Geology, Mining, 
And Uses Of 
Strategic Pegmatites

by Richard H. Jahns

Fig. 1—Principal pegmatite areas and districts of the United States.

Such minerals as beryl, lepidolite, sheet muscovite, spodumene, and 
tantalite-columbite are obtained chiefly from pegmatite bodies that are 
internally zoned. As shown by examples of such pegmatites from the 
Southwestern andSoutheastern States during World War II, studies of 
their internal and external structure have value in prospecting and the 
planning of exploration, development, and mining.

Granitic pegmatite deposits are the chief source 
of commercial feldspar, sheet mica, beryllium, 
tantalum-columbium, and lithium minerals, and 
certain types of kaolin. They also have yielded sig-
nificant quantities of cassiterite, gems, scrap mica, 
molybdenite, tungsten minerals, uranium-thorium 
and rare-earth minerals, and zircon, either directly 
or as the sources of placer deposits. The output from 
pegmatite mines in the United States is small as 
compared to other mineral products in terms of bulk 
or value, and much of it comprises minor metals and 
nonmetals. Nevertheless, pegmatite minerals play a 
vital part in domestic industrial economy, particu-
larly in the ceramic and electrical industries. numer-
ous special purpose uses also are important, even 
though they require small quantities of raw ma-
terials.

Never was United States dependence upon pegma-
tite mining more clearly emphasized than during 
World War II, when greatly expanded demands 
and uncertainties of foreign sources of supply caused 
much concern. Such commodities as beryl, tantalite, 
and sheet muscovite remained high on the critical 
list for months at a time, and for some minerals 
there was a real struggle to achieve and maintain 
a favorable ratio of supply to demand. Satisfactory 
stock piles of certain sizes and qualities of sheet 
mica, for example, were not built up until late in 
1944, when wartime requirements already had be-
gun to level off or even to decrease. Production of 
all the strategic pegmatite minerals from domestic 
deposits during World War II constituted only 10 pct 
or less of the total domestic consumption of these 
minerals, but the importance of this contribution 
should not be minimized. Domestic production often 
represented the difference between increase and 
further reduction of existing stocks of commodities 
already in seriously short supply, and in the early

Beryllium Minerals

Beryllium is the present commercial source of beryl-
lium metal and beryllium compounds, which are 
used in ceramics, in the preparation of X-ray tubes 
and fluorescent lamps and screens, in special pro-
cesses of paint and textile manufacture, and in the 
optical systems of some electrical instruments. The 
metal also is used in nuclear physics, chiefly as a 
source of neutrons. Beryllium is alloyed with alumi-
num for certain light-metal uses and is a consti-
tuent of some nickel and iron alloys. Currently the 
chief demand, however, is for copper-base alloys, 
which are exceptionally resistant to fatigue and 
wear, are responsive to hardening treatments after

Richard H. Jahns, Member AIME, Professor, California In-
stitute of Technology, Pasadena.

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being worked soft, and are harder and otherwise superior to copper in structural characteristics. In addition, they are good electrical conductors, nonmagnetic, and nonsparking. Alloys of the beryllium-copper group are used, for example, in nonsparking tools and in springs, contact plates, bushings, shims, and corrosion-resistant parts of motors and gages. They also are employed for parts in precision instruments and machines.

Prices for clean-cobbled domestic beryl at the mine were quoted at $30 to $35 per short ton for several years prior to 1941, but they gradually rose during the succeeding wartime months until by May 1943 a price of $12 per dry short-ton unit was guaranteed by the Metals Reserve Co. for ore containing a minimum of 8 pct beryllium oxide (BeO). In June 1944, the price was raised to $14.50 per unit, but federal purchases were discontinued on Jan. 1, 1945. Subsequent open market transactions were carried on at distinctly lower price levels for a time, but prices since have risen to points well above the previous wartime high.

The BeO content of pure beryl varies with the proportion of certain alkalies present, notably sodium and cesium and, in general, ranges from less than 10 pct to a theoretical maximum of about 14 pct. Although satisfactory analytical methods have been developed for the determination of beryllium in ores, they are time-consuming and expensive. Accurate analysis of low-grade material is particularly difficult. A fairly rapid qualitative method for recognition of BeO in minerals has been devised and is reliable for material containing 1 pct or more of the oxide. An improved photometric method of analysis also has been reported, and spectrochemical analysis, which is rapid and only moderately expensive, has been used successfully for numerous BeO determinations, especially in low-grade ores. Dr. W. T. Schaller of the Geological Survey has been investigating the relations between indices of refraction, which are easily determined, and the BeO content of beryl, and this work promises to yield a rapid and inexpensive means for approximate analysis.

The beryl produced in the southwestern and southeastern United States is a byproduct derived from deposits of feldspar, lithium minerals, mica, or other pegmatite constituents, and hence the general output ordinarily varies according to market conditions for these other minerals. The beryl is recovered from the host pegmatite by rough copping and hand sorting, so only deposits containing coarse crystals and masses are of current economic interest. Several laboratory investigations, however, have demonstrated that at least some pegmatite containing small and scattered masses of beryl can be milled with reasonably good recovery of the mineral in the form of marketable concentrates.

The Black Hills area of South Dakota is the leading source of domestic beryl, and small quantities are obtained at irregular intervals from deposits in at least 14 additional states. The bulk of the beryl consumed in the United States, however, is imported from South American and other countries.

Other beryllium-bearing minerals, such as chrysoberyl, gadolinite, and phenakite, occur in many pegmatites, both in this country and abroad, but no deposits of present commercial importance are known. Phenakite, with a BeO content of about 45 pct, is a

Table I. Composition of Principal Beryllium Minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Simplified Formula</th>
<th>Theoretical Content of BeO, Pct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beryl</td>
<td>Be₃Al₂(SiO₄)₃</td>
<td>13.97</td>
</tr>
<tr>
<td>Phenakite</td>
<td>Be₃AlO₃</td>
<td>45.45</td>
</tr>
<tr>
<td>Chrysoberyl</td>
<td>Be₃Al₂O₆</td>
<td>10.71</td>
</tr>
<tr>
<td>Helvite</td>
<td>Be₃Fe₂(PO₄)₂</td>
<td>12.58 to 13.52</td>
</tr>
<tr>
<td>Gadolinite</td>
<td>Be₃Fe₂(PO₄)₂</td>
<td>10.69</td>
</tr>
<tr>
<td>Beryllonite</td>
<td>NaBe₃PO₄</td>
<td>18.80</td>
</tr>
</tbody>
</table>

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Other beryllium-bearing minerals, such as chrysoberyl, gadolinite, and phenakite, occur in many pegmatites, both in this country and abroad, but no deposits of present commercial importance are known. Phenakite, with a BeO content of about 45 pct, is a
matite, Amelia County, Va. A reserve of several tons of this mineral might well be present, but most of the phenakite masses are too small to be recovered by ordinary hand sorting. Helvite and danalite, commonly in the Iron Mountain district, N. Mex. The deposits are of contact metamorphic rather than pegmatitic origin. Most are low in grade, and the composition of principal beryllium minerals is given in Table I.

Lithium Minerals

Salts of lithium are used in pharmaceuticals, storage batteries, flares and fireworks, fluxes and other special lubricants, as well as in the curing of meat, manufacturing of textiles and ceramics, refining of metals, smelting of iron ore, purifying of helium and dehumidifying of air in air-conditioning equipment. Lithium hydride has been employed as an effective transporter of hydrogen in self-inflating rafts, balloons, and other devices, and the metal is a minor constituent of some special-purpose alloys. The chief raw materials used for the manufacture of lithium compounds are the pegmatite mineral spodumene and the lithium-bearing brines of several saline lake deposits. Other pegmatite source minerals include amblygonite, zinnwaldite, and triphylite, but neither these nor spodumene contain large proportions of lithium or lithium oxide, as shown in Table II.

Spodumene can be employed directly in the manufacture of glass to neutralize shrinkage during cooling and also is an ingredient of some ceramic mixes. Lepidolite, the lithia mica, is much more widely used in glass making than as a source of lithium salts and is commercially as important as spodumene. Not only is it an excellent fluxing material, but it increases the luster, weather resistance, and strength characteristics of glasses, while reducing their coefficients of expansion. Such glasses are in great demand for high-pressure gages, electronic tubes, and other devices subject to mechanical stresses or sudden temperature changes. Lepidolite also is an ingredient of many high-quality porcelains and enamels in which it is an effective opacifier.

The average price quoted for spodumene during recent years has been about $30 per short ton of clean cobbed or milled material, generally with a minimum acceptability limit of 6 pct contained Li$_2$O. Prices for amblygonite, which contains a higher proportion of lithium, ordinarily have ranged from $40 to $50 per short ton. Lepidolite containing 3 pct Li$_2$O generally has commanded a price of $15 to $27 per short ton at the mine. Spodumene was allocated to consumers during the wartime period Dec. 5, 1942, to Sept. 30, 1944, when foreign supply was uncertain and domestic production facilities were not adequate in terms of demand. During this time prices rose to $50 or more per ton.

Most domestic spodumene has been obtained from deposits in North Carolina, South Dakota, and New Mexico. A group of pegmatites in the Kings Mountain area of the Carolina Piedmont constitutes by far the greatest domestic reserve of the mineral. This reserve may well amount to several million tons. Amblygonite is mined from time to time in

Table II. Composition of Commercial Lithium Minerals from Pegmatites

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Simplified Formula</th>
<th>Theoretical Content of Li$_2$O, Pct</th>
<th>Proportion of Li$_2$O in Marketable Concentrates, Pct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spodumene</td>
<td>LiAlSi$_3$O$_8$</td>
<td>8.03</td>
<td>&gt;6.0</td>
</tr>
<tr>
<td>Lepidolite</td>
<td>LiAlSi$_3$O$_8$</td>
<td>6.95</td>
<td>&gt;2.5</td>
</tr>
<tr>
<td>Amblygonite</td>
<td>LiAlFe$_3$O$_8$</td>
<td>10.15</td>
<td>&gt;8.0</td>
</tr>
<tr>
<td>Zinnwaldite</td>
<td>LiFe$_3$O$_8$</td>
<td>3.40</td>
<td>&gt;1.5</td>
</tr>
<tr>
<td>Triphylite</td>
<td>LiFePO$_4$</td>
<td>8.47</td>
<td>&gt;3.5</td>
</tr>
<tr>
<td>Lithiophyllite</td>
<td>Li$_2$MnPO$_4$</td>
<td>9.52</td>
<td>&gt;2.5</td>
</tr>
<tr>
<td>Petalite</td>
<td>LiAlSi$_3$O$_8$</td>
<td>4.89</td>
<td>&gt;3.0</td>
</tr>
</tbody>
</table>

* Concentrates containing as little as 4.0 pct Li$_2$O are sometimes marketed.

Table III. Composition of Principal Tantalum-Columbium Minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Simplified Formula</th>
<th>Theoretical Content of Ta$_2$O$_5$ or Cr$_2$O$_3$ in Chb$_2$O$_3$, Pct</th>
<th>Proportion of Ta$_2$O$_5$ or Cr$_2$O$_3$ in High-Grade Concentrates, Pct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tantalite*</td>
<td>(Fe,Mn)Ta$_2$O$_5$</td>
<td>&gt;85 Ta$_2$O$_5$</td>
<td>&gt;70 Ta$_2$O$_5$</td>
</tr>
<tr>
<td>Columbite*</td>
<td>(Fe,Mn)Cr$_2$O$_3$</td>
<td>&gt;78 Cr$_2$O$_3$</td>
<td>&gt;70 Cr$_2$O$_3$</td>
</tr>
<tr>
<td>Microlite*</td>
<td>(Na,Ca)Ta$_2$O$_5$</td>
<td>&gt;85 Ta$_2$O$_5$</td>
<td>&gt;70 Ta$_2$O$_5$</td>
</tr>
<tr>
<td>Pyrochlore*</td>
<td>Na$_2$Ta$_2$O$_7$</td>
<td>73.05 Cr$_2$O$_3$</td>
<td>&gt;50 Cr$_2$O$_3$</td>
</tr>
<tr>
<td>Hatchetolite</td>
<td>(Na,Ca, U)Ta$_2$O$_5$</td>
<td>&gt;85 Ta$_2$O$_5$ + Cr$_2$O$_3$</td>
<td>&gt;60 Ta$_2$O$_5$ + Cr$_2$O$_3$</td>
</tr>
<tr>
<td>Samarskite*</td>
<td>(Y,Er,Ce,U,Th)Ta$_2$O$_5$</td>
<td>&gt;55 Ta$_2$O$_5$ + Ta$_2$O$_5$</td>
<td>&gt;45 Cr$_2$O$_3$ + Ta$_2$O$_5$</td>
</tr>
<tr>
<td>Tepidolite*</td>
<td>(Fe,Mn)Ta$_2$O$_5$</td>
<td>91.01 Ta$_2$O$_5$</td>
<td>&gt;85 Ta$_2$O$_5$</td>
</tr>
<tr>
<td>Fergusonite*</td>
<td>(Y,Er,Ce,Fe)Cr$_2$O$_3$</td>
<td>&gt;50 Cr$_2$O$_3$</td>
<td>&gt;50 Cr$_2$O$_3$</td>
</tr>
<tr>
<td>Formanite*</td>
<td>(Y,Er,Ce)Ta$_2$O$_5$</td>
<td>&gt;85 Ta$_2$O$_5$</td>
<td>&gt;70 Ta$_2$O$_5$</td>
</tr>
<tr>
<td>Euxenite*</td>
<td>(Y,Er,Ce,U,Th)Cr$_2$O$_3$</td>
<td>&gt;85 Cr$_2$O$_3$</td>
<td>&gt;70 Cr$_2$O$_3$</td>
</tr>
</tbody>
</table>

* Includes minerals of present and potential commercial importance.

End member of a tantalum-columbium mineral series.

For material with Fe:Mn ratio of 1:1.

Tantalum-columbium mineral series that include high-tantallum members but probably no corresponding high-columbium members.

General name for members of a columbium-tantalum-titanium mineral series that are relatively rich in Ta and Cr.
This view of the south wall shows the upper half of the gently dipping pegmatite dike. Note the well-defined layering.

South Dakota, and lepidolite has been recovered recently from deposits in South Dakota, Colorado, and New Mexico. Both minerals were obtained from the Stewart mine in southern California prior to 1926, and production of lepidolite from this mine was large.

Some lithium minerals are imported from Southwest Africa, Argentina, Brazil, Sweden, central and southwestern Europe, Australia, and Canada, but during most years the consumption of such materials in this country does not greatly exceed domestic production.

Recovery of lithium minerals from the host pegmatite ordinarily is a simple matter, involving hand cobbing and picking. Many crystals or crystalline aggregates of spodumene, lepidolite, or amblygonite are so large that they can be broken and shipped without sorting. In other places these minerals are intimately intergrown and can be marketed as mixed lithium-bearing material. Lithium minerals have been recovered by milling in at least three places during recent years. The flotation plant of the Solvay Process Co. near Kings Mountain, N. C., yielded commercial spodumene concentrates during the period 1943 to 1945.

Tantalum-Columbium Minerals

The metals tantalum and columbium are derived mainly from members of the tantalite-columbite series and to an appreciable extent from microlite and other minerals, see Table III. Columbium is alloyed with nickel, copper, and aluminum. Columbium-bearing alloy steels, with their favorable welding characteristics and high-temperature strength properties, are in demand for turbine and aircraft engine parts. Tantalum metal is used in radio and neon tubes, where its gas absorption properties are important, and its chemical inertness makes it unusually suitable for instruments and equipment that are exposed to corrosive liquids and fumes. It is employed in the manufacture of synthetic rubber and is uniquely satisfactory as a surgical metal. Tantalum is alloyed with columbium and tungsten to form dies and cutting tools, which also are made with cemented tantalum carbides. Tantalum-bearing glass is used in special camera lenses and other optical equipment.

The most desirable ores are microlite, low-tantalum columbite, and low-columbium tantalite that contain little tin or titanium. Columbium ore was valued at $0.22 to $0.40 per lb, and tantalum ore at $1.80 to $2.75 per lb in the years preceding World War II, but prices rose much higher as a result of wartime demands after 1941. The highest prices paid by the Metals Reserve Co. were in effect during the period July 1943 to January 1945, after which most purchases were discontinued. They ranged from $2.20 per lb of contained tantalum oxide for concentrates assaying 40 pct Ta₂O₅ to $4.65 for 75 pct concentrates, see Table IV. Columbite containing 50 pct Cb₂O₅ or more was purchased at $0.50 per lb of contained oxide.

Accurate determination of grade is accomplished by chemical analysis, a slow and costly process, but rough estimates for members of the tantalite-columbite series can be made on the basis of the consistent relation between specific gravity and Ta₂O₅ content. In general, the specific gravity rises with increase in proportion of tantalum oxide as shown in Fig. 2. The specific gravity of most columbite ranges from 5.2 to 6.5 and that of all material commercially marketable as tantalite is greater than 6.5. Determinations can be made easily and quickly by means of gravity balances, which are available in many laboratories. Preliminary investigations of microlite from several deposits in the United States suggest that a similar relation holds for varieties of this mineral, with a general rise in specific gravity from 5.5 for material containing less than 60 pct Ta₂O₅, to as much as 7.0 for very high grade material.

Tantalum-columbium minerals occur in many pegmatite districts of the United States, but the
average annual output has amounted to little more than 6000 lb during the past 30 years. Crystals and irregular chunks of tantalite and columbite are recovered from time to time as hand-cobbled byproducts from operations for feldspar and other pegmatite minerals, but very few pegmatites have been mined for tantalum-columbium minerals alone. Notable exceptions are the Harding pegmatites of northern New Mexico, which during World War II yielded the bulk of domestic tantalum production in the form of microelite concentrates. Additional microelite has been obtained since 1942 as a byproduct from other pegmatites in New Mexico, Colorado, and South Dakota.

Nearly all tantalum-columbium ore consumed in the United States is tantalite-columbite obtained from deposits in other countries, mainly Africa, South America, and Australia. Much of the highest-grade tantalite occurs in Australia and parts of South America. During recent years some tantalum was brought into this country in the form of smelter slags derived from central African tin ores, but this material contained very low percentages of Ta₂O₅.

Other tantalum-bearing minerals such as microlite, hatchettolite, samarskite, and fergusonite, are widespread in their occurrence but are so sparsely distributed in most tantalum-bearing pegmatites that they ordinarily are of little economic interest.

Sheet Muscovite

The uses of sheet muscovite are based upon its perfect cleavage, remarkably low conductivity of heat and electricity, high dielectric strength, non-inflammability, mechanical strength, flexibility, elasticity, transparency, luster, and the ease with which it can be worked into final form. The degrees of emphasis placed upon given properties by purchasers depend upon the specific end uses involved. Flexibility is particularly important, for example, in the “cigarette” mica used in spark plugs for aircraft engines. This material, in films twelve or more thousandths of an inch or less thick, is wrapped around rodlike spindles a little more than 1/8 in. in diam.

Condenser mica, in contrast, is valued because of its dielectric properties, and the use of mica for windows in furnace walls and doors is founded upon its transparency, heat resistance, and mechanical strength.

A very high proportion of sheet mica is used as an electrical insulating material. Washers, disks, and other small trimmed or stamped forms are not only employed as such, but they can be built up into

<p>| Table IV. Price Schedule for Domestic Tantalite Concentrates, July 1943 to January 1945 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Proportion of Ta₂O₅ in Lb of Concentrate</th>
<th>Price per Lb of Concentrate</th>
<th>Proportion of Ta₂O₅ in Lb of Concentrate</th>
<th>Price per Lb of Concentrate</th>
<th>Proportion of Ta₂O₅ in Lb of Concentrate</th>
<th>Price per Lb of Concentrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%</td>
<td>2.39</td>
<td>62</td>
<td>3.04</td>
<td>64</td>
<td>3.88</td>
</tr>
<tr>
<td>41%</td>
<td>2.77</td>
<td>57</td>
<td>3.11</td>
<td>63</td>
<td>4.02</td>
</tr>
<tr>
<td>42%</td>
<td>2.34</td>
<td>54</td>
<td>3.18</td>
<td>66</td>
<td>4.02</td>
</tr>
<tr>
<td>43%</td>
<td>2.41</td>
<td>55</td>
<td>3.22</td>
<td>77</td>
<td>4.06</td>
</tr>
<tr>
<td>44%</td>
<td>2.48</td>
<td>56</td>
<td>3.22</td>
<td>68</td>
<td>4.16</td>
</tr>
<tr>
<td>45%</td>
<td>2.55</td>
<td>57</td>
<td>3.27</td>
<td>69</td>
<td>4.23</td>
</tr>
<tr>
<td>46%</td>
<td>2.62</td>
<td>58</td>
<td>3.46</td>
<td>70</td>
<td>4.20</td>
</tr>
<tr>
<td>47%</td>
<td>2.68</td>
<td>57</td>
<td>3.51</td>
<td>74</td>
<td>4.23</td>
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<tr>
<td>48%</td>
<td>2.76</td>
<td>60</td>
<td>3.60</td>
<td>72</td>
<td>4.44</td>
</tr>
<tr>
<td>49%</td>
<td>2.84</td>
<td>61</td>
<td>3.72</td>
<td>71</td>
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</tr>
<tr>
<td>50%</td>
<td>2.90</td>
<td>62</td>
<td>3.74</td>
<td>74</td>
<td>4.58</td>
</tr>
<tr>
<td>51%</td>
<td>2.97</td>
<td>63</td>
<td>3.81</td>
<td>76</td>
<td>4.83</td>
</tr>
</tbody>
</table>

* Purchases made by Metals Reserve Co. at designated depots; schedule applies to lots in excess of 200 lb dry weight.
* Minimum acceptable Ta₂O₅ content is 40 pct; maximum allowable contents of SnO₂ and TiO₂ are 3 pct.

Fig. 7—Specimens of tantalum-lithium ore from the Harding pegmatite, Toos County, N. Mex.

High-grade ore. Aggregates of microelite, lithia mica, and minor tantalite are enclosed by beds of epidote. Dark strips in specimen at left are smoky quartz.

rods, tubes, or other articles by cementing them with shellac, glyptol, or a similar bonding medium. Simple and composite pieces are used, for example, as sleeves, studs, tubes, washers, bushings, laminations, and thin perforated plates in condensers, transformers, small heating elements, rheostats, fuses, incandescent bulbs, radio and electronic tubes, various types of coils, and in acoustic, X-ray, and other specialized equipment. Thin splittings are built up into mica board or applied as facing on paper, cloth, and other materials used in the manufacture of heater elements; commutators; boards, panels, and other mounting forms; parts of condensers; and many other electrical devices.

The properties most desired in sheet muscovite of superior quality are flatness, uniform splitting characteristics, reasonable hardness and flexibility, elasticity, transparency, freedom from inclusions of other minerals, and freedom from such structural imperfections as cracks, tears, pinholes, warps, and ripples, see Fig. 3. The first rough separation of mica generally is made at the mine, where obvious scrap material is separated from the better books. Adhering fragments of quartz, feldspar, and other foreign material are then cobbed away from those books that contain sheet mica of usable quality. Some of this rough cobbed or selected mine-run mica is sold as such to jobbers or manufacturers, but at most mines it is prepared further. The books are split or “rifled” by means of knives, generally into plates 3/16 in. or less in thickness. Most defective laminae removed during this rifiting process are discarded as shop scrap, which is distinctly less impure than typical mine scrap.

After rifiting, the ragged and broken edges of many plates are removed with the fingers, a process known as thumb trimming. This is an especially common practice in districts where much of the mica is marred by structural imperfections. Some thumb-trimmed material is sold to manufacturers as such, but most is further trimmed with knives or shears and its value thereby increased. During recent years attempts have been made in the United States to employ several forms of blades and saws for semi-mechanized mica trimming, but without much success.
A large proportion of sheet mica is consumed in the form of splittings. These are films 0.0007 to 0.001 in. thick that generally are cleaved from the smaller sizes of sheet stock. Some also are derived from thin films or skimmings that are accumulated during the rifting of larger sheet material. Splittings are used in the manufacture of built-up mica board and other forms of electrical insulation. Although many mechanical devices have been tested for their preparation, most splittings are still made outside the United States by hand methods, generally in places where labor costs are very low.

The cut mica blocks that represent sheet material are further processed into disks, washers, and thin plates of various sizes and shapes. This processing generally involves additional splitting, followed by trimming, cutting, punching, or stamping into more or less standardized patterns. Most of this material is then cut to final form, if necessary, by the manufacturers of the devices in which the mica is to be used. Composite forms can be built up to any desired thickness by the cementing together of individual pieces.

In general, only a small proportion of the rifted and trimmed sheet mica is represented in the finished product. The bulk of such material is trimmed or cut away as waste, which is then marketed as scrap of superior grade.

Heavy demands for sheet mica of good quality are made during modern wartime periods. Such mica is used, for example, as splittings in the form of built-up mica commutator segments and coil insulations for motors and generators, and in transformers, switchboards, blasting apparatus, and aircraft generators and sparkplugs. In addition, an unprecedented problem was caused during World War II by the demands and exacting requirements for condenser mica. Developments in the field of military radio and electronic equipment focused attention on mica condensers, owing to the constancy and excellence of their electrical properties under varying physical conditions.

Some of the problems encountered in increasing the domestic supply of so-called strategic sheet mica have been described and discussed in recent literature. To stimulate production of such mica, the Metals Reserve Co., a subsidiary of the Reconstruction Finance Corp., designated the Colonial Mica Corp. as its agent, with authority to purchase mica of certain types and to assist the operators of mines with equipment leases, development loans, and consulting services on problems of mica mining and preparation. A market for mica of superior quality was assured at favorable prices and for specified periods.

### Table V. Price Ranges of Clear and Stained Sheet Mica in the Southeastern States During the Period 1910-1940

<table>
<thead>
<tr>
<th>Size, In.</th>
<th>Clear</th>
<th>Stained</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x2x2</td>
<td>0.12 - 0.60</td>
<td>*</td>
</tr>
<tr>
<td>2x2x2</td>
<td>0.22 - 1.05</td>
<td>0.00 - 0.40</td>
</tr>
<tr>
<td>2x3x2</td>
<td>0.35 - 1.45</td>
<td>0.16 - 0.60</td>
</tr>
<tr>
<td>3x3x2</td>
<td>0.58 - 2.00</td>
<td>0.15 - 1.25</td>
</tr>
<tr>
<td>4x4x2</td>
<td>0.70 - 2.30</td>
<td>0.30 - 1.50</td>
</tr>
<tr>
<td>5x5x2</td>
<td>0.90 - 2.70</td>
<td>0.48 - 1.75</td>
</tr>
<tr>
<td>6x6x2</td>
<td>1.25 - 3.25</td>
<td>0.70 - 2.25</td>
</tr>
<tr>
<td>8x8x2</td>
<td>1.85 - 7.25</td>
<td>1.25 - 3.50</td>
</tr>
<tr>
<td>10x10x2</td>
<td>3.00 - 11.50</td>
<td>2.00 - 3.00</td>
</tr>
</tbody>
</table>

* Under ordinary conditions the smallest size of stained mica purchased as sheet material in the Southeastern States is 2x2 in.

### Table VI. Price Schedules for Domestic Clear Sheet Mica During Period December 1941-February 1945

<table>
<thead>
<tr>
<th>Prices, $ per Lb</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Private Purchasers</strong></td>
</tr>
<tr>
<td><strong>Colonial Mica Corp.</strong></td>
</tr>
<tr>
<td><strong>February 1945</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size, In.</th>
<th>April-May 1942</th>
<th>June 1942</th>
<th>November 1942</th>
<th>May 1943</th>
<th>February 1944</th>
<th>August 1944</th>
<th>February 1945</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch</td>
<td>0.12 - 0.16</td>
<td>0.22</td>
<td>0.30</td>
<td></td>
<td>6.00</td>
<td>0.08 - 0.19</td>
<td></td>
</tr>
<tr>
<td>1x2x2</td>
<td>0.50 - 0.65</td>
<td>1.10</td>
<td>2.40</td>
<td></td>
<td>6.50</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>2x2x2</td>
<td>0.95 - 1.10</td>
<td>1.75</td>
<td>3.60</td>
<td></td>
<td>6.00</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>2x3x2</td>
<td>1.50 - 1.85</td>
<td>2.75</td>
<td>4.64</td>
<td></td>
<td>6.00</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>3x3x2</td>
<td>2.00 - 2.35</td>
<td>3.50</td>
<td>5.12</td>
<td>5.00</td>
<td>6.00</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>3x4x2</td>
<td>2.25 - 2.60</td>
<td>4.35</td>
<td>6.05</td>
<td>6.00</td>
<td>6.00</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>3x5x2</td>
<td>2.75 - 3.00</td>
<td>5.00</td>
<td>7.00</td>
<td>6.00</td>
<td>6.00</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>4x4x2</td>
<td>3.25 - 4.00</td>
<td>6.25</td>
<td>8.00</td>
<td>6.00</td>
<td>6.00</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>5x5x2</td>
<td>5.50 - 6.00</td>
<td>8.00</td>
<td>9.12</td>
<td></td>
<td>6.00</td>
<td>2.25</td>
<td></td>
</tr>
</tbody>
</table>

* Adapted in part from Billings and Montague. The Wartime Problem of Mica Supply: Engineering and Mining Journal (1944) 146, p. 94.
* Punch material required to yield 20 pct or more of trimmed pieces 1x1 in. or larger; price scale for larger mica based on No. 1 quality and half trim, with max bonuses of 30 pct and 40 pct for three-quarter trim and full trim, respectively.
* Based on full-trimmed punch and three-quarter trimmed sheet mica.
* Full-trimmed mica.
* Three-quarter trimmed mica.
* Based on untrimmed punch and three-quarter trimmed sheet mica.
Prices for sheet mica not only fluctuate widely in response to variations in demand, but vary at any given time according to the size and quality of the material involved. The ranges for clear sheet mica are great, and during a 30-year period the price for 3 x 3 in. trimmed sheets in the southeastern United States, for example, ranged from $0.58 to $2 per lb, and that for 1 1/2 x 2 in. trimmed sheets ranged from $0.12 to $0.60 per lb as shown in Table V. During war periods, when demands are greatly increased and problems of supply often are complex, prices characteristically reach very high levels. Thus the trend rose rapidly during the period December 1941 to December 1944, until a flat price of $8 per lb for full-trimmed sheets 2 x 2 in. and larger was in effect, see Table VI. Subsequent price scales have been considerably lower and again have been based upon size and quality of the prepared sheets.

Most of the world’s sheet muscovite is obtained from India, and much smaller quantities are recovered from deposits in Brazil, Argentina, the United States, Russia, and several other countries. Domestic production rarely amounts to more than 20 pct of consumption, and during most war periods this proportion decreases distinctly. Exhaustive tests have shown that there is little intrinsic difference in electrical and other physical properties between American and Indian muscovites, but much of the imported material is consistently better prepared and more carefully graded.

Pegmatite Deposits

Most pegmatites can be classified as sills or dikes, depending upon whether or not they are conformable with the structure of the enclosing country rock. Variations of these forms include markedly pinching-and-swelling bodies and series of disconnected lenses and pods. In addition, trough-like, funnel-like, cigar-shaped, mushroom-shaped, and various branching forms have been recognized. Studies in all parts of the United States have shown that, despite numerous complexities of detail, most pegmatite bodies of commercial interest are rather regular in general structure. Plunging bodies are especially common, and many pegmatites that appear to be simple sills or dikes actually are shaped in three dimensions more like laths or flattened cigars, with long axes that plunge gently to moderately. Such plunging structures are extremely important as far as economic exploration of the deposits is concerned.

Pegmatite bodies that cannot be divided readily into units of contrasting composition and texture appear to constitute the great bulk of pegmatitic material in some areas. In general, however, these have received much less attention than pegmatites that are lithologically and structurally more complex. This latter group includes nearly all pegmatites that contain rare minerals, as well as most of those with minable concentrations of feldspar, mica, beryl, and other minerals. A general systematic arrangement of lithologic units such pegmatites has been recognized, and bands, barrels, columns, layers, lenses, pipes, pods, ribs, shoots, streaks, veins, and zones are terms commonly used by miners and referred to in geologic literature.

An essentially regular and orderly internal structure in many pegmatites was described and discussed by some earlier geologists, and even was shown on maps and sections by a few, but the attention of most investigators was directed more toward questions of mineralogy and genesis than toward structural considerations. It has remained for more recent investigators to place greater emphasis upon detailed mapping and structural interpretation of individual parts of pegmatite bodies and to demonstrate more fully the economic value of such studies in prospecting and in the planning of exploration, development, and mining. In many areas it has been shown by careful studies—and in places confirmed by subsequent mining—that concentrations of economically desirable pegmatite minerals commonly occur in rock units quite distinct from adjacent barren units. Moreover, the shape and dis-
of zones prior to albitization and development of other minerals.

The distribution of many of these units reflect the general shape or structure of the host pegmatite body. Where ideally developed, they are concentric about an innermost zone, or core. Where not ideally developed, they are successive shells, complete or incomplete, that commonly reflect the shape or structure of the containing pegmatite body. Where ideally developed, they are concentric about an innermost zone, or core. Typical pegmatite units are shown in Fig. 4. Such units range widely in size, shape, and texture. The smallest are tiny fracture-filling veinlets and the thin outermost zones of many pegmatite bodies, and the largest are masses several hundred feet long and more than 50 ft in minimum dimension. Many units are easily distinguished and sharply bounded from adjacent units, especially where they differ markedly from them in composition or texture. Contacts between others are gradational, and in some bodies of very coarse-grained pegmatite they are difficult to locate within narrow limits. Even where adjacent units are mineralogically similar, however, their boundaries can be mapped conveniently on scales of 20 or 25 ft to the inch, and independent assignments of such boundaries by more than one geologist generally agree within narrow limits.

The distribution, structure, and economic significance of many pegmatites and pegmatite units in the southwestern and southeastern United States can be most briefly explained by means of examples. The Harding pegmatites, Taos County, N. Mex., nearly flat dike that lies within a zone of probable thrust faulting in steeply dipping metamorphic rocks of pre-Cambrian age. It dips southward, has an average thickness of 50 to 55 ft, and is known to contain beryl, tantalum-columbium, and lithium minerals for distances of 350 ft along the strike and 650 ft down the dip. Its upper half is exceptionally well exposed along the face of a large quarry shown in Fig. 5, and its down-dip extensions were diamond drilled in 1943 and 1948 as a part of a program of thorough exploration by the U. S. Bureau of Mines. This dike is strikingly layered, each layer consisting of a distinct rock type whose general position within the dike is remarkably consistent, although a given layer may show considerable variation in thickness and width. The layered structure has been a helpful and reliable guide in the prediction of ore-mineral distribution.

Most of the commercially recoverable beryl occurs in two 6-in. to 5-ft layers of quartz-microcline-muscovite-albite pegmatite, one of which lies between others are gradational, and in some bodies of very coarse-grained pegmatite they are difficult to locate within narrow limits. Even where adjacent units are mineralogically similar, however, their boundaries can be mapped conveniently on scales of 20 or 25 ft to the inch, and independent assignments of such boundaries by more than one geologist generally agree within narrow limits.

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concentration of coarse, partly albitized mica books near pegmatite-thickest parts. The beryl is white, pale yellowish green, and pinkish in color, and generally lacks crystal form. Some of the masses are extremely large, weighing 20 tons or more, and hence much of the material is readily recoverable by hand cobbing.

Immediately beneath the hanging-wall beryl-bearing layer is a somewhat thicker zone of massive quartz, which in turn grades downward into a thick zone of quartz with long, slender laths of spodumene in that are spectacularly exposed on the quarry walls as shown in Fig. 5. Irregular masses of white to pinkish beryl, ½ in. to 2 ft in maximum dimension, are locally interstitial to the spodumene laths near the base of the exposed part of this unit. The beryl is associated with white to green microcline in a few places, but nowhere in the zone is either of these minerals as abundant as the quartz. The core of the dike is a coarse-grained aggregate of spodumene, microcline, and quartz, with varying quantities of albite, muscovite, lithium muscovite, lepidolite, and tantalulum-columbite minerals. The pegmatite would have been symmetrically zoned at one time were not many of the original lithologic units in its lower half obscured or even obliterated by albitization, and locally through replacement by mica. The present distribution of rock types is marked by albitization, and locally through replacement by mica. The present distribution of rock types is marked asymmetry, see Fig. 6.

The high-grade tantalum ore consists of small crystals and grains of yellow to brownish microlite and subordinate manganotantalite in a matrix of lithium mica, or locally in quartz, spodumene, muscovite, albite, or aggregates of these minerals as shown in Figs. 7 and 8. Small masses of such ore occur in a rather well-defined belt near the center of the dike. This belt appears to be 100 to 150 ft wide, and concentrations of tantalum minerals occur through a vertical range of about 15 ft. The distribution of rich ore is very irregular in detail but is surprisingly uniform within many large blocks of ground. Individual shoots have been mined by means of irregularly branching drifts, inclines, and low rooms.

Tantalite-columbite, yellowish brown to black microlite, and minor quantities of hatchettolite are disseminated throughout the central, spodumene-rich unit in the pegmatite body, see Fig. 9. This unit consists mainly of pinkish to gray, coarse but even-grained pegmatite to which the name "spotted rock" has been applied, as shown in Fig. 8. Most of the spodumene masses are nearly equidimensional, in contrast to the spodumene laths in the zone immediately above, and they average about 1 in. in diam. They are associated with microcline, albite, and quartz. Replacement of the potash feldspar and spodumene of the "spotted rock" by lepidolite has yielded large bodies of pegmatite rich in the lithia mica. The aggregates of this mica contain numerous remnants of the earlier minerals, showing all stages of replacement. Several of the lepidolite concentrations were mined out during the period 1920 to 1930.

In general the spotted rock, or low-grade tantalum-lithium-bearing pegmatite, lies immediately west of the high-grade microlite shoots. The shape of this large rock unit, as determined by observations of surface exposures and diamond-drill cores, appears to be similar to that of a loaf of French bread, with one prominent constriction and an equally prominent vertical bulge as shown in Fig. 9. Its long axis plunges 2° to 7° SW, and thus rakes slightly westward down the gentle southerly dip of the dike. The mass is about 175 ft wide and 25 to 40 ft thick, with a long, or down-plunge, dimension of at least 750 ft from the original outcrop. Its position is reflected in some places by a broad bulge in the hanging wall of the dike, and in others by a sag in the footwall, see Fig. 6.

Although much of the tantalum and some of the beryllium and lithium minerals apparently were developed by deuteric replacement of pre-existing pegmatite, their vertical distribution is broadly controlled by the layered or zonal structure of the dike. Moreover, their along-strike and down-dip distribution is in accord with discontinuities and changes in thickness of the zones. A few small fracture-controlled replacement bodies of albite and quartz with varying quantities of beryl, microcline, tantalite, hatchettolite, and bismuth minerals transect zones and zone boundaries at distinct angles, but these bodies are not abundant and are of little economic significance.

Pegmatite deposits in the Petaca district of Rio Arriba County, N. Mex., have been sources of commercial muscovite since the seventeenth century, and some of the mines may well represent the oldest systematic operations for sheet mica in this country.
These and similar deposits elsewhere in northern New Mexico have been investigated in detail during recent years by the U. S. Geological Survey, U. S. Bureau of Mines, and other organizations.

The Petaca pegmatite bodies include dikes, sills, troughlike and funnel-like masses, and masses of more irregular shape, and are abundant in an elongate area of pre-Cambrian schist, quartzite, metachert, and granite. Most of the pegmatites are discordant, with strikingly uniform westward trends, steep dips, and moderate westward plunges. These plunges are consistently formable with those of numerous minor structural elements in the adjacent country rock, mainly the axes of drag folds, intersections of bedding and foliation planes, and axes of "stretched" phenocrysts in the metavolcanic rocks and tectonically elongated pebbles in several conglomerate beds.

Microcline and quartz, the chief pegmatite minerals, commonly form easily distinguishable zones within individual pegmatite bodies. In general, cores of massive quartz are surrounded successively by zones of coarse, blocky microcline or of massive quartz with euhedral to subhedral microcline crystals 2 ft or more in diam, and by outer zones of fine to coarse-grained microcline-quartz pegmatite with granitoid texture as shown in Fig. 10. The border selvages of a few deposits contain albite-oligoclase. Some of the cores can be traced along their strikes into veinlike masses of quartz, and offshoots from others transect the enclosing zones and continue into the country rock as thinly tabular masses. Superimposed upon the nearly concentric structural pattern of the zones are fracture fillings and tectonically controlled replacement bodies of quartz, cleavelandite, muscovite, and other minerals, either singly or in combinations, see Fig. 10. An association of book muscovite with albite, particularly the variety cleavelandite, is strikingly prevalent throughout the district. Little mica is present in deposits or parts of deposits that contain little albite, whereas all deposits rich in mica are also rich in the late-stage soda feldspar. The amount of muscovite in a given pegmatite unit generally is proportional to the amount of albite, but this relation does not always hold where the pegmatite consists almost entirely of albite. Such albite-rich units may contain the remnants of many mica books that appear to have been attacked and partly replaced by the plagioclase, see Figs. 11 and 12. There seems to be no correlation between the size of a given pegmatite body and its mica content. Both large and small pegmatites contain rich and extensive mica shoots, yet some of the largest dikes in the district are relatively barren of mica.

Concentrations of albite and mica are present in deposits of all general forms. They are most abundant at the keels and along the lower flanks of plunging dikes, and hence appear near the eastern ends of such bodies at their outcrops as shown in Fig. 13. They also are common at and near the keels of plunging troughlike bodies, which are U-shaped, hook-shaped, or boomerang-shaped in plan. The muscovite is thus most abundant at and near the main bends, which generally constitute the easternmost exposed parts of such pegmatites. On the other hand, the mica in plunging inverted troughlike bodies is most abundant near their western exposed parts and so is concentrated near and along their crests. In other less regular bodies, mica shoots commonly occur along bulges, indentations, "rolls," or junctions with branches, see Figs. 11 and 12.

The shapes of the mica shoots characteristically reflect the shape and structure of the enclosing zones, although in detail many shoots transect zone boundaries at distinct angles. In this latter respect the Petaca deposits are fundamentally different from most of the mica-bearing pegmatites of New England and the Southeastern States in which commercial concentrations of muscovite are largely restricted to specific zones and appear to have been developed earlier during formation of the zones.

Mica-bearing pegmatite has been mined extensively in western North Carolina for nearly 50 years, and this region has accounted for more than half the total domestic production of sheet and punch mica during that time. At least 3300 deposits are known to have been worked, and during the recent war period substantial quantities of mica were obtained from more than 1200 deposits. The Spruce Pine district, which occupies parts of Avery, Mitchell, and Yancey Counties in the Blue Ridge province, is the largest in North America, both in total production of mica and in the number of mines and prospects that lie within its limits. Since 1900 the output from at least 800 mines in this district has been marketed, and hundreds of other deposits have been prospected.

The pegmatites in North Carolina and adjacent states have been studied in considerable detail during recent years, chiefly by the U. S. Geological Survey and the U. S. Bureau of Mines. Most of the mica-bearing pegmatites occur in a metamorphic terrane that may be pre-Cambrian in age. The country rock comprises mica schist and
gness, impure quartzite, and hornblende schist and gneiss, with minor interlayered kyanite gneiss, silimanite gneiss, graphitic schist, recrystallized limestone and dolomite, and various types of chloritic rocks. Large masses of silicic intrusive rocks, probably late Paleozoic in age, are exposed in many areas. They range in composition from quartz monzonite to quartz diorite, and commonly are surrounded and locally transected by somewhat finer grained satellitic sills and dikes of similar composition. Most of the pegmatites that contain commercial concentrations of muscovite also are similar in composition to the large intrusive masses, and in some areas they are demonstrably related to them in genesis. Some of the pegmatites occur within, rather than adjacent to, the larger igneous masses, but they are in the minority and account for only a small proportion of the mica produced in the State.

The pegmatites are granodioritic rather than truly granitic in composition and consist of plagioclase and quartz with subordinate microcline, muscovite, biotite, and accessory minerals. Muscovite is present in some deposits as disseminated flakes, foils, and tiny books, but in others it occurs as very large books, a few of which are as much as 2 ft in diam and weigh several hundred pounds. All variations between these extremes are known, and many pegmatites contain book muscovite in a wide variety of types and forms. In general, however, the concentrations of muscovite occur within certain zones and are restricted to those zones. Thus the distribution of mica within a given deposit reflects the shape of the containing pegmatite body, although there appears to be little correlation between the size of the body and the quantity of mica within it.

Some deposits of book muscovite in the Southeastern States occur in lenses, tongues, or other pegmatite bodies that are not clearly zoned. Few such bodies are more than 6 ft thick, and many are less than 1 ft thick, see Fig. 14. In general, however, the mica deposits are in well-defined units that ordinarily are quite distinct from adjacent barren units. Their distribution is clearly governed by zonal structures. Entire zones in some pegmatites are sufficiently rich in mica to be mined, but most mica deposits are confined to certain parts of zones and hence occur as shoots not unlike the shoots of ore minerals in metalliferous deposits. The position and distribution of such shoots commonly can be correlated with the overall shape of the containing zones, or with rolls, bends, constrictions, bulges, protuberances, or other irregularities in the zones, see Fig. 15.

Only a small quantity of merchantable sheet mica is associated with fracture fillings or replacement bodies, particularly in the pegmatites of greatest output. This relation is in marked contrast to that in the pegmatites of New Mexico in which nearly all the book-mica concentrations were developed in part after formation of the respective pegmatite zones that contain them. Most of the sheet muscovite produced from the Southeastern deposits is obtained from zones near the pegmatite walls. Substantial quantities also are recovered from disseminated books in poorly zoned pegmatites, especially those that are thin and lenticular, and from concentrations along the margins of quartz cores or interior zones of coarse-grained quartz and microcline.

Detailed field studies have demonstrated that the mica within a given zone is rather consistent in color, clarity, type and distribution of structural defects, and other physical properties, whereas the books from different zones within the same pegmatite commonly differ very strikingly. Green mica with numerous ridges and crenulations, or reeves, is especially abundant along the edges of quartz cores in many pegmatites, for example, whereas the mica in the earlier-formed wall zones of the same pegmatites is cinnamon brown, brown, or brownish olive, and is relatively free from structural defects. Severely reeved mica is most abundant in the pegmatites and pegmatite zones that are rich in potash feldspar, and books of the best quality generally are most numerous in oligoclase-rich zones.

**Pegmatite Mining: Operations**

Most pegmatite mining is done on a small scale, with crews rarely comprising more than six men. Methods of mining and types of mine workings vary according to the size, shape, attitude, and degree of weathering of the deposits, as well as the type of labor and mining equipment available at the time. Nearly all mines are outgrowths of prospecting operations on promising surface exposures and thus represent enlargements of trenches, shallow pits, and small, irregular cuts. As prospect openings are deepened or extended horizontally in deposits rich enough to sustain mining activities, a change to underground operations is made. This is particularly common in pegmatites with moderate or gentle dips, or in other deposits where further open-cut work would require excessive timbering or the removal of much overburden. Crosscuts, drifts, stopes, and other openings are developed from adits, shafts, and inclines as the pegmatite is mined. Some
Fig. 16—Mica mining in kaolinized pegmatite.

Large micas books in weathered wall zone of White Peak No. 1 pegmatite, Powhatan County, Virginia. Quartz core is exposed on left wall of cut, country-rock schist on right wall.

of these underground workings follow definite patterns, but others are developed by highly irregular and unsystematic mining operations known as gophering or jayhawking. Such tortuous openings are especially common in the near-surface parts of weathered pegmatites.

Methods of mining are characteristically simple. The soft, decomposed pegmatite of numerous areas in the Southeastern States, for example, is easily handled with a pick and shovel. Crystals of muscovite, beryl, and other minerals that are resistant to chemical decay can be picked out of the kaolinized host rock, as shown in Figs. 16 and 17, and the waste material then can be hoisted away in buckets or small skips, dragged away in scrapers, or trammed in wheelbarrows or cars. The general simplicity of such operations has underlain the miners' preference for working in soft rock wherever possible, despite the constant danger of caving and the need for timbering. Timbering ordinarily is kept to an absolute minimum, and many of the workings collapse soon after they are opened.

Ordinary quarrying methods are employed in the mining of many unweathered pegmatites, even in some places where relatively large quantities of barren rock must be handled to permit recovery of marketable minerals. Irregular drifts, stopes, and additional underground workings are developed from surface openings in other pegmatites, and still other deposits are reached by means of shafts, inclines, or adits driven through the adjacent country rock. Drilling was done by hand in many of the older pegmatite mines, but during recent years, especially during World War II, portable compressors and mechanical drills have been widely used. Power hoists, motor-generator sets, high-capacity pumps, and other types of modern equipment are also employed in numerous current operations.

Stripping methods have found increased favor during recent years, both for removing overburden from gently dipping deposits and for eliminating dangerously steep or overhanging walls of cuts. Highly mechanized techniques, involving the use of drag-line scrapers, bulldozers, and power shovels, have proved effective at several deeply weathered deposits. One of the most spectacular operations of this type resulted in the removal of enormous quantities of country-rock schist from the gently dipping, mica-rich Big Bess pegmatite in Gaston County, North Carolina, see Fig. 17. More than 70 ft of overburden was successfully removed from parts of this pegmatite in 1944 and 1945, and very little blasting was necessary. Similar operations in some mica-bearing Brazilian pegmatites appear to have yielded satisfactory returns. Several weathered pegmatites in the Southeastern States have been mined by bulk methods, chiefly with bulldozers or drag-line scrapers. Most other minerals that had been left in pillars and walls of old, shallow underground mine workings were thereby recovered.

Production and Yields

The bulk of pegmatite mineral output in this country ordinarily is obtained from a relatively few mines at any given time. During the period 1942 to 1945, for example, only 83 mines in the Southeastern States qualified as very large, i.e., each of them yielded 3000 or more lb of trimmed punch and sheet muscovite. They represented only 4.5 pct of all mines and prospects in the Southeastern States from which production was obtained during that period, and yet their combined output amounted to more than 71 pct of the total from all the productive deposits as shown in Fig. 18.

In general the large and very large mica mines were operated at a profit during the period of war-time prices and other subsidies, and some of them have been satisfactory sources of commercial muscovite during other less favorable periods as well. Analyses of operating data indicate that most of these mines owe their productivity either to relatively high proportions of recoverable muscovite in the pegmatite handled, to relatively high proportions of sheet stock in the mine-run mica, or to combinations of these factors. This is in full accord with the results of similar analyses of the mica-producing districts in New England. In commenting upon the yields of sheet mica from New England mines, Bannerman and Cameron state that “there is no sharp division between rich and lean mines. Barring a price scale so low that no mines can operate, prices cannot be set that will eliminate the problem of marginal mines, and every revision of price during the war has brought a new group of mines into the marginal field.”

The relatively large number of mica mines gives great statistical value to data bearing on their production and yields. The less abundant and widespread data that are available for beryllium, lithium, and tantalum-columbium-bearing pegmatites show similar relations. Only a few beryllium-bearing pegmatites, for example, furnish the bulk of domestic beryl production, and in general the productivity of such deposits is directly ascribable to their high yields of coarse, readily recoverable beryl per ton of rock mined. Similar relations appear to obtain in the case of other pegmatite groups, the only notable exception comprising the deposits from which relatively minor constituents are recovered as by-products.

Development of Reserves

Mining operations in pegmatite deposits have been cited repeatedly as poor financial risks, owing in large measure to uncertainties arising from the
smallness and irregularity of minable concentrations of marketable minerals. Pegmatite mining traditionally has been started on promising outcrops and has been continued only until the exposed concentrations of desirable minerals were worked out or until other conditions made operations unprofitable. Thus reserves rarely are developed in advance of actual mining, and individual operations are characteristically short-lived. Moreover, the selective mining of the richest parts of mica shoots and other mineral concentrations leads to development of tortuous gopherhole workings, as well as to the leaving of much valuable material in the ground. Not only are such methods plainly wasteful, but they impose limitations on the depth to which a given shoot can be worked effectively, and they fail to uncover reserves in the form of adjacent shoots.

Uncertain market conditions, limitations of available capital, and the low margin of profit commonly obtained from the sale of many pegmatite commodities militate against aggressive exploration and development of reserves. Numerous attempts have been made and a few have been conspicuously successful, but most have antedated the accumulation of adequate structural data on the deposit being tested. In the Petaca district of New Mexico, for example, several adits and shafts were aimed at down-dip extensions of known deposits, but were developed without knowledge of the gentle to moderate plunges of those deposits. Several low-level adits that were driven to intersect productive parts of pegmatite bodies thus passed entirely beneath the keels of these bodies. Although they actually emphasize the geometric significance of the plunges involved, such disappointments nevertheless have been mentioned repeatedly in support of the thesis that pegmatite bodies are too irregular to be developed in advance of mining.

It is no accident that the exploitation of rich mica concentrations in the Petaca district downward from their outcrops has led to the development of inclines and inclined stopes that generally slope in a westward direction. It is this raking, or down-plunge, direction of mica shoots and of the pegmatite bodies themselves that plainly should receive prime consideration in the planning of future exploration and development in the district. Comparable structural features exist in other pegmatite areas, and guides for prospecting commonly can be worked out by careful analysis of each pegmatite body involved.

**Outlook**

The rate of discovery of new pegmatite deposits in this country has dwindled markedly during the past few decades. During the period of World War II, when prospecting and mining activities reached an all-time high, the proportion of mica and most other strategic pegmatite minerals obtained from deposits newly discovered was smaller than ever before. With the steadily increasing need for accurate appraisal of pegmatites and pegmatite groups, it has therefore become more and more necessary to focus attention on mineral concentrations not exposed at the surface and upon those only partly mined out during earlier periods of activity.

Serious problems generally confront the operator who considers reopening a pegmatite mine. The workings of many mines are inaccessible, owing to flooding, boulders, or fouling with tons of backfill. For many mines, maps are not available, and reports concerning the size and distribution of workings are incompletely or inaccurately. Production and cost data rarely are complete and reliable, and often deposits must be judged solely on their general reputation among local residents. Ordinarily it is difficult to determine whether previous mining was discontinued because of intrinsic shortcomings of the deposit, poor planning or inefficiency of operations, or market conditions, or because of other factors, and it is frequently impossible to contact former operators for discussion of such matters.

Available surface exposures of pegmatites generally are little more satisfactory than mines for furnishing readily usable information. Few contain promising shoots of mica or other desirable minerals, and many are so small or discontinuous that they do not provide a clear picture of the pegmatite or its structure. Other outcrops, however, can be used to determine the internal structure of the pegmatite body and hence to determine the probable existence or distribution of mineral concentrations.

Despite the numerous difficulties involved, prediction of future possibilities for pegmatite mining is far from a hopeless task. The recent war period of high prices and subsidies led to an unprecedented expansion of pegmatite mining and prospecting in this country. Of necessity, much was done hastily and unsystematically, but opportunities for the study of pegmatites and pegmatite deposits in three dimensions were provided on a broader scale than ever before. It was possible to record and collate data on internal structure of the deposits, lithologic sequences in certain kinds of pegmatite bodies, types of book mica and other minerals, and many other features of direct or indirect economic application. More maps and detailed sections were obtained during the short period of wartime activity than had been accumulated throughout all preceding periods. The advantages of such maps and diagrams in planning and executing future operations are evident.

After they were opened during World War II, some pod and lenslike pegmatites were found to have been essentially mined out during previous periods of activity, but the mine workings in a great many other pegmatites are now known to be short of the limits of workable mineral concentrations.
Large quantities of mica and other minerals were recovered from old fill, from pillars, and from thin skims of unmined pegmatite in some deposits; and recent operations in others were successful in part because of favorable market conditions and in part because of improvements in mining techniques over those previously used.

Methods of prospecting and early-stage development were much improved, especially in regions of thoroughly weathered rocks. Judicious search for pegmatite in areas of abundant float mica flakes or quartz blocks was accomplished by means of shallow trenching, deeper trenching with bulldozers or drag-line scrapers, and boring of test holes with hand augers. Such methods also were successful in many of the deeply weathered pegmatites of Brazil.

The need for adequate surface exploration in advance of extensive underground development was repeatedly demonstrated, and it was further shown that the diamond drill can be an effective tool if its use is directed in close accord with known structural features of the pegmatite body being tested. Numerous blank holes bear testimony to the risks of over-enthusiastic extrapolation from inadequate surface or subsurface data. Moreover, drill cores rarely provide satisfactory information on such features as the size and quality of mica books, coarseness of beryl, and general grade of the pegmatite. Nevertheless, the drill is valuable for locating extensions of known shoots or other lithologic units in pegmatites, or even for locating adjacent pegmatite bodies or shoots not elsewhere exposed and hence is useful in gathering data for rough calculations of reserves. In general, drill cores are most helpful if they are carefully interpreted in the light of structural and lithologic information from more complete exposures nearby.

Few pegmatites are completely exposed in three dimensions, so mineral shoots and incomplete zones may escape detection, either through lack of exposure or through removal by erosion, see Fig. 4. Commercial concentrations of pegmatite minerals rarely are coextensive with the pegmatite bodies that contain them, and hence they may lie undetected beneath the surface. In summarizing the structure of New England mica deposits, Bannerman and Cameron state that the "pegmatites are mostly intrusive, sive lenses, which . . . . occur . . . . at various levels with respect to the present erosion surface. Erosion has removed only the tops of some bodies, while others have been partly or almost entirely removed. If only the crest of a lens is exposed, whereas the minable mica-bearing zone is developed only along the flanks or keel, the pegmatite will be barren in surface exposures." Such relations undoubtedly are very common in most pegmatite districts, and hence hold considerable promise for future development of reserves of commercially desirable minerals.

Future operations in pegmatite districts might well be more efficient and less costly if conducted on the basis of extensive geologic data. Although there are few present criteria for recognition of workable concentrations not exposed at the surface, it commonly is possible to identify those pegmatites that offer little promise; hence they can be profitably eliminated from programs of exploration and development. The other deposits can be explored by means of trenches and test pits, and subsequently by diamond drilling and additional subsurface means if the results of the earlier work are sufficiently encouraging.

The history of mining in most pegmatite districts clearly indicates a correlation between activity and market conditions. Periods of great demand, high prices, and intensive mining are separated by longer periods of lower prices and small-scale, often sporadic, activity. The low production levels during these longer periods plainly are not caused by dwindling reserves or by suddenly increased difficulties in exposing additional shoots of commercial minerals. Thus, if market conditions appear to justify an increased production, attention might well be directed toward continuous operation of those mines known to yield the most return per unit of rock moved.

More efficient methods of mining, systematic recording of data on costs and yields for all parts of the mine, the recovery of larger proportions of the mineral shoots, and the simultaneous recovery of more than one marketable product should greatly increase the chances for successful operations. More systematic and efficient mining might well be the result of a shift in attention from high-grade, pocket deposits to more extensive and continuous deposits of somewhat lower grade. The latter would lend themselves more readily to exploration in advance of mining, and efficient methods of mining and milling might lead to profitable operations. Careful mineralogic study of pegmatites and lithologic units within pegmatites is of great potential value, especially for recognition of recoverable byproducts. The possibilities for tantalum production from the Harding pegmatites, for example, might well have been recognized years ago if mineralogic studies had been carried on during the period of lepidolite mining. Studies of placer deposits, particularly those derived from pegmatites not previously worked, should yield information of possible value, so far as future mining of the heavier pegmatite minerals is concerned.

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