Reedmergnerite, NaBSi₃O₈, 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 NaBSi₃O₈, isostructural with albite, NaAlSi₃O₈, 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 magnesioriebeckite (across middle, gray), in black oil shale. Thin section, ordinary light. X7.5
in which reedmergnerite has been found are:

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinclair Senior Mortenson No. 1</td>
<td>Sec. 7, T. 3 S., R. 2 W.</td>
</tr>
<tr>
<td>Carter Oil Co.</td>
<td>Sec. 13, T. 4 S., R. 4 W.</td>
</tr>
<tr>
<td>Willis Moon No. 1</td>
<td>Sec. 8, T. 4 S., R. 3 W.</td>
</tr>
<tr>
<td>Elmer Moon No. 1</td>
<td>T. 3 S., R. 5 W.</td>
</tr>
<tr>
<td>Duchesne County No. 1</td>
<td>Sec. 16, T. 3 S., R. 5 W.</td>
</tr>
<tr>
<td>Joseph Smith No. 1</td>
<td>Sec. 31, T. 3 S., R. 4 W.</td>
</tr>
<tr>
<td>Kermit Poulson No. 1</td>
<td></td>
</tr>
</tbody>
</table>

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 leucoesphene, nahcolite, NaHCO₃, and shortite, Na₂Ca₂(CO₃)₃, are abundantly present; also eitelite, Na₂Mg(CO₃)₂, searlesite, NaBSi₂O₆·H₂O, acmite, NaFeSi₅O₆, analcite, NaAlSi₂O₆·H₂O, and magnesioriebeckite, Na₂(Mg,Fe)₃Fe³⁺Si₆O₂₂(OH)₂; all of which are likewise authigenic, not detrital.

Later papers will describe leucoesphene, 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.
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:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>1.554 ± 0.001</td>
</tr>
<tr>
<td>β</td>
<td>1.565 ± 0.001</td>
</tr>
<tr>
<td>γ</td>
<td>1.573 ± 0.001</td>
</tr>
</tbody>
</table>

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

\[ \alpha' = 1.558 \quad \text{and} \quad \gamma' = 1.567 \text{ at } 25° \text{ C}. \]
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 (\(\lambda\) MoK\(\alpha\) = 0.7107 Å), were used to measure the cell dimensions. Reedmergnerite is triclinic and the presence of a center of symmetry is assumed from study 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 \(\overline{1}10/\overline{1}10/00\overline{1}\). 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

<table>
<thead>
<tr>
<th></th>
<th>Reedmergnerite</th>
<th>Feldspar orientation</th>
<th>Albite</th>
<th>Present study</th>
<th>Cole, Sörum, and Taylor (1951)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>7.21 Å</td>
<td>7.85 Å</td>
<td>8.14 Å</td>
<td>8.153 Å</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>7.44 Å</td>
<td>12.38 Å</td>
<td>12.79 Å</td>
<td>12.7883</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>6.81 Å</td>
<td>6.81 Å</td>
<td>7.15 Å</td>
<td>7.1542</td>
<td></td>
</tr>
<tr>
<td>α</td>
<td>100°37'</td>
<td>93°27'</td>
<td>94°10'</td>
<td>94°13.6°</td>
<td></td>
</tr>
<tr>
<td>β</td>
<td>107°04’</td>
<td>116°23’</td>
<td>116°36’</td>
<td>116°31.2’</td>
<td></td>
</tr>
<tr>
<td>γ</td>
<td>115°16’</td>
<td>91°57’</td>
<td>87°43’</td>
<td>87°42.5’</td>
<td></td>
</tr>
</tbody>
</table>

Space Group
Z
Volume
Density (calc.)
Density (obs.)

| Reedmergnerite | 2[NaBSi$_2$O$_6$] | 4[NaBSi$_2$O$_6$] | 294.8 Å$^3$ | 589.6 Å$^3$ | 2.77 g.cm.$^{-3}$ | 2.69 |
| Albite         | 4[NaAlSi$_4$O$_{10}$] | 663.5 Å$^3$ | 664.16 Å$^3$ | 2.6241 g.cm.$^{-3}$ | 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 $\pm 0.03$ Å; axial angles all $\pm 10'$.
2 Transformation matrix $PI$ to $CT$: $1\overline{1}0/1\overline{1}0/001$.
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 ($\lambda$CuK$\alpha$ = 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 20 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 Reedmengerite, NaBSi₂O₅
Triclinic P\text{I}: a = 7.21, b = 7.44, c = 6.81 Å (all \(\pm 0.03\) Å);
\(\alpha = 100°37', \beta = 107°04', \gamma = 115°16' (all \(\pm 10°\))\)

<table>
<thead>
<tr>
<th>Measured(^1)</th>
<th>Calculated(^2)</th>
<th>Measured(^1)</th>
<th>Calculated(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I)</td>
<td>(I)</td>
<td>(d_{hkl})</td>
<td>(d_{hkl})</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>12</td>
<td>3</td>
<td>6.28</td>
<td>6.28</td>
</tr>
<tr>
<td>9</td>
<td>13</td>
<td>6.16</td>
<td>6.16</td>
</tr>
<tr>
<td>15</td>
<td>18</td>
<td>5.55</td>
<td>5.56</td>
</tr>
<tr>
<td>100</td>
<td>60</td>
<td>3.87</td>
<td>3.88</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>3.75</td>
<td>3.75</td>
</tr>
<tr>
<td>35</td>
<td>15</td>
<td>3.65</td>
<td>3.66</td>
</tr>
<tr>
<td>18</td>
<td>50</td>
<td>3.57</td>
<td>3.56</td>
</tr>
<tr>
<td>14</td>
<td>18</td>
<td>3.45</td>
<td>3.44</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>3.33</td>
<td>3.33</td>
</tr>
<tr>
<td>25</td>
<td>25</td>
<td>3.23</td>
<td>3.22</td>
</tr>
<tr>
<td>30</td>
<td>18</td>
<td>3.14</td>
<td>3.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measured(^3)</th>
<th>Measured(^4)</th>
<th>Measured(^5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I)</td>
<td>(I)</td>
<td>(d_{hkl})</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>18</td>
<td>4</td>
<td>2.441</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>2.403</td>
</tr>
<tr>
<td>20</td>
<td>18</td>
<td>2.383</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>2.369</td>
</tr>
<tr>
<td>2</td>
<td>—</td>
<td>2.269</td>
</tr>
<tr>
<td>13</td>
<td>9b</td>
<td>2.238</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>2.162</td>
</tr>
<tr>
<td>—</td>
<td>1</td>
<td>2.130</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2.111</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>2.061</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>2.015</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1.940</td>
</tr>
<tr>
<td>5</td>
<td>3m</td>
<td>1.900</td>
</tr>
</tbody>
</table>

\(^1\) No correction for film shrinkage; \(b\) = broad, \(m\) = incompletely resolved multiplet.
Radiation: Cu/Ni, \(\lambda \text{CuK}_\alpha = 1.5418\) Å. Lower limit of 2\(\theta\) 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.
are \( a\{100\}, b\{010\}, c\{001\}, m\{110\}, o\{\overline{1}11\} \) and \( o\{\overline{1}12\} \). The measured interfacial angles are as follows:

\[
(001) \angle (110) = 65^\circ 04' \\
(112) \angle (001) = 29^\circ 17' \\
(112) \angle (111) = 29^\circ 21' \\
(010) \angle (110) = 57^\circ 30' \\
(100) \angle (110) = 28^\circ 57'
\]

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. 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.

---

**Fig. 7.** Reedmergnerite, Duchesne County, Utah. Forms indicated are conventional ones of albite. \( a\{100\}, b\{010\}, c\{001\}, m\{110\}, o\{\overline{1}11\}, o\{\overline{1}12\} \).
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), (112), and (111); (110) to (001) and (111).

<table>
<thead>
<tr>
<th>Table 3. Chemical Composition of Reedmergnerite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>B₂O₃</td>
</tr>
<tr>
<td>Na₂O</td>
</tr>
<tr>
<td>Al₂O₃</td>
</tr>
<tr>
<td>MgO</td>
</tr>
<tr>
<td>BaO</td>
</tr>
<tr>
<td>Fe₂O₃</td>
</tr>
<tr>
<td>TiO₂</td>
</tr>
<tr>
<td>K₂O</td>
</tr>
<tr>
<td>H₂O (−)</td>
</tr>
<tr>
<td>H₂O (+)</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

† 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 + H₂SO₄. 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 − H₂SO₄, brought to fumes of sulfuric acid, diluted and digested with water, filtered, and barium was
determined gravimetrically as BaSO₄. The filtrate from BaSO₄ 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 Na₂SO₄ + K₂SO₄. Potassium was determined flame photometrically, and the sodium calculated from the combined K₂SO₄ + Na₂SO₄ by deducting the K₂SO₄.

The oxine precipitate was ignited under cover of oxalic acid and weighed and then dissolved by fusing with a small amount of K₂S₂O₇ 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 K₂S₂O₇ and titanium was determined colorimetrically with H₂O₂ and iron colorimetrically with o-phenanthroline.

The filtrate from the cupferron separation was evaporated and excess cupferron destroyed by HNO₃ followed by gentle ignition. This filtrate contained aluminum and magnesium. Aluminum was precipitated with NH₄OH and determined gravimetrically. The magnesium in the filtrate was precipitated as magnesium ammonium phosphate and ignited to Mg₃P₂O₇ 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 Na₂CO₃ and treating the melt with HCl. Three dehydrations with HCl in the presence of methyl alcohol were made to isolate the SiO₂ 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.

H₂O(+) is ignition loss at 800° C. Iron was calculated as Fe₂O₃.

**THERMAL STUDY**

Morey (1951) had previously studied the system Na₂O-B₂O₃-SiO₂ (Fig. 8) and found only one ternary compound Na₂O·B₂O₃·2SiO₂, 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
Fig. 8 (Adapted from Morey, 1951). System Na₂O-B₂O₃-SiO₂ liquidus diagram, incomplete in high silica end. Compositions of ternary compounds Na₂O-B₂O₃-2SiO₂ and Na₂O-B₂O₃·6SiO₂ reedmergnerite are shown. The field of the congruently melting compound Na₂O·B₂O₃·2SiO₂ was not determined. Reedmergnerite has been crystallized under hydrothermal conditions. One quaternary compound in the H₂O-Na₂O-B₂O₃-SiO₂ system exists (searlesite, Na₂O·B₂O₃·4SiO₂·2H₂O).

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 Na₂O·B₂O₃·6SiO₂ 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.
REEDMERGERITE, THE BORON ANALOGUE OF ALBITE

References


*Manuscript received June 1, 1950.*