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Pegmatites in Southwestern Montana

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PEGMATITES IN SOUTHWESTERN MONTANA

A Thesis Submitted to the Department of Geology
in Partial Fulfillment of the Requirements for the Degree
of Bachelor of Science in Geological Engineering

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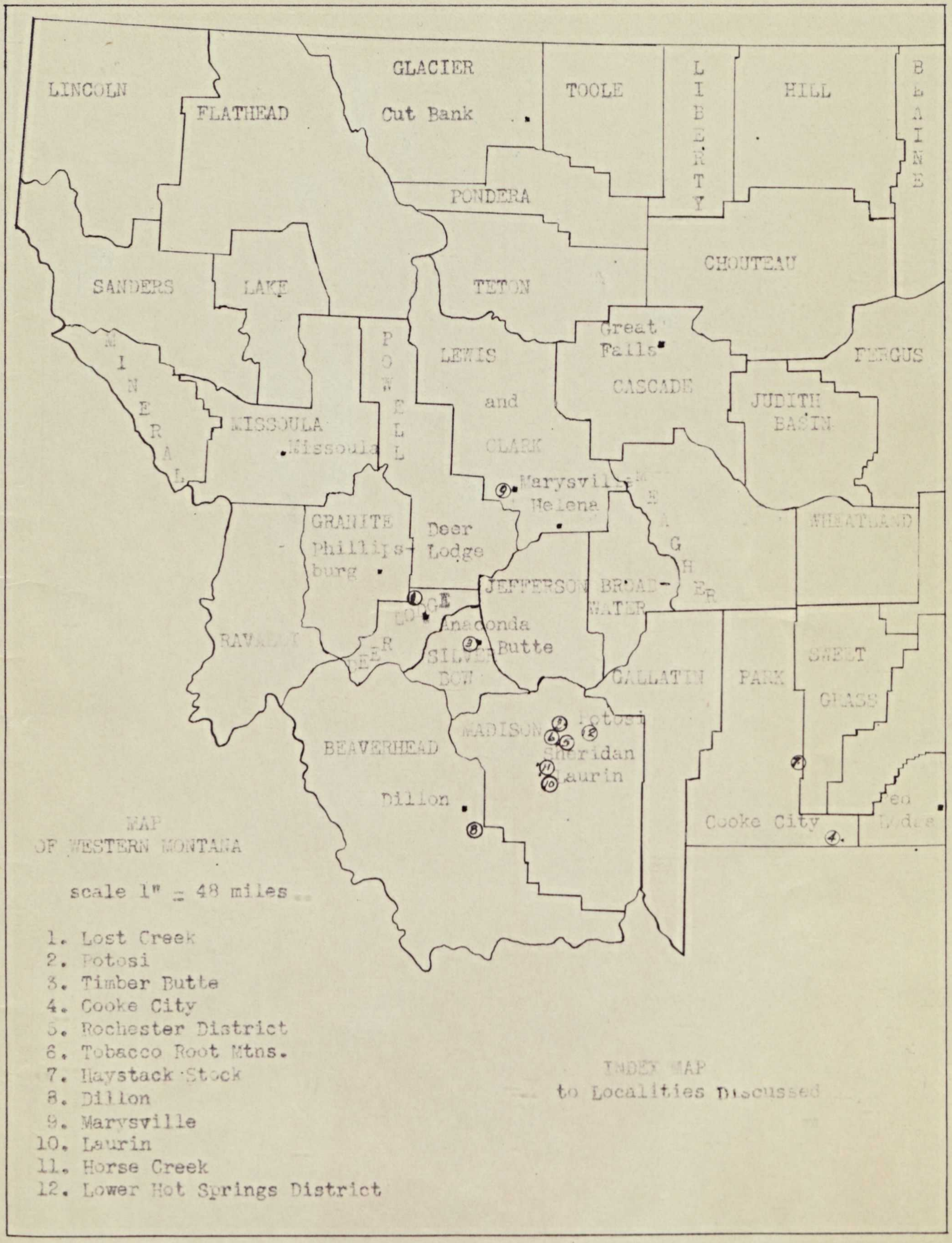
INTRODUCTION

But little has been written on pegmatites in Montana except in conjunction with reports on mining districts. This subject was chosen as a senior thesis to see what facts could be ascertained regarding pegmatites alone, and an attempt has been made by the writer to assemble all written material on pegmatites in southwestern Montana,and to study specimens from those that could be reached, or from which specimens were available. The writer has tried to bring out relationships between pegmatites of different areas as to type or age, and mineral relationships, and also to discuss the economic possibilities that may be connected with some.

The work was carried on during the school year 1940-1941 at the Montana School of Mines. Only a limited amount of field work was done because of early snows and consequent inaccessibility of most of the pegmatites. Specimens from Potosi, Lost Creek, Laurin, Timber Butte, Horse Creek, and the Lower Hot Springs Mining district were studied in the laboratory.

The writer is greatly indebted to Dr. E . S. Perry and Dr. G. F. Seager for their help and guidance. The writer also wishes to acknowledge valuable information gained from Mr. Ernest E. Thurlow and Mr. Russell Chadwick. Mr. Roy Earhart of the W.P.A. Mineral Survey furnished much valuable information regarding the Potosi deposits.


LINCOLN
FLATHEAD
GLACIER
Cut Bank
TOOLE
LIBERTY
HILL
BLAINE
PONDERA
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Great Falls
CASCADE
LEWIS and CLARK
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MINERAL
MISSOULA
Missoula
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GRANITE
Phillipsburg
Deer Lodge
JEFFERSON
BROADWATER
Anaconda
Butte
SILVER BOW
GALLATIN
PARK
SWEET GRASS
MADISON
Potosi
Sheridan
Laurin
BEAVERHEAD
Dillon
Cooke City
MAP OF WESTERN MONTANA
scale 1" = 48 miles
1. Lost Creek
2. Potosi
3. Timber Butte
4. Cooke City
5. Rochester District
6. Tobacco Root Mtns.
7. Haystack Stock
8. Dillon
9. Marysville
10. Laurin
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GEOLOGY OF PEGMATITE DEVELOPMENT

Definition of Pegmatite

The word pegmatite was originally coined by Haüy in the early part of the 19th century as a descriptive term applied to igneous rocks with a graphic texture. Later it was used to designate a coarse granite, and gradually the term was extended to include all exceptionally coarse plutonic rocks whether they exhibited graphic structure or not. Landes defines pegmatite as "an intrusive holocrystaline rock composed essentially of rock-making minerals which are developed in part in individuals larger than the grains of the same minerals occurring in the normal plutonic equivalent". There are exceptions to this definition. As Landes points out, many pegmatites contain an abundance of large crystals of minerals which are not rock formers and may not even be a constituent of any other type of rock.

Size and Shape

Pegmatites are found in a great variety of sizes and shapes. Perhaps the most common are the tabular masses or dikes which have their width as one fairly definite dimension; however, irregularity in shape is indeed characteristic. The major number of economically important pegmatites are either tabular masses of steeply inclined or vertical bodies of circular or elliptical cross-section. The size of pegmatites also varies greatly; they range from a mere

Landes (see Bibliography) has gone into considerable detail on geology of pegmatites, and has reviewed much literature. The descriptions under the heading of Definition and Origin in this report have been condensed from Landes' work, and all of the various references cited by Landes are not included in the bibliography accompanying this paper.

sliver to the enormous masses that have been reported over the world; one in Ontario, Canada is over 250 feet wide and 4 miles long; one in Colorado is 400 feet thick; and another in the eastern highlands of Scotland is 700 yards in breadth. The depth, as with the other dimensions, has wide ranges also. Some pegmatites have been known to continue down for several hundred feet while others pinch out at a depth of 20 feet.

Origin

The various theories which have been advanced to account for the formation of pegmatites may be classed as follows:

A. Aqueous
   1. lateral secretion
   2. selective solution

B. Igneous
   1. viscous magma
   2. precipitation from highly attenuated solutions
   3. hydrothermal replacement, which is a combination of the above two.

Aqueous Theories

Lateral Secretions---The source of the materials is the surrounding rock, and ground water is the medium of solutions, transportation and reprecipitation. Saussure is credited as being the original proponent of this idea; T. S. Hunt and G. H. Williams were the strongest supporters in the United States.

Selective Solution---The main idea behind this hypothesis is that rock minerals in the presence of interstitial water will go into solutions under an increase in temperature and pressure, and that the solutions thus formed may or may not travel before reprecipitation takes place. This would produce a rock igneous in appearance and pegmatitic in character. If the rock is layered, one layer may go into solution more readily than another. This would explain the lit-par-lit pegmatites in which an apparently igneous rock alternates with metamorphic rock. A modification of this theory was advanced by Goodchild when he said that lenses of pegmatites might be formed due to local fusion caused by relief of pressure in rock masses which were potentially molten but kept solid by pressure. Van Hise, Julien, Lane, Kalkowsky, and Goodchild are supporters of the idea that some of the pegmatites are of this origin. K. K. Landes believes that this theory does not offer a solution to the problem as all gradations are found in the kinds of pegmatites.

Igneous Theories

Viscous Magma Theory---The first of the igneous theories to be accepted by any number of geologists was the viscous magma theory. Charpentier was the first to clearly describe an igneous origin for pegmatites. Other writers for the igneous origin were De la Beche, Bronn, Fournet, Durocher, Augelot, and Naumann. This theory gave way to the aqueous magma theory, but was revived in 1923 by Merritt in his paper on the function of colloids in pegmatite growths. Merrit explains the large spherically radiating spodumene crystals in the Etta mine in the Black Hills by this theory.

Aqueous Magma Theory---Elie de Beaumont first advanced this theory which quickly replaced the older viscous magma theory. According to this theory, pegmatites are formed by crystallization from solutions that are very high in volatile constituents, and are therefore very fluid in reactions. These aqueous-igneous solutions are the "residual magma" which is left after differentiation, and the high water and vaporous content helped to keep the constituents of the primary magma in solution. Lehman, Crosby, Fuller, and J. F. Kemp were strong supporters of this theory.

Hydrothermal Replacement Theory---This theory is essentially a combination of the two previous igneous theories. Several stages in the formation of pegmatites may be represented, different factors operating in each case. Many investigators since 1920 have brought forth much evidence to prove that many pegmatites are formed in several successive stages.

Complex pegmatites may be formed by the following steps:

1. A quartz-feldspar eutectic is intruded as a dike or dike-like mass. This is in the form of a viscous magma at the time of intrusion.
2. Very thin liquid solutions or gases penetrate through the quartz-feldspar mass after it has cooled somewhat and may replace some of the existing minerals with others or may take more into solution than is deposited and thus leave a cavity.
3. Later solutions of hydrothermal type may penetrate this mass and deposit sulphides and other lower temperature minerals.

The true quartz-feldspar eutectic, when the feldspar is microcline, is composed of 25% quartz and 75% feldspar, and many or most pegmatite intergrowths approach this composition.

Many rare minerals such as those containing rare earth metals, lithium, boron, and others are characteristically found as replacements in the quartz and feldspar.

The pegmatites of the Black Hills have been used by many authors as a good illustration of this theory of origin. Hess (2) in his paper on the natural history of pegmatites cites evidence gathered at the Peerless claim, Keystone, S. D., where quartz is replaced by albite which in turn is replaced by muscovite, and which again in turn, is replaced by columbite. Other cases of replacement in pegmatite dikes near Keystone, S. D. as found by Hess are:

1. amblygonite replaced by albite with some muscovite and apatite
2. microcline replaced by albite
3. albite replaced by apatite
4. quartz replaced by muscovite which is replaced by albite which in turn is replaced by beryl and more muscovite
5. albite replaced by columbite and cassiterite; quartz replaced by albite, muscovite, and apatite
6. spodumene replaced by muscovite
7. At Camp Harding, New Mexico, Hess (2) found microcline replaced by albite and lepidolite and a great body of lepidolite that replaced quartz, spodumene, and all other minerals in its way.

Hess favors a replacement theory for the origin of the great spodumene "logs" in the Etta mine in the Black Hills.

He states, (2:295) "A striking peculiarity of the arrangement of the minerals is the radial disposition of crystals from 3 to 6 feet long, and another peculiar fact is that the centers of the masses are fine-grained pegmatite. Radial disposition in three dimensions, with crystal terminations of the minerals at the outer ends, may, I believe, be accepted as a sign of replacement. Crystals formed in vugs have their terminations pointing toward a center, but if radial crystals are to form at all, they must be supported in every direction".

Hess also states that the enormous amount of replacement that has gone on around some pegmatites can only be explained by a long continued flow of solutions. The solutions travel along the path of least resistance which is the center of the pegmatite, as it is the hottest part, and therefore the minerals there are more susceptible to solution. In some places solution takes place faster than deposition and cavities are formed. It is in these cavities that crystals, often of gem quality, are found. As the solutions continue to flow, more and more of the original pegmatite is replaced until sometime none of it is left.

In conclusion Hess (2:298) states, "The assumption of the passage of great quantities of fluids through the masses of rocks also makes understandable the origin of coarsely porphyritic and orbicular rocks, for individual crystals or orbicules probably grow at the expense of their neighbors space, and in part possibly at the expense of their substance, as they feed from passing solutions and the solutions simultaneously dissolve and carry away the neighbors. Whether these fluid solutions are liquid or gas is not known, but I find it hard to conceive them as other than gas".

James Furman Kemp (3) points out that the order of crystallization in a pegmatite is usually the same as that of a normal granite. He also states that great freedom of growth and lack of interference must be assumed for the huge undeformed mica books that are found, as this mineral is easily bent and deformed.

Proof of the great penetrating power of pegmatitic solutions is found near New Haven, Connecticut where all gradations from schist and gneiss to pegmatite are found with intermediate steps showing included angular fragments of gneiss grading through rounded inclusions of gneiss to some inclusions that are so penetrated with pegmatitic material that only a "ghost" structure remains. (3)

The temperature of formation of pegmatites as given by studies of quartz, is approximately 575°C. Alpha quartz goes to beta quartz at 575°C. There is a difference between these two varieties; and studies of quartz under a microscope will determine which one it is. Thus the temperature of formation of quartz may be determined. Quartz taken from pegmatites may be either of the alpha or beta variety which shows that the temperature of formation was around 575°C.

Concentration of Rarer Elements (4)

As a product of differentiation pegmatite dikes are formed which carry a greater concentration of the rare elements than any other rock type. Many minerals formed by rare elements are characteristically found only in pegmatites. In many cases rare elements are present, but they may not be present as distinct minerals, usually because they are not present in sufficient concentration to produce distinct minerals. What happens to the rare elements then is explained by the premise that rare elements are camouflaged in minerals of baser elements, the baser element having an ionic radius equal or nearly equal to that of the element thus hidden.

The average composition of igneous rocks, showing the major and common metals in order of abundance is as follows: Al, Fe, Ca, Na, K, Mg, Ti, Mn, Cr, Ni, V, CeYt, Cu, U, W, Z n, NbTa, Ha, Th, Pb, Co.

The following table shows similarities in ionic radii between rare and common metals of equal valence:

	Å		Å		Å		Å		Å
Mg	0.78	Si	1.27	Al	0.57	Si	0.39	Zr	0.87
Ni	0.78	Pb	1.32	Ga	0.63	Ge	0.44	Hf	0.86

The Yttrium series of trivalent elements is difficult to separate into its respective elements by the chemist, and the same tendency toward close association occurs in nature. Furthermore, the average concentration of these elements is extremely low. They are not removed by the usual processes of differentiation and are left concentrated in the residual liquors which may be intruded to form the pegmatites. These are often found as the constituents of rare oxide minerals.

The following table shows the similarity in ionic radii of the trivalent yttrium series:

	A°		A°
Gd	1.11	Ho	1.05
Tb	1.09	Er	1.04
Dy	1.07	Yb	1.00
Y	1.06	Cp	0.99

The following table shows pairs of elements (rare and common) of similar ionic radii but of different valence:

	A	Valency		A	Valency
Li	0.78	1	Ca	1.06	2
Mg	0.78	2	Y	1.06	3
Na	0.98	1	Sc	0.83	3
Ca	1.06	2	Zr	0.87	4
K	1.33	1	Ti	0.64	4
Ba	1.43	2	Nb	0.69	5

Goldschmidt and Peters showed that germanium should be associated with silicon in silicates. Papish by spectrographic methods proved that it is widely distributed in silicate minerals. Goldschmidt and Peters then found 1.6% of GeO_2 in the ashes of certain English coals showing that it could be concentrated by plant action.

Rhenium is now extracted from molybdenite as a by-product in the production of molybdenum. This is due to the fact that rhenium and molybdenum have similar ionic radii. It illustrates the principle that rare elements may be present in rock or mineral masses without developing individual grains of a mineral of the rare element.

Classification of Pegmatites (1)

The following is a classification of pegmatites taken from Landes' Origin and Classification of Pegmatites.

A. Acid (alaskite, normal granite, alkaline granite, granodiorite, quartz monzonite, and quartz diorite)
   1. Simple
   2. Complex, with the following phases (aside from albitization): lithium, fluorine, beryllium, boron, phosphate, graphite, rare earth, ore mineral, and quartz vein

B. Intermediate (syenite, alkaline syenite, monzonite, diorite)
   1. Simple
   2. Complex, with the following phases: rare alkaline mineral, calcite, radioactive mineral, and sulphide

C. Basic (gabbro, diabase, anorthosite, and pyroxenite)
   1. Simple
   2. Complex (calcite-apatite-phlogopite-phase)

Pegmatites are found in all gradations from the simple quartz, the simple feldspar, or he quartz-feldspar types to the very complex types which have several stages in formation represented. Although the complex types are usually the most important economically, in number and distribution the simple pegmatites are found to be greatly in preponderance.

Causes and Probable Routes of An Injection

Intrusion of igneous bodies generally accompanies or follows mountain building. Pegmatites are intruded after the main body of igneous material and represent a late residual product of differentiation. In the advanced stages of mountain building, faulting occurs. The pegmatites may follow the fault zones or zones of weakness in the overlying rock produced by structural deformation, or they may follow an easily replaceable bed. They are also commonly found intruded into fractured outer zones of the parent mass; for example, the Boulder batholith.

Age and Distribution of Pegmatites (5)

Pegmatites are found on every continent in the world, and are widespred wherever extensive plutonic intrusives exist. They have been formed during periods of intrusive igneous activity throughout all geologic time from earliest pre-Cambrian to the present.

Most of the pegmatites in the world are pre-Cambrian in age, perhaps because the areas of outcrop of pre-Cambrian rocks are much greater than that of later crystalline rocks, and because the time represented by the pre-Cambrian is over two-thirds of the known span.

Paleozoic pegmatites in the United States are found in Maine, Connecticut, Massachusetts, New York, Virginia, and the Carolinas.

Mesozoic pegmatites are found abundantly in connection with the igneous activity of western North America, extending from Alaska into Mexico.

A few Cenozoic pegmatites are found where some Tertiary igneous activity has taken place. A basic pegmatite of probable Tertiary age is found near Cooke City, Montana. Since Tertiary plutonic activity must for the most part still be deeply buried, due to lack of erosion, bodies of this age are not to be expected to be so plentiful at the surface.

The pegmatites in Montana are associated with the igneous rocks in the western part of the state, which are commonly considered late Cretaceous or Tertiary in age. Both simple granitic and basic types are found, and complex types may be present.

Mineralogy of Pegmatite Deposits

The mineralogy of pegmatite bodies is indeed complex, particularly when minerals of the rare elements are included. The list of minerals found is long, and many of the minerals are species with which the average good mineralogist is unfamiliar. The recognition of the more rare species requires detailed laboratory determinations, generally with aid of the Petrographic microscope, and for this reason it is probable that many mineral occurrences have been overlooked by the prospector and average mining engineer. The study of pegmatite dikes is a task for a specialist in the field of rare minerals. Such a study for Montana pegmatite has not been made. The following lists of minerals characteristically associated with pegmatite dikes emphasizes the complexity of the study of pegmatite bodies:

quartz	spodumene	emerald
feldspar	petalite	topaz
muscovite	epidote	moonstone
biotite	beryl	anatase
lepidolite	titanite	cordierite
tourmaline	rutile	phenacite
cassiterite	spinel	axinite
wolframite	fluorite	cyanite
columbite	cryolite	danburite
tantalite	ilmenite	sphene
thorite	amblygonite	corundum
monazite	triplite	(sapphire)
gadolinite	triphylite	(ruby)
allanite	molybdenite	diopside
yttrialite	arsenopyrite	gold
euxenite	lollingite	chalcopyrite
samarskite	leucopyrite	pyrite
zircon	bismuth	chalcocite
apatite	galena	sphalerite
garnet	stannite	pyrrohotite
andalusite	bismuthinite	scheelite
magnetite	hubnerite	hornblende

Minerals found in pegmatites in Montana:

quartz	arsenopyrite
plagioclase	galena
orthoclase-microcline	sapphire
muscovite	gold
biotite	chalcopyrite
tourmaline	pyrite
samarskite	sphalerite
apatite	magnetite
garnet	hubnerite
molybdenite	scheelite
hornblende	andalusite

Although many of these minerals are believed to be present in pegmatites in Montana, quartz and feldspar greatly predominate. Muscovite, magnetite, tourmaline, and biotite are found as common accessory minerals.

DESCRIPTION OF AREAS

Lost Creek

Lost Creek is approximately three miles north of Anaconda, Montana, and is almost entirely in Deer Lodge County. It flows through a deep narrow U-shaped valley which has been glaciated at some previous time as evidenced by terminal moraines with numerous huge round granitic erratics along the lower part of the valley. The walls of the middle part of the valley are very steep and are covered with talus slopes in many places. Elsewhere they are bare, or else covered with coniferous trees and brush.

Mr. Kolesar (6:31), in a thesis prepared for the Department of Geology at the Montana School of Mines, states that: "Dikes of aplite and pegmatite are exposed on the steep canyon walls north and south of Lost Creek and about one mile northwest of Trask Hill.----The pegmatite taken from the rocks of the Algonkian series is composed primarily of quartz, white feldspar, muscovite, and small black prisms of tourmaline which are conspicious in the white background of the matrix."

Fig. 1. View on Lost Creek looking south.

The specimens collected by the writer came from a dike on the north side of the valley. This dike cuts through a pre-Cambrian gneiss without regard to the structure of the gneiss. It is three to four feet in width and could be traced for a distance of at least 500 feet. It has been displaced by faulting in several places. This white pegmatite is a prominent feature where it crops out, because of the contrast afforded between it and the dark gneiss. The walls are quite definite, but in some places a stringer of pegmatite leaves the main body and cuts into the gneiss for a short distance. A sharp angular inclusion of gneiss about two feet by one foot by one foot, which showed some alteration was found in the pegmatite, and no doubt this phenomenon is general.

Quartz and white plagioclase feldspar are the principal constituents of the pegmatite, but considerable muscovite, black tourmaline, and small amounts of magnetite and biotite are found as accessory minerals.

The feldspar is not found with crystal faces, but only in massive form. It was d etermined to be albite by oil immersion methods, a mineral not particularly common as an essential constituent of igneous rock.

The quartz is found in irregular grains throughout the rock and locally shows graphic intergrowth. It is also found in large irregular veinlets throughout the rock. Some of these veinlets reach a width of three inches, and they may be a foot or two long. These veinlets cut everything they encounter. Mica, black tourmaline, and pyrite are associated with the late quartz.

This pegmatite is characterized by numerous long acicular crystals of black tourmaline, which accompanies the late quartz and feldspar. The tourmaline in numerous places is surrounded by small flakes of muscovite. The crystals show the characteristic spherical triangular cross-section of tourmaline. Most of the crystals are not continuous for their whole length, but have been broken into several segments and the spaces between the segments have been filled with quartz. Some tourmaline occurs as networks in minute veinlets in the quartz and feldspar.

The muscovite is quite abundant through the pegmatite, and is found as small bright scales in, or with, all the minerals except the pyrite and magnetite. It is found in books up to two inches in diameter in the late quartz; however, smaller books are present in the feldspar, and it occurs as abundant flakes along with tourmaline.

The pyrite was found with the late quartz, and magnetite as small bright shiny blue-black flakes on an inclusion of gneiss.

From the mineral relations observed in the field and the laboratory, this pegmatite seems to fall into the class of complex pegmatites, because more than one phase is represented in its formation. This pegmatite was probably formed in two steps: a first intrusion of albite and quartz in nearly eutectic proportions, and a second intrusion of a very liquid quartz-mica-tourmaline-rich solution which replaced some of the original quartz and feldspar and deposited mica, tourmaline, pyrite, magnetite, and a late quartz.

Potosi

The Potosi district is situated about four miles from the eastern margin and three miles from the northern margin of the Tobacco Root Batholith. It is near the head of Willow Creek, about eight miles southwest of Pony, Montana. The Tobacco Root Batholith is about 18 miles long and 5 miles wide, extending in a northwesterly and southeasterly direction. This batholith, as with many other similar igneous bodies of the Cordilleran trough, was intruded in late Cretaceous or early Tertiary time. Regarding it, Tansley (7:14) states that: "The mass of the batholith is a quartz monzonite, a medium-grained rock containing about equal proportions of quartz, orthoclase, and plagioclase, with hornblende or biotite. It differs from a true granite in some localities. Different phases of quartz monzonite are due to variations in the amount of hornblende, biotite, muscovite, and augite."

Hart makes the following statements: "The mineralization varies throughout the district, and a rude zonal distribution is observed to be dependent upon the position of the deposit relative to the granite intrusive. In this way, mineralization nearest the granite contact is characteristically composed of auriferous pyrite, chalcopyrite, and quartz. This grades outwardly to mineralization in which galena and silver become important constituents along with lesser amounts of auriferous pyrite. Within the granite, this relation is not as well defined, but the deposits are probably produced through the effects of local, internal mineralization sources. The Potosi district is probably the best representative of high temperature or hypothermal mineralization as it contains important occurrences of fluorite and hubnerite. The other veins in which silver minerals occur, probably represent lower temperature deposits or a much later period of metallization. At the Bismark mine, near the head of South Boulder Creek, the mineralization in veins at or near the granite-gneiss contact consists of chalcopyrite, pyrite, and molybdenite in quartz." (7:25)

"In line with genetic relations, attention is called to the frequent association of ore with pegmatite dikes. It appears most likely that these dikes represent an earlier phase of magmatic differentiation, preceding the introduction of hydrothermal solutions. The fact that pegmatite dikes often occupy breaks or fissures which now also contain the veins merely indicates the existence of the major structural breaks at the time of the dike injection, and further suggests that post dike stresses were also relieved along these same pre-existing z ones of weakness. Thus post dike mineralization often both replaces dike minerals and occurs at a distance from any dike. Similarly, it is logical to assume that at points where fissures were permanently sealed by dike intrusions, the later hydrothermal solutions could not enter. This condition gives rise to apparent gradations from true hydrothermal veins to true pegmatite dikes and thereby imply a closer relationship between the two than is actually the fact." (7:25-26).

Hart (7:32) also makes the following statements about tungsten deposits: "The tungsten mineral hubnerite occurs as seams in wide, massive, white quartz veins or dikes of pegmatitic character. Along the hanging wall fluorite filling may be noted. The hubnerite occurrences, although of great extent, vary greatly in intensity and only lens-like zones constitute possible ore resources, but it is apparent that under favorable market conditions, the veins would warrant further exploration."

Winchell (8:125) in describing the ore deposits of the Dillon quadrangle states that: "The Potosi region is remarkable for the large number of minerals it affords, the list including quartz, pyrite, molybdenite, fluorite, hubnerite, cerargyrite, native silver, pyrolusite, and limonite. The tungsten ore (hubnerite and its oxidation products) is found in quartz veins on at least a dozen different claims. In the western part of the region, the veins strike east and dip 60°-80°N; in the eastern part they strike about north and dip about 60°W. The veins are in general persistent in strike and dip. They are highly quartzose and vary from 1 to 6 feet in thickness. The hubnerite is commonly confined to streaks 1 to 18 inches thick, but a width of 20 inches was found on the Rockefeller claim a sample from which assayed 4.5 percent of tungstic acid. Apparently the tungsten ore was formed late in the history of the veins; some thin layers of chalcedony were formed later, and some quartz crystallized simultaneously with the tungsten ore, but the other minerals, including the silver ores, were formed earlier. Pyrolusite and fluorite are commonly associated with the hubnerite and are also found without tungsten ore in a large quartz vein on the contact of quartz monzonite and gneiss. The fluorite varies in color remarkably, being purple, green, blue, white, or black."

The Potosi tungsten deposits have been scrutinized closely for their economic possibilities by many prospectors and mining engineers. The sparcity of the tungsten minerals has led to lack of development. Nevertheless, it is quite possible that local concentrations have been overlooked, and the district merits additional prospecting. The following are assays reported by Dr. E. R. Griggs:

Lincoln:---3 feet wide--by Colorado Assaying Co., Nov. 21, 1936
Tungsten Trioxide (WO_3) 4.6%

Lincoln:---4 feet wide--by Ledoux & Co., New York Aug. 19, 1937
(WO_3) 4.47%

Wilson:----sample from dump by C. C. Case (WO_3) .69%

Wilson:----6 feet wide (by C. C. Case)--by Ledoux & Co., New York
September 1, 1937---(WO_3) 1.8%

Lincoln:---3 feet wide--sample by N. S. Pulliam for Colorado people--1937, assayed by E. B. Hill, Boulder, Colorado
(WO_3) 1.9%

Grant:-----40 inches wide--sample taken by Dr. E. R. Griggs
April 7, 1939 assayed by Smith-Emery Co., Los Angeles
for Arizona Molybdenum Corp. (WO_3) 5.31%

Regarding the origin of these deposits Winchell (8:125-126) states that: "The ores of the Pony district were probably formed by solutions proceeding upwards and outward from the quartz monzonite magma. This is indicated by their geographic position near the margin of the quartz monzonite; by their gradation to pegmatite at the Strawberry mine; and by their association with the pneumatolytic mineral fluorite in the Potosi region. That the ores were formed by uprising solutions is indicated by their occurrences beneath impervious fault gauge 1 to 6 feet thick in the Boss Tweed mine. That they were formed after the crystallization of the quartz-monzonite is proved by their presence in veins cutting the latter, but that their formation took place not long afterward is indicated by their association with fluorite, pegmatite, and aplite, all of which were probably derived from the residual magma after crystallization of the portion now penetrated by these veins and dikes."

Schafer and Tansley (7:16) in studying the deposits make the following observations: "Quartz bodies occur abundantly as irregular masses, pipes or chimneys, and veins. In some, quartz is the sole constituent, but others containing both quartz and potash feldspar are true pegmatites. There are al gradations in a single vein from pure quartz to both quartz and feldspar varieties. The quartz is coarsely crystalline and white. In places feldspar crystals are a foot or more in length. Metallization rarely occurs in this type of quartz vein. These masses of quartz increase in number near the batholith."

Megascopic Study of Potosi Hand Specimens

The ore specimens are composed of two minerals, massive white quartz and needle-like or bladed crystals of hubnerite. Some of the hubnerite is found in clusters of long acicular or bladed crystals that radiate from a common center. In general the crystals are all oriented in a direction which is more or less perpendicular to the walls of the dike. Observers who have examined the deposit in the field report that the hubnerite is found in two streaks in otherwise barren white quartz (Plate III A). One of these is a small streak of hubnerite which produces a "smoky" appearance to the quartz due to the small size of the numerous crystals. The other streak is of larger crystals which are easily visible to the unaided eye. Some of these crystals reach a length of six inches and may be one-fourth to three-eighths of an inch thick.

A very prominent feature of these specimens is the fracturing

A. Potosi specimen showing broken and displaced hubnerite crystals in quartz. x 4/5

B. Potosi specimen showing hubnerite in cracks in quartz. x 4/5 as shown by broken and displaced crystals (Plate II). The fractures are marked by a series of parallel bands of relatively barren quartz which has some included fragments of hubnerite.

The following analysis was made from carefully sorted Potosi hubnerite to find the percentages of elements present:

WO_3	MnO	FeO	SiO_2
72.1	23.1	0.87	2.80

Analysis by Harry J. Harrity, Butte, Montana.

Microscopic Study of Potosi Specimens

Polished specimens made in the Montana School of Mines laboratories for microscopic study showed that many of the crystals contained included quartz. Most of the crystals are straight, but some show definite replacement characteristics (PLate III C). A few crystals showed intergrowth of crystals as evidenced by cleavage traces (Plate III B). The quartz showed later fracturing with no movement along the planes. A thin thread of hubnerite was observed in one very irregular thread-like fracture.

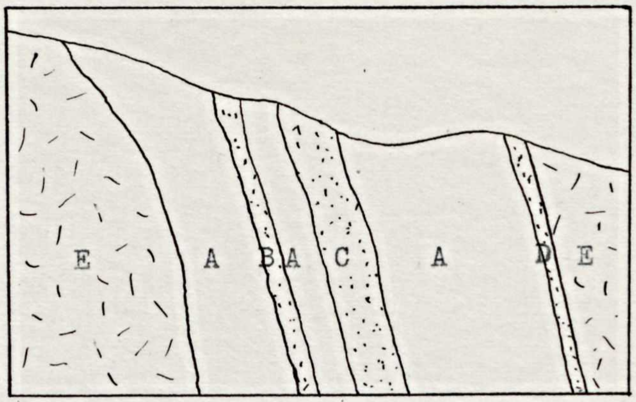
With these few facts at hand, the writer advances the following hypothesis for the origin and paragenesis of these vein-like pegmatites.

1. Intrusion of a massive white quartz.

2. Replacement of some quartz by hubnerite ($Mn\ WO_4$) while the quartz was still hot.

3. Cracks developed parallel to the walls and some very slight movements along the cracks which offsets the broken crystals of hubnerite.

4. Hydrothermal action to produce quartz filling of cracks, and some late hubnerite. This also produced the fluorite and galena found in the border zone.



after Hart (7:32)

A . Sketch of Typical Tungsten Deposit in Potosi District

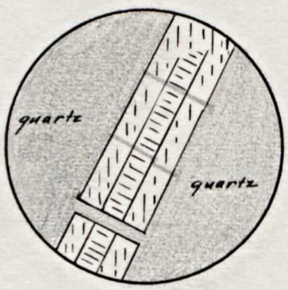
A. barren quartz

B. smoky bands -- microscopic segregations of hubnerite in quartz

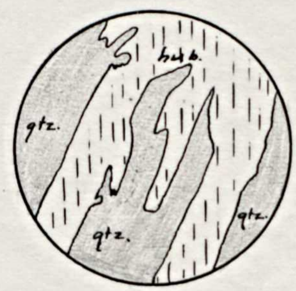
C. 24" -- 30" band containing numerous bands of $\frac{1}{4}$" to $\frac{1}{2}$" crystals of hubnerite

D. altered band -- 12" wide contains much fluorite

E. alaskite



B. Intergrowth of hubnerite crystals as shown by cleavage traces



C. Hubnerite replacing quartz

Lower Hot Springs Mining District*

Several pegmatite dikes have been reported about three miles east of Norris in what is known as the Lower Hot Springs district. In general the dikes are about three feet in width. They are believed to be associated with the Tobacco Root batholith, and are probably early Tertiary in age.

Most of the dikes grade from quartz and feldspar to nearly pure bull quartz in the center. A few dikes show zone arrangement due to early deposition of quartz and feldspar near the walls and a predominance of quartz in the center. One dike of this type found on the Little Rock prospect in the southern part of the Lower Hot Springs district shows a graphic structure of quartz in microcline. The arrangement of the irregular quartz grains in the microcline is very regular, as shown in the accompanying picture (Plate IV). Other minerals present are: muscovite, sodic plagioclase feldspar, pyrite, chalcopyrite, and hematite.

Timber Butte

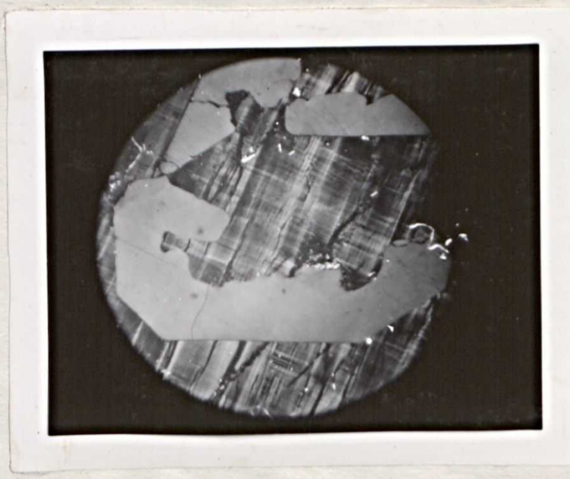
Timber Butte is a prominent topographic feature that lies about one mile directly south of Butte, Montana. It is composed mainly of quartz monzonite of the Boulder Batholith, but several aplite and pegmatite dikes are found cutting the main mass.

The pegmatites found on this butte are highly variable in width. Most of the pegmatites are found within the aplite but some narrow pegmatite dikes were observed in the quartz monzonite. One dike observed on the north slope of Timber Butte was followed southward up

*Personal communication with Mr. Ernest E. Thurlow

Courtesy E . Thurlow

A. Specimen from the Lower Hot Springs Mining District showing the graphic relations between microcline and quartz. x $\frac{1}{2}$



Courtesy E. Thurlow

B. Photomicrograph of a thin section of the above specimen. x 7

A. View of Timber Butte looking south from Butte, Montana.

B. View of Butte from Timber Butte.

the butte by scattered outcrops in a nearly straight line to the top, a distance of at least 1000 feet. The terminations were not found but the width at the base of the butte was approximately six inches while that at the top where last seen was approximately three feet.

The pegmatites that are found in the aplite usually do not have a true contact with it, but simply grades into it. The aplite grades into a micro-graphic granite rock in which the grains grade to larger sizes toward the center of the pegmatite, and this causes the graphic structure to show plainly. The graphic structure of the quartz and feldspar almost disappears at the center of the pegmatites, and large crystals of feldspar and quartz are formed in small cavities in the rock. Smoky quartz crystals half an inch in diameter and up to two inches long and feldspar crystals up to two inches in length are common. Larger feldspar and quartz crystals have been found on the butte as this writer has observed several crystals of smoky quartz a foot long and up to six inches in diameter that have been collected from this place. The graphic structure in the outer part of the pegmatites often occurs in bands which are more or less parallel to the walls.

Weed (9:37) in describing rocks of the Butte district writes as follows: "Aplite---The rock grades into micropegmatite, and at times into true pegmatite, in which the constituent minerals are easily recognizable by the eye. In one instance such pegmatites showed tourmaline.- -In the smaller intrusions, however, it tends to become a pegmatite, and in places grades into such. More generally, however, the pegmatite forms veinlike masses in the main body of the aplite. The pegmatite may be fine-grained graphic granite or a coarse, open-spaced aggregate of quartz and feldspar crystals, showing very little hornblende."

Black tourmaline is more plentiful in parts of the Butte district than one would be lead to believe from Week's description. West of the townsite of Butte coal-like pieces of tourmaline are rather plentiful

A. Narrow pegmatite in quartz monzonite.

B. Coarse crystals and the top of a pegmatite as found in the quartz monzonite.

in pegmatitic bodies.

Pegmatites are found under the same conditions in an aplite body near Roosevelt drive, 12 miles south of Butte. (10).

Winchell (8:41) referring to the pegmatites of the Boulder batholith states that: "The aplite of the Boulder batholith varies locally to pegmatitic phases. Such rocks may be found in special abundance on Timber Butte, about 2 miles south of Butte. They commonly contain coarsely crystalline feldspar and quartz, with some tourmaline and mica. The coarseness of crystallization is believed to be due to the decrease of viscosity resulting from the presence of such volatile constituents of tourmaline and mica as boron and fluorine. Similar pegmatites are associated with minor ore deposits at Hecla, and have been observed on South Boulder Creek at the Bismark mine, about 4 miles above Mammoth. Pegmatite without tourmaline is found at the Strawberry mine near Pony."

The minerals found in these pegmatites are smoky quartz (massive) and in crystals), clear quartz (massive and in crystals), orthoclase, albite, magnetite, black tourmaline, and biotite.

Most of the quartz is of the clear variety and is found in the graphic structure. Occasionally a crystal of clear quartz is found. Smoky quartz usually occurs as crystals in small cavities or vugs. An interesting feature was observed on one specimen taken from a vug. The specimen was a mass of feldspar with crystal faces developed on the vug side. Protruding through these crystal faces were a number of small smoky quartz crystals which were all oriented in the same direction. These crystals showed perfect crystal terminations in the vug; but when a cross-section through the feldspar was made, perpendicular to the orientation of the crystals, it was observed that these crystals had a highly irregular appearance as found in graphic granite and appeared to be resorbed.

The feldspar occurs throughout the rock in mixed white and pink grains which may develop crystals faces in vugs.

Tourmaline was found in many specimens but in only one did it

Layered or banded aplite on Timber Butte around large crystals of quartz and feldspar in a pegmatite.

show any crystal faces. In that one specimen the black tourmaline had grown into an irregular crystal which resembles elbow twinning with two elbows bent in opposite directions. The specimen showed the characteristic vertical striations found on tourmaline and also showed an irregular coal-like fracture. Tourmaline was found in fine irregular veinlets shot through a feldspar crystal. Most of the tourmaline is found in small irregular coal black masses associated with the more crystalline rock.

Many irregular grains of magnetite were found throughout the rock. The largest found was approximately one half inch in diameter. It was very noticeable as it was usually surrounded by a stain of limonite in the rock which was caused by its oxidation. A small amount of biotite was observed in one specimen.

These pegmatites probably represent the replacement of aplite by hot gaseous solutions at a time when the aplite was still hot. This would explain the gradational contact of pegmatite and aplite, and the more definite contact of aplite and quartz monzonite. Continued passage of these hot gaseous solutions would account for larger crystals in the center rather than along the border, and also the tourmalinezation of feldspar crystals. It would also explain the graphic structure in feldspar crystals ending in quartz crystals in small cavities.

Cooke City District

Pegmatites are found in connection with some deposits of magmatic chalcopyrite which occur near Goose Lake about ten miles northeast of Yellowstone National Park. These intrusives are called

Tertiary because they are similar in character to rocks which intrude Neocene lavas about five miles to the southwest.

Lovering (11:636-637) in discussing the occurrence of magmatic chalcopyrite near Cooke City states that: "The ore body occurs a few hundred feet from the edge of a gabbro stock consisting chiefly of diallage and bytownite. This gabbro is seamed by basic pegmatites containing large crystals of hornblende, magnetite, apatite and plagioclase. The stock and the nearby country rocks are cut by a series of intrusives which show a progressive increase in acidity from the oldest to the youngest. The ore body appears to be a late phase of the magmatic differentiation which gave rise to the intrusives just mentioned, and so far as could be determined, it is the youngest rock in the region. The activity of mineralizers may be inferred in the field from the abundance of pegmatites in the younger as well as the older rocks. When followed along their outcrop many of these coarse grained intrusives may be observed grading into the rocks which form their walls elsewhere. Large crystals of biotite, apatite, muscovite, and plagioclase occur in these later pegmatitic dikes and sills."

"A granodiorite mass 1500 feet east of the mine is cut by nearly flat sheets of microperthite pegmatite. The development of these pegmatites as horizontal sills suggests that their intrusion occurred near the roof of a granodiorite boss."

According to Lovering the ore body consists essentially of chalcopyrite and a perthitic intergrowth of orthoclase and albite. Muscovite, biotite, apatite and magnetite occur as accessory minerals. Several generations of minerals are present but because of the lack of any evidence of hydrothermal action and the presence of platinum in the ore, this is classed as a magmatic deposit.

Rochester District

Sahinen (12:23) in studying a complex series of pre-Cambrian gneisses and schists near the old mining camp of Rochester noted pegmatitic bodies. He describes them as follows: "Pegmatites--- Although not as plentiful as granite dikes and sills, pegmatite dikes and irregular masses of pegmatitic rocks are quite common in the zone of hypabyssal (dike) rocks. They differ greatly in size, shape, and attitude as well as in composition. The pegmatites are later than the granites. The usual rock is composed solely of feldspar and quartz in different proportion with feldspar usually the predominant mineral. Some pegmatites are composed almost entirely of feldspar with only a small amount of quartz, usually graphically intergrown. Such dikes may eventually become a source of feldspar for pottery making, if that branch of the ceramic industry ever becomes established in Montana. An interesting pegmatite dike occurs in the "island" of Schist in the southwest part of Nez Perce Basin, Sec. 13, T. 3 S., R. 8 W. It is composed almost entirely of quartz and black tourmaline. A small amount of oxidiz ed copper minerals occurs along the contact of this dike with the intruded rock. Near this dike is another very coarsely crystalline pegmatite dike in which "books" of muscovite mica as much as $1\frac{1}{2}$ inches in diameter have been developed. The balance of the rock is composed essentially of white quartz."

These pegmatites are believed to be related to the Boulder batholith, andin age are very late Cretaceous or early Tertiary.

Tobacco Root Mountains

Pegmatite bodies are quite widespread in the Tobacco Root Mountain area, however they are much more plentiful in some localities than in others. In describing an area near Virginia City, Tansley and Schafer (7:16) state that: "Locally, over a small area, the ground is cut by innumerable granite pegmatite dikes; such a point is the divide between Barton and Alder gulches, east of the Barton Gulch mine. These are nearly white, coarsely crystalline, unfoliated rocks, composed almost entirely of quartz and feldspar. Many of the dikes contain fine intergrowth of quartz and feldspar producing a variety known as graphic granite. Microscopic measurements were made by the Rosiwal method, on two such specimens; one from a dike on the Mountain Flower claim of the Smith group, located about 7 miles southeast of Alder. In both specimens the composition was within one percent of the calculated quartz feldspar eutectic proportions, 28% quartz and 72% feldspar (microcline)."

"Quartz bodies occur as irregular masses, pipes or chimneys and veins. In some, quartz is the sole constituent, but others, containing both quartz and potash feldspar, are true pegmatites. There are all gradations in a single vein from pure quartz to both quartz and feldspar varieties. The quartz is coarsely crystalline and white. In places feldspar crystals are a foot or more in length. Metallization rarely occurs in this type of quartz vein. These masses of quartz increase in number near the batholith."

The age of these pegmatites is also very late Cretaceous or early Tertiary.

Haystack Stock Region

The Haystack stock is located near the head of Boulder River near Cowles Post-Office, Park County, Montana.

Emmons (13:197) writes as follows concerning it: "The crystalline complex is cut by dikes of pegmatite which is composed of feldspar, quartz and mica. Such dikes are especially well developed on Lake Plateau----where red feldspar occur in large crystals which inclose smaller bodies of quartz, most of them about two inches in the longest dimension, and thick six-sided plates of mica about half as large. The pegmatite is not mashed and, therefore, is later than the metamorphism of the gneiss and schist, but since it does not cut the Cambrian sediments, it is probably of pre-Cambrian age."

Dillon Region

Winchell (14) describes the occurrence of deposits of high-grade flake or crystalline graphite in the southern part of the Dillon quadrangle about eight miles southeast of Dillon. The deposits are found chiefly on the ridge between Van Camp Creek and Timber Gulch Creek near the southwest end of the Ruby Mountains. The graphite occurs in seams in sedimentary rocks, in faults and veins, in marbleized limestone, in schists, and on both sides of a graphic granite intrusion. Some irregular lenticular masses have been observed that were 6 to 8 inches thick and 2 to 4 feet in diameter.

According to Winchell (14), the most probable idea of the origin of this graphite is that carbon in bituminous shales was oxidized by water (aqueous gas) at high temperatures and was carried in solution until the solutions reached lower temperatures (900°C) where it was precipitated by the action of a reducing agent which was probably hydrogen.

Marysville

Pegmatites are found along the eastern edge of the Marysville batholith. Barrell (15) states that they are uniformly white and coarse grained. Quartz and feldspar are the chief constituents. In places they exhibit a ribbon structure and other gradations toward quartz fissure veins. The age of these rocks is late Cretaceous or early Tertiary.

Laurin

A sample of a heavy black mineral was sent to the Montana Bureau of Mines for determination by Mrs. Clara Danforth of Virginia City. This mineral was recovered in placer operations for gold on California gulch near Laurin. The mineral itself is in extremely angular grains which may reach a size of one-fourth inch. It is an extremely vitreous black mineral which resembles obsidian except for its specific gravity (5.43) and its grayish oxidized coating. A spectrograph analysis of it showed the presence of much columbium, some tantalum, uranium, thorium and other elements. From its physical properties Dr. E. S. Perry identified it as a mineral closely related to samarskite. As this mineral has only been known to occur in pegmatites, it must have originated from a complex pegmatite only a short distance away from the placer ground.

The following characteristics were observed by the writer during microscopic studies carried on at the Montana School of Mines:

Hardness---not scratched by a needle.

Color--------galena white when observed immediately after polishing; quickly tarnishes to a cream-gray color (in 5 minutes after polishing).

Reagents:

HNO_3 ---fumes seem to have a tarnishing action around the drop, causing the mineral to turn brown-gray, no other action definitely visible.

HCL ----negative.

KOH ----fumes tarnish a slight yellow brown around drop, otherwise negative; blue tarnish in one place.

KCN --- fumes quickly tarnish gray-black around drop, otherwise negative.

$HgCl_2$---negative.

$FeCl_3$---negative.

This mineral is isotropic.

Some grains show much internal reflection in yellows and oranges; others show some patches that do not exhibit this.

The internal reflection is much more prominent along the edges that show the effect of oxidation and weathering.

Horse Creek

Horse Creek is four miles south and four miles east of Sheridan, Montana.* An interesting pegmatite is found here which cuts pre-Cambrian gneiss.* This pegmatite is approximately one foot wide and continues for some distance.* A plagioclase feldspar, quartz, and biotite are the only minerals observed in specimens from this dike. The feldspar which is very white, shows polysynthetic twinning according to the albite law as a prominent feature visible to the eye as conspicuous striations on cleavage faces. This feldspar was determined to be oligoclase by means of oil immersions. Abundant quartz found in the specimens was rounded and irregular. The biotite occurred in small books with hexagonal outline.

*Personal communication with Mr. Russell Chadwick

ECONOMIC ASPECTS

Most of the pegmatites observed are worthless for any commercial uses. The following is a list of districts where pegmatites are found that may prove to be of value:

Dillon	graphite
Laurin	gold and samarskite (rare earth metals)
Cooke City	chalcopyrite (copper)
Potosi	hubnerite (tungsten)
Rochester, and elsewhere	feldspar for ceramic uses

The Potosi tungsten deposit is marginal because of the irregular and lens-like distribution of the ore, but may be opened and mined if the prices and conditions indicate that a profit may be made. The Laurin pegmatite has not been found; but if it is, it may become a producer of gold and rare earth metals. The Cooke City and Dillon deposits are not being worked and not sufficient information has been gathered by the writer to state whether or not they may be worked with profit. Feldspar pegmatites are dependent upon the local development of the ceramic industry for exploitation. Numerous specimens of sheet muscovite (mica) of pegmatite origin are received from time to time by the Montana School of Mines. Although some sheets may be five inches or more in diameter, they are generally defective due to imperfect crystal growth. However, it is quite possible that some of these mica-bearing pegmatites may be of commercial character.

SUMMARY

Simple and complex pegmatites of both basic and acidic types are found in Montana. Most of them are late Cretaceous or early Tertiary in age, but some are pre-Cambrian, and at least one is Tertiary. They are a potential source of copper, gold, rare earth metals, feldspar, mica, tungsten, and graphite. It is possible that prospecting may bring to light pegmatites in Montana which contain commercial deposits of one or more of the minerals listed on page 13.

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