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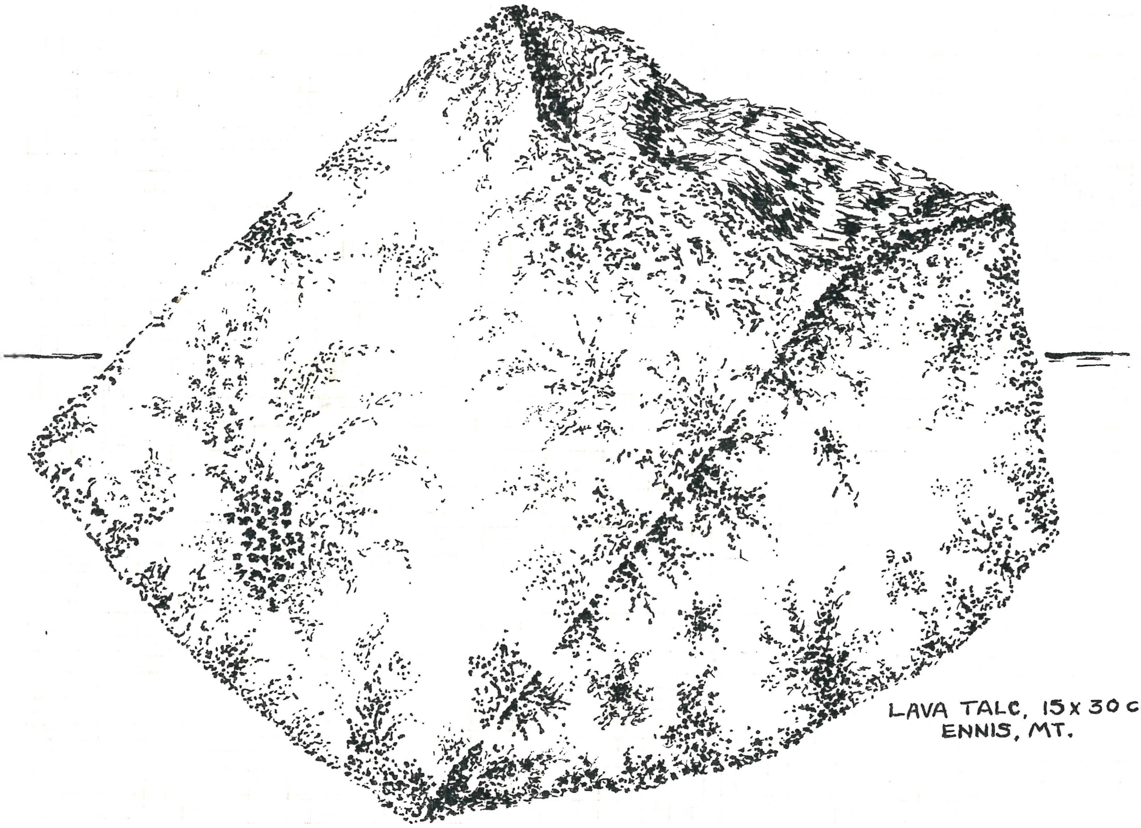
TALC AND CHLORITE DEPOSITS IN MONTANA

by

Richard B. Berg



MEMOIR 45

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Preface

This memoir is one in a series of reports on nonmetallic mineral commodities published by the Montana Bureau of Mines and Geology. The main purpose of this study is to provide information that will be useful to those engaged in exploration for new talc and chlorite deposits. For that reason, mapping of areas that were thought most likely to contain talc was emphasized, as was the mapping and examination of talc prospects and inactive mines that have not been described in the literature. In an effort to make this publication more useful to the individual unfamiliar with talc and chlorite in Montana, published information on all known talc occurrences is also included in abbreviated form.

The contributions of the following field assistants were important to the completion of the project and are much appreciated: Will Goldberg (1973), Hal Koechlein (1974), Roger Kuhns (1975), Leroy Swanson (1976) and Steve Czehura for a short time in 1977. I enjoyed working with each of them. Sam Maloney, Pete Womack and Bob Nolte were very helpful in showing us talc prospects. Ken Wier showed interest in our work in the Greenhorn Range and offered suggestions for the improvement of the geologic map of that area. Review of the manuscript by Keith Papke and Willis Johns resulted in many improvements.

Alice Blount of the Newark Museum, Newark, New Jersey, ran infrared scans on samples of stream sediment and soil. She, Bob Root, Dick Olson, Ed Houser and John Brady also provided me with an opportunity to discuss my ideas on the origin of Montana talc deposits. Charles Knowles of the Idaho Bureau of Mines and Geology kindly ran microprobe scans of a talc specimen in an effort to determine the composition of some very small opaque grains.

Individuals involved with the operating talc mines showed us their operations, and perhaps most important, expressed interest in our work. They include Jim Mulryan, Don Kennedy and Max Tilford (Cyprus Industrial Minerals), Tad Dale (Pfizer, Incorporated), John Burk (formerly with Pfizer, Incorporated), Peter Bixby and Van Stewart (Resource Processors, Incorporated), and Carl Hafer (owner of Willow Creek mine).

Richard B. Berg
Economic Geologist
Montana Bureau of Mines
and Geology

Butte
August 27, 1979

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Cover— Lava talc exhibiting dendritic patterns. Specimen No. 7330 M, courtesy: Mineral Museum, Montana Tech. Eleanor Herndon sketch, MBMG.

Title Page— Talc mines in the Ruby Range (9/1/79). Foreground: Treasure mine (Pfizer, Inc.); background: Beaverhead mine (Cyprus Industrial Minerals). Photo by Aero Tech Surveys, Inc., Riverside, CA, courtesy: Pfizer, Inc., Dillon, MT.

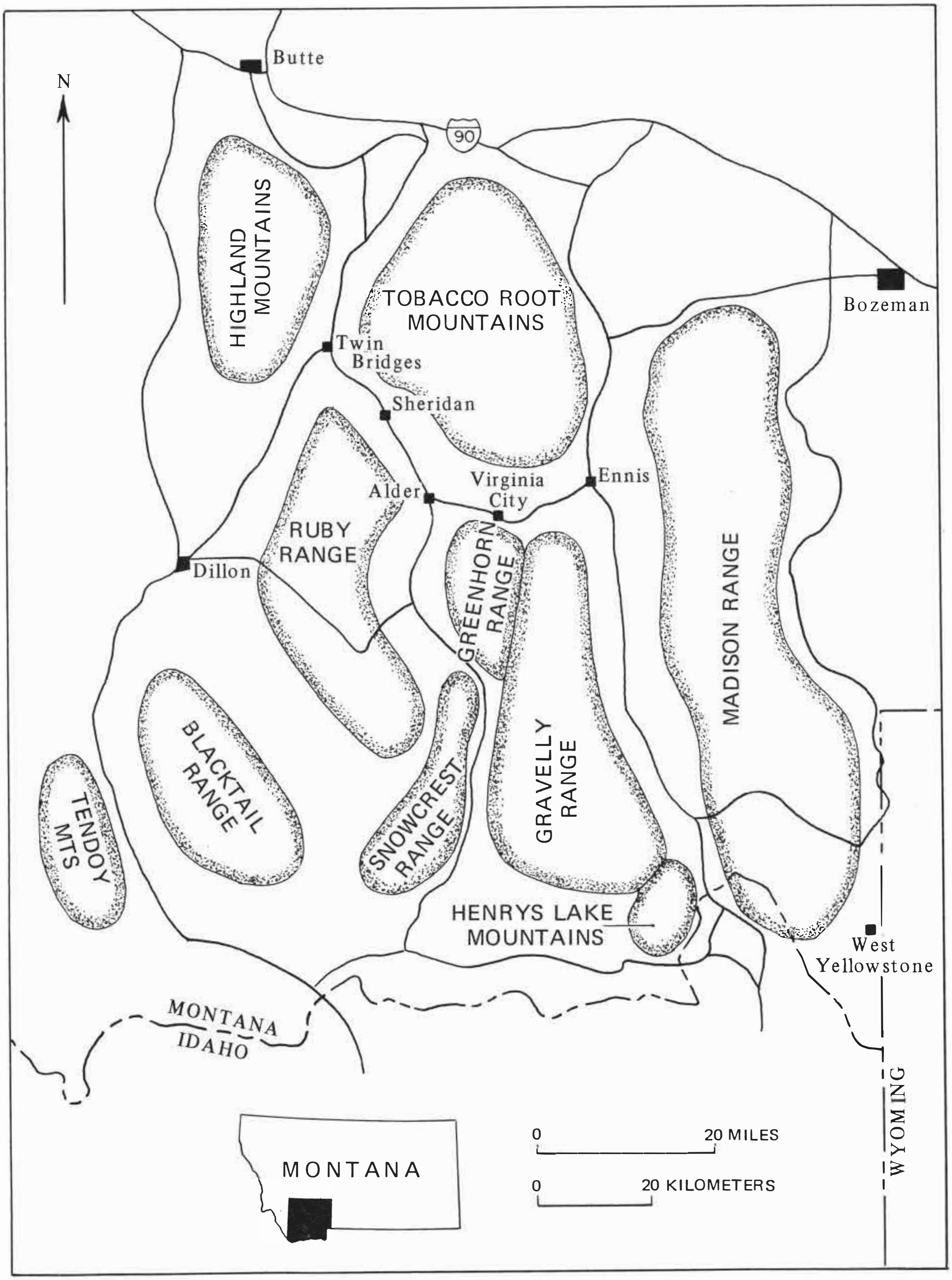


Figure 1—Mountain ranges and major roads in area of talc and chlorite occurrences in southwestern Montana.

Abstract

Talc occurrences range from small veinlets and pods less than one centimeter thick to one body of talc 30 meters thick. Chlorite (variety clinochlore) is disseminated in some talc and also forms relatively pure bodies adjacent to some talc deposits. Both talc and chlorite formed during greenschist facies retrograde metamorphism that affected the upper amphibolite facies pre-Belt metamorphic rocks. This Precambrian retrograde event has been tentatively dated at 1600 m.y.

Most of the talc was produced by the reaction:

$$3 \text{ dolomite} + 4 \text{ quartz} + H_2O = \text{talc} + 3 \text{ calcite} + 3 \; CO_2$$

Because the dolomitic marble contains insufficient SiO_2 for this reaction, it is suggested that SiO_2 was introduced by aqueous fluids of meteoric origin. A small amount of talc was produced by the replacement of tremolite. Most of the chlorite replaced rocks such as quartzofeldspathic gneiss and diabase, which are more aluminous than the marble. The estimated temperature of talc formation is between 400 and 500° C. There is some evidence that talc is more abundant in areas where the marble has been tightly folded or where there are numerous faults.

Fifty talc or chlorite occurrences are described and the localities of 57 additional minor occurrences are given. All except two deposits lie in southwestern Montana. Talc occurrences in the Greenhorn Range are described in detail and are plotted on a geologic map of this range.

Introduction

Location

All of the known talc deposits of economic importance in Montana occur in Precambrian marble within the sequence of pre-Belt metamorphic rocks exposed in the southwestern part of the state **(fig. 1)**.

In 1978 there were five active talc mines and one active chlorite mine in Montana. Most of the talc is produced from three large mines, the Beaverhead, Treasure and Yellowstone. In 1976 Montana talc production ranked second in tonnage and first in value among the talc-producing states. The paper, paint and ceramics industries are major consumers of the unusually pure Montana talc.

Previous work

The best compilation of information on the talc deposits of southwestern Montana is a lengthy article by Olson (1976, p. 99-143). This article emphasized the geology and talc deposits of the Ruby Range, which were described in further detail by Okuma (1971) and Garihan (1973a). The dissertation by Okuma dealt with the southwestern part of the Ruby Range, and Garihan's dissertation covered the central part of the range. Perry (1948) described the talc mines that were operating then and also mentioned two prospects. A description, including maps, of the Johnny Gulch talc deposit (now the Yellowstone mine), put on open-file by the U.S. Geological Survey (James, 1956), was based on field work that was done in 1943 when this large talc deposit was exposed only by underground workings of modest extent and by minor surface excavations. Chidester, Engel and Wright briefly described Montana talc deposits in their summary of the talc resources of the U.S. (1964, p. 33-35). References on the geology of specific areas are cited in the appropriate sections of this memoir.

Present work

Work on this project was begun late in the summer of 1973 when a period of several weeks was spent visiting all of the active talc mines in Montana and most of the previously described talc occurrences in the Ruby Range. A total of four months during the summers of 1974 and 1975 was spent mapping the Precambrian geology of the Greenhorn Range and searching for talc occurrences there. The preliminary results of the work in the Greenhorn Range were put on open file with the Montana Bureau of Mines and Geology in April 1976 (Open-File Report MBMG 19). The open-file report is superseded by this memoir and a forthcoming report on the Precambrian geology of the Greenhorn Range.

Mapping the Precambrian geology of an area including part of the Henrys Lake Mountains required one and a half months during the summer of 1976. The area is approximately 45 miles (72 km) south of Ennis and next to the Idaho border. Talc occurrences are described in this memoir, but a description of the geology will be included in a report on the geology of the Centennial Valley to be published by the Montana Bureau of Mines and Geology.

Most of the other prospects and inactive mines were mapped during the summer and early fall of 1976, but several prospects were examined during two weeks in the summer of 1977. This report was written during the fall and winter of 1977-1978.

The geology of the Greenhorn Range was mapped directly on 7½-minute quadrangle maps that had been enlarged to a scale of 4 inches equal 1 mile. A pocket altimeter was very useful in locating points accurately on the base map, particularly when working on heavily timbered slopes. All prospects were mapped with tape and compass, most at a scale of 1 inch equals 50 feet. A few were mapped at a scale of 1 inch equals 20 feet and then reduced for publication.

Selected talc and chlorite specimens were examined in thin section. Pulverized splits of additional specimens were examined in immersion oils, and the mineralogy of many specimens was checked by x-ray diffraction using a Norelco diffractometer. Some individual mineral grains were identified by using the Debye-Scherrer camera. Representative specimens collected during the study are stored at the Montana Bureau of Mines and Geology, where they are available for study.

Both British and metric units are given for measurements made in the field. Where the measurement was originally made in metric units, these are cited first followed by the British equivalent. If the measurement was made or estimated in British units, these are given first followed by the metric equivalent.

Commercial aspects of talc and chlorite

The mineral talc

Talc is a hydrous magnesium silicate with the ideal formula $Mg_6 [Si_8O_{20}](OH)_4$. Reported chemical analyses of presumably pure talc indicate that the major deviations from the formula are in the presence of Al, Fe^{+2}, and Fe^{+3}. Both talc and chlorite are classified as layer silicates because the arrangement of constituent ions produces a layered structure. Because of that structure, talc, chlorite, and other layer silicates such as mica can be split into very thin sheets. This ability to split into thin sheets contributes to the slippery feel of talc and also to the ability of small flakes to slide easily past one another, a property called "slip", which is important in some uses of the mineral.

Other physical properties of talc that are important in many of its uses are its softness and light color. Talc is one of the softest minerals, and most pure talc can be easily scratched with the fingernail. The unusual softness, together with the ease with which talc splits into flakes, make it practical to pulverize talc into very small particles only a few microns in size. Many of the uses of talc require such extremely fine-grained material. Also required in many applications is a material of light color, almost white. Pure talc when pulverized produces a powder that looks dead white to the eye. Montana talc that is very pale green in hand specimen produces a white powder when pulverized. In those applications where talc is used as a filler, its chemical inertness is an important property. For example, inertness is very important when talc is used as a diluent in pills.

The mineral chlorite

Unlike talc, chlorite has a wide range in chemical composition, as shown by the general formula $(Mg, Al, Fe)_{12} [(Si, Al)_8 O_{20}] (OH)_{16}$. Actually, chlorite is a group of minerals that can be divided into individual species on the basis of the Fe:Mg ratio, Al:Si ratio, or crystal structure. Although not nearly as valuable commercially as talc, the chlorite group is very important mineralogically. Chlorite specimens from Montana that were identified are of the magnesian variety, clinochlore.

Some chlorites possess the desirable physical properties of talc, but to a lesser degree than talc. Chlorite is slightly harder than talc, does not have as light a color as most talc when pulverized, and is not quite as slippery as talc. Like talc, it is relatively inert and can be pulverized into very small flakes.

Commercial talc

The industrial commodity talc can be very different than the mineral talc. Much of the talc used commercially contains a large concentration of tremolite **(Table 1)**. Other minerals that may be present in commercial talc are chlorite, mica, dolomite, magnesite, pyrophyllite, serpentine, anthophyllite, quartz and montmorillonite.

Roe (1975, p. 1134) classified commercial talc into the following four categories based on mineralogy and physical properties.

Steatite: This is massive cryptocrystalline talc that can be sawed, drilled, or machined and is used for electrical insulators. After the soft talc is machined into the required shape, it is fired to produce a tougher product in which the talc has been changed to clinoenstatite and quartz. The fired product is called "lava", and talc suitable for this use is sometimes called "lava talc". Some steatite talc used for electrical insulators has been mined at the Yellowstone mine. (The designation steatite has also been used to describe talc of high purity although it may not possess the physical properties required of "lava talc". Much of the talc mined in Montana has been described as steatite-grade talc.)

Soft platy talc: This variety of talc has been formed by the replacement of magnesium carbonate rocks and commonly contains minor chlorite. Almost all of the Montana talc could be included in this category.

Tremolite talc: (Also called "hard talc" or "hard ore".) In addition to talc and tremolite, this variety of commercial talc may contain anthophyllite, calcite, dolomite, and serpentine. New York talc and some of the California talc are of this variety.

Mixed talc ores: Soft friable talc that contains dolomite, calcite, serpentine and other minor impurities is included in this category. Alabama talc is an example of this type.

Fibrous minerals

Within the last few years there has been great concern about the carcinogenic effects of exposure to asbestos and to a lesser extent exposure to other fibrous minerals. Accompanying this concern there has been much confusion as to what is an asbestos mineral. Some confusion can be avoided by applying the term asbestos only to the mineral chrysotile, the major constituent of much commercial asbestos. Besides chrysotile, other minerals that *may* have a fibrous habit are the amphiboles amosite, anthophyllite, crocidolite, tremolite and actinolite. To the talc producer or consumer, tremolite and anthophyllite are the most important minerals of this group because they occur in some talc. A very important distinction must be made between the fibrous and nonfibrous habits of these minerals. Tremolite and anthophyllite occur in both prismatic and fibrous habit. Specimens having prismatic habit produce small prisms and not fibers when crushed. Anthophyllite has a greater tendency to occur in the fibrous habit than tremolite, which is only rarely fibrous (Ampian, 1976, p. 4). For more information on amphiboles in talc, the reader is referred to Goodwin, 1974.

Uses of talc

As with many of the nonmetallic mineral commodities, talc has a wide range of uses. Although the various uses of talc have specific requirements, most of them are based on the unusual physical properties of talc that make it possible to produce a very fine grained white powder that is chemically inert and not abrasive. In 1977 the domestic consumption of talc was ceramics, 33 percent; paints, 24 percent; paper, 8 percent; plastics, 8 percent; roofing, 7 percent; cosmetics, more than 5 percent; insecticides, 3 percent; rubber, 2 percent; and numerous other minor uses (Clifton, 1978, p. 166).

Table 1—Comparison of mineralogy of commercial talc from New York, California and Montana (*from* Mulryan, 1974, p. 16). Mineral concentrations are expressed in percent.

Source	Talc	Carbonate	Tremolite	Anthophyllite	Quartz	Other
New York	62		30	5	3	
Silver Lake, California	54	3	43			
Panamint, California	82	12			Trace	2 montmorillonite, 4 mica
Yellowstone mine, Montana	99	1			< 0.5	
Beaverhead mine, Montana	98	1				1 chlorite

Talc is used in many ceramic products, especially in wall and floor tile and dinnerware. It is also used in some ceramic glazes. Talc improves the firing characteristics of the ceramic product, and in some applications it permits reduction of the time required for the firing cycle. Synthetic lava talc for electrical insulators can be made from ground steatite talc. Electrical insulators can also be made of synthetic cordierite produced by firing a mixture of talc and clay.

Talc is used as a filler and extender in paint. It can be used to replace some of the more expensive pigments such as titanium dioxide and in this use would be regarded as an extender. The addition of talc to paint helps to prevent settling of the pigment when paint is stored and to avoid sagging when paint is applied. Talc is also added to paint to decrease gloss.

A very important use of talc in the paper industry is in the control of pitch. Pitch from the wood pulp may adhere to the equipment and may also produce brown spots in the finished paper. Finely pulverized talc adsorbs the resins, thus helping to keep them dispersed in the pulp. Talc of high purity and whiteness is required for this market. Talc can also be substituted for titanium dioxide, which is added to pulp to increase the whiteness of the finished paper.

In addition to the major uses of talc in ceramics, paint and paper, there are many other uses, which together account for almost half the market. In the manufacture of plastics and rubber, talc is used as a filler, to reduce the cost of the finished product, and to give desirable physical properties to the product. The addition of talc to some plastics increases their strength and toughness. Talc increases the physical stability and resistance to weathering of roofing materials. A small amount of talc dusted on the surface of roofing also helps to prevent layers of the roofing from sticking together during storage. Because of its chemical inertness and fine particle size, talc is used as a carrier for insecticides. Talc of extremely high purity (both chemical and mineralogical) is used in the cosmetic and pharmaceutical industries. Although talcum powder accounts for only a miniscule fraction of the market, it may be the best known use of talc.

Talc can be used to produce other layer silicates that are similar to hectorite, the lithium-bearing smectite mined in California and valued for its high swelling and gelling characteristics. United States patent number 3,954,943 was granted May 4, 1976, to Laporte Industries Limited, Luton, England, for a process utilizing talc in the manufacture of a hydrous magnesium silicate, which has a crystal structure similar to that of hectorite but which is reported to have rheological properties superior to natural hectorite. Another U.S. patent (number 3,666,407) was granted May 30, 1972, to Pfizer, Incorporated, for a process for producing synthetic hectorite-type clay from talc. To the best of the author's knowledge, neither process has yet been used commercially.

Prices reported for talc in the January 1978 issue of Engineering and Mining Journal (McGraw-Hill, New York) range from $10.50 to $151 per ton, depending mainly on the quality of the talc and the degree to which it has been processed. Although prices were not given for Montana talc, it is probably most closely represented by the California talc, which ranged from $37 to $104 per ton, with very finely ground (micronized) talc of unusual whiteness at the high end. Cosmetic-grade steatite from California ranges from $44 to $65 per ton.

Production, mining and processing of talc and chlorite

Major talc producing areas

In recent years New York, Vermont, Texas, Montana and California have been major domestic sources of talc. The U.S. Bureau of Mines ranks the states in terms of total production of talc, soapstone and pyrophyllite, but provides no annual ranking for talc alone. A large amount of talc is mined in the Balmat-Edwards area of northern New York, where talc occurs in marble of the Grenville Series (Precambrian). Talc ore bodies are in the same stratigraphic unit as zinc ore mined in the district. Most of the talc in this district is of the tremolitic variety. Talc deposits in Vermont that have been formed by the alteration of ultramafic bodies consist of an impure mixture of talc and other minerals. Froth flotation is used to beneficiate the ores. The ceramic industry is a major consumer of talc from the Allamoore district, in west Texas. Talc from this district ranges from white to black. Although the black rock consists mainly of talc, it looks more like black argillite than talc. Both tremolitic talc and high-purity talc are mined from an extensive district near Death Valley in California, which extends northeast into Nevada. Alabama and North Carolina both produce talc, but production is substantially less than that of the states just mentioned. Olson (1976, p. 101-108) gave a more detailed discussion of talc producing areas in the United States. Some other countries that produce talc are Canada (Ontario), Italy, France, Finland, Australia, China, Japan, Russia, South Korea, India and Brazil.

Mining and processing of talc

Talc deposits in the United States are mined by conventional methods, both openpit and underground. Some of the talc mined in New York, Vermont and California is produced from underground mines, but Montana production is now (1978) entirely from open pits. In openpit mines it is a common practice to sample the talc ore body by closely spaced holes drilled after removal of the overburden. Cuttings are analyzed for purity, and the brightness of the pulverized talc is determined. Analysis of the drill hole samples enables the operator to plan the sequence of mining to provide talc of various grades for different markets. By stockpiling talc of different grades, it may also be possible to blend talc to produce the maximum amount of material of a particular grade.

The processing of talc consists essentially of beneficiation and pulverization. The methods used to beneficiate talc differ from area to area, depending on the nature of the ore as well as the purity required for the finished product. For example, Vermont ore consists of a mixture of talc and magnesite and contains minor iron oxide, pyrrhotite and gersdorffite ($NiAsS$). Froth flotation is employed to produce high-purity talc from this ore. Froth flotation supplemented by high-intensity magnetic separation is used on some other talc ores.

In some deposits, including most of those in Montana, the talc is of high purity but blocks of talc are mixed with country rock to such an extent that some waste must be mined with the talc. In this situation, removal of the waste rock by hand sorting has proved to be a practical means of beneficiating the talc ore. Mechanical sorting, using an electro-optical sorter that rejects material of low reflectivity, has been tried on an experimental basis for this type of ore. As deposits of high-purity talc are depleted, more sophisticated beneficiation techniques will be used to upgrade impure talc.

Much of the present market requires talc of high brightness and of extremely fine grain size. Because of its softness talc can be finely pulverized (micronized) in fluid-energy or jet mills. After initial pulverization in roller mills, the talc is fed into the fluid-energy mill, where it is pulverized by attrition in a circular chamber in which either compressed air or steam propels the talc particles through a circular path. The finer talc particles leave the chamber through a central port while the coarser particles continue to travel around the periphery of the chamber. A fluid-energy mill can produce a product in which the talc particles are in the range of 0.5 to 10 μm.

Brightness of the pulverized talc is an important property for many uses. The brightness is a measure of the reflectivity of the talc sample as compared to an MgO standard. Because General Electric has developed carefully calibrated instruments for its determination, this characteristic is commonly termed GE brightness.

Montana talc production

The Montana talc industry has grown to its present size mainly since the late 1940s. Chidester and others (1964, p. 35) stated that total Montana talc production through 1956 was approximately 200,000 short tons and that most of it was produced after 1949. In 1976 Montana talc mines produced 224,753 tons of talc with a reported value of $2,960,000 (Clifton, 1978, p. 1311). Montana was the leading state in the value of talc produced and second to Vermont in the amount of talc produced during 1976.

Many of the currently active talc mines in Montana were initially underground mines. The ore bodies at the Yellowstone, Beaverhead, Regal and Smith-Dillon mines were all developed by underground workings, but more recent production has been from open pits. (For an interesting account of the history of talc mining in Montana, see Olson, 1976, p. 108-109.)

Production of talc in 1977 was from five mines operated by three companies. Cyprus Industrial Minerals of Cyprus Mines Corporation produced talc from the Yellowstone and Beaverhead mines. Pfizer, Incorporated mined most of its Montana talc from the Treasure mine and a much smaller amount from the Regal mine. Resource Processors mined talc at the Willow Creek mine. A small quantity of chlorite, which was mined at the Golden Antler mine, was sold to Cyprus Industrial Minerals.

Both Cyprus and Pfizer have plants equipped with fluid-energy mills for fine grinding of talc. Cyprus' plant is situated at Three Forks, and Pfizer's plant is at Barretts siding south of Dillon. Cyprus also ships crude talc to its plants at Grand Island, Nebraska, and Gent, Belgium. Crude talc from the Willow Creek mine is shipped to Resource Processor's mills in the eastern United States.

The most recent figures available for the consumption of Montana talc are for 1972 when the distribution was as follows: paper, 36 percent; paint, 29 percent; ceramics, 8 percent; toilet preparations, 6 percent; and other uses, 21 percent (Welch, 1974, p. 433). In that year, 5 percent of Montana talc was exported from the United States.

Although the annual production of talc in Montana has increased greatly over the last 30 years, production increases have not been at a uniform rate. **Table 2** shows the changes in talc production for the period from 1970 through 1976.

From all indications, the talc industry in Montana will continue to grow, and there will be continuing exploration for new deposits as well as reevaluation of inactive mines and raw prospects. Of possible significance in the future market of Montana talc is the projected growth in the paper industry, a major market for the talc mined in Montana. The U.S. paper industry, which used 80,000 short tons of talc in 1973, is predicted to use 250,000 short tons of talc in the year 2000 (Wells, 1976, p. 1087).

Geology and mineralogy of talc and chlorite deposits

Pre-Belt metamorphic rocks

With the exceptions of the talc deposit southwest of Helena (O-1) and the deposit northeast of Troy (O-2), all known talc occurrences of Montana are in marble of Precambrian age within a sequence of metamorphic rocks. These metamorphic rocks, now known as pre-Belt metamorphic rocks, were divided into Archean gneiss and the overlying "Cherry Creek beds" by Peale (1896) during his work in the Tobacco Root Mountains, Madison Range and Gravelly Range. The "Cherry Creek beds", described by Peale as marble, mica schist, quartzite and gneiss, were named for exposures between Cherry Creek and Wigwam Creek in the Gravelly Range. Later Tansley, Schafer and Hart (1933, p. 8) divided the Precambrian metamorphic rocks of the Tobacco Root Mountains into the Pony Series and the overlying Cherry Creek Series. The Pony Series included the Archean gneiss of Peale and was so named because it is exposed in the vicinity of Pony, a small town on the northeast flank of the Tobacco Root Mountains. The Cherry Creek Series included the metasedimentary rocks of the "Cherry Creek beds" as originally described by Peale. Tansley, Schafer and Hart recognized that there was no evidence for designation of the Pony Series as Archeozoic and the Cherry Creek Series as Proterozoic (Algonkian). For this reason and because the Cherry Creek Series is overlain by sedimentary rocks of the Belt Supergroup (Precambrian), they designated the Pony Series and Cherry Creek Series as pre-Beltian. This designation, frequently shortened to pre-Belt, is now in general use. The Belt Supergroup is a thick section of sedimentary rocks of Precambrian Y age (800 to 1600 m.y.), which is exposed in western Montana and northern Idaho. In western Montana most rocks of the Belt Supergroup are no higher than the biotite grade of metamorphism.

Table 2—Change in Montana talc production from 1970 through 1976, compiled from U.S. Bureau of Mines Minerals Yearbooks referenced below.

Year	Change from previous year	Reference
1970	8% decrease in tonnage	West, 1972, p. 435.
1971	6% decrease (in tonnage?)	Welch, 1973, p. 447.
1972	"substantial increase"	Welch, 1974, p. 433.
1973	48% increase in tonnage	West, 1976, p. 426.
1974	27% increase in value	Krempasky and Lawson, 1977, p. 421.
1975	52% decrease in tonnage	Krempasky and Lawson, 1978, p. 457.
1976	84% increase in tonnage 96% increase in value	Krempasky and Lawson, in press.

The distinction between rocks belonging to the Pony Series and those belonging to the Cherry Creek Series is difficult. Reid (1957, p. 6, 7) in his discussion of the metamorphic rocks of the northern Tobacco Root Mountains stated:

> *It must be emphasized that the distinction between Pony and Cherry Creek depends not on peculiarities visible in every outcrop, but rather depends on the aggregate of rock types present in a rather thick section. Because of possible lateral variation in rock composition, the criteria listed above for distinction may be valid only in the immediate vicinity of the map area.*

Further, the age relationship between the Pony Series and the Cherry Creek Series is not without uncertainty. Reid (1957, p. 14) reported that in the northern Tobacco Root Mountains, rocks of the Cherry Creek Series dip under rocks of the Pony Series and he therefore concluded that unless there is major overturning of the entire section, the Pony Series is younger than the Cherry Creek Series. Heinrich and Rabbitt (1960) described rocks of the Cherry Creek Group and pre-Cherry Creek gneiss from the Ruby Range southwest of the Tobacco Root Mountains. In the Ruby Range the rocks of the Cherry Creek Group are separated from the pre-Cherry Creek rocks by the Dillon granite gneiss, a thick layer of quartzofeldspathic gneiss. The division of the pre-Belt metamorphic rocks into the Pony and Cherry Creek Series seems premature at this stage in our understanding of those rocks. Because of isoclinal folding, the establishment of a stratigraphic section even within one mountain range is difficult, and the correlation of units from one range across a valley to another range is extremely uncertain. Talc occurs in marble layers within a sequence of rocks, mainly metasedimentary, which can best be described as Cherry Creek lithology.

Mineralogy

Talc

Most of the talc from southwestern Montana is pale green to white in hand specimen, exhibits a waxy luster, and when pulverized yields a powder,that to the naked eye, appears white. The variation from light green to dark green in material from some deposits is a function of the chlorite content of the talcose rock; the greater the concentration of chlorite, the darker the color of the rock. The apparent hardness of talc varies considerably. Some of the very fine grained massive talc can be scratched by the fingernail only with difficulty, whereas coarser-grained talc can be easily scratched with the fingernail.

Talc from southwestern Montana is relatively pure. The major impurity in some of the talc is fine-grained chlorite, which is not recognizable in hand specimen nor even in some thin sections. X-ray diffraction analysis showed chlorite present in concentrations of a few percent in many of the light-green talc specimens.

In thin section, talc shows a variety of textures. The block or lava talc (now known also as carving talc) from the Yellowstone mine and vicinity consists of talc grains only 1 to 2 μm across and of random orientation. At the other extreme is dolomite-tremolite-talc schist from the Tait claims (GR-1) that consists of well oriented talc flakes several millimeters across. The grain size of most Montana talc falls between these two extremes. Some talc displays a feathery texture caused by sheaves of talc grains as much as 0.6 mm long that are surrounded by talc grains only 10 μm across. Several specimens exhibit a mosaic texture that is produced by 0.2- to 4-mm patches of fine-grained talc with almost uniform extinction position **(Plate 1)**. This is possibly a relict texture inherited from marble that was replaced by talc. Fine-grained talc may be veined by coarse-grained talc in which individual flakes are several millimeters across.

Chemical analyses of two talc specimens **(Table 3)** show that both specimens contain a significant concentration of iron. Analyses of other talc samples from southwestern Montana presented by Olson (1976, p. 111) show that they contain between 0.51 and 1.51 percent total iron expressed as Fe_2O_3. Also talc analyses presented in Deer, Howie and Zussman (1962, p. 122, 123), although incomplete in terms of analysis for FeO and Fe_2O_3 in the same specimen, show high values of 2.46 percent FeO and 1.49 percent Fe_2O_3 for different specimens. Both specimens of talc reported in **Table 3** contain opaque grains 1 to 2 μm across that were first thought to be a possible source of iron. Those grains are not abundant enough to explain the iron reported in the talc analyses, however, even if the unidentified mineral were an iron oxide. Because the talc specimens were prepared in a ceramic mortar and pestle, iron contamination during sample preparation can be ruled out. The iron reported in these analyses must then be a constituent of the mineral talc. Specimen 83 also contains a few small grains of apatite.

Talc specimen 3317-5b likewise contains a significant concentration of iron, 2.24 percent FeO and 0.51 percent Fe_2O_3. This specimen contains an estimated 2 to 4 percent chlorite and small opaque grains that appear similar to those in specimen 83. If the chlorite has about the same composition as the analyzed chlorite from the same deposit (**Table 3**, specimen 3316-6), it would not contribute as much iron as reported in the analysis. Because the concentration of opaque grains is too low to account for the iron reported in the analyses, it can be concluded that most of the iron is in the talc lattice.

Chlorite

Most of the chlorite-rich rock can be distinguished from talc in hand specimen by its darker green color and greater hardness; most rocks consisting mainly of chlorite cannot be scratched by the fingernail. Although generally the greater the concentration of talc in the chloritic rock the lighter the shade of green and the softer it is. Some specimens that are almost pure chlorite are light tan and softer than some specimens of talc. X-ray diffraction analysis of many specimens of chloritic rock showed that almost all contain talc. Zircon, apatite and rutile are trace constituents of much chlorite. Except for rare silvery-gray chloritized biotite crystals 1 to 2 cm across, all of the chlorite is microcrystalline.

Two and possibly three distinct varieties of chlorite can be recognized in thin section by differences in color and texture. The most abundant variety is clinochlore, identified by chemical analyses of two specimens in which it is the only chlorite **(Table 3)**. The grain size of most clinochlore is between 2 and 100 μm, and radial sheaves of grains form a common texture **(Plate 1)**. In plane light clinochlore is colorless to very pale green and with crossed nicols the interference colors are gray to yellowish orange depending on the grain size.

Pennine(?), which shows bright blue and violet interference colors, forms grains as much as 0.5 mm long and vermiform growths. This chlorite, although colorless to pale green in plane light, tends to be greener than the clinochlore. The third possible variety of chlorite also forms coarse flakes but is grayish green when viewed with crossed nicols and is colorless in plane light. All three varieties of chlorite can occur within the area covered by a single thin section.

Two of the purest specimens of chlorite were analyzed for major elements **(Table 3)**. A plot of these chlorite samples on Foster's classification scheme **(fig. 2)** shows that both specimens lie within the clinochlore field. Structural formulas calculated from these analyses are shown in **Table 4**. Na_2O, K_2O, CaO, and TiO_2 were excluded from these formulas because it is probable that those constituents where present can be attributed to impurities in the chlorite. The high concentration of TiO_2 in specimen 1451 is caused by the abundant rutile. Specimen 3316-6 is, except for its unusual purity, typical of fine-grained clinochlore associated with talc.

The chlorite polytype was determined for chlorite specimens from localities H-1, TR-7, TR-9, TR-10, GH-28, GH-42, GR-1, and R-10. As would be expected from the geologic environment, all of these specimens are the IIb polytype. Brown and Bailey (1962, p. 834, 835) found in their survey of chlorite from different environments that approximately 80 percent of the 303 chlorite samples tabulated are the IIb polytype and that this polytype is characteristic of chlorite from metamorphic rocks and high-temperature ore deposits.

Table 3—Chemical analyses of talc and chlorite specimens.

	Talc		Chlorite	
	83	3317[illegible]5b	1451	3316-6
SiO_2	62.84	62.42	31.54	32.41
TiO_2	0.11	0.04	1.47	n.d.
Al_2O_3	0.37	0.45	18.59	18.16
Fe_2O_3	0.34	0.51	0.74	0.61
FeO	1.02	2.24	3.74	6.16
MgO	30.43	29.35	31.70	31.24
CaO	0.04	0.01	0.17	0.04
Na_2O	0.04	0.02	0.01	0.01
K_2O	0.02	0.01	0.02	0.01
H_2O^+	4.51	4.79	12.16	12.73
H_2O^-	0.29	0.09	0.62	0.31
Total	100.01	99.93	100.76	101.68

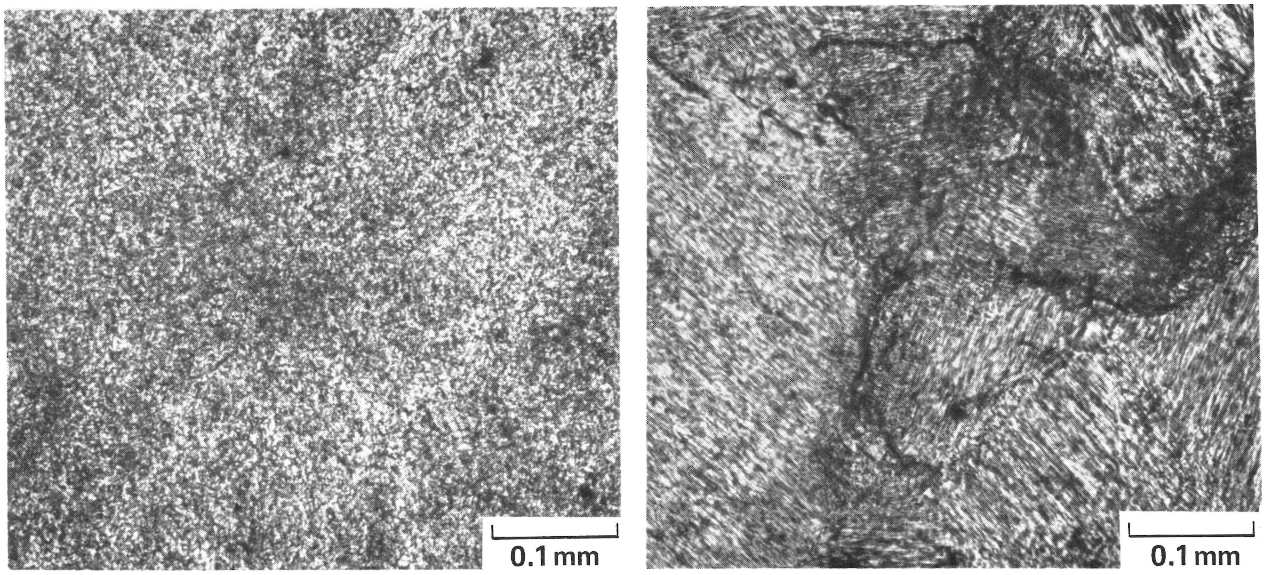
83: Talc from the Cherry Gulch prospect (GR-2).
3317-5b: Talc from the Willow Creek mine (GH-42).
1451: Chlorite from Ruby claims (GH-28).
3316-6: Chlorite from the Willow Creek mine (GH-42).
See Plate 1 for photomicrographs of these specimens.
Analyses performed in the Analytical Laboratory of the Montana Bureau of Mines and Geology.
Analyses by Larry Wegelin, Frank P. Jones and Gayle LaBlanc.

Associated minerals

The following 25 minerals are associated with either talc or chlorite. Twenty were observed in the deposits examined during the present study. Descriptions of the other five were taken from the literature. Some have little genetic significance for the formation of talc or chlorite because they are either relict phases remaining from the rock replaced by talc or chlorite or they were deposited after the formation of talc and chlorite. Others seemingly are contemporaneous with the talc or chlorite and thus can help in the understanding of the conditions of formation of the talc or chlorite.

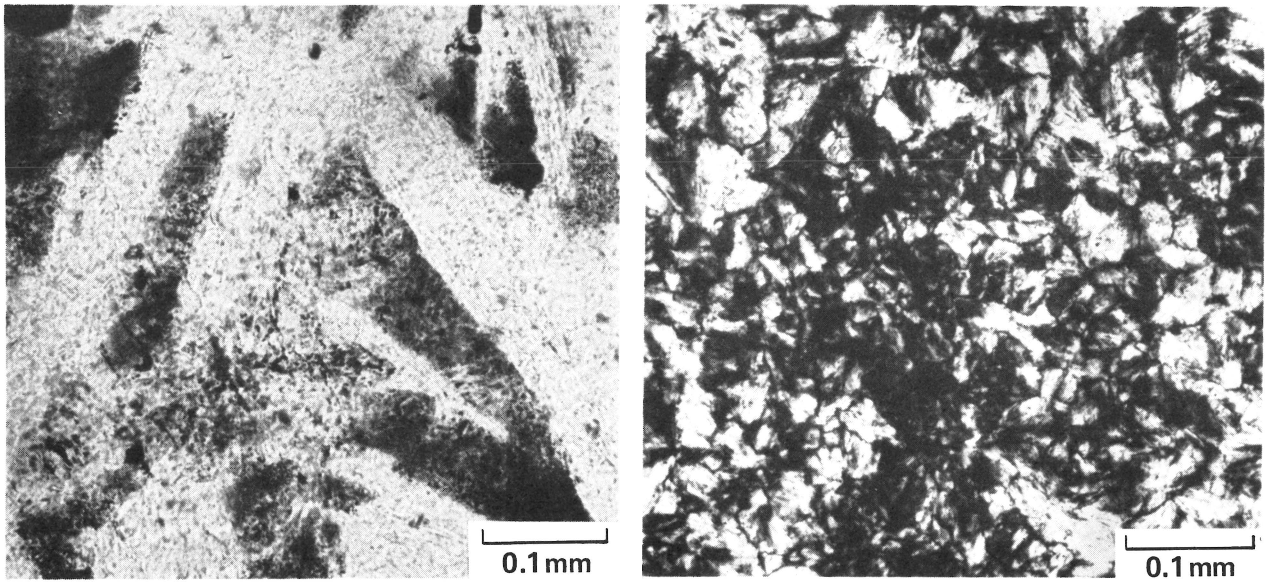
Table 4—Structural formulas and characteristics of analyzed chlorite.

	1451 from Ruby claims (GH-28)	3316-6 from Willow Creek mine (GH-42)
Structural formula	$(Al_{1.09}\ Fe^{+3}_{0.04}\ Fe^{+2}_{0.28}\ Mg_{4.50})\ (Al_{0.99}\ Si_{3.01})\ O_{10}\ (OH)_8$	$(Al_{1.05}\ Fe^{+3}_{0.04}\ Fe^{+2}_{0.48}\ Mg_{4.37})(Al_{0.95}\ Si_{3.05})\ O_{10}\ (OH)_8$
Variety	Clinochlore IIb polytype	Clinochlore IIb polytype
Index of refraction	1.583 ± 0.005	1.586 ± 0.005
Color	Light olive gray 5Y 6/1	Dark greenish gray 5G 4/1
Grain size	3 to 700 μm	20 to 100 μm
Impurities	Rutile grains 5 to 52 μm long	None detected
Origin	Replacement of diabase dike	Replacement of quartzofeldspathic gneiss



A. Specimen 83 of fine-grained talc from Cherry Gulch prospect. Polars crossed.

B. Specimen 3317-5b of talc from Willow Creek mine. Polars crossed.



C. Specimen 1451 of chlorite that has replaced diabase dike at the Ruby claims. Relict ophitic texture shown by masses of pure chlorite that has replaced plagioclase and dark areas where chlorite-rutile mixture has replaced a pyroxene. Plane light.

D. Specimen 3316-6 of unusually pure chlorite from the Willow Creek mine. Polars crossed.

Plate 1
Photomicrographs of analyzed talc and chlorite.

Ankerite: James (1956, p. 2) reported crystals of ankerite as much as 1 inch (2.54 cm) across found in vugs in siderite at the Yellowstone mine (GR-3). Both siderite and ankerite were described as secondary carbonates.

Apatite: Pale greenish-blue apatite crystals < 1 cm long have been identified in chlorite from the Beaverhead mine (R-10). Milky white apatite crystals several millimeters long are a trace constituent of some of the chlorite from the Willow Creek mine (GH-42). On the basis of indices of refraction (ϵ = 1.6353, ω = 1.6397) this is fluorapatite.

Brucite: Millholland (1976, p. 50) reported the occurrence of brucite in marble north of Cherry Gulch in the Gravelly Range. Brucite grains < 0.5 mm long are intimately associated with fine-grained dolomite and talc.

Calcite: Calcite coats fractures and fills vugs in some of the talc deposits. The mode of occurrence suggests that the calcite was deposited after the time of talc formation and thus was not produced by the reaction: 3 dolomite + 4 quartz + H_2O = talc + 3 calcite + $3CO_2$.

Chalcopyrite: Chalcopyrite is a rare constituent of talc, having been reported from only two localities. Garihan (1973a, p. 164) mentioned scattered chalcopyrite grains in talc at the Bennett Owen claim (R-8). Minor chalcopyrite occurs in talc at the Cherry Gulch prospect (GR-2).

Dolomite: Coarse-grained dolomite in which some individual rhombs are more than 5 cm across is associated with some talc occurrences. Because dolomite grains this large are found only next to talc bodies, it is inferred that such coarse-grained dolomite is related to the formation of the talc.

Graphite: Graphite in the marble was not affected by replacement of the marble by talc and is now a minor constituent in some talc.

Gypsum: Both Okuma (1971, p. 93) and Garihan (1973a) reported the rare occurrence of gypsum in talc in the Ruby Range. Garihan specifically described gypsum in the talc at two prospects north of the Treasure mine (R-6 and R-7) and at the Spring Creek deposit (R-2). Gypsum has not been reported in talc from other mountain ranges.

Hematite: Millholland (1976, p. 50) identified minute hexagonal plates of hematite in some talc from the Gravelly Range.

Limonite: Most fractures in pyrite-bearing talc are coated with limonite derived from the weathering of pyrite. Limonite pseudomorphs after pyrite can be found in some talc, for example, the Grandview prospect (TR-7).

Magnesite: A maroon rock exposed at the Burlington Northern prospect (GR-5) consists of magnesite accompanied by minor dolomite and talc. Millholland (1976, p. 50) also mentioned magnesite in

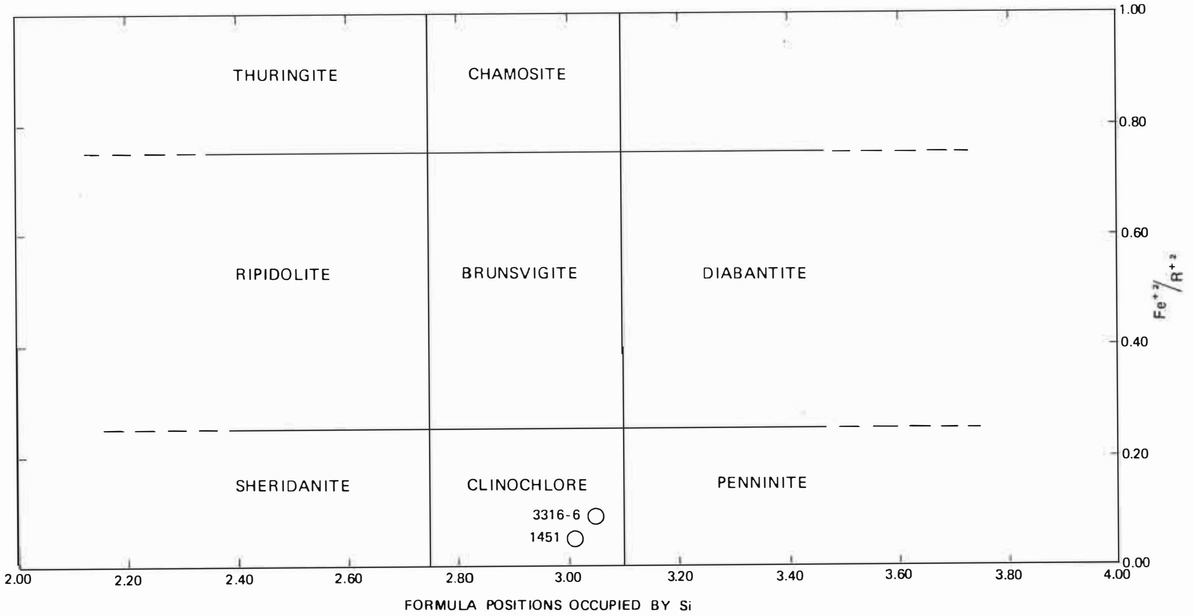


Figure 2—Plot of compositions of analyzed chlorite.

marble in this general area. Another talc locality where magnesite is reported is in the NW¼ sec. 13, T. 8 S., R. 4 W., in the Greenhorn Range, where a specimen of marble contains magnesite, dolomite, talc and minor chlorite. Magnesite also occurs at the Treasure mine (R-9).

Malachite: Weathering of chalcopyrite has formed malachite at the Cherry Gulch prospect (GR-2). Garihan (1973a, p. 164) described malachite along fractures at the Bennett Owen claim (R-8).

Muscovite (Sericite): Feldspars in quartzofeldspathic gneiss and schist next to many talc or chlorite occurrences have been altered to sericite. Sillimanite in pelitic schist at the Bivens Creek talc deposit (TR-5) also has been replaced by sericite.

Prehnite: Prehnite has been identified at only one locality, a small prospect in the Greenhorn Range (GH-38) where prehnite grains as much as 1.5 mm across are associated with fine-grained chlorite and coarser-grained calcite.

Pyrite: Pyrite is found only rarely in talc or in quartz veins associated with talc. Most of the pyrite pyritohedrons have been replaced by limonite.

Pyrolusite(?): Black dendrites in the block talc from the Yellowstone mine (GR-3) and vicinity are probably pyrolusite; they are found only in the block talc.

Quartz: Irregular masses of quartz are locally abundant in some talc deposits.

Rutile: Garihan (1973a, p. 151, 171) reported a trace of rutile in some of the talc at the Treasure mine (R-9) and also mentioned secondary euhedral rutile intergrown with talc and chlorite at the Whitney claims (R-4). Rutile is a trace constituent of much of the chlorite and is particularly abundant in chlorite at the Ruby claims (GH-28).

Sepiolite: Masses of splintery sepiolite as much as 10 cm long are exposed in the lowest cut at the prospect north of Willow Creek (GH-43). Alice Blount (personal communication, 1977) has also identified sepiolite from marble just south of the pit at the Willow Creek mine.

Serpentine: According to Garihan (1973a, p. 180) thin chrysotile veinlets cut some of the talc at the Gem claim (R-3).

Siderite: Siderite is reported to be a secondary carbonate at the Yellowstone mine (GR-3) (James, 1956, p. 2).

Tremolite: Tremolite in talc is reported only from the Ruby Peak occurrence (R-1). At some other localities tremolite blades as much as 3 cm long have been completely replaced by talc. An example can be seen in the longest cut at the Harris Creek prospect (TR-6) where tremolite was formed in the marble during an earlier stage of metamorphism and was later replaced by talc.

Unidentified mineral: Extremely small (1 to 3 μm) grains of an opaque mineral are scattered in cloudlike concentrations in some of the talc. Efforts to concentrate the mineral and identify it by x-ray diffraction analysis were unsuccessful.

Vermiculite: Vermiculite was identified in talc at only one locality south of Virginia City (GH-45). The size and shape of the vermiculite grains suggest that they were formed by the replacement of phlogopite present before replacement of the marble by talc.

Zircon: Zircon is a trace constituent of some chlorite. Most zircon grains are subrounded to euhedral and between 0.1 and 0.2 mm in length. A few are as much as 0.5 mm long. The zircon grains were originally present in the quartzofeldspathic gneiss or schist and were not destroyed during the replacement of those rocks by chlorite.

Origin of talc and chlorite

Conditions of formation

The following discussion of the genesis of talc and chlorite applies only to those occurrences in the pre-Belt metamorphic rocks of southwestern Montana and not to the deposit northeast of Troy; the deposit southwest of Helena; or those associated with metagabbro dikes in the Henrys Lake Mountains. The chlorite at the Golden Antler mine (H-1) also may be of different origin than the deposits discussed here.

Most of the talc in southwestern Montana was formed by the reaction:

$$\text{3 dolomite} + \text{4 quartz} + H_2O = \text{talc} + \text{3 calcite} + 3\ CO_2.$$

A minor amount of talc has been formed by the replacement of tremolite. Possible equations for this reaction are presented in the following sections. The rarity of calcite in close association with talc indicates that this product of the above reaction was flushed from the area of talc formation by a large quantity of water passing through the deposits.

There is not sufficient quartz in the dolomitic marble to satisfy the above reaction, which requires 32 volume percent quartz for the complete replacement of dolomite by talc. Quartz is only a minor constituent of the marble. For example, in the Greenhorn Range the marble is estimated to contain less than 10 percent quartz. The other constituent that must be added to produce talc is H_2O, and it is suggested that silica-rich aqueous solutions caused the replacement of marble by talc. The general lack of quartz in association with talc deposits suggests that the availability of SiO_2 was the limiting factor in the replacement of marble at a particular locality. Obviously dolomite was plentiful, and the presence of hydrous minerals (sericite, chlorite and serpentine) in rocks adjacent to talc deposits indicates that H_2O permeated these rocks beyond the limits of talc bodies. The source of this SiO_2-bearing water is not definitely known. A probable source is meteoric water that has dissolved silica from the overlying rocks during its downward and perhaps lateral movement.

It has been suggested (Olson, 1976, p. 113) that hydrothermal fluids from Precambrian plutons, now metamorphosed to quartzofeldspathic gneiss, were a source of silica for talc formation. There is good evidence that both talc and chlorite formed long after any Precambrian plutons had crystallized and been metamorphosed, thus precluding such plutons as sources of hydrothermal fluids at the time of talc formation. Evidence for the time of formation of talc and chlorite is presented in the next section.

Another possible source of hydrothermal solutions might be post-metamorphic pegmatite dikes that are found in the pre-Belt rocks of southwestern Montana. These dikes seem an unlikely possibility because they are rare in the marble and are not reported in the vicinity of talc deposits. In the Greenhorn Range, pegmatite dikes are most prevalent in the quartzofeldspathic gneiss.

With the exception of the Golden Antler chlorite deposit (H-1), which is quite possibly of different origin than the talc and chlorite deposits being discussed here, all chlorite deposits are associated with talc deposits, but not all talc deposits are associated with chlorite deposits. This association of chlorite with talc can be explained by the movement of cations in solution between marble and the other rock types such as quartzofeldspathic gneiss. Without the addition of magnesium, quartzofeldspathic gneiss cannot be replaced by chlorite, because the gneiss does not contain sufficient magnesium for the growth of chlorite (clinochlore). If H_2O was available to promote the movement of magnesium from the dolomitic marble to the gneiss, it could also have caused the replacement of dolomitic marble by talc, perhaps using silica from the quartzofeldspathic gneiss in this reaction.

Chlorite, because of its close association with talc, is thought to have formed at the same time as the talc. A comparison of the chemical analyses of chlorite (clinochlore) and talc from the Willow Creek mine **(Table 3)** shows that the main differences are in the content of SiO_2 and Al_2O_3. The talc contains approximately twice as much SiO_2 as the chlorite and almost no Al_2O_3 as compared to approximately 18 percent Al_2O_3 in the chlorite. Aluminum present in impurities in the dolomitic marble could not be accommodated in the talc lattice, so a minor amount of chlorite formed in the talc body as a result.

Field relationships indicate that some of the rock consisting almost entirely of chlorite was produced by the complete replacement of quartzofeldspathic gneiss, as at the Grandview prospect (TR-7). A crude comparison between compositions of quartzofeldspathic gneiss in southwestern Montana as reported in the literature and that of chlorite shows that magnesium must have been added and silicon removed if the gneiss was completely replaced by chlorite. The removal of some silicon from the gneiss would increase the aluminum concentration to that of chlorite. Sodium, calcium and potassium in the gneiss must also have been removed because these elements could not be accommodated in the chlorite lattice. If it is assumed that aluminum was immobile, then silicon from the quartzofeldspathic gneiss could have been added to the marble to make talc, and some magnesium from the dolomitic marble could have been used in the replacement of quartzofeldspathic gneiss by chlorite. The same transfer of cations may have occurred at the Ruby claims (GH-28) where a diabase dike was replaced by chlorite when talc replaced the adjacent marble.

The replacement of tremolite by talc allows an estimate of the temperature of talc formation to be made. The same temperature range is inferred for the formation of chlorite, because of its close association with talc. On the basis of thermodynamic extrapolations from experimentally determined points, Slaughter, Kerrick and Wall (1975) showed the effect of mole fraction of CO_2 (X_{CO_2}) on the temperature of reaction when fluid pressure (H_2O and CO_2) remains constant. Several of the reactions are pertinent to the replacement of tremolite by talc. These curves were established for fluid pressures of 1 kb, 2 kb and 5 kb, and it is likely that the talc and chlorite formed within that range of pressure.

Several possible reactions may explain the replacement of tremolite by talc, one of which is:

$$\text{tremolite} + \text{dolomite} + H_2O + CO_2 = 2\ \text{talc} + 3\ \text{calcite}.$$

Changes in mole fraction of CO_2 and fluid pressure do not cause a large change in the temperature at which this reaction occurs. Within the range of conditions for which Slaughter, Kerrick and Wall presented data, the reaction takes place at temperatures between approximately 410 and 470°C.

A second possible reaction is:

$$\text{tremolite} + 4\ CO_2 = 2\ \text{dolomite} + \text{talc} + 4\ \text{quartz}.$$

The temperature range for this reaction under the described conditions is 420 to 575°C.

Tremolite may also have been replaced by talc according to the following reaction:

$$3\ \text{tremolite} + 6\ CO_2 + 2\ H_2O = 5\ \text{talc} + 6\ \text{calcite} + 4\ \text{quartz}.$$

Under the same conditions the temperature range for this reaction is approximately 400 to 460°C.

The reaction for the replacement of dolomite by talc is:

$$3\ \text{dolomite} + 4\ \text{quartz} + H_2O = \text{talc} + 3\ \text{calcite} + 3\ CO_2.$$

Again, according to the curves of Slaughter, Kerrick and Wall, the maximum temperature of the reaction is approximately 460°C and the minimum temperature is below 400°C.

Consideration of the possible reactions shows that the talc in these deposits probably formed at temperatures between 400 and 500°C if the fluid pressure was less than 5 kb. Pressure greater than 5 kb during the retrograde metamorphic event seems unlikely. Burger (1967, p. 10) suggested that a pressure of 3 kb was attained during almandine-amphibolite facies metamorphism in the Tobacco Root Mountains.

In the vicinity of the Yellowstone mine (GR-3), lava or block talc is found in addition to the typical waxy green talc (ceramic grade). A comparison of the chemical compositions of block talc and typical talc from the Yellowstone mine shows no significant difference between the two **(Table 5)**. James (1956, p. 5) stated that most of the block talc at the Yellowstone mine is in a zone of deep weathering. Examination of other occurrences of block talc in this area also shows that block talc is underlain by waxy green talc at depth, suggesting that the block talc has formed by weathering of the usual waxy green talc. The formation of block or lava talc would be an interesting problem for further study.

Table 5—Analyses of ceramic and lava talc from the Yellowstone mine (GR-3) (*from* James, 1956, p. 5).

	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O
Ceramic grade (typical talc) from pit 5	61.70	1.29	1.55	trace	32.44	0.37	0.46
Ceramic grade (typical talc) from pit 7	61.29	1.36	1.34	trace	31.26	0.26	0.33
Lava grade (block talc) from pit 9	61.76	1.33	1.51	trace	31.95	0.27	0.32

Time of formation

Because of the close association of talc and chlorite at many localities, these two minerals are thought to have formed at the same time. It is suggested that the talc and chlorite were produced during greenschist-facies metamorphism caused by a retrograde event tentatively dated as having occurred 1600 m.y. ago. This is not an original idea. Other workers also have suggested that talc in the Ruby Range formed by retrograde metamorphism during the Precambrian (Garihan, 1973b; Olson, 1976, p. 113; Okuma, 1971, p. 42). The work described here adds further support to this hypothesis.

All of the known talc deposits in southwestern Montana are in dolomitic marble of the pre-Belt sequence of metamorphic rocks. Although there are dolomitic formations of Cambrian, Ordovician and Devonian age in the area, there are no reported occurrences of talc in these rocks. For this reason a Precambrian age is inferred for the talc deposits.

Before discussing further the time of talc formation it is necessary to review the metamorphic history of the pre-Belt rocks in this region. Scattered occurrences of granulite-facies rocks in the Ruby Range, Tobacco Root Mountains and Greenhorn Range have been interpreted as relicts of an earlier metamorphic event. Most of the mineral assemblages preserved in these areas are indicative of upper amphibolite-facies metamorphism. Minerals indicative of a later greenschist-facies metamorphic event are reported in the Tobacco Root Mountains and Ruby Range. In the Greenhorn Range, sericitization of feldspars, chloritization of biotite, serpentinization of calcsilicate minerals, and alteration of ultramafic rocks to talc and serpentine are evidence for this event. Rb-Sr whole-rock age dates from the southern Tobacco Root Mountains indicate a minimum age of 2667 ± 66 m.y. for the upper amphibolite metamorphism (Mueller and Cordua, 1976, p. 33). These authors suggested that dates of approximately 1600 m.y. obtained by Giletti (1966) on biotite, muscovite and K-feldspar by K-Ar and Rb-Sr methods represent the later greenschist metamorphic event. It is reasonable to conclude that a greenschist assemblage was produced during the waning stages of metamorphism and that with the introduction of water along fractures the alteration to hydrous minerals could go to completion locally.

Talc and chlorite are thought to be retrograde rather than prograde minerals because if the talc and chlorite that we see now were formed during prograde metamorphism, they would have been converted to a higher-temperature assemblage of minerals during the granulite- and amphibolite-grade metamorphism. Also both talc and chlorite replaced higher temperature minerals; talc replaced tremolite and chlorite replaced biotite. Sericite replaced sillimanite in pelitic schist next to some talc deposits.

In addition to the dates clustered around 1600 m.y. (1410 to 1790 m.y.), Giletti (1966) also reported dates of 2130 to 3270 m.y. A northeast-trending boundary separates the region of the 1600 m.y. dates to the northwest from the much older dates to the southeast, and all of the talc occurrences lie within the area of 1600 m.y. dates except those in the Henrys Lake Mountains. Talc occurrences in the Henrys Lake Mountains are related to the metagabbro dikes and are of different origin than the replacement bodies being described here, which have no igneous association. The necessary dolomitic marble host rock is exposed in the area southwest of the "date" boundary. This correlation between 1600 m.y. dates and talc occurrences further supports the hypothesis that talc mineralization occurred about 1600 m.y. ago.

An alternative explanation for the 1600 m.y. dates is that the dated minerals were partly reset by the heating effect of the Boulder and Tobacco Root batholiths farther to the northwest, both of which were emplaced between 68 and 78 m.y. ago (Tilling, Klepper and Obradovich, 1968). If those plutons partly reset Precambrian dates over this large area, then it is reasonable to think that talc and chlorite were formed at the same time. There are two major objections to this idea. The first is that if the talc and chlorite were formed in pre-Belt rocks during late Cretaceous time, the same minerals should also have been formed in Paleozoic dolomite in this area. With the exception of the Helena deposit, talc and chlorite deposits in Montana are confined to Precambrian rocks. The second objection is that it is unlikely for a Cretaceous event to partly reset Precambrian dates over a large area to within the relatively small range of 1410 to 1790 m.y.

Stratigraphic and structural control

Talc is confined to dolomitic marble units, which are more abundant than calcitic marble in the pre-Belt sequence of metamorphic rocks. Heinrich and Rabbitt (1960, p. 20) reported that dolomitic marble is about twice as abundant as calcitic marble in the Ruby Range. Both Garihan (1973a, p. 183-186) and Okuma (1971, p. 95) suggested that specific marble layers were particularly susceptible to replacement by talc. For instance, in the Ruby Range many of the talc occurrences are in one unit, the Regal marble.

All of those who have described talc deposits in the Ruby Range state that there is a tendency for talc to occur at the hinge lines of folds or where the marble has been tightly folded. The same tendency is noted for some of the talc occurrences in the Greenhorn Range, where minor occurrences of talc are numerous within one layer of marble that has been strongly deformed.

Faults also exerted a control on the localization of talc in the Ruby Range, according to Garihan (1973b) and Okuma (1971, p. 96-98). A map by Okuma (1971, p. 97) particularly points out a spatial relationship between northwest-trending faults and talc occurrences in the southern Ruby Range. Faults are evident in all talc prospects and mines where the talc is well exposed. Displacement of talc along these faults indicates that some of the movement occurred after formation of the talc. Whether these faults preceded and controlled talc formation or whether all movement occurred after talc deposition is more difficult to establish.

The replacement of dolomite by talc will result in an appreciable reduction of volume if the products calcite and CO_2 have been removed from the system, as is the case in Montana talc deposits. If the assumptions are made that no magnesium was introduced by the talc-forming solutions and that all of the SiO_2 and H_2O were introduced, the final volume of talc would be 71 percent of the initial volume of dolomite. If all of the SiO_2 required for this reaction was present in the marble initially, then the final volume of talc would be 48 percent of the volume of the starting material. The actual case lies somewhere between these two extremes, and because of the purity of most dolomitic marble, probably closer to the example in which all the SiO_2 was introduced. The surrounding marble may have adjusted to a volume decrease by flowage and by recrystallization in the vicinity of small talc pods. Where large masses of marble have been replaced by talc, the decrease in volume may have caused local faulting. Many of the faults now exposed in talc mines may have developed in response to talc formation, and thus *those* faults did not control talc formation.

There is also another possibility, namely, that faults in the talc are of Laramide age and were concentrated in the talc because of its mechanical weakness as compared to the surrounding marble or gneiss. Probably the faults seen in talc mines are of all three types. Talc-forming solutions followed faults, shear zones, or minor fractures in the marble, a volume decrease caused post-talc movement along those same surfaces, and they were also sites of Laramide movement. Because of good exposures in talc mines, the abundance of faults in these talc bodies may be overemphasized as compared to the abundance in surrounding metamorphic rocks.

Exploration for talc

The most direct way to find talc is to examine marble outcrops for talc veins and pods. The most promising areas are seemingly those where the marble is strongly folded or where faults are abundant. The recognition of areas in which the marble is highly deformed may be difficult without good exposures and the presence of distinct lithologic layering in the marble.

Talc prospecting in southwestern Montana has continued for many years, and there are few talc-bearing outcrops that do not show signs of having been recognized by the prospector. During field work in the Greenhorn Range, only one talc-rich outcrop was discovered that did not show signs of previous discovery, and that outcrop was in thick timber.

Talc is more stable chemically at surface conditions than most minerals, so there is a tendency for it to be concentrated in the soil. Many talc occurrences have been discovered by recognizing chips of talc in the soil. By careful examination of loose soil, talc chips only a few millimeters across can be identified, although a surface coating of iron and manganese minerals on both talc and quartz granules weathered from the marble can make the visual identification of these two minerals difficult. The easiest way to identify the grains is to try to streak them on a piece of steel. Because of its softness talc will easily leave a white streak on the steel, whereas quartz, because of its greater hardness, will not leave a distinct streak.

In heavily timbered areas where the soil is thick, especially on north-facing slopes, prospecting by looking for talc in the soil is not very effective. Exposures on these slopes are partly hidden by timber and are not very abundant. Because of the difficulty of finding talc in these areas, the alternative possibility of examining stream sediments for talc was considered. Although soft and easily reduced to fine-grained sediment by abrasion, talc should persist in stream sediments because of its chemical stability. Three samples of stream sediment were collected from Jasmine Creek (NE¼ SE¼ sec. 10, T. 8 S., R. 4 W.) in the Greenhorn Range at a point less than 1 mile downstream from localities where talc chips had been found in the soil. Although talc could not be identified by x-ray diffraction analysis of the < 325

mesh (< 44 μm) size fraction of these samples, talc was positively identified in the < 10 μm fraction by Alice Blount of the Newark Museum, New Jersey. Blount also identified talc in these samples by infrared spectroscopy.

A sample of stream sediment was collected from Harris Creek in the southern Tobacco Root Mountains approximately 1 mile downstream from two talc prospects (TR-6 and TR-7). Talc could only be tentatively identified by x-ray diffraction analysis of the < 10 μm size fraction of this sample and was not identified by infrared spectroscopy.

Perhaps the analysis of stream sediment for talc would be a useful method of talc exploration in areas of thick timber cover, but obviously further testing of the method is required. For example, the optimum size fraction for talc analyses should be determined. This will of course depend on the size distribution of the sediment, but it is likely that talc will be concentrated in a fine fraction such as < 2 μm.

In the future, more sophisticated methods will be used in the exploration for talc deposits that are not exposed. Geophysical and geochemical methods have been suggested by some as worth consideration in the search for talc.

For orderly description, occurrences of talc and chlorite are grouped by mountain range. The occurrences are shown in **Figure 3**. Information on the occurrences is summarized in **Table 6**.

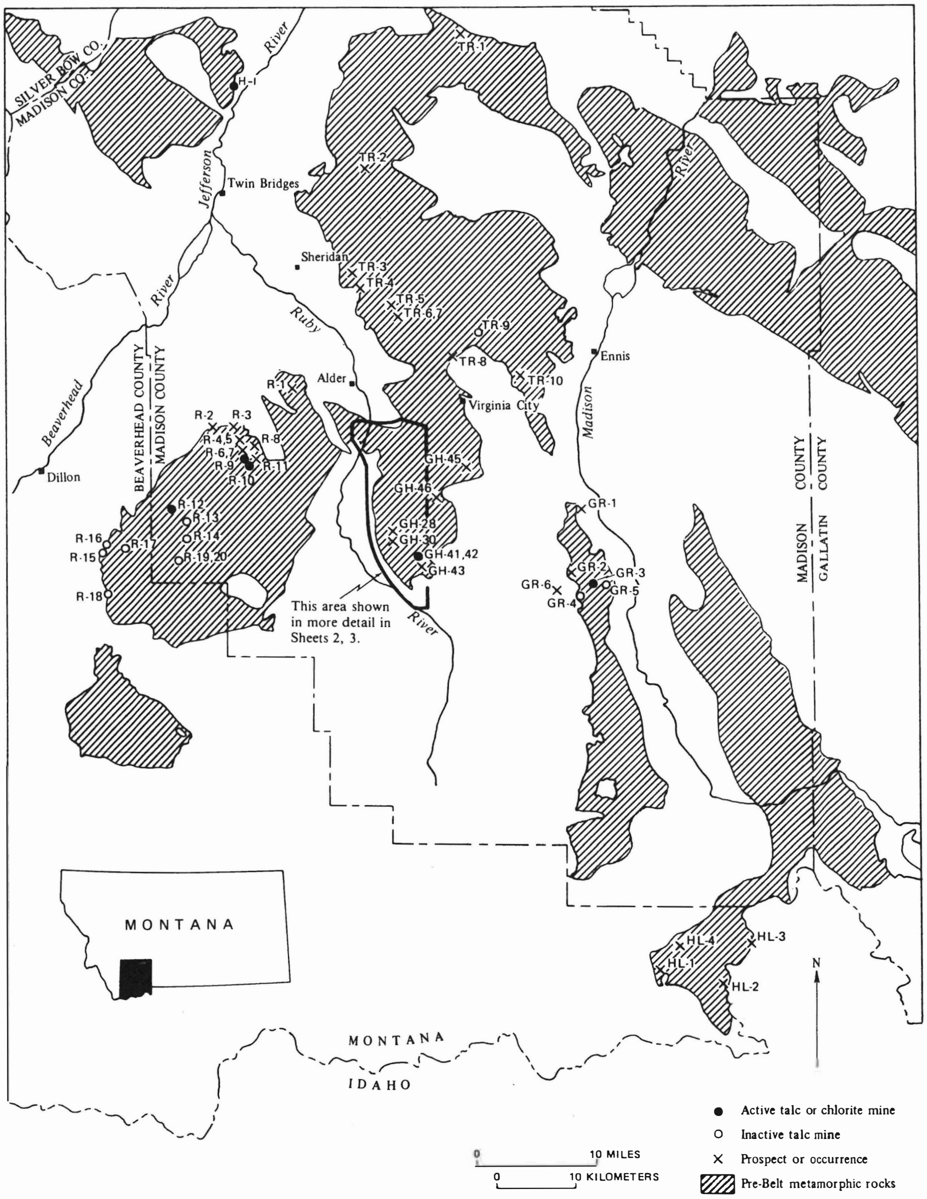


Figure 3—Talc and chlorite occurrences in southwestern Montana.

Table 6—Talc and chlorite occurrences. Except as noted, occurrences are plotted on Figure 3.

No.	Name	Major mineral	Extent of development	Comments	Page reference in this memoir	Additional references
Highland Mountains						
H-1	Golden Antler mine	Chlorite	Active mine	Production of chlorite began in 1977.	p. 19	Berg, 1979, p. 266.
Tobacco Root Mountains						
TR-1	Mineral Hill pegmatite	Talc	Short adit	Little published information.	p. 21	Reid, 1957, p. 7, 23.
TR-2	Spuhler Gulch occurrence	Talc	Unknown	Talcose rock contains serpentine, diopside, graphite and other minerals.	p. 22	Reid, 1957, p. 23.
TR-3	Latest Out mine	Talc(?)	Inactive precious-metal mine	Occurrence of talc has not been confirmed.	p. 22	Levandowski, 1956, p. 278-288.
TR-4	Horse Creek prospect	Chlorite	Caved adit	Small body of chlorite exposed.	p. 22	Levandowski, 1956, p. 223.
TR-5	Bivens Creek prospect	Talc	Inclined shaft and cuts	Talc pods over a large area, minor graphite.	p. 22	Levandowski, 1956, p. 222-224.
TR-6	Harris Creek prospect	Talc	Large cut	Concordant talc layer 4 ft. (1.3 m) thick.	p. 24	
TR-7	Grandview prospect	Talc	Adit and shallow cuts	Talc pods exposed over a large area.	p. 26	
TR-8	Granite Creek prospect	Talc	Inclined shaft and cuts	Concordant layer of talc 2 ft. (0.7 m) thick.	p. 26	
TR-9	Bear claims (Granite Creek mine)	Talc	Inactive mine	Numerous talc pods in two large cuts.	p. 26	
TR-10	Prospect southwest of Ennis	Talc and chlorite	Cuts	Talc disseminated throughout marble.	p. 30	
Ruby Range						
R-1	Ruby Peak occurrence	Talc	Shallow prospect pit	Talc chips in soil over a large area. Minor tremolite in one specimen.	p. 32	
R-2	Spring Creek prospect	Talc	Prospect cuts and drill holes	Talc occurrences extend for 1.5 km (5,000 ft.) along strike. Much variation in color.	p. 32	Garihan, 1973a, p. 177-180; Olson, 1976, p. 129-130.
R-3	Gem claim	Talc	Two cuts	Graphitic talc.	p. 32	Garihan, 1973a, p. 180-181; Olson, 1976, p. 129.
R-4	Whitney claims	Talc	Cuts	Irregular body of generally light green talc.	p. 33	Garihan, 1973a, p. 171-174; Olson, 1976, p. 130.
R-5	Prospect southwest of Whitney claims	Talc	Cuts	Talc bodies in zone 20 m (64 ft.) wide.	p. 33	Garihan, 1973a, p. 174-175; Olson, 1976, p. 130.
R-6	Prospect north of Treasure mine	Talc	Cuts	Main body of talc is 2 to 3 m (7 to 10 ft.) thick.	p. 33	Garihan, 1973a, p. 169-171.
R-7	Prospect northeast of Treasure mine	Talc	Cut	Talc body of 3 m (10 ft.) exposed width.	p. 33	Garihan, 1973a, p. 166-168; Olson, 1976, p. 129.
R-8	Bennett Owen claim	Talc	Cuts	Dark-green talc body 5 by 35 m (16 by 112 ft.).	p. 33	Garihan, 1973a, p. 162-166; Olson, 1976, p. 128.
R-9	Treasure mine	Talc	Active mine	Major talc mine owned by Pfizer, Incorporated.	p. 34	Garihan, 1973a, p. 149-156; Olson, 1976, p. 121-125.
R-10	Beaverhead mine	Talc	Active mine	Major talc mine owned by Cyprus Industrial Minerals.	p. 34	Garihan, 1973a, p. 156-160; Olson, 1976, p. 125-126.
R-11	Prospect east of Beaverhead mine	Talc	Cut	Pods of talc exposed in cut.	p. 35	Garihan, 1973a, p. 160-162; Olson, 1976, p. 129.
R-12	Regal (Keystone) mine	Talc	Active mine	Increased production in recent years. Mine owned by Pfizer, Incorporated.	p. 35	Olson, 1976, p. 126; Perry, 1948, p. 6.
R-13	American Chemet mine	Talc	Inactive mine	Talc was mined from three pits by American Chemet Corporation.	p. 35	Okuma, 1971, p. 108-111.
R-14	Estelle (Sweetwater) mine	Talc	Inactive mine	Concordant layers of green talc exposed in open cut.	p. 36	Okuma, 1971, p. 106-107; Olson, 1976, p. 128.

Table 6—Talc and chlorite occurrences. Except as noted, occurrences are plotted on Figure 3. *(continued)*

No.	Name	Major mineral	Extent of development	Comments	Page reference in this memoir	Additional references
			Ruby Range *(continued)*			
R-15	Smith-Dillon mine	Talc	Inactive mine	Talc was first mined underground and then in an open pit.	p. 36	Okuma, 1971, p. 99-102; Olson, 1976, p. 128; Perry, 1948, p. 4-6.
R-16	Banning-Jones mine	Talc	Inactive mine	Talc lenses in marble scattered over an area 250 by 300 ft. (75 by 90 m).	p. 36	Geach, 1972, p. 161-162; Olson, 1976, p. 127.
R-17	Bozo-Zobo mine	Talc	Inactive mine	In 1960s about 8,000 tons of talc ore mined.	p. 37	Olson, 1976, p. 127-128.
R-18	Crescent prospect (Timber Gulch deposit)	Talc	Shallow inclined shaft, cuts	Graphite abundant in talc.	p. 37	Okuma, 1971, p. 105; Olson, 1976, p. 129; Perry, 1948, p. 6.
R-19	Sauerbier mine	Talc and chlorite	Inactive mine	Talc mined by Resource Processors, Incorporated, in 1974.	p. 37	Okuma, 1971, Plate 1; Olson, 1976, p. 126-127.
R-20	Owen-McGovern prospect	Talc	Cuts and drill holes	Talc layers 1 to 2 ft. (0.3 to 0.6 m) thick are exposed in cut.	p. 38	Okuma, 1971, p. 107-108, Plate 1; Olson, 1976, p. 129.
Note: Eighteen additional talc occurrences in the Ruby Range are listed in **Table 7**.						
			Greenhorn Range			
GH-28	Ruby claims	Chlorite	Shallow cuts and small pit	Mainly tan chlorite, minor talc.	p. 40	
GH-30	Doubtful claim	Talc	Cuts	Unusually soft talc, some limonite.	p. 42	
GH-41	Greenhorn claims	Talc	Cuts	Sheared and contorted talcose marble exposed in cut.	p. 42	
GH-42	Willow Creek mine	Talc and chlorite	Active mine	Openpit mine operated by Resource Processors, Incorporated.	p. 43	
GH-43	Claims north of Willow Creek	Talc	Six cuts	Talc veinlets and pods exposed in four cuts.	p. 46	
GH-45	South of Virginia City	Talc	One cut	Minor talc in marble adjacent to quartz vein.	p. 46	
GH-46	Calverts claims	Talc	Five cuts	Talc veinlets and pods exposed in four cuts.	p. 46	
			Gravelly Range			
GR-1	Tait Mountain claims	Chlorite and talc	Shaft and cuts	Light-colored chlorite and minor talc are exposed in cuts.	p. 49	
GR-2	Cherry Gulch prospect	Talc	Cuts	Some block talc exposed in cuts.	p. 50	
GR-3	Yellowstone mine	Talc	Active mine	Major talc mine owned by Cyprus Industrial Minerals.	p. 53	James, 1956.
GR-4	Queen claim	Talc	Inactive mine	Small open pit owned by Cyprus Industrial Minerals.	p. 55	
GR-5	Burlington Northern mine	Talc	Inactive mine	Talc is exposed in several cuts.	p. 55	
GR-6	Talc-bearing conglomerate	Talc	None	Source of talc in conglomerate inferred to be deposit at Yellowstone mine.	p. 56	
			Henrys Lake Mountains			
HL-1	Occurrence	Talc	No development	Minor occurrence, no economic potential.	p. 58	
HL-2	Occurrence	Talc	No development	Minor occurrence, no economic potential.	p. 58	
HL-3	Occurrence	Talc	No development	Minor occurrence, no economic potential.	p. 58	
HL-4	Occurrence	Talc	No development	Minor occurrence, no economic potential.	p. 58	
			Other Montana talc occurrences			
O-1	Talc mine south of Helena*	Talc	Inactive mine and prospect cuts	Reported bodies of talc 6 ft. (2 m) thick.	p. 59	Perry, 1948, p. 10-11.
O-2	Lynx Creek (Mathews) talc prospect*	Talc	Drill holes	Sericitic talc in shades of yellow and gray.	p. 59	Johns, 1970, p. 152-153.

*Not plotted on **Figure 3.**

Highland Mountains

Pre-Belt metamorphic rocks are exposed only in the southern part of the Highland Mountains. The northern part of the range is underlain by plutons of the Boulder batholith, sedimentary rocks of the Belt Supergroup and Paleozoic and Mesozoic sedimentary rocks. The pre-Belt rocks have been intruded by two plutons of the Boulder batholith, which have been dated in the range of 72 to 77 m.y. by the K-Ar method (Robinson, Klepper and Obradovich, 1968, p. 564).

Duncan (1976) mapped the pre-Belt metamorphic rocks in the Highland Mountains during his structural study and was able to distinguish three major lithologic units: quartzofeldspathic gneiss, garnetiferous gneiss and micaceous gneiss. Thin layers (maximum thickness 2 m) of amphibolite, magnetite gneiss, anthophyllite gneiss and calcitic marble are found only in the garnetiferous gneiss. Duncan (1976, p. 26-27) reported that the marble occurs at only a few localities, is no thicker than 2 m, and has a maximum exposed strike length of approximately 10 m. In addition to calcite, the marble contains tremolite-actinolite, phlogopite, plagioclase, diopside, apatite and quartz.

No talc occurrences have been reported in the pre-Belt rocks of the Highland Mountains. The chlorite veins at the Golden Antler mine are in quartzofeldspathic gneiss.

H-1 Golden Antler mine

Location: SW¼ sec. 14, T. 2 S., R. 6 W., Madison County. Approximately 2.5 miles (4 km) southwest of Silver Star. Twin Bridges 15-minute quadrangle.

Accessibility: Newly constructed road follows an indirect course 1.1 miles (1.8 km) from Montana Highway 41 to the claims.

Ownership: Golden Antler claims located by Robert Nolte and Sylvan Donegan, both of Twin Bridges, Montana

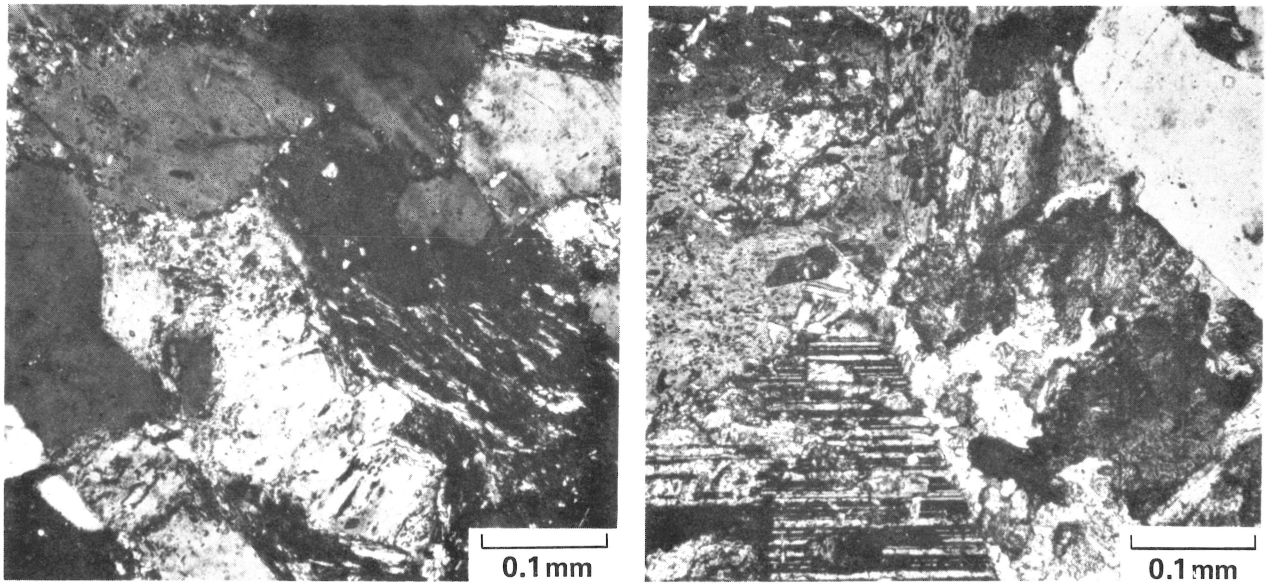
Description: Chlorite veins crosscut pre-Belt biotite-quartz-feldspar gneiss, a layer of amphibolite, and another of metagabbro **(Sheet 1-A)**. Foliation of the gneiss strikes approximately west and dips to the north. The chlorite veins parallel well-developed near-vertical joints that strike north to a few degrees east of north. Some joint surfaces are coated with epidote.

The purest chlorite is pale green on a fresh surface and some breaks into thin plates a few centimeters thick, which are translucent on thin edges. Chlorite veins are eroded more rapidly than the unaltered gneiss and can be found by the abundance of small chips of chlorite a centimeter or two across in the soil. The chlorite veins are broken by perpendicular fractures spaced less than 1 centimeter apart. Rare veins of milky quartz are the only impurity recognized in the chlorite in the field. The only impurities recognized by microscopic examination of the chlorite are zircon in a trace concentration ($\ll$ 1 percent) and rutile, also in trace concentration, in a few specimens. This mineral must be a relict from the biotite-quartz-feldspar gneiss, and remained unaltered during the chloritization of the gneiss.

Chlorite clearly was produced by the alteration of the biotite-quartz-feldspar gneiss and probably also by the alteration of amphibolite and metagabbro (Berg, 1979, p. 266). Photomicrographs **(Plate 2)** show a typical sequence of alteration from gneiss to chlorite. The specimens photographed in this sequence were collected along a traverse 1.5 meters long parallel to the foliation of the gneiss and extending a few centimeters into the chlorite vein. Most of the chlorite veins are surrounded by a quartz-sericite-chlorite zone, which is recognized in the field by its lighter color (white to very pale green) as compared to the darker green of pure chlorite and also by its tendency to break into larger fragments than the pure chlorite. Propylitic alteration of the quartzofeldspathic gneiss was observed adjacent to the quartz-sericite-chlorite zone.

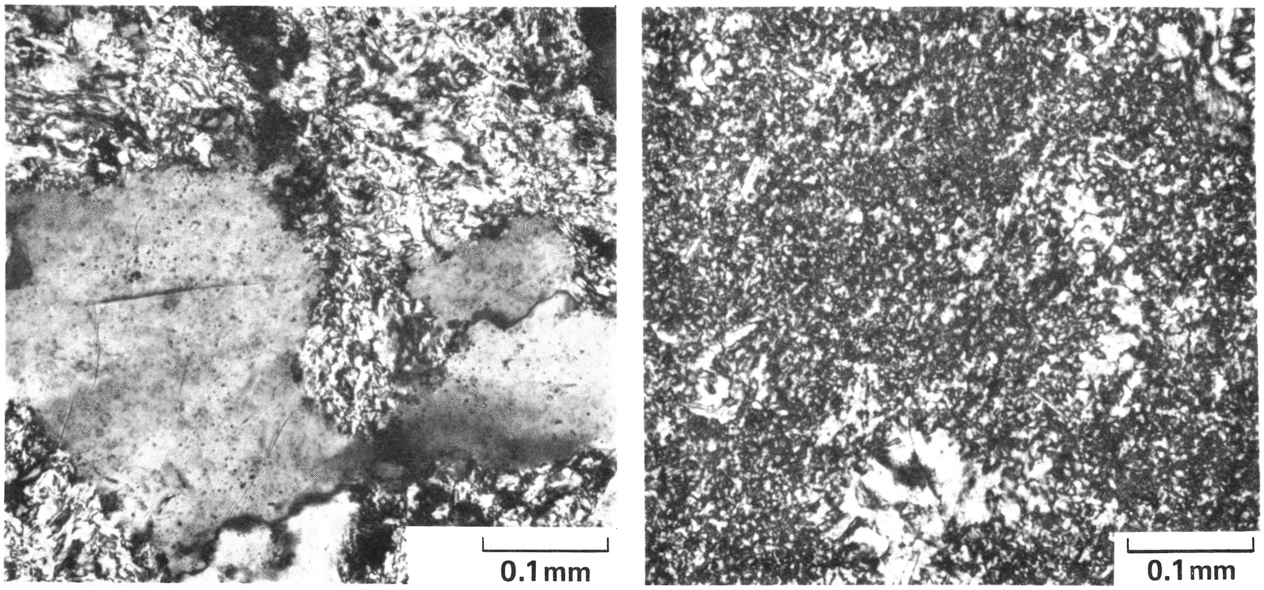
There is no obvious genetic relationship between the gold-bearing veins of the Silver Star district and the chlorite veins. No sulfide minerals or their alteration products have been recognized in the chlorite deposit, and only a minor amount of sericite and lesser chlorite are reported from the metalliferous veins of the district (Fritzsche, 1935, p. 60). Metalliferous veins strike west to northwest as compared to the north strike of the chlorite veins, and the closest metalliferous vein to the chlorite deposit is 2,000 ft. (610 m) west at the Golden Rod mine. This gold-bearing vein within pre-Belt gneiss strikes N. 85° W. and dips 45° SW. (Sahinen, 1939, p. 49).

The proximity of the chlorite deposit to two plutons of the Boulder batholith suggests that the



A. Slight sericitic alteration of feldspars, minor epidote and chlorite.

B. More intense alteration. Sericite, epidote, and chlorite much more abundant than in A.



C. Quartz surrounded by fine-grained chlorite.

D. Fine-grained chlorite.

Plate 2
Photomicrographs of alteration sequence at the Golden Antler mine.

replacement of gneiss by chlorite may have been caused by hot water, possibly meteoric water heated by one of those plutons. The Hell Canyon pluton is exposed 1.5 miles (2.4 km) southwest of the chlorite deposit, and the Rader Creek pluton, also of the Boulder batholith, is exposed 2 miles (3.2 km) northeast of the deposit. A possible source of the magnesium required for the replacement of quartzofeldspathic gneiss by magnesian chlorite is the Jefferson Limestone (Upper Devonian). The Jefferson Limestone, which is known to contain dolomitic beds, is exposed about 3 km northeast of the Golden Antler mine. Ground water passing through the Jefferson Limestone could have acquired Mg as well as Ca by the solution of dolomite and calcite. Convective circulation of this heated water along fractures in the quartzofeldspathic gneiss could have produced the local replacement of gneiss by chlorite. From field relationships it can be concluded only that the chlorite is younger than the youngest Precambrian metamorphic event that affected the gneiss.

Besides the chlorite veins at the Golden Antler, there are other chlorite occurrences in the vicinity. According to Bob Nolte (oral communication, 1977), one of these is situated less than 1 mile (1.6 km) northwest of the Golden Antler mine.

Tobacco Root Mountains

The Tobacco Root Mountains are an uplifted block of pre-Belt metamorphic rocks that have been intruded by the Tobacco Root batholith. The batholith is of quartz monzonite composition, and biotite from this body has been dated by the K-Ar method to be 72 m.y., whereas hornblende dated by the same method gives an age of 118 m.y. (McDowell, 1971, p. 9). Paleozoic and Mesozoic sedimentary rocks are exposed on the north and west flanks of the mountain range. The pre-Belt metamorphic rocks extend south into the Greenhorn Range and east into the Madison Range.

Because the Indiana University Geologic Field Station is in the northern part of the Tobacco Root Mountains, this area has been more thoroughly studied than most other areas of pre-Belt rocks in Montana. Some sources of information on the geology of the range, done by Indiana students and others, are: Burger (1967), Cordua (1973), Gillmeister (1972), Hanley (1975), Hess (1967), Johns (1961), Koehler (1976), Levandowski (1956), Reid (1957, 1963), and Tansley, Schafer and Hart (1933).

The pre-Belt rocks of the Tobacco Root Mountains are similar to those exposed in other mountain ranges in southwestern Montana. Rocks described from the Tobacco Root Mountains include quartzofeldspathic gneiss, hornblende gneiss, amphibolite, marble, aluminous schist, quartzite, iron formation, anthophyllite (gedrite) gneiss and metamorphosed mafic and ultramafic intrusive rocks. Diabase dikes of Precambrian age are much more abundant in the Tobacco Root Mountains than in the Greenhorn Range to the south. There are also numerous Precambrian pegmatite dikes in the Tobacco Root Mountains.

Evidence has been presented by some authors (Cordua, 1973; Reid, 1963) for three episodes of Precambrian metamorphism. Metamorphism of granulite grade was followed by metamorphism of amphibolite grade, which did not completely destroy the granulite assemblage. Alteration of these rocks is attributed to later greenschist-facies metamorphism. Although interpretations of the Precambrian structural history of the Tobacco Root Mountains differ, there is ample evidence for large isoclinal folds (Burger, 1967). Hanley (1975, p. 272) found that Precambrian rocks along the northwest-trending Mammoth fault have been displaced more than Paleozoic formations, thus indicating Precambrian movement on the fault, which is a major structure in the northern part of the range.

Most of the talc occurrences in the Tobacco Root Mountains are in the southern part of the range, which is an area of relatively moderate relief. Most of the metal mining has been farther north in the northeastern and western parts of the range.

TR-1 Mineral Hill prospect

Location: W½ sec. 26, T. 1 S., R. 3 W., Madison County. Approximately 8 miles (13 km) northwest of Harrison. Harrison 15-minute quadrangle.

Accessibility: The Carmichael Canyon road, which goes between the South Boulder River road and Harrison, is within 1 mile of the prospect.

Ownership: Not known.

Description: Reid (1957, p. 7, 23) described a body of almost pure talc at the west end of the Mineral

Hill pegmatite. Although Reid did not mention the size of the talc body, he reported that a small adit had been driven into the talc. The Mineral Hill pegmatite was described by Reid as a mixture of pegmatitic material, gneiss, amphibolite, biotite schist and serpentine-pyroxenite layers. This talc prospect was not visited during the present investigation. The Gilliam vermiculite deposit is less than 1 mile (1.6 km) south of the talc prospect.

TR-2 Spuhler Gulch occurrence

Location: NE¼ sec. 21, T. 3 S., R. 4 W., Madison County. Approximately 11 miles (18 km) northeast of Twin Bridges. Waterloo 15-minute quadrangle.

Accessibility: The closest road is the Wisconsin Creek road that passes approximately 1.5 miles (2.4 km) west and many feet lower than the talc occurrence.

Ownership: Not known.

Description: This deposit was not visited during the present investigation, and all of the information on this deposit is from Reid (1957, p. 23). The talc body, which is described as bluish-gray talc-graphite rock, is exposed on the south wall of Spuhler Gulch. The talc layer is 40 feet (12 m) thick and perhaps 1,000 to 1,500 feet (305 to 460 m) in length. The estimated mineralogical composition of one specimen is 40 percent talc, 25 percent serpentine (antigorite), 25 percent diopsidic augite, 5 percent magnetite, 5 percent graphite and a trace of spinel (pleonaste).

TR-3 Latest Out mine

Location: Sec. 32, T. 4 S., R. 4 W., Madison County. Copper Mountain 7½-minute quadrangle. Approximately 4 miles (6 km) southeast of Sheridan.

Accessibility: The road to the mine branches to the north at the Horse Creek road in sec. 5, T. 4 S., R. 4 W.

Ownership: Not known.

Description: All of the following information is from Levandowski (1956, p. 278-288). This mine produced a small amount of gold and silver, and in 1956 it was reported flooded to within 30 feet (9 m) of the collar of the shaft. It is mentioned here only because several samples were described as talc on an assay sheet (Levandowski, 1956, p. 286-287). The samples may be fault gouge mistakenly identified as talc. Because marble, the host rock for talc deposits, is present in the biotite schist at the mine, the occurrence of talc is a reasonable possibility.

TR-4 Horse Creek prospect

Location: SE¼ SW¼ NW¼ sec. 5, T. 5 S., R. 4 W., Madison County. Sheridan 7½-minute quadrangle. Approximately 4 miles (6.5 km) southeast of Sheridan.

Accessibility: The prospect is visible from the Horse Creek road.

Ownership: Not known.

Description: This prospect was explored by an adit, now caved, in biotite-quartz-feldspar schist (**fig. 4**). Malachite occurs in some of the schist and on pieces of vein quartz found at the adit. Fine-grained material from the malachite-bearing schist was identified by x-ray diffraction analysis as a mixture of sericite and kaolinite, probably formed by alteration of feldspar. Some pale-green partly altered sillimanite occurs in the biotite-quartz-feldspar schist.

The only talc recognized is in a layer of talcose marble 2 feet (0.7 m) thick exposed just west of the biotite-quartz-feldspar schist. Chlorite is much more abundant at this prospect, but is poorly exposed where it occurs within the marble east of the schist. A sample of this green rock consists mainly of chlorite but contains minor quartz and sericite and a trace of rutile. The rutile forms feathery clusters of needles within the chlorite. A trace of clinozoisite occurs in the chlorite.

The presence of rutile in the chlorite and the suggestion of a relict ophitic texture observable in thin section indicate that the chlorite may have formed by alteration of a basic dike within the marble, similar to the chlorite occurrence at the Ruby claims (GH-28).

TR-5 Bivens Creek prospect

Location: N½ NE¼ sec. 14, and S½ SE¼ sec. 11, T. 5 S., R. 4 W., Madison County. Copper Mountain 7½-minute quadrangle. Approximately 8 miles (13 km) southeast of Sheridan.

Accessibility: The Bivens Creek road to Copper Mountain passes within 1,500 feet (500 m) of the prospect. A road that goes directly to the prospect branches from the Bivens Creek road at the west boundary of sec. 14, T. 5 S., R. 4 W.

Ownership: James G. McLaughlin, Sheridan, Montana.

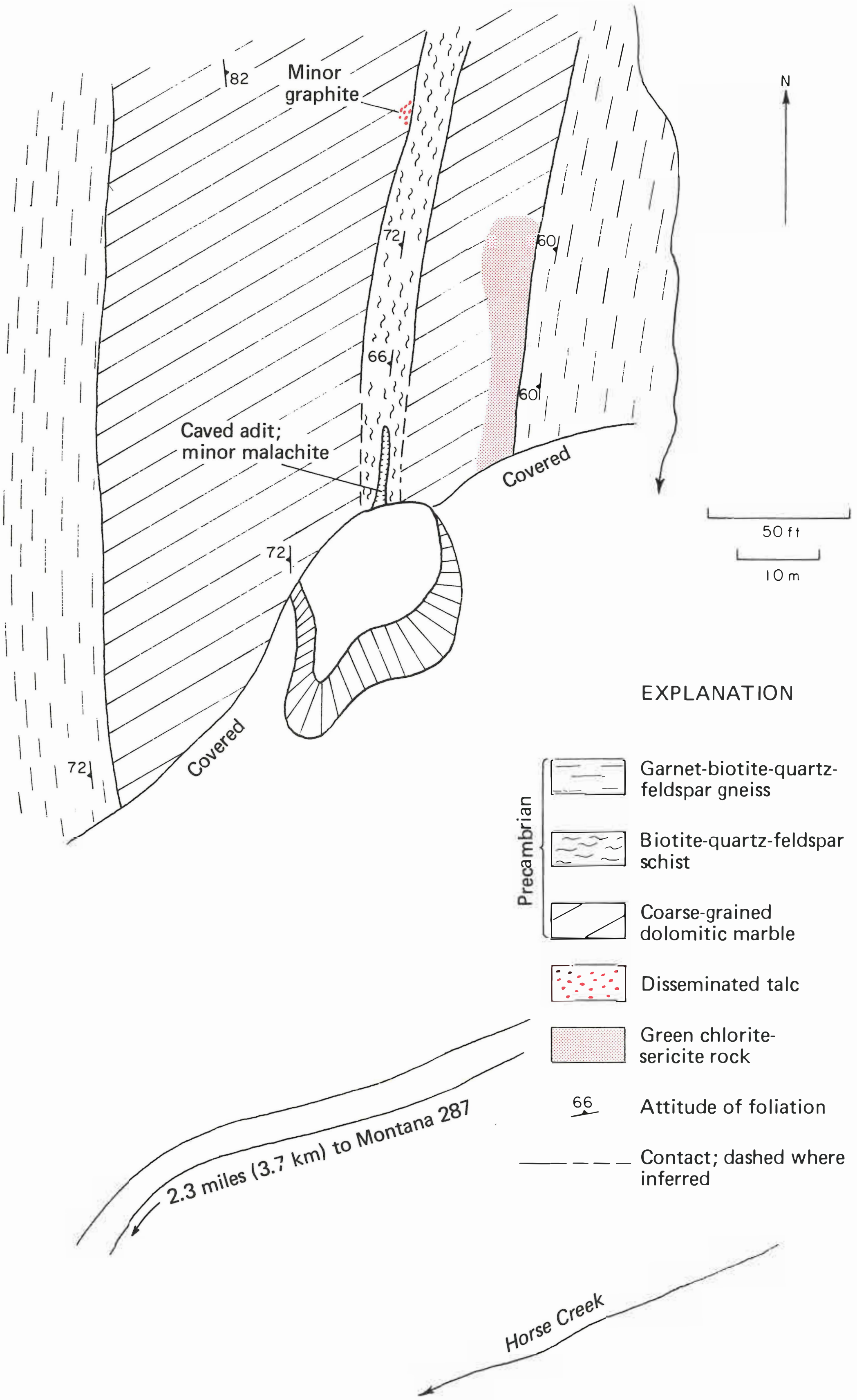


Figure 4—Horse Creek prospect, Tobacco Root Mountains (R. B. Berg, October 1976).

Description: This prospect has been explored by a shallow inclined shaft 20 feet (7 m) deep, now partly caved, and also by many cuts **(Sheet 1-B)**. Coarse-grained, white dolomitic marble strikes northwest and is in contact with sillimanite schist to the northeast and garnetiferous amphibolite to the southwest. The marble is thickest in the vicinity of the shaft, where it has an inferred thickness of 135 feet (45 m), and it can be traced for a distance of 1,000 feet (330 m) along the strike. Judging from the talc piled near the shaft, the greatest concentration of talc is in the shaft and in the shallow cuts 75 feet (25 m) southeast of the shaft. Minor green chlorite is associated with the talc where the chlorite has formed by alteration of the sillimanite schist and hornblende gneiss. Graphite occurs in some of the talc, and talc pseudomorphs after tremolite blades 1 to 2 cm long were recognized in several exposures. The talc is white, pale green and light gray.

Minor talc is exposed in the cuts just northwest of the shaft, but the two northwesternmost cuts contain more talc, and much milky white quartz is found in this vicinity.

Alteration of the sillimanite schist has produced green chlorite. In most exposures relatively pure waxy green chlorite is confined to shear surfaces within the schist. Partial alteration of sillimanite to sericite can be recognized in most cuts, where this alteration changed the typical white sillimanite needles in the schist to pale green needles. Biotite in the sillimanite schist also altered to chlorite.

A shallow prospect pit 1,200 feet (400 m) south of the shaft exposes a small area of chloritic alteration of hornblende gneiss. The area of chlorite is 3 feet by 3 feet (1 m by 1 m).

The geology of this part of the southern Tobacco Root Mountains was described by Cordua (1973), and Levandowski (1956) described the Bivens Creek prospect, which he incorrectly reported as being situated in sec. 13, T. 5 S., R. 4 W. At the time of Levandowski's work, evidently talc was exposed only in the northernmost cut and in the inclined shaft.

TR-6 Harris Creek prospect

Location: SW¼ sec. 13, T. 5 S., R. 4 W., Madison County. Copper Mountain 7½-minute quadrangle. Six miles (10 km) northeast of Alder.

Accessibility: The Harris Creek road branches from the California Creek road in the S½ sec. 23, T. 5 S., R. 4 W. The major cut is at the end of this road, approximately 1.2 miles (1.9 km) from its junction with the California Creek road. The other prospects on Harris Creek are within 2,000 feet (650 m) of this cut.

Ownership: James E. Katz, Sheridan, Montana.

Description: The largest body of talc exposed in these prospects is exposed in a cut along the northwest side of Harris Creek **(fig. 5)**. Layering of the metamorphic units strikes northeast and dips northwest. The exposed sequence from southeast to northwest is garnet-biotite-quartz-feldspar gneiss, hornblende gneiss, biotite schist, dolomitic marble and talc. A fault at the top of the talc layer separates it from the overlying sequence of interlayered marble and biotite-quartz-feldspar gneiss. The talc layer can be traced for 160 feet (49 m) in the cut and is 4 feet (1.3 m) thick at its thickest point. The overlying impure marble has been altered to a rock that consists of chlorite and lesser quartz and graphite and traces of zircon and rutile. The most distinctive feature of the talc at this cut is the abundance of talc pseudomorphs after tremolite, which are as much as 1 cm long. Talc has completely replaced the tremolite that was formed in the marble during earlier metamorphism.

Talc also is exposed in a shallow prospect cut at an altitude of 6,180 feet (2,026 m) at a bearing of N. 52° E. from the cut just described. The small amount of talc, which is poorly exposed, is typically gray, although some is pale green. A chrysotile veinlet, which has a maximum thickness of 2 cm, cuts the dolomitic marble. Talc is exposed in a small pit approximately 400 feet (130 m) southeast from this cut. The attitude of layering is N. 53° E., 45° NW. A conformable talc layer 4 feet (1.3 m) thick is in contact with an overlying chlorite layer 6 inches (15 cm) thick. The chlorite grades into biotite-quartz-feldspar gneiss to the west and undoubtedly has been produced by alteration of the gneiss. Malachite coats some fractures in the talc.

Another talc occurrence is exposed by shallow scraping **(fig. 6)** situated 900 feet (300 m) N. 68° E. from the large cut on Harris Creek first described in this section. Dolomitic marble and biotite-quartz-feldspar gneiss are exposed. Some of the biotite quartz-feldspar gneiss is chloritized. Small talc pods in the dolomitic marble are poorly exposed where the bedrock has been partly exposed by scraping. The marble layer could not be traced to the north of this prospect but was traced south to the Grandview prospect.

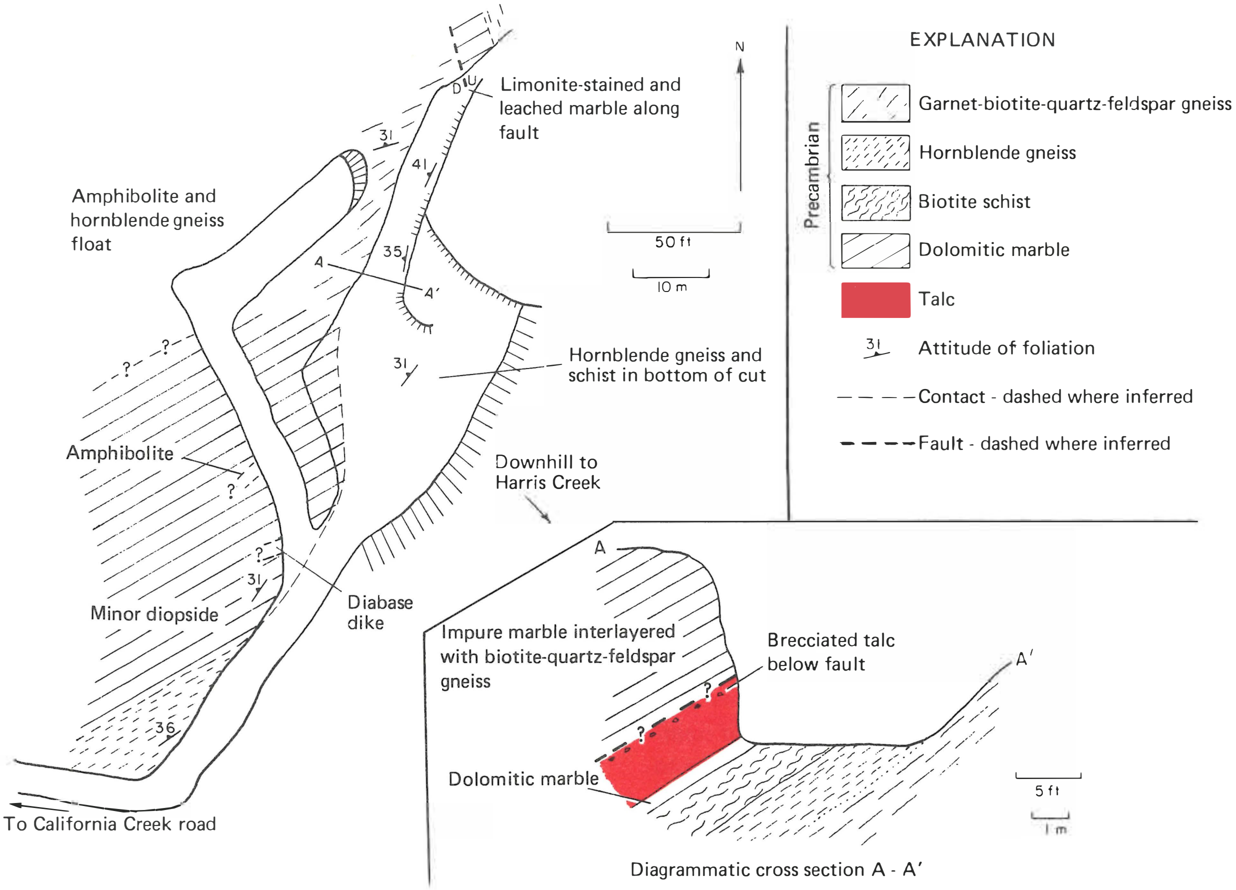


Figure 5—Cut northwest of Harris Creek, Tobacco Root Mountains (R. B. Berg, October 1976).

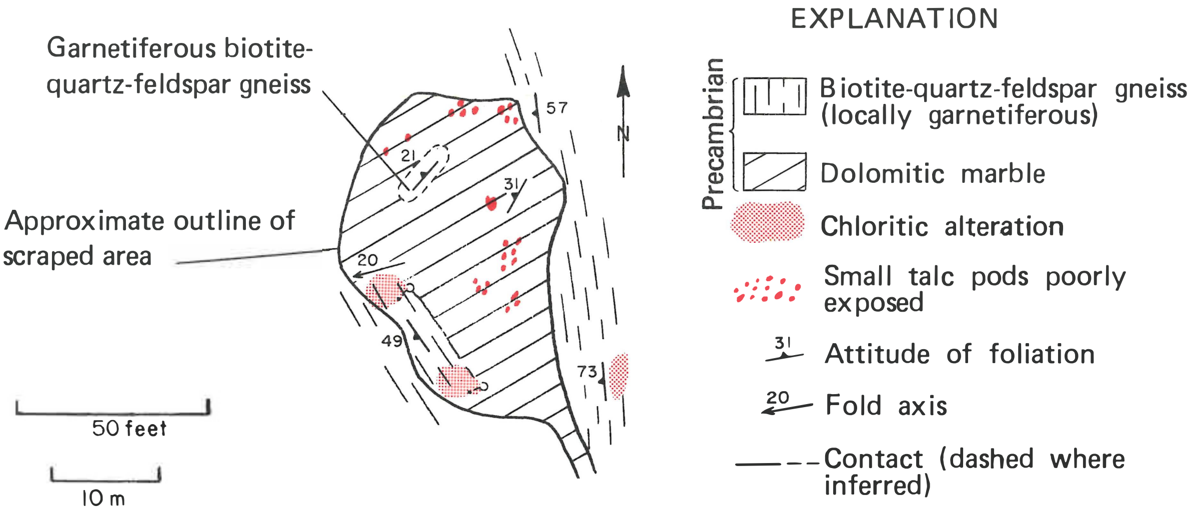


Figure 6—Prospect southeast of Harris Creek, Tobacco Root Mountains (R. B. Berg, October 1976).

TR-7 Grandview prospect

Location: SE¼ SW¼ sec. 13, T. 5 S., R. 4 W., Madison County. Copper Mountain 7½-minute quadrangle. Six miles (10 km) northeast of Alder.

Accessibility: The prospect is 6.5 miles (10 km) up the California Creek road from Montana Highway 287.

Ownership: George Davies, Butte, Montana.

Description: The prospect has been explored by four trenches perpendicular to the strike of the marble, by many small pits, and by an adit downhill to the northeast **(Sheet 1-C)**. The adit is now partly caved where it intersects brecciated talc along a fault. Talc also is exposed in a shallow cut northwest toward Harris Creek. It is unlikely that any surface shows of talc on this prospect have not been investigated by scraping away the soil.

Interlayered biotite-quartz-feldspar gneiss and dolomitic marble, with northwest strike and near-vertical attitude, are in contact with amphibolite to the southwest. A steeply inclined fault, also of northwest strike, separates dolomitic marble and talc from biotite-quartz-feldspar gneiss. This fault and the brecciated talc along its west side are the cause of caving in the adit. The greatest concentration of talc at this prospect is in the marble just west of the fault. Because the fault seems to be only a short structure limited to the area of talc mineralization, and because post-talc movement on it is obvious, it seems likely that the talc layer influenced the location of the fault rather than that the fault controlled the formation of talc.

The talc is white except for some material piled near the mouth of the adit, which is stained with limonite along fractures. Chlorite from the prospect contains trace concentrations of zircon, apatite and rutile.

This prospect provides a good opportunity to study the relationship between talc and chlorite. The talc, with the exception of the large body west of the fault, forms small pods a few feet (1 m) across within the dolomitic marble. The chlorite occurs in the gneiss and is commonly adjacent to talc pods in the marble, thus illustrating the effect of the composition of the host rock in determining whether talc or chlorite forms. In the gneiss, where sufficient aluminum was available, chlorite formed; but in the marble, where aluminum was not available in sufficient concentration, talc formed. It is likely that the excess silica left from the alteration of gneiss to chlorite contributed to the formation of the talc in the marble.

TR-8 Granite Creek prospect

Location: SW¼ sec. 3, T. 6 S., R. 3 W., Madison County. Virginia City 15-minute quadrangle. Three miles (5 km) northwest of Virginia City.

Accessibility: A ranch road from Granite Creek goes past the prospect.

Ownership: W. D. Conklin, Alder, Montana.

Description: The main occurrence of talc is in the SW¼ SW¼ sec. 3, where a small amount has been mined from a shallow inclined shaft **(fig. 7)**. Shallow pits near the shaft expose talcose marble and talc pods within the marble. Two other prospect pits were excavated in altered pegmatite along a jasper vein. The feldspar in the pegmatite has been altered to a fine-grained mixture of quartz, clinozoisite, and chlorite. Blades of tremolite in marble show evidence of having been partly replaced by talc. X-ray diffraction analysis of a specimen of talc failed to show the presence of impurities. Cordua (1973) showed that the marble layer exposed at this prospect extends S. 70° W. from Granite Creek for 3,500 feet (1,150 m) to a point where it is covered by Tertiary volcanic rocks.

Both talc and chlorite are exposed in a prospect cut along the road in the NW¼ SW¼ sec. 3, T. 6 S., R. 3 W. **(fig. 8)**, but slumping in the cut has obscured the relationship between the talc layer and chlorite. A 2-foot (0.7-m) layer of talc containing minor graphite is exposed in the cut. X-ray diffraction analysis of the chlorite shows that it contains a small amount of talc. A pale-green rock from the same cut consists of serpentine and minor quartz and contains a trace of calcite. Talc and chlorite are also exposed in a small pit along the road north of the cut described above. The talc occurs in a marble layer or pod less than 10 feet (3 m) thick, which is surrounded by quartzofeldspathic gneiss. The talc layer is less than 3 feet (1 m) thick. An adit 20 feet (7 m) long is situated across a small gulch south of the talc. No talc was seen in the adit, only yellowish-green serpentine.

TR-9 Bear claims (Granite Creek mine)

Location: The northern cut is in the SW¼ NE¼ sec. 25, T. 5 S., R. 3 W., Madison County, and the southern cut is in the NE¼ NE¼ SW¼ of the same section. Virginia City 15-minute quadrangle. Approximately 6 miles (10 km) northeast of Virginia City.

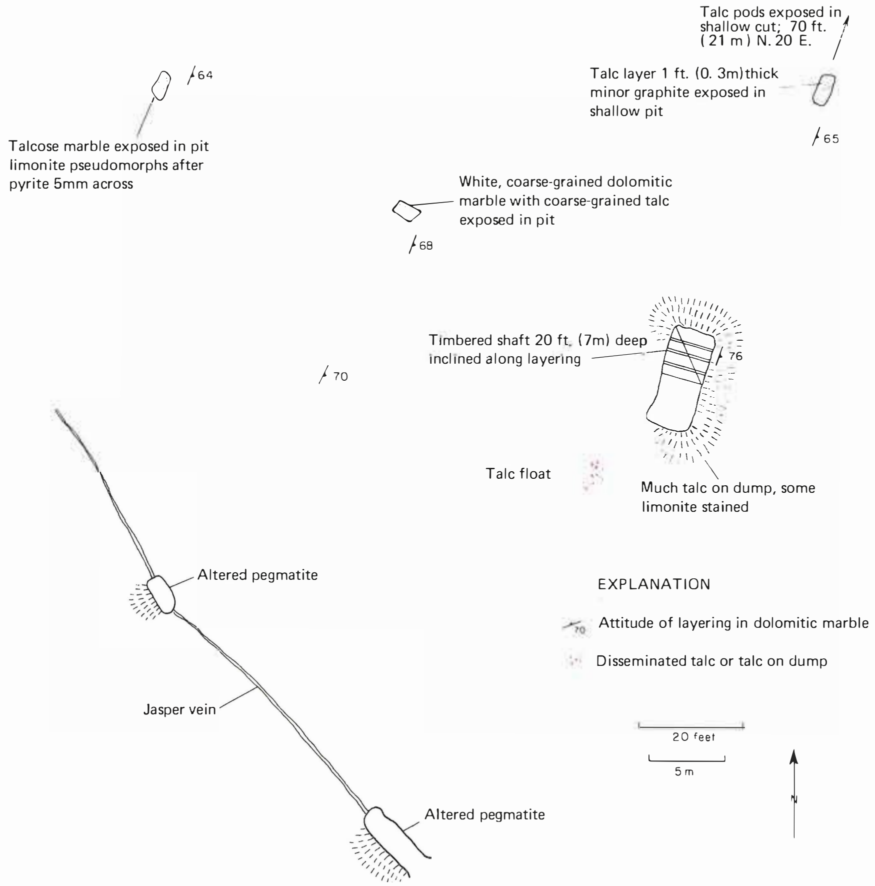


Figure 7—Southern Granite Creek prospect, Tobacco Root Mountains (R. B. Berg, September 1976).

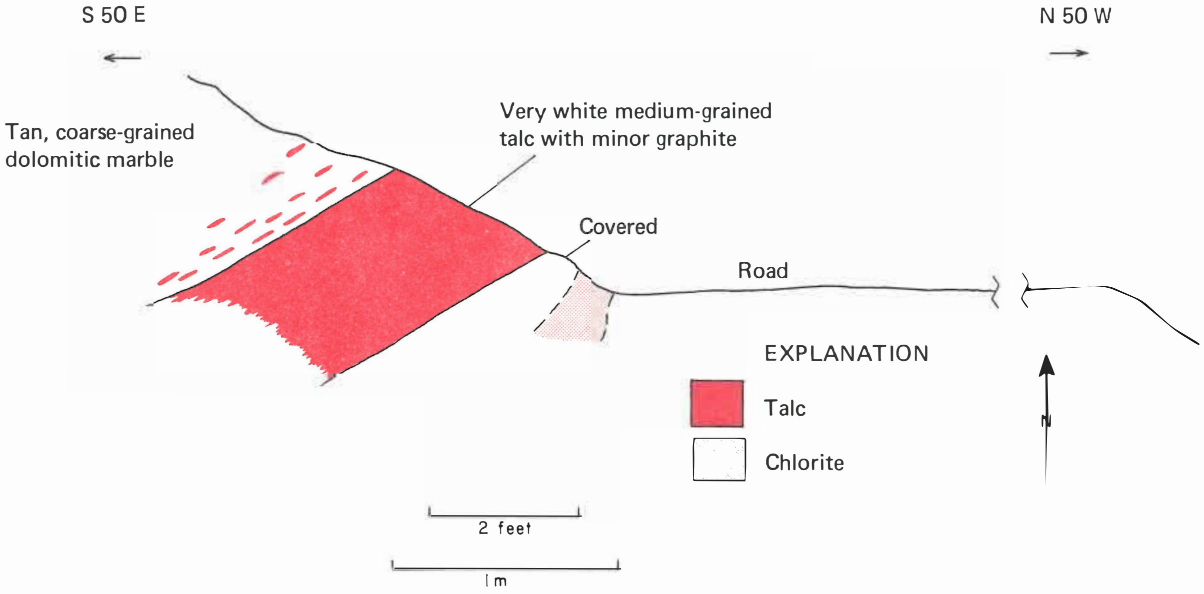


Figure 8—Northern Granite Creek prospect, Tobacco Root Mountains (R. B. Berg, September 1976).

Accessibility: The road to the mine branches from the Granite Creek road 4.4 miles (7 km) from the junction of the Granite Creek road with Highway 34. The northern cut is 1.1 miles (1.8 km) by road from the Granite Creek road.

Ownership: Albert Kingrey, Virginia City, Montana.

Description: The claims have been developed by two cuts on the southeast slope of a ridge, which is parallel to the strike of the foliation of the metamorphic rocks. The cuts are 1,500 feet (450 m) apart. Talc has been mined from the cuts, and more recently (1973) some exploratory drilling has been done in the southern cut. The claims are within the area mapped by Cordua (1973).

The largest talc body exposed in the northern cut is a layer 17 feet (5.6 m) long and 2.2 feet (0.7 m) in vertical dimension, which is surrounded by dolomitic marble **(fig. 9)**. Although the talc is generally fine grained, a few flakes are 3 to 5 mm across. Pyrite pyritohedrons in some of the talc have been replaced by limonite. Loose blocks of a rock consisting of both talc and chlorite are the only other recognized occurrences of talc in the cut. Biotite-quartz-feldspar gneiss and pegmatitic pods within the gneiss have been partly altered to green chlorite.

Both talc and chlorite are exposed in the southern cut. The talc has been formed by alteration of marble, and the chlorite by alteration of biotite-quartz-feldspar gneiss. The greatest concentration of talc is at the northern part of the cut, where two concordant layers of talc are exposed **(fig. 10)**. One layer is 2 feet (0.7 m) thick and the other is at least 1 foot (0.3 m) thick, but its true thickness is obscured by slumped material. Talcose marble is exposed near the north end of the cut and also near the south end, where a high-angle fault separates it from gneiss. A talc pod 1 by 2 feet (0.3 by 0.7 m) is exposed at the southern end of the cut. In the central part of the cut a near-vertical vein of green chlorite 6 feet (2 m) thick cuts strongly chloritized quartzofeldspathic gneiss. X-ray diffraction analysis of a specimen of the chlorite shows the only impurity to be a trace of quartz.

A thin section of the quartzofeldspathic gneiss shows that the biotite has been altered to chlorite and the feldspar to sericite. Apatite and zircon are trace constituents. At some localities this altered quartzofeldspathic gneiss grades into a rock that in a hand specimen is judged to consist entirely of chlorite.

Exposures along the road between the two cuts are mainly in biotite-quartz-feldspar gneiss; minor talcose marble is also exposed.

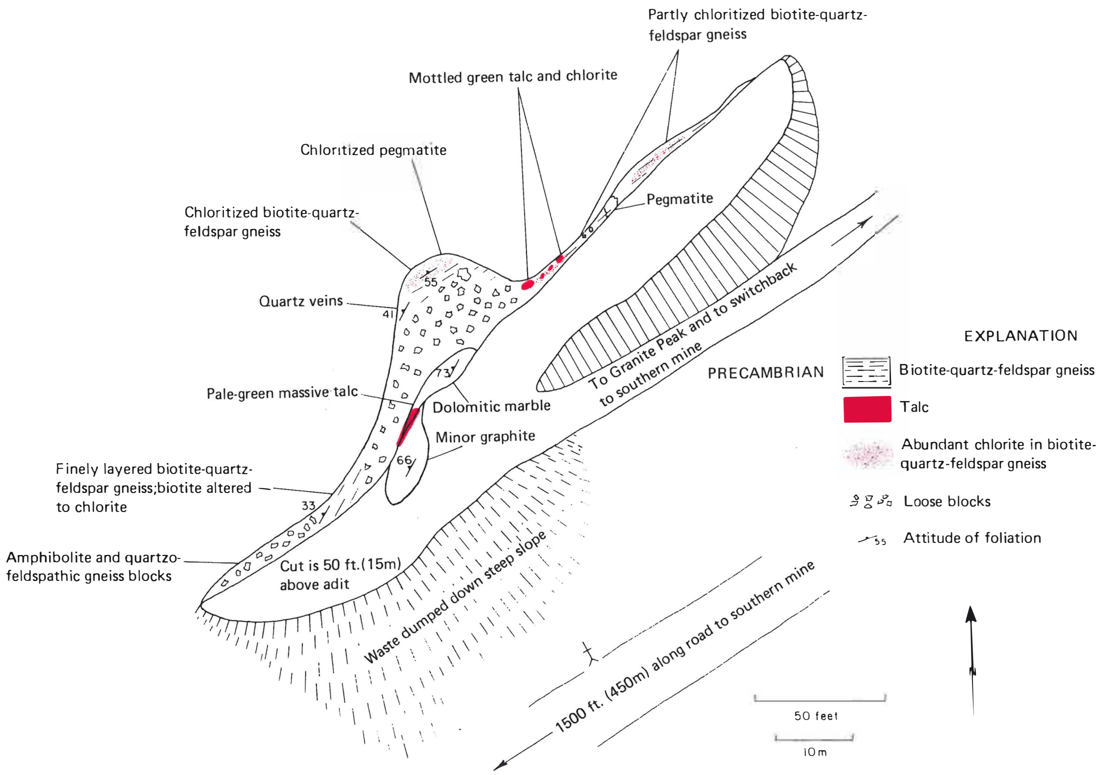


Figure 9—Northern cut at Bear claims, Tobacco Root Mountains (R. B. Berg, September 1976).

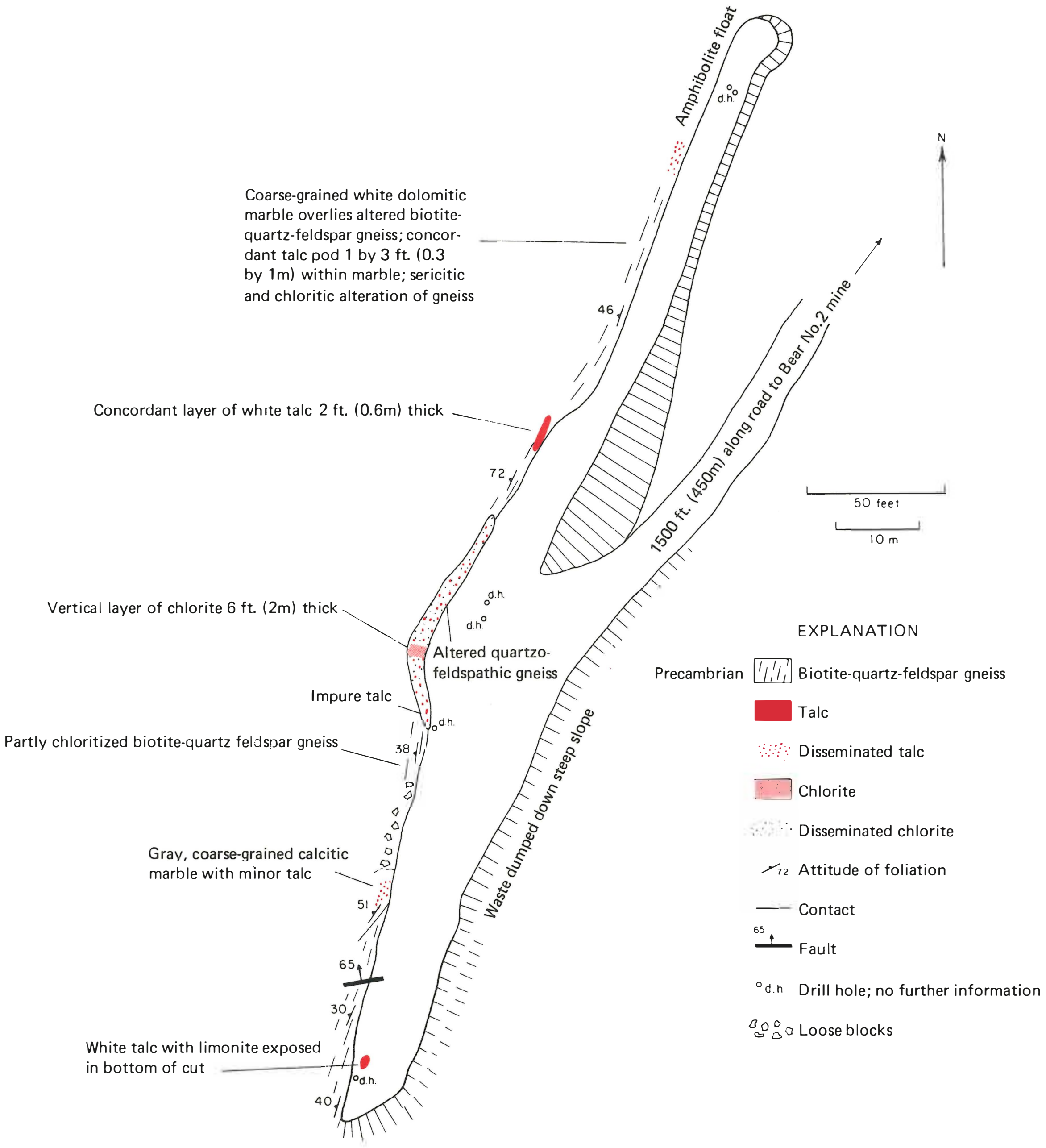


Figure 10—Southern cut at Bear claims, Tobacco Root Mountains (R. B. Berg, September 1976).

TR-10 Talc prospect southwest of Ennis

Location: SE¼ NE¼ sec. 9, T. 6 S., R. 2 W., Madison County. Virginia City 15-minute quadrangle. Approximately 6 miles (10 km) southwest of Ennis.

Accessibility: The prospect is 0.5 mile (0.8 km) north of Montana Highway 34.

Ownership: Mr. Schulz of Sheridan, Montana.

Description: Talc is disseminated or in small pods within a layer of coarse-grained dolomitic marble **(fig. 11)**, which is of variable attitude and has an average thickness of 120 feet (36 m). Cordua (1973) traced the marble layer for 3 miles (5 km) to the north. Several concentrations of float of quartz-chlorite rock within the marble layer are interpreted to be small pegmatite lenses in which the feldspar has been altered to chlorite. Pink microcline and quartz in one specimen are surrounded by a fine-grained matrix of chlorite.

The biotite-muscovite-quartz-feldspar schist southeast of the marble layer locally contains sillimanite and garnet. Biotite altered to chlorite whereas feldspar altered to sericite and possibly chlorite in the schist exposed in the southern part of this prospect. A green chloritic rock at this prospect consists mainly of chlorite but contains minor sericite, and a trace of quartz was detected by x-ray diffraction analysis. A specimen of talc contains, in addition to talc, a minor concentration of quartz and a trace of chlorite.

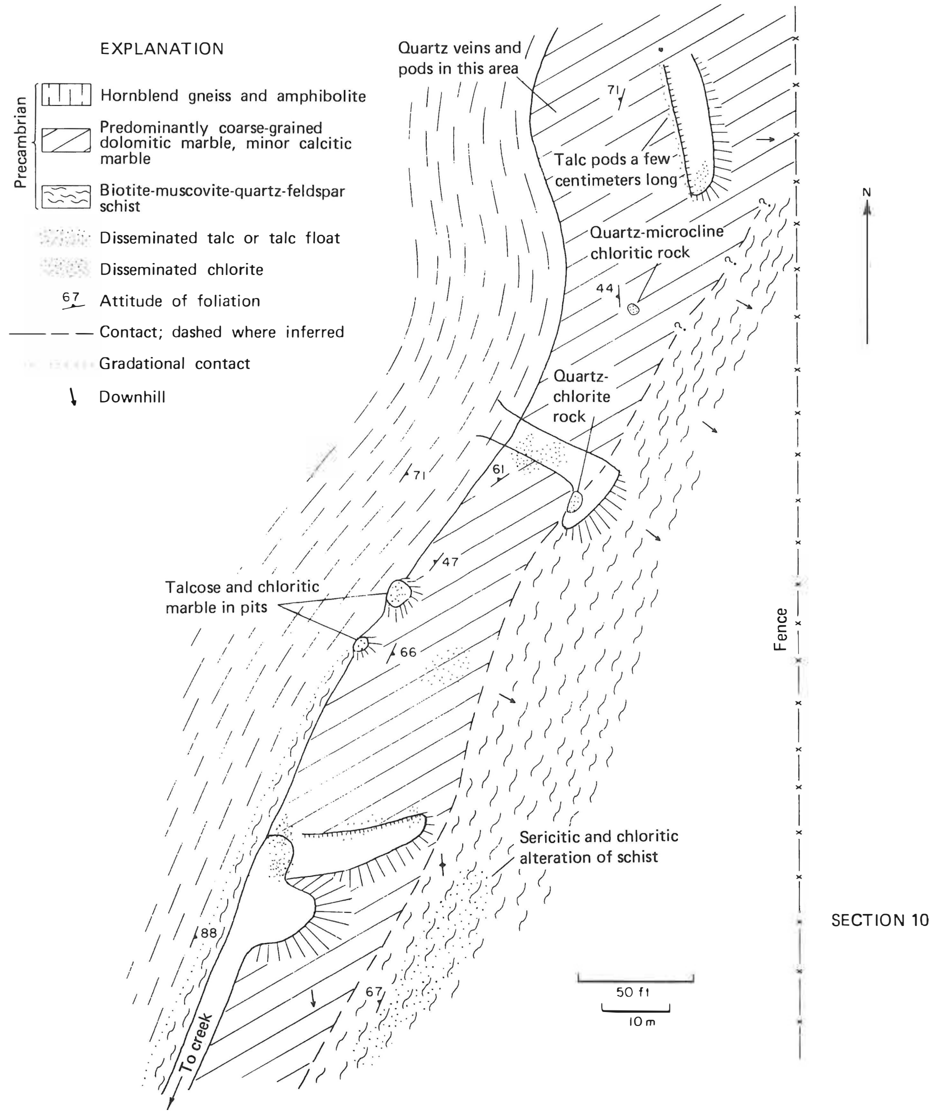


Figure 11—Prospect southwest of Ennis, Tobacco Root Mountains (R. B. Berg, September 1976).

Ruby Range

Talc occurrences are more numerous in the western part of the Ruby Range than in any other area in southwestern Montana. Besides the many talc prospects and several inactive mines, there are three operating mines in this range, the Beaverhead, Treasure and Regal mines. Although the geology and talc occurrences in the Ruby Range have been well described by Olson (1976, p. 115-133), they are summarized here for completeness. A dissertation by Okuma (1971) on the geology and structure of the southwestern part of the Ruby Range, and a similar dissertation by Garihan (1973a) on the central part of the range, are the other main sources of information on the Precambrian geology and talc deposits of this area. Talc occurrences in a small area in the southern part of the Ruby Range are described in a thesis by Whitehead (1979). In addition, Heinrich and Rabbitt (1960) described the geology of the southwestern part of the range, and James, Wier and Shaw (1969) mapped the geology of the Christensen Ranch 7½-minute quadrangle and surrounding area in the southern part of the range. A detailed map of the Carter Creek iron deposit, which lies within the Christensen Ranch quadrangle, has been published by James and Wier (1972). The geology of the northern part of the Ruby Range has been mapped by Tysdal (1976), who concentrated his efforts on the Paleozoic, Mesozoic and Cenozoic formations and did not map individual rock types in the sequence of pre-Belt rocks. Larry Karasevich, a graduate student at Pennsylvania State University, is now (1978) working on the pre-Belt metamorphic rocks of the northern part of the range.

The Ruby Range is a northeast-trending uplifted block, principally of pre-Belt metamorphic rocks. With the exception of a small "bridge" of metamorphic rocks connecting the Ruby Range with the Greenhorn Range to the east, the Ruby Range is surrounded by intermontane basins partly filled with Tertiary sediments. Paleozoic and younger sedimentary rocks are exposed only in the northern part of the Ruby Range, where they generally flank the Precambrian core.

The pre-Belt metamorphic rocks of the Ruby Range have been divided into three major categories, Cherry Creek-type rocks, Dillon Granite Gneiss, and pre-Cherry Creek rocks. The Cherry Creek-type rocks are the most significant group for this study because the dolomitic marble layers that are the host rock for all of the talc deposits occur in the Cherry Creek-type rocks. These rocks, which are exposed along the northwestern flank of the range, are truncated to the northwest by the range-front fault. The general strike of layering is northeast, roughly parallel to the northwest flank of the range. Numerous steeply inclined faults that strike northwest cut across the pre-Belt metamorphic rocks.

Marble, quartzite, calc-silicate rock, sillimanite schist, chlorite schist, actinolite schist, corundum schist, muscovite schist, biotite schist, amphibolite, hornblende gneiss, magnetite-bearing iron formation and anthophyllite gneiss have been recognized within the sequence of Cherry Creek-type rocks. The marble layers range in thickness from a few tens of meters to 400 meters. One layer of marble, informally designated the Regal marble, can be traced more than 16 km (10 mi.) from a point south of Carter Creek north to Spring Creek.

The Dillon Granite Gneiss crops out in the middle of the Ruby Range and separates Cherry Creek-type rocks to the northwest from pre-Cherry Creek rocks to the southeast. The Dillon Granite Gneiss consists mainly of quartzofeldspathic gneiss but contains lesser pegmatite and aplite. Layers or stringers of the Dillon Granite Gneiss are present in both the Cherry Creek-type rocks and the pre-Cherry Creek rocks. Unlike the Cherry Creek-type rocks, which are for the most part clearly metasedimentary, the Dillon Granite Gneiss has a less obvious precursor. Some workers have concluded that this mass of quartzofeldspathic gneiss was produced by metamorphism of a synkinematic batholith emplaced during the Precambrian (Heinrich and Rabbitt, 1960). On the other hand, Garihan and Okuma (1974) cited evidence that the Dillon Granite Gneiss could have been formed by isochemical metamorphism of arkosic rocks. Their most convincing argument for a sedimentary precursor is the presence of thin layers of marble well within the Dillon Granite Gneiss and traceable for 6 km (3.6 mi.). They also noted that compositional variation within the Dillon Granite Gneiss is more nearly compatible with a sedimentary than an igneous origin.

The pre-Cherry Creek rocks, which lie southeast of the Dillon Granite Gneiss, have generally been judged to be older than the Cherry Creek-type rocks because they lie stratigraphically below them. Units described in the pre-Cherry Creek sequence are biotite-quartz-feldspar gneiss, hornblende gneiss, amphibolite, sillimanite gneiss and chlorite schist. Ultramafic bodies and diabase dikes thought to be of Precambrian age also occur within rocks belonging to the pre-Cherry Creek, Cherry Creek and Dillon Granite Gneiss of the Ruby Range.

The metamorphic history of the pre-Belt rocks of the Ruby Range is similar to that of the metamorphic rocks exposed in the other mountain ranges of southwestern Montana. The rocks were subjected to multiple periods of Precambrian deformation, which produced isoclinal folds and a mineral assemblage of the amphibolite facies. Local granulite facies assemblages may be relicts of an earlier metamorphic event. Evidence of retrograde greenschist facies metamorphism is widespread in the Ruby Range.

Most of the descriptions of talc occurrences and mines in the Ruby Range are summarized from the publications of Okuma (1971), Garihan (1973a), or Olson (1976). Although most of the prospects and mines were visited during the early stages of this project, they are not mapped or described in detail, because of the above earlier investigations. The sources of information are included in the description of each deposit.

R-1 Ruby Peak occurrence

Location: W½ sec. 16, T. 6 S., R. 5 W., Madison County. Laurin Canyon 7½-minute quadrangle. Approximately 6 miles (10 km) west of Alder.

Accessibility: A private road up Hinch Creek goes within 0.5 mile (0.8 km) of the summit of Ruby Peak, within 0.2 mile of the southernmost talc occurrence.

Ownership: State school section.

Description: This occurrence of talc was found by Larry Karasevich during his mapping of the pre-Belt rocks of the northern Ruby Range in the summer of 1977. Tysdal (1976) had previously mapped the Paleozoic, Mesozoic and Cenozoic rocks of this part of the range. Both dolomitic marble and calcitic marble are well exposed over a large area surrounding Ruby Peak. Scattered chips of pale-green to green talc can be picked up along the ridges that extend southwest and northeast from Ruby Peak. Although talc chips are scattered over a large area, no concentration of talc was found here. Some talc found southwest of Ruby Peak is poorly exposed in a small prospect pit in the small saddle just east of the point where the southwest-trending ridge crosses the western edge of section 16. An old discovery post shows that prospectors may have located a claim here without realizing that they were on a state section; and in order to mine they would have to lease the mineral rights. Tremolite grains, most less than 1 mm in length, were observed in a thin section of one specimen of talc, but there is no evidence that the talc replaced the tremolite.

R-2 Spring Creek prospect

Location: SE¼ sec. 32, SW¼ sec. 33, T. 6 S., R. 6 W., and NE¼ sec. 5, T. 7 S., R. 6 W., Madison County. Beaverhead Rock SE 7½-minute quadrangle. Approximately 14 miles (23 km) northeast of Dillon.

Accessibility: The prospect can be reached by a road that goes up Spring Creek.

Ownership: Not known.

Description: The talc deposit is in the Regal marble on the northwest limb of a synform. Talc occurrences in this marble can be traced 1.5 km (5,000 ft.) (northeast) to the point where the marble is overlain by Paleozoic formations. A body of talc 3 to 7 meters (10 to 22 ft.) wide is exposed for 20 meters (64 ft.) in one of the cuts. Talc from this deposit shows an unusually wide variation in color, including white, green, pink, purple and yellow varieties. Limonite, gypsum and graphite are reported to occur in the talc. Other minerals in the marble or very impure talc are serpentine(?), chlorite, chrysotile, tremolite, diopside, rutile, scapolite, phlogopite and garnet. The Spring Creek prospect is unusual in its long strike length, which led Olson to conclude that it is worthy of further exploration.

Sources of information: Garihan, 1973a, p. 177-180; Olson, 1976, p. 129-130.

R-3 Gem claim

Location: SE¼ sec. 34, T. 6 S., R. 6 W., Madison County. Approximately 16 miles (26 km) northeast of Dillon. Beaverhead Rock SE 7½-minute quadrangle.

Accessibility: The road along Spring Creek goes within 1 mile of the claim.

Ownership: Pfizer, Incorporated.

Description: This deposit is in the Regal marble, which is exposed on the southeast limb of a northeast-trending synform. The Spring Creek prospect (R-2) is on the northwest limb of the same structure. A zone of micaceous, graphitic talc 2 to 3 meters (6 to 9 ft.) wide is exposed in the lower cut. Lenses of graphitic talc only a few centimeters across are exposed in the upper cut. Garihan noted that a pegmatite dike that cuts the talcose marble has been partly altered to chlorite, presumably during the same event that produced talc in the enclosing dolomitic marble.

Sources of information: Garihan, 1973a, p. 180-181; Olson, 1976, p. 129.

R-4 Whitney claims

Location: SW¼ sec. 2, T. 7 S., R. 6 W., Madison County. Mine Gulch 7½-minute quadrangle. Approximately 16 miles (26 km) northeast of Dillon.

Accessibility: A road to the claims branches off to the north from the road along the Left Fork of Stone Creek in the NW¼ sec. 14, T. 7 S., R. 6 W. The claims are 1.6 miles (2.5 km) by road from the road along the Left Fork of Stone Creek.

Ownership: Pfizer, Incorporated.

Description: Garihan described a talc body exposed in bulldozer cuts as being digitated, locally discordant to layering in the enclosing marble, and variable in thickness. Faulting has extensively fractured the talc. Limonite and pyrite are abundant in some of the talc.

Sources of information: Garihan, 1973a, p. 171-174; Olson, 1976, p. 130.

R-5 Prospect southwest of Whitney claims

Location: SE¼ sec. 3, T. 7 S., R. 6 W., Madison County. Mine Gulch 7½-minute quadrangle. Approximately 16 miles (26 km) northeast of Dillon.

Accessibility: The prospect can be reached from the road to the Whitney claims, which branches to the north from the road along the Left Fork of Stone Creek in the NW¼ sec. 14, T. 7 S., R. 6 W. The distance by road from the Left Fork of Stone Creek to the prospect is 1.6 miles (2.5 km).

Ownership: Not known.

Description: Cuts at this locality expose talc in the same marble layer as that exposed on the Whitney claims. Garihan reported that somewhat graphitic talc occurs along fractures in the dolomitic marble and also noted the presence of a body of dark-blue and light-green talc. In another cut irregular talc bodies form a zone reported to be 20 meters (65 ft.) wide.

Sources of information: Garihan, 1973a, p. 174-175; Olson, 1976, p. 130.

R-6 Prospect north of Treasure mine

Location: SW¼ sec. 11, T. 7 S., R. 6 W., Madison County. Mine Gulch 7½-minute quadrangle. Approximately 16 miles (26 km) east of Dillon.

Accessibility: The road to the Whitney claims, which branches from the road along the Left Fork of Stone Creek in the NW¼ sec. 14, T. 7 S., R. 6 W., passes within 0.25 mile (0.4 km) of the prospect.

Ownership: Not known.

Description: The main body of talc, which is exposed in two bulldozer cuts, is 2 to 3 meters (7 to 10 ft.) thick and is underlain by a layer of dark-green graphitic talc 2 meters (7 ft.) thick. The talc is concordant to layering in the enclosing marble and can be traced for 25 meters (82 ft.) along strike. In addition there are discordant stringers, layers and small lenses of talc in the surrounding marble. Garihan identified talc, graphite, chlorite, serpentine and gypsum in the enclosing dolomitic marble.

Source of information: Garihan, 1973a, p. 169-171.

R-7 Prospect northeast of Treasure mine

Location: SE¼ sec. 11, T. 7 S., R. 6 W., Madison County. Mine Gulch 7½-minute quadrangle. Approximately 17 miles (28 km) northeast of Dillon.

Accessibility: A road that branches from the Left Fork of Stone Creek in the NW¼ sec. 13, T. 7 S., R. 6 W., leads directly to the prospect.

Ownership: Not known.

Description: A talc body approximately 3 meters (10 ft.) wide and traceable for 10 meters (32 ft.) is exposed in a cut. Graphite and limonite discolor the talc. Garihan mentioned that gypsum is associated with some smaller talc pods in the marble.

Sources of information: Garihan, 1973a, p. 166-169; Olson, 1976, p. 129.

R-8 Bennett Owen claim

Location: NW¼ sec. 12, T. 7 S., R. 6 W., Madison County. Mine Gulch 7½-minute quadrangle. Approximately 17 miles (28 km) northeast of Dillon.

Accessibility: The closest road to the prospect is a road along Cottonwood Creek, which continues to within a mile of the prospect.

Ownership: Not known.

Description: The talc body has an outcrop of approximately 5 by 35 meters (16 by 112 ft.) and is dark green. Garihan described subrounded masses of talc recognized in thin section, which may be pseudomorphs after serpentine. Chlorite was also recognized within the talc. Serpentine has replaced olivine and pyroxene in the adjacent marble.

Sources of information: Garihan, 1973a, p. 162-166; Olson, 1976, p. 128.

R-9 Treasure mine

Location: N½ sec. 14, T. 7 S., R. 6 W., Madison County. Mine Gulch 7½-minute quadrangle. Approximately 16 miles (26 km) east of Dillon.

Accessibility: The haul road for this mine is along the Left Fork of Stone Creek.

Ownership: Pfizer, Incorporated.

Description: Mining of this deposit began at the openpit Treasure State mine, which was closed when a larger body of talc to the east was mined at the Treasure Chest mine, also an openpit mine. More recently the Treasure State and Treasure Chest ore bodies have been mined from one large pit now known as the Treasure mine, which is an important producer of high-quality talc. Talc mined here is hauled to Pfizer's mill at Barretts siding 8 miles (13 km) south of Dillon, where it is sorted, pulverized and bagged for shipment.

The ore body at the Treasure mine is a tabular body of talc formed by the almost complete replacement of dolomitic marble. Only a few blocks of unreplaced dolomitic marble remain within the talc body. The west-striking layer of talc is cut by numerous high-angle faults that trend northwest. Movement on all of these faults is such that the southwest block has moved up relative to the northeast block. One such fault, known as the Treasure Fault, separates the Treasure Chest ore body to the east from the Treasure State ore body to the west. Seemingly the same talc layer forms both ore bodies but has been offset along the Treasure Fault.

The Treasure Chest ore body ranges in thickness from 30 to 50 meters (96 to 160 ft.), is 360 meters (1,188 ft.) long, and the dip ranges between 45 and 65° N. The Treasure State ore body is reported to range from 20 to 30 meters (66 to 98 ft.) in width where exposed in the pit. It is more than 100 meters (330 ft.) long and dips approximately 45° N.

The hanging wall at the Treasure mine is Dillon Granite Gneiss, and the footwall is garnet-biotite schist. Both the gneiss and schist have been extensively altered, the biotite being altered to chlorite, the plagioclase to white mica. The altered footwall schist presents a problem in slope stability when the overlying steeply inclined layer of talc is removed. Olson reported that in the mid-1960s the waste-to-ore ratio at this mine was 3:1 or 4:1 and that by 1976 it had increased to something on the order of 15:1.

Garihan identified graphite, limonite, chlorite, gypsum(?), apatite and rutile in talc at this mine. Although interesting mineralogically, those minerals do not occur in sufficient concentration to significantly affect the quality of the talc.

Sources of information: Garihan, 1973a, p. 149-156; Olson, 1976, p. 121-125.

R-10 Beaverhead mine

Location: SE¼ sec. 14, T. 7 S., R. 6 W., Madison County. Mine Gulch 7½-minute quadrangle. Approximately 16 miles (26 km) east of Dillon.

Accessibility: The haul road for this mine goes up Cottonwood Creek after branching from the Ruby River road.

Ownership: Cyprus Industrial Minerals.

Description: The Beaverhead mine is situated just across a ridge southeast of the Treasure mine, and the talc body at the Beaverhead mine may be in the same layer of marble as the ore body at the Treasure mine. The strike of the dolomitic marble at the Beaverhead mine is roughly west and the dip is 35 to 70° N. The footwall schist at the Treasure mine is similar to the schist exposed in the hanging wall at the Beaverhead mine, suggesting the possibility that the deposits are on opposite limbs of an isoclinal fold. The footwall at the Beaverhead mine is dolomitic marble, which is underlain by amphibolite. The best talc at the Beaverhead mine is in the upper part of the ore body close to the contact with the overlying biotite schist, which has been severely altered.

The talc body at the Beaverhead mine is at least 800 feet (244 m) long and is offset by relatively minor faults. Olson and Garihan suggested that the talc body pinches out along strike rather than being displaced by faults. The horizontal width of the talc body ranges between 25 and 100 feet (8 and 31 m) where exposed in the mine. Blocks of unreplaced dolomitic marble are numerous within the talc body.

The Beaverhead mine has increased substantially in size in recent years as the result of a major stripping program in 1974 and 1975 and additional stripping in 1976. Because the ore body dips into the hillside, much overburden must be removed as the mine is deepened.

Talc from the Beaverhead mine is hauled to Alder, 25 miles (40 km) to the northeast, where it is washed and sorted before either being shipped directly or being hauled to Three Forks for pulverizing and bagging.

Sources of information: Garihan, 1973a, p. 156-160; Olson, 1976, p. 125-126.

R-11 Prospect east of Beaverhead mine

Location: NW¼ sec. 13, T. 7 S., R. 6 W., Madison County. Mine Gulch 7½-minute quadrangle. Approximately 17 miles (28 km) east of Dillon.

Accessibility: This prospect is several hundred feet north of the haul road to the Beaverhead mine and is easily visible from the road.

Ownership: Not known.

Description: Layers and irregular masses of talc are exposed in a cut in dolomitic marble along strike to the east of the marble at the Beaverhead mine. The thickest body of talc is approximately 1 meter (3 ft.) thick and dips 50 to 60° N. Garihan noted the occurrence of small pods of talc along bedding planes, which are still recognizable in the marble, suggesting that some layers in the marble were more easily permeated by talc-forming aqueous solutions or alternatively were of such composition that they were more susceptible to replacement by talc. Planes of rhombohedral cleavage are still recognizable in some of the coarse-grained rhombohedral carbonate (dolomite?) that has been replaced by talc. Most of the talc exposed in this cut is dark green or grayish green.

Sources of information: Garihan, 1973a, p. 160-162; Olson, 1976, p. 129.

R-12 Regal (Keystone) mine

Location: N½ sec. 2, T. 8 S., R. 7 W., Madison County. Christensen Ranch 7½-minute quadrangle. Approximately 11 miles (17 km) southeast of Dillon.

Accessibility: The mine is adjacent to the Sweetwater road.

Ownership: Pfizer, Incorporated.

Description: The Regal mine, originally known as the Keystone mine, was first developed by a shaft 60 feet (18 m) deep with more than 300 feet (92 m) of drifts at the bottom. The underground workings have long been inaccessible. More recently, talc has been mined from an openpit 450 feet (138 m) long, 50 to 100 feet (15 to 31 m) wide, and 20 to 30 feet (6 to 9 m) deep.

The talc ore lies within a layer of dolomitic marble close to the core of a tightly refolded synform. The strike of the marble is N. 45° E. to S. 80° E. and the dip is 30 to 75° N. The talc zone is exposed for more than 750 feet (229 m) along strike and is more than 300 feet (92 m) wide. Because of the lack of soil cover, the talc zone can be traced beyond the limits of the pit. The zone consists of talc lenses in a dolomitic marble unit, which is cut by numerous faults. Micaceous quartz schist forms the footwall of the deposit; the hanging wall is partly altered coarse-grained dolomitic marble. A zone of brecciated talc 1 to 2 feet (0.3 to 0.6 m) thick separates the main mass of ore from the hanging wall marble.

A near vertical diabase dike 60 to 100 feet (18 to 31 m) thick trending at right angles to the strike of the marble is exposed at the western end of the area of major talc concentration. Marble adjacent to the dike has been altered to a fine-grained rock that consists of talc and serpentine.

The talc deposit at the Regal mine, although of good size, has not been mined extensively because of the dark color of the talc, at least part of which is due to limonite.

Sources of information: Okuma, 1971, p. 102-104; Olson, 1976, p. 126; Perry, 1948, p. 6.

R-13 American Chemet mine

Location: SE¼ sec. 1, NE¼ sec. 12, T. 8 S., R. 7 W., Madison County. Christensen Ranch 7½-minute quadrangle. Approximately 12 miles (20 km) southeast of Dillon.

Accessibility: A road that branches to the north from the Sweetwater road in the N½ sec. 13, T. 8 S., R. 7 W., leads directly to the mine, a distance of 1.3 miles (2.1 km).

Ownership: Not known.

Description: This mine, now inactive, was operated by American Chemet Corporation, East Helena, Montana. Development consists of three pits, from which talc was mined, and several bulldozer cuts. The mine is situated in a complexly deformed layer of marble that in the vicinity of the mine strikes northeast and dips 45 to 75° NW. Although the marble is generally surrounded by Dillon Granite Gneiss, there are layers of amphibolite southwest of the mine. A northwest-trending metagabbro dike cuts the marble between two of the pits. Although Okuma suggested that some of the talc-like rock exposed in the workings may have been produced by the alteration of an ultramafic rock, most of the talc is in the marble. This dark-greenish-gray rock contains chlorite, quartz and minor phlogopite in a fine-grained matrix of either white mica, or talc.

Sources of information: James, Wier and Shaw, 1969; Okuma, 1971, p. 108-111; Olson, 1976, p. 127.

R-14 Estelle (Sweetwater) mine

Location: E½ sec. 13, NE¼ sec. 24, T. 8 S., R. 7 W., Madison County. Christensen Ranch 7½-minute quadrangle. Approximately 13 miles (21 km) southeast of Dillon.

Accessibility: The main pit is situated on the northeast side of the Sweetwater road. Prospect pits southwest of the Sweetwater road can be reached by taking a road that branches from the Sweetwater road in the SE¼ sec. 13, T. 8 S., R. 7 W. The prospects are 0.5 mile (0.8 km) southwest of the Sweetwater road.

Ownership: Pfizer, Incorporated.

Description: The Estelle mine, now inactive, is an open pit just northeast of the Sweetwater road. Some bulldozer cuts and prospect pits have been dug farther southwest, in the area between Sweetwater Creek and the Sweetwater road. The mine and prospect cuts are in a layer of dolomitic marble of unusually unifom thickness and attitude, which is enclosed by Dillon Granite Gneiss. The marble layer is approximately 400 feet (122 m) thick, strikes northeast, and dips 50° NW. at the Sweetwater mine. Abundant shear zones subparallel to the marble layer are prominent in the pit. The talc generally forms concordant layers and pods within the dolomitic marble. Most of the talc is various shades of green or gray.

Sources of information: James, Wier and Shaw, 1969; Okuma, 1971, p. 106-107; Olson, 1976, p. 128.

R-15 Smith-Dillon mine

Location: E½ sec. 23, T. 8 S., R. 8 W., Beaverhead County. Ashbough Canyon and Dillon East 7½-minute quadrangles. Approximately 8 miles (13 km) southeast of Dillon.

Accessibility: The mine is adjacent to the road in Axes Canyon, which crosses private land and may have a locked gate.

Ownership: Pfizer, Incorporated.

Description: The Smith-Dillon mine, now inactive, originally was an underground mine, but more recently talc has been mined from an open pit. The underground mine consisted of 1,500 feet (465 m) of adits and drifts on the main haulage level 30 feet (9 m) above creek level and another 400 feet (124 m) of drifts on a level 60 feet (19 m) lower. Perry noted that the talc holds well in underground workings and that very little timbering was required in exploratory work.

The talc is in a layer of dolomitic marble estimated to be 1,300 feet (400 m) thick. The marble strikes N. 30 to 40° E. and dips 60 to 70° NW. To the west of the mine the marble is covered with alluvium, and to the southeast the footwall of the deposit is a thin layer of amphibolite with many slickensided surfaces. Dillon Granite Gneiss is exposed farther to the southeast.

The lenticular ore body is approximately 750 feet (233 m) long and has a horizontal width of approximately 100 feet (31 m). Even within the talc zone, dolomitic marble veined by milky white quartz is more abundant than talc. Perry observed clay gouge and crushed zones within the talc zone where it was exposed in the underground workings. Left-lateral displacement along a west-striking fault at the north end of the open pit has displaced the talc zone approximately 70 feet (22 m) to the west. Talc from the mine is light greenish gray to light bluish gray and only rarely contains graphite.

Sources of information: Okuma, 1971, p. 99-102; Olson, 1976, p. 128; Perry, 1948, p. 4-6.

R-16 Banning-Jones mine

Location: SW¼ sec. 13, T. 8 S., R. 8 W., Beaverhead County. Dillon East 7½-minute quadrangle. Approximately 8 miles (13 km) southeast of Dillon.

Accessibility: A road to the Banning-Jones mine branches from the Axes Canyon road near the center of sec. 23, T. 8 S., R. 8 W. The distance by road from Axes Canyon to the mine is approximately 1 mile (1.6 km).

Ownership: State section.

Description: In 1964 the property was leased to Wallace Banning and Lester Jones of Dillon. Although some talc was mined from this deposit in the years since 1964, the property is now inactive. The mine is situated on both sides of a gully 1 mile (1.6 km) northwest of the Smith-Dillon mine, and the talc is in the same layer of dolomitic marble as at that mine. A sketch map by Geach illustrates well the relationship between marble and talc at the Banning-Jones mine. A talc zone approximately 40 feet (12 m) wide is exposed in a cut on the east side of the gully. On the basis of talc float and outcrops, the talc zone may be more than 100 feet (31 m) in width. The thickest layer of talc within this zone is approximately 10 feet (3 m) wide. On the west side of the gully there are indications of three lenticular bodies of talc, the largest of which is probably 100 feet (31 m) wide and 200 feet (62 m) long. Talc from this deposit is gray green and of steatite grade.

A granite dike 40 feet (12 m) thick and trending a little north of east has intruded the marble just south of the talc deposit. Geach suggested that this dike was a source of aqueous solutions that reacted with the dolomitic marble to form talc.

Sources of information: Geach, 1972, p. 161-162; Olson, 1976, p. 127.

R-17 Bozo-Zobo mine

Location: NE¼ sec. 19, T. 8 S., R. 7 W., Beaverhead County. Dillon East 7½-minute quadrangle. Approximately 9 miles (15 km) southeast of Dillon.

Accessibility: The road up Axes Canyon passes within 0.25 mile (0.4 km) of the mine. The Axes Canyon road crosses private land and may have a locked gate.

Ownership: Not known.

Description: The Bozo-Zobo mine is now inactive but in the mid-1960s it is reported by Olson that American Chemet Corporation shipped 8,000 tons of ore. The talc was mined from an opencut 25 to 30 feet (8 to 9 m) wide and approximately 50 feet (16 m) deep. Only about 50 percent of the marble exposed in the cut has been replaced by talc. Some of the talc is stained by manganese oxides to such an extent that it is not suitable for the usual markets. The talc zone is in a layer of marble that strikes northeast and dips northwest.

Source of information: Olson, 1976, p. 127-128.

R-18 Crescent prospect (Timber Gulch deposit)

Location: SW¼ sec. 1, T. 9 S., R. 8 W., Beaverhead County. Ashbough Canyon 7½-minute quadrangle. Approximately 11 miles (18 km) southeast of Dillon.

Accessibility: A road up Timber Creek on the Brown ranch passes within several hundred feet of the prospect.

Ownership: Not known.

Description: This prospect is the southernmost known occurrence of talc in the Ruby Range. Talc occurs in two layers of marble 10 to 15 feet (3 to 5 m) thick separated by 150 feet (47 m) of micaceous gneiss, all of which is surrounded by Dillon Granite Gneiss. Metamorphic units follow the regional trend of northeast strike and northwest dip. A shallow inclined adit and a few prospect excavations prove the continuation of talc to a depth of 10 to 20 feet (3 to 7 m). Perry reported that intermittent exposures of talc can be followed for 800 to 1,000 feet (248 to 310 m) along strike. An unusually high concentration of graphite in the talc probably has been the main deterrent to the development of the deposit.

Sources of information: Okuma, 1971, p. 105; Olson, 1976, p. 129; Perry, 1948, p. 6.

R-19 Sauerbier mine

Location: NW¼ sec. 25, T. 8 S., R. 7 W., Madison County. Elk Gulch 7½-minute quadrangle. Approximately 13 miles (22 km) southeast of Dillon.

Accessibility: A road to the Sauerbier mine branches from the Sweetwater road in the SW¼ sec. 20, T. 8 S., R. 6 W. The distance from the Sweetwater road to the mine is approximately 2.5 miles (4 km).

Ownership: Karl L. Sauerbier, Alder, Montana.

Description: The Sauerbier mine, although now (1978) inactive, was operated by Resource Processors, Incorporated, in 1974. More recently the property has been leased to Cyprus Industrial Minerals. Both the Sauerbier mine and the Owen-McGovern prospect lie within a body of marble that has a teardrop-shaped outline. The layering in the marble generally strikes northeast and dips 50 to 80° NW. The marble body is bordered on the southwest and northeast by major northwest-trending faults, and it is surrounded by Dillon Granite Gneiss. The mine consists of a north-south cut 100 feet (31 m) wide, 300 feet (93 m) long, and 50 feet (16 m) deep at the south end where it is deepest. Talc pods within dolomitic marble are most abundant in the southern half of the cut, where evidently most of the talc was mined. Numerous steeply inclined faults are exposed in the pit. Chlorite layers within both the talc and the dolomitic marble can be recognized in the southern part of the pit. The thickest layer of chlorite, which is 10 to 20 feet (3 to 6 m) thick, is exposed on the west wall of the pit, and is perhaps a basic dike or layer of quartzofeldspathic gneiss that has been completely replaced by chlorite.

A specimen, thought to be impure talc when it was collected in the field, can be recognized in thin section as thoroughly altered quartzofeldspathic gneiss. Biotite has been replaced by chlorite, and feldspar has been replaced by a mixture of sericite and chlorite. Garnet grains in the gneiss have been altered to sericite along fractures. X-ray diffraction analysis shows that the specimen contains minor talc in addition to chlorite and sericite.

Sources of information: Okuma, 1971, Plate 1; Olson, 1976, p. 126-127.

R-20 Owen-McGovern prospect

Location: SE¼ sec. 23, E½ sec. 26, T. 8 S., R. 7 W., Madison County. Elk Gulch 7½-minute quadrangle. Approximately 13 miles (22 km) southeast of Dillon.

Accessibility: The road to the Sauerbier mine, which branches from the Sweetwater road in the SW¼ sec. 20, T. 8 S., R. 6 W., goes within 0.25 mile (0.4 km) of the Owen-McGovern prospect at a distance of approximately 2.5 miles (4 km) from the Sweetwater road.

Ownership: Not known.

Description: The Owen-McGovern prospect is in the same body of dolomitic marble as the Sauerbier mine to the east. The marble body is 4,000 feet (1.2 km) long; is teardrop shape in outline; is surrounded by Dillon Granite Gneiss; and is bordered to the northeast and southwest by major northwest-trending faults. The marble strikes northeast and generally dips 50 to 80° NW. Pegmatite and diabase dikes intrude the marble, and amphibolite is also exposed at this prospect. Exploration includes trenching and some drilling. Talc layers exposed in the trenches are 1 to 2 feet (0.3 to 0.6 m) thick. Olson (1976, p. 129) concluded:

> *There is no talc deposit in Montana known to the writer whose geological relationships are so difficult to decipher as this one.*

Sources of information: Okuma, 1971, p. 107-108, Plate 1; Olson, 1976, p. 129.

Other talc occurrences

Many other occurrences of talc in the Ruby Range, about which little information has been published, are summarized in **Table 7**. Also Okuma (1971, p. 97) has plotted ten new talc occurrences on a map. Most of these talc occurrences have been described by Olson and are referenced to his 1976 article because it provides the most detailed locality information.

Table 7—Additional talc occurrences in the Ruby Range not plotted on Figure 3.

Location	Description	Reference
SW¼ sec. 17, T. 7 S., R. 6 W.	Lenses and layers of talc a few centimeters thick and less than 1 m long.	Garihan, 1973a, p. 181-182.
SW¼ sec. 18, T. 7 S., R. 5 W.	Dark-green talc float, locally graphitic.	Garihan, 1973a, p. 182.
SW¼ sec. 11, T. 7 S., R. 6 W.	Medium- to light-green talc float and some graphite.	Garihan, 1973a, p. 182.
SW¼ NW¼ sec. 2, T. 8 S., R. 7 W.	Light-colored talc float can be traced for 200 ft. (62 m) along strike over a width of 100 ft. (31 m).	Olson, 1976, p. 131.
SW¼ SW¼ sec. 3, T. 8 S., R. 7 W.	Light-green talc float can be traced for 600 ft. (186 m) along strike and has a maximum width of 825 ft. (101 m).	Olson, 1976, p. 131.
SW¼ SE¼ sec. 5, T. 8 S., R. 7 W.	No available information.	Henrich and Rabbitt, 1960, pl. 2.
SE¼ NW¼ sec. 8, T. 8 S., R. 7 W.	No available information.	Henrich and Rabbitt, 1960, pl. 2.
E½ sec. 10 and NW¼ sec. 11, T. 8 S., R. 7 W.	Talc in outcrop and float over a total strike length of 7,000 ft. (2.2 km).	Olson, 1976, p. 131.
NE¼ sec. 15 and SW¼ sec. 11, T. 8 S., R. 7 W.	Green talc float of sporadic distribution over a strike length of 4,000 ft. (1.2 km).	Olson, 1976, p. 131.
NE¼ sec. 21 and NW¼ sec. 22, T. 8 S., R. 7 W.	One talc zone extends for approximately 500 ft. (155 m) along strike.	Olson, 1976, p. 131.
SW¼ NW¼ sec. 19, T. 8 S., R. 7 W.	Zone of dark talc exposed for 1,350 ft. (419 m) along strike.	Olson, 1976, p. 130.
NE¼ NW¼ sec. 26, T. 8 S., R. 8 W.	No available information.	Heinrich and Rabbitt, 1960, pl. 2.
SE¼ SE¼ NE¼ sec. 26, T. 8 S., R. 8 W.	Green talc exposed for several hundred feet along strike, widths of 5 to 30 ft. (1.6 to 9 m).	Olson, 1976, p. 131.
SW¼ sec. 25, T. 8 S., R. 8 W.	Valley View prospect body of dark talc 150 ft. (47 m) long by 90 ft. (28 m) wide.	Olson, 1976, p. 131.
NW¼ NW¼ sec. 36, T. 8 S., R. 8 W.	Dark-green talc exposed in bulldozer cuts.	Olson, 1976, p. 130.
W½ NE¼ sec. 35, T. 8 S., R. 8 W.	Light-green talc can be traced for approximately 900 ft. (280 m) along strike. Some talc layers 10 ft. (3 m) thick.	Olson, 1976, p. 130.
SE¼ SE¼ sec. 35, T. 8 S., R. 8 W.	No available information.	Henrich and Rabbitt, 1960, pl. 2.
sec. 1 and 2, T. 9 S., R. 8 W.	Zone of talcose rocks can be traced for 5,000 ft. (1.6 km) along strike (east-northeast).	Olson, 1976, p. 131.

Greenhorn Range

Because much time was devoted to studying the geology and talc occurrences of the Greenhorn Range, more detailed information is presented on the geology of this range than for other areas, where only talc and chlorite prospects were mapped. The information, which is only summarized here, will be covered in more detail in a forthcoming MBMG publication.

The Greenhorn Range is structurally the northwest limb of a large syncline, the axis of which plunges to the southwest. Pre-Belt metamorphic rocks in the Gravelly Range are on the eastern limb of the same structure but their outcrops are separated from those of the pre-Belt rocks in the Greenhorn Range by outcrops of Paleozoic and Mesozoic sedimentary formations. Pre-Belt rocks extend west from the Greenhorn Range in the vicinity of Ruby Dam to connect with the large area underlain by these rocks in the Ruby Range (**fig. 3**). The Precambrian rocks also extend north past the Virginia City district to the Tobacco Root Mountains. East of Virginia City, pre-Belt rocks are overlain by Eocene andesite-dacite porphyry (K-Ar age of 50 m.y.), which is in turn overlain by Oligocene basalt (K-Ar age of 33 to 34 m.y.) as reported by Marvin, Wier, Mehnert and Merritt (1974). A rhyolite plug just east of Ruby Dam, dated as 45 m.y. by the K-Ar method, intruded pre-Belt metamorphic rocks (Marvin, Wier, Mehnert and Merritt, 1974). Tertiary sediments are exposed in the upper Ruby Valley, which separates the Greenhorn Range from the Ruby Range to the west. Monroe (1976) described the stratigraphy and depositional history of those sediments.

The most abundant rock type in the Greenhorn Range is quartzofeldspathic gneiss, which is similar to the Precambrian quartzofeldspathic gneiss exposed in other mountain ranges of southwestern Montana. Most of the gneiss shown on **Sheets 2, 3** as quartzofeldspathic gneiss is biotite-quartz-feldspar gneiss. Some hornblende-quartz-feldspar gneiss occurs within the quartzofeldspathic gneiss. The amphibolite assemblage contains hornblende gneiss, granulite and metagabbro in addition to the predominant amphibolite. Marble, mainly dolomitic, is the most abundant of the rocks that are clearly metasedimentary. Other metasedimentary units are quartzite, anthophyllite gneiss and sillimanite schist. Several small ultramafic bodies, now partly serpentinized, are exposed in the Greenhorn Range. Post-metamorphic granite and pegmatite dikes are abundant in the northern part of the range.

The Snowcrest fault extends west from the Gravelly Range into the Greenhorn Range, where pre-Belt rocks have been thrust over Paleozoic formations in the vicinity of the Willow Creek talc mine. Farther to the south pre-Belt metamorphic rocks have been thrust over Paleozoic rocks along the Greenhorn fault. The north end of the Greenhorn Range is partly bounded by a high-angle fault, and a shear zone is well developed in quartzofeldspathic gneiss along the west flank of the range.

Included in the following descriptions are all localities where talc was found, either as small fragments in the soil or in outcrop. The numbered localities are shown on **Sheets 2, 3**, with the exception of GH-45 and GH-46, which lie outside the area covered by that map. Although there are a few scattered occurrences of talc north of Davey Creek, the greatest concentration is in the area south of Idaho Creek. Talc was found both in the outcrop and in the soil at several localities (numbers 12 to 20) within a marble layer exposed north of the North Fork of Greenhorn Creek. There are also several occurrences of talc within the large area underlain by marble at Dunegan Mountain. Dunegan Mountain is not named on the topographic map, but it is situated in sec. 14, T. 8 S., R. 4 W. The largest known concentration of talc in the Greenhorn Range is the deposit at the Willow Creek mine (locality GH-42). Prospects and abandoned metal mines encountered during mapping are listed in a section following the list of talc and chlorite occurrences. The following is a description of the occurrences, the first 27 of which are described only briefly.

West of the Ruby River

GH-1 SE¼ SW¼ sec. 32, T. 6 S., R. 4 W. Minor talc in soil below exposure of calcitic marble.

GH-2 SW¼ SW¼ sec. 33, T. 6 S., R. 4 W. Talc pods (5 cm maximum length) in calcitic marble adjacent to shear zone approximately 1 m thick. Prospect tunnel in malachite-stained marble along shear zone.

GH-3 NE¼ NW¼ sec. 4, T. 7 S., R. 4 W. Coarse-grained silvery talc in one piece of dolomitic marble.

GH-4 SE¼ NE¼ sec. 5, T. 7 S., R. 4 W. Minor coarse-grained silvery talc in marble. Also one piece of float found that contains minor green talc.

GH-5 NE¼ NE¼ sec. 8, T. 7 S., R. 4 W. Coarse-grained silvery talc and chlorite in one piece of marble float, which also contains graphite.

East of the Ruby River and north of Idaho Creek

Although the large exposures of marble north of Barton Gulch and near the mouth of Idaho Creek were examined specifically for talc, the only talc found in the area is north of Davey Creek.

GH-6 SE¼ SW¼ sec. 35, T. 6 S., R. 4 W. Several small fragments of fine-grained talc in soil.

GH-7 SW¼ SE¼ sec. 35, T. 6 S., R. 4 W. Several small fragments of fine-grained talc in soil. No outcrop, but concentration of marble float here.

GH-8 SW¼ NE¼ sec. 2, T. 7 S., R. 4 W. A few small fragments of fine-grained talc in soil.

GH-9 SW¼ NW¼ sec. 1, T. 7 S., R. 4 W. One fragment of fine-grained talc in soil.

GH-10 NW¼ SW¼ sec. 1, T. 7 S., R. 4 W. Several pieces of marble float that contain silvery, coarse-grained talc.

Between Idaho Creek and the North Fork of Greenhorn Creek

GH-11 SE¼ NE¼ sec. 6, T. 8 S., R. 3 W. Fine-grained talc veinlet about 8 mm thick.

GH-12 SE¼ SW¼ sec. 6, T. 8 S., R. 3 W. Minor fine-grained talc in outcrop.

GH-13 NE¼ NW¼ sec. 7, T. 8 S., R. 3 W. Minor talc in float.

GH-14 SE¼ NW¼ sec. 7, T. 8 S., R. 3 W. Minor fine-grained talc in float.

GH-15 SW¼ NE¼ sec. 7, T. 8 S., R. 3 W. Small (1 to 2 mm) blebs of white to light-green talc in outcrop.

GH-16 SW¼ NE¼ sec. 7, T. 8 S., R. 3 W. Marble float contains veinlets and pods of fine-grained talc. Talc float concentrated in an area 2 by 3 m.

GH-17 SW¼ NE¼ sec. 7, T. 8 S., R. 3 W. Trace of talc float below outcrop.

GH-18 NW¼ NE¼ sec. 7, T. 8 S., R. 3 W. Minor talc in float.

GH-19 NW¼ NE¼ sec. 7, T. 8 S., R. 3 W. Abundant talc veinlets in outcrop of intensely deformed marble. Talc constitutes approximately 10 percent of the outcrop, which is 3 by 10 m.

GH-20 NW¼ NE¼ sec. 7, T. 8 S., R. 3 W. Trace of talc in soil.

GH-21 SW¼ NW¼ sec. 11, T. 8 S., R. 4 W. Very small (less than 1 cm) chips of fine-grained talc in soil found for 200 m in a north-south traverse.

GH-22 NW¼ SW¼ sec. 11, T. 8 S., R. 4 W. Minor fine-grained talc in soil.

GH-23 SE¼ NW¼ sec. 11, T. 8 S., R. 4 W. Minor fine-grained talc in soil here and between 22 and 23.

GH-24 SW¼ NE¼ sec. 11, T. 8 S., R. 4 W. Trace of fine-grained talc in soil.

GH-25 SE¼ SE¼ sec. 11, T. 8 S., R. 4 W. One small fragment of talc in soil.

GH-26 NW¼ NE¼ sec. 14, T. 8 S., R. 4 W. Trace of talc in outcrop of marble.

GH-27 NW¼ NE¼ sec. 14, T. 8 S., R. 4 W. Several small fragments of talc in soil.

GH-28 Ruby claims

Location: NE¼ NW¼ sec. 14, T. 8 S., R. 4 W., Madison County. Ruby Dam 7½-minute quadrangle. Approximately 14 miles (22 km) south of Alder.

Accessibility: The claims can be reached by taking a road that branches to the south from the Jasmine Creek road. This is the only road that branches to the south from the Jasmine Creek road east of the point where the road enters the timber and begins to ascend.

Ownership: Ruby No. 1 and Ruby No. 2 claims were located by Sam Maloney of Alder, Montana.

Description: A diabase dike, presumably of Precambrian age, intruded dolomitic marble at this prospect **(fig. 12)**. The relations here illustrate well the effect of the composition of the host rock on the final alteration product. Light-tan to gray chlorite was produced by alteration of the more aluminous diabase, whereas white talc was produced from the alumina-poor marble.

Exposures are sparse at this prospect, which is mainly within the timber, and without the benefit of shallow cuts; the geology of the occurrence would be very difficult to decipher. Talc and chlorite are exposed only in the cuts. On the basis of the chlorite exposed in cuts made across the dike, it can be inferred that alteration of the diabase was locally of sufficient intensity to completely replace the diabase by chlorite, but in other places along the dike only pods and irregular veinlets of chlorite were produced. Petrographic examination of the fresher diabase shows some alteration of the plagioclase to sericite in addition to secondary chlorite, epidote and actinolite.

A photomicrograph **(Plate 1)** shows the relict ophitic texture characteristic of some of the chlo-

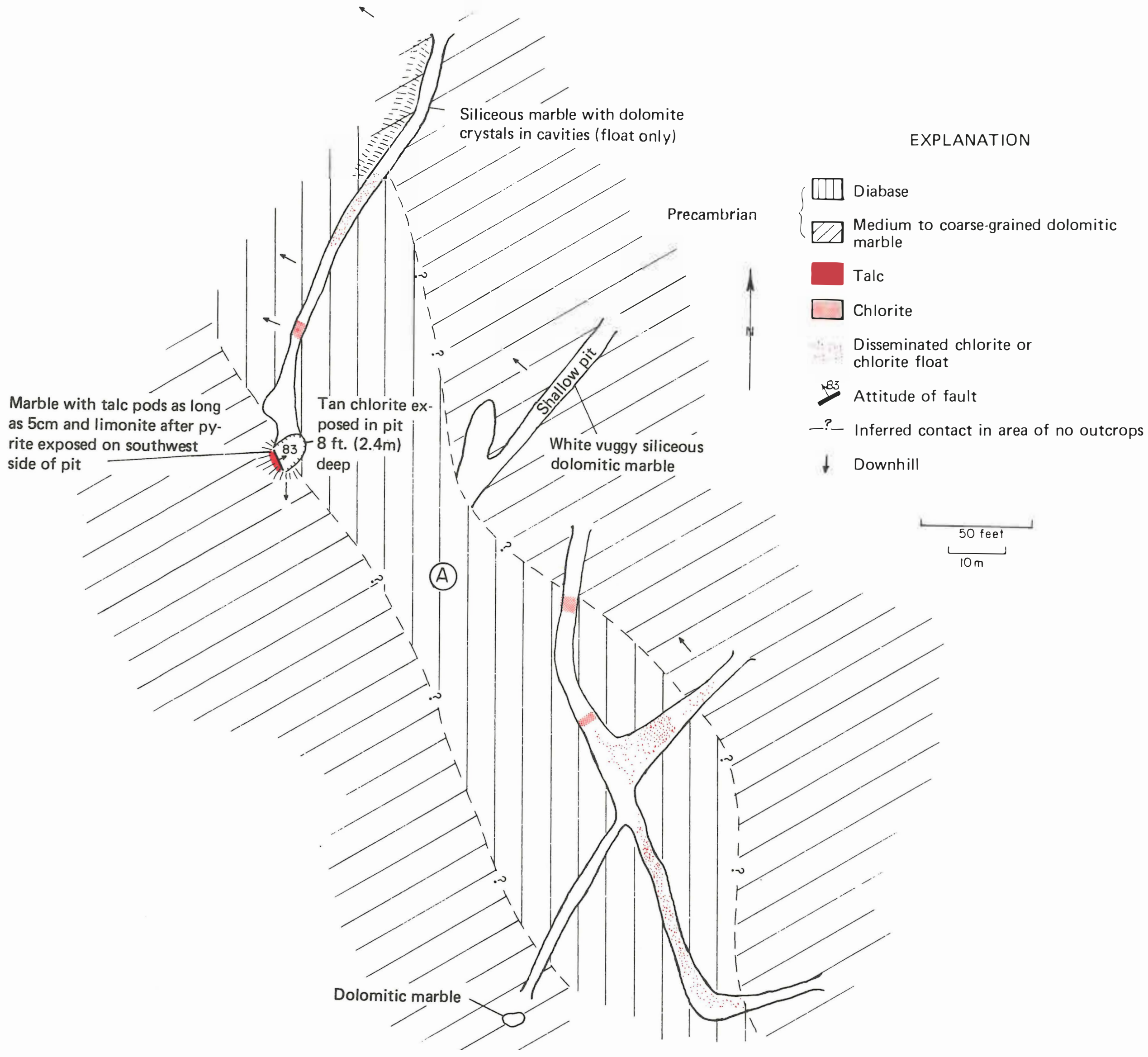


Figure 12—Ruby claims, Greenhorn Range (R. B. Berg, September 1976). Most of the chlorite north of A is tan and most of the chlorite south of A is yellowish green.

rite. The clear relict plagioclase laths, now completely replaced by the chlorite, are surrounded by chlorite that contains many small rutile grains. Presumably the chlorite could not accept all of the titanium originally present in the pyroxene of the diabase and thus rutile was formed. **Table 3** gives a chemical analysis of chlorite from this prospect.

Talcose dolomitic marble and minor talc are exposed in the large prospect pit on the southwest side of the dike. No other talc was found in the marble adjacent to the dike.

GH-29 SW¼ NW¼ sec. 14, T. 8 S., R. 4 W. Sheared and altered marble exposed in shallow cut. Trace of coarse-grained silvery talc in marble.

GH-30 Doubtful claim

Location: NW¼ SW¼ sec. 14, T. 8 S., R. 4 W., Madison County. Ruby Dam 7½-minute quadrangle. Approximately 14 miles (22 km) south of Alder.

Accessibility: The claim can be reached by ranch roads not shown on the topographic map. It can also be approached within 1 mile from a road that branches north from the North Fork of Greenhorn Creek, in sec. 26, T. 8 S., R. 4 W. This junction is not shown correctly on the topographic map because changes have been made in the road since the map was made.

Ownership: Sam Maloney, Alder, Montana.

Description: Unusually soft, limonite-stained talc has been dug from a small pit just below limonite-stained silicified marble exposed in the northern cut **(fig. 13)**. The body of talc was concealed by loose rock, but it is probably no more than 1 by 2 meters in horizontal dimension. A specimen of talc consists of clasts 1 mm across of fine-grained talc (grain size 4 μm) surrounded by coarser-grained talc (grain size 30 to 150 μm). This texture suggests that brecciation followed the formation of fine-grained talc and provided fractures in which coarser-grained talc was deposited. This brecciated talc, although not common, is seen in many of the talc deposits in southwestern Montana. A layer of chlorite containing blue apatite is poorly exposed in the southern cut. Microscopic examination of a sample from the southern cut shows that it consists of chlorite containing trace concentrations of apatite, sphene, zoisite, zircon and talc(?). Veinlets of chlorite 1 to 10 cm thick are exposed in small pits dug in the knob above the talc pod. Talc mineralization is confined to the one pod.

GH-31 NW¼ SE¼ sec. 14, T. 8 S., R. 4 W. Trace of talc in soil.

GH-32 SW¼ SE¼ sec. 14, T. 8 S., R. 4 W. Minor concentration of talc in float.

GH-33 NE¼ SW¼ sec. 13, T. 8 S., R. 4 W. Small blebs of talc in some of the marble float.

GH-34 SW¼ SW¼ sec. 13, T. 8 S., R. 4 W. Minor talc in soil.

GH-35 SW¼ SW¼ sec. 13, T. 8 S., R. 4 W. Minor talc in soil here and between 34 and 35.

GH-36 SE¼ SW¼ sec. 13, T. 8 S., R. 4 W. Trace of talc in soil.

GH-37 NW¼ NE¼ sec. 23, T. 8 S., R. 4 W. Talc pod 2 by 10 cm in outcrop; talc float in soil.

GH-38 SE¼ NW¼ sec. 23, T. 8 S., R. 4 W. Minor talc in two marble layers each approximately 4 inches (10 cm) thick, exposed in a shallow prospect pit. Prehnite and chlorite have been identified from this prospect.

GH-39 SE¼ NE¼ sec. 23, T. 8 S., R. 4 W. Minor talc along two shear zones exposed in shallow cut.

GH-40 SE¼ NE¼ sec. 23, T. 8 S., R. 4 W. Dark-green talc poorly exposed for a distance of 45 feet (15 m) in cut, which trends N. 25° W. Another cut on the ridge to the east trends N. 75° W. and exposes fragments of dark-green talc in the marble saprolite for approximately 50 feet (16 m). Loose blocks of massive white quartz contain small talc pods. Most of the talc from this prospect is a dark-green variety, probably chloritic.

Area south of the North Fork of Greenhorn Creek

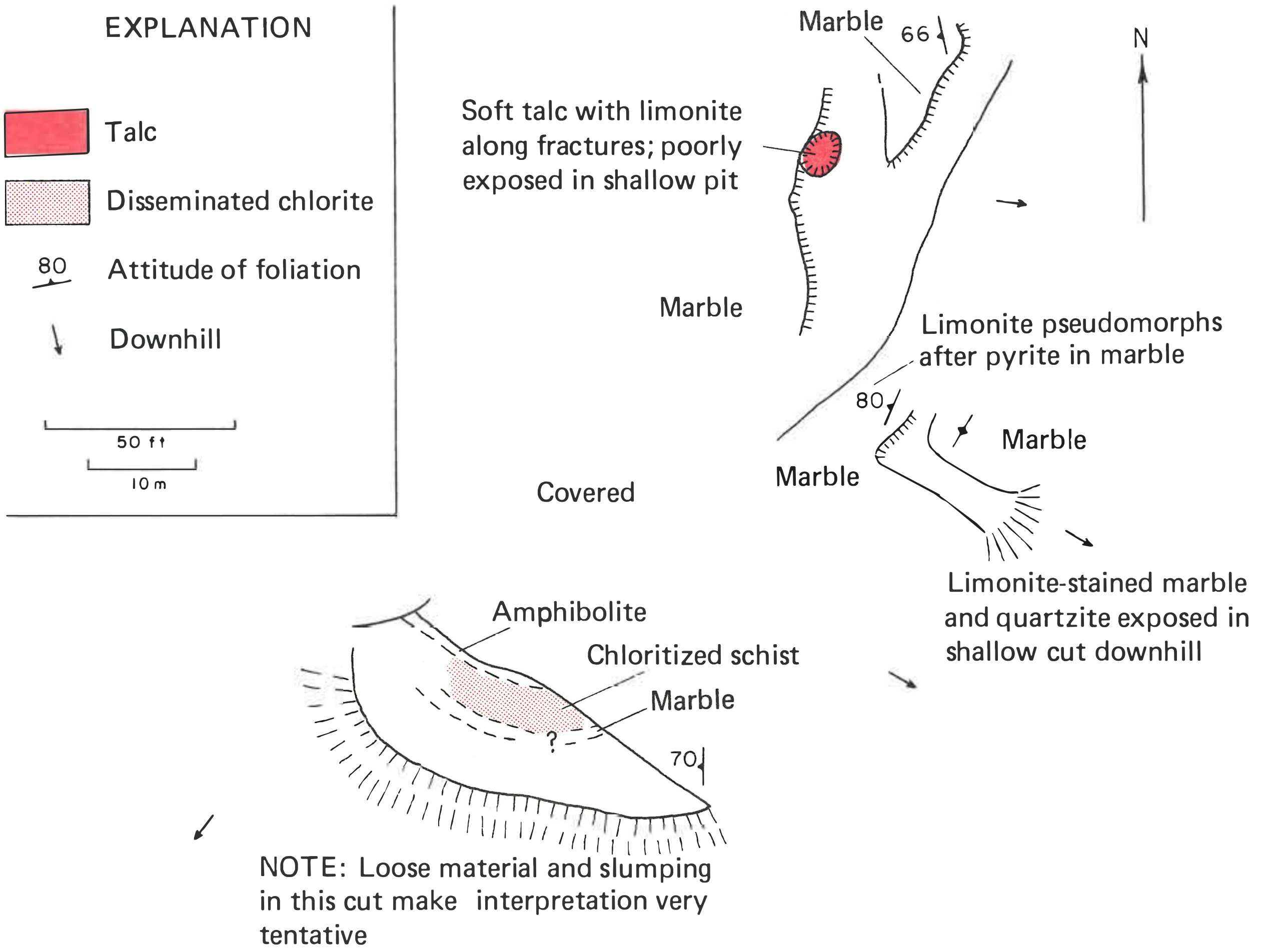
Several talc prospects are present in this area in addition to the Willow Creek talc mine.

GH-41 GREENHORN CLAIMS

Location: SW¼ NW¼ sec. 30, T. 8 S., R. 3 W., Madison County. Home Park Ranch 7½-minute quadrangle. Approximately 16 miles (26 km) southeast of Alder.

Accessibility: A bulldozer trail leads from the haul road for the Willow Creek mine to these cuts, which are approximately 1,400 feet (430 m) west of the point where the haul road turns northeast at an altitude of approximately 7,160 feet (2,183 m). This haul road is not shown on the topographic map.

Ownership: Mr. and Mrs. Carl Hafer, Sr., Butte, Montana.



NOTE: Loose material and slumping in this cut make interpretation very tentative

Figure 13—Doubtful claim, Greenhorn Range (R. B. Berg and L. Swanson, June 1976).

Description: Sheared and contorted talcose marble and graphite schist are exposed in the deepest part of the cuts, but pods of pure talc are not exposed. Because of a lack of exposures uphill and to the south of the area shown in **Figure 14**, the areal extent of the body of marble can only be approximately inferred, but the body is not a continuation of the talc-bearing marble at the Willow Creek mine; the two marble bodies are separated by a large area of calcitic marble **(fig. 15)**.

GH-42 Willow Creek mine (Ruby Ridge mine)

Location: NE¼ sec. 30, T. 8 S., R. 3 W., Madison County. Home Park Ranch 7½-minute quadrangle. Approximately 16 miles (26 km) southeast of Alder.

Accessibility: The sorting yard is adjacent to the Willow Creek road, and the haul road to the talc mine goes through the sorting yard.

Ownership: The mine is owned by the Madison Minerals Corporation, Butte, Montana, and is operated by Resource Processors.

Description: Although a small amount of talc was mined underground many years ago, the only significant production has been that by Resource Processors between 1970 and 1979. Mining ceased in June 1979. Talc ore is hauled to the sorting yard and after sorting is trucked to Alder for rail shipment.

The mine is situated within a small body of marble, which is surrounded by quartzofeldspathic gneiss **(fig. 15)**. Pre-Belt metamorphic rocks have been thrust over Paleozoic formations, which are exposed north and east of the mine. Because of poor exposures the position of this fault north of the Willow Creek mine is only approximately known. In the mine, metamorphic units strike con-

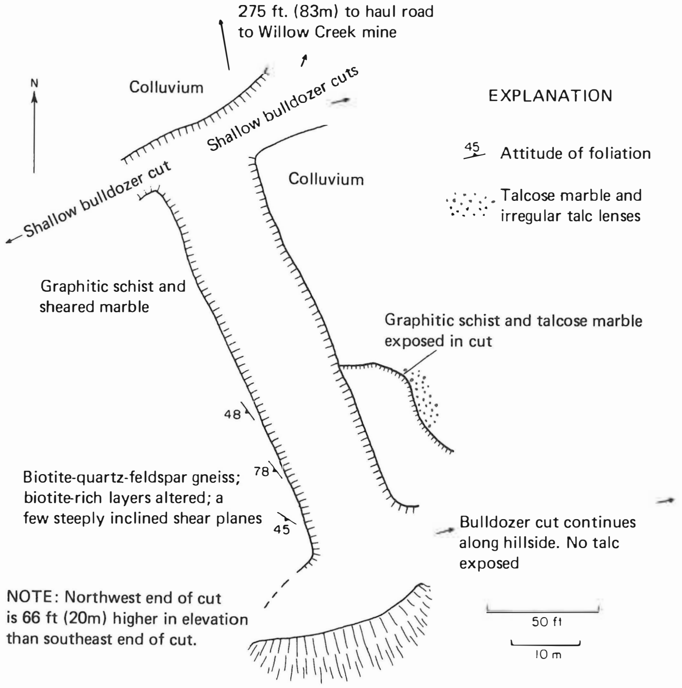


Figure 14—Greenhorn claims, Greenhorn Range (R. B. Berg and L. Swanson, July 1976).

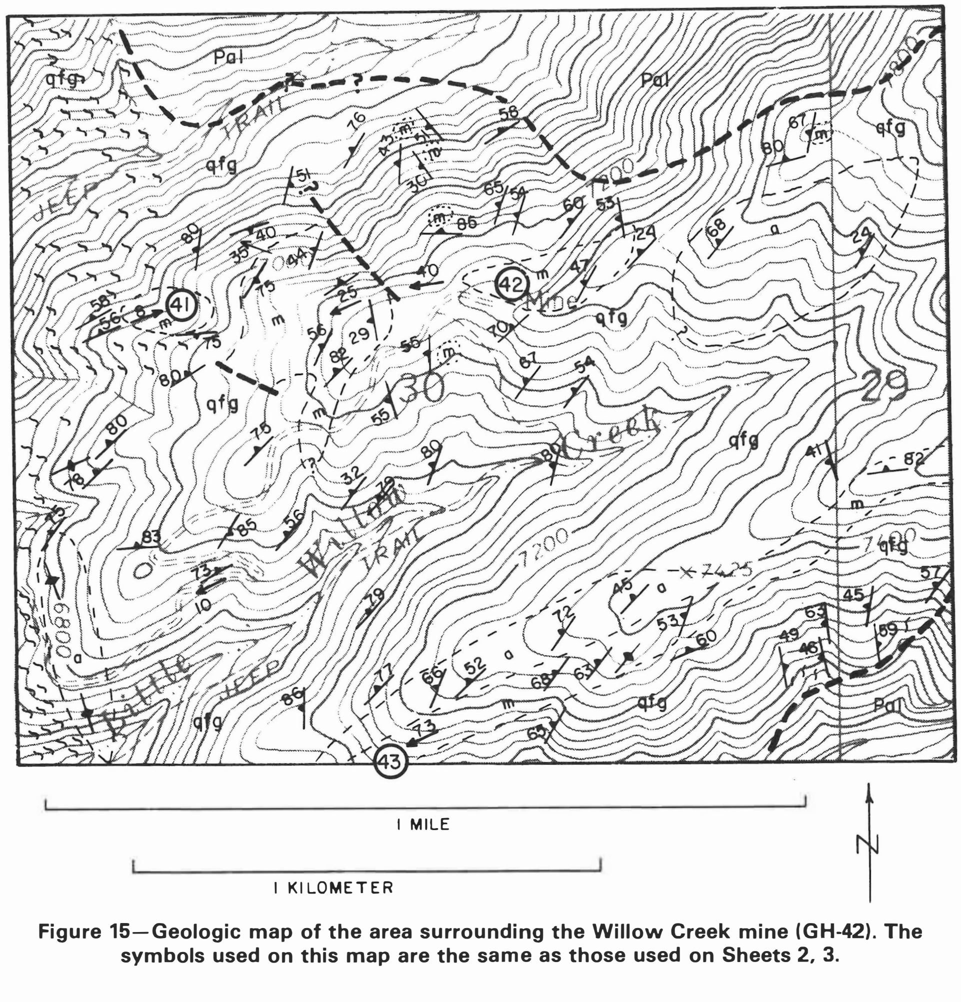


Figure 15—Geologic map of the area surrounding the Willow Creek mine (GH-42). The symbols used on this map are the same as those used on Sheets 2, 3.

sistently northeast and dip 40 to 70° NW. There is greater variation in the attitude of foliation north of the mine where outcrops are scarce on the heavily timbered north-facing slope. Shear planes cutting talc, chlorite and country rock are abundant at the mine. The large isolated body of calcitic marble west of the mine is barren of talc.

Figure 16 is a diagrammatic cross section through the Willow Creek ore body and shows the relationship between talc and associated rock types. The effect of post-talc faulting is not shown on this simplified cross section. The hanging wall of the deposit is biotite-quartz-feldspar gneiss, which has been altered to varying extent, the ultimate alteration product being chlorite. The first effect of the alteration was the replacement of biotite by chlorite. Further alteration resulted in the sericitization of the feldspar, and more intense alteration produced a rock that consists of chlorite and quartz. The final stage in the alteration sequence was dark-greenish-gray chlorite. A chemical analysis of a typical specimen of the chlorite is given in **Table 3**. Grain size of the chlorite varies considerably within the area of one thin section, for example from 10 to 150 μm. The chlorite contains rare local concentrations of idiomorphic zircon and idiomorphic crystals of apatite. On the basis of $\epsilon = 1.6353 \pm 0.0005$ and $\omega = 1.6397 \pm 0.0005$, one specimen of apatite is estimated to be approximately 76 percent fluorapatite, 12 percent hydroxyapatite and 12 percent chlorapatite. Some large flakes of silvery chlorite a centimeter across presumably have been formed by the replacement of coarse-grained biotite in the quartzofeldspathic gneiss. Rutile needles occur in some of the coarse-grained chlorite. Some specimens of chlorite are cut by many veinlets of talc a few millimeters to a centimeter in thickness. Most specimens of chlorite contain talc in sufficient concentration to be detected by x-ray diffraction analysis.

The alteration that produced chlorite from the biotite-quartz-feldspar gneiss also resulted in the formation of talc from the subjacent dolomitic marble. Large blocks of marble have been completely replaced by fine-grained white to pale-green talc. Some of the talc is medium green, colored by small grains of dark-green chlorite.

Most of the talc is very fine grained, some grains are less than 2 μm across, but even within a specimen of fine-grained material there are patches of coarser-grained feathery talc in which individual grains are 1 mm long. Talc pseudomorphs after tremolite blades are observed in one specimen. Veins of white quartz are rare in both the talc and the chlorite. Clasts of green chlorite 1 cm across in one specimen from a quartz vein are rimmed by a layer of talc about 1 mm thick. Perhaps talc formed by reaction of chlorite with silica-rich solutions, which added the necessary silica to make chlorite from talc and removed the alumina left over from that reaction.

Dolomitic marble on the footwall side of the ore body contains many small veinlets and pods of talc. The abundance of talc in this marble decreases to the southeast away from the ore body. Calcitic marble that contains abundant forsterite, mainly in grains smaller than 5 mm across, is exposed on the ridge just south of the mine. Some porphyroblasts of brown forsterite are several centimeters across, and a few of these are cut by chrysotile veinlets. Serpentine was also observed in thin sections of both the calcitic marble and the dolomitic marble. The serpentine occurs in small blebs, which may have formed by the complete re-

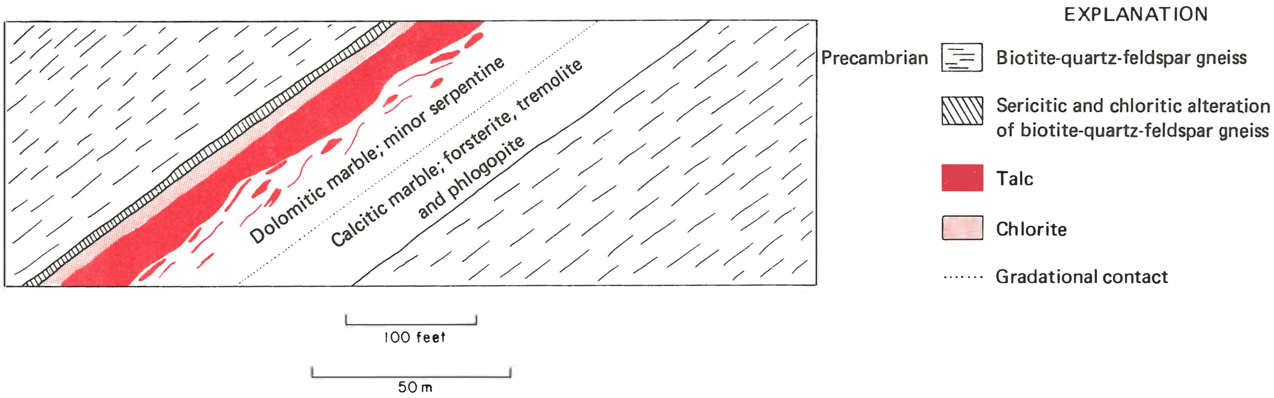


Figure 16—Diagrammatic cross section of the talc deposit at the Willow Creek mine showing the probable relationship between talc and host rock before post-talc faulting.

placement of forsterite. Phlogopite and tremolite also occur in the calcitic marble. Tremolite is typically gray to black because of abundant included graphite, and is concentrated in almost monomineralic layers a centimeter or two in thickness. No talc was identified either optically or by x-ray diffraction analysis from the calcitic marble. Sepiolite has been identified from this locality (Alice Blount, personal communication, 1977).

GH-43 Claims north of Willow Creek (Adam and Eve No. 1 and No. 2)

Location: SW¼ SE¼ sec. 30, T. 8 S., R. 3 W., Madison County. Home Park Ranch 7½-minute quadrangle. Approximately 16 miles (26 km) southeast of Alder.

Accessibility: The road to the prospect branches from the haul road for the Willow Creek mine at a sharp switchback above Little Willow Creek at an altitude of 6,920 feet (2,110 m). The haul road for the Willow Creek mine joins the Willow Creek road at the site of the talc-sorting plant.

Ownership: Sam and Goldie Maloney of Alder, Montana.

Description: Marble, quartzofeldspathic gneiss and sillimanite-biotite-garnet schist are exposed in six prospect cuts, all of which trend nearly perpendicular to lithologic layering of the metamorphic units. Marble is exposed in all but the highest cut, which is 240 feet (73 m) higher than the lowest cut. Talc pods less than 5 cm long and talc veinlets 3 to 4 cm thick, parallel to compositional layering of the marble, are exposed in the lower four cuts. Talc chips are found in the soil between the cuts in the area underlain by marble and also in a small area just east of the cuts. Although there is no large concentration of these chips, they were found in the soil over an area of approximately 300 by 1,500 feet (100 by 500 m).

Masses of sepiolite as long as 10 cm were found in the lowest cut. The sepiolite resembles splintered wood that has weathered grayish tan. A few thin chrysotile veinlets 2 mm thick occur in calcitic-marble.

GH-44 SW¼ NW¼ sec. 31, T. 8 S., R. 3 W. A trace of talc was found in the bottom of a prospect trench, which exposes marble for a distance of 45 feet (15 m).

GH-45 Talc occurrence south of Virginia City

Location: NW¼ NW¼ sec. 23, T. 7 S., R. 3 W., Madison County. Varney 15-minute quadrangle. Approximately 5 miles (8 km) south of Virginia City.

Accessibility: This area is 100 feet (33 m) south of the road between Barton Gulch and Alder Gulch where this road descends into Alder Gulch.

Ownership: Not known.

Description: A nearly vertical quartz vein 1 to 3 feet (0.3 to 1 m) thick separates quartzofeldspathic gneiss from calcitic marble. Foliation in the marble is parallel to the vein. Adjacent to the quartz vein the marble contains talc, tremolite and a trace of vermiculite. The bright-green vermiculite grains are less than 5 mm across and have presumably been produced by alteration of phlogopite. The bright green color suggests that this vermiculite is nickel bearing.

GH-46 Calverts claims

Location: SW¼ SE¼ sec. 32, T. 7 S., R. 3 W., Madison County. Varney 15-minute quadrangle. Approximately 8 miles (13 km) southwest of Virginia City.

Accessibility: The claims may be reached by following the Idaho Creek road to its end in the NW¼ of sec. 33. From that point the road to the claims is unimproved and steep in some places.

Ownership: The Calverts No. 1 through No. 4 claims were located by Frank Ludwick and Jim Ludwick (Alder, Montana), Jim Eby (Billings, Montana), and Carl Hafer, Sr. (Butte, Montana).

Description: A dolomitic marble layer with an exposed width of approximately 250 feet (76 m) strikes northeast and dips northwest **(fig. 17)**. Amphibolite lies northwest of the marble, and amphibolite and quartzofeldspathic gneiss lie to the southeast. Irregular veinlets and pods of talc, most of which are less than 10 cm thick, are exposed in all but the easternmost cut. Talc is most abundant in the largest cut, where a small amount of waxy green chlorite is also exposed. Because the chlorite is intermingled with the talc and there is no evidence of replacement of quartzofeldspathic gneiss, it is concluded that both the talc and the chlorite formed by alteration of dolomitic marble. Tremolite is found scattered throughout much of the marble, and in the westernmost cut, tremolite layers 3 to 5 cm thick have been replaced by talc.

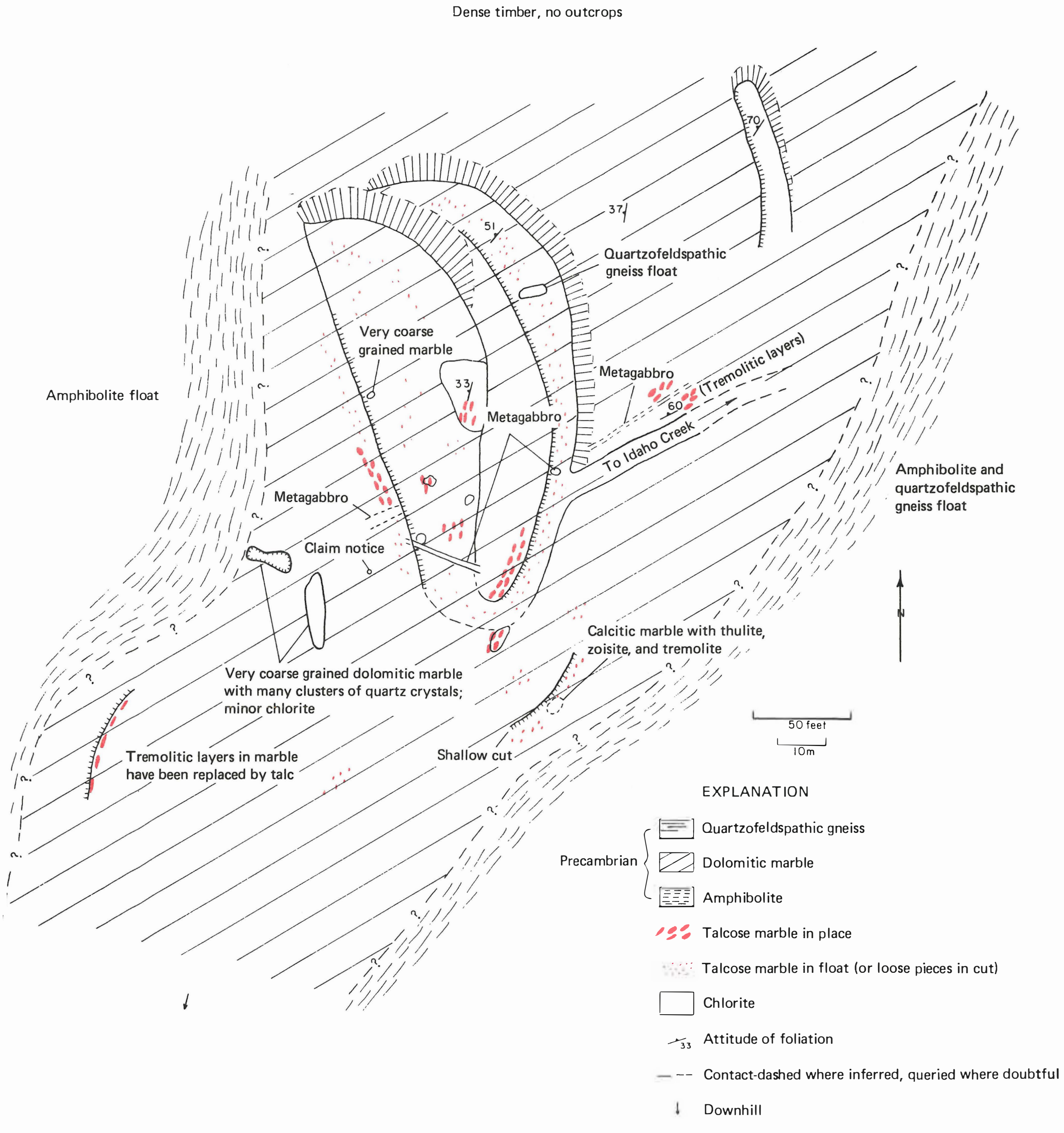


Figure 17—Calverts claims, Greenhorn Range (R. B. Berg, September 1977).

Very coarse-grained dolomitic marble containing clusters of quartz crystals is exposed west of the claim notice. Some individual dolomite crystals are 8 cm across. Minor green chlorite (but no talc) occurs in this rock.

Thulite (pink) and zoisite (white) occur at several places on these claims but are most abundant in the shallow cut in the southern part of the area, where some zoisite crystals are 5 mm across. Minor tremolite and diopside occur in the calcitic-marble that contains the thulite and zoisite.

Other prospects and inactive mines

Several prospects and inactive mines presumably excavated for metals were encountered during the mapping in the Greenhorn Range and are listed below. Most of these are in shear zones within the quartzofeldspathic gneiss. In addition to these workings there are many shallow prospect pits, also mainly in shear zones in the quartzofeldspathic gneiss.

NW¼ SE¼ sec. 5, T. 7 S., R. 4 W. Vertical shaft at least 30 feet (10 m) deep into sheared quartzofeldspathic gneiss and some malachite on dump.

SE¼ SE¼ sec. 3, T. 7 S., R. 4 W. Several prospect cuts and an adit (caved) in the marble. The only evidence of mineralization recognized was black manganese minerals in the cut at the adit. Fault surfaces are prominent in that cut.

NW¼ SE¼ sec. 14, T. 7 S., R. 4 W. Two caved adits and a prospect pit in a steeply inclined shear zone in schist and quartzofeldspathic gneiss.

NW¼ SE¼ sec. 13, T. 7 S., R. 4 W. Prospect pits in sheared biotite schist. Sheared and limonite-stained quartzofeldspathic gneiss is present in this area.

NW¼ NE¼ sec. 19, T. 7 S., R. 3 W. Bull Frog mine. An adit extends at least 36 feet (12 m) into the hill. Sheared rock of the amphibolite assemblage and minor calcitic marble are on the dump. A second adit (caved) is several hundred feet uphill. Schist is predominant on the dump and contains traces of chalcopyrite.

Sec. 16, 17, 21, T. 7 S., R. 4 W. Barton Gulch. The lower part of Barton Gulch, within 1 mile of its mouth, has been dredged for gold. More recently mineral collectors have recovered garnets from the gravel at the mouth of Barton Gulch. Many of these garnets have weathered out of the Tertiary sediments.

SW¼ SW¼ sec. 26, T. 7 S., R. 4 W. Prospect pits have been dug in sheared quartzofeldspathic gneiss, reportedly in search for uranium.

SE¼ SW¼ sec. 12, T. 8 S., R. 4 W. Silver Bell claim. Three adits are in sheared and limonite-stained quartzofeldspathic gneiss. Two of the adits extend approximately 20 feet (7 m) into the hillside, and the third adit goes straight in for approximately 50 feet (17 m) and then curves. Malachite and minor chalcocite were found on the dump.

SE¼ SW¼ sec. 24, T. 8 S., R. 4 W. Adit extends approximately 80 feet (27 m) into hillside. The adit is in a sheared ultramafic body, which contains minor chalcopyrite and malachite. Sillimanite schist and altered quartzofeldspathic gneiss, in addition to sheared ultramafic rock, are found on the dump.

SE¼ SE¼ sec. 25, T. 8 S., R. 4 W. Cuts above a caved adit expose intensely sheared rock over an area approximately 50 feet (17 m) high by 150 feet (50 m) long. Quartzofeldspathic gneiss, pegmatite and amphibolite are all present in this zone of shearing. Minor malachite coats some fractures. The shaft shown on the topographic map is now filled.

Gravelly Range

The Gravelly Range lies along the east limb of a large syncline that plunges to the southwest. The outcrops of pre-Belt metamorphic rocks of the Greenhorn Range on the west limb of the syncline are separated from those of the Gravelly Range by outcrops of Paleozoic and Mesozoic sedimentary rocks. Pre-Belt metamorphic rocks are exposed in a north-south belt along the east front of the Gravelly Range and are covered by Quaternary alluvium in the Madison Valley farther to the east. In the southern part of the range, Tertiary volcanic rocks cover the pre-Belt rocks and separate the area of exposed pre-Belt rocks in the Gravelly Range from exposures of pre-Belt rocks in the Henrys Lake Mountains.

The geology of the northern part of the Gravelly Range has been mapped by Hadley (1969a, 1969b), and Heinrich and Rabbitt (1960) have mapped and studied the geology of a part of this same area. Information on the pre-Belt rocks of the southern part of the range is much less complete. A map by Wier (1965) shows the geology of an area of approximately 18 square miles (47 square km) surrounding the Black Butte iron deposit in T. 11 S., R. 1 W. Mann (1954) described the geology of a large part of the Gravelly Range but concentrated on the Phanerozoic rocks and did not describe the pre-Belt rocks in detail.

Metasedimentary rocks are exposed in the northern part of the range, and it was in the area between Wigwam Creek and Cherry Creek that Peale (1896, p. 2) originally described what he called the Cherry Creek beds, more recently designated the Cherry Creek Group. The Cherry Creek Group and the terminology of the pre-Belt rocks are discussed in the section on pre-Belt geology of southwestern Montana.

There is much variety in the metamorphic rocks of this range, particularly in that part of the sequence that is clearly metasedimentary. Pre-Belt rock types recognized are quartzofeldspathic gneiss, amphibolite, hornblende gneiss, dolomitic marble, quartzite, banded quartz-magnetite iron formation, phyllite, schist and metadiorite. The schist can be separated into mica, sillimanite, kyanite, kyanite-staurolite, andalusite and staurolite-andalusite varieties.

Greenschist-facies metamorphic rocks are exposed in a segment of the Gravelly Range approximately 7.5 miles (12 km) long, which includes the Yellowstone talc mine. In this area fine-grained marble and phyllite are exposed rather than the coarse-grained marble and schist typical of pre-Belt rocks in the Ruby Range, Greenhorn Range and Tobacco Root Mountains. A very detailed study of the petrology of these rocks (Millholland, 1976) showed that the transition from low-grade to higher-grade metamorphic rocks is abrupt and that the low-grade assemblage is not retrograde (Millholland, 1976). Approximately 10 miles (16 km) south of the Yellowstone mine there is another transition zone from amphibolite-facies rocks on the north side of Horse Creek to greenschist-facies rocks on the south side (Jahn, 1967). Jahn dated biotite and muscovite from rocks across this transition zone and found that biotite from the rocks north of Horse Creek gave a K-Ar age of 1.6 b.y., whereas the biotite from rocks south of the transition gave an age of 2.6 b.y. Both Millholland and Jahn mentioned evidence of cataclasis in some of the rocks of their respective areas. Perhaps these abrupt changes in metamorphic grade can be explained by Precambrian faulting that juxtaposed rocks of different metamorphic grade. The pre-Belt metamorphic rocks exposed farther south in the Henrys Lake Mountains are of greenschist facies.

What may be the greatest concentration of talc in Montana is in the dolomitic marble of the Gravelly Range at the Yellowstone mine and vicinity. The deposit of talc at the Yellowstone mine and the surrounding occurrences are within a thick sequence of marble, which is probably made up of thinner layers that have been isoclinally folded. The known talc occurrences at this locality are limited to the southeastern half of the area underlain by marble.

GR-1 Tait Mountain claims

Location: S½ sec. 5, T. 8 S., R. 1 W., Madison County. Varney and Cameron 15-minute quadrangles. Approximately 12 miles (20 km) south of Ennis.

Accessibility: The claims can be reached from a ranch road that branches from the road along the west side of the Madison River in sec. 32, T. 8 S., R. 1 W.

Ownership: Pete Womack, Ennis, Montana.

Description: Chlorite and talc are exposed in two areas about 400 feet (130 m) apart separated by a shallow saddle in which no bedrock is exposed **(figs. 18, 19)**. The northern area has been more extensively explored by seven trenches, and chlorite is exposed in all trenches. It is likely that at least some of the chlorite, that exposed in the westernmost cut, has been produced by the alteration of pegmatite. In other prospects in southwestern Montana there is clear evidence that chlorite

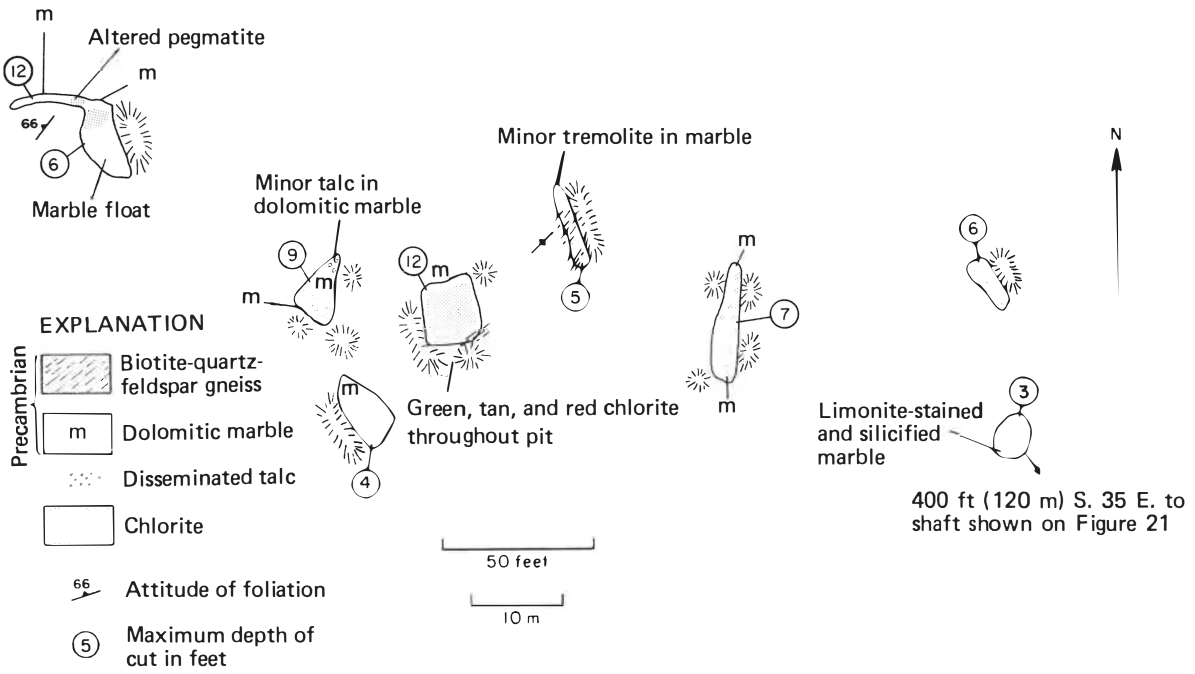


Figure 18—Tait Mountain claims (northern part), Gravelly Range (R. B. Berg, September 1976).

has been formed by alteration of quartzofeldspathic gneiss (for example, see the description of the Golden Antler mine). At the Tait Mountain prospect, with the exception of the altered pegmatite, the lithology of the rock that has been replaced by chlorite is not clear. A heavy-liquid separation was made on two specimens of chlorite in an effort to separate zircons from the chlorite. No zircons were recovered, suggesting that the chlorite replaced a zircon-free rock, presumably impure dolomitic marble. At other localities zircons can be recognized in chlorite that on the basis of field relationships is presumed to have replaced quartzofeldspathic gneiss. Talc is exposed in only one excavation. The general lack of talc in the dolomitic marble exposed in these trenches is puzzling.

The chlorite in the northern area ranges from green to tan and is locally stained red by hematite along fractures. Talc is a trace constituent of the chlorite. Tremolite is a widespread trace constituent of the dolomitic marble and has been replaced by talc at some places.

Because of the slumping in the cuts and the lack of exposures between them, it was impossible to trace the contacts between cuts. Judging from folds in the marble exposed north and west of the cuts, it is likely that the marble in and near the cuts has been isoclinally folded. An old prospect pit in limonite-stained and silicified marble was probably dug in an effort to find a metalliferous vein rather than chlorite or talc.

In the southern area, better exposures make it possible to trace the contact of marble with quartzofeldspathic gneiss around a gentle fold. Tertiary freshwater limestone (Hadley, 1969a) overlies the marble and gneiss to the southwest. Crumbly green chlorite is exposed in a prospect trench along the contact between dolomitic marble and quartzofeldspathic gneiss that is in part pegmatitic. One of the chlorite specimens that was checked in vain for zircons was from this cut.

Minor tremolite and talc are scattered throughout the dolomitic marble exposed west of this cut. A 25-foot (8-m) shaft was sunk in talc at the north end of the area of marble exposures. The work was done prior to 1948 by Tri-State Minerals, but the shaft was abandoned because of the low grade of the talc and the small quantity present (Perry, 1948, p. 8). The talc on the dump is unusually coarse grained and is accompanied by abundant tremolite.

GR-2 Cherry Gulch prospect

Location: NE¼ SW¼ and NW¼ SE¼ sec. 31, T. 8 S., R. 1 W., Madison County. Varney 15-minute quadrangle. Approximately 18 miles (29 km) southwest of Ennis.

Accessibility: The claims are located just south of the Cherry Gulch road, which branches from the road along the west side of the Madison River. Both of these roads cross private land.

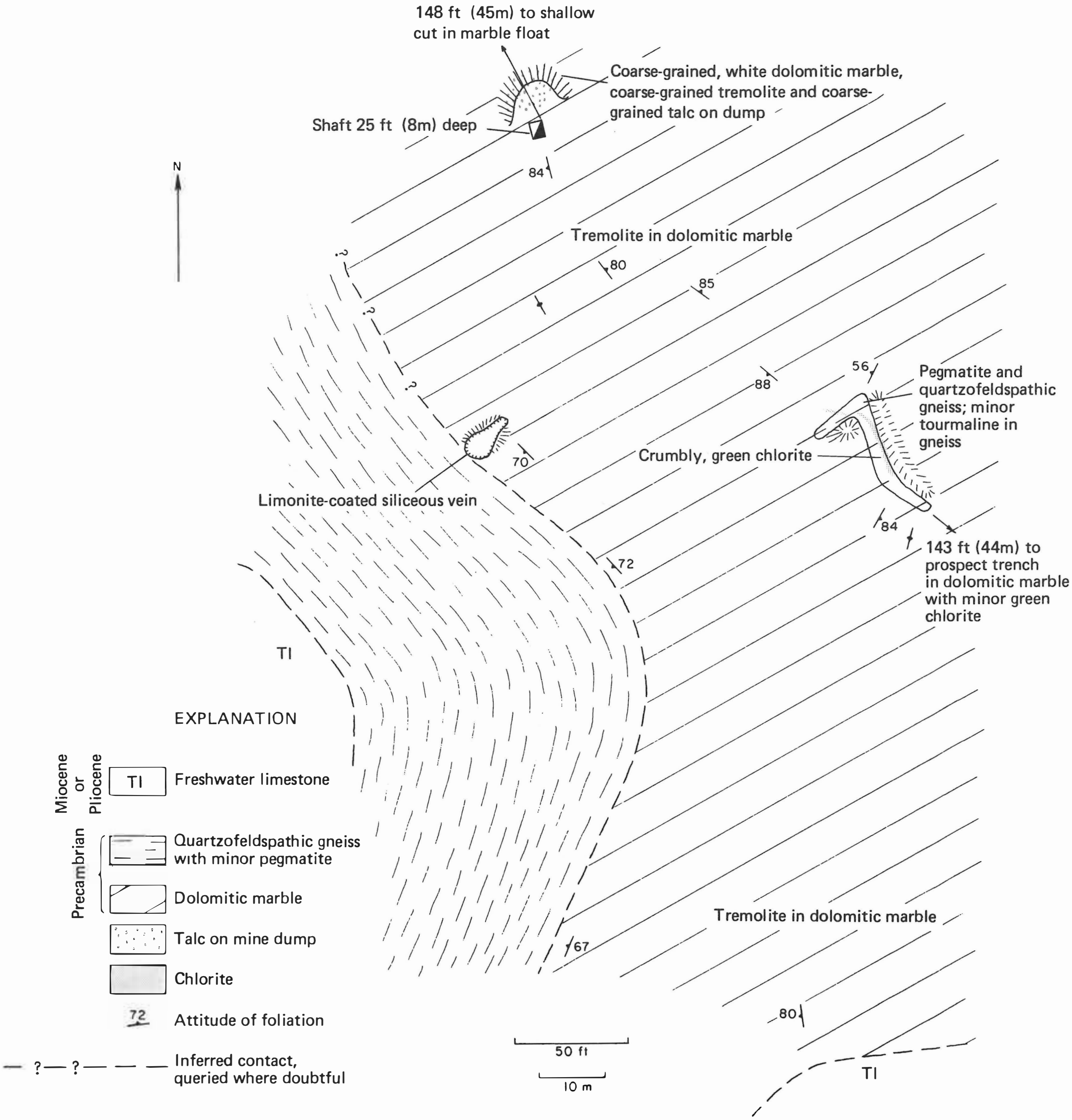


Figure 19—Tait Mountain claims (southern part), Gravelly Range (R. B. Berg, September 1976).

Ownership: A patented claim is owned by Albert Thexton, and adjacent claims are owned by Pete Womack, both of Ennis, Montana.

Description: Layering in the Precambrian metamorphic rock strikes northeast and is near vertical **(Sheet 1-D)**. The Flathead Quartzite (Cambrian) unconformably overlies the metamorphic rocks to the south (Hadley, 1969b, and **fig. 20**), and bentonite was encountered in prospect pits dug south and east of the talc occurrence. Two layers of medium-grained dolomitic marble are separated by a layer of staurolite schist in which many of the staurolite porphyroblasts are between 1 and 3 cm in length. Biotite-quartz-feldspar schist is exposed in the gully west of the talc, and a thin layer of quartzite is poorly exposed at the contact between dolomitic marble and staurolite schist. Chalcopyrite, malachite, and cuprite are exposed in a prospect trench cut in the quartzite. Blades of kyanite can be found in some of the white quartz float.

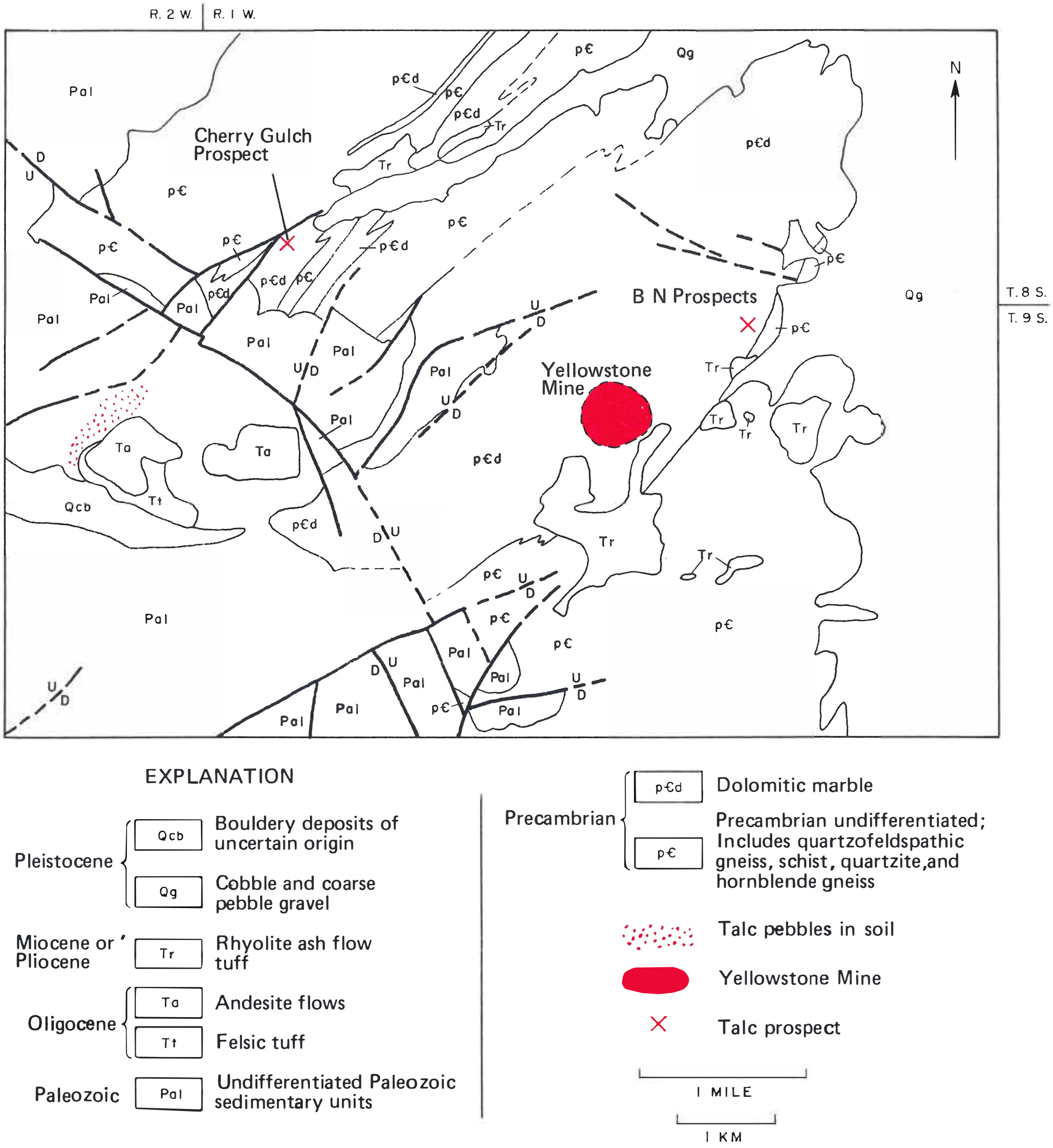


Figure 20—Generalized geologic map of the Cherry Gulch-Johnny Gulch area of the Gravelly Range. Geology from the more detailed geologic maps of the Varney and Cameron quadrangles by Hadley (1969a, 1969b).

An adit, which is now caved at the portal, may have been driven in search for copper. Some talc is scattered on the dump at this adit. Chalcopyrite and malachite are trace constituents of some of the talc exposed here.

A concordant layer of talc 1.5 to 2 feet (0.4 to 0.6 m) thick, some of which is lava talc, is exposed in two small pits on the east side of the small gully just west of the adit. These pits are situated along the south boundary of sec. 31, T. 8 S., R. 1 W., close to the unconformity between the Precambrian metamorphic rocks and Flathead Quartzite. An additional shallow exploration trench 25 feet (8 m) long exposed additional hard lava talc in the same layer of dolomitic marble.

Talc also is exposed in two shallow cuts in marble on the east side of the small gully just east of the area shown in **Sheet 1-D**. Concordant talc pods 2 to 4 inches (5 to 10 cm) thick are exposed in these cuts. Another poorly defined talcose zone 5 feet (1.5 m) thick is exposed in a small prospect pit north of these cuts toward Cherry Gulch. The chemical analysis of a specimen of unusually hard block talc from this pit is given in **Table 3**. The specimen contains irregular patches of small grains (4 μm) of an opaque mineral and a trace of apatite. Although there are some patches of relatively coarse-grained talc in the specimen, most of the talc grains are about 4 μm across. Some of the lava talc from this prospect has been selectively mined for the carving market.

The presence of bentonite in this small area surrounded by pre-Belt rocks is unusual. Presumably volcanic ash accumulated in a depression or a small pond along the ridge and subsequently was altered to bentonite. The bentonite may be equivalent in age to the Oligocene felsic tuff mapped by Hadley (1969b) 1.7 miles (2.7 km) to the southwest. The mineralogy of the sand-size fraction of this smectite clay shows that it is of volcanic origin and not a result of hydrothermal alteration of metamorphic rocks. Biotite, plagioclase, K-feldspar, quartz, zircon, partly devitrified glass, a zeolite and calcite were identified in the >325 mesh (>44 μm) fraction of six samples of bentonite. None of the pits within the area of the bentonite occurrence exposed bedrock under the bentonite, but the deepest pit is only 15 feet (4.5 m) deep.

GR-3 Yellowstone mine

Location: Sec. 4, T. 9 S., R. 1 W., Madison County. Cameron 15-minute quadrangle. Approximately 18 miles (29 km) south of Ennis.

Accessibility: The Johnny Gulch road is the haul road for the mine.

Ownership: Cyprus Industrial Minerals.

Description: The Yellowstone mine, which is one of the largest talc mines in the United States, is an important producer of high-purity talc. The following description of the geology of the mine is based mainly on the work done by James (1956) and to a lesser extent Perry (1948), Olson (1976) and the author's observations.

Talc occurs in fine-grained dolomitic marble forming pods and layers generally concordant to the layering (relict bedding?) in the marble. Many of the pods are less than 1 foot (0.3 m) thick and are offset along small shears that are similar to those shown in the sketch of a pit face on the Burlington Northern mine **(fig. 21)**. James (1956, p. 4) reported talc lenses 70 feet (21 m) or more in length and 35 feet (11 m) thick in the Johnny Gulch area but pointed out that most lenses are much smaller. Because of the small size of most talc bodies at the Yellowstone mine it is impractical to selectively mine pure talc and all of the ore is hand sorted. Talc is picked from waste at a sorter situated at the pit, and the higher-grade ore is sorted at the main facility at Johnny Gulch where the waste is removed from the talc. Ore that is of such low grade that it cannot be hand sorted is stockpiled and will undoubtedly be an important source of talc in the future.

Raw talc from this mine ranges in color from green through pale green and light gray to white. Unlike some of the other talc mines, the Yellowstone mine has no chlorite in association with the talc.

Impetus was given to the development of this mine during World War II because of the presence of block or lava talc here. Lava talc was in demand because it could be machined into objects such as insulators and then fired without cracking. Typical talc, sometimes designated ceramic or cosmetic talc depending on purity, contains many minute fractures and will easily break if subjected to physical or thermal stress. Lava talc, because of its durability, is also in demand by talc carvers, who are particularly interested in material that contains dendritic patterns of black manganese minerals. Most lava talc is white or cream and is not translucent as is the typical pale-green ceramic or cosmetic talc.

James (1956, p. 2) reported that some of the dolomitic marble has been altered to coarse-grained

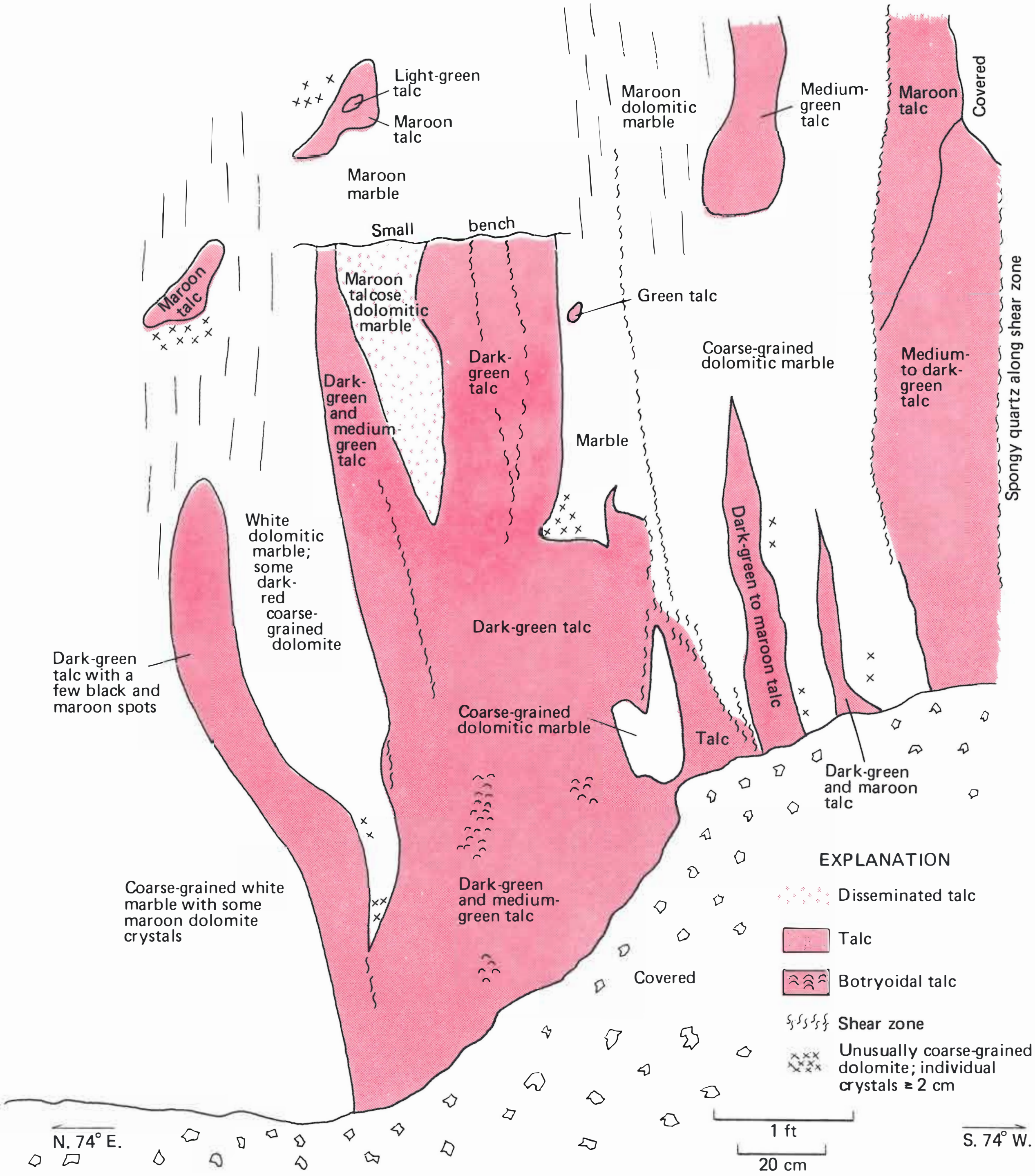


Figure 21—Burlington Northern mine, Gravelly Range. Projection of pit face on a vertical plane perpendicular to layering of the marble (R. B. Berg, September 1976).

siderite (red weathering) and ankerite. Lava talc was mined from a deeply weathered part of a zone of siderite and ankerite in the marble. Because lava talc has been found only near the surface, it presumably formed from typical talc by weathering, but a comparison of a chemical analysis of lava talc and analyses of ceramic talc shows no significant difference **(Table 5)**.

Although lava talc was important in the early development of the Yellowstone mine, essentially all of the production from this mine has been ceramic- or cosmetic-grade talc, which has found a variety of uses from the paper industry to the plastics industry.

The talc in this area was reportedly discovered by Lewis Clark on his homestead in the early part of the twentieth century. Significant development of the property was begun in 1942 when the 240-foot (72-m) Madison Tunnel was driven by the Tri-State Minerals Company and a 75-foot (23-m) shaft was sunk by the U.S. Bureau of Mines. The first shipment of lava talc was made in December 1942 and consisted of 4,000 pounds (1,812 kg). Perry (1948, p. 9) reported that in 1943 and 1944, 127 tons (115 mt) of lava-grade talc was shipped. Sierra Talc acquired the mine in 1948 and began openpit mining of ceramic or cosmetic talc rather than the lava talc. The mine, formerly known as the Mountain Talc mine, was renamed the Yellowstone mine. The choosing of this new name as related by James D. Mulryan, Western Area Production Manager of Cyprus Industrial Minerals, is quoted from Olson (1976, p. 109):

> *The original name of the Yellowstone Mine was the Mountain Talc Mine. Sierra Talc, largely through my father's efforts, acquired the property in 1948. The mine was renamed the Yellowstone Mine at that time and the story behind this is that Henry Mulryan and Otis Booth, both of Sierra Talc, were driving to Montana to look over the property after having acquired it. One commented to the other that since they had now bought the mine, they ought to figure out some sort of name for it. About that time, there was occasion for a panic-type stop in the car they were driving, and a bottle of Yellowstone whiskey, which had been under the front seat, rolled out and hit the passenger on the foot. They felt that this must have been an omen of some sort, and the mine was named Yellowstone Mine. It is therefore named for the Yellowstone whiskey, in spite of the fact it is only about 50 miles from West Yellowstone, Montana.*

In 1964 the Yellowstone mine changed ownership when Cyprus Mines Corporation acquired Sierra Talc. The mine has been a significant producer of high-purity talc and will continue to be a major producer in the foreseeable future.

GR-4 Queen claim

Location: SE¼ NE¼ sec. 8, T. 9 S., R. 1 W., Madison County. Cameron 15-minute quadrangle. Approximately 19 miles (30 km) south of Ennis.

Accessibility: The mine on this claim is 100 feet (31 m) south of the Johnny Gulch road.

Owner: Cyprus Industrial Minerals.

Description: A small amount of talc has been mined from the eastern end of the northern cuts, where the greatest concentration of talc is now exposed **(fig. 22)**. Although talc is exposed in other cuts, they seem to be exploration cuts. The host rock is fine-grained dolomitic marble exposed at the mine and in outcrops to the west. Pale-green talc at the mine is in conformable layers generally 4 to 10 inches (10 to 25 cm) thick. Some of the talc is of lava grade.

GR-5 Burlington Northern mine

Location: NW¼ sec. 3, T. 9 S., R. 1 W., Madison County. Cameron 15-minute quadrangle. Approximately 18 miles (29 km) south of Ennis.

Accessibility: A short road leads to the prospect from the Johnny Gulch road.

Ownership: Burlington Northern, Incorporated, Energy and Minerals Department.

Description: The description of this deposit was provided by Ed Houser of Burlington Northern, Incorporated.The deposit can be divided into three areas, the northern, central and southern—each showing a predominance of green talc chips in the soil. The best talc is in the central zone, followed by the southern, then the northern. American Chemet removed several thousand tons in the early 60s from a pit in the central zone. A sketch of a pit face is shown in **Figure 21**.

Talc in the deposit is principally of the light-green variety, but all colors and shades are seen. The host rock generally is slightly siliceous light-tan to light-gray microcrystalline to fine-grained dolomitic marble. Very coarsely crystalline dolomitic marble also occurs on the property, but rarely is it adjacent to or near the talc. Some small conformable stringers and pods of white quartz are present in the host rock, which trends northeast and dips steeply to the northwest. Most of the talc seems to be conformable, with little crosscutting of the host. Post-talc deformation is minimal, as only minor displacements are seen in the ore zones.

Detailed mapping, trenching, and drilling of the prospect by Burlington Northern during the summer of 1977 confirmed that the greatest concentration of talc is in the central zone. The trenching also exposed some zones of chlorite formed by the alteration of phyllite; in all cases the chlorite is bounded by deformed talc.

A specimen of maroon rock from this cut was identified by x-ray diffraction as magnesite containing traces of talc and dolomite.

GR-6 Talc-bearing conglomerate north of Johnny Gulch

Location: S½ sec. 1 and N½ sec. 12, T. 9 S., R. 2 W., Madison County. Varney 15-minute quadrangle. Section inferred from Beaverhead National Forest map. Approximately 20 miles (32 km) southwest of Ennis.

Accessibility: The road along the south side of Johnny Gulch leads to this area.

Ownership: Beaverhead National Forest.

Description: In 1974 Pete Womack of Ennis discovered pebbles of talc in the soil in an area underlain by Lodgepole Limestone (Mississippian) **(fig. 20)**. The pebbles range in color from white to tan to pale green and in size from 0.5 to 4 cm. Further examination by Pete Womack showed that a conglomerate exposed in the N½ sec. 12, T. 9 S., R. 2 W., contains talc pebbles and was a likely source for the pebbles found in the soil. The pebbles recovered from the soil at this locality are more rounded (subrounded to rounded) than the angular talc chips found in the vicinity of talc veins elsewhere.

The talc-bearing conglomerate, which is only poorly exposed, is within Oligocene felsic tuff mapped by Hadley (1969b). The felsic tuff overlies Lodgepole Limestone (Mississippian) and Three Forks Formation (Devonian). The tuff is overlain by andesite also suggested by Hadley to be of Oligocene age. The conglomerate consists of pebbles of pink to brown dolomitic marble, talc, schist, white quartz, limestone, dolomite and reddish-brown quartzite in a fine-grained matrix that is cemented with calcite. Some calcite crystals line cavities in the conglomerate. Talc pebbles are only a minor constituent of the conglomerate. The pebbles of marble, schist and quartz are obviously derived from Precambrian metamorphic rocks. The pebbles of limestone and dolomite were

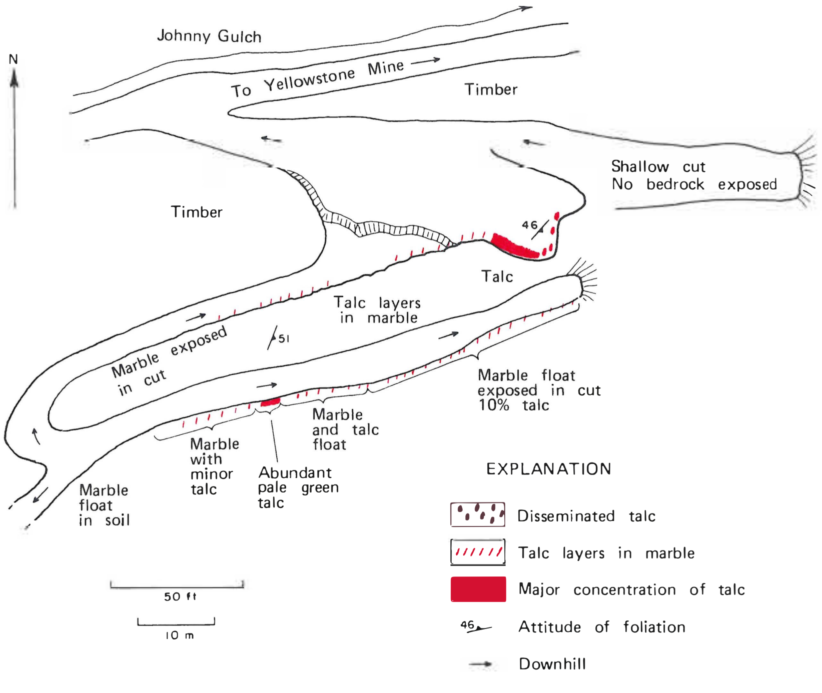


Figure 22—Inactive pit on the Queen claim, Gravelly Range (R. B. Berg, September 1976).

probably derived from Paleozoic carbonate units, and the reddish-brown quartzite pebbles are typical of the Flathead Quartzite (Cambrian) in this area.

The source of the talc pebbles in the soil and in the conglomerate is unknown. Examination of the area north of Johnny Gulch by Pete Womack, Roger Kuhns, and the author failed to find any areas of Precambrian rock other than that shown by Hadley (1969a, b) 1 mile (1.6 km) to the east.

Schist and dolomitic marble similar to the pebbles in the conglomerate are exposed to the east. In addition, Flathead Quartzite is exposed to the east where it unconformably overlies the Pre cambrian metamorphic rocks. The closest exposure of Flathead Quartzite to the west is 12 miles (19 km) northwest. The fine-grained schist (almost a phyllite) in the conglomerate does not resemble coarser-grained schist exposed to the west in the Greenhorn Range. Thus on the basis of the lithology of pebbles in the conglomerate, an eastern source is indicated. The most likely source of the talc is the deposit at the Yellowstone mine, which is 3 miles (4.8 km) east of the conglomerate and approximately 1,320 feet (403 m) lower than the conglomerate. Although Hadley (1969a, b) showed one fault (the east side down) between the conglomerate and the Yellowstone mine, the displacement on that fault cannot approach 1,300 feet. The most reasonable inference is that the talc deposit at the Yellowstone mine was exposed at a higher elevation during the Oligocene, perhaps 1,300 feet (397 m) above the present erosion surface near the mine.

At the Yellowstone mine, talc and dolomitic marble are unconformably overlain by rhyolite and rhyolitic welded tuff, which according to James (1956, p. 3) may have filled a topographic depression or valley. The rhyolite and rhyolitic tuff are designated as Miocene or Pliocene in age by Hadley (1969b). Without the benefit of absolute age determinations on the andesite that overlies the conglomerate and on the rhyolitic welded tuff that overlies the talc at the Yellowstone mine, no precise limit can be put on the interval of time during which talc was eroded from this deposit. Paul Pushkar of Wright State University collected samples of both the andesite and the welded tuff during the summer of 1978, and he will attempt to date these rocks by the K-Ar method.

Madison Range

Pre-Belt metamorphic rocks are exposed along the west flank of the Madison Range but are separated from the metamorphic rocks of the Gravelly Range by the intervening Madison Valley. Hadley (1969a) mapped quartzofeldspathic gneiss, quartzite, hornblende gneiss, anorthosite gneiss, dolomite marble, iron-rich quartzite, mica schist, phyllite and metadiorite in that part of the Madison Range that lies in the Cameron quadrangle. South of the Cameron quadrangle the geology of the Precambrian rocks is less well known. Eric Erslev, a graduate student at Harvard, is now (1978) working on the Precambrian geology of that part of the Madison Range.

Fine-grained dolomite is abundant in the debris deposited by the 1959 earthquake-induced slide that partly filled the Madison River Canyon. Farther to the south, Witkind (1972) showed large areas underlain by dolomite at the southern end of the Madison Range just north of Henrys Lake, Idaho. Other pre-Belt metamorphic rocks shown on Witkind's map are metagranodiorite, amphibolite, quartzite, mica schist, diabase and gabbro.

Eric Erslev (personal communication, 1978) reported that impure talc is associated with ultramafic bodies in the Madison Range. This talc contains chlorite, actinolite, serpentine and anthophyllite, and occurs in bodies that are probably too small to be of economic interest. The only other known occurrence of talc in the Madison Range is south of the Madison River, where a small amount of talc is exposed at the Cliff Lake mine. (See Perry, 1948, p. 39-40, for a description of this mine.)

Henrys Lake Mountains

The Henrys Lake Mountains are situated along the Idaho-Montana boundary west of Henrys Lake, Idaho. These mountains are underlain by metamorphic rocks, which are a continuation of the same units exposed in the southern Madison Range across a valley to the east. Witkind has mapped metamorphic rocks in the Henrys Lake 15-minute quadrangle and also in the southern half of the Upper Red Rock Lake 15-minute quadrangle to the west (1972 and 1976, respectively). He has designated these rocks Precambrian X (1,600 to 2,500 m.y. old), which would make them approximately equivalent in age to the pre-Belt metamorphic rocks of southwestern Montana. Metamorphic rocks from this area are typically finer grained and of lower metamorphic grade than the pre-Belt metamorphic rocks to the northwest in the Gravelly and Greenhorn ranges. Rather than the coarse-grained marble of those other areas, the carbonate units of the Henrys Lake area are fine-grained dolomite; average grain size being between 0.05 and 0.1 mm. In addition to dolomite, Precambrian rocks of this area are mica schist, quartzite, amphibolite, metagranodiorite, diabase and gabbro.

During the summer of 1976 Leroy Swanson and the author mapped the geology of a 40-square-mile (104-square-km) area of pre-Belt metamorphic rocks just north of the area in the southern part of the Upper Red Rock Lake quadrangle mapped by Witkind (1976) and including a small part of the Cliff Lake and Hebgen Dam 15-minute quadrangles. This area was chosen for study because of a reported occurrence of talc and the abundance of dolomite, the host rock for talc deposits in southwestern Montana. The results were disappointing. Only one small talc occurrence was found in the mapped area and three others nearby but outside the mapped area. Work on the petrography of the metamorphic rocks from this area is in progress, and the results, including the geologic map, will be included in a separate report by the Montana Bureau of Mines and Geology, on the geology of the Centennial Valley and surrounding area.

Known talc occurrences in the Henrys Lake Mountains are limited to four localities where small amounts of talc are exposed in dolomite adjacent to dikes or other igneous bodies. None of these talc occurrences is large enough to warrant development. Most of the areas underlain by dolomite in the Upper Red Rock Lake quadrangle were checked, but talc was found at only two localities (described below) within that quadrangle.

HL-1 North of Hackett Creek in the SW¼ sec. 5, T. 14 S., R. 1 E. Upper Red Rock Lake 15-minute quadrangle. A poorly exposed diabase dike approximately 175 meters (575 ft.) in outcrop width has intruded dolomite. A few small chips of talc can be seen in the soil adjacent to the dike.

HL-2 NW¼ sec. 18, T. 14 S., R. 2 E. Upper Red Rock Lake 15-minute quadrangle. Talc blebs approximately 1 cm long are scattered throughout dolomite in an area one meter square. This occurrence of talc is at the contact of dolomite and a small body of metagranodiorite.

HL-3 A diabase dike trending northeast near the state line is exposed in sec. 24, 27, 33, T. 13 S., R. 2 E. Targhee Peak 7½-minute quadrangle. The dike is well exposed and ranges in thickness from 10 to 50 meters (33 to 160 ft.). Minor talc was found in the dolomite at the contact with the diabase. The greatest concentration of talc is in an area 0.5 by 1 meter (1 by 3 ft.) in which round talc blebs 5 to 10 mm across constitute approximately 50 percent of the rock. Dolomite adjacent to other diabase dikes in this area was not checked for talc.

HL-4 Northeast side of Elk Mountain in the NE¼ sec. 33, T. 13 S., R. 1 E. Upper Red Rock Lake 15-minute quadrangle. Talc blebs less than 1 cm long are found scattered through dolomite within 3 meters (10 ft.) of a gabbro dike. No significant concentration of talc was recognized.

Other talc occurrences

Besides the described talc occurrences in the pre-Belt metamorphic rocks of southwestern Montana, there are only two other known talc occurrences in the state, one south of Helena and one northeast of Troy. Both are described below.

O-1 Talc mine south of Helena

Location: SW¼ SE¼ sec. 35, T. 10 N., R. 9 W. (adit), NE¼ SW¼ sec. 36, T. 10 N., R. 4 W. (quarry), Lewis and Clark County. Helena 15-minute quadrangle. The quarry is approximately 2 miles (3.2 km) southwest of the center of Helena.

Accessibility: Both talc occurrences are adjacent to the road along Grizzly Gulch southwest of Helena.

Ownership: Not known.

Description: Beginning in 1935 talc was mined from what had formerly been a limestone quarry. The duration of talc mining at this quarry is not known, but there has been no mining in recent years. Perry reported (1948) that talc was first recognized as an impurity remaining after the limestone was heated to make lime. The remains of the lime kilns are still standing (1978) between the quarry and the Grizzly Gulch road.

The quarry is in Hasmark Dolomite (Upper Cambrian). (The unit called the Hasmark Dolomite in the Helena area is now generally referred to as the Pilgrim Limestone.) Perry reported that irregular veinlike bodies and stringers of talc range in thickness from less than 1 inch (2.5 cm) to 6 feet (2 m) and that these bodies may have a vertical dimension of 12 feet (4 m). The largest stope in the talc was 35 feet (11 m) long, 6 feet (2 m) wide, and 8 feet (2.5 m) high. On the surface talc has been traced intermittently for 350 feet (109 m). Most of the talc is white, but limonite derived from the weathering of pyrite has locally stained the talc.

An adit (now caved) and several small cuts have been excavated into the Hasmark Dolomite approximately 1 mile (1.6 km) southwest of the limestone quarry. Although the author did not find any talc in these cuts, some pieces of coarse-grained dark-green talc were found next to an old loading platform. Perhaps some talc was encountered in the adit, which is within 50 feet (16 m) of the loading platform. The Hasmark Dolomite has been metamorphosed in this area to medium-grained white dolomitic marble, presumably by a small nearby granodiorite pluton.

Sources of information: Knopf, 1963, map; Perry, 1948, p. 10, 11.

O-2 Lynx Creek (Mathews) talc prospect

Location: Because sections are not shown on the map in this area, the prospect is located by UTM coordinates. The UTM northing is 5372220, the easting is 592110, and the locality is in zone 1, Lincoln County. The prospect is on the northeast-trending ridge between King Mountain on the southwest and China Mountain on the northeast, Kootenai Falls 7½-minute quadrangle, and is in the first major saddle northeast of King Mountain. The Lynx Creek road crosses the ridge between King Mountain and China Mountain in this saddle. The talc deposit is approximately 6 miles (10 km) northeast of Troy.

Accessibility: The Lynx Creek road branches from the O'Brien Creek road northeast of Troy in the S½ sec. 32, T. 32 N., R. 33 W. The distance by road from O'Brien Creek to the deposit is approximately 6 miles (10 km).

Ownership: The deposit was located by a Mr. Mathews prior to 1958.

Description: The host rock for the talc is the Striped Peak Formation of the Belt Supergroup (Precambrian). At this locality the Striped Peak Formation consists of argillite and quartzite, strikes northeast, and dips 20 to 30° SE. **(fig. 23)**. Johns (1970, p. 152) reported that the deposit has been investigated by 15 vertical drill holes ranging in depth from 2 to 43 feet (0.6 to 13 m). The ore body is 100 by 250 feet (31 by 78 m) and extends to a depth of at least 40 feet (12 m). The talc is gray, yellow gray, yellow brown and green gray, and is described as sericitic talc that contains disseminated pyrite; secondary iron minerals; and some quartz.

Source of information: Johns, 1970, p. 152-153.

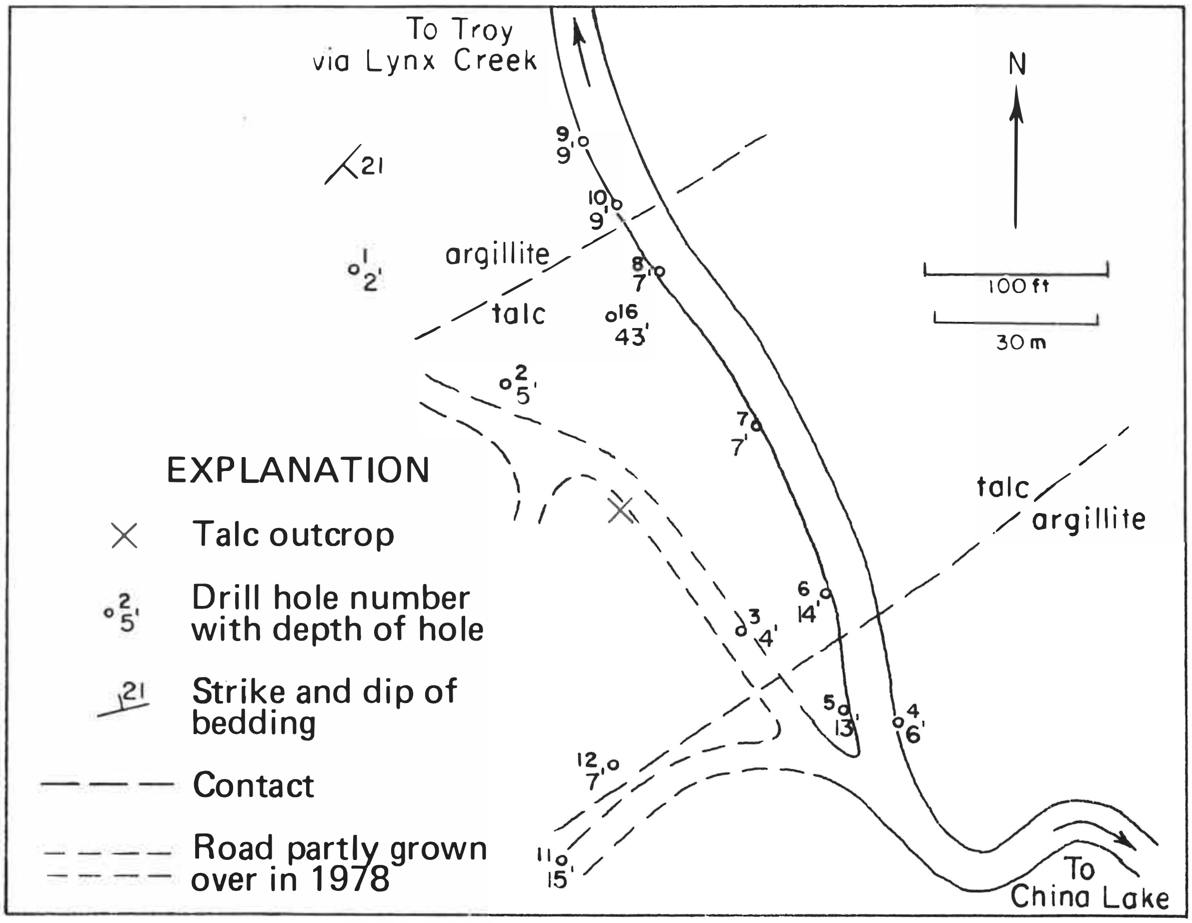


Figure 23—Lynx Creek (Mathews) talc prospect, Lincoln County (*modified from* Johns, 1970, p. 152).

Other areas of pre-Belt metamorphic rocks

Pre-Belt metamorphic rocks are exposed in seven or possibly eight areas in Montana in addition to those mountain ranges in which talc and chlorite deposits are known to occur. Talc deposits are lacking in these areas simply because dolomitic marble is lacking or very sparse.

Blacktail Range

The Blacktail Range is situated south of the talc-rich Ruby Range. No marble is reported from the Blacktail Range (Heinrich and Rabbitt, 1960, p. 36-38). The major pre-Belt metamorphic rock types exposed in this range are Dillon Granite Gneiss, pre-Cherry Creek gneiss, and an ultramafic body.

Tendoy Mountains

Scholten, Keenmon and Kupsch (1955, p. 351) described marble, mainly calcitic, within the sequence of pre-Belt metamorphic rocks exposed in the Tendoy Mountains southwest of Dillon. The marble is a minor unit in this area, in which quartzofeldspathic gneiss dominates. They did not mention talc in the marble.

Snowcrest Range

A small area on the northwest flank of the Snowcrest Range, southeast from the Ruby Range, is underlain by pre-Belt metamorphic rocks. Although most of the metamorphic rock is quartzofeldspathic gneiss, a layer of marble 30 feet (9 m) thick is reported (Heinrich and Rabbitt, 1960, p. 35-36). Tremolite and fine-grained chlorite but no talc are found in the marble. This area of Precambrian metamorphic rocks is not shown on the Geologic Map of Montana (Ross, Andrews and Witkind, 1955).

Spanish Peaks area

A large part of the Spanish Peaks area at the north end of the Madison Range is underlain by pre-Belt metamorphic rocks. Spencer and Kozak (1973) described the geology of a large area that extends from the Tobacco Root batholith in the center of the Tobacco Root Mountains east to the Gallatin River. The only marble described in that area crops out southwest of Cherry Lake where it is 20 feet (6 m) thick. Cherry Lake is approximately 11 miles (18 km) northeast of Ennis. The marble contains calcite accompanied by minor tremolite, antigorite and diopside, but no talc (Spencer and Kozak, 1973, p. 43).

Northern part of the Gallatin Range

Pre-Belt metamorphic rocks are exposed south of Bozeman in the northern part of the Gallatin Range. Descriptions of the geology of this area by McMannis and Chadwick (1964), Tysdal (1966), and Weber (1965) make no mention of marble. The most abundant rock is quartzofeldspathic gneiss, which is associated with amphibolite.

Beartooth Mountains

All of the known talc areas of southwestern Montana could fit within the area of pre-Belt metamorphic rocks exposed in the Beartooth Mountains, which are situated in south-central Montana just north of Yellowstone National Park. The predominant metamorphic rock types are granitic gneiss, migmatite and amphibolite (Poldervaart and Bentley, 1958). Marble is reported only in the North Snowy Block in the northwestern part of the range (Reid, McMannis and Palmquist, 1975, p. 14-15). The marble layer, named the George Lake Marble, is as much as 192 feet (60 m) thick and can be traced for more than 18 miles (29 km) around the core of a nappe. Although it is mainly dolomitic, some calcitic marble is intimately intermixed. Diopside in the marble is in some places replaced by tremolite. Reid, McMannis and Palmquist concluded that growth of coarse-grained tremolite was followed by the growth of fine-grained tremolite and talc. No mention is made of the abundance of the talc.

The major Precambrian rock types in the Jardine district, in the southwestern part of the Beartooth Mountains, are schist and what is thought to be a Precambrian granitic pluton (Seager, 1944, p. 21-34). No marble is described in this area.

Little Belt Mountains

The core of the Little Belt Mountains of central Montana consists of pre-Belt metamorphic rock, mainly schist, gneiss and the Pinto metadiorite (Catanzaro and Kulp, 1964, p. 88-93), but marble is not described. Henry G. McClernan, who has studied an area on the southwest flank of the Little Belt Mountains, reported that no marble was recognized within the sequence of pre-Belt metamorphic rocks (personal communication, 1978).

Other areas of possible pre-Belt rocks

High-rank metamorphic rocks exposed along the eastern edge of the Idaho batholith in the Bitterroot Range have been suggested by some to be pre-Belt in age. Whether they are pre-Belt or metamorphosed sedimentary rocks of the Belt Supergroup or equivalent is an interesting question, but more important to talc exploration is the lack of marble (Berg, 1977; Chase, 1973). Carbonate bodies in the metamorphic rocks of southern Ravalli County thought to be carbonatites contain rare-earth elements. Detailed study of the mineralogy of the carbonate rocks by Crowley (1960) failed to find talc.

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