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THE GEOLOGY OF MONTANA TALC DEPOSITS

Richard H. Olson*

ABSTRACT

Talc deposits in the Precambrian rocks of southwestern Montana (Beaverhead and Madison Counties) are unique within the U.S. in that large bodies of tremolite-free talc ore can be open-pit mined. All known deposits are in pre-Beltian dolomite units. The origin is suspected to be metasomatic, the siliceous component having been contributed by an intrusive body of Precambrian granite gneiss. Precambrian deformation was extreme and is characterized by multiple periods of folding and the flowage of less competent rocks, rather than by faulting. Post-Precambrian folding has been negligible; the characteristic Laramide structure is block faulting along northwest trends.

The talc is thought to have been formed in Precambrian time; the high-angle block faults have no significance with regard to the formation of the talc but do tend to complicate mining operations.

Tremolite-free talc ore bodies that have horizontal widths of more than 200 feet, vertical depths of several hundred feet, and strike lengths of as much as ½ mile are known in the Ruby and Gravelly Ranges. Where dolomite is interbedded with tremolite-free talc in the Gravelly Range the scale of this relationship permits the use of conventional open-pit mining methods with subsequent upgrading by hand-sorting techniques.

Underground mining has been used in the past, but all current Montana talc-mining operations are on the surface. The hand-sorted crude ore, some of which is shipped overseas, is finely ground or micronized in roller mills and fluid-energy mills. The products are distributed nationwide and abroad.

TALC-MINING INDUSTRY

The talc-mining industry, like that of many other industrial mineral commodities, has a complex and varied structure. This is necessitated by the fact that products made from such ores have a multitude of uses; literally hundreds of products, most of them manufactured from roughly similar ores, are currently on the market.

Talc, which has the composition $3MgO \cdot 4SiO_2 \cdot H_2O$, is a valid mineral species and has long been recognized as such by mineralogists. The term "talc", however, to talc miners, talc processors, talc salesmen, and talc consumers, covers a multitude of sins and when so used may pertain to material that contains little or none of the mineral talc. Among such persons, the term "talc" may be freely applied to any talc-like rock or mixture of such rocks that can be used to manufacture products acceptable to a customer.

Talc may be regarded as the pure end member of a series, soapstone being the impure end member of that series. Soapstone is a rock name, not a mineral name, and soapstone is generally composed predominantly of impure talc containing relatively minor amounts of chlorite, mica, and various amphibole and pyroxene minerals.

Tremolite, which has a theoretical chemical composition $2CaO \cdot 5MgO \cdot 8SiO_2 \cdot H_2O$, is, more commonly than not, the major component in "talc" ores, at the expense of the mineral talc itself, which may be of only minor volumetric importance. This relationship may hold throughout large talc-mining districts, e.g., the New York and California-Nevada districts.

Other talc-like minerals (i.e., chemically or physically similar) that may constitute various proportions of "talc" ores are anthophyllite, antigorite, chlorite, pyrophyllite, and serpentine.

The mechanics of the formation of talc bodies and the inherent compositions of the rocks from which such bodies have been formed dictate that some impurities will be present, even if none of the "talc-like" minerals are present; such indigenous impurities include calcite, dolomite, magnesite, and quartz. By "indigenous" is meant those materials that will be generated *in situ* by incomplete alteration to the mineral talc, i.e., the reconstitution of the pre-existing parent material without any appreciable addition of extraneous material.

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Many other impurities may also be introduced and modified during epigenetic processes of mineralization; the most common of these are calcite, dolomite, graphite, hematite, limonite, magnetite, pyrite, pyrolusite, quartz, and various sulfates.

"Steatite" is a much-abused name, which means, unfortunately, different things to different people. It was originally a mineralogical name used to denote massive talc or talcose rock. It has subsequently been used to designate a grade of talc ore that can be used to manufacture electronic insulators, thereby having primarily a physical connotation rather than mineralogical and chemical connotations. At one time the term was even synonymous with soapstone, but the present meanings of these two terms are far apart. In order to qualify as steatite-grade today, talc ore must contain less than 1.5% CaO, less than 1.5% Fe_2O_3, less than 4.0% Al_2O_3, and only minute quantities of "other impurities", and it must be suitable for the manufacture of high-frequency electrical insulators. Virtually all of this country's reserves of steatite-grade talc ore are in southwestern Montana. That grade of talc is present in several other districts, but those bodies are comparatively small, and most must be mined in conjunction with the lower-grade ores, the market for whose products dictates the rate at which the steatite-grade ores may be economically mined.

The term "steatite" will not be employed in this paper in the discussion of Montana's talc deposits. The term "talc" will be used in the mineralogical sense for ores that are predominantly composed of that mineral alone and contain little or none of the "talc-like" minerals. For those ores that contain measurable amounts of tremolite or other "talc-like" minerals, the term "talc-rock" will be used. This usage is not an attempt to establish nomenclatural rules but merely a desire to accentuate the difference in purity between Montana talc ores and the ores from the other five major talc-mining districts of North America.

High-purity talc ores, which can be mined as such without extracting other, lower grade ores and which can be used for the manufacture of high-purity talc products, are at present known in the United States only in southwesternmost North Carolina and southwestern Montana. Those in North Carolina are mined underground; only in Montana may such ores be mined by open-pit methods at relatively low cost.

The writer first became acquainted with Montana's talc deposits and their geology when Pfizer, Inc., by whom he was employed, purchased Southern California Minerals Company, which was then, as Pfizer is now, one of the two major producers of Montana talc ores and their products. It would not be possible to thank all of those Pfizer employees who willingly shared their knowledge, but Messrs. John V. Burk, Otto D. Rohlfs, Jr., Walter W. Weid, and L. R. Wood in particular worked in the field with the writer and their help and contributions and good company are herewith specifically acknowledged.

During his tenure with Pfizer the writer also had the privilege and the pleasure of working with Dr. Rudolph M. Hogberg and Mr. C. F. Joy, consultants, both of whom freely shared the results of their considerable prior experience in the Montana talc district and made numerous extremely helpful suggestions and contributions.

Also while with Pfizer the writer was privileged to participate in the supervision of two Ph.D. dissertations at Pennsylvania State University. Drs. John M. Garihan and Angelo F. Okuma studied the central and southern parts of the Ruby Range, respectively, particularly those specific areas that seem to have the greatest potential for the discovery of commercial talc deposits. Their work was a general areal study encompassing mainly stratigraphy, structure, and general geology; it was never intended that they, by themselves, solve the riddle of talc genesis. Their excellent contributions (Okuma, 1971; Garihan, 1973), however, serve as the firm background upon which all future work on the talc deposits of the Ruby Range will be based. Pfizer, Inc., deserves credit and sincere thanks for its generous support of these two investigations.

Messrs. Ed Stevens, James D. Mulryan, and Donald F. Kennedy of Cyprus Industrial Minerals Company have also shared their knowledge over the years and have extended the courtesy of conducting the writer on visits to their mines and mill in Montana.

Several geologists of the U.S. Geological Survey, particularly Mr. Kenneth L. Wier and Ms. Karen Shaw, have through years of dedicated effort and detailed mapping (much of it still unpublished) contributed to the knowledge of the extremely complicated pre-Beltian stratigraphy and structure of the southwestern part of the Ruby Range, particularly in the Christensen Ranch 7½-minute quadrangle. A particularly significant map (James, Wier, and Shaw, 1969) was open filed primarily in order to enhance the knowledge of potential talc-bearing areas for those economic geologists then involved in the search for new talc mines in the Ruby Range. For many most informative and constructive suggestions, as well as the benefits of numerous pleasant field excursions, the writer is fondly indebted to Mr. Wier and Ms. Shaw.

Mr. Walter K. Skeoch, formerly President and owner of Southern California Minerals Company, and Mr. James D. Mulryan of Cyprus Industrial Minerals Company have kindly supplied background information on the history of the growth and development of the Montana talc industry, which is incorporated into this paper.

Messrs. Tom McGovern and Bennett Owen of Dillon, Montana, have been involved in the prospecting for and the mining and processing of Montana talc for more than four decades between them. They have freely shared their considerable knowledge, have showed the writer several deposits of which he had not been aware, have pointed out features that he had not seen, and have described some that had been destroyed or mined out.

Little of the investigations documented in this paper could have been made without the cooperation of ranchers in the area, particularly Fred W. ("Buster") Brown and Art Christensen of Dillon, Montana. Both of these fine gentlemen not only allowed access to all of their large land holdings but also accompanied the writer on many field trips and pointed out several features that would otherwise have gone unknown to him.

Mr. Raymond Olson served as a most capable field assistant in 1974 and made many significant and meaningful contributions to this study.

TALC VS. TREMOLITE CONTROVERSY

Rightly or wrongly, in recent governmental investigations into health and safety matters tremolite has been likened to asbestos. The results of a symposium on the health hazards of respirable dust in the mining and milling of talc and "talc-like" ores, convened by the U.S. Bureau of Mines in Washington, D.C., on May 8, 1973, have recently been published (Goodwin, 1974). This and other such investigations have led many consumers to switch from products manufactured from tremolitic ores to those manufactured from high-purity talc ores, such as those mined in Montana. The production of talc ore in Montana has more than doubled in the period 1969-1974, and much of that sharp and relatively sudden increase must be attributed to that factor.

While "the jury is still out" on this controversial matter, the Montana talc-mining industry stands to benefit at the expense of all the other districts, with the possible exception of North Carolina.

USES

Talc products, whether manufactured from high-purity talc ores, tremolitic ores, or other types of "talc-like" ores, are numerous and have myriad uses and applications. These are well documented in the literature, particularly by Johnstone and Johnstone (1961), Cooper and Hartwell (1970), Olson (1970), Wells (1972), Patton (1973), and Roe (1975).

The natural color of Montana talc ores ranges from white or very pale green at the lightest to dark green, greenish gray, or even black at the darkest. In most of these ores, except for the darkest ones or the ones containing graphite, the color (whiteness) improves noticeably upon fine grinding (particularly in the 5-micron size). Blending of darker ores with some of the lightest ores can extend the life of ore bodies. Darker ores may be used in place of lighter ores if color is not a particularly important product specification.

The ceramics, paint, and paper industries consume more than half the dollar value of talc products currently sold in the United States, and it is in these three industries that virtually all of Montana's talc products are used. It is the development of high-quality pigment-grade products that has enhanced the rapid growth of Montana's talc industry in recent years, and these product lines have been brought about by the development of extremely fine grinding or "micronizing" techniques in "jet" or fluid-energy mills. Many of the Montana talc products currently sold by both present producers will have more than 50% of their weight in the −4 micron size, and almost all of them will have considerably more than 50% of their weight in the −10 micron size.

OTHER NORTH AMERICAN TALC DISTRICTS

Before embarking upon a description of Montana's talc deposits, it would be well to briefly describe the other five major talc-mining districts of North America and to cite similarities and differences, so that the reader will then have a background for comparison.

The geological settings of talc deposits in the United States and Canada are as varied and diverse as would be expected for any naturally occurring mineral commodity, but there are some broad similarities. First, talc is invariably a secondary mineral formed *in situ* from pre-existing or introduced material or both. Second, commercial bodies are generally tabular and concordant (at least in the overall sense, if not everywhere locally), being "molded" after the shape of the parent material, which is generally a sedimentary or metasedimentary rock unit. Third, most of the talc ore bodies occur within Precambrian rock units; the few that do not are in rock units no younger than Early Paleozoic age. Finally, in almost every deposit where genesis can either be firmly established or confidently inferred, the time of the talc formation is Precambrian as well.

The reasons for this almost total restriction of talc to the Precambrian in both space and time are unclear. It may be easier to understand in the case of ultramafic rocks, for they may be much more abundant in the Precambrian than in younger rocks. It is somewhat more difficult to understand with regard to dolomitic rocks, for they are certainly much more common in the Cambrian and younger systems than in the Precambrian. It may be that deep burial and the consequent conditions of dynamic metamorphism could have attained sufficient intensities only during the Precambrian; such a theory would perhaps explain the formation of talc in Montana and New York, for instance, but would probably not be applicable to some of the other districts, which have undergone deep burial but do not show conditions of extreme dynamic metamorphism and isoclinal structure, such as are common, for instance, in Montana and New York. It seems safe to say, however, that even though conditions of dynamic metamorphism have not necessarily been attained in all six districts, or at least cannot definitely be proved, conditions of burial beneath miles of rock cover have been attained in every district. The answers to what conditions have effected the origin of talc may well have to await solution by workers in academia, for few economic geologists have the time and the resources to devote to such problems.

Until such questions are answered it should suffice to say that if one wants to find talc in commercial quantities then one should restrict the search to Precambrian and possibly Early Paleozoic sequences in geosynclinal areas; in other words, stick to "elephant country"!

The six major talc-mining districts in the United States and Canada are: New York, Vermont-Quebec, North Carolina-Georgia-Alabama, Texas, California-Nevada, and Montana (Fig. 10-1). The history, geology, and several other aspects of the first five districts will be treated briefly below; Montana will then be described and discussed in detail.

NEW YORK

Talc was first produced and milled in the United States in northern New York in 1876 between the towns of Fowler and Balmat in St. Lawrence County. Before the turn of the century this operation became known as the International Pulp Company, which changed its name to the International Talc Company in 1944, and was acquired by the R. T. Vanderbilt Company in 1974. The Gouverneur Talc Company, a Vanderbilt subsidiary from the beginning, began operations near the zinc-mining town of Balmat in 1948. Prior to their acquisition of International Talc Company in 1974, Gouverneur shared with them in the New York talc district's annual production on an approximately 50-50 basis.

The New York talc district has long been and still may barely be the most important in the United States in terms of total annual production. It is most peculiar that this district, although dominant in production for the last century, and even more dominant in terms of proved and potential ore reserves, is the smallest in area of all six talc-mining districts in North America. All of the known commercial talc and talc-rock occurs within the Balmat-Edwards or Gouverneur mining district. A comprehensive study of talc in the United States by the U.S. Geological Survey (Chidester and others, 1964) indicated that New York then had almost 75 percent of this country's "measured and indicated" talc ore and about 40 percent of its "inferred" talc ore. All of the known talc and talc-rock lies within a narrow belt, which probably averages only 500 feet in width and is only about 8 miles long.

The bedrock complex of the Gouverneur mining district consists exclusively of metamorphic rocks of Precambrian age (the Grenville Series), but two specific types, namely, gneiss and marble, dominate. The gneiss is the older unit and is about 3,000 feet thick; the marble is the younger unit and has a maximum known thickness of about 2,000 feet. Thin sheets and lenses of amphibolite occur within both the marble and the gneiss but are minor in total volume. Brown and Engel (1956) subdivided the marble sequence into fifteen units, of which only Unit #13, the "talc unit", is known to contain commercial deposits of talc, tremolite, or zinc minerals. Unpublished geological investigations indicate that the composition of most of the marble in the district is relatively simple and probably does not and did not differ greatly along strike. The "talc unit", a dolomitic marble, shows evidence of being only 250 feet thick in its least contorted areas; greater thickness may be due to structural flowage.

The zinc and the talc ores occur within the same stratigraphic unit, but not together except at a few localities. Locally, the siliceous dolomite of Unit #13 has been converted to tremolite under conditions of dynamic metamorphism or metasomatism; subsequently, talc, anthophyllite, and serpentine have locally been formed from the tremolite. In the northeasternmost part of the district, anthophyllite may locally be the major constituent of the ores.

New York talc ores are commonly more than half tremolite. Tremolitic ores have been proven by underground workings to downdip depths of at least 1,100 feet and by core drilling (generally in the search for commercial zinc deposits) to downdip depths of more than 3,000 feet. Mineable bodies of almost tremolite-free talc (platy or "scaly" variety) have been discovered and recently exploited in mines near Talcville; these, however, are near the hanging-wall contact and are difficult to mine by themselves, so their scale of production tends to be directly related to that of the tremolitic ore being produced at the same time. Field mapping by U.S. Geological Survey workers has indicated that the tremolite and talc and associated minerals were formed prior to 1.0×10^9 years ago.

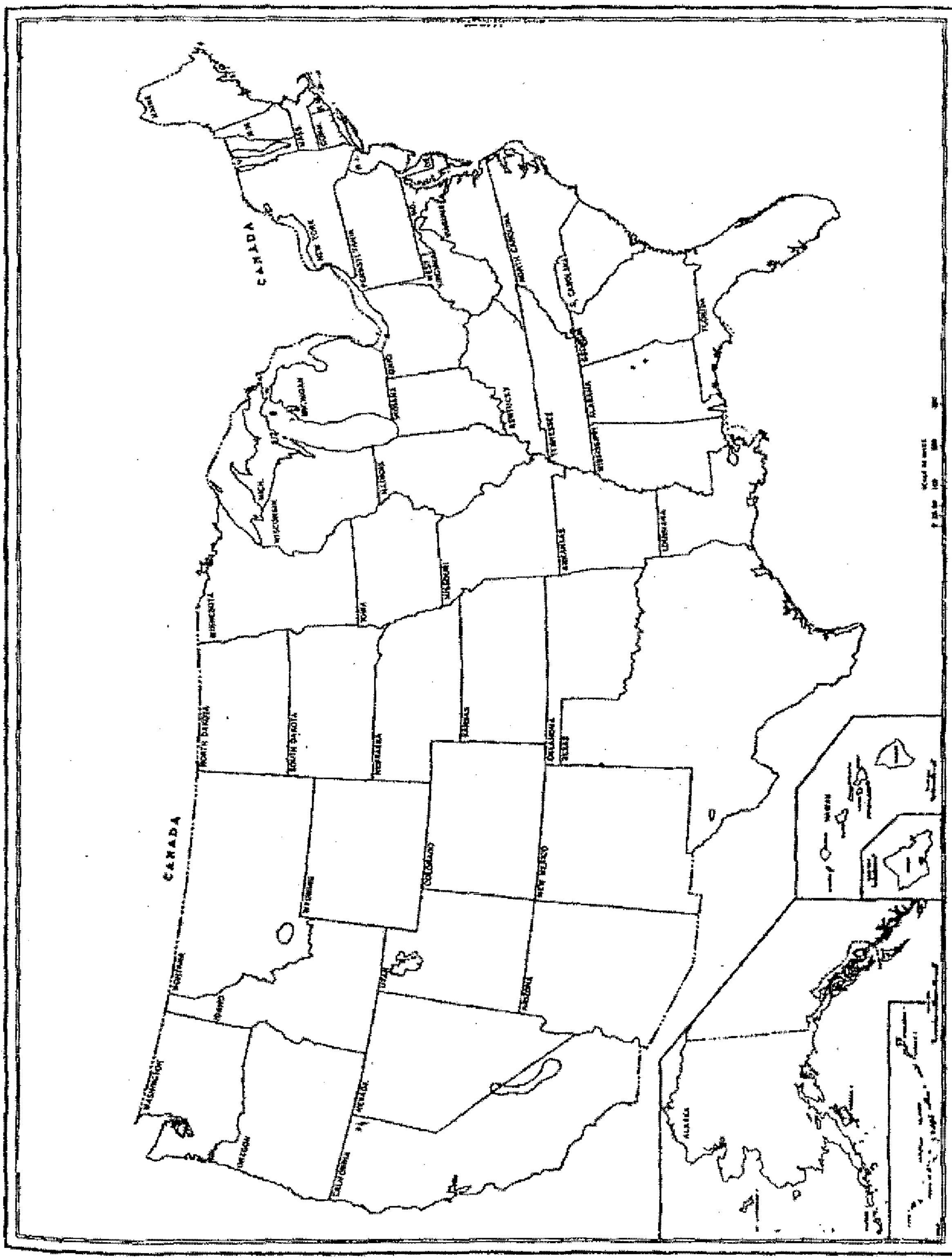


Fig. 10-1. —Major talc-mining districts of United States.

The zones of commercial talc-rock locally pinch and swell, but they are on the whole conformable to the dolomitic marble layers. The regional dip is about 45° to the northwest, and departures are only locally significant. Tight and contorted cross-folds superimposed upon the main talc belt have locally resulted in the thickening of the talc-rock sequence by at least 50 percent. All of the rocks are complexly folded, and metamorphism to the amphibolite facies is common, if indeed not ubiquitous.

Both open-pit and underground mining methods are employed. A large crushing facility is installed within one underground mine.

The deposits of the New York talc-mining district may well constitute the largest reserves of tremolitic-type ore in the world, for nothing described in the literature at the present time is of similar magnitude. In the late 1960's the total production of the New York talc-mining district was on the order of 225,000 tons annually. Although the most recent production figures issued by the U.S. Bureau of Mines group New York's production with that of several other states, it can be safely inferred that New York is now producing on the order of 250,000 tons annually.

New York talc ores are milled as is, i.e., without any beneficiation of any sort. Milling is accomplished in ball mills and in fluid-energy ("jet") mills and the product is then air-classified.

VERMONT-QUEBEC

The district that is commonly known as the Vermont talc-mining district runs through the central part of that state but also extends southward into Massachusetts and northward into Quebec.

Bodies of ultramafic rock have been intruded into a sequence of phyllite, schist, gneiss, greenstone, and amphibolite rocks; the ultramafic bodies have been locally serpentinized and partly converted into talc. These talc-rock deposits are commonly associated with dunite, peridotite, and serpentinite, which were probably the parent rock. These ultramafic rocks "form part of a belt more than 2,000 miles long, which extends from Alabama to Newfoundland" (Chidester and others, 1951). The talc-rock itself is more of a talc-carbonate complex, which locally grades into a carbonate complex rich in magnesite. The talc-rock is dark, gray to dark gray, has a schistose structure, and is relatively high in iron content. The mineral talc itself is minor in all the known deposits.

The ultramafic bodies are as much as 1 mile in width and as much as 3½ miles in length (Chidester and others, 1951). The commercial bodies, which occur in those ultramafic bodies known as the "verde antique" type, are zoned around cores of serpentinite. The talc-containing zone ("steatite zone") forms the outer shell or zone of the body; between it and the serpentinite core is the "grit zone", which is commonly several feet to several tens of feet thick. "Grit" is the miner's term for rock that is composed of talc and carbonate minerals only.

Although there are few masses of high-purity talc in the Vermont-Quebec district large enough to mine as such, tremolite is not known, and talc itself is the only talc-like mineral contained within the ultramafic bodies. The major problem hindering the production of pure talc is the fineness of its physical admixture with its contained impurities.

In northern Vermont, entire ultramafic bodies have been converted into grit and have widths on the order of 100 feet or so; in southern Vermont one similar body has a width of about 175 feet. In the state of Vermont alone at least 145 occurrences are known in an area having a strike length of about 150 miles and a width ranging from 5 to 25 miles. Homoclinal folding is the regional structure; isoclinal folding is thought to be uncommon, for little repetition by folding has been noted.

Few workers have attempted to date either the host rocks of the Vermont talc-mining district or the time of steatization, but studies by Christman (1959) and Christman and Secor (1961) suggested that the age of the parent rocks is Early Paleozoic, probably Ordovician.

Open-pit mining has been done in the past, but in recent years all production has come from underground workings, some of which extend to vertical depths of more than 1,000 feet.

The ore reserve situation in the Vermont-Quebec district has never been seriously investigated by anyone who would be at liberty to disclose the results of such a study. Proved ore reserves probably do not exist, for these producers seldom block out tonnage far ahead of the producing faces. Judging from the geographical distribution of the known bodies in Vermont alone, however, the reserves of talc-rock must be extremely large.

Producers have historically had the choice of grinding the talc-rock as mined and processing it for relatively low priced dusting compounds and fillers or of beneficiating the talc-rock by flotation or other means in order to derive high-value products containing major amounts of the mineral talc. If one wants to manufacture the most profitable product line in this district, he is faced with the necessity of employing wet-processing beneficiation techniques. The Eastern Magnesia Talc Company, Inc. (now Engelhard Minerals and Chemicals Corporation) has been using wet-beneficiation methods on ores near Johnson, Vermont, since 1937. The ore is subjected to froth flotation, then dewatered in a rotary vacuum drum filter. The filter cake is then dried, pulverized, and air-classified; Harrah (1956) has described this operation in detail. Eastern Magnesia Talc Company, Inc., established another, much more modern froth flotation plant at West Windsor, Vermont, in 1964; since 1972 this operation has been known as Windsor Minerals, Inc., a wholly owned subsidiary of the Johnson & Johnson Company. Trauffer (1964) has described this operation in detail.

The U.S. Bureau of Mines noted production of 251,087 tons of "talc, soapstone, and pyrophyllite" in Vermont in 1973.

QUEBEC

Deposits in the serpentine belt of the Eastern Townships of Quebec have been described as being altered from peridotite. These deposits are similar to those in Vermont and have been described by previous workers as "soapstone". Baker Talc Limited in Highwater, Quebec, used to mine such ore and dry-grind it for low-grade low-value fillers and dusting compounds. In the late 1960's wet-processing methods were introduced, particularly froth flotation and high-intensity wet magnetic separation; consequently, products now being manufactured from the same ores are being sold to the paint, cosmetic, and paper industries at considerably higher unit values.

NORTH CAROLINA-GEORGIA-ALABAMA

Although several deposits of talc and soapstone are known in the Appalachian Mountain province between Vermont and western North Carolina, none of them have such a history of past or present production, nor in the writer's opinion the future potential, to even suggest the possibility of their becoming major talc-mining districts. These occurrences in Massachusetts, Connecticut, Rhode Island, New Jersey, Pennsylvania, Maryland, and Virginia were described by Chidester and others (1964).

Several talc occurrences and ore deposits are known between Murphy in western North Carolina and Dadeville in eastern Alabama. Compared with those of the other major talc-mining districts, these are relatively small deposits, but some of them are important in that they are of high quality and serve specialized consumer needs.

NORTH CAROLINA

The Murphy talc district is about 85 miles long, extending from southwesternmost North Carolina into northern Georgia. Although talc is found in sedimentary rocks and also associated with ultramafic bodies in North Carolina, it is only those in sedimentary rocks that are of commercial interest at present. The host rock for these ore bodies is the Murphy Marble, which is generally more dolomitic than calcitic. Although the marble has been reported to be as thick as 400 feet or so, such thickness may be caused by structural deformation and therefore may be totally anomalous. The Murphy Marble in the vicinity of Murphy, North Carolina, has been divided into as many as eleven zones, only one of which (about 45 feet thick) is known to contain commercial talc deposits. Little information is available about the geology of the marble belt and its talc zone in areas away from mining activity, probably because climatic conditions cause outcrops to be few and far between.

Despite the relatively small size of the North Carolina talc deposits, the operations can be profitable because the purity and the color of the talc are extremely high and the products can compete with those manufactured from Montana talc ores as the only pure talc products of high color in North America that can be produced without the use of wet beneficiation methods. Tremolite is minor; indeed, even talc formed after tremolite, which is common in most other districts, is rare here.

The talc seems to have originated by "relatively simple metasomatic processes" (Chidester and others, 1964). Although the white talc-bearing zone in the Murphy area is dolomitic marble, which is locally "slightly sandy", Van Horn (1948) did not believe that the parent material contained sufficient magnesia and silica to permit the talc to form by dynamic metamorphism alone. Owens (1968), however, on the basis of a petrologic study of diamond drill cores, felt that the talc is of metamorphic origin. The age of the Murphy Marble has not yet been definitely determined. The general consensus, however, is that it is either latest Precambrian or Cambro-Ordovician.

Both open-pit and underground mining methods have been employed in the past, but recently the trend has been toward deeper underground mining. The developmental costs of shaft-sinking to relatively small ore bodies are among the highest such costs known to the writer, further testifying to the superior quality of these carbonate-derived ores.

Production figures for North Carolina talc are lumped together with those for pyrophyllite and soapstone by the U.S. Bureau of Mines in the Minerals Yearbook, making it difficult to determine the levels of talc production, but in recent years the total production of all three has ranged from 80,000 to 100,000 tons annually. Because North Carolina has in recent years been the only domestic producer of pyrophyllite, it is likely that North Carolina's talc production is less than 50,000 tons annually. North Carolina is at present the only domestic producer of talc crayons or welders pencils, a relatively minor but extremely lucrative product line.

Work being conducted by the North Carolina State Minerals Research Laboratory on the possibilities of beneficiating talc-rock from those deposits associated with ultramafic rocks is reportedly encouraging. Further advances in the wet beneficiation of talc-rock ores would increase the prospects that such deposits, which are similar to those in Vermont, would become of economic interest.

GEORGIA

A few occurrences of talc are known in the Canton area in northern Georgia, which is the southwesternmost part of the Murphy Marble Belt, but Georgia's principal talc deposits are in Murray County. Individual talc deposits may be tens of feet wide and several thousand feet long and may extend for several hundred feet downdip (Chidester and others, 1964). Furcron and others (1947), in the most detailed investigation to date, concluded that the talc has been formed by the alteration of dolomitic portions of the Cohutta Schist of Precambrian age; earlier workers, however, believed that it has been derived from peridotite. Needham (1972) thought that the soapstone and other talcose rocks of Murray County were formed by serpentinization, followed by metasomatism and metamorphism. Chidester and others (1964) stated that ultramafic bodies are not rare in Georgia, but no talc is known to be associated with them.

Talc in Murray County was discovered about 1872 and mining was begun shortly thereafter. Open-pit operations have historically been hampered by the presence of adverse surficial staining; mining operations are now conducted underground. The principal product lines have been crayons and finely ground products of both dark and light colors, but at the present time only the latter are being produced.

The U.S. Bureau of Mines stated (Minerals Yearbook) that the production of "talc, soapstone, and pyrophyllite" in Georgia in 1973 amounted to 38,000 tons.

ALABAMA

Pure white talc is mined near Winterboro in Talladega County, Alabama; as far as is known, all of this production goes to cosmetic and pharmaceutical uses. The parent rock is a carbonate sequence of probable Cambro-Ordovician age, which underlies the area, but the geological relationships are far from clear (McMurray and Bowles, 1941).

Talc and anthophyllite asbestos deposits, first noted in 1873, are present in Tallapoosa and Chambers Counties, Alabama, where they are associated with ultramafic bodies (Neathery, 1968). The talc content ranges from 3 to 26 percent, probably averaging 20 percent for the better deposits, and annual production is about 5,000 tons (Neathery, 1970). Neathery and others (1967) have described flotation-concentration feasibility studies, which show that "good-grade talc concentrates" can be made from these ores, but the economics of such an operation are yet to be proved.

TEXAS

Texas has two talc districts – the Llano district in the central part of the state and the Allamoore district northwest of Van Horn in the westernmost part of the state. The latter district, the more recently put into production, is now the only one of importance and is the only one that will be discussed here.

The Allamoore district extends about 20 miles east-west and is as much as 5 miles wide. Its ore deposits are in the Allamoore Formation, of Precambrian age, which consists of "thousands of feet" of carbonate rocks, volcanic rocks, and phyllite (King and Flawn, 1953). The talc is associated with dolomite, but it may be observed to intergrade with phyllite in certain parts of the district. The talc-rock deposits are large tabular masses, which pinch and swell to widths as great as 300 feet and may be several thousand feet long. The strata, which are in the lower plate below a large overthrust fault (the upper plate having been almost entirely eroded), are vertical or dip steeply to the south. No ore body of which the writer is aware has ever been "bottomed-out" by either drilling or mining. Large iron-oxide-stained "horses" of either carbonate rock or volcanic rock are fairly common but are generally easily eliminated by the use of selective mining methods. Talc is commonly found "from the grass roots down", and the soil cover is generally less than 1 foot thick. Caliche is abundant in the uppermost 5 feet or so of these dark ore bodies but seldom causes any problems at greater depths.

Petrographic and X-ray studies of the ores indicate that tremolite is not present to any significant degree but dolomite is so finely admixed with the talc as to make it extremely unlikely that pure talc can ever be produced from the known ore bodies by present beneficiation techniques. There is little indication of a hydrothermal origin for these ores. The talc ore (ceramic-type) is generally strongly foliated, the individual folme ranging from paper-thin to as thick as ¼ inch. This dark Texas crude ore looks little like talc ore when one first visits the district, even to the trained observer. The first impression is to identify it as black shale or perlite or some other non-talc-bearing rock. Despite its dark or even black color and its "non-talc look", however, this talc-rock is a superior ceramic crude ore and has superior pressing qualities and excellent firing characteristics.

Flawn (1958) described the district in a stage of infancy, and King and Flawn (1953) described in detail the overall geology of the district and the surrounding areas. A more recent detailed study has been financed by the Texas Bureau of Economic Geology, but the results have not yet been compiled and made available.

All of the production has been from large open pits, with the exception of minor amounts of light-colored (generally pink to white) talc, which have been mined in small underground workings and then finely ground into filler and extender products. Almost all of the ore produced is shipped out of the district to the east, and even into Mexico, as crude unprocessed ore for use in the ceramic industry, particularly for the manufacture of wall tile.

Mining costs are probably the lowest anywhere for talc ores. Flawn (1958) gave the "costs of mining, transportation, and loading into cars" as ranging from \$1.75 to 3.00 per ton, and it is unlikely that these costs have subsequently increased more than would be expected from inflation and increased labor and equipment costs.

It is by far the youngest of all the major talc-mining districts of North America, for production commenced in 1952. The U.S. Bureau of Mines credited Texas with the production of 232,514 tons of ore in 1973.

CALIFORNIA-NEVADA

Of the major talc-mining districts of North America, the one that combines the largest area with the greatest number of productive commercial deposits is the one in southeastern California, which barely extends northward into Nevada. It is about 200 miles long and has an average width of 30 miles but is locally as much as 75 miles wide. Engel and Wright (1960) divided this long "belt" into three separate areas, each of which contains a slightly different characteristic type of deposit. This district is too large and its geology too complicated to be satisfactorily summarized within the scope of this paper. In general, however, all the deposits have been formed by the "metamorphism and hydrothermal replacement of siliceous and silicated magnesian marbles and limestones" (Engel and Wright, 1960).

The deposits come in all sizes. The Western-Acme mine complex near Tecopa in San Bernardino County, California, is more than 5,000 feet long (although locally severely complicated by cross-faulting) and as much as 80 feet wide and has been mined downdip for at least 350 feet. The deposits in the southern two areas occur in Precambrian sedimentary rocks, were probably formed in Precambrian time, and are spatially associated with a thick diabase sill intruded near the base of a widespread carbonate member. In the northernmost of the three areas, which has not been historically as important a producer as have the other two areas, deposits occur in Lower Paleozoic formations and are thought to have been formed by replacement processes, probably in Cretaceous or Tertiary time.

There are two main types of ore in this district: the "hard" ore of the miners is tremolitic, and the "soft" ore is talc schist. Many deposits contain both types, but their distribution is erratic and unpredictable. Most of the ore is markedly tremolitic, but there are some relatively small bodies of high-grade talc. The problem with these high-purity talc bodies, however, is that they generally cannot be mined by themselves, but must be extracted along with the tremolitic ores; therefore, the production of high-grade talc in California-Nevada today generally has to be a function of the production of tremolitic ores to supply the market for their products.

Most of the mining in the California-Nevada district has been done underground, relatively little mechanization is involved, and timbering costs are high. A small proportion of the district's production has been obtained by open-pit mining methods, but most such operations are decidedly sporadic.

In no other talc-mining district anywhere in North America are the mines so far from rail transportation as those in the California-Nevada district, but it serves mainly a special local market, especially southern California, and seemingly can meet and beat the current potential competition from other districts. Mills and other processing facilities are not located at or near the mines but in the Los Angeles area or at various points along the two railroad lines serving the Los Angeles area. Haulage routes to either a processing facility or the railroad are on the order of 50 miles or more.

Soapstone was mined from small deposits along the foothills of the western Sierra Nevada in the mid-1800's, but the current California-Nevada talc-mining district was established during World War I, when the area around Darwin in Inyo County, California, supplied block-grade steatite talc to compensate for the temporary elimination of foreign supplies. California production slacked off in the post-war period but was rejuvenated during World War II; since that time, however, California has not been a significant factor in the supply of steatite-grade talc. In the mid-1930's the use of California tremolitic ores for the manufacture of wall tile began to come into its own, and the ceramic industry became the major market, as it is today. The talc content of such ores is not critical, and a considerable amount of carbonate material can be tolerated, indeed may even be desirable.

HISTORY OF THE MONTANA TALC INDUSTRY

The only prior significant description of Montana talc deposits in the literature is that of Perry (1948). This excellent work, however, was compiled and published in the very early days of the Montana talc industry. In the almost thirty years since its publication that industry has undergone a period of amazing growth and development; therefore it is thought appropriate to present here some of the available background on the history of that period.

Much of the credit for the growth and development of the Montana talc industry belongs to two fine gentlemen who recognized, among other things, the unique quality of its ores and by their intelligent foresightedness, hard work, and perseverance paved the way for the current prominent position of Montana in North America's talc picture. Mr. Henry Mulryan (deceased, formerly President of Sierra Talc Company) and Mr. Walter K. Skeoch of Honolulu, Hawaii (formerly President of Southern California Minerals Company) began their involvement with Montana talc in the 1940's and are hereby acknowledged as the pioneers of that industry. Mr. Skeoch and one of Mr. Mulryan's sons have been so kind as to supply invaluable background information regarding the history of their contributions.

The following information concerning his part in the growth and development of the Montana talc industry has been supplied by Mr. Walter K. Skeoch . . .

"During the summer of 1942, the non-metallics division of the U.S. Bureau of Mines asked me to investigate and, if possible, develop a small outcrop of talc near Ennis, Montana. Samples from the Johnny Gulch outcrop and from a small exploratory pit were sent to several 'steatite ceramic' manufacturers who were then trying to find an American source for block talc. They insisted this was necessary for the supply of spacers or dividers used in radio filament lamps. They were dependent on imported material called 'Wonderstone' from Africa, which was satisfactory for gas lite tubes but could not withstand the high-intensity shock required for other products.

The samples were interesting but almost all had fine hair cracks when sawed into shape. The open pit proved hazardous, so a shaft was sunk and exploratory drifts driven. The market was for 2" x 2" x 8" blocks and we were offered 8¢ to 10¢ per pound for blocks sawed to size and delivered to railhead. The Vermont talc suppliers could supply such products, but the iron content was too high. The manufacturers refused to buy the ground material so we were obliged to cancel our lease when the owner, a Mr. Clark, would not sell the property. Sierra Talc was later successful in purchasing the property — now known as the Yellowstone Mine.

From that experience we learned of an outcrop of talc southeast of Dillon, Montana. No work had been done upon this property, and we purchased the mineral rights from a rancher, Mr. Clyde Smith. The original purchase of 40 acres was located in Axes Canyon. Originally we explored underground by vertical shaft and laterals and later by open-cut methods. This property, the Smith-Dillon Mine, produced a very pure talc that was much in demand as a steatite ceramic material. The U.S. Government stockpiled forty carloads of it for emergency use. The property was worked continuously from 1943 until the late 1960's, after the sale of Southern California Minerals Company to Pfizer, Inc. A second 40 acres was purchased from Mr. Smith about 1960 but did not prove productive.

Our Ogden, Utah, mill was completed in 1944. At first only a Raymond roller mill was installed, then later a high-speed Raymond hammer mill; still later Fine Pigments Corporation produced the extremely low-micron talc '399' at this facility.

The Barratts,* Montana, crushing plant was installed in 1943. The intention was to blend the Montana talcs at Ogden, Utah, with much whiter California ore – this was done successfully for the paint and paper trade. Then better talc was developed from the Stone Creek claims (Treasure State Mine) purchased from Mr. Claude Brown in 1952. The Barratts mill was completed in December 1954 with a large Raymond roller mill, a high-speed Raymond hammer mill, and a large Kidwell mill for Fine Pigments Corporation. At that time, starting in 1947 and lasting until 1965, Fine Pigments Corporation was owned 60% by Tri State Minerals Company (a division of Southern California Minerals Company) and 40% by Whittaker, Clark and Daniels Company, then of New York City. Tri State Minerals Company purchased the W.C.D. interest in 1965. The Ogden mill was closed and most of that equipment was moved to Barratts, but some of the equipment was moved to a new modern mill built at Dunn Siding, California (on the Union Pacific) in 1964-65 by Southern California Minerals Company.

Several other talc claims in Montana were purchased during the period 1946-1966. The largest, and the only one of these mined, is the Keystone-Regal, east of Dillon, Montana, purchased in 1947. The property was explored by a vertical shaft 110 feet deep and 100-foot long tunnels driven in all four directions – *all in talc*! This may be the largest body of talc on record. The quality is excellent, but not of such a good color as are the Stone Creek grades (Treasure Chest Mine).

The color on all the Montana grades was very much improved by the installation of sorting belts and vibrating-screen sizing devices and magnetic separators. An electric sorting table was installed but was discarded, as the manual maintenance work required was to great."

In February 1966 Mr. Walter K. Skeoch sold Southern California Minerals Company to Pfizer, Inc. of New York City. Its Montana talc mines and mill have been operated since then by the Minerals, Pigments, and Metals Division of that firm.

Mr. Henry T. ("Joe") Mulryan is President of Cyprus Industrial Minerals Company, the successor of Sierra Talc Company. His brother, Mr. James D. Mulryan, is Western Area Production Manager of Cyprus Industrial Minerals Company and is in charge of that firm's Montana talc operations, based at Three Forks, Montana, and has supplied the following information concerning, among other things, his father's part in the development and growth of the Montana talc industry.

"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 a 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. Cyprus took over the mine in late 1964 when they acquired Sierra Talc.

The Beaverhead Mine was discovered by a group including Bennett Owen and Bob Dutton. This property was nothing more than a prospect and was purchased by Sierra on a lease option in the early 1950's. Here again, Cyprus took over this property in 1964 when they acquired Sierra Talc.

The Yellowstone Mine began with Mr. L. F. Teutsch's operations as a small underground glory-holing type of operation. The talc was being mined primarily in the block lava area where there was a high percentage of manganese dendrites. This material was being used in the electronics industry for the manufacture of non-fired ceramic pieces, such as insulator bases for high-frequency electronic tubes. In the late 1940's, when Sierra took over, there was some extensive underground work primarily to try to delineate the deposit and to find out whether open-pit mining was feasible and also to get some larger samples than we had had in the past to work with in our lab to determine what could be done with the talc. In the early 1950's the mine was opened up as an open pit and there has been no underground work since.

At the Beaverhead Mine the previous owners had done very little, if anything, other than assessment work. In the mid-1950's, when Sierra took over, some exploratory underground work was done. In the early 1960's assessment work was being done in the form of stripping, with the idea of eventually opening up the deposit. By the late 1960's the mine was opened up for open-pit operations and all underground work ceased. This mine operates on a seasonal basis normally because of the altitude and weather conditions at that altitude.

At the Yellowstone Mine all of the talc shipped from the mine is hand sorted. The first sorting shed was installed in either the late 1940's or early 1950's. In this shed the waste is picked from the talc by the sorters. A new sorting shed was built in 1958-59 and the reason for this was to improve the facilities as well as to increase the capacity. In 1971 we installed a pit sorter, as we call it, into which the lower-yield material is fed and the talc is picked from the waste. Basically, this is the processing history of the Yellowstone Mine at the mine site.

At the Beaverhead Mine there were no facilities of this type until 1974, at which time we put in a pilot-size pit sorter, which differs from the Yellowstone pit sorter in that basically the need to pick waste is lower at the Beaverhead than it is at the Yellowstone; therefore, the process more resembles the sorting shed at the latter than it does the pit sorter. Certain difficulties with the Beaverhead ore required, however, that it be washed prior to sorting; the nearest point at which this could reasonably be done was Alder, Montana. In the late 1960's or early 1970's a wash plant was installed at Alder, and the crushed ore was run through a log washer and the waste was then picked from the washed material. This system has remained basically unchanged since it was installed, except that occasionally we have found that the need to wash the ore has decreased with materials from certain areas of the pit.

*Spelled Barretts on Dillon West 7½-minute quadrangle

The Three Forks, Montana, grinding plant was built in 1960-61 with one roller mill and one Double Eighty-eight fluid-energy mill. A second such fluid-energy mill was added in 1963. A pellet system was added in 1970, and we have undergone a major expansion in 1973-74 in which we have added a third such fluid-energy mill, storage silos, etc., plus pneumatic conveying systems. We have also added a Stedman mill for the preparation of feed for the fluid-energy mills.

The Grand Island, Nebraska, grinding plant was built, I believe, in 1952 with only one roller mill. We put in the first fluid-energy mill, which was a single mill rather than a double mill, in 1955. The second one was installed about 1958. The plant was generally remodelled in 1962 and the two single fluid-energy mills were replaced by one Double Eighty-eight, and improvements were made in the packaging system. A second roller mill was added in 1969.

The basic difference in the two fluid-energy plants is the fact that Three Forks has a pelletizing system and a more sophisticated materials handling system, whereas Grand Island has only the basic necessities of such an operation. The flow sheet at Grand Island would be basically a crude-unloading and storage area, a jaw crusher, one of two roller mills, either of which can feed a packer bin or a feed bin for the fluid-energy mills, which in turn feed a second packaging system.

At Three Forks we have essentially the same system through the jaw crusher, but then we split to either a roller mill or a Stedman cage mill. Basically, the Stedman mill feeds the fluid-energy circuits, and the roller mill feeds the packer bin. The fluid-energy mills then feed silos from which material can be reclaimed to go either into the second packer bin directly or into the pelletizing feed system, from which it then goes to a third packaging station. Finished products are then loaded out as in any normal operation.

The sales in Europe of our fluid-energy-mill products from plants in the United States reached the point where we could justify the building of a plant in Europe. Gent, Belgium, was the site selected. This plant was constructed in 1965-66 and was basically comparable to the original Three Forks setup. We have installed a pellet mill and a second fluid-energy mill plus silos and pneumatic conveying since the plant was built. The products made in Europe are manufactured in large part from crude ore from the Yellowstone Mine; this has been the basic raw material used in the Belgium operation. Periodically we accumulate between 15,000 and 20,000 tons of crude ore and make single shipments of this size as needed in order to keep the Gent plant supplied with mill feed.

As indicated above, we originally used only Yellowstone crude in Europe, but as the Beaverhead crude became available we began to ship smaller quantities of it to Europe. When we established a working agreement with a talc producer in Australia, we began shipping crude talc from that country to Gent for grinding. The basic supplies of ores used at Gent, however, are still those from Montana.

Generally speaking, we started at the Montana operations in the steatite talc business for the ceramics market. Later, we began to produce material for the control of pitch in paper-pulp mills. This has become the predominant market for our Three Forks plant, the ceramic and paint industries being secondary. We have also begun recently to move into the synthetic rubber and plastics industries with our Montana talc products. Over the years the shifts in our product line have by and large been gradual."

GEOLOGY OF MONTANA TALC

The geology of Montana talc deposits has been described extensively in only one prior publication (Perry, 1948) but has been described briefly in three other publications (Heinrich, 1960; Heinrich and Rabbitt, 1960; Chidester and others, 1964).

High-purity talc deposits in southwestern Montana are *totally* restricted to dolomitic marble of the pre-Beltian sequence of "Cherry Creek-type rocks". The talc occurs as generally conformable lenses and stringers within the marble. If they are anywhere discordant, it is commonly at relatively low angles. Talc is invariably localized within a narrow stratigraphic range. Structural control, in the strictest sense, has not been recognized, but there is an *apparent* restriction of talc mineralization to that part of the marble that is spatially close to large bodies of the Dillon Granite Gneiss. The complete restriction of the talc mineralization to the marble *only* must indicate that the aqueous solutions that contributed to the deposition of talc were amenable to doing so in the *dolomite only*. Winkler (1974) gave the following reaction:

$$3 \text{ dolomite} + 4 \text{ quartz} + 1\ H_2O = 1 \text{ talc} + 3 \text{ calcite} + 3\ CO_2$$

This seems to be the most likely reaction to account for the formation of Montana talc deposits; inasmuch as the host dolomite is not notably siliceous adjacent to the talc, it is likely that most of the silica required was metasomatically introduced, probably along with the water.

In the Ruby Range the Dillon Granite Gneiss *may* have been emplaced before the talc was formed, but if this be the case, then the close spatial relationship between the talc and the granite gneiss suggests the probability of a relationship that must be explained in some manner. Garihan (1973) has noted that finer-grained dolomite and thin-bedded marble "are notably barren of talc" and his studies suggest that high-purity talc has invariably been formed as a replacement of pure coarsely crystalline dolomite marble. Furthermore, he concluded that "with the exception of one occurrence, talc mineralization in marble above the main mass of Dillon Gneiss is confined to one stratigraphic unit, the Regal marble". The Regal (Keystone) Mine and the Treasure Mines all occur within the Regal marble of Garihan (1973), who further concluded that "In general, talc is associated with tight folds, fractures, marble breccia zones, bedding planes and faults" and that all of these factors, along with texture and compositional and chemical factors, are important in localizing the formation of the talc.

Both Okuma (1971) and Garihan (1973) believed that the talc is genetically associated with the north northwest to northwest high-angle fault system. The writer disagrees, on the basis of his study of producing mines during the late 1960's, in which no evidence was found of differing composition, mineralogy, texture, etc., in areas proximal to such fault surfaces. It would seem that if those faults have been a factor in the formation of the talc, such changes and lateral variations would be readily recognized within the ore bodies – unless, of course, they have been masked by subsequent retrograde metamorphism.

It is peculiar that although tremolite has been noted by many workers near high-purity talc in southwestern Montana, all of the ores mined at present and in the past are and have been, to the writer's knowledge, totally free of detectable tremolite. Most chemical analyses of Montana talc ores express CaO as being present only in "trace" amounts, rather than as a definitive quantitative value. Of dozens of such samples collected by the writer and subjected to X-ray diffraction analysis, not a single one has shown a detectable amount of tremolite. The purity of Montana talc ores is shown in Table 10-1, as modified from Chidester and others (1964).

In the discussions of the individual Montana talc mines, deposits, and prospects, the term "talc-zone" will be used to denote that stratigraphic zone that is susceptible to the formation of talc. All of this zone may be converted to talc, or none of it, or any part between these two extremes.

In large areas of numerous talc occurrences and considerable future talc potential, such as the area of the southern Ruby Range between Timber Gulch and Stone Creek and the area between Johnny Gulch and Cherry Creek along the eastern flank of the Gravelly Range, overlying soil cover is either completely absent or extremely thin. It would be most unusual over much of these areas to find soils (particularly in the low ground beneath timber stands) that are more than 1 foot thick. Indeed, at the Regal (Keystone) Mine, soil cover over the talc and dolomite bedrock is generally completely absent. In the high country north of Gordon Peak in the Ruby Range and in the central part

Table 10-1. —Chemical analyses of talc ore from the Dillon-Ennis district, Montana.

	Bozo Group mine[1]	Key-stone mine[2]	Smith-Dillon mine					Sweet water mine[1]	Treas-ure mine[2]	Yellowstone mine	
			Stea-tite[2]	SD-1[3]	SD-2[4]	SD-3[5]	SD-S[6]			Stea-tite[7]	Y-1[8]
SiO_2	58.2	57.72	58.46	62.25	62.06	61.78	62.37	61.0	60.40	62.65	62.73
Al_2O_3	1.50	1.13	1.90	.27	.50	.57	.50	.90	1.91	.31	.10
Fe_2O_3	.51	.48	.84	.71	.67	.75	.63	.10	.27	1.51	1.45
CaO	.20	1.34	.30	$<.05$	$<.05$	$<.05$	$<.05$	.20	.80	Trace	$<.05$
MgO	31.0	30.72	31.78	31.13	31.12	31.06	31.32	31.7	30.81	30.23	30.32
K_2O	....	Trace	Trace	.02	.01	.02	.01	....	.14	.05	.01
Na_2O	....	Trace	Trace	.06	.07	.08	.07	....	.20	.15	.03
H_2O-				.14	.18	.17	.10			.08	.27
H_2O+	5.8	5.94	6.22	5.03	5.09	5.17	4.90	5.6	5.15	4.87	5.14
CO_2				Nil	Nil	Nil	Nil			.27	Nil

[1]Analyst unknown. Data from S. W. Stockdale, American Chemet Corp.
[2]Analysis by Raymond G. Osborne Laboratories, Inc.
[3]Massive white to pale-green opaque to translucent fine-grained to dense talc rock with intermixed splotches and veinlets of gray and darker green talc. Contains scattered tiny flakes of graphite and a few dendrites of manganese oxide. Analysis by Leonard Shapiro, U.S. Geological Survey.
[4]White to pale-green or cream-colored massive talc rock, predominantly fine grained but with variable proportion of disseminated medium-sized folia or plates of talc. Analysis by Leonard Shapiro.
[5]Fine-scale intermixture of types SD-1 and SD-2. Analysis by Leonard Shapiro.
[6]Material representative of whiter and denser parts of sample SD-1. Analysis by Leonard Shapiro.
[7]Analysis by A. J. MacArthur, Sierra Talc and Clay Co.
[8]Dense pale-green talc. Analysis by Leonard Shapiro.

of that range to the north of Stone Creek thicker soils are developed, however, particularly in stands of timber. It is in such areas that a geochemical approach to ore-finding, should such prove feasible, would prove invaluable for the discovery of concealed talc deposits – the normal system of "float-prospecting" does not work well in such areas.

Over large areas of the northwesternmost part of the southwestern flank of the Ruby Range the bedrock has been sharply pedimented and major parts of large acreages have bedrock actually exposed or have "bedrock-at-the-grassroots". The area between Carter Creek and the divide between Hoffman Creek and Winnipeg Creek, from the Regal (Keystone) Mine northwesterly to the floor of the Beaverhead Valley is an excellent example.

Along the southwest edge of the Ruby Range, thick alluvial terrace deposits conceal vast areas of bedrock that could contain talc, but it is unlikely that methods will ever be found to assess whether or not talc deposits may be present there at depth. Going downhill to the northwest from the range divide, one comes into the pedimented area, then into the terraced area, and finally into the alluvial fill of the Beaverhead Valley.

The crucial reason that we have not attained a better and more nearly complete understanding of the geology of Montana talc deposits is that no geologist has ever "lived with" a Montana talc deposit or mine from the time of its discovery through its developmental stages and on into its period of mining activity. Any field geologist who has attempted to decipher geological relationships in trenches dug long ago in talcose rocks knows what an exercise in frustration it can be! The talc exploration geologist should be afforded the opportunity to map and sample while the bulldozer is there. Talc producers generally feel that talc mines can be operated without geological control or advice. Until daily geological studies are made upon such deposits, it stands to reason that they will continue to remain enigmas!

ORIGIN OF TALC IN MONTANA

Commercial talc ores in Montana have formed *only* in dolomitic marble of pre-Beltian age. Although talc in other districts has formed through the alteration of ultramafic rocks, no such origin is known to the writer for any commercial deposit in Montana.

Garihan (1973) has recognized that many marble layers in the Ruby Range that have been host to the formation of talc deposits are not quartzose nor do they contain interbeds of metaquartzite; therefore, he believed that the silica needed for the formation of the talc had to be introduced. The writer has made several similar observations and fully agrees with Garihan's conclusion. Garihan (1973) also stated that "the talc was derived chiefly from low-grade regional metamorphism of dolomitic marbles, through the action of hydrothermal solutions containing silica and perhaps magnesia". Retrograde metamorphism of tremolite to form talc, so common and important in other districts, is thought not to have been a factor in the Ruby Range because tremolite is not known to be present in Montana talc ores.

Okuma (1971) thought that some of the talc in the Ruby Range may have been formed as the result of the replacement of serpentine and tremolite. The writer does not dispute this possibility but stresses that *all* of the known *commercial* talc bodies have been formed from dolomitic marble *only*. It seems very unlikely that such ore bodies have been invariably *completely* altered to talc, leaving no contained tremolite or serpentine remaining whatsoever; many such ore bodies, however, do contain large "horses" of unaltered dolomite, which are either mined around or thrown to waste.

All of the pre-Cherry Creek rocks and the "Cherry Creek-type rocks" and most of the rock types of the Dillon Granite Gneiss have been subjected to upper amphibolite grades of regional metamorphism, a long-lived metamorphic event of pre-Beltian time, which included the development of intense isoclinal deformation. It is unlikely that the talc was formed during the period of upper amphibolite regional metamorphism, but it could well have been formed during the period of regional metamorphism of greenschist grade, which post-dated the amphibolite period and predated the intrusion of the diabase dikes. If the age of the dikes is Precambrian, which although not absolutely proved is very likely, then the talc was almost certainly formed in Precambrian time. This age of formation seems most likely, for were the talc to have been formed in Cambrian or later time it would be extremely unlikely that no talc at all would have been formed in the thick dolomite units of the Cambro-Ordovician Systems in the northern third of the Ruby Range (Tysdal, 1970). Garihan (1973) noted that talc has not been found in those Paleozoic dolomite strata in the northern third of the range, yet talc has been formed in the pre-Beltian dolomites at many localities very near the Paleozoic outcrops. This, plus the fact that the Paleozoic rocks are completely unmetamorphosed, led him to conclude that the age of the talc mineralization was Precambrian. Okuma (1971) also thought that the most likely age of the talc mineralization was Precambrian. Although the writer has no firm proof one way or the other, he concurs fully with this age assignment for the formation of the talc. Okuma (1971) stated that "The talc bodies result from the replacement of dolomitic marbles by aqueous solutions rich in silica" and he further stressed that "Areas of retrograde metamorphism may be of special significance in talc prospecting".

Van Horn (1948) has studied in detail the talc deposits of the Murphy Marble Belt in southwesternmost North Carolina. It is interesting that the geology of this district is similar in many ways to that of Montana and that many of his conclusions concerning the genesis of the Murphy talc ores are also appropriate for the genesis of Montana talc ores. Van Horn thought that simple dynamic metamorphism could not, by itself, have accounted for the formation of the Murphy talc ores because of the lack of silica and magnesia in the original marble, but he believed that such metamorphism might have formed zones of weakness in the marble. The subsequent introduction of hot aqueous solutions may have partly silicified the dolomite and at about the same time, or possibly somewhat later, may have formed talc bodies in such zones of weakness.

The writer believes that the mechanism of formation of Montana talc bodies was probably extremely similar to that postulated by Van Horn (1948) for the Murphy, North Carolina, talc ores. The dynamic metamorphism of the earlier upper amphibolite period may have formed zones of weakness and allowed the introduction of siliceous material (probably from the Dillon Granite Gneiss) and possibly some magnesia also (probably remobilized from amphibolite and other ultramafic rocks). After this metasomatic event had afforded the opportunity for the introduction of all the constituents necessary for the formation of the talc, it is thought that the talc itself could have been formed during the retrograde metamorphism; i.e., the event of greenschist grade that Okuma (1971) and Garihan (1973) judged to have been widespread over both of their areas. This theory of origin can neither be proved nor disproved at this time; the final solution must await detailed studies of paragenesis by workers who can follow the mining of these talc ore bodies over sufficiently lengthy periods of time.

GEOGRAPHICAL DISTRIBUTION OF MONTANA TALC

All commercial Montana talc deposits of which the writer is aware are contained within pre-Beltian metasedimentary strata. They are also geographically restricted to a relatively small area in southwesternmost Montana (Fig. 10-2) bounded by the Beaverhead-Jefferson, Madison, and Red Rock Rivers; more specifically to parts of the Ruby Range, the Greenhorn Range, and the Gravelly Range. Talc occurrences are known in adjacent ranges, especially in the Tobacco Root Mountains, but these have not yet produced any ore.

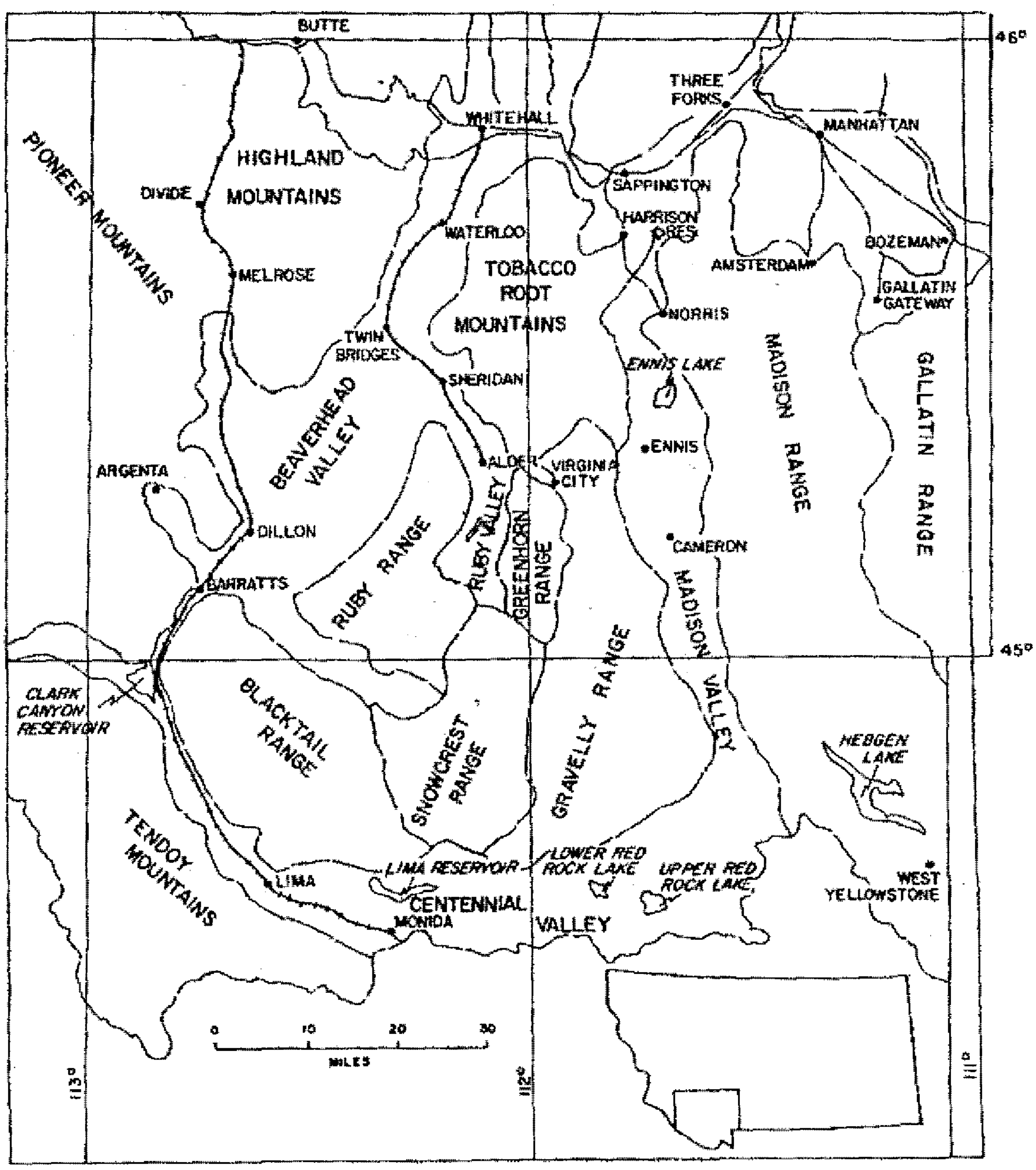
The talc has invariably been developed within dolomite marble of pre-Beltian age. These marble and associated metasedimentary strata are known as the Cherry Creek Group and were originally studied and described by Peale (1896) south of Ennis, Montana. The Pony Series, as described by Tansley and others (1933) in the Tobacco Root Mountains, is not known to occur with the dolomitic marble of the Cherry Creek in any area where the latter contains commercial talc deposits. The Dillon Granite Gneiss is younger than the dolomitic marble but still pre-Beltian in age.

Ross and others (1955) have mapped the unit in which all of the known commercial talc occurs as "Pre-Belt gneiss, schist, and related rocks" and it constitutes significant portions of an area about 180 miles long in an east-west direction (Red Lodge to Bannack) and 85 miles wide (Three Forks to the Idaho-Montana line near Upper Red Rock Lake). The unit is a conspicuous and predominant one over this area of 15,000 square miles and locally makes up single homogeneous blocks of several hundred square miles each. The dolomitic marble, however, is not an integral part of this unit over its entire extent. As known today, admittedly from fragmental and incomplete information, the dolomitic marble is probably significant only in the Ruby Range, the Greenhorn Range, the Gravelly Range, the Tobacco Root Mountains, and possibly in part of the Madison Range.

Perry (1948) has described several talc deposits in the Ruby Range, the Gravelly Range, and the Greenhorn Range, and his work is of interest in that it describes the Montana talc-mining district and its deposits in their early productive stages. Much mining and prospecting have been accomplished since then, however, and it is one of the purposes of this paper to update Perry's work.

The two ranges that contain all of the large Montana talc deposits, namely the Ruby and Gravelly Ranges, will be the ones dealt with at most length in this paper. They have the most obvious present potential and may well have the best future potential. The other areas and ranges mentioned above are, at the present time, still strictly wildcat areas.

The areal geology of the Greenhorn Range has never been published. The Ruby Range has been described in reconnaissance fashion by Klepper (1950). The entire Ruby Range has been mapped in recent years by student investigators, but the results of this work have not yet been published. Tysdal (1970) mapped the northern third of the Ruby Range, which



10-2. —Index map of southwestern Montana.

consists for the most part of Paleozoic strata. Garihan (1973) in the central part of the Ruby Range and Okuma (1971) in the southern part, in a joint study that was subsidized by Pfizer, Inc., mapped all of that range that has, in the writer's opinion, any significant chance of containing commercial talc deposits.

Mann (1954, 1960) mapped much of the Gravelly Range, including significant amounts of pre-Beltian rocks, but did not differentiate them into separate units. Hadley (1969a, 1969b) mapped key areas along the eastern flank of the Gravelly Range, which give considerable insight into the talc potential of that area. Student investigators are currently working in and mapping portions of the Gravelly Range, but it will be some time before that work is reported.

It is difficult to discard a stratigraphic name such as "Cherry Creek", because of its longevity and widespread usage, but the writer chooses not to use it without qualification (except at its type area), for there is no way to be certain that one is always referring to sequences of the same age when widely scattered outcrops of pre-Beltian dolomitic marble are being considered. The Cherry Creek Group, as defined by Peale (1896) south of Ennis, Montana, consists of more than 7,000 feet of interlaminated gneiss, mica schist, marble, crystalline limestone, and quartzite. Heinrich and Rabbitt (1960) restudied the type area and characterized the Cherry Creek Group as containing the following major classes of rock types:

1. Marble, calc-schist, and lime-silicate gneiss
2. Quartzite and quartz schist
3. Phyllite
4. Mica schist
5. Kyanite schist and kyanite-staurolite schist
6. Sillimanite schist and gneiss
7. Magnetite schist and related rocks ("iron formation")
8. Amphibole gneiss, schist, and amphibolite
9. Quartz-feldspar gneiss, granitic gneiss, biotite, and injection gneiss

The marble layers form the thickest and the most persistent of the units within the group at this locality, and individual marble layers as much as 1,500 feet thick have been noted. Quartzite units as thick as 550 feet have also been noted. The "total minimum thickness of the Cherry Creek group in its type area is estimated to be about 30,000 feet" (Heinrich and Rabbitt, 1960).

Heinrich (1960) studied the Cherry Creek Group in the Ruby Range and reported the following as the characteristic rock types:

1. Marble and calcium-magnesium-silicate gneiss
2. Quartzite and conglomeratic quartzite
3. Muscovite and biotite schist, some garnetiferous
4. Biotite gneiss, some containing various amounts of garnet
5. Sillimanite schist and gneiss, some garnetiferous
6. Hypersthene-magnetite schist
7. Pyroxene schist and gneiss
8. Chlorite schist
9. Corundum schist
10. Hornblende gneiss, amphibolite, and schist
11. Anthophyllitic gneiss and schist

The marble units are the most conspicuous; individual units as thick as 1,600 feet have been noted, but such thicknesses may not be original. They may have resulted from flowage that occurred during the epochs of intense folding in Precambrian time.

In the Tobacco Root Mountains, Tansley and others (1933) described the Cherry Creek Group as consisting of "quartzites, limestones, schists, and gneisses whose sedimentary origin is unquestionable, whereas the Pony group possesses features common to both sedimentary and igneous rocks. No limestone or true quartzite occurs in the Pony group".

"Cherry Creek-type rocks" will be discussed and described below in detail; the use of the foregoing terminology will allude to the fact that the term Cherry Creek Group, as used in the past for occurrences outside the type locality area, should not necessarily imply stratigraphic correlation or time equivalence. Therefore, except for the type locality in the Gravelly Range, the term "Cherry Creek-type rocks" will be used in this paper to denote a series of pre-Beltian strata of unquestionable sedimentary origin, characterized by marble and quartzite and containing abundant schist and minor gneiss, with no implication whatsoever that any of the geographically isolated sequences can be correlated stratigraphically with any other.

GEOLOGY OF THE RUBY RANGE

The Ruby Range is elongate in the general direction of N. 40° E., being about 30 miles long and having a width of 10 to 15 miles. Altitudes along the base of the range are generally 6,000 feet or so above sea level; the highest peaks are in the northern third of the range, Ruby Peak at 9,391 feet above sea level being the highest point in the range. The Ruby Range may be divided into several geological blocks, each having certain unifying characteristics.

A generalized geological map (Fig. 10-3) has been compiled by the writer from his own field work and from unpublished maps by James, Wier, and Shaw (1969), Tysdal (1970), Okuma (1971), and Garihan (1973). These four unpublished maps cover the entire Ruby Range except for a very small triangular segment at its southeasternmost extremity. Six geological units are shown on Figure 10-3; three of Precambrian age, one "mixed" Precambrian-Paleozoic, one almost entirely Paleozoic, and one Tertiary-Quaternary. The second oldest unit is that one along the southwestern flank of the range that contains "Cherry Creek-type rocks". Virtually all of the known dolomitic marble in the range is within the boundaries of this unit; those that are not are contained within the undifferentiated Precambrian portions of the "mixed" Precambrian-Paleozoic unit. The granite gneiss unit along the southeastern flank of the range is the one that previous workers have called the "Dillon Granite Gneiss". The distribution of this unit on Figure 10-3 has been delineated so as to exclude all known marble units. The "mixed" Precambrian-Paleozoic unit has been established because it covers an area where the relationships between the intensely folded Precambrian units and the homoclinal Paleozoic formations have been complicated by Laramide block faulting, resulting in a mosaic-like complex of the two very different sequences. The Paleozoic block consists almost entirely of Cambrian-Pennsylvanian formations, but has some scattered and relatively minor outcrops of Cretaceous, Tertiary, and Quaternary units. A Tertiary-Quaternary block is shown along the central portion of the eastern flank of the range where units of such ages are so widespread that they can readily be shown, even on the scale of Figure 10-3.

ROCK UNITS

PRE-CHERRY CREEK ROCKS

Both Okuma (1971) and Garihan (1973) recognized the presence of rocks pre-dating "Cherry Creek-type rocks" along the southern margin and the eastern margin, respectively, of the Ruby Range. Okuma listed the main rock types of this group as:

Biotite-garnet-quartz-feldspar gneiss
Biotite-garnet gneiss
Amphibolite and hornblende gneiss

and stated that most of these rocks are coarse grained and banded. He believed that the discontinuous nature of some of the amphibolite bodies indicates their origin as mafic sills and provides evidence for an intrusive origin. Okuma mapped this group as being confined to the southeasternmost part of his area and described it as being composed of metasedimentray, meta-igneous, and migmatitic units.

Garihan (1973) described "a belt two kilometers wide between Sage and Mormon Creeks" of pre-Cherry Creek rocks along the central part of the eastern flank of the range, but the area that is so exposed is too small to allow the establishment of firm and reliable relationships to other lithologic sequences in the range. This group of pre-Cherry Creek rocks includes gneiss, schist, amphibolite, and migmatite – but no marble or metaquartzite.

Heinrich (1960) described rocks of the "pre-Cherry Creek group" in the Ruby Range as "gneissic, banded, and coarse-grained" and noted the absence of distinctive laterally persistent units. Schist was noted as markedly subordinate to gneiss.

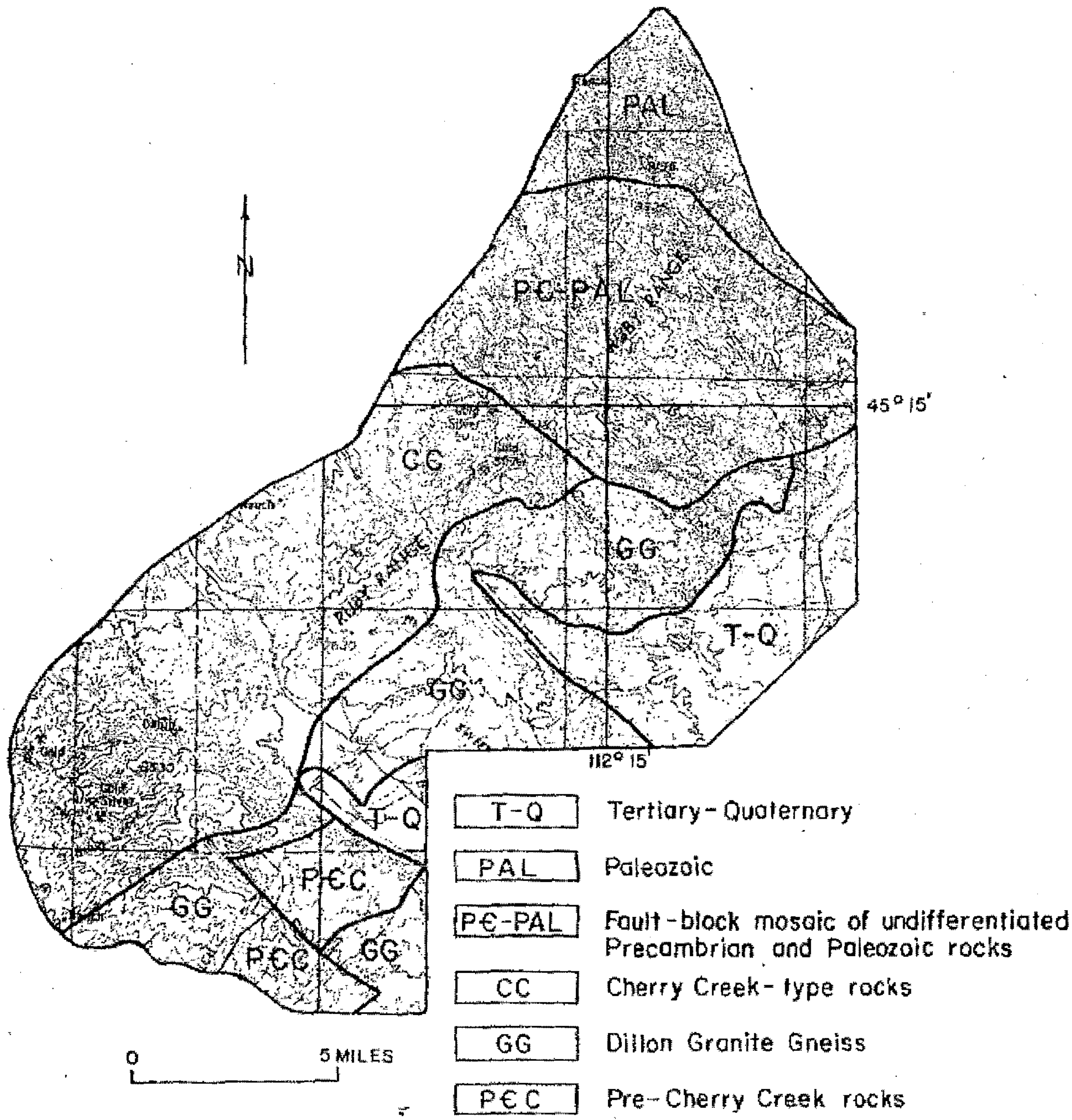
"CHERRY CREEK-TYPE ROCKS"

Particular attention was paid to the "Cherry Creek-type rocks" by both Okuma (1971) and Garihan (1973) because a good deal of their attention was devoted toward talc occurrences, and *all* of the known commercial deposits of talc in the Ruby Range, and all of Montana for that matter, are found within the boundaries of dolomitic marble units of the "Cherry Creek-type rocks".

Okuma (1971) listed the following as the distinctive rock types of his "Cherry Creek Group":

1. Marble
2. Quartzite
3. Calcium-magnesium schist and quartzite
4. Amphibolite and hornblende gneiss
5. Mica schist
6. Sillimanite schist and sillimanite gneiss
7. Magnetite schist (Iron Formation)
8. Other rock types (not mapped separately)

The marble layers are conspicuous and invaluable as structural marker units and have been mapped as 30 to several hundred feet thick. They are generally well-bedded, individual layers ranging from 6 inches to 4 feet in thickness. The dolomite generally crops out



10-3. —Generalized geologic map of Ruby Range, Beaverhead and Madison Counties.

better than its enclosing units, but is further sharply delineated by dense growths of greasewood and the presence of a light-orange lichen, which seemingly grows only upon the dolomite rock. The dolomite is generally white to light gray in fresh color. Actinolite and tremolite occur locally in the marble, but generally only near contacts with the ultramafic rocks; both minerals are unknown within commercial talc bodies. Garnets are also locally developed within the marble. Quartzite layers range from 15 to 180 feet in thickness, and although they are decidedly subordinate in volume compared to the marble, they do make excellent structural marker units. Amphibolite and hornblende gneiss are decidedly important volumetrically, and these units range from 6 inches to 1,500 feet in thickness. Most of the "Cherry Creek Group" is of sedimentary origin, according to Okuma (1971), but the amphibolite bodies probably were originally igneous dikes and sills.

Garihan (1973) stated that in the southern part of the Ruby Range the rocks of the "Cherry Creek Group" trend uniformly northeasterly, but in the central part of the range, especially along Stone Creek, they bend easterly and then southeasterly, and then continue in a general easterly direction into the Greenhorn Range in the vicinity of Ruby Dam. He recognized the following lithologic subdivisions of the "Cherry Creek Group":

1. Marble
2. Calc-silicate rock
3. Metaquartzite
4. Sillimanite schist
5. Biotite gneiss and schist
6. Chlorite schist and related rocks
7. Actinolite schist
8. "Iron Formation"
9. Amphibolite and related rocks
10. Anthophyllite gneiss and related rocks

and further specified that this order of listing does not in any way connote stratigraphic succession. He mapped marble layers 100 feet to approximately 1,500 feet thick and noted the presence of both calcitic and dolomitic marble; the calcitic variety is finer grained than the dolomitic variety, which is only locally fine grained and sugary textured as is the calcitic marble. Garihan (1973) stated that the marble commonly grades into calc-silicate rock and diopsidic marble, which is much more common than tremolitic marble. The calc-silicate rock, a relatively minor rock type, may or may not contain carbonate and is relatively rare in the central part of the range; it is much more widespread, however, in the southern part, where it has been used as marker beds for mapping. Sillimanite schist constitutes only 8 percent of Garihan's measured section along Stone Creek on the western flank of the range. This rock type is easily eroded, and several valleys, such as Mine Gulch, have been cut from it. It can be mapped locally by the micaceous soil formed upon it. Amphibolite constitutes more than 20 percent of the thickness of the "Cherry Creek Group" according to Garihan (1973) and is thus one of its more important lithologic units. He recognized one such unit as being about 1,000 feet thick and stated that some of these units can be traced "for several kilometers" laterally. Anthophyllitic amphibolite is common. Anthophyllite is also found in the gneiss and schist, as is cummingtonite; the two minerals are indistinguishable in the field but were not found together in thin section. Garihan (1973) also noted the occurrence of cordierite-anthophyllite gneiss, which is associated with amphibolite. There seems little doubt that these metamorphic units originally formed a sedimentary sequence.

Heinrich (1960) made a petrographic study of some of the marble in the "Cherry Creek Group" of the Ruby Range and by the use of staining techniques he found that dolomitic marble is about twice as abundant as calcitic marble.

The Carter Creek iron deposit, which bridges the Beaverhead-Madison County line southeast of Dillon, is in "Cherry Creek-type rocks". A detailed geological map of this deposit has been published (James and Wier, 1972).

DILLON GRANITE GNEISS

The Dillon Granite Gneiss of southwestern Montana has been described by Heinrich (1953, 1960).

The major rock types in the Dillon Granite Gneiss in the southern part of the Ruby Range, according to Okuma (1971) are:

1. Reddish-brown quartz feldspar gneiss
2. Foliated, light-colored pegmatitic gneiss
3. Coarse-grained biotite-feldspar-quartz gneiss
4. Olive-gray granite gneiss
5. Epidote-rich gneiss

The Dillon Granite Gneiss is generally conformable with those metasedimentary rocks that it has intruded (here the "Cherry Creek-type rocks"), and any cross-cutting relationships are generally minor in degree and angularity. Okuma (1971) favored a magmatic origin but recognized that this is not the only plausible genetic model.

In the central part of the Ruby Range, Garihan (1973) recognized three major rock types in the Dillon Granite Gneiss:

Biotite-hornblende-garnet gneiss
Pegmatitic Dillon Granite Gneiss
Chloritic Dillon Granite Gneiss

and stated that the Dillon Granite Gneiss is concordant with the "Cherry Creek-type rocks". All of those workers who have published major contributions upon the pre-Beltian rocks of the Ruby Range view the Dillon Granite Gneiss as a large tabular intrusive body, of batholithic proportion, which is in regional concordance with its enclosing rocks. Other alternatives, however, must be considered, such as granitization and the regional metamorphism of sedimentary sequences. Garihan (1973) provided detailed petrographic descriptions of the various types of rocks within the Dillon Granite Gneiss in his area.

Heinrich (1960) described "non-foliated pegmatites, which commonly are zoned", which transgress the grain of the country rock that includes them. These pegmatite bodies are not abundant, and although Heinrich judged them to be genetically related to the Dillon Granite Gneiss, he recognized that they may be much younger, possibly even of Laramide age. Unfortunately they are not known to come into contact anywhere with rocks younger than Dillon Granite Gneiss, and thus can be dated only as post-Dillon and probably pre-Tobacco Root batholith in age.

ULTRAMAFIC ROCKS

Ultramafic rock units, which Okuma (1971) referred to as peridotite, intrude the pre-Cherry Creek rocks, the "Cherry Creek Group", and the Dillon Granite Gneiss in the southwestern part of the Ruby Range. They are fifteen feet to several hundred feet wide.

Similarly, in the central part of the Ruby Range, Garihan (1973) described the pre-Cherry Creek rocks, the "Cherry Creek Group", and the Dillon Granite Gneiss as all playing host to ultramafic bodies. For the most part, he stated, the ultramafic bodies are concordant, i.e., parallel to the regional foliation, but they are locally discordant. The three major types of ultramafic rocks are metaperidotite, metapyroxenite, and serpentinite. Garihan (1973) thought that the ultramafic rocks were probably introduced at least as early as the complex isoclinal folding and upper amphibolite metamorphic event.

Heinrich (1960) described these ultramafic intrusive bodies as "unmetamorphosed" and noted that they are cut by the younger diabase bodies and also by the master faults of the Ruby Range (northwest system).

GRANULITES

Granulite rocks have been recognized by Garihan (1973) only in the northern part of the Mine Gulch 7½-minute quadrangle. In the field they are difficult to distinguish from amphibolite, and their outcrops are generally poor, but they have been recognized as granulites after thin-section study. They are common in terranes underlain by the Dillon Granite Gneiss, less common in those underlain by the "Cherry Creek Group", and are of interest because of their proximity to at least two talc-bearing marble units.

DIABASE DIKES

Diabase dikes, with preferred orientation in the north-northwest octant, are common along the southern two-thirds of the western flank of the Ruby Range. Okuma (1971) described them as ranging from 5 to 500 feet in width and extending as much as 5 miles. They commonly occupy long and relatively narrow distinctly depressed swales, which are generally free of all vegetation except grass and contain few or no outcrops. Their intrusion has had little or no effect upon the older country rocks, except for the marble, which may locally have had small amounts of serpentine developed. These dikes have not been subjected to the high-grade amphibolite metamorphic event, but have been metamorphosed to the greenschist facies. Okuma (1971) speculated about the age of these diabase dikes — as to whether they are of Precambrian, Paleozoic, or Tertiary age — and concluded that they are *probably* Precambrian.

Garihan (1973) stated that such diabase dikes are also common in the central part of the Ruby Range and that they may be as wide as 100 feet and as long as 1 mile, possibly more. They are easily recognized and traced upon aerial photographs. They generally cut the foliation of the enclosing pre-Beltian rocks at high angles and are not folded as are those older rocks. They are vertical or subvertical, as judged by the linear nature of their traces over extremely rugged topography, and they are decidedly less metamorphosed (generally only to the greenschist facies stage) than the enclosing rocks. Their lack of folding and foliation suggests that they were emplaced later than the phases of shearing and recrystallization that are associated with the ultramafic rocks and the other older pre-Beltian rocks. The mapping by Garihan (1973) and Tysdal (1970) suggests that these dikes have no intrusive relationship whatsoever with the Paleozoic strata of the northern third of the Ruby Range, despite their locally close proximity to those strata. If this inference is correct, the diabase dikes are of Precambrian age and are possibly the youngest Precambrian unit in the range.

A large diabase dike cuts what may well be the largest single talc deposit in the Ruby Range, the Regal (Keystone) Mine in sec. 2, T. 8 S., R. 7 W., Madison County. This dike is more than 200 feet wide at the mine and, with two other similar bodies along approximately the same strike, can be traced for about 4 miles in a north to north-northwest direction. It is probably vertical, or at least very close to vertical, as deduced from its almost linear trace over rugged topographic relief.

Heinrich (1960) described one diabase dike in Axes Canyon near the southwesternmost extremity of the Ruby Range as being 600 feet wide and 6 miles long. He stated that these bodies are generally intruded along faults, particularly the master fault set of the range (north to northwest system).

UNDIFFERENTIATED PRECAMBRIAN

Tysdal (1970) has mapped large areas of Precambrian rocks in the northern third of the Ruby Range but has not differentiated them into separate lithologic units or groups. He mentioned "metadolomite" as one of the five dominant rock types, however, so it is likely that "Cherry Creek-type rocks" are present.

PALEOZOIC

Tysdal (1970) described the Precambrian-Cambrian unconformity in the northern third of the Ruby Range as a nearly planar contact, and he mapped and measured Cambrian, Devonian, Mississippian, and Pennsylvanian formations that have an aggregate thickness of about 5,300 feet, of which approximately 1,500 feet (mostly Cambrian and Devonian) is dolomite or markedly dolomitic. No talc is known to have been formed in these younger dolomite beds.

CRETACEOUS-TERTIARY

Tysdal (1970, p. 94) asserted that the Beaverhead Formation, of Cretaceous-Tertiary age, contains quartzite clasts that have been eroded from Beltian rocks. Belt strata, completely absent from the Ruby Range, are known in the Pioneer Mountains to the west; this was probably the source.

TERTIARY-QUATERNARY

Late Tertiary and Quaternary strata are present in the Ruby Range, especially in its northern third along the lowermost flanks.

METAMORPHISM

All pre-Cherry Creek rocks, the "Cherry Creek Group", and most of the rock types of the Dillon Granite Gneiss have been subjected to upper amphibolite grades of metamorphism, according to Garihan (1973), "as part of a prolonged pre-Beltian episode which included isoclinal deformation and subsequent intrusion of basic dikes". He thought that the available information strongly suggests that the pre-Cherry Creek rocks may date back to 3.1×10^9 years ago and that the Dillon Granite Gneiss is on the order of 1.6×10^9 years old. He further inferred a second regional metamorphism of greenschist grade of an undetermined (but certainly Precambrian) absolute age.

Okuma (1971) also agreed that the Precambrian rocks of the Ruby Range have been subjected to regional metamorphism of the upper amphibolite facies and further observed that garnet is ubiquitous in rocks of the Ruby Range. He saw no clear evidence to suggest multiple metamorphism, i.e., multiple metamorphism of the highest rank achieved (upper amphibolite facies). His study of thin sections indicated that the later retrograde metamorphism of the greenschist facies was widespread and that the formation of the talc may well be related to this later metamorphism.

STRUCTURAL GEOLOGY

According to Okuma (1971) "the southwestern portion of the Ruby Range has remained relatively stable since its intense deformation in late Precambrian time". Almost throughout his area the foliation is "invariably parallel to the formational contacts of the different rock types". Isoclinal folds are characterized by parallel or near-parallel limbs, and Okuma recognized three phases of Precambrian folding. The prominent northwest- and north-northwest-trending master faults, which are readily recognized locally by the abrupt juxtaposition of radically different rock types, have essentially no topographic expression whatsoever, despite their large displacements. The Elk Creek Fault, trending N. 40° W., displaces the "Cherry Creek Group" – Dillon

Granite Gneiss contact a horizontal distance of 2 miles; the Red Canyon Fault displaces it about 1 mile. Okuma (1971) thought that the age of the high-angle faulting could be Laramide; if the strikes of the diabase dikes indicate Precambrian lines of weakness, however, then these faults could have originated in Precambrian time and been reactivated in the Tertiary. Okuma suggested that the pre-Cherry Creek rocks, the "Cherry Creek Group", and the Dillon Granite Gneiss were deformed contemporaneously. According to him, Precambrian structural deformation "was primarily by a combination of flexural-flow, slip or shear along schistosity, and plastic flow".

Those investigating in detail the pre-Beltian rocks of the Ruby Range recognize either two, three, or four phases of folding in Precambrian time. Tight isoclinal folding is common in such rocks throughout this area. The master northwest-trending faults, which are post-folding in age, are superimposed throughout the range at approximately right angles to the strike of the Precambrian foliation. This faulting is probably much more pervasive and important in scale than is presently recognized; the faults can be easily recognized where they cut the Precambrian-Paleozoic unconformity, but they may be extremely difficult to trace where areally confined to the Precambrian sequences. The range-bounding faults in the central part of the eastern flank of the range have an overall trend of about N. 50° E., but in the northern part of the eastern flank they trend north-northwest. The age of this high-angle faulting is difficult to ascertain. Garihan (1973) thought that the northwest-trending faults may have been initiated in Precambrian time, if one considers that the diabase dikes represent the establishment of weakness surfaces in the north-northwest octant in Precambrian time. He favored the theory of recurrent movement on these faults in Precambrian, Laramide, and post-Laramide times; the writer agrees that this is most plausible.

Tysdal (1970) described the Ruby Range as being on the western edge of the foreland of the Rocky Mountains in a structural setting that is characterized by:

a) high-angle faults cutting basement rocks.
b) extensive exposures of Precambrian metamorphic rocks in the cores of mountain uplifts.
c) relatively thin cover of Paleozoic and Mesozoic sedimentary rocks.

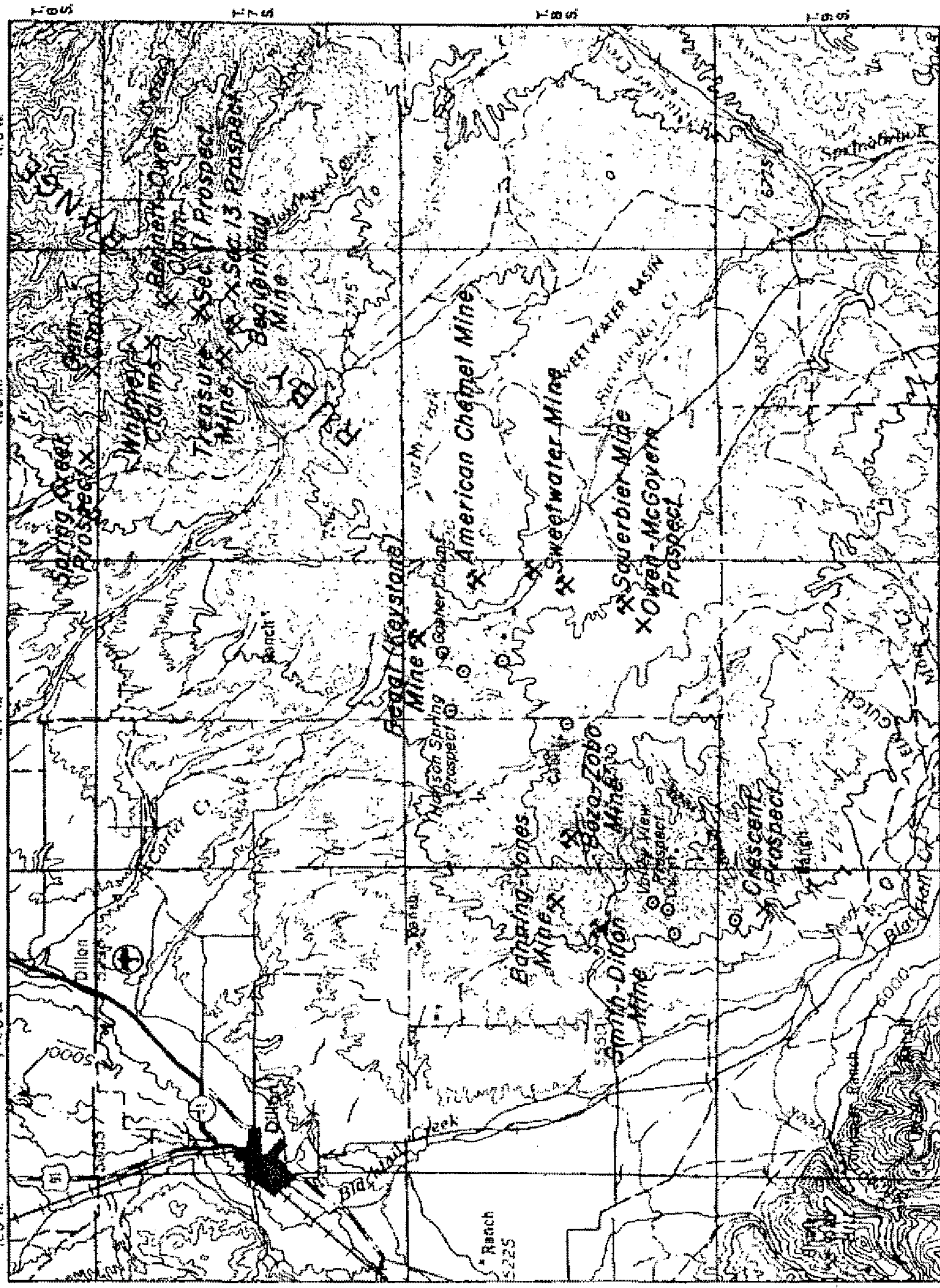
The Paleozoic and Mesozoic strata in the Ruby Range had an aggregate thickness of about 10,000 feet or less during deformation in the Late Cretaceous-early Tertiary, according to Tysdal (1970). Major normal faults border the western, northern, and much of the eastern sides of the range in Tysdal's area. He showed seven major fault blocks within the range, all delineated by en echelon northwest-trending high-angle faults; all except one of these faults are downthrown on the southwestern side and upthrown on the northeastern side. These basement blocks have been tilted to the northeast and plunge to the northwest. Tysdal (1970) described the northwest to north-northwest master faults in his area as having throws of 6,000 to 7,000 feet and stated that they generally truncate the northeast-trending faults, which are relatively minor in magnitude and importance. He has mapped broad anticlinal folds involving Cambrian formations, referring to them as flexural flow folds, but these structures are totally different than the tight isoclinal folds developed in the pre-Beltian rocks. He has also mapped synclinal folds, whose limbs locally become vertical and overturned. These anticlinal and synclinal folds are closely associated with the northwest to north-northwest master faults and were most likely formed as a consequence of their proximity to those major faults.

ACTIVE TALC MINES IN THE RUBY RANGE

TREASURE CHEST MINE

The Treasure Chest Mine, near the head of the Left Fork of Stone Creek in the north-central part of the Ruby Range, is owned by Pfizer, Inc. It is and has long been the most important producer in that range. The Treasure State Mine, which has not produced any talc ore for more than a decade, lies a few hundred feet downhill and to the west of the Treasure Chest Mine. The two are believed to be faulted-off segments of what was once a single ore body, and the writer has named the structure that separates them as the Treasure Fault (Fig. 10-4).

The Treasure Chest Mine lies midway on the south hillslope of the Left Fork of Stone Creek in the NW¼ sec. 14, T. 7 S., R. 6 W., Madison County, Montana (Mine Gulch 7½-minute quadrangle). This large tabular ore body has a strike length of about 1,000 feet (of which 700 feet of strike length on the western end has the greatest commercial potential) and horizontal width as great as 120 feet, and has been mined to a vertical depth of about 250 feet. Its strike ranges from east to N. 60° E., and the dip averages 55° northerly. The actual local strike must be determined by close scrutiny of the outcrops, for an intricate system of right-lateral faults has imparted an overall trend to the entire ore body of somewhat south of east.



10-4.—Talc mines and prospects, Ruby Range, Beaverhead and Madison Counties.

The Treasure Chest Mine is unusual among talc deposits in the Ruby Range in that throughout parts of its lateral extent a thick dolomitic marble unit has been completely converted to talc. The footwall is dark biotite schist, called "The Blackwall" by miners, and the hanging wall is Dillon Granite Gneiss, which is generally chloritic. The footwall schist is locally garnetiferous and extensively serpentinized and chloritized. The extensive alteration has resulted in a crumbly and relatively incoherent mass, which renders much of this schist susceptible to widespread and unpredictable sloughing into the pit. The presence of numerous but generally unmappable undulatory fault surfaces is indicated by the abundance of slickensides on fresh surfaces. The alteration and the faulting, plus the fact that the talc generally has been formed and is therefore mined right up to the vein-schist contact, all combine to constitute an extremely difficult safety problem. Several slides of schist footwall blocks have occurred during periods of mining activity; as the pit goes deeper, attaining a satisfactory amount of stability of the steep footwall will become an increasingly difficult problem.

The hanging wall is a medium- to coarse-grained variety of Dillon Granite Gneiss, which contains biotite and garnet. Individual beds are well layered, and the gneiss is concordant with both the talc-containing marble and the footwall schist.

The Treasure Chest Mine is situated along the nose of the major broad structural arch of the Ruby Range as mapped by Garihan (1973, Plate I). In the general vicinity of the mine the strata generally strike east to N. 60° E. and although the dips may range from 25° northerly to vertical, the common range is 45° to 65° northerly. Along with this regional dip, the major structural features include a strongly developed en echelon set of high-angle to vertical right-lateral faults striking N. 20° W. These faults may be as closely spaced horizontally as 100 feet or so, but the spacing is generally wider than this. The southwestern block has moved relatively upward along each one of the faults that has been recognized to date. The Treasure Fault is the most important of these within the mine area; it has displaced the Treasure ore body in right-lateral direction 150 to 200 feet. Present evidence within the mine area does not conclusively indicate whether the formation of the talc preceded or post-dated the faulting. The writer's work in the late 1960's suggested that the talc was formed prior to the faulting, but this conclusion is still unproved. The character of the "talc-zone" was nowhere observed to change appreciably, near or adjacent to the fault surfaces, and it is generally uniform within each individual fault-block. Geological relationships observed during the writer's investigations of this mine suggest that the alteration of dolomitic marble to talc within the "talc-zone" occurred first, and that subsequent high-angle block faulting jostled individual fault blocks around so that rocks of different lithology were directly juxtaposed.

The presence of the right-lateral faults went unrecognized for many years during the early operation of this open pit. This is understandable, for little if any structure can be observed within the "talc-zone", which reacts plastically to deformative forces. A further complication is that lithologic contacts must generally be observed during the mining operations; even only a few days after they have been originally unearthed, and certainly at the end of the mining season, such relationships have generally become totally obscured by the movement of mining machinery, by slumping, or by concealment under waste material. During the plane-table-and-alidade mapping performed by the writer in 1969 it was even necessary to call upon earth-moving machines equipped with ripper teeth in order to locate lithologic contacts within the pit floor, so pervasive and obscuring were the huge amounts of dust generated by the mining activity. The extent of the faulting cannot be accurately mapped nor truly understood until one works in the footwall schist or the hanging-wall granite gneiss in areas close to the "talc-zone" itself.

The westernmost block of the Treasure Chest Mine, between the Treasure and Pit Faults, (see Garihan, 1973, Fig. 42, p. 150) has not over the years contained appreciable amounts of the highest-grade talc ore. Chloritic material and white quartz veinlets have been locally so abundant that no ore whatsoever could be recovered from this portion of the "talc-zone", and it has thus either gone to waste or has been left. The area between the Pit Fault and the westernmost exposure of the Dolomite Fault has contained the best ore mined on this property. During the late 1960's the "talc-zone" between the footwall schist and the hanging-wall gneiss was composed entirely of the highest-grade talc over a horizontal width of 120 feet (true vein width of about 95 feet). From the Dolomite Fault eastward, the quality of the ore within the "talc-zone" becomes lower and lower, and the talc is contaminated by large "horses" of dolomite and dolomitic talc as well as by large "knobs" of silicified material. Where these contaminants are present in large masses they can easily be mined around and left or can be sorted out and sent to waste by the use of mining machinery, but inasmuch as hand-sorting methods are not employed at this mine, much material containing appreciable quantities of pure talc is thrown to waste from areas where contamination by waste is intimate and on a small scale. In recent years efforts have been made to extend the Treasure Chest Mine to the east, but present exposures indicate that these attempts have met with little success. Much high-grade talc is present in the easternmost reaches of the present mine area, but its recovery will require the use of sorting methods rather than large earth-moving machinery alone, which is the present method of operation.

In the mid-1960's the waste:ore ratio was on the order of 3:1 or 4:1, but it is now on the order of 15:1 and will soon be at least as great as 20:1. Present mining costs may be approaching the point that would justify considering the alternative of underground mining. Even if the operating costs of the latter were greater, the improved safety that would result from eliminating the high-standing dangerous "Blackwall" might help to offset them. In addition to the recent large increases in the waste:ore ratio, it is now necessary to transport waste greater and greater distances from the mine area.

The highest grade talc from the Treasure Chest Mine must rank with the purest grades of talc known throughout the world. Large blocks have been mined (consisting of several thousand tons each) that are either white or pale greenish and are homogeneously cryptocrystalline and massive pure talc. Garihan (1973) has petrographically identified minor amounts of apatite, chlorite, graphite, limonite, and rutile in the talc ores of this mine, but these impurities have not commonly been abundant enough to render the talc unsuitable for the mill. Talc that is darker green than usual is termed "#2 ore" by the miners, but compositional differences between it and the lighter-colored "#1 ore" are slight; it is the color that is the important difference.

All of the marble that has been observed within the mine area by the writer is dolomitic, not calcitic. The Treasure Chest Mine does not have enough recorded history to indicate whether the "talc-zone" is thinning or thickening with depth, i.e., are we within the upper half or the lower half of a lenticular body? The most easterly of the right-lateral high-angle to vertical faults that has been recognized within the mine area lies about 400 feet east of the easternmost recognizable part of the Dolomite Fault. If the ore body or indeed even the "talc-zone" is present east of this unnamed fault, and if the pattern of right-lateral displacement *only* persists, then the talc would have to be uphill from and southeast of the present mine area. Efforts to locate such an easterly extension by bulldozing and drilling have thus far been, to the writer's best knowledge, unsuccessful.

Talc ore from the Treasure Chest Mine is trucked 30 miles or so to the Pfizer mill at Barratts Siding on the Union Pacific Railroad about 8 miles southwest of Dillon.

TREASURE STATE MINE

The Treasure State Mine was in operation long before the presence of talc ore in the Treasure Chest Mine area was even known. Shortly after the latter mine was opened, the Treasure State Mine was closed; it has been inactive ever since, although much high-grade pure talc ore obviously remains in this lower deposit. It is situated in the NW¼ sec. 14, T. 7 S., R. 6 W., Madison County (Mine Gulch 7½-minute quadrangle), downhill and to the west across the Treasure Fault from the Treasure Chest Mine.

The Treasure State Mine is obviously a faulted-off extension of the same ore body as that which produces at the Treasure Chest Mine. Its offset has been right lateral, the same direction of relative movement as is shown along all of the known faults within the Treasure Chest Mine area. The geology of the two mines is almost identical. Talc in the Treasure State Mine has been proved to have a strike length of at least 400 feet and a horizontal width of 75 to 100 feet and has been mined down dip to a depth of about 200 feet. The writer did not have the opportunity to observe this mine during its operation, but it is likely that blocks of high-purity talc without dolomitic or siliceous "horses" were not as large here as those in the Treasure Chest Mine. This grade factor plus the greater length and width of the latter deposit were probably the principal reasons that the Treasure State Mine was abandoned in favor of the Treasure Chest Mine; nevertheless, it is certainly true that much recoverable ore-grade talc remains in the Treasure State Mine, awaiting the day when its cost of recovery will become compettitive with then-present sources. In the last days of its operation this mine was certainly "high-graded"; before it can be reactivated some of the sins of the past must be redeemed and paid for.

As in the "talc-zone" of the Treasure Chest Mine, talc in the Treasure State Mine may locally extend from the footwall schist to the hanging-wall granite gneiss. Garihan (1973), however, has described some interesting relationships in this mine that are not well shown in the Treasure Chest Mine. He described a four-fold division of rock types from south (footwall) to north (hanging wall): schist, pale-green talc, a dark blue-green talcose-rock zone with gneissic foliation, and finally less-altered varieties of Dillon Granite Gneiss.

He further described the talcose-rock zone as being "probably highly altered Dillon Gneiss". The presence of a "transitional zone" between the "talc-zone" and the hanging wall in the Treasure Chest Mine has been locally noted by the writer, but it is either not nearly as well developed there as in the Treasure State Mine or else it may be present but a lack of exposures does not allow its widespread recognition in this active mining area.

Any westward extension of the talc of the Treasure State Mine is presently enigmatic. Poorly developed evidence suggests that it might be faulted uphill by a totally anomalous left-lateral fault, but such a possibility would have to be proved with the bulldozer or the drill. It is extremely unlikely, however, that the present westernmost exposures of this ore body are identical with its actual westernmost extent.

Both the Treasure Chest Mine and the Treasure State Mine are owned by the Minerals, Pigments and Metals Division of Pfizer, Inc., which obtained them through the acquisition of the assets of Southern California Minerals Company in 1966.

BEAVERHEAD MINE

The Beaverhead Mine, owned and operated by Cyprus Industrial Minerals Company, lies southeast of the Treasure Chest and Treasure State Mines and over the crest of an east-west ridge from them. Present operations are within the NW¼ SE¼ sec. 14, T. 7 S., R. 6 W., Madison County (Mine Gulch 7½-minute quadrangle). The mine lies high on a steep hillslope north of the head of the Middle Fork of Stone Creek, only 2,000 feet or so southeast of Pfizer's Treasure Chest Mine.

The geology of this mine is similar to that of the Pfizer mines to the north, except for the strong possibility that the strata of the Beaverhead Mine have been overturned with respect to the strata of the Pfizer mines. At the Beaverhead Mine we have essentially a single body of talc that has at least 800 feet of strike length, and is offset by relatively minor lateral faults. It ranges in horizontal width from 25 to 100 feet (probably averaging near 75 feet), and has locally been mined to a vertical depth of 150 feet. The strata dip homoclinally north 35° to 70°; the average dip is probably close to 45°. The strike ranges from east to slightly north of east.

The footwall is dolomitic, and the hanging wall is composed of schist and gneiss. This relationship is exactly the opposite to that of the Treasure Mines; coupled with the fact that the dips are about the same, this suggests the possibility that the Beaverhead Mine may be on the same isoclinal fold as the Treasure Mines but on the opposite limb. Field mapping by Garihan (1973) and the writer, however, has not been able to prove or disprove this possibility. As contrasted with the Treasure Mines, the "talc-zone" of the Beaverhead Mine is only locally a single homogeneous talc body from the footwall to the hanging wall; almost everywhere it contains numerous large "horses" of non-talc rock, especially dolomite that has not been altered to talc. Seemingly the dolomite is more abundant in the lower half (southern part) of the "talc-zone" than in the upper half (northern part), and the purest talc occurs along the hanging-wall contact.

The footwall of the "talc-zone" is well-layered granite gneiss, which is very similar to that which forms the hanging wall of both Treasure Mines. Between this gneiss and the talc ore is a dolomitic zone, suggesting that for some reason the "talc-zone" was not entirely converted to talc ore, as it was at places in the Treasure Mines. The hanging-wall rock adjacent to the "talc-zone" is biotite schist, which is in turn overlain by well-layered granite gneiss, which has been locally chloritized. Garihan (1973) stated that the hanging-wall country rock is similar to the footwall material of the Treasure Chest, and the writer fully agrees. In this mine, in both of the Treasure Mines, and in the Smith-Dillon Mine there is the suggestion that the best talc lies along the contact of the "talc-zone" with biotite schist, suggesting that this sharp contact may have represented a pronounced permeability barrier and thus may have locally channelized and impounded the mineralizing solutions.

The present exposures of the Beaverhead Mine probably constitute its full possible extent, for it is likely that the western and eastern extremities are "pinch-outs" rather than faults. If the Treasure Fault extends this far south, the Beaverhead Mine probably lies entirely east of it. Several small high-angle to vertical northwest-trending right-lateral faults are present within the mine area, but their offsets seem to be even less than those of analogous faults in the Treasure Chest Mine. All of these faults that have been recognized in the Beaverhead Mine have their southwestern side thrown upwards, as is also true of all those in the Treasure Mines.

Whereas topography is the friend of the miner at the Treasure Mines, where the talc is dipping in the same direction as the hillslope, topography is the firm enemy of the miner at the Beaverhead Mine. Stripping ratios, at present probably similar to those at the Treasure Chest Mine, will become pronouncedly greater and at a faster rate for similar rates of production than they will at the Treasure Mines. The Beaverhead Mine has yielded most of its production in less than the last decade. Garihan (1973) noted that the mine area tripled in size during the period 1968-73, and a massive 1974-75 stripping operation has increased the mine area even further.

Ore produced from the Beaverhead Mine is trucked southeast down the Cottonwood Road to the Ruby drainage and thence to a small washing plant at the terminus of a Burlington Northern spur at Alder, Montana. From this plant it may go to Belgium for processing there for European markets, or to Cyprus' domestic mills in Grand Island, Nebraska, or Three Forks, Montana.

REGAL (KEYSTONE) MINE

The Regal (Keystone) Mine is situated alongside the Sweetwater Road in the NW¼ NE¼ and NE¼ NW¼ sec. 2, T. 8 S., R. 7 W., Madison County (Christensen Ranch 7½-minute quadrangle). It is owned by Pfizer, Inc., having been acquired by them in 1966 along with all other assets of Southern California Minerals Company.

Okuma (1971) described the mine as occurring close to the core of a tightly refolded synform. The ore body is complex in that there are many large lenses of talc enclosed within a large body of dolomitic marble; this relationship has been further complicated by widespread faulting. Except for intrusive diabase, rock types other than talc and marble are rare upon this fairly large property. The marble strikes N. 45° E. to S. 80° E. and dips 30° to 75° north; although the structural geology in the area around the mine is extremely complex, this uniform attitude holds throughout the exposed extent of talc on the surface. A diabase dike more than 200 feet wide, seemingly vertical to subvertical, cuts the foliation of the marble almost at right angles along the western edge of the best exposures of the talc. Okuma (1971) has observed that at many places where the diabase has intruded the marble, no talc has been formed along the contact, but rather the dolomitic marble has been contact-metamorphosed to calcite and fine-grained serpentine.

Bedrock talc is exposed at the Regal Mine along more than 750 feet of strike length and over a horizontal width of more than 300 feet perpendicular to strike. A small open-pit mine has been developed along the southern margin of the Regal talc deposit. It is about 450 feet long (approximately along strike) and 50 to 100 feet wide, and the vertical depth is 20 to 30 feet. Perry (1948) described a shaft 60 feet deep and 300 feet of drifts off the bottom of the shaft, all of which are in talc, but these workings have been inaccessible for many years.

The Regal Mine is of particular interest geomorphologically. It is a true "pedimented" talc deposit, for over several acres bedrock talc appears in large outcrops right at the surface without any grass or soil cover whatsoever.

Talc-marble contacts are abrupt and have been locally faulted, as shown by numerous small lateral offsets. Talc float is locally so abundant that one's boot can hardly be placed upon the ground surface without touching some of it.

A conjugate fracture set may be observed along the north wall of the open pit on the southern side of the Regal Mine area; these fractures are vertical or subvertical and strike N. 60° W. and N. 30° E., the former being apparently better developed. The bedrock faults that displace talc-marble contacts so spectacularly at many places on the ground surface have the same azimuth traces as the aforementioned fractures, and similarly the northwesterly ones are better developed; however, the existing exposed relationships do not allow even a well-educated guess as to the relative directions of movement along these presumably minor faults.

The Regal Mine could well be the largest single mass of talc in the entire Ruby Range. Unfortunately, its operation has thus far been controlled strictly by sales considerations; i.e., the talc at the surface makes relatively poor products (mainly because of the dark color) and consequently low sales and profit figures do not result in the generation of sufficient funds to explore its potential at depth. This is a common failing in the industrial-minerals field and is certainly not restricted to talc alone! As the Regal talc ores are known now, it is true that the color is bad, owing to the presence of graphite and limonite (altered from contained pyrite), but the character of the talc at depth is almost completely unknown.

SAUERBIER MINE

The Sauerbier Mine is the newest talc mine in the Ruby Range, having been established upon almost virgin ground in 1973. It is situated in the NW¼ NW¼ sec. 25, T. 8 S., R. 7 W., Madison County (Elk Gulch 7½-minute quadrangle). It lies just south of a major fault zone developed along the southwestern edge of the flats south of the Sweetwater Road; the Carter Creek Fault may connect with this zone. It is unlikely that any large commercial talc ore bodies will be found east of this property, for it is seemingly the easternmost extent of the marble in this general vicinity.

The talc has been developed within a marble zone, which strikes N. 35° E. and dips from vertical to an estimated 70° southeast. Downhill northward from the mine toward the valley of Sweetwater Creek, shallower southeast dips (as flat as 30° or so) may be locally observed. The east and southeast dips in sec. 25 contrast with west and northwest dips in sec. 26 and over much of the Owen-McGovern Prospect and indicate the degree of local structural complexity, which is probably due to the proximity of the aforementioned major fault zone. The talc is more sporadic and erratic in its distribution within this "talc-zone" than in that of any other Montana talc deposit of which the writer is aware. Hand sorting has been necessary at this mine from the beginning, and unless pronounced changes in the geological relationships are encountered, it will probably always be so.

The American Talc Company, of Summit, New Jersey, has mined this property under lease from Mr. Karl L. Sauerbier of Alder, Montana. The hand-sorted ore is trucked along the Sweetwater-Ruby Road to Alder, where it is stockpiled on concrete pads for shipment by rail to mills in South Plainfield, New Jersey, and Alpine, Alabama.

INACTIVE TALC MINES IN THE RUBY RANGE

AMERICAN CHEMET MINE

The American Chemet Mine is situated in the NE¼ sec. 12, T. 8 S., R. 7 W., Madison County (Christensen Ranch 7½-minute quadrangle). It was once operated by the American Chemet Corporation of Chicago, Illinois. The workings consist of three open pits and several minor bulldozer trenches.

The talc is contained within "a complexly folded northeast-trending belt of marble" (Okuma, 1971), which is isolated within large expanses of Dillon Granite Gneiss extending both northwest and southeast.

BANNING-JONES MINE

A talc deposit in the SW¼ sec. 13, T. 8 S., R. 8 W., Beaverhead County (Dillon East 7½-minute quadrangle) was leased by the State of Montana in 1964 to Messrs. Wallace Banning and Lester Jones, both of Dillon, Montana (Geach, 1972). It is situated within the same belt of marble as is the Smith-Dillon Mine, which lies along strike from it about 1 mile to the southwest.

Talc has formed within a marble zone as much as 100 feet wide, but the widest zone of talc known (without included marble bodies) is only about 10 feet wide, and few such dolomite-free talc bodies are more than 5 feet wide. The talc is exposed on both sides of a major north-flowing gully and has seemingly been displaced at least 100 feet laterally by a right-lateral fault, which has determined the course of the gully.

Small amounts of talc were mined here, hand sorted, and trucked to Sheridan, Montana, where they were purchased by American Chemet Corporation.

BOZO-ZOBO MINE

The Bozo-Zobo Mine lies in the NE¼ sec. 19, T. 8 S., R. 7 W., Beaverhead County (Dillon East 7½-minute quadrangle) on the northern wall of Axes Canyon near its head. The strata here strike N. 50° E. and dip 80° northwest. The best exposures are in a large open cut near the southwest edge of the property, where the talc is 25 to 30 feet wide and has been mined to an estimated maximum depth of 50 feet or so. Seemingly less than half of the mineralized zone was converted into talc, as shown in this cut, rendering selective mining difficult and hand sorting probably absolutely necessary.

The occurrence of talc at several different levels along the north wall of Axes Canyon may indicate either the presence of several veins or the repetition of a single vein by tight isoclinal folding or faulting, but this puzzle will be solved only by careful mapping, aided by the results of the previous drilling program. Manganese oxides have locally stained the talc so intensely as to render it useless.

The Bozo-Zobo Mine lies roughly along strike from a similar prospect in the SW¼ NW¼ sec. 19, which is described elsewhere in this article. The two may represent the same stratigraphic zone and therefore a potential strike length of talc of 3,000 feet or so, but such a possibility, of course, would have to be proved by detailed mapping of this relatively small area.

The property was drilled by R. T. Vanderbilt Company in 1962-63 under the direction of Mr. L. R. Moretti; four core holes and at least 23 rotary drill holes were sunk during the course of that exploration program.

American Chemet Corporation of Chicago, Illinois, reportedly shipped approximately 8,000 tons of ore from this property in the mid-1960's.

SMITH-DILLON MINE

The Smith-Dillon Mine, topographically the lowest talc mine in the Ruby Range, is situated almost at the mouth of Axes Canyon near the southwestern corner of the range in the W½ sec. 23, T. 8 S., R. 8 W., Beaverhead County (Ashbough Canyon 7½-minute quadrangle). Although this mine was an important producer of high-grade ore in the early days of the Montana talc district, it has been inactive for several years now. Originally an underground operation, it was open-pitted in its last days.

The marble unit in which the talc occurs is about 1,300 feet thick according to Okuma (1971). The regional strike is N. 30° to 40° E. and the dip is 60° to 70° northwest. Although all of the talc occurs in dolomitic marble, relatively little of the "talc-zone" has been converted into talc. Marble ribs, locally veined with white quartz, are common within the talc bodies and have long created a problem in the mining of this deposit. Okuma (1971) also noted the presence of small thin folded "stringers" of talc within the marble of the "talc-zone". The footwall in the mine area is dark mica schist, which is extensively slickensided, as in the footwalls of the two Treasure Mines.

The talc, as proved thus far by the open-pit mining, occurs over a strike length of about 750 feet and has an average horizontal width of about 50 feet; it has been mined to down-dip depths of about 125 feet in the open pit, and according to Perry (1948), to depths of more than 200 feet underground. The talc has been abruptly truncated at the northern end of the pit by an east-west fault, which dips 55° to 60° south. Left-lateral displacement along this fault is on the order of 70 feet.

It is probable that the talc exposed in shallow diggings at the Crown Mine, about 700 feet to the northeast, represents the same zone as that at the Smith-Dillon Mine, but to the writer's best knowledge this has yet to be proved by exploration. The presence of abundant talc float over the concealed area between these two properties, however, suggests that they may represent the same ore zone and that there may be a fair degree of lateral continuity of talc mineralization.

Although it is obvious that talc would have to be mined much more selectively upon this property than upon other Pfizer properties – indeed, hand-sorting may even be an absolute necessity here – much of the talc on the Smith-Dillon and adjacent properties is pure and of good light color.

Mining rights on this and adjacent properties are owned by the Minerals, Pigments and Metals Division of Pfizer, Inc., which obtained them through their acquisition in 1966 of the assets of Southern California Minerals Company.

SWEETWATER MINE

Numerous workings along the Sweetwater Road about 16 miles southeast of Dillon are collectively known as the Sweetwater Mine (Okuma, 1971). These workings are situated in the E½ sec. 13 and NE¼ sec. 24, T. 8 S., R. 7 W., Madison County (Christensen Ranch 7½-minute quadrangle).

The talc lies completely within a marble unit, which is about 460 feet wide, strikes N. 20° to 30° E. and dips 50° northwest (Okuma 1971). The marble is a relatively thin unit completely isolated within a large mass of Dillon Granite Gneiss, similar to the situation at the American Chemet Mine only a mile or so to the north. Okuma (1971) cited convincing evidence that, in this particular deposit at least, the talc has definitely formed from dolomitic marble and not by the alteration of ultramafic rocks.

TALC PROSPECTS IN THE RUBY RANGE

BENNETT OWEN CLAIM

The Bennett Owen Claim is located near the head of Cottonwood Creek in the NW¼ sec. 12, T. 7 S., R. 6 W., Madison County (Mine Gulch 7½-minute quadrangle). The strata here strike N. 70° E. and dip 55° north. Talc is shown in place by bulldozer cuts over a strike length of at least 80 feet and a width of at least 20 feet. Although the exposed talc is everywhere dark green, it powders surprisingly to white or near-white colors. Garihan (1973) described this as the largest body of uniformly dark green, low-purity talc known to him in the central part of the Ruby Range. His petrographic work has shown the presence of opaque minerals and minor chlorite in the talc. The footwall rock is dolomitic marble and the hanging-wall rock is either dolomitic marble or reddish Dillon Granite Gneiss, depending upon the location; therefore, the geology is similar to that of the Treasure and Beaverhead Mines a mile or so to the southwest.

CRESCENT PROSPECT

The Crescent Prospect was acquired by Pfizer, Inc., when they obtained the assets of Southern California Minerals Company in 1966. It has not been mined, chiefly because of its graphite content and the presence of dark staining throughout the talc. This deposit is situated in the SW¼ sec. 1, T. 9 S., R. 8 W., Beaverhead County (Ashbough Canyon 7½-minute quadrangle). The talc occurs within marble layers 10 to 15 feet thick, which have been intruded by pegmatite and granite gneiss bodies. The marble strikes northeasterly, dips northwest at 50° or so, and is locally so decomposed that it is friable. Perry (1948) described talc float as having an extent of 800 to 1,000 feet along strike. A shaft and some small workings have proved the talc to a depth of at least 20 feet.

GEM CLAIM

Two small bulldozer cuts in the SE¼ sec. 34, T. 6 S., R. 6 W., Madison County (Beaverhead Rock SE 7½-minute quadrangle) have exposed small bodies of dark-green talc, which are not of economic interest, as exposed, because of their small size and dark color. These showings are on the Gem Claim, which is owned by Pfizer, Inc.

OWEN-McGOVERN PROSPECT

The Owen-McGovern Prospect is covered by the Badger #1-8 mining claims in the SE¼ sec. 23 and the E½ sec. 26, T. 8 S., R. 7 W., Madison County (Elk Gulch 7½-minute quadrangle). Although the geology of these deposits is not yet satisfactorily understood, it is apparent that they are a continuation of the talc at the Sauerbier Mine, which is to the northeast. Several bodies of dolomitic marble are present upon this property, and all of the known talc occurs within such rock. There is no talc deposit in Montana known to the writer whose geological relationships are so difficult to decipher as this one! The dolomite bodies have been intruded by pegmatite, amphibolite, and diabase dikes. The soil and tree cover are thick and exposures are rare. The regional strike of the strata is N. 20° E. and the dip ranges from 50° to 80° northwest. Okuma (1971) stated that this property has "now been thoroughly investigated", but the writer strongly disagrees. No detailed geological map has ever been made of this complex area, and the relatively minor amount of excavations and drilling cannot rule out the possibility of ore bodies within this large area.

SECTION 11, T. 7 S., R. 6 W.

Bulldozer cuts in the S½ sec. 11, T. 7 S., R. 6 W., Madison County (Mine Gulch 7½-minute quadrangle) just north of the Left Fork of Stone Creek have exposed several showings of talc. The strata in this area strike roughly east-west and dip 50° to 60° north. These talc bodies, which are developed within dolomitic marble, are as thick as 10 feet and have lengths of as much as 80 feet. Minor amounts of the talc are of the light-colored variety sought for commercial uses, but most of it is somewhat darker; furthermore, the common presence of limonite and graphite renders that talc which is exposed of minimal economic interest.

SECTION 13, T. 7 S., R. 6 W.

Cyprus Industrial Minerals Company has cut a small prospect pit into the same marble unit as that of the Treasure Mines. This pit is located about 4,000 feet southeast of the Treasure Chest Mine and is in the W½ sec. 13, T. 7 S., R. 6 W., Madison County (Mine Gulch 7½-minute quadrangle). The relationships of the talc bodies are poorly exposed, this being an old pit, but the largest talc body is less than 5 feet wide. The strike is roughly east-west and the dip is 50° to 60° north. Graphite is locally present, and most of the talc is dark green, but minor quantities have the light-green commercial color.

SPRING CREEK PROSPECT

Talc in dolomitic marble is exposed along the north side of Spring Creek in the SE¼ SE¼ sec. 32, T. 6 S., R. 6 W., Madison County (Beaverhead Rock SE 7½-minute quadrangle). This same zone of talc extends (seemingly continuously) southwestward into the NE¼ sec. 5, T. 7 S., R. 6 W. and northeastward into the central part of sec. 33, T. 6 S., R. 6 W., where it seemingly extends underneath the Cambrian strata. This zone, which extends for about 6,000 feet in a northeasterly direction, shows the longest single strike length of talc known to the writer in the Ruby Range or anywhere else in Montana. Talc widths of more than 20 feet and continuous lengths of 100 feet or more are exposed in the old workings along the north side of Spring Creek. The marble unit, which contains all of the known talc showings on this property, strikes N. 50° E., dips 60° to 70° northwest, and has a horizontal width of about 1,500 feet over most of its strike length; Garihan (1973) called this unit the "Regal Marble", the same dolomitic marble unit as that which contains the Regal (Keystone) Mine, and he stated that it may be traced to the south from this prospect for a distance of about 10 miles.

Much of the talc exposed upon the Spring Creek Prospect is darker than that now being used (except for that of the Regal Mine), and this deposit contains more different colors of talc than any known to the writer in Montana; nevertheless, the presence of some suitable-colored talc plus the extremely large size of this prospect make it worthy of a serious exploration effort.

WHITNEY CLAIMS

The Whitney Claims were acquired by Pfizer, Inc., when it obtained the assets of Southern California Minerals Company in 1966. They lie to the north of the Treasure Mines on the steep hillslope north of the Left Fork of Stone Creek in and around the SW¼ sec. 2, T. 7 S. R. 6 W., Madison County (Mine Gulch 7½-minute quadrangle).

As at the nearby Treasure Mines of Pfizer and the Beaverhead Mine of Cyprus, the strike is roughly east-west and the dip is to the north or northwest, in this area about 50° or so. The talc is entirely enclosed within dolomitic marble, and much of it is light green and cryptocrystalline, as are the best commercial talc ores elsewhere in the Ruby Range. Its quality and desirability, however, are downgraded by the presence of pyrite and limonite, by the intense shearing to which it has been subjected, and by the presence of bodies of quartz and dolomite within the talc bodies.

Southwest of the main Whitney Claim, some small cuts in the SE¼ sec. 3, T. 7 S., R. 6 W., Madison County (Mine Gulch 7½-minute quadrangle) have exposed small quantities of green graphitic talc in fractures within dolomitic marble. This talc body is as much as 15 feet thick. Other cuts below the timber line have exposed additional talc occurrences, one of which is more than 20 feet wide. These talc bodies, which are in the westernmost exposure of the marble of the Whitney Claims, are contaminated by the presence of marble "horses" and locally abundant graphite.

MISCELLANEOUS PROSPECTS IN THE CENTRAL RUBY RANGE

Garihan (1973) has noted the occurrence of talc bodies in dolomite in the SW¼ sec. 17, T. 7 S., R. 6 W., and the presence of talc float in the SW¼ sec. 18, T. 7 S., R. 5 W., and in the SW¼ sec. 11, T. 7 S., R. 6 W., all in Madison County and all on the Mine Gulch 7½-minute quadrangle. These do not seem to be of interest in themselves as exposed, but they may well indicate areas worthy of further investigation.

MISCELLANEOUS PROSPECTS IN THE SOUTHWESTERN RUBY RANGE

Talc occurrences are numerous throughout the southwestern part of the Ruby Range, especially upon the Benson Ranch which, to the writer's best knowledge, has never been thoroughly prospected or studied. The writer has never done any field work on the Benson Ranch, but from oral descriptions given by others, it is obvious that it would take some time for any worker to even visit, let alone inspect and study these occurrences. None of the prospects described below are on the Benson Ranch.

Talc in place is exposed fairly continuously for about 1,350 feet of strike length along the crest of the northern wall of Axes Canyon in sec. 19, T. 8 S., R. 7 W., Beaverhead County (Ashbough Canyon and Dillon East 7½-minute quadrangles). The strata here strike N. 55° E. and dip 55° northwest. Most of this talc is in the SW¼ NW¼ sec. 19. This talc, for the most part, is much darker than any currently being mined in Montana, indeed some of it is black – but the large size of this showing would seem to render it worthy of further exploration.

Several talc prospects in the southwestern part of the Ruby Range, discovered and developed by Messrs. Tom McGovern and Bennett Owen of Dillon, Montana, are now under lease to J. M. Huber Corporation of Atlanta, Georgia. The remaining properties discussed in this section all belong to this group.

Talc in place may be traced fairly continuously over a strike length of about 900 feet in the W½ NE¼ sec. 35, T. 8 S., R. 8 W., Beaverhead County (Ashbough Canyon 7½-minute quadrangle). The strata strike N. 55° E. at this locality and dip 70° north to vertical. At least three clearly separate stratigraphic zones contain talc, and solid widths of at least 10 feet have been locally proved by shallow trenches. The talc is light green and at depth could probably be as good as most of that which is now being mined in Montana, assuming that impurities such as pyrite and graphite were absent.

Bulldozer cuts have exposed talc in place at two localities in the NW¼ NW¼ sec. 36, T. 8 S., R. 8 W., Beaverhead County (Ashbough Canyon 7½-minute quadrangle). The talc exposed is generally dark green. Mining rights are owned by the State of Montana.

The Valley View Prospect, in the SW¼ sec. 25, T. 8 S., R. 8 W., Beaverhead County (Ashbough Canyon 7½-minute quadrangle) is, with the exception of the

Regal (Keystone) Mine, the largest body of dark talc known to the writer in the southwestern part of the Ruby Range. Bulldozer excavations have exposed a probable horizontal width of talc of about 90 feet, and the talc may be traced for at least 150 feet along strike. The strata at this locality strike N. 50° E. and dip 55° northwest.

Green talc, somewhat resembling that of the Regal (Keystone) Mine, occurs in place along a ridge crest for several hundred feet and has horizontal widths of 5 to 30 feet in the SE¼ SE¼ NE¼ sec. 26, T. 8 S., R. 8 W., Beaverhead County (Ashbough Canyon 7½-minute quadrangle). The enclosing dolomite strata are essentially vertical. This showing and other isolated outcrops to the southwest and northeast make up a total strike length of at least 1,200 feet in sec. 26 and adjacent sec. 25. This talc is megascopically very similar to that of the Valley View Prospect.

In sec. 1 and 2, T. 9 S., R. 8 W., Beaverhead County (Ashbough Canyon 7½-minute quadrangle) a well-developed zone of talcose rocks may be traced for 5,000 feet along strike (east northeast) from the Brown Ranch Road along the base of the range in the SE¼ SW¼ sec. 2 on into the SE¼ NW¼ sec. 1. Talc ore, per se, has never been observed upon the surface by the writer, but the extent of the talcose development in rocks in place certainly warrants further exploration of this large and long zone.

Talc float of high purity and light-green color has been traced continuously along relatively horizontal land over more than 600 feet of strike length to the southwest of Hanson Spring in the SW¼ SW¼ sec. 3, T. 8 S., R. 7 W., Madison County (Christensen Ranch 7½-minute quadrangle). The horizontal width of the talc zone perpendicular to the strike is locally as much as 325 feet. The strata here strike N. 30° E. and dip 70° to 75° northwest. Outcrops are rare, but the host rock can clearly be observed to be dolomitic marble. Darker talc crops out in higher stratigraphic positions to the northwest over a stratigraphic thickness of about 200 feet and along strike lengths of at least 300 feet.

In the writer's opinion, one of the most attractive talc exploration targets in Montana occupies an estimated 480 acres in sec. 10 and an estimated 220 acres in sec. 11, T. 8 S., R. 7 W., Madison County (Christensen Ranch 7½-minute quadrangle). Along the northern boundary of this area, talc is exposed both in place and as abundant float in several separate stratigraphic zones over about 7,000 feet of strike length before being truncated on the eastern end by the Carter Creek Fault. In the SW¼ NE¼ sec. 10, abundant talc float has been traced along a 650-foot strike length and over at least 170 feet of horizontal width in an area where the enclosing dolomite strata strike N. 50° E. and dip 80° northwest.

High-purity talc lying in a gentle swale on the Gopher #1-3 mining claims in the SW¼ NW¼ sec. 2, T. 8 S., R. 7 W., Madison County (Christensen Ranch 7½-minute quadrangle) probably represents a southwestward extension of the talc of the Regal Mine, owned by Pfizer, Inc. The light-colored talc float, which may be traced over about 200 feet of strike length and a horizontal width of 100 feet, is probably the equal in quality of any talc being mined in the Ruby Range.

Talc float is abundant along both sides of a ridge of dolomitic marble that extends from the NE¼ sec. 15 on into the SW¼ sec. 11, T. 8 S., R. 7 W., Madison County (Christensen Ranch 7½-minute quadrangle). Sporadic talc float has been detected by brief reconnaissance studies over a strike length of 4,000 feet or so; but a puzzling riddle lies in the fact that there are so few outcrops of talc compared to the large abundance of float. Most of the talc observed is green, somewhat darker than the grades that are being mined in Montana. This long ridge of dolomitic marble has the structure of a synform, its axis striking N. 30° E. and dips averaging 50° or so on both the northwest and southeast limbs. The dolomite strata seemingly wrap around the southwestern nose of the ridge, giving structural closure there, but on the northeastern end the dolomite is truncated by the Carter Creek Fault.

A large thick band of dolomitic marble north of Gordon Peak in sec. 21 and 22, T. 8 S., R. 7 W., Beaverhead and Madison Counties (Christensen Ranch 7½-minute quadrangle) contains several talc prospects in dolomite strata, which strike east-west and dip 40° to 65° north. This large belt of predominantly dolomitic rock averages about 2,500 feet in width over almost 3 miles of strike length. One talc zone in the NE¼ NE¼ NE¼ sec. 21 extends for about 500 feet along strike.

GENERAL GEOLOGY OF THE GRAVELLY RANGE

The name "Cherry Creek" was first used by Peale (1896) for rocks in an area 15 to 20 miles south of Ennis, Montana, along the base of the eastern flank of the Gravelly Range. He stated that "The Cherry Creek beds consist of a series of marbles, or crystalline limestones, and interlaminated mica-schists, quartzites, and gneisses" and that "They are all highly inclined and are perfectly conformable to one another occupying an area of 30 to 40 square miles." Their total thickness, according to Peale, "is certainly not less than several thousand feet" and in his columnar section he showed a thickness of 7,000 feet or more for the "Cherry Creek" portion of the Precambrian section.

The most detailed study of the type area of the Cherry Creek Group has been made by Heinrich and Rabbitt (1960). In general the grade of the metamorphism increases slightly as one goes northward, but it is puzzling how rocks of different metamorphic grades can exist together in the same area, e.g., phyllite, mica schist, and kyanite schist along the Cherry Creek drainage. Heinrich and Rabbitt (1960) recognized the following major classes of rocks in the type area of the Cherry Creek Group:

1. Marble, calc-schist, and lime-silicate gneiss
2. Quartzite and quartz schist
3. Phyllite
4. Mica schist
5. Kyanite schist and kyanite-staurolite schist
6. Sillimanite schist and gneiss
7. Magnetite schist and related rocks ("iron formation")
8. Amphibole gneiss, schist, and amphibolite
9. Quartz-feldspar gneiss, granitic gneiss, biotite, and injection gneiss

The marble layers are the thickest and the most laterally persistent of these rock types. Heinrich and Rabbitt reported one dolomitic marble as nearly 6,000 feet thick, but later workers and the writer believe that much of this thickness is likely due to structural flowage during folding and to repetitions caused by tight folding. Heinrich and Rabbitt also noted the relatively rare presence of tremolitic marble in the area, but the ores produced thus far from the Johnny Gulch area have characteristically contained no detectable tremolite. It may be readily seen from a comparison with the rock types mapped as "Cherry Creek-type rocks" in the Ruby Range by Okuma (1971) and Garihan (1973) that the sequences there and in the Gravelly Range are very much alike. One of the most striking differences involves the amphibolite rocks, for Heinrich and Rabbitt (1960) stated that "dark-colored amphibole gneisses are much less common in the Cherry Creek area than some other pre-Beltian areas, as for example, in the Ruby Mountains." They estimated the total minimum thickness of the Cherry Creek Group in its type area as about 30,000 feet.

Hadley (1969a, 1969b) has mapped the geology of two key 15-minute quadrangles in the area of the producing talc mines of the Gravelly Range and has shown in detail, within that restricted area, the distribution of the dolomitic marble of the type Cherry Creek Group.

Mann (1954, 1960) has described the general geology of that part of the Gravelly Range that is of interest for its talc potential. Most of his attention was devoted to the Paleozoic and Mesozoic Systems; rock types within the Cherry Creek Group were not differentiated.

GEOLOGY OF TALC IN THE GRAVELLY RANGE

There are three known areas of significant talc mineralization in the Gravelly Range: the Yellowstone Mine in sec. 4, T. 9 S., R. 1 W., the Johnny Gulch Prospect in sec. 34, T. 8 S., R. 1 W., and sec. 3, T. 9 S., R. 1 W., and the Tri-State Prospect in sec. 5, T. 8 S., R. 1 W., all in Madison County. Several other occurrences of talc are known in the Gravelly Range, but only these three will be discussed at length here.

Hogberg (1963) generalized that in the Gravelly Range the lens-shaped talc bodies "may be as much as 100 feet wide, 1,000 feet long, 150 feet deep, and are generally concordant with the regional structure". All of the talc that is known in the Gravelly Range occurs within dolomitic marble units and is generally concordant with the metamorphic foliation.

The largest single mass of marble in the Gravelly Range is that one situated between Johnny Gulch and Cherry Creek, which forms an area about 5 miles long and 1½ miles wide, roughly parallels the strike of the strata, and contains all of the currently known commercial talc deposits in the area.

The nature of the formation of talc in the Gravelly Range is similar to that in the Ruby Range, as are the mineralogy and the chemistry of the ores. In addition, the general geology of the two areas is very similar, the starting materials for the talc are everywhere the same, and the structural evolution of the two areas is also similar. For reasons unknown, however, the relationships of the talc ore bodies to their enclosing rocks is markedly different in the two ranges. In the Ruby

Range, for instance, it is not uncommon for an entire wide zone of dolomite between other, non carbonate rock types to have been converted almost completely into talc containing few or no "horses" of foreign rock. Even where the entire "talc-zone" has not been converted to talc, it is common in the Ruby Range to have large thick tabular masses of talc "interbedded" with other rock types within the "talc-zone". This relationship has been nowhere observed in the Gravelly Range, where there is invariably an intimate and small-scale intercalation of talc with dolomite and where there are few bodies of pure talc more than 5 feet thick containing no foreign rock types. The behaviour of the talc in the Gravelly Range is markedly digitate on a small scale; the behaviour of the talc in the Ruby Range is generally tabular and in much larger bodies. Even where the behaviour of talc in the Ruby Range could be described as digitate, it would be more subtly so and on a much larger scale than in the Gravelly Range.

Throughout this area the removal of the talc by either powered shovel or front-end loader is made easier by the profusion of post-talc fracturing and shearing, which is strongly developed and closely spaced as shown in all of the existing workings.

Therefore, if past history is to be a reliable guide, we can generalize that although ore bodies can be mined in the Ruby Range with large mining machinery but without hand sorting, the ore bodies in the Gravelly Range will continue to be mined with similar equipment but the resulting mill feed will necessarily continue to be subjected to hand sorting.

Current investigations by graduate students of the University of Indiana will shed new light upon the intricate problems of the type Cherry Creek sequence, especially with regard to metamorphic events. The major difference between the Cherry Creek sequences of the Ruby Range and those of the Gravelly Range lies in the maximum degree of metamorphism undergone in Precambrian time – upper amphibolite grades having been reached in the areas of talc mineralization in the Ruby Range, whereas in some areas of talc mineralization in the Gravelly Range it may be that only greenschist grades were attained. In the Ruby Range a widespread regional metamorphic event of greenschist grade was experienced after the higher-grade events; therefore, it is possible that the talc in both ranges formed during periods of similar intensity of Precambrian metamorphism (i.e., greenschist grade), whether or not contemporaneously.

TALC MINES AND DEPOSITS IN THE GRAVELLY RANGE

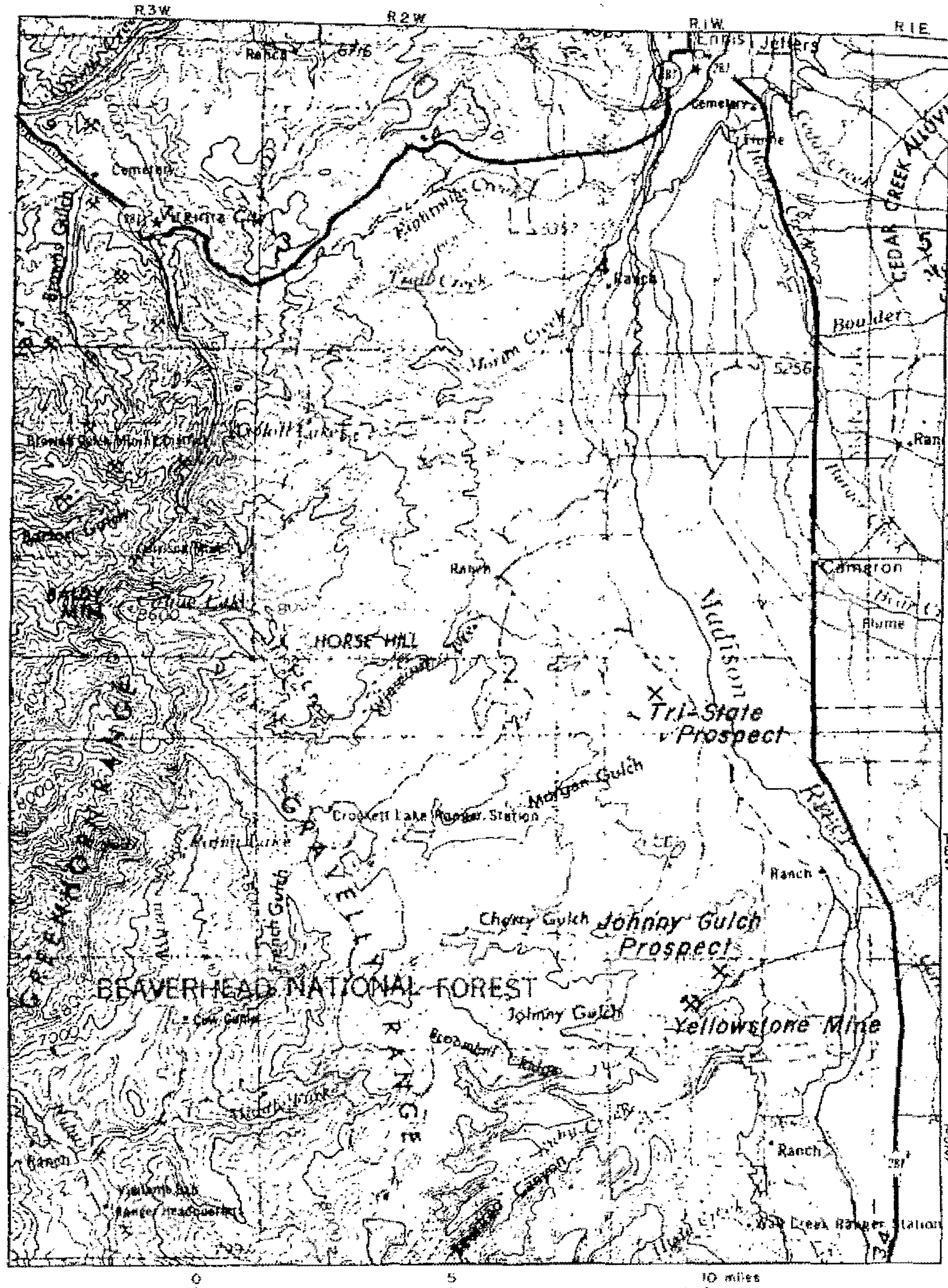
YELLOWSTONE MINE

The Yellowstone Mine, in the S½ sec. 4, T. 9 S., R. 1 W., Madison County (Cameron 15-minute quadrangle) is the primary Montana source of talc ore for Cyprus Industrial Minerals Company and has been so for more than twenty years (Fig. 10-5).

The mineralized area, according to Perry (1948), is at least 2,000 feet long in a northeast direction and about 800 feet wide. Within this area there are several large bodies of talc within the main dolomite mass, but these large talc-bearing bodies enclose abundant dolomite "horses".

The writer was allowed to study the geology of the Yellowstone Mine in the summer of 1974. There are several workings, both underground and open pit, within this large mineralized area. Many of these workings, including all of the underground ones, have been inactive for many years. The main pit, which is also the deepest one, has been developed along an azimuth of N. 20° W. for the most part – a direction that is not exactly parallel to the foliation of the strata but is fairly close to being so. Such a relationship is common throughout the mine area, i.e., a slight directional variance is common between the strike of the dolomite foliation and the longest dimension of the talc ore bodies. The strike of the strata within the main mine area ranges from north to N. 20° E. and dips range from vertical to 50° east. The main pit is now about 2,500 feet long, averages about 200 feet wide, and has been mined to down-dip depths of 150 to 200 feet.

Unlike the producing talc ore bodies of the Ruby Range, talc at the Yellowstone Mine does not form large enough individual bodies to permit the mining of high-purity talc ore by the use of machinery alone; all of the ore now exposed within the area of the Yellowstone Mine must be hand sorted in order to derive suitable mill-feed material. In one area of the Treasure Chest Mine (Ruby Range), the entire dolomite unit ("talc-zone"), about 120 feet wide horizontally, had been converted into commercial talc of the highest grades. In the Yellowstone Mine, thicknesses of more than 5 feet of high-purity talc without included dolomite are uncommon. Talc was noted to be abundant in one local area of the main pit of the Yellowstone Mine, but not a single thickness of more than 1 foot of pure



10-5. –Talc mines and prospects, Gravelly Range, Madison County.

talc was observed. The talc is commonly seen to "make" in a gray fine- to medium-crystalline dolomite, which is generally thin bedded (laminae or foliae commonly less than 6 inches thick). Although most of the talc-dolomite contacts seem to follow primary features, there are indications that many of them may represent fractures or faults of extremely small displacement. It is more common for the contacts of the small bodies of high-purity talc to cross-cut the dolomite foliation at low angles than for them to be concordant, although in the lowermost levels of the main pit such cross-cutting relationships were observed to form at angles of 30° or more. Shear surfaces developed at such angles to the foliation may have locally exerted a control upon the attitude and shape of individual talc bodies. Most of the talc at the Yellowstone Mine is green or light gray (almost the color of the enclosing dolomite), not pale green to white, as is much of the talc in the Ruby Range.

All of the ore at the Yellowstone Mine is taken to sorting facilities where workers remove either the waste from the ore or the ore from the waste, depending upon grade. The high-grade ore is taken to an old enclosed and permanent hand-sorting facility along the north hillslope of Johnny Gulch, where the waste is picked out and the talc is discharged from the end of the conveyor belts into holding bins. The lower-grade ore is taken to a portable hand-sorting facility in one of the upper pits, where the talc is picked out and the waste is discharged off the end of the conveyor belt. This portable facility was placed in operation in 1972 and will result in a much longer life for this mine. The lowest-grade material, not regarded as waste, is taken to large stockpiles north of the mining area. These stockpiles, called "bone piles" by the miners, consist of material that is too low in grade to justify hand sorting at present but which may prove to be susceptible to flotation-beneficiation processes in the future. If such methods of beneficiation ever prove feasible, these "bone piles" would constitute an immense supply of high-purity Montana talc ore. All of the hand sorting or "picking" at the Yellowstone Mine is done upon dry rock, unlike the Pfizer operations, where hand sorting at their Barratts mill is performed upon wet rock.

The hand-sorted ore from the Yellowstone Mine is trucked either to Alder, Montana, for shipment to Cyprus' processing facilities in Belgium or Grand Island, Nebraska, or to their mill at Three Forks, Montana.

During World War II, the Yellowstone Mine area became extremely important because the U.S. was shut off from foreign sources of "block talc" or "lava talc". Underground exploratory work was performed during that war with governmental support (U.S. Bureau of Mines) in an effort to locate a replacement source for such denied material, which had formerly been readily obtainable from Italy. These underground workings proved one talc lens to extend to a depth of about 80 feet and another talc outcrop was traced at that time through a vertical distance of 150 feet. Seemingly the "block talc" (also known as "lava talc" or "carving talc") occurred only in the deeply weathered siderite zone, from the surface down to a depth of no more than 45 feet or so. Ankerite and black manganese dioxide were also abundant within this intensely weathered zone. The "block talc" graded downward into ceramic grades of talc, which in turn were underlain by hard unaltered dolomite.

Hogberg (1963) has described the history of the exploration and development of the Yellowstone Mine. Tri-State Minerals Company leased the property in 1942 and began exploratory work under the direction of Mr. L. F. Teutsch. The Sierra Talc Company of South Pasadena, California, purchased the land from Mr. Lewis Clark, the original discoverer, in January 1949 and then went from underground prospecting to open-pit mining. Hogberg (1963) gave the Yellowstone Mine "approximately 75 years of reserves based upon an annual production rate of about 20,000 tons of cleaned talc". Initial construction on the Three Forks, Montana, mill was completed in 1961 at a cost of about $400,000; the expansion, which was completed in 1974, is reported to have cost about $2,500,000.

JOHNNY GULCH PROSPECT

Those talc occurrences in sec. 34, T. 8 S., R. 1 W., and sec. 3, T. 9 S., R. 1 W., Madison County (Cameron 15-minute quadrangle), which have been intermittently prospected over the years, are here referred to as the Johnny Gulch Prospect. These occurrences lie within the same thick dolomite unit as do those of the Yellowstone Mine less than a mile to the southwest, but unless isoclinal folding has afforded an incredible coincidence they are not in equivalent strata.

Talc has been mined from deep strike trenches and is exposed in shallow bulldozer scrapings over a strike length of about 1,500 feet. The foliation of the dolomite strikes on the average N. 25° E. and dips 75° to 80° northwest. In the area of the main pit in sec. 3, where talc was mined to depths estimated at 30 to 40 feet over a total strike length of 425 feet, talc in place is sporadic over a horizontal width of as much as 275 feet.

The talc forms more or less concordant lenses with digitate outlines and most are less than 6 inches thick. The talc is generally darker than that in the Yellowstone Mine.

In the 1960's the American Chemet Corporation of Chicago, Illinois, mined talc on this property in the SW¼ NW¼ sec. 3.

TRI-STATE PROSPECT

During World War II, the Tri-State Minerals Company prospected by pits and a 25-foot shaft a talc lens 5 feet thick and several tens of feet long in the NE¼ SE¼ sec. 5, T. 8 S., R. 1 W., Madison County (Cameron 15-minute quadrangle). This property "was abandoned because of low grade and lack of quantity" (Perry, 1948).

MINOR OCCURRENCES SOUTH OF YELLOWSTONE MINE

A small talc prospect has been opened in the SE¼ NE¼ sec. 8, T. 9 S., R. 1 W., Madison County (Cameron 15-minute quadrangle) about 1 mile southwest of the Yellowstone Mine. Dark talc is here associated with weathered and altered marble.

Several small nearly vertical talc bodies are known in the NW¼ NW¼ sec. 9, T. 9 S., R. 1 W., Madison County (Cameron 15-minute quadrangle), and the pattern of the dispersion of the talc float indicated to Hogberg (1963) that the aggregate thickness may be 100 feet. This area, unlike the others described in the Gravelly Range, is complicated by a local cover of Tertiary volcanic rocks.

GEOLOGY AND TALC DEPOSITS OF THE GREENHORN RANGE

The Greenhorn Range lies between the Ruby Range on the west and the Gravelly Range on the east. A belt of "Cherry Creek-type rocks" extends from the east-central part of the Ruby Range eastward into the Greenhorn Range in the vicinity of Ruby Dam. Little is known of the overall geology of this range, but several talc occurrences are known within it.

TALC RIDGE MINE

The most notable talc deposit in the Greenhorn Range is the Talc Ridge Mine, along Little Willow Creek on the western flank of the range in the SW¼ NE¼ sec. 30, T. 8 S., R. 3 W., Madison County (Home Park Ranch 7½-minute quadrangle). This deposit was recently leased by American Talc Company of Summit, New Jersey, and has been mined by them during the period 1973-75. The ore is trucked to Alder, Montana, where it is stockpiled on concrete pads for shipment by rail to processing facilities in South Plainfield, New Jersey, and Alpine, Alabama. The writer has not seen this deposit since American Talc Company began recent mining operations; the following description is based upon a brief visit to the property in 1969.

All of the observed talc is contained within dolomitic marble units. The "talc-zone" is not completely converted to talc but contains abundant intercalated carbonate rock. The strata strike N. 45° E. and dip 25° to 40° northwest. Small pits on the property suggest that small-scale high-angle to vertical faulting is widespread and well developed and would severely complicate the conduct of large-scale open-pit mining operations. Left-lateral fault displacements were noted, but their magnitudes could not be determined. Individual veins of high-purity white talc are as much as 20 feet wide. Footwall and hanging-wall rocks are either dolomite, granite gneiss, or mica schist; locally the rock type of the footwall of one talc vein will be similar to that of the hanging wall of an adjacent talc vein and vice versa, suggesting that some of the talc veins may be repeated by isoclinal folding. Although on a large scale the talc is generally concordant with the foliation of the dolomitic marble, the contacts of the talc bodies are locally strongly discordant over relatively small distances.

The American Chemet Corporation of Chicago, Illinois, once held a lease upon this property, at which time the existence of the uppermost talc vein was seemingly unknown.

WILLOW CREEK PROSPECT

The Willow Creek Prospect, in the NW¼ NE¼ sec. 31, T. 8 S., R. 3 W., Madison County (Home Park Ranch 7½-minute quadrangle) is covered by the Willow Creek #1 and #2 mining claims. Exposures in a small trench on this property indicate that the strata strike N. 40° E. and dip about 30° northwest. No talc thicknesses in excess of 10 feet were observed, and despite the presence on the property of a small stockpile of talc in 1969, no appreciable lateral extension of the talc had then been proved. The geology is extremely similar to that of the nearby Talc Ridge Mine, which lies less than 1 mile north of this prospect. It is extremely unlikely that this deposit could be an extension of the one at the Talc Ridge Mine, but it may represent a structural repetition of the same strata by isoclinal folding.

OTHER DEPOSITS

Perry (1948) reported the presence of a talc deposit "southwest of Virginia City on Idaho Creek" along the western flank of the Greenhorn Range. No locality information is given, and the writer has not visited this reported occurrence. Although Perry described the talc as "good" in hand specimens, he further stated that "as a whole the deposit is said to be small and the average material impure".

Many questions concerning the geology of the Precambrian strata in the Greenhorn Range, particularly the relationships of its "Cherry Creek-type rocks" and its bearing on the origin of talc in Montana, may be answered by the ongoing investigations of Dr. Richard B. Berg of the Montana Bureau of Mines and Geology, who is currently mapping and studying the relationships of the dolomitic marble and associated pre-Beltian rocks within the Ruby Dam and adjacent 7½-minute quadrangles.

GEOLOGY AND TALC DEPOSITS OF THE TOBACCO ROOT MOUNTAINS

The Tobacco Root Mountains lie north of the Ruby, Greenhorn, and Gravelly Ranges and contain the northernmost significant exposures of pre-Beltian rocks in this area of southwestern Montana.

Tansley, Schafer, and Hart (1933) have described a sequence of metasedimentary rocks in the southern and southwestern parts of the Tobacco Root Mountains, which they refer to as the "Cherry Creek Series". The lithologic types that they recognized in this series are quartzite, limestone, schist, and gneiss, whose sedimentary origin is unquestionable, and they noted the high garnet content in many of its members. The major difference that they brought out in comparing the Tobacco Root sequence to that of the type section at Cherry Creek along the eastern flank of the Gravelly Range is the great abundance of garnet rock in the Tobacco Root region, a rock that is rare near Cherry Creek. They divided the "Cherry Creek Series" into three divisions, of which the limestone occurs in the medial division. The thicknesses of the limestone units range from 1,500 feet, where they have been thickened by intense folding, to complete "pinch-outs" where stretched out on the limbs of folds. In certain areas, units that were once calcareous have been replaced by abundant garnet and hornblende and lesser amounts of tremolite, actinolite, epidote, and quartz, suggesting widespread contact metamorphism. This relationship is further complicated by the local development of a more intense metamorphism imposed upon these rocks in proximity to the Tobacco Root Batholith, of Laramide age. There is the strong possibility that limestone members have been repeated in overturned tight isoclinal folds of the type that is well known in the Ruby Range to the south.

Reid (1957, 1959, 1963) has studied and mapped large exposures of the "Pony" and "Cherry Creek" metamorphic rocks over large areas in the northern Tobacco Root Mountains. Despite the detailed lithologic descriptions in these texts, no differentiation of individual lithologic types within these two major metamorphic rock groups was made in his mapping. Within his map area in the north end of the Tobacco Root Mountains (Reid, 1957), the only marble found is calcitic rather than dolomitic.

Gillmeister (1971) described a coarse, dominantly calcitic marble, which has restricted occurrence along the southwestern part of the Tobacco Root Mountains. The thickness of this marble unit ranges from 0 to 1,000 feet. He has named this unit the "Occidental Marble" after the Occidental Mine on the ridge between the North and South Forks of Indian Creek.

Burger (1967) has described the bedrock geology of the Sheridan District along the western flank of the Tobacco Root Mountains. He described both marble and calc-silicate rocks, the latter being relatively uncommon. Thicknesses of marble units range from 100 to 800 feet and average 300 feet.

Hess (1967) noted the presence of both calcitic and dolomitic marble in the central and southern Tobacco Root Mountains and further contributed toward an eventually better understanding of local Precambrian geology by pleading against the dogmatic usage of such stratigraphic terms as "Cherry Creek" and "Pony" when one is unable to prove stratigraphic equivalence from place to place. He suggested that a "single, long-lasting metamorphism took place in the Tobacco Root Mountains between 1550 and 1700 million years ago", accompanied by the development of isoclinal folding along northeast-trending axes and the intrusion of ultramafic and mafic rocks. This is a similar history to that described in the central and southern parts of the Ruby Range by Garihan (1973) and Okuma (1971), respectively.

Cordus (1973) cited evidence which suggests that the marble in the southern part of the Tobacco Root Mountains was impure siliceous dolomite prior to metamorphism. He further described the continuity of at least one of the marble layers for more than 30 miles along strike and described it as uniformly dolomitic.

Perry (1948) described a small talc occurrence in marble of "Cherry Creek-type rocks" along Granite Creek about 2 miles north of Virginia City, Montana. Small stringers of high-grade talc are present within a marble unit 65 feet thick, but commercial talc cannot be extracted from this deposit under current conditions.

Levandowski (1956) described thicknesses of marble units in the Sheridan-Alder area along the southwestern flank of the Tobacco Root Mountains as ranging from only a few feet to as much as 1,700 feet. He described two talc deposits as having maximum known widths of 25 feet and lengths of 55 feet. Both of these talc bodies have been developed within marble and are spatially associated with garnet schist and granite gneiss.

Although the Tobacco Root Mountains have dolomitic marble similar to that found in the Ruby Range to the south, and the conditions of regional metamorphism and granitic intrusive activity are similar in both areas, relatively few talc occurrences are known in the Tobacco Root Mountains. It is not yet clear whether this discrepancy might be due to lack of attention and prospecting or to actual paucity of talc there. The range has been studied for several decades by graduate students of the University of Indiana, which maintains a summer field camp near Whitehall, at the northeastern corner of the range. These investigations, both past and ongoing, will contribute to a better understanding of the detailed geology of the Tobacco Root Mountains and may well help to result in the discovery of new talc deposits – but only time will tell.

OTHER ASSOCIATED MINERAL DEPOSITS

Several other mineral commodities are closely associated spatially or stratigraphically with Montana talc deposits, the most important being graphite, sillimanite, iron formation, kyanite, and manganese.

GRAPHITE

High-grade crystalline graphite has been mined from deposits in the Axes Canyon area of the Ruby Range southeast of Dillon (Perry, 1948; Ford, 1954). The graphite occurs in veins and veinlets in gneiss and pegmatite as well as being disseminated in smaller masses and flakes in those same host rocks. Ford (1954) suggested that the deposition of graphite occurred after the emplacement of the pegmatite and after the period of regional metamorphism. Despite their close spatial association, the graphite was obviously deposited long after the dolomitic marble in the "Cherry Creek-type rocks" was recrystallized.

SILLIMANITE

Sillimanite deposits in the central and southern parts of the Ruby Range have been described by Heinrich (1950). The most common types of occurrence and the ones having the greatest economic potential are biotite-sillimanite schist and biotite-garnet-sillimanite gneiss. The sillimanite also occurs in pegmatite and locally as a massive rock, the latter type commonly being found as residual cobbles and boulders. There seems to be some relationship between the abundance of pegmatite and the abundance of the sillimanite; furthermore, sillimanite "pods" are commonly developed along pegmatite contacts. The most promising deposit, situated on the Art Christensen Ranch near the Sweetwater Road east of Dillon, is a silvery biotite-muscovite schist, which contains differing amounts of sillimanite. Locally, there is also the possibility of placer sillimanite deposits. All of the sillimanite occurrences are in rocks that are closely associated, both spatially and stratigraphically, with the dolomitic marble that contains all of the known commercial talc deposits.

IRON FORMATION

A unit of banded "iron formation" (magnetite schist) as much as 1,000 feet wide and 2 miles long is present to the west of and across the Carter Creek Fault from the Regal (Keystone) talc mine in the southwestern part of the Ruby Range. Mapping by James and Wier (1972) shows the complexity of this small local area. Similar bands of "iron-formation" are present in the type area of the Cherry Creek Group along the base of the eastern flank of the Gravelly Range south of Ennis. In both of these mountain ranges, the iron is closely associated both spatially and stratigraphically with the dolomitic marble that contains all of the known commercial talc bodies.

KYANITE

Kyanite gneiss and schist and kyanite pegmatite and veins have been described by Heinrich and Rabbitt (1960) in the type area of the Cherry Creek Group along the base of the eastern flank of the Gravelly Range south of Ennis, but only the layers of kyanite gneiss and schist seem to have any potential economic significance. Although these kyanite occurrences are not far from the talc deposits to the south in Johnny Gulch, it must be noted that their metamorphic grade is considerably higher than that of the Johnny Gulch area, and it is possible that structural events have placed these two areas in much closer juxtaposition than they were originally.

MANGANESE

Manganese oxide minerals have been widely developed in the pre-Beltian marble of the Ruby Range and the Gravelly Range. Such mineralization, as described by Heinrich (1960) in the southwesternmost part of the Ruby Range, "is generally low-grade but highly variable". This impregnation and subsequent alteration has been locally so intense that the marble may be converted to a crumbly, porous, and commonly incoherent rock. The manganese minerals have formed in the same marble that contains all of the known commercial talc bodies, but even though both the manganese and the talc must have formed in Precambrian time, the possibility of any genetic relationship is unknown.

PROSPECTING HINTS

In most mining districts, whether they produce metals or industrial minerals, the original discoveries are made by prospectors and miners; geologists come along later and refine the details. This is certainly true of the Montana talc-mining district, for the writer is aware of only a single talc occurrence that has been discovered by a geologist. This situation will obviously change in time to come as future talc deposits are sought on the fringes of the now-known "elephant country" and as more sophisticated techniques are developed to find buried deposits, but for the time being, the Montana talc prospector must be given full and well-deserved credit for his most significant contributions to the development of the Montana talc industry.

Guidelines for talc prospecting may be presented here based on present knowledge, but the main problem with applying them dogmatically is that it is still not certain whether they are truly diagnostic for areas of talc mineralization *only*, or whether they might include features that could be present or even abundant in barren areas as well. Their diagnostic reliability, by and large, must await more thorough geological studies in larger areas away from known areas of mineralization.

The only certain criterion known at this time is that *all* of Montana's known commercial talc ore bodies occur within dolomitic marble of the pre-Beltian sequence of "Cherry Creek-type rocks". Therefore, there seems little to be gained by searching for talc in other lithologic units or formations.

From his work in the southern part of the Ruby Range, Okuma (1971) has formulated guidelines for prospecting for talc, and these are quoted verbatim:

"a) All the commercial talc deposits are intimately associated with the marble units. Dolomitic marbles seem to be a prerequisite for the formation of high quality talc in the Ruby Range.

b) The talc generally occurs in areas of structural weakness, such areas being marked by faulting, brecciation, silicification and, in many cases, recrystallization.

c) The talc deposits are related to the presence of intrusive rocks, probably of granitic or other composition, from which they obtained their supply of hydrothermal solutions. To some degree the nearness to Dillon Granite Gneiss especially of the olive-gray variety may be a useful guideline for prospecting.

d) Areas of retrograde metamorphism may be of special significance in talc prospecting."

Garihan (1973) has likewise developed similar guidelines, derived from his work in the central part of the Ruby Range, and these are also quoted verbatim:

"1) Look in areas of structural complexity in the vicinity of known mines, both along the trend of the marble host and in adjacent coarse dolomites; the deposits tend to occur in groups spatially. Isolated occurrences are unusual. All the marbles should be walked out, with an eye out for float chips on the ground or stringers of talc in outcrop. This is considerably easier than mapping all lithologies.

2) Look in areas where non-carbonate rocks have been chloritized and talcified. This is certainly the case in the vicinity of the Treasure mines, where the Dillon Gneiss has been chloritized extensively. Elsewhere, however, rocks such as the Dillon Gneiss are not altered near known talc deposits, so that this is at best a secondary criterion.

3) Bulldoze and drill prospects to evaluate the talc body in the third dimension.

4) Rely on prospector's scratchings; they usually mean something!"

To these valuable guidelines the writer will add here some from his own experience. Occurrences of bedrock talc should not be ignored simply because they are relatively thin. In the first place, one might be looking at the edge or the top of what might continue downward or laterally into a much larger body. In the second place, it must be remembered that the form or shape of Montana talc bodies may be markedly digitate and that only an extremely thin apophysis of a large ore body may have been exposed by erosion at the time one comes across it. Talc ore bodies characteristically swell and pinch, thinning on the limbs of folds and thickening on the crests and in the troughs of folds. This plasticity, plus the natural lenticular habit, renders this caution against cavalier treatment of such occurrences advisable here.

The time-honored technique of tracing float chips of talc uphill to their source will continue to be useful, but this method of course can aid in locating only those talc bodies that have already been breached by erosion. With practice one may develop the ability to discern the presence of talc float chips as small as ¼" or so from the standing position; when one has thus determined that talc is indeed present and then gets down on hands and knees, the distribution of float chips smaller than a matchhead may be readily traced.

The aid of digging and burrowing animals, evidence free for the taking, should be utilized wherever possible. Badgers digging their burrows commonly throw out talc fragments in areas where such would not otherwise be exposed on the surface, so never pass by a badger hole in pre-Beltian dolomite country without inspecting its spoils pile! Ants will commonly build their abodes of the coarsest rock chips available, and the writer has seen many such anthills composed of an abnormally high percentage of talc chips; therefore, anthills in pre-Beltian dolomite country should also be inspected, even though (unlike badger and gopher holes) such debris would represent only surficial material.

In areas of talc mineralization still undisturbed by mining, the writer has observed that one of more of the following associated features will be present:

a) Dolomitic marble is exceptionally coarse grained.

b) Dolomitic marble is exceptionally closely foliated, individual foliae being commonly 1 inch thick or less.

c) Silicification is common, not as veins but as irregular masses, adjacent to and near the talc.

d) Large calcite rhombs, 1 inch or more on a side, are locally developed.

e) Pervasive "soaking" of dolomitic marble by iron oxides or manganese oxides.

POSSIBLE FUTURE TRENDS IN THE MONTANA TALC INDUSTRY

It is likely, in the writer's opinion, that solid, thick, homogeneous talc ore bodies without included waste rock (e.g., Treasure Chest Mine) will not continue to be the source of such ores in Montana for a much longer period of time. More and more, I think that talc ores will be procured from deposits such as the Yellowstone Mine, which are characterized by the digitate interfingering of talc with included waste rock on a relatively small scale. This will require sorting, of course, either by manual labor or possibly by some mechanical or photoelectrical means yet to be perfected, but the grade of talc fed into the mill in the future should not suffer as compared with today's mill feed.

This will be most advantageous from a conservation standpoint, for it is an unfortunate but nevertheless true fact that many thousand tons of high-grade talc ore has been thrown onto the dumps of Montana talc mines because operators did not want to bear the expense of setting up sorting methods. This reluctance to establish such installations may have been due to budgetary reasons or to competition for investment dollars with other divisions within large companies — whatever the reason, it has been and still is a dolefully wasteful procedure and should be stopped! Whether or not a sorting method can be installed at any given time is not as important as the fact that many operators have been reluctant to even go to the added expense of separately stockpiling such "middling" fractions for later sorting or other up-grading processes. A case in point may be found in Stone Creek in the Ruby Range, where many thousand tons of high-grade talc lie irretrievably lost because they are now hopelessly mixed with abundant waste rock in those large dumps. It becomes increasingly more difficult to locate new sources of Montana talc ore; such waste should not be allowed to continue!

Of the two talc-grinding mills in Montana at the present time, one is served by only two mines and the other obtains virtually all of its feed from only one mine. Future milling operations in the Montana talc industry may not be so fortunate; it seems likely to the writer that such operations will instead be served by numerous mines. This may not only become necessary, but it may also become desirable if it affords the opportunity for carefully performed and intelligently directed blending of ores from numerous sources.

Underground operations have been pursued at the Yellowstone Mine in the Gravelly Range and at the Smith-Dillon Mine in the Ruby Range, but all present operations are open pit. The reluctance of present operators to adopt underground mining methods in the face of open-pit competition is fully understandable, but it should be understood by them and by others contemplating new entries into the Montana talc industry that the profit margin in such operations can probably withstand the increased costs of underground mining, particularly when such advantages as year-round operation, increased selectivity in extraction, and other factors inherent in underground mining are considered. Therefore, it may well be that future exploration for Montana talc deposits will not be confined to areas where only open pitting is feasible — as has generally been the case in the past.

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