Composition and structural state of K-feldspars from some U.S. pegmatites

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Abstract

Concentrations of Ba, Sr, Rb, and Cs, X-ray monoclinic and triclinic ordering, and Ab content in 66 samples of K-feldspars (Kfs) from different pegmatites of the Appalachians and Rocky Mountains have been determined. Maximal contents of Ba and Sr and minimal Rb and Cs are found in the earliest generations of Kfs in muscovite pegmatites. The Kfs of raremetal pegmatites contain maximal Rb and Cs but minimal Ba and Sr. As a rule, the Kfs of raremetal-muscovite and non-specialized pegmatites have intermediate geochemical characteristics.

In all pegmatites Rb (and Cs) contents increase and Ba (and Sr) contents decrease from earliest to latest generations of Kfs. The Ba:Rb ratio is a sensitive indicator of pegmatite specialization (using early Kfs) or recrystallization (using comparison of Kfs generations). It is suggested that high pressure can enhance the isomorphism of Ba and Sr in Kfs and inhibit that of Rb and Cs.

Maximum microclines are predominant among Kfs of U.S. pegmatites. Orthoclase or high and intermediate microcline structures are characteristic of Kfs containing large quantities of Ab, Ba, and Rb, if the pegmatites have not been altered.

Introduction

The potash feldspars (Kfs) are major components of granites and granite pegmatites. The study of their structural state and composition has always been one of the most interesting directions in petrology and mineralogy. It is enough to recall the generalizing works by Barth (1969), Laves (1952), and Marfunin (1962), where Kfs composition and structure were correlated with the formation conditions, and the effect of ordering factors on crystal structure was demonstrated.

With the appearance of new analytical techniques and rapid methods of X-ray crystallographic study, the significance of Kfs as typomorphic minerals of granites and pegmatites has increased. The diagnostic importance of trace-elements (Solodov, 1962; Shmakin and Kostyukova, 1969; Gordienko, 1976), and the good possibilities for quick and accurate determination of Kfs structural state by powder diffractometry (Shmakin and Afonina, 1967; Afonina et al., 1976; Sosedko, 1976) have been shown many times.

The mineralogy and internal structure of U.S. pegmatites were investigated in the 1940s and 1950s. However, the composition and structural state of Kfs were not extensively studied. There are geochemical observations for some pegmatite veins only (Bray, 1942; Shimer, 1943; Carl, 1962). It thus seemed promising to study the composition and structure of Kfs for American pegmatites in order to compare them with the pegmatite Kfs of Siberia and other regions previously studied. The possibility of such an investigation was realized at the time of the author's scientific mission to the U.S. (April and May of 1975).

Deposits of muscovite, rare metals, and ceramic raw materials in pegmatites, and many pegmatite veins without clear industrial utilization, were visited. They occur in the two largest pegmatite regions of the U.S., the Appalachians (from Georgia to Connecticut) and the Rocky Mountains (Colorado, Wyoming, and South Dakota). The Appalachian pegmatites are confined to Paleozoic metamorphic and intrusive rocks. Their absolute age determined by different methods is between 250 and 420 × 10⁶ years (Brookins et al., 1969). The pegmatites of the Rocky Mountains (including the Black Hills area) are confined to Precambrian rocks: granites, gneisses, am-
phibolites, and crystalline schists of varied composition. The absolute age of these rocks is from 850 to 1400 × 10⁶ years, and the larger figure is thought to be more correct (Jack A. Redden, personal communication).

**Methods**

The sampling of pegmatites and preliminary diagnosis of minerals was done by the author at quarries, mines, roadcuts, and natural exposures. In the case of zonation in the pegmatite body, separate Kfs samples were taken from the endocontact zone, from graphic, apographic, and hypidiomorphic texture zones, and from idiomorphic crystals in druses and block structure. Sometimes the granites from the exocontact zone were sampled as well.

The preparation of monomineralic Kfs separates, and the analyses, were carried out in laboratories of the A. P. Vinogradov Institute of Geochemistry, Siberian Branch of the USSR Academy of Sciences.

Primary samples had a weight of 50–200 grams. They were parts of large Kfs crystals or intergrowths of Kfs and quartz and/or plagioclase. The representativity of sampling big pegmatite crystals by small portions was proved by our special study (Ogneva et al., 1971). The uniform distribution of minor elements in Kfs crystals of one pegmatite zone has been shown by many authors.

The weight of the final monomineralic Kfs samples was 2 g ± 100 mg. Their freshness was checked with a microscope and by color reactions. The albite content in the pure material was determined by an X-ray method with an accuracy of ±10 percent. As a rule we had 85–95 percent Kfs content in the samples.

The samples were powdered in a jasper mortar to pass 200 mesh and were divided into three parts: for X-ray crystallography, emission spectrography, and flame photometry. Using a new X-ray method (Afonina et al., 1976), monoclinic ordering Δ₂ and triclinicity Δ₃, approximately corresponding to Thompson's (1969) coefficients Z and Y, were measured. The accuracy of this method is ±0.05.

Ba and Sr contents were determined by emission spectrography, and Rb and Cs by flame photometry. The measurement error of both methods is characterized by a variation coefficient of 5–15 percent, depending on the element concentration. The correctness of results was guaranteed by using state standards.

**Results**

Tables 1–4 present the minor-element contents and structural states of 66 Kfs samples. The first two tables include data on Appalachian pegmatites, separately for Georgia and Connecticut (Table 1) and North Carolina (Table 2).

Table 1 shows that Kfs from muscovite pegmatites (Newton Prospect mine) are sharply enriched in Ba and Sr, whereas Rb and Cs contents are relatively low. In contrast, the Kfs of the Tollgate pegmatite (Connecticut), which is of the rare-metal–muscovite type, contain the lowest quantity of Ba (and Sr), and elevated Rb concentrations. As a result of such differ-

<table>
<thead>
<tr>
<th>Pegmatite field, state</th>
<th>Specialization of pegmatites</th>
<th>Place of sampling</th>
<th>Texture (zone)</th>
<th>Spec.</th>
<th>Ba</th>
<th>Sr</th>
<th>Rb</th>
<th>Cs</th>
<th>Ba:Rb</th>
<th>Δ₂</th>
<th>Δ₃</th>
<th>%Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gladesville, Georgia</td>
<td>Muscovite</td>
<td>Newton Prospect Mine</td>
<td>Graphic</td>
<td>13</td>
<td>6400</td>
<td>540</td>
<td>364</td>
<td>5</td>
<td>17.6</td>
<td>0.92</td>
<td>0.89</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fl.-gr.</td>
<td>15</td>
<td>5800</td>
<td>540</td>
<td>296</td>
<td>7</td>
<td>19.6</td>
<td>0.93</td>
<td>0.92</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Raremetal-muscovite</td>
<td>Feldspar</td>
<td>Graphic</td>
<td>3</td>
<td>1100</td>
<td>330</td>
<td>372</td>
<td>6</td>
<td>2.96</td>
<td>0.94</td>
<td>0.89</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Company quarries</td>
<td>Block</td>
<td>7</td>
<td>85</td>
<td>66</td>
<td>466</td>
<td>9</td>
<td>0.19</td>
<td>1.0</td>
<td>0.89</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hale</td>
<td>Graphic</td>
<td>376</td>
<td>65</td>
<td>50</td>
<td>787</td>
<td>57</td>
<td>0.083</td>
<td>1.0</td>
<td>0.94</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roadcut</td>
<td>Graphic</td>
<td>378</td>
<td>76</td>
<td>63</td>
<td>742</td>
<td>55</td>
<td>0.103</td>
<td>0.94</td>
<td>0.96</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>Hale</td>
<td>Graphic</td>
<td>378</td>
<td>65</td>
<td>50</td>
<td>787</td>
<td>57</td>
<td>0.083</td>
<td>1.0</td>
<td>0.94</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roadcut</td>
<td>Graphic</td>
<td>378</td>
<td>76</td>
<td>63</td>
<td>742</td>
<td>55</td>
<td>0.103</td>
<td>0.94</td>
<td>0.96</td>
<td>10</td>
</tr>
</tbody>
</table>

Abbreviations as follows: Apogr. - apographic; Endoc. - endocontact; Co.-gr. - coarse-grained; Fl.-gr. - fine-grained; Med.-gr. - medium-grained; Sm.-bl. - small-block.
Table 2. Contents of trace elements (ppm) in K-feldspars of North Carolina pegmatites, their monoclinic ($\Delta_2$) and triclinic ($\Delta_\beta$) ordering, and albite content (Ab, weight percent)

<table>
<thead>
<tr>
<th>Pegmatite field</th>
<th>Specialization of pegmatites</th>
<th>Place of sampling</th>
<th>Texture (zone)</th>
<th>Spec. Ba</th>
<th>Sr</th>
<th>Rb</th>
<th>Cs</th>
<th>Ba:Rb $\Delta_2$</th>
<th>$\Delta_\beta$</th>
<th>%Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kings Mountain Raremetal Mine</td>
<td>Foot</td>
<td>Fi.-gr.</td>
<td>75</td>
<td>48</td>
<td>45</td>
<td>2400</td>
<td>60</td>
<td>0.020</td>
<td>0.91</td>
<td>0.91</td>
</tr>
<tr>
<td>Lithium Corporation Mine</td>
<td>Endoc.</td>
<td>Co.-gr.</td>
<td>89</td>
<td>31</td>
<td>38</td>
<td>1760</td>
<td>132</td>
<td>0.018</td>
<td>0.88</td>
<td>0.80</td>
</tr>
<tr>
<td>Wiseman Mine</td>
<td>Block</td>
<td>84</td>
<td>10</td>
<td>19</td>
<td>3370</td>
<td>198</td>
<td>0.014</td>
<td>0.94</td>
<td>0.92</td>
<td>5</td>
</tr>
<tr>
<td>Chestnut Flats Mine</td>
<td>Graphic</td>
<td>100</td>
<td>8000</td>
<td>420</td>
<td>280</td>
<td>4</td>
<td>28.6</td>
<td>0.92</td>
<td>0.80</td>
<td>10</td>
</tr>
<tr>
<td>Spruce Pine Muscovite</td>
<td>Block</td>
<td>104</td>
<td>2200</td>
<td>230</td>
<td>440</td>
<td>4</td>
<td>5.0</td>
<td>0.97</td>
<td>0.97</td>
<td>15</td>
</tr>
<tr>
<td>Spruce Pine Raremetal-Muscovite</td>
<td>Apg.</td>
<td>127</td>
<td>120</td>
<td>44</td>
<td>1168</td>
<td>21</td>
<td>0.103</td>
<td>0.95</td>
<td>0.95</td>
<td>10</td>
</tr>
<tr>
<td>Spruce Pine Absent</td>
<td>Block</td>
<td>108</td>
<td>800</td>
<td>67</td>
<td>640</td>
<td>12</td>
<td>1.25</td>
<td>0.97</td>
<td>0.97</td>
<td>5</td>
</tr>
<tr>
<td>Spruce Pine Absent</td>
<td>Med.-gr.</td>
<td>124</td>
<td>420</td>
<td>68</td>
<td>984</td>
<td>14</td>
<td>0.45</td>
<td>0.95</td>
<td>0.95</td>
<td>5</td>
</tr>
<tr>
<td>Asheville Absent</td>
<td>Med.-gr.</td>
<td>140</td>
<td>8800</td>
<td>520</td>
<td>332</td>
<td>tr.*</td>
<td>0.73</td>
<td>0.40</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations as follows: tr.* = traces; n.d. = not discovered.

Table 3. Contents of trace elements (ppm) in K-feldspars of some pegmatites and granites from Black Hills and Medicine Bow, their monoclinic ($\Delta_2$) and triclinic ($\Delta_\beta$) ordering, and albite content (Ab, weight percent)

<table>
<thead>
<tr>
<th>Pegmatite field, state</th>
<th>Specialization of pegmatites</th>
<th>Place of sampling</th>
<th>Texture (zone)</th>
<th>Spec. Ba</th>
<th>Sr</th>
<th>Rb</th>
<th>Cs</th>
<th>Ba:Rb $\Delta_2$</th>
<th>$\Delta_\beta$</th>
<th>%Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscovite New York Mine</td>
<td>Graphic</td>
<td>197</td>
<td>8800</td>
<td>500</td>
<td>376</td>
<td>tr.*</td>
<td>0.23.4</td>
<td>0.92</td>
<td>0.86</td>
<td>5</td>
</tr>
<tr>
<td>Hugo Mine</td>
<td>Apg.</td>
<td>202</td>
<td>590</td>
<td>72</td>
<td>5540</td>
<td>128</td>
<td>0.307</td>
<td>0.95</td>
<td>0.95</td>
<td>5</td>
</tr>
<tr>
<td>Hugo Mine</td>
<td>Apg.</td>
<td>207</td>
<td>340</td>
<td>140</td>
<td>2610</td>
<td>120</td>
<td>0.130</td>
<td>0.95</td>
<td>0.95</td>
<td>5</td>
</tr>
<tr>
<td>Hugo Mine</td>
<td>Block</td>
<td>195</td>
<td>120</td>
<td>632</td>
<td>132</td>
<td>0.032</td>
<td>0.95</td>
<td>0.95</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Black Hills, South Dakota Raremetal</td>
<td>Sarr.</td>
<td>167</td>
<td>42</td>
<td>140</td>
<td>1730</td>
<td>63</td>
<td>0.024</td>
<td>0.95</td>
<td>0.94</td>
<td>15</td>
</tr>
<tr>
<td>Etta Mine</td>
<td>Block</td>
<td>167</td>
<td>35</td>
<td>52</td>
<td>3600</td>
<td>748</td>
<td>0.070</td>
<td>0.95</td>
<td>0.92</td>
<td>10</td>
</tr>
<tr>
<td>Tin Queen Mine</td>
<td>Apg.</td>
<td>169</td>
<td>690</td>
<td>190</td>
<td>1824</td>
<td>644</td>
<td>0.373</td>
<td>0.95</td>
<td>0.94</td>
<td>10</td>
</tr>
<tr>
<td>Tin Min.</td>
<td>Block</td>
<td>198</td>
<td>42</td>
<td>130</td>
<td>1928</td>
<td>92</td>
<td>0.022</td>
<td>0.97</td>
<td>0.95</td>
<td>9</td>
</tr>
<tr>
<td>Gray Rocks</td>
<td>Block</td>
<td>210</td>
<td>29</td>
<td>100</td>
<td>2356</td>
<td>1360</td>
<td>0.012</td>
<td>0.95</td>
<td>0.99</td>
<td>9</td>
</tr>
<tr>
<td>Absent Willow Creek</td>
<td>Med.-gr.</td>
<td>226</td>
<td>580</td>
<td>190</td>
<td>360</td>
<td>tr.*</td>
<td>1.61</td>
<td>0.97</td>
<td>0.95</td>
<td>5</td>
</tr>
<tr>
<td>Uranium Line vein Wyoming</td>
<td>Granite</td>
<td>284</td>
<td>7720</td>
<td>170</td>
<td>290</td>
<td>tr.*</td>
<td>28.9</td>
<td>0.85</td>
<td>0.80</td>
<td>25</td>
</tr>
<tr>
<td>Absent Outcrop</td>
<td>Apg.</td>
<td>285</td>
<td>5000</td>
<td>200</td>
<td>405</td>
<td>tr.*</td>
<td>12.4</td>
<td>0.88</td>
<td>0.80</td>
<td>15</td>
</tr>
<tr>
<td>Medicine Bow, rare-earths</td>
<td>Block</td>
<td>268</td>
<td>16</td>
<td>20</td>
<td>550</td>
<td>15</td>
<td>0.084</td>
<td>0.90</td>
<td>0.83</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Block</td>
<td>290</td>
<td>510</td>
<td>39</td>
<td>1675</td>
<td>15</td>
<td>0.304</td>
<td>0.92</td>
<td>0.86</td>
<td>15</td>
</tr>
</tbody>
</table>

Abcences, the Ba:Rb ratio ranges over three orders of magnitude.

There is a distinction between generations of Kfs similar to differences established at other deposits (Oftedal, 1961; Solodov, 1962; Sretenskaya, 1964). As an example of these relations, compare the three samples of the Feldspar Company pegmatites (Georgia): from the graphic (earliest) zone to the fine block and then to the block (central) zone there is a progressive decrease of Ba and Sr concentrations in Kfs. Rb and Cs increase in the same direction, though not so strongly.

The Strickland quarry Kfs have low Rb concentrations and a higher Ba: Rb ratio, because these results are not for the latest generations of Kfs. This pegmatite is of the raremetal type, containing spodumene,
lepidolite, amblygonite, lithiophilite, and columbite, and the Cs content is high even in the early generation of Kfs.

As to structural state, all Kfs in Table 1 are maximum microclines. The $\Delta_2$ value is usually slightly higher than $\Delta_0$. In three cases the relation is inverted, but the differences are very small and less than measurement error. The Ab content in Kfs is very low except for sample 393 from the raremetal Strickland pegmatite.

The studied Kfs from three North Carolina pegmatite fields (Table 2) are very different in minor-element contents. Again the largest concentrations of Ba and Sr are in Kfs of muscovite pegmatite and of some non-specialized pegmatite veins, which contain abundant magnetite crystals and occur in hypersthene metagabbro in a roadcut not far from Asheville (US Highway 19). In well-known raremetal pegmatites near Kings Mountain (lithium specialization) the Kfs contain maximal Rb and Cs concentrations, but Ba contents are sometimes lower than 0.001 percent (the edge of detectability), and in the region as a whole the Ba:Rb value has three-order variation.

The differences of Kfs generations in one vein are easily seen (see specimen pairs 89 and 100, which are from earliest Kfs generations, show a slight reduction of $\Delta_0$. Two specimens, 140 and 141, however, stand out sharply from the rest. These two samples, from the Asheville pegmatites, have to be designated intermediate microcline (#140) and intermediate orthoclase (#141). The reasons for this anomaly are the high Ba concentrations and the absence of intensive postmagmatic processes in those pegmatites. This question will be discussed later.

The Ab content is low in all Kfs specimens of Table 2.

Table 3 presents Kfs of Precambrian pegmatites in South Dakota and Wyoming. These pegmatites differ widely in specialization. The elevated Ba and Sr content in the earliest Kfs generation of muscovite pegmatite is very close to that of similar pegmatites in Appalachians. Kfs of the State Line uranium-rare-earth pegmatite also show high Ba concentrations. Such pegmatites are more deep-seated than muscovite ones. In raremetal pegmatites the contents of Rb and particularly Cs in Kfs are high, but Ba concentrations and the Ba:Rb value are very low.

Sharply higher Rb and Cs concentrations in apogropic Kfs from muscovite pegmatites at the New York mine are uncommon. This pegmatite vein is unique in several respects (thickness of block zone, albite and beryl abundance, some lithium mineralization) and is abnormal for typical muscovite pegmatites. Nevertheless, the New York mine must be classified as a muscovite (and not raremetal-muscovite) pegmatite, in view of the large quantity and good quality of mica mined there (Redden, 1963).

X-ray investigations show that every Kfs of Table 3 is maximum microcline. Some decrease of $\Delta_0$ value is noticed in Ba-rich specimens 197, 284, and 285, plus specimen 288 containing 35 percent Ab. The samples of State Line pegmatite all have a higher Ab content than most others.

Table 4 is devoted to Kfs of Colorado pegmatites, which, though variously mineralized (Landes, 1935), are mostly without commercial deposits except for ceramic raw materials. We don't see here large Ba and Sr contents as in the Kfs of muscovite pegmatites, or high Rb and Cs concentrations as in the Kfs of raremetal pegmatites. Differences between veins and between generations particularly are manifested, and the Ba:Rb value decreases strongly (1-2 orders) from the early Kfs generations to the latest ones.

Two specimens of druse Kfs are interesting. One can compare them with Kfs surrounding block pegmatite. The druse feldspar of the White Cloud vein differs by its lower Ab content and Ba concentration, and the monoclinic and especially triclinic ordering is greater. The main difference in the Rosking druse Kfs is a sharply elevated Rb (and Cs) concentration; its triclinicity is even lower than that of the surrounding block feldspar.

There are many Kfs samples with a low degree of ordering in Table 4, and they include all studied specimens of the White Cloud, Huge, and Rosking veins. These samples contain as a rule not less than 15 percent Ab and elevated quantities of Rb or Ba. But the rubidium and barium concentrations in speci-
Table 4. Contents of trace elements (ppm) in K-feldspars of Colorado pegmatites, their monoclinic ($\Delta_z$) and triclinic ($\Delta_p$) ordering, and albite content (Ab, weight percent)

<table>
<thead>
<tr>
<th>Pegmatite Field</th>
<th>Specialization of pegmatites</th>
<th>Place of sampling</th>
<th>Texture (zone)</th>
<th>Spec.</th>
<th>Ba</th>
<th>Sr</th>
<th>Rb</th>
<th>Cs</th>
<th>Ba:Rb</th>
<th>$\Delta_z$</th>
<th>$\Delta_p$</th>
<th>%Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Platte</td>
<td>Rare-earths Absent</td>
<td>Roadcut Block</td>
<td>Graphic</td>
<td>265</td>
<td>550</td>
<td>100</td>
<td>370</td>
<td>tr.</td>
<td>1.49</td>
<td>0.97</td>
<td>0.95</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>266</td>
<td>600</td>
<td>68</td>
<td>220</td>
<td>tr.</td>
<td>2.73</td>
<td>0.93</td>
<td>0.95</td>
<td>5</td>
</tr>
<tr>
<td>Devils Head</td>
<td>Absent</td>
<td>Roskeling Block</td>
<td>352</td>
<td>29</td>
<td>13</td>
<td>648</td>
<td>tr.</td>
<td>0.045</td>
<td>0.85</td>
<td>0.80</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>353</td>
<td>44</td>
<td>33</td>
<td>3062</td>
<td>33</td>
<td>0.14</td>
<td>0.90</td>
<td>0.68</td>
<td>25</td>
</tr>
<tr>
<td>Buckhorn Canyon</td>
<td>Absent</td>
<td>Roadcut Block</td>
<td>Graphic</td>
<td>280</td>
<td>2700</td>
<td>160</td>
<td>330</td>
<td>7</td>
<td>8.18</td>
<td>0.94</td>
<td>0.92</td>
<td>15</td>
</tr>
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<td></td>
<td></td>
<td></td>
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<td>282</td>
<td>310</td>
<td>73</td>
<td>500</td>
<td>17</td>
<td>0.62</td>
<td>0.95</td>
<td>0.93</td>
<td>10</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>273</td>
<td>76</td>
<td>66</td>
<td>1050</td>
<td>29</td>
<td>0.072</td>
<td>0.90</td>
<td>0.86</td>
<td>20</td>
</tr>
<tr>
<td>Glen Haven</td>
<td>Absent</td>
<td>Outcrop Block</td>
<td>Med.-gr.</td>
<td>329</td>
<td>1500</td>
<td>160</td>
<td>465</td>
<td>3</td>
<td>3.25</td>
<td>0.95</td>
<td>0.94</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>332</td>
<td>1400</td>
<td>160</td>
<td>440</td>
<td>3</td>
<td>3.18</td>
<td>0.91</td>
<td>0.93</td>
<td>10</td>
</tr>
<tr>
<td>Prairie Divide</td>
<td>Absent</td>
<td>Topaz Prospect Block</td>
<td>Sn-Bnl</td>
<td>333</td>
<td>110</td>
<td>67</td>
<td>780</td>
<td>4</td>
<td>0.141</td>
<td>0.95</td>
<td>0.98</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>337</td>
<td>35</td>
<td>37</td>
<td>2075</td>
<td>42</td>
<td>0.017</td>
<td>0.95</td>
<td>0.96</td>
<td>20</td>
</tr>
</tbody>
</table>

m cases 253, 358, and 352 are not unusual, and height-
ened Ab contents in KFs from other veins (see ## 321, 333, 337) do not correlate with their ordering.

Discussion

In spite of many investigations dealing with com-
position and structure of KFs, many questions of their
 crystallochemistry are not answered. The feldspar
 world is one of metastable crystal lattices undergoing
 many ordering and disordering processes. It is a fam-
 ily of solid solutions of several main components and
  scores of isomorphic elements (Ribbe, 1975).

The objectives of this paper are to compare KFs of
 some U.S. pegmatites with earlier-studied examples
 from other regions and to explain several dis-
crepancies from the established generalizations.

Data in Tables 1–4 show first of all that the main
features of KFs composition of the pegmatites studied
are the same as those of Indian, East Siberian, and
Karelian pegmatites (Gordienko and Leonova, 1976; Shmakin, 1976). The KFs of muscovite pegmatites are
characterized by high Ba and Sr contents, raremetal
 pegmatites by high Rb and Cs contents. The KFs of
raremetal-muscovite pegmatites have an interme-
diate composition. The Ba:Rb ratio in the earliest
generations of KFs shows well the geochemical (and
commercial) specialization of pegmatites. Increase of
Rb and Cs contents and decrease of Ba and Sr oc-
curred during the formation of all pegmatites studied.

There are limits of fluctuation of Ba and Rb con-
tents for early KFs (endocontact rims, graphic and
fine-grained textures) in Table 5. KFs of the same
pegmatite class in the U.S., India, and Eastern Si-
beria are amazingly similar. (Note that all results

Table 5. Limits of Ba and Rb contents (weight percent), and Ba:Rb ratios for the earliest K-feldspar generations from pegmatites of different types in three pegmatite regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Muscovite pegmatites</th>
<th>Raremetal-muscovite pegmatites</th>
<th>Raremetal pegmatites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ba:Rb</td>
<td>Ba:Rb</td>
<td>Ba:Rb</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>0.06-0.9</td>
<td>0.03-0.04</td>
<td>18-30</td>
</tr>
<tr>
<td>India</td>
<td>0.2-1.1</td>
<td>0.02-0.08</td>
<td>10-50</td>
</tr>
<tr>
<td>East Siberia</td>
<td>0.6-1.3</td>
<td>0.02-0.05</td>
<td>12-50</td>
</tr>
</tbody>
</table>
used here were obtained by the same analytical methods in the A. P. Vinogradov Institute of Geochemistry. The obvious similarities in the level of Ba and Rb concentrations depend of course not on regional reasons but on the similar composition of magma and analogous conditions of pegmatite formation.

The essential geochemical distinctions between pegmatites of different specialization are caused mainly by conditions of magma differentiation, and contents of trace elements on Kfs depend apparently on temperature and pressure at the time of crystallization. Since the temperatures of beginning crystallization are quite similar for all granite pegmatites, the pressure value can be considered as the main factor of minor-element concentrations in the feldspar structure.

Geological data suggested that muscovite pegmatites formed at a depth of 5-8 km, and the raremetal pegmatites formed at 3.5-5 km (Ginzburg and Rodionov, 1960). Studies of gas-liquid inclusions in minerals have confirmed such differences and gave for magmatic muscovite pegmatites 5.7-7.7 kbar initial pressure (Shmakin and Makagon, 1972) and for raremetal pegmatites 1.5-4 kbar (Bazarov and Motornina, 1969; Makagon, 1974). Evidently raremetal-muscovite pegmatites begin to form at 4-5.5 kbar pressure.

Shmakin (1971) suggested that increase of pressure of Kfs crystallization must promote Ba (and Sr) isomorphic replacements but hinder those of Rb (and Cs). A detailed investigation of Kfs containing Ba shows a reduction of unit-cell size as a result of isomorphism $\text{Ba}^{2+} + \square \rightarrow 2\text{K}^+$. This fact indirectly supports the above-mentioned suggestion. With decrease of temperature, and consequently of volatile-produced pressure, such an isomorphism becomes more difficult, but the isomorphism $\text{Rb(Cs)} \rightarrow \text{K}$, to the contrary, is facilitated. Therefore, reduction of the Ba: Rb value in successive generations of Kfs seems to be generally true.

For Kfs generations of similar formation time the Ba: Rb ratio can be used as an indicator of pressure and geochemical specialization. This ratio, instead of K: Rb, was proposed as a sensitive geochemical indicator for rocks (Heier and Adams, 1964). We can see now that for potassium minerals such an indicator may be well-grounded, because of the rules governing isomorphism. Table 5 shows that the variation of Ba: Rb values for Kfs of the three pegmatite types hardly overlap, so this is a valid discriminant for pegmatite type.

Data on structural states and Ab contents in Kfs are of definite interest. Side by side with predominant maximum microclines among the studied Kfs are orthoclases and high and intermediate microclines. As was mentioned above, they are characterized by elevated concentrations of Ba (samples 140 and 141, Table 2; 361, Table 4), Rb and/or Ab (samples 253, 256, 353, Table 4). There is only one specimen, 358 (Table 4) from the Huge mine, where reduced triclinicity is not correlated with high contents of trace elements.

The influence of Na, Ba, Rb, and Cs as "hinderers" of the ordering process in the Kfs crystal lattice has been mentioned previously (MacKenzie, 1954; Frondel et al., 1966; Gordienko and Kamentsev, 1967; Afonina and Shmakin, 1970). The presence of "strange" elements in the structure is obviously a negative factor when a metastable monoclinic Kfs modification changes spontaneously into a stable triclinic one. But the influence of intensive ordering factors (tectonic processes, postmagmatic replacement, radiation, etc.) can cause triclinization even in Kfs crystals containing a high quantity of trace elements (Shmakin et al., 1975). Such factors apparently explain the rather high $\Delta_\varepsilon$ and $\Delta_p$ values in samples 13, 15 (Table 1), 17, 202, 207, 167, 210, 284, 285 (Table 3), 280 and 337 (Table 4), which contain elevated Ba and Rb. The same reasons may apply to specimens 393 (Table 1), 288 (Table 3), and 321 (Table 4) containing 30-35 percent Ab.

It is noteworthy that Kfs samples from the Asheville pegmatites (Table 2) and from muscovite pegmatites in the Wiseman (Table 2) and New York (Table 3) mines have similar levels of Ba content but a different ordering. The Asheville veins were not altered by postmagmatic processes, whereas in the muscovite pegmatites postmagmatic processes were very intensive. The "hinder" effect of Ba in Kfs of muscovite pegmatites is as a rule noticeable where Ba is more than 1 percent (Makagon and Shmakin, 1970).

The mentioned exception, viz., that specimen 358 (Table 4) has $\Delta_p = 0.58$ and normal contents of trace elements, may be explained by the absence of intensive postmagmatic processes in the Huge pegmatite. The Ba content in Kfs of the exocontact granite (sample 361) is also too low to explain a $\Delta_p$ value of 0.40. These two specimens are in a metastable structural state. When there is no ordering influence, then even a low Ab content (15 percent) may be a sufficient hindrance for spontaneous ordering.
Conclusions

1) The maximal contents of Ba (0.6–0.9 percent) and Sr (0.04–0.06 percent) are characteristic of primary KFs of muscovite pegmatites and some other deep-seated pegmatite veins.

2) For primary KFs, the maximal concentrations of Rb (near 0.2 percent) and Cs (more than 0.01 percent) are in raremetal pegmatites.

3) In successive generations of KFs in pegmatites of both the muscovite and raremetal types, there is an increase of Rb (and Cs) and a decrease of Ba (and Sr) contents.

4) The value of the Ba:Rb ratio for the earliest generations of KFs can be an indicator of geochemical specialization of granite pegmatites.

5) Trace-element concentrations in KFs from the U.S., India, and Eastern Siberia are very similar in pegmatites of the same class.

6) The pressure of pegmatite formation can promote or prevent the isomorphic substitution of one or the other element for K in KFs.

7) Most of the KFs from U.S. pegmatites are maximum microclines. Structures of orthoclase and high or intermediate microcline are characteristic of KFs containing high Ab contents or Ba and Rb concentrations from pegmatites that have not been affected by intensive postmagmatic processes.

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