79	12.7883
c	6.81	6.81	7.15	7.1542
α	100°37′	93°27′	94°10′	94°13.6′
β	107°04′	116°23′	116°36′	116°31.2′
γ	115°16′	91°57′	87°43′	87°42.5′
Space Group	$P\bar{1}$	$C\bar{1}$	$C\bar{1}$	
Z	$2[NaBSi_3O_8]$	$4[NaBSi_3O_8]$	$4[NaAlSi_3O_8]$	
Volume	294.8 Å³	589.6 Å³	663.5 Å³	664.16 Å³
Density (calc.)		2.77_0 g.cm.$^{-3}$		2.6241 g.cm.$^{-3}$
(obs.)		2.69		2.6280

Axial ratio $a:b:c = 0.634:1:0.550$ for feldspar orientation.
$a:b:c = 0.969:1:0.915$ for primitive cell.

[1] Axial lengths all ±0.03 Å; axial angles all ±10′.

[2] Transformation matrix $P\bar{1}$ to $C\bar{1}$: $\bar{1}10/\bar{1}10/00\bar{1}$.

[3] Albite from Amelia, Virginia.

[4] Albite from Kodarma, Bihar, India.

X-ray powder data

The x-ray powder diffraction patterns were taken with a Debye-Scherrer camera (114.59 mm. diameter) with Cu/Ni radiation (λCuKα = 1.5418 Å). Patterns made using a rolled cylindrical mount (film 7180) show definite, but not extreme, preferred orientation, and patterns made using a spherical mount (film 7179) show no evidence of preferred orientation. Measurements from the films were indexed down to $d = 2.5$ Å (Table 2). The lower limit of 2θ measurable on both films is approximately 7°(= 13 Å). Intensity measurements are given for both patterns to facilitate future identification by comparison with patterns made by techniques which, respectively, permit or eliminate preferred orientation (Hildebrand, 1953). The marked differences in strong line intensities are shown in Fig. 6.

Morphology

The characteristic and almost invariable shape of the crystals is shown in the feldspar orientation in Fig. 7. Forms commonly present

TABLE 2. X-RAY POWDER DATA FOR REEDMERGNERITE, NaBSi$_3$O$_8$

Triclinic $P\bar{1}$: $a = 7.21$, $b = 7.44$, $c = 6.81$ Å (all ± 0.03 Å);
$\alpha = 100°37'$, $\beta = 107°04'$, $\gamma = 115°16'$ (all $\pm 10'$)

Measured[1]			Calculated[2]		Measured[1]			Calculated[2]	
I[3]	I[4]	d_{hkl}	d_{hkl}	hkl	I[3]	I[4]	d_{hkl}	d_{hkl}	hkl
12	3	6.28	6.28	010	70	25	3.08	3.08	$2\bar{2}0$, 112
9	13	6.16	6.16	$1\bar{1}0$	25	100	3.03	3.04	002
15	18	5.55	5.56	$10\bar{1}$	18	18	2.96	2.96	200
100	60	3.87	3.88	$11\bar{1}$	9	35	2.94	2.93	$\bar{1}21$
6	13	3.75	3.75	011	40	25	2.84	$\begin{cases}2.85\\2.82\end{cases}$	$\begin{matrix}\bar{2}21\\\bar{1}12\end{matrix}$
35	15	3.65	3.66	$1\bar{2}0$					
18	50	3.57	3.56	101	2	2	2.77	2.78	$20\bar{2}$
14	18	3.45	3.44	$2\bar{1}0$	15	18	2.68	2.68	$2\bar{1}1$
4	9	3.33	3.33	$10\bar{2}$	3b	3b	2.53	$\begin{cases}2.54\\2.53\end{cases}$	$\begin{matrix}1\bar{2}2\\21\bar{1}\end{matrix}$
25	25	3.23	3.22	$01\bar{2}$					
30	18	3.14	3.14	020					

Measured[1]			Measured[1]			Measured[1]		
I[3]	I[4]	d_{hkl}	I[3]	I[4]	d_{hkl}	I[3]	I[4]	d_{hkl}
18	4	2.441	6	4m	1.860	2	1	1.538
6	6	2.403	6	3	1.828	4	2	1.523
20	18	2.383	2	—	1.800	5b	4b	1.485
6	6	2.369	6	6	1.775	7	4	1.445
2	—	2.269	4	7	1.752	4	3	1.420
13	9b	2.238	—	2	1.728	2	2	1.414
5	5	2.162	3	9	1.707	3	3	1.388
—	1	2.130	9	18	1.698	3b	3b	1.376
3	1	2.111	2	2	1.678	1	—	1.365
14	6	2.061	6	4	1.655	—	1	1.350
4	3	2.015	4	6b	1.623	6	3	1.341
6	4	1.992	4	4	1.599	3	4	1.328
4	2	1.940	2	—	1.571	plus additional lines,		
5	3m	1.900	6	13	1.562	all with I≤3		

[1] No correction for film shrinkage; b=broad, m=incompletely resolved multiplet. Radiation: Cu/Ni, λ CuKα=1.5418 Å. Lower limit of 2θ measurable: approximately 7° (13 Å).

[2] Calculated and indexed from direct cell elements given above.

[3] Intensities read from film no. 7179, preferred orientation minimized.

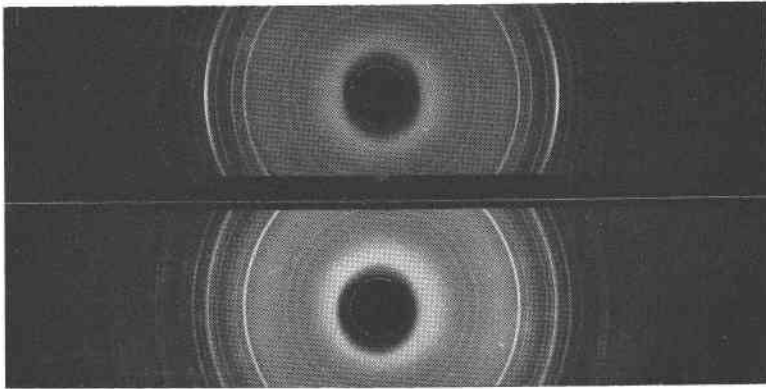[4] Intensities read from film no. 7180, preferred orientation present.

FIG. 6. *X*-ray powder diffraction patterns of reedmergnerite. Film 7180 (above) shows effects of preferred orientation; rolled cylinder mount. Film 7179 (below) shows minimization of preferred orientation; spherical mount.

are a {100}, b{010}, c{001}, m{110}, o{$\overline{1}11$} and δ {$\overline{11}2$}. The measured interfacial angles are as follows:

$$(001) \wedge (110) = 65°04'$$
$$(\overline{11}2) \wedge (001) = 29°17'$$
$$(\overline{11}2) \wedge (\overline{11}1) = 29°21'$$
$$(010) \wedge (110) = 57°30'$$
$$(100) \wedge (110) = 28°57'$$

In some crystals, especially in larger ones, there are jagged ends (skeletal growth) replacing the two terminal faces (100) and (010) (Fig. 4). The natural crystals are always single, never twinned or composite, and the largest are about 2 mm. long. Cleavage is perfect parallel to {001}.
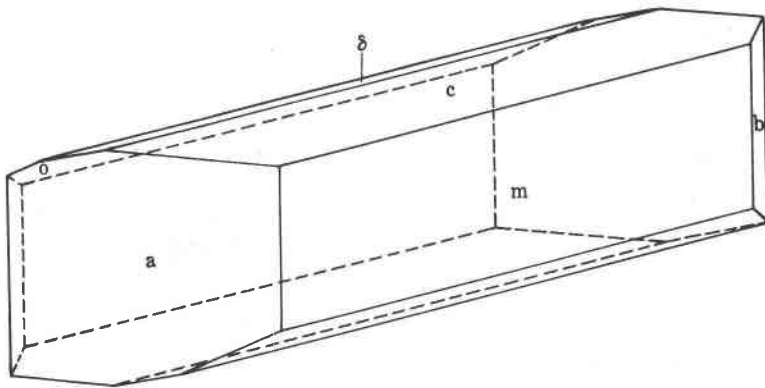

FIG. 7. Reedmergnerite, Duchesne County, Utah. Forms indicated are conventional ones of albite. a 100, b 010, c 001, m 110, o $\overline{1}11$, θ $\overline{11}2$.

Most crystals show oriented inclusions concentrated along the apparent growth traces of crystal edges, giving rise to a flattened cross in section (Figs. 3 and 4). The (010) face is very small or absent so it is not clear whether the inclusions are along the growth trace of the whole face or only along the trace of one edge. With this reservation, the inclusions are present along the following edges in decreasing amount: (010) to (110); (100) to (001), ($\overline{1}12$), and ($\overline{1}11$); (110) to (001) and (11$\overline{1}$).

TABLE 3. CHEMICAL COMPOSITION OF REEDMERGNERITE

	Chemical analysis[1]	Theoretical composition $Na_2O \cdot B_2O_3 \cdot 6SiO_2$
SiO_2	73.13	73.25
B_2O_3	14.27	14.15
Na_2O	12.15	12.60
Al_2O_3	0.15	
MgO	0.09	
BaO	0.09	
Fe_2O_3	0.08	
TiO_2	0.03	
K_2O	0.03	
H_2O (−)	0.00	
H_2O (+)	0.08	
Total	100.10	100.00

[1] Analyst, Frank S. Grimaldi.

CHEMICAL STUDY

Reedmergnerite is insoluble in nitric or hydrochloric acids, which permits its removal from its dolomitic or carbonaceous matrix. The mineral is decomposed by $HF + H_2SO_4$. Approximately one-half gram of handpicked crystals of reedmergnerite was chemically analyzed. The chemical composition is given in Table 3. The sum of determined oxides other than the three essential being but 0.55 per cent, the analyzed sample contained less than 1 per cent impurities and closely approximated the theoretical composition.

A semiquantitative spectrographic analysis by Charles Annell, U. S. Geological Survey, showed more than 10 per cent Si, Na, 1 to 5 per cent B; 0.1 to 0.5 per cent Al, Ba; 0.05 to 0.1 per cent Fe, Ti; 0.01 to 0.05 per cent Zr, K, Mg; and 0.001 to 0.005 per cent V.

Method of chemical analysis

A 0.2-gram portion was treated with $HF-H_2SO_4$, brought to fumes of sulfuric acid, diluted and digested with water, filtered, and barium was

determined gravimetrically as $BaSO_4$. The filtrate from $BaSO_4$ was treated with 8-hydroxyquinoline in ammoniacal solution to precipitate and isolate magnesium, aluminum, iron, titanium, and zirconium as oxinates.

Sodium was determined in the filtrate by evaporating and igniting to destroy 8-hydroxyquinoline, and the salts were weighed as Na_2SO_4 $+K_2SO_4$. Potassium was determined flame photometrically, and the sodium calculated from the combined $K_2SO_4+Na_2SO_4$ by deducting the K_2SO_4.

The oxine precipitate was ignited under cover of oxalic acid and weighed and then dissolved by fusing with a small amount of $K_2S_2O_7$ and leaching with a small amount of $(1+9)$ HCl. The iron, zirconium, and titanium were precipitated with cupferron, and the combined cupferrates were filtered, ignited, and weighed. The residue was brought in solution with a small amount of $K_2S_2O_7$ and titanium was determined colorimetrically with H_2O_2 and iron colorimetrically with o-phenanthroline.

The filtrate from the cupferron separation was evaporated and excess cupferron destroyed by HNO_3 followed by gentle ignition. This filtrate contained aluminum and magnesium. Aluminum was precipitated with NH_4OH and determined gravimetrically. The magnesium in the filtrate was precipitated as magnesium ammonium phosphate and ignited to $Mg_2P_2O_7$ which was weighed. Weighings were made on a semi-micro balance.

Silica was determined on a separate (0.2 gm.) portion by fusing with a small amount of Na_2CO_3 and treating the melt with HCl. Three dehydrations with HCl in the presence of methyl alcohol were made to isolate the SiO_2 free from boron.

A separate sample (0.15 gm.) was used for the boron determination which followed essentially the method of Allen and Zies (1918) involving distillation of methyl borate and titration of boric acid with NaOH after the addition of mannitol. The blank in the procedure amounted to 0.10 ml. of $0.1N$ NaOH. Of this blank about 0.08 ml. was due to the difference in end point between the paranitrophenol and phenolphthalein indicators. Thus, only 0.02 ml. blank was due to the distilling operation.

$H_2O(+)$ is ignition loss at 800° C. Iron was calculated as Fe_2O_3.

Thermal Study

Morey (1951) had previously studied the system $Na_2O\text{-}B_2O_3\text{-}SiO_2$, (Fig. 8) and found only one ternary compound $Na_2O \cdot B_2O_3 \cdot 2SiO_2$, n 1.572. It was first prepared hydrothermally, using very low water pressure, but later was crystallized dry, and found to melt congruently at 766° C. Morey (written communication) found that the natural crystals
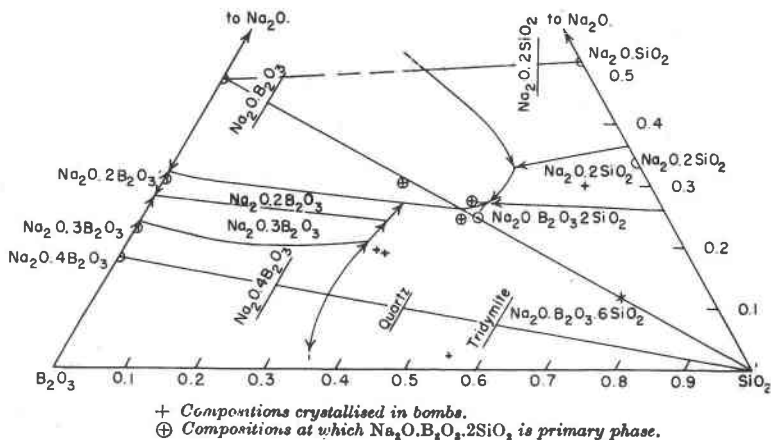
+ *Compositions crystallised in bombs.*
⊕ *Compositions at which Na$_2$O.B$_2$O$_3$.2SiO$_2$ is primary phase.*

FIG. 8 (Adapted from Morey, 1951). System Na$_2$O-B$_2$O$_3$-SiO$_2$ liquidus diagram, incomplete in high silica end. Compositions of ternary compounds Na$_2$O·B$_2$O$_3$·2SiO$_2$ and Na$_2$O·B$_2$O$_3$·6SiO$_2$ reedmergnerite are shown. The field of the congruently melting compound Na$_2$O·B$_2$O$_3$·2SiO$_2$ was not determined. Reedmergnerite has been crystallized under hydrothermal conditions. One quaternary compound in the H$_2$O-Na$_2$O-B$_2$O$_3$-SiO$_2$ system exists (searlesite, Na$_2$O·B$_2$O$_3$·4SiO$_2$·2H$_2$O).

of reedmergnerite melted incongruently at 862° C. in 44 hours to form a glass crowded with crystals of quartz and tridymite. The glass obtained from the natural crystals, containing the inclusions noted, had an index of refraction of 1.48, which is lower than that of a glass of exact Na$_2$O·B$_2$O$_3$·6SiO$_2$ composition, made by Morey. This had an index of refraction 1.505 ± 0.003. Attempts to crystallize this glass under hydrothermal conditions yielded quartz and other unidentified crystalline phases, none of them reedmergnerite.

Subsequently using considerably higher pressures (30,000 psi) Hans Eugster prepared crystals with the optics and x-ray diffraction pattern of reedmergnerite. A later paper will present his data on synthetic reedmergnerite and other boron analogues of feldspars and feldspathoids.

REFERENCES

ALLEN, E., AND ZEIS, E. G. (1918), Methods of glass analysis with special reference to broic acid and the two oxides of arsenic: *Am. Ceramic Soc. Journ.*, **1**, 739–786.

BRADLEY, W. H. (1931), Origin and microfossils of the oil shale of the Green River formation of Colorado and Utah: *U. S. Geol. Survey Prof. Paper* **168**, 58 p.

COLE, W. F., SÖRUM, H., AND TAYLOR, W. H. (1951), The structures of the plagioclase felspars. I: *Acta Cryst.* **4**, 20–29.

HILDEBRAND, F. A. (1953), Minimizing the effects of preferred orientation in x-ray powder diffraction patterns: *Am. Mineral.*, **38**, 1051–1056.

MILTON, CHARLES, AXELROD, J. M., GRIMALDI, F. S. (1954), New minerals, reedmergnerite ($Na_2O \cdot B_2O_3 \cdot 6SiO_2$) and eitelite ($Na_2O \cdot MgO \cdot 2CO_2$), associated with leucosphenite, shortite, searlesite, and crocidolite in the Green River formation, Utah (abstract): *Geol. Soc. America Bull.*, **65**, 1286–1287.

MOREY, G. W. (1951), The ternary system Na_2O-B_2O_3-SiO_2: *Soc. Glass Technology Jour.* **35**, 270–283.

Manuscript received June 1, 1959.