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THE GEOLOGY OF KYANITE, ANDALUSITE DEPOSITS
GOAT MOUNTAIN IDAHO AND PRELIMINARY BENEFICIATION TESTS ON
THE ORE

By

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MOSCOW, IDAHO
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THE GEOLOGY AND PRELIMINARY SEPARATION TESTS ON
KYANITE AND ANDALUSITE DEPOSITS, GOAT MOUNTAIN, IDAHO

ABSTRACT

On the south slope of Goat Mountain, Idaho, in strongly metamorphosed rocks of the pre-Cambrian Belt series there are three zones that contain potentially commercial deposits of kyanite and andalusite. Two of the zones are kyanite-andalusite mica schist; the third one is andalusite gneiss. The aluminum silicate minerals were probably formed during regional metamorphism of the Belt sediments, more or less contemporaneously with the formation of the Idaho batholith a number of miles to the south, but probably not as contact metasomatic products of the intrusion. Other rocks include garnet amphibole, anorthosite and garnet mica schist.

Tonnage estimates of the amount of aluminum silicate minerals in the three zones, assuming an open cut mining depth of 50 feet, total 341,000 tons.

Preliminary batch tests have indicated that the kyanite in the rock would be amenable to flotation concentration. Rougher concentrates varying from 70 to as high as 90 per cent kyanite have been made with recoveries in the range of 80 to 85 per cent. These tests have also indicated that it should be possible to selectively float a fairly clean concentrate of mica in addition to the kyanite product.
PART I

THE GEOLOGY OF Kyanite, Andalusite Deposits, Goat Mountain, Idaho

INTRODUCTION

Purpose and Scope

This section of the report presents the results of approximately two weeks geologic field work on deposits of kyanite and andalusite by Agatin T. Abbott during the month of August, 1953. The purpose of the geologic examination was to confirm reports of kyanite and other aluminum silicate minerals in the Goat Mountain area of southern Shoshone County, Idaho; and to map the deposits in order to determine their extent, geologic relationships and ore content.

A geologic and topographic map of the Blackdome Mining Co. property was constructed, on the scale of 1 inch to 200 feet, using as control a closed Brunton compass - pace traverse to which auxiliary compass traverses were tied. The closed traverse is 10,168 feet in length and before correction failed to close by 120 feet. Elevations were determined by a Paulin altimeter calibrated to one foot. Before the survey was begun, temporary bench marks were established at convenient intervals in the area after repeated checking. The bench mark taken as datum is at the base of the U. S. Forest Service Lookout tower on the summit of Goat Mountain. The elevation at this point, as shown on the BooHs Butte quadrangle, is 6,375 feet above sea level.

Location and Access

The area is located on the southern flank of Goat Mountain and Blackdome Peak in the southern part of Shoshone County, Idaho, approximately four miles north of the boundary between Shoshone and Clearwater Counties. This region lies 35 air line miles south of the town of Hullan which is in the famous Coeur d'Alene mining district. The eastern part of the area is within the St. Joe National Forest and the western part is on Idaho State land. The deposits are mostly within Sec. 16 and in parts of Sec. 9 and 15, T. 42N., R. 5E., Boise Meridian. The latitude is 46° 59' N.; the longitude is 115° 50' W.

The area is approximately in the center of the "Panhandle" of northern Idaho, an undeveloped, unsettled, mountainous region. By either of two routes access to the property is difficult. From Clarkia, Idaho, a small settlement and railhead 32 miles to the east, the area is reached by a narrow, crooked mountain road. From Elk River, Idaho, the property is reached over the Diamond Match road, which is owned by the company whose name it bears, and is usually closed to public travel. It is 26 miles by this road from Elk River to BooHs Cabin, which consists of several buildings and facilities maintained by the
Potlatch Forest Protective Association as a fire camp. Boehls Cabin is the nearest place to Goat Mountain to obtain lodging and meals. From Boehls it is 16 miles to the area over a steep winding road that climbs 5000 feet. During wet weather this road and most of the others within the district are dangerous and may be impassable. From November through June the property is inaccessible due to snow.

Topography, Geomorphology and Drainage

The topography in this area is similar to that of many parts of northern Idaho and generally conforms to the physiographic pattern of the northern Rocky Mountain Province. The relief is high, the hillslopes are steep, and the summit areas are more or less rugged, but do not form outstanding peaks. The elevation at Boehls Cabin, at the junction of the Little North Fork of the Clearwater River and Stanton Creek is 1500 feet; the elevation at Goat Mountain Lookout is 6375 feet above sea level, a difference of 4875 feet. The crest of the rugged Bitterroot Range, which forms the boundary between Idaho and Montana, lies 40 miles east of Goat Mountain.

From study of the landscape from a high point of observation, such as the Goat Mountain Lookout, it is evident that most of the relief in the region is negative. That is to say, the general level of the upland surface, as marked by the summits of the mountains would, if shown in profile, present a rolling surface, sloping to the south. There are few peaks that rise appreciably above this reconstructed theoretical surface. The great changes in elevation that occur below this plane have been brought about by downcutting of the streams due in most part to rejuvenation of the region that has continued intermittently through the Tertiary period. Anderson has found at least three erosion surfaces, and proposes that the highest one was formed in late Cretaceous time.

The area lies within the general drainage of the Clearwater River. The south-flowing tributaries of the Clearwater that extend into this region are the North Fork of the Clearwater, the Little North Fork of the Clearwater, Floodwood Creek, and Cedar Creek. During the spring when the snow is melting rapidly these streams carry enormous volumes of water; and during high water logging companies float timber down the North Fork to mills at Lewiston, Idaho.

Previous work

Parts of Shoshone County north of the present areas were mapped during reconnaissance surveys by Collier in 1905 and by Hayes and Lindgren in 1910.
It was not until recently that the aluminum silicate minerals on Goat Mountain were reported. The first person to realize their potential value was Mrs. Anna Histenan of the U. S. Geological Survey, who was conducting a large scale study of the metamorphic rocks in northern Idaho. During the summer of 1951 Mrs. Histenan mapped these rocks and mentioned their possible commercial importance to six men who were camping in the area and who were familiar with it. These men, who will be named shortly, located the ground by staking six lode mining claims and by filing a 640-acre State of Idaho mineral lease. (See claim map).

Geologists of private mining companies and engineers from the U. S. Bureau of Mines inspected the area last summer, but to the writer's knowledge have published nothing on their work.

**FLORA AND FAUNA**

The thick, lush, primeval forest of the lower slopes and valleys is not present in the higher elevations, where the aluminum silicate minerals are exposed. The principal tree in the high elevation is alpine fir. In the valleys, the forests contain Douglas fir, spruce and cedar.

The large animals in the area are deer, bear, elk and cougar.

**ACKNOWLEDGMENTS**

The writer is indebted to the owners of the claims who not only allowed access to the property but extended their hospitality as well. The original locators and owners of the Blackstone Mining Company are: Fred Crowe, John Denoo and Lewis Denoo of Tekoa, Washington; and Gordon Leuty, Clarence Isabel and Harry Kammerzell of Desmet, Idaho.

The writer also wishes to acknowledge the aid received from Dr. H. F. Yancy and Mr. Hal Kelley of the U. S. Bureau of Mines Experiment Station in Seattle, Washington, in testing the refractory properties of the aluminum silicate minerals.

**GENERAL GEOLOGY**

**INTRODUCTORY STATEMENT**

The rocks containing the aluminum silicate minerals are strongly metamorphosed sediments of the Belt series (Prichard formation?) which is pre-Cambrian in age. The kyanite and andalusite, which may occur together, are in
biotite schist with minor garnet, which grades into biotite paragneiss. The andalusite gneiss of one zone contains only small amounts of biotite or garnet and no kyanite. Other rock units in the vicinity are anorthosite, apparently of replacement origin, and garnet amphibolite, which has probably been metamorphosed from dikes of igneous rock of basic or intermediate composition, that intruded Belt sedimentary rocks previous to their metamorphism. The main body of the Idaho batholith, as shown on the geologic map of Idaho (1947) lies about 8 miles south of Goat Mountain.

A marked increase in the degree of metamorphism from the Coeur d'Alene mining district south to the region of the Idaho batholith has been described by many workers. In 1905, A. J. Collier noted:

"In the northern part of the district (the Coeur d'Alene mining area) the rocks are unaltered and only the softer beds are affected by slaty cleavage. In the southern part, however, from the St. Joe River to the southern limit of the region examined, the rocks become progressively more schistose, the softer beds being altered to mica schist, often studded with garnet and staurolite. All gradations between the unaltered sediments of the northern part of the district and these schists can be observed."

In 1923, J. B. Umpleby and E. L. Jones mapped portions of Shoshone County and, although their work did not include the immediate area of Goat Mountain, they show Prichard formation to the east and west. On the basis of Umpleby's and Jones' maps the metamorphic rocks on Goat Mountain are tentatively placed in the Prichard formation.

**ROCK UNITS**

**Anorthosite**

The anorthosite of the Goat Mountain area is a light gray rock possessing a poorly-defined gneissic structure. Magascopic examination with a hand lens reveals that the mineral composition is approximately 90 per cent plagioclase feldspar. The foliation is accentuated by alignment of scattered specks of dark minerals, mostly hornblende. The weathered surface of the anorthosite is particularly distinctive because it consists of parallel, closely-spaced, corrugations that reflect the foliation and project 1 to 2 mm, above the surface of the rock. This phenomena may result from differential weathering of closely-spaced, mylonitic zones.

Microscopically, the anorthosite consists of a confused and indistinctly foliated mesh of plagioclase anhedra and minor amounts of hornblende, epidote
and clinocoidsite. That shearing stresses were intense is shown by the many zones
of mylonite which consist principally of crushed grains of plagioclase feldspar,
and cleavage spindles of hornblende which have been torn loose from the parent
 crystal and strewn for 5 to 10 millimeters along the mylonite zones. Recrystall-
ization of the feldspar fragments within these zones is common. Broken crystals
of plagioclase that show twinning are identified as calcio andesine. Later
feldspar selectively replaces earlier grains. The boundaries between the earlier
and later plagioclase anhedral are complexly sutured. The latter feldspar is
untwinned. It is bielacial positive and the index of refraction indicates a
composition of labradorite. This later feldspar is less altered and not severely
crushed. Hornblende is the principal mafic constituent. It comprises approx-
imately 5 per cent of the rock. Replacement of hornblende by plagioclase is
very marked. The hornblende may be uralitel, but if it is, the original pyroxene
has been completely altered and no trace remains as corus in the hornblende.
The hornblende is fairly fresh and shows no alteration to biotite or chlorite.

Epidote and clinocoidsite together comprise approximately 5 per cent of the
rock. Most of the crystals of epidote and clinocoidsite are subbedral and show
no effect of cataclasis, indicating that they formed after the main shearing
stress had ceased. Some of the epidote grains display a poikiloblastic texture,
resulting from growth along intergranular boundaries of the plagioclase, and
from encroachment and incomplete replacement of plagioclase grains.

Because feldspathization has completely altered the fabric and composition
of the original rock it is uncertain whether the anorthosite was derived from an
igneous or sedimentary source. The field relationships show that if it was
igneous it was not intrusive. It may have been a tuff or flow of intermediate
basic composition. If the rock was originally sedimentary, it may have been a
calcareous, argillaceous sandstone.

About 5 miles north of the present area outcrop of anorthosite have been
briefly described by Hayes and Lindgren. Outcrop of this work may be traced to
Goat Mountain and unquestionably represent the same unit. These early workers
classed the anorthosite as intrusive - "with a gneissoid texture due to streaking
out of hornblende and other dark minerals." The anorthosite in the area studied
shows no intrusive characteristics, structural or lithologic.

Mrs. Hictoman said that she found anorthosites that are similar to those
in the Goat Mountain region over wide areas in Shoshone and Clearwater Counties.
She suggested that the anorthosite may grade into quartzite north of the Goat
Mountain area and that she has noted microscopically in some specimens that relics of
quartz grains are enclosed in plagioclase crystals. In describing the metamorphic
processes in the general region north of the Idaho batholith, Mrs. Hictoman states:

"The main folding was accompanied by small intrusions of gabbro,
diorite, and tonalite, intense metamorphism, and metasomatic

"introduction of hornblende, biotite, andesine, and accessaries. Locally, a second period of metasomatism obliterated the folded structures and is interpreted as having caused the formation of monomineralic rocks like hornblondites and anorthosites. This second period of metasomatism may be contemporaneous with the emplacement of the quartz dioritic border zone of the batholith. Small intrusions of tonalite west of the batholith and the rocks of the quartz monzonite series in the center and north of the batholith were emplaced after the second period of metasomatism."

"Chemical analyses show that mainly silica was expelled and Fe, Mg, Al, Ca, and Ti were introduced during the metasomatism."

**Garnet Amphibolite**

Two zones trending north-south through the area (See geologic map) are composed of coarse-grained amphibolite containing local concentrations of red garnet. The amphibolite is usually foliated. Megascopically, the amphibole appears to be hornblende, but microscopic examination shows that it is probably pargasite (See below). The amphibolite bodies appear to crosscut the general trend of the other metamorphic rocks in the area and are believed to be dikes that were originally intermediate to basic in composition and have been converted to garnet amphibolite during the metamorphism that produced kyanite-andalusite mica schists and biotite paragneiss from the sedimentary beds.

Hayes and Lindgren noted numerous dikes of diabase in the northern part of the St. Joe River basin. In the southern part of the basin they reported that the dikes had been converted to amphibolite and that the farther the dikes extend toward the border of the Idaho batholith the more complete was the conversion. Hayes and Lindgren state:

"Of all the igneous rocks diabases have suffered the most radical change of texture and mineral constitution. Where metamorphism is thorough, the diabase is altered to a black, schistose amphibolite studded with red garnet."

Microscopically, the rock is composed mostly of aligned, elongate crystals of amphibole which is not ordinary hornblende. The mineral is biaxial positive, possesses an extinction angle of about 130°, is colorless to pale pinkish brown and plain light, and is slightly pleochroic. It is probably pargasite, an amphibole resembling hornblende microscopically, but possessing somewhat different optical properties.

The garnet shows an extremely poikiloblastic texture. Relics of minerals included within the anhedral garnet porphyroblasts are not aligned with the foliation of the amphibole around the porphyroblasts, suggesting rotation of the
garnets during or following their formation. A strange relation exists between quartz and garnet. On the "loe side" of many garnet crystals there are wedge-shaped clusters of quartz crystals. It is as though the garnet were a cannon ball shot into the amphibole minerals which are compacted in front and the "slip stream" is marked by quartz. This is probably a result of metamorphic differentiation of the silica.

Plagioclase and biotite are minor minerals as inclusions in the garnet.

**KYANITE-ANDALUSITE MICA SCHIST**

Because in two general areas kyanite and andalusite are closely associated in the same rock they will be discussed together. The two minerals are rather easily distinguished in the mica schist in which they occur by the following properties:

<table>
<thead>
<tr>
<th>Kyanite</th>
<th>Andalusite</th>
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<tbody>
<tr>
<td>Small crystals - one inch</td>
<td>Larger crystals - 12 inches</td>
</tr>
<tr>
<td>maximum length</td>
<td>maximum length</td>
</tr>
<tr>
<td>Transparent to sub-transparent</td>
<td>Translucent</td>
</tr>
<tr>
<td>Colorless or bluish tinge or blue spots</td>
<td>Light gray color occasionally pinkish</td>
</tr>
<tr>
<td>Perfect cleavage parallel to (100) and cross parting</td>
<td>Cleavages less well developed</td>
</tr>
<tr>
<td>Crystals may be curved</td>
<td>Straight crystals, rectangular cross sections</td>
</tr>
<tr>
<td>Oriented parallel to foliation of rock</td>
<td>May be oriented in any direction</td>
</tr>
<tr>
<td>Hardness 4 parallel to length of crystal and 6-7 transverse to length</td>
<td>Hardness about 6.5 regardless of direction</td>
</tr>
<tr>
<td>A few inclusions of country rock</td>
<td>May contain abundant inclusions of mica usually parallel to length of andalusite crystal</td>
</tr>
</tbody>
</table>

Kyanite and andalusite have the same chemical formula, Al₂SiO₅. Kyanite crystallizes in the triclinic system, andalusite in the orthorhombic system.
There are four restricted zones of kyanite-andalusite schist within the two general areas mentioned above. Three parallel zones outcrop on the east side of the large mass of garnet amphibolite. The fourth zone is on the west side of the amphibolite, and its strike does not parallel that of the other three. It is represented by large boulders of kyanite-andalusite schist that are probably residual. The three zones on the east side of the amphibolite will be considered first.

The upper of the three kyanite-andalusite schist zones is exposed along the north side of the road east of the contact with garnet amphibolite. Although the top and bottom of the kyanite-andalusite bearing schist are not exposed the thickness is probably about 20 feet. The visible length is approximately 1400 feet. The general strike of the foliation is N. 50° W., and the dip is 30° NE. Bedding planes have been destroyed during metamorphism, but the strike of the bedding was probably not greatly different from the direction of foliation. This fact is illustrated by parallelism of planes of foliation and distinctive layers (such as garnet-rich bands) within the rock which probably result from varying composition of the banded sediments. The upper zone of kyanite-andalusite schist contains more garnet than other exposures within the area. The garnet is red, poorly transparent, often chocked with inclusions and is identified as the iron-aluminum variety, almandite. The distribution of garnet locally along this zone may explain the distinctive differential weathering effects in the boulders. (See Plate 1). Kyanite and andalusite are less abundant in this upper zone than in other occurrences to be described. The average kyanite-andalusite content probably does not exceed 10 percent.

It should be explained that the percentage content of the aluminum silicate minerals in their containing rocks is based on visual examination of the weathered rock surface, and estimation of the volume percentage of the aluminum silicate minerals. This type of estimation is readily made and is fairly accurate, because the minerals are more resistant than the rock matrix and project from the weathered surface in the distinct shapes of crystals or as irregular-shaped knobs. (See Plate 2).

The middle kyanite-andalusite-schist zone east of the garnet amphibolite is separated from the upper zone by a band of muscovite mica schist containing small rod garnets. This barren zone is concordant with the kyanite-bearing schists above and below and contains minor kyanite or andalusite. The zone is approximately 25 feet thick. The middle zone of kyanite-andalusite schist extends about 1000 feet and strikes generally N. 50° W., except near the amphibolite, where the strike is E-W. The dip varies locally, but it averages 50° NE. Kyanite and andalusite are quite abundant in this zone, the average content being approximately 20-25 percent. Near its west end the zone is covered. It may be traced principally by kyanite crystals in the soil. Very locally in an exposure on the north side of the road between stations N and N coarsely-grained hornblende and kyanite are in close association. This place
Plate 1. Differential weathering in mica schist containing kyanite, andalusite, and garnet in an outcrop above the road northeast of station O.
Plate 2. Andalusite crystals weather out of the rock matrix.
probably marks the contact between the smaller garnet amphibolite dike and the kyanite-andalusite schist. Nothing else in the area do kyanite and hornblende coexist in the same rock. Because of heavy soil and forest cover the kyanite-andalusite schist cannot be traced to the southeast beyond this point.

The thickness of the middle zone cannot be determined because the lower portions are obscured by an apron of soil and talus through which the road from stations C to I is cut. The soil contains high concentrations of kyanite and andalusite crystals that have weathered out of the two zones upelope.

Below the road there is a third zone of kyanite-andalusite schist that contains abundant aluminum silicate minerals, but the formation is not exposed over as great a length as the two higher zones (those previously described). It is probable that this zone extends between the two amphibolite bodies. Visible out-crops extend for approximately 500 foot along the strike which is N. 70° W. The dip is 30° NE. Kyanite-andalusite content of this zone, which is about 30 foot in thickness, is roughly 25 per cent.

Kyanite-andalusite schists west of the large garnet amphibolite mass are less well-defined than those to the east, but the rocks that are exposed contain higher percentages of the aluminum silicate minerals. The outline and extent of this body is somewhat vague, being marked by large scattered boulders some of which are 40 foot in length. Close examination of the boulder-like out-crops reveals that they are undoubtedly residual in origin, and, if they have been moved at all, rest very close to their original location. Rotation of some of the smaller boulders is evident from the divergence of strike from that in the large ones.

The geologic map shows that the strike of the foliation and the general trend of the outcrops on the west side of the amphibolite mass is more northerly than the strike of the zones on the east side. The average strike is about 25° N.W and the dip about 30° NE. After the kyanite-andalusite schist crosses the ridge, it assumes the approximate strike of the body east of the amphibolite and continues for some distance north of the mapped area. The divergence of strike noted above may have been caused by the forceful intrusion of the dike (diabase?) which rotated the block on the west side. The divergence may also be due to post-intrusive faulting along the schist-amphibolite contact. Because the actual contact is covered, the true cause of the divergence in trend cannot be determined at the present time.

In the boulder-shaped outcrops, the kyanite and andalusite are plentiful. Locally the aluminum-silicate minerals compose 80 per cent of the rock. (See Plate 3). As an average, the kyanite and andalusite probably comprise 40 per cent of the rock. The upper and lower boundaries of this zone are indefinite; however, it can safely be estimated that the kyanite-bearing zone is 50 foot in width. The extent to the south of this zone is not known because forest growth and soil mantle the surface.
Plate 3. Andalusite and kyanite crystals in a large boulder south of station Y.
-11-

Microscopically, the schist contains subhedral crystals of kyanite and andalusite. In thin sections examined andalusite is more abundant than kyanite. Other minerals are plagioclase feldspar, muscovite, biotite, quartz and garnet. Feldspar is moderately abundant and usually occupies intergranular openings and occurs as inclusions in andalusite. Some feldspar grains are untwinned and biaxial positive. Twinned grains of plagioclase have a composition of calcic oligoclase. Of significance is the fact that the rock and minerals as a whole are very fresh. There is no tendency of the andalusite or kyanite to alter to muscovite; the biotite is not going to chlorite; and the feldspar grains are clear.

ANDALUSITE GNEISS

Approximately 2200 feet southeast of the prominent saddle shown on the topographic map a zone of andalusite gneiss is exposed at the foot of the steep cliff walls that form Blackdome Ridge. On the west side the andalusite gneiss is separated from the kyanite zones described earlier by anorthosite. East of the andalusite zone, Blackdome Ridge is composed of garnet-rich muscovite schist and contains no aluminum silicate minerals. The rock composing Blackdome Ridge is composed of garnet-rich muscovite schist and contains no aluminum silicate minerals. The rock composing Blackdome Ridge resembles the garnet-mica schist that lies between the upper and middle kyanite schist zones on the east side of the large amphibolite body.

The andalusite gneiss is easily identified in the field by its knobby weathered surface (See Plate 4). The knobs are large clusters of fibrous, radiating, spindle-shaped andalusite crystals. Because of this fibrous structure the mineral was tentatively identified in the field as sillimanite. Microscopic examination shows that it is andalusite.

The color of the weathered surface of the rock is uniformly light gray. Biotite is the principal mafic mineral, but it is not abundant. Garnet is exceedingly scarce. Muscovite, feldspar, and quartz compose the rest of the rock matrix between knobs of andalusite. The gneissic texture is imparted to the rock by pinching and swelling of the imperfectly foliated rock matrix around the clusters of andalusite.

The zone of andalusite gneiss strikes generally S. 50° E. and dips 50-70° NE. The top and bottom of the zone are obscured in most places, but the thickness is at least 30 feet. Good exposures are available for inspection at intervals along the zone which may be followed for about 1000 feet. North of the ridge line shown on the geologic map the extension of the andalusite gneiss is covered by thick forest. Near the southern end of the zone the andalusite-rich zone disappears beneath talus from Blackdome. The average andalusite content in this area is about 30 per cent.

Over one-half mile southeast of the place where the andalusite gneiss is
Plate 4. Andalusite gneiss near the road to Indian Dip. The knobby surface is produced by differential weathering; each knob is a cluster of small andalusite crystals.
covered by talus from Blackdome, the gneiss reappears, but this time in two zones. The road from Goat Mountain to Indian Dip crosses the outcrops approximately 0.9 mile southeast of station L (See map). It is probable that these zones are continuous with the one that disappears beneath the talus from Blackdome Peak. A southeast-trending strike fault along the edge of a small ridge is responsible for duplications of the beds. The andalusite clusters are abundant in this locality. The rock is free from garnet and contains only minor amounts of mafic minerals.

Thin sections cut from the protruding knobs of andalusite are composed 95 per cent of andalusite. The mineral grains show poliklinalastic texture, the inclusions being small spots of muscovite and quartz which make up the other 5 per cent of the cluster. The rock matrix between the knobs which protrude from the weathered surface is also high in andalusite, but contains in addition variable amounts of muscovite, biotite, staurolite, quartz and unmixed plagioclase. Andalusite comprises about 50 per cent of this matrix material. Kyanite is absent from thin sections examined.

**Origin of the Aluminum Silicate Minerals**

There are two opposing theories on the origin of some aluminum silicate deposits. One theory proposes that most aluminum silicate deposits are formed by magmatically derived aluminum-rich hydrothermal solutions which percolate the country rock and by contact metamorphism are responsible for the formation of one or more of the aluminum silicates. This theory is apparently championed by Stuckey, although there are many other workers who explain the genesis of some deposits by this method. Some who have found this to be the origin include Perrotte near Troy, Idaho, Stuckey[12] in North Carolina, Korn[12] near White Mountain, California, Kunheim[13] in the Mackaibo Mountains in California, Hash and Van Horn[11] in North Carolina and Pucron and Teague[12] in Georgia.

The other theory proposes that the aluminum silicate minerals are developed under more or less isothermal conditions, or at least that magmatically derived solutions are not necessary to form deposits of the aluminum silicates. This genetic interpretation is championed by Dunn[12] who cites work in California, North Carolina and northern India.

In the Goat Mountain area deposits of the aluminum silicates do not seem to be located with strict respect to any igneous intrusion. The great mass of granitic and metamorphic rocks that compose the Idaho batholith lies a number of miles to the south of this area. If addition of material from the batholith had any influence on the formation of the aluminum silicate minerals, zoning, or concentration of minerals along channelways that might have transported magmatic juices, cannot be recognized. There is no increase in the content of aluminum silicate minerals toward the batholith, nor was any other lithologic
or mineralogic change observed that could be interpreted as contact metasomatic. The intrusion of the diabase dikes that are now garnet amphibolite had virtually no effect on the country rock. The lithology of the kyanite-andalusite mica schists is the same at the contact with the amphibolite as away from it. Hayes and Hindgron noted this fact farther north, for they stated:

"... diabase now altered to ... amphibolite, but these have suffered more metamorphism than they caused. The diabase, where it occurs apart from other intrusive rocks, can be seen to have caused relatively slight metamorphism."

There are no other igneous bodies within the immediate area that might have supplied metasomatizing solutions.

In the Goat Mountain area it is probable that the aluminum silicate deposits were formed during and after regional metamorphism, perhaps more or less contemporaneously with the formation of the Idaho batholith, but with little addition of material metasomatically from igneous sources. Kyanite, a stress mineral, formed synkinematically and the andalusite, an anti-stress mineral, formed after the major regional stresses had ceased. The andalusite apparently did not form pre-kinematically, as there are no andalusite crystals that have been cataclastically shattered.

The concentrations of the aluminum silicates follow parallel zones that are highly suggestive of original bedding. It is probable that the kyanite-andalusite zones were formed from comparatively pure argillaceous sediments high in alumina whereas the intervening zones barring of aluminum silicate minerals, were higher in iron, magnesium and calcium. There is no evidence of change of metamorphic facies around a center as might be the case if an intrusive body were the cause of metamorphism and metasomatism. All the rocks in the area are in approximately the same metamorphic facies, and have undergone approximately the same degree of metamorphism. The difference in present lithology is best explained as the difference in original sedimentary composition, and the aluminum silicate-bearing zones as being originally alumina-rich, sandy argillites.

RESERVES AND MINING

The Goat Mountain kyanite-andalusite bearing rocks contain an enormous amount of aluminum silicate minerals. The following estimates of tonnage are based upon the extent of the zones as shown on the accompanying geologic map. Unquestionably the zones continue beyond the boundaries of the map, and they may be more extensive within the area, but are obscured by surface cover. An arbitrary depth of 50 feet is used in the tonnage calculations although there
is probably no change of rock composition at greater depths.

The percentage of aluminum silicate minerals is estimated from visual inspection of the volume of those minerals in the rock. In computing tonnages the andalusite gneiss is assumed to weigh about 185 pounds per cubic foot; the kyanite-andalusite schist about 170 pounds per cubic foot. The specific gravity of the aluminum silicate minerals is approximately 3.2.

The andalusite gneiss beneath Blackdome and Blackdome ridge is exposed over a linear extent of 1900 feet including the two segments that outcrop 0.7 of a mile to the southeast along the road to Indian Dip. The average width of this zone is 30 feet and the estimated average content of andalusite is 30 per cent. This zone contains 87,000 tons of andalusite.

The three zones of kyanite-andalusite schist east of the main mass of amphibolite have a combined linear extent of approximately 3100 feet. The average width of each of the zones is 25 feet and the estimated average content of aluminum silicates is 15 per cent. This zone contains 177,000 tons of aluminum silicates.

The zone on the west side of the garnet amphibolite has irregular and poorly defined boundaries, consequently the estimates of its size are very approximate. The length of the zone is 1200 feet, the width 50 feet. The average content of aluminum silicate is 25 per cent. This zone contains 77,000 tons of aluminum silicates.

The total tonnage of aluminum silicate minerals, assuming a 50-foot mining depth in all zones, is 341,000 tons.

The deposits can readily be worked by open-cut methods. The amount of overburden to be stripped is negligible; in fact, the soil overlying the ore zones contains high concentrations of the aluminum silicate minerals and could probably be processed. At the present time two localities appear more favorable than the others for beginning production because of higher grade of ore and ease of accessibility. These are in the andalusite gneiss on the Indian Dip road, and in the kyanite-andalusite schist zone of residual boulders above and below the road on the west side of the garnet amphibolite.

USES

The products of the aluminum silicate minerals have a wide range of uses. Some of the uses as listed by Riddle and Foster are given here: a host of the refractory products used by the metallurgical, enameling, glass, ceramic, chemical, electrical and cement industries; spark-plug insulators, expansion
sleeves, pyrometer protection tubes, extrusion dies, mill balls and mill linings.

Recent experiments with high-temperature jet and rocket engine linings have indicated the aluminum silicates may be effective in this field.

Experimental work is currently underway by one of the major mining and smelting companies to produce aluminum from aluminum silicate ore.
BIBLIOGRAPHY

3. ________, op. cit. p. 131.
9. ________, op. cit. p. 45.
10. ________, op. cit. p. 50.
11. Hietenan, Anna, oral communication.


PART II
PRELIMINARY SEPARATION TESTS ON THE KYANITE SCHIST FROM
GOAT MOUNTAIN, SHOSHONE COUNTY, IDAHO

INTRODUCTION

The primary purpose of the tests described here was to determine whether the kyanite\(^*\) in the schist rock from Goat Mountain could be concentrated by flotation. The sample on which the work was done consisted of about 400 lbs. of rock that was provided by the claim holders. Individual pieces ranged up to a foot or more in diameter, many of them being characteristically tabular in shape.

Visual examination indicated that in some of the pieces, fairly large bladed crystals of kyanite were quite abundant and readily observed. In others the crystals were much smaller and more sparsely scattered and some of the rock apparently carried little or no kyanite. Biotite mica, feldspar and quartz were the principal gangue minerals present. No particular attempt was made to determine the relative amount of each, but biotite appeared to be the most abundant. Due to its flaky character, however, it tends to more or less mask the other constituents. An occasional crystal of garnet could be observed in the rock but nowhere was it found in significant quantity.

ACKNOWLEDGMENTS

The writer wishes to thank Mr. C. R. Kurtak, Chemist for the Idaho Bureau of Mines and Geology, who made all of the chemical analyses required in the progress of the work. Dr. A. T. Abbott, co-author of this report, arranged to have the pyrometric cone equivalent tests on the kyanite made at the laboratories of the U. S. Bureau of Mines in Seattle. Thanks are also due to Mr. H. F. Yancey, Chief, Fuels Technology Division, Region II, U. S. Bureau of Mines, for his cooperation in having these tests run.

TESTS AND DATA

Preparation of the Sample

The entire lot was progressively crushed and sampled following standard procedure. A chemical analysis of the head sample for the principal constituents gave the following results:

- SiO\(_2\): 49.6%
- Al\(_2\)O\(_3\): 33.8%
- Fe\(_2\)O\(_3\): 3.7%

\(^*\)The term kyanite, as used in this portion of the report, will include the andalusite which was a minor constituent in the sample tested. Both minerals apparently respond similarly to flotation.
Test Control

Because both alumina and silica are present in the minerals associated with the kyanite, it was not possible to base the control of the tests on chemical analyses, but sink and float separation in tetrabromomethane (S.G. 2.795) was found to be a satisfactory method for isolating the kyanite from the other constituents. Although this procedure did not make a perfect separation, it was sufficiently accurate to determine the course of the work and little difficulty was encountered in obtaining check results. The specific gravity of the micro was only slightly less than that of the separating liquid, which made it necessary for the samples to stand overnight; particularly on finely ground material, but this did not unduly delay the work. Should more rapid separations be desired, they could be obtained by centrifuging. There was not enough garnet or other heavy mineral in the rock to upset the results.

Screen Analysis and Heavy Liquid Separation

The stockpile from which the individual test samples were drawn was material that had been passed through the laboratory cone crusher set at approximately 8 mesh. A screen analysis was made on a sample split from this lot, followed by sink-float separation of each of the size fractions to determine the kyanite distribution.

**TABLE I**

<table>
<thead>
<tr>
<th>Screen Analysis</th>
<th>Sink Product From Sink-Float Separation (assumed to be all kyanite)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Weight</td>
</tr>
<tr>
<td>Size (mesh)</td>
<td></td>
</tr>
<tr>
<td>4-8</td>
<td>2.9</td>
</tr>
<tr>
<td>8/16</td>
<td>4.6</td>
</tr>
<tr>
<td>16/30</td>
<td>13.6</td>
</tr>
<tr>
<td>32/50</td>
<td>14.9</td>
</tr>
<tr>
<td>63/100</td>
<td>12.4</td>
</tr>
<tr>
<td>25/48</td>
<td>11.2</td>
</tr>
<tr>
<td>50/100</td>
<td>8.8</td>
</tr>
<tr>
<td>100/200</td>
<td>5.0</td>
</tr>
<tr>
<td>200/600</td>
<td>3.0</td>
</tr>
<tr>
<td>600/1200</td>
<td>1.0</td>
</tr>
<tr>
<td>800/1200</td>
<td>0.8</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100.0</td>
</tr>
</tbody>
</table>

If it is assumed that the small bulk of plus 8 mesh, which was not fractionated, has the same composition as the 8/10 mesh portion and similarly
that the minus 200 mesh is identical to the 150/200 mesh fraction, the calculated kyanite content of the head sample is 18.8 per cent.

**Pyrometric Cone Equivalent**

At the outset of the work it was desired to have information on the fusibility of the kyanite. Two samples were prepared and sent to the laboratory of the U. S. Bureau of Mines at Seattle for p.c.e. determinations. One consisted of hand picked crystals and the other was prepared by sink-float separation. The results of these determinations were:

- Hand Picked - cone 38 minus
- Sink-Float - cone 37½ plus

In other words, the two samples softened at almost identical temperatures of approximately 1850° C.

** Hindered Settling Classification**

Incidental to the preparation of the sink-float sample above, some data were obtained on gravity concentration of the kyanite. In order to cut down on the bulk of material that was to be treated by sink-float, a preliminary separation was made by classifying each size fraction in a hindered settling column to scalp out the lighter constituents. Each underflow product from the classifier was then separated by sink-float. A summary of these data are given in Table II.

**TABLE II**

<table>
<thead>
<tr>
<th>Screen Analysis</th>
<th>Classifier Underflow</th>
<th>Sink Product from Sink-Float Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (mesh)</td>
<td>% of Size Fraction</td>
<td>% of Total Sample</td>
</tr>
<tr>
<td>8/10</td>
<td>5.5</td>
<td>46.2</td>
</tr>
<tr>
<td>10/14</td>
<td>12.3</td>
<td>28.2</td>
</tr>
<tr>
<td>14/20</td>
<td>14.1</td>
<td>12.3</td>
</tr>
<tr>
<td>20/28</td>
<td>13.1</td>
<td>40.9</td>
</tr>
<tr>
<td>28/35</td>
<td>10.5</td>
<td>50.1</td>
</tr>
<tr>
<td>35/48</td>
<td>8.3</td>
<td>10.3</td>
</tr>
<tr>
<td>48/63</td>
<td>7.9</td>
<td>19.0</td>
</tr>
</tbody>
</table>

Although both the above sample and the one used in Test No. 1 were from the same stockpile, there are some small differences in the screen analyses. The large amount of mica, and to some extent the long bladed particles of kyanite, made it difficult to obtain concordant results in screening, but the data in Tables I and II may be compared to advantage.
There was no definite cut-off in the classifier between kyanite and the lighter gangue minerals and it was, therefore, necessary to make the separation between underflow and overflow more or less arbitrarily. Except for the 10/14 mesh fraction, however, between 50 and 60 per cent was removed as a classifier overflow waste product from each size fraction with no significant loss of the kyanite values. It may be observed by comparing Tables I and II that when each of the classifier underflow products was separated by sink-float (Table II) almost as much kyanite was recovered in each case as when the entire size fraction was similarly separated. (Table I).

On the 10/14 mesh portion, where an excessive amount was removed as classifier overflow, the underflow product was the same proportion of the whole as the entire sink product in Test No. 1. Obviously, there was some loss of kyanite, but the classifier underflow had been graded up to 79.5 per cent.

The particle shape of neither the kyanite nor the mica is conducive to uniform gravity concentration, but the above results would indicate that the possibility of a preliminary upgrading by jiggling should not be overlooked in any proposed flowsheet. No gravity concentrator could produce a finished product, however.

**Flotation Testing**

In the preliminary work a considerable number of flotation tests, using various reagent combinations, were made in an effort to selectively collect the kyanite, but with little success. The chief difficulty encountered was the floatability of the mica under virtually all of the conditions tried. In the progress of the work, however, qualitative observation of the test products indicated that proper adjustment of the pH of the pulp during conditioning and flotation materially improved the selectivity and a process by which the mica could be almost completely depressed was evolved. Briefly, this included the following steps: 1) scrubbing in an acid circuit; 2) conditioning with a fatty acid in the acid circuit; 3) removal of the acid water, and 4) flotation in a neutral circuit with the addition of a frothing agent as required.

Two tests following this general procedure are outlined below. In Test No. 17 the scrubbing and conditioning were done in tap water, but distilled water was used in the flotation circuit. Tap water was used exclusively in Test No. 20.
Procedure:

1) Ore = 1/4 of grind No. A.
2) Deslimed at 1½ minutes settling time in a shallow pan.
3) Scrub in flotation cell for 5 minutes with 5 c.c. of 50 per cent H₂SO₄.
4) Condition for 2 minutes with 10 drops (approx. 0.125 gram) of oleic acid.
5) Pulp filtered, washed and repulped in distilled water. No additional frother required for flotation.

### TABLE III

**METALLURGICAL RESULTS BY ASSAY (TEST #17)**

<table>
<thead>
<tr>
<th>Product</th>
<th>Weight (grams)</th>
<th>% Weight</th>
<th>SiO₂ Assay %</th>
<th>Al₂O₃ Assay %</th>
<th>Fe₂O₃ Assay %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slimes</td>
<td>124</td>
<td>27.6</td>
<td>46.8</td>
<td>26.9</td>
<td>28.0</td>
</tr>
<tr>
<td>Conc.</td>
<td>64</td>
<td>13.2</td>
<td>35.5</td>
<td>9.7</td>
<td>58.9</td>
</tr>
<tr>
<td>Tails</td>
<td>287</td>
<td>59.2</td>
<td>51.6</td>
<td>63.4</td>
<td>26.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>482</td>
<td>100.0</td>
<td>48.1</td>
<td>100.0</td>
<td>30.9</td>
</tr>
</tbody>
</table>

### TABLE IV

**METALLURGICAL RESULTS BY SINK-FLOAT (TEST #17)**

<table>
<thead>
<tr>
<th>Product</th>
<th>Weight (grams)</th>
<th>% Weight</th>
<th>Kyanite Weight %</th>
<th>Dist. %</th>
<th>Mica, Feldspar, Qtz, etc. Weight %</th>
<th>Dist. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conc.</td>
<td>64</td>
<td>18.2</td>
<td>90.8</td>
<td>87.5</td>
<td>9.2</td>
<td>2.1</td>
</tr>
<tr>
<td>Tails</td>
<td>287</td>
<td>81.8</td>
<td>2.9</td>
<td>12.5</td>
<td>97.1</td>
<td>97.9</td>
</tr>
<tr>
<td>TOTAL</td>
<td>351</td>
<td>100.0</td>
<td>18.9</td>
<td>100.0</td>
<td>81.1</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**NOTE:** The slimes, which could not be fractionated by sink-float, are omitted from the above calculations. The sink products are assumed to be 100 per cent kyanite.
Procedure:

1) Ore = 1/4 of Grind No. 5.

2) Deslimed lightly at 3 minutes settling time in a shallow pan.

3) Scrub in flotation cell for 5 minutes with 5 c.c. of 50 per cent \( H_2SO_4 \).

4) Condition for 5 minutes with 10 drops (approx. 0.125 gm.) of oleic acid.

5) Pulp filtered - pH of filtrate = 1.9.

6) Sands washed and repulped in tap water. Three drops of frother 77 added for flotation.

7) pH of pulp at conclusion of frothing = 7.67

**TABLE V**

**METALLURGICAL RESULTS BY ASSAY (TEST NO. 20)**

<table>
<thead>
<tr>
<th>Product</th>
<th>Weight (grams)</th>
<th>%</th>
<th>( SiO_2 )</th>
<th>Assay %</th>
<th>Dist. %</th>
<th>( Al_2O_3 )</th>
<th>Assay %</th>
<th>Dist. %</th>
<th>( Fe_2O_3 )</th>
<th>Assay %</th>
<th>Dist. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slimes</td>
<td>91</td>
<td>17.6</td>
<td>45.6</td>
<td>17.2</td>
<td>27.6</td>
<td>15.4</td>
<td>5.82</td>
<td>25.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conc.</td>
<td>91</td>
<td>17.9</td>
<td>38.1</td>
<td>24.7</td>
<td>54.2</td>
<td>31.0</td>
<td>1.95</td>
<td>6.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tails</td>
<td>236</td>
<td>64.5</td>
<td>42.2</td>
<td>68.1</td>
<td>28.1</td>
<td>55.6</td>
<td>4.02</td>
<td>65.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>518</td>
<td>100.0</td>
<td>46.2</td>
<td>100.0</td>
<td>31.4</td>
<td>100.0</td>
<td>3.98</td>
<td>100.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE VI**

**METALLURGICAL RESULTS BY SINK-FLAT (TEST NO. 20)**

<table>
<thead>
<tr>
<th>Product</th>
<th>Weight (grams)</th>
<th>%</th>
<th>Kyanite</th>
<th>Weight %</th>
<th>Dist. %</th>
<th>Mica, Feldspar, Qtz, etc.</th>
<th>Weight</th>
<th>Dist. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conc.</td>
<td>91</td>
<td>21.8</td>
<td>71.8</td>
<td>83.0</td>
<td>28.2</td>
<td>7.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tails</td>
<td>236</td>
<td>76.2</td>
<td>6.1</td>
<td>17.0</td>
<td>95.9</td>
<td>32.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>427</td>
<td>100.0</td>
<td>18.8</td>
<td>100.0</td>
<td>81.2</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** Slimes omitted from above calculation.
It was found, in the course of the testing work that the mica could be
selectively floated. If a market could be found for it, it is believed that
the production of both a mica product and a kyanite concentrate from the rock
should not be too difficult. In some exploratory tests with an amine collector
(Armac C D) it was found to be quite selective toward the mica, provided the pH
was kept within certain limits. When the pH was not adjusted by any regulating
agents and sufficient Armac was added to the cell, it was found to be a strong
collector for all the minerals in the rock. In one such test, all but 7 per
cent of the charge was floated and most of that which was not collected was
apparently non-floating due to the particle size rather than the mineral com-
position.

Qualitatively, it has been observed that as the pH is raised, the Armac be-
comes more selective toward the mica, possibly reaching an optimum at a pH of
10.5 to 11.0. As the pH goes beyond 11, the mica is also depressed and little
or no mineral is collected in the concentrate. The effects of the several
variables on the mica flotation have not been thoroughly investigated, but one
test in which it was floated, followed by collections of a kyanite concentrate
as previously outlined is summarized below:

**TEST NO. 21**

Procedure:

Ore = 1/4 of Grind No. 5.

Deslimed lightly at 3 minutes settling time in a
shallow pan.

**Mica concentrate**

1) Condition 3 or 4 minutes with 0.75 gram of
Na OH.-pH of pulp = 10.9.

2) Armac CD = 0.04 gram - added in 4 equal stages.

3) Frother 77 - added as required - approx. 4 drops.

4) Frothing time =12 minutes.

5) pH at conclusion of frothing = 10.0

**Kyanite concentrate**

1) Scrub the mica tailings for 5 minutes with 5 c.c. of
50 per cent H₂SO₄.

2) Condition for 5 minutes with 10 drops (approx. 0.125 gram)
of oleic acid.

3) Pulp filtered - pH of filtrate = 1.9.

4) Sand washed and repulped in tap water.

5) Frother 77 - 4 drops added to cell.

6) Frothing time = 4 to 5 minutes.
<table>
<thead>
<tr>
<th>Product</th>
<th>Weight (grams)</th>
<th>%</th>
<th>$\text{SiO}_2$ Assay %</th>
<th>Dist. %</th>
<th>$\text{Al}_2\text{O}_3$ Assay %</th>
<th>Dist. %</th>
<th>$\text{Fe}_2\text{O}_3$ Assay %</th>
<th>Dist. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slimes</td>
<td>71</td>
<td>14.9</td>
<td>15.6</td>
<td>14.4</td>
<td>12.6</td>
<td>12.4</td>
<td>4.82</td>
<td>22.7</td>
</tr>
<tr>
<td>Conc. #1</td>
<td>223</td>
<td>22.8</td>
<td>23.2</td>
<td>22.6</td>
<td>22.9</td>
<td>22.9</td>
<td>7.63</td>
<td>57.6</td>
</tr>
<tr>
<td>Conc. #2</td>
<td>46</td>
<td>9.5</td>
<td>8.9</td>
<td>7.9</td>
<td>13.7</td>
<td>14.5</td>
<td>1.66</td>
<td>1.2</td>
</tr>
<tr>
<td>Tails</td>
<td>223</td>
<td>45.7</td>
<td>52.5</td>
<td>52.1</td>
<td>31.6</td>
<td>16.1</td>
<td>1.26</td>
<td>15.5</td>
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<tr>
<td>TOTAL</td>
<td>478</td>
<td>100.0</td>
<td>47.0</td>
<td>33.0</td>
<td>100.0</td>
<td>3.80</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE VIII**

<table>
<thead>
<tr>
<th>Product</th>
<th>Weight (grams)</th>
<th>%</th>
<th>Kyanite Weight %</th>
<th>Dist. %</th>
<th>Mica, Feldspar, Vit. etc. Weight %</th>
<th>Dist. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conc. #1</td>
<td>138</td>
<td>33.9</td>
<td>1.4</td>
<td>2.7</td>
<td>98.6</td>
<td>40.5</td>
</tr>
<tr>
<td>Conc. #2</td>
<td>46</td>
<td>11.3</td>
<td>75.6</td>
<td>47.1</td>
<td>24.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Tails</td>
<td>223</td>
<td>54.8</td>
<td>15.4</td>
<td>4.2</td>
<td>84.6</td>
<td>56.2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>497</td>
<td>100.0</td>
<td>17.8</td>
<td>100.0</td>
<td>82.5</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**NOTE:** Slimes omitted from calculations.
Visual examination of the float product from concentrate 1 indicated that it was virtually all mica.

**Grinding**

The fineness of the grind was not investigated as a variable. All grinding was done in batches, consisting of 2000 grams of solids with equal water, for a 15 minute period in the laboratory ball mill. In one grind that was made at 57 per cent solids, the pulp was a thick plastic mud that would barely flow from the mill without dilution. The large proportion of mica in the rock apparently accounts for this condition at a relatively low pulp density. The wet and dry screen analysis of a 1/4 split from one of the standard grinds is summarized below.
TABLE IX
SCREEN ANALYSIS OF 1/4 OF GRIND #5

<table>
<thead>
<tr>
<th>Size (mesh)</th>
<th>Weight (grams)</th>
<th>% Weight</th>
<th>Cum. % Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>2.0</td>
<td>0.43</td>
<td>0.43</td>
</tr>
<tr>
<td>32/48</td>
<td>10.0</td>
<td>2.17</td>
<td>2.6</td>
</tr>
<tr>
<td>48/55</td>
<td>16.1</td>
<td>3.2</td>
<td>6.1</td>
</tr>
<tr>
<td>65/100</td>
<td>30.1</td>
<td>6.5</td>
<td>12.6</td>
</tr>
<tr>
<td>100/150</td>
<td>46.2</td>
<td>10.0</td>
<td>22.6</td>
</tr>
<tr>
<td>150/200</td>
<td>64.2</td>
<td>13.9</td>
<td>36.5</td>
</tr>
<tr>
<td>200</td>
<td>292.3</td>
<td>65.5</td>
<td>100.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>462.0</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: The plus 100 mesh fractions were virtually all mica.

CONCLUSIONS

The purpose of these tests has been to determine a general procedure by which the kyanite may be selectively floated, rather than to work out the optimum conditions for conducting the process. One such procedure has been outlined and it is also suggested that if market conditions were favorable, it should be possible to concurrently produce a mica concentrate. Additional tests would be required to establish the effects of all the variables involved.

The metallurgical results reported are all based on rougher concentrates that have not undergone any cleaning. It is believed, however, that considerable upgrading could be effected in cleaning circuits since the selectivity of the rougher tests was good. If critical limits are established on the maximum iron allowable in the product, this phase of the problem might require more study. Although the iron content of the various kyanite concentrates was only a fraction of that of the head sample, it still ran 1.1 per cent in the best concentrate produced.

Several items that might be suggested for more complete investigation are summarized below.

All the tests reported here were made on pulp that had been deslimed prior to flotation, but it has not been determined whether or not this step would be absolutely necessary. The rock carries no clay or limonitic material that characteristically forms slimes detrimental to flotation, and little or no difference was observed between tests in which the desliming had been quite thorough and those in which the pulp was lightly deslimed. In a continuous grinding operation, much of the over-grinding that is inherent in batch operation would be eliminated and it is entirely possible that desliming would not be necessary.
It has been found that in order to selectively coat the kyanite particles with a water repellent oleate film the conditioning must be done in an acid circuit, but the optimum pH for conditioning has not been determined. It would be important in any commercial operation to keep the acidity to a minimum, particularly since the testing work indicated that suitable froth characteristics could not be obtained at the acidity used for conditioning. The degree to which the acid water must be removed prior to flotation and the most economical method for doing it should also be investigated. The sandy pulp filtered quite rapidly in the testing work, but such a procedure would probably not be economic on a commercial scale. One or two tests indicated that thickening and decantation would be equally effective. In either case, it should be possible to re-use the reclaimed water, effecting a considerable saving in the amount of acid required for conditioning.

Garnet was not an objectionable impurity in the sample on which the testing work was done but it is rather abundant in parts of the deposit. Before developing any of the garnetiferous rock, its behaviour in the above flotation environment should be investigated.

The rate at which the kyanite was floated was quite rapid. In an average test, the total frothing time was 4 to 5 minutes but the bulk of the product was collected in the first minute or two. The mica was also collected quite rapidly with Armac, but due to the greater volume of it present in the rock, a frothing time of 10 to 12 minutes was the average. It was never possible to produce a tailing entirely free of mica.

As is commonly found in soap flotation, the hardness of the water used in the circuit is apparently an important factor. In the one test that was made using distilled water, the metallurgical results were far superior to those that were made with ordinary tap water.
AREAL GEOLOGIC MAP
OF
PROPERTY OF BLACKDOME MINING CO.
AND VICINITY
Shoshone County, Idaho

April 15, 1954
Agatim T. Abbott

Fig. 3