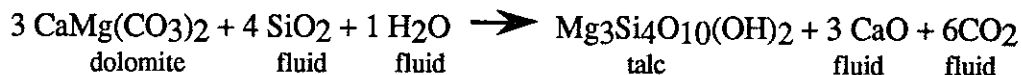


TALC FORMATION IN THE REGAL-KEYSTONE MINE OF THE RUBY RANGE, DILLON, MONTANA

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Introduction:

Proterozoic talc deposits have been reported across the Ruby Range of southwestern Montana in dolomitic marbles of Archean age. The dominate process governing talc formation is the replacement of dolomite by talc. James (1990) postulates that the addition of silica in solution, under correct pressure and temperature, to a dolomitic marble produces talc, calcium oxide, and carbon dioxide. The process can be described by the following reaction:



Previous studies suggest hydrothermal fluids to be the agent of this talc forming process (Berg, 1979; Anderson, Mogk, and Childs, 1990; James, 1990).

The purpose of this study is to learn as much as possible about the Regal-Keystone talc mine in order to constrain possible models of talc forming processes at this site. Understanding the formation of the talc bodies in the Regal-Keystone mine may offer insight into the formation of other talc deposits across the Ruby Range.

Description of Study Area:

The Regal-Keystone talc mine, owned by Pfizer, Inc., is located approximately 11 miles southeast of Dillon, MT on the Christensen Ranch quadrangle (NW1/4, NE1/4, and NE1/4, NW1/4, sec. 2, T. 8S., R.7W) of the Ruby Range (Olson, 1976). Structurally, the mine is located in a synformal marble unit, the axis of which is oriented northeast/southwest with its nose to the southwest. The mine area consists of an open-pit mine, approximately 150 meters long and 15 to 35 meters wide, and twenty trenches that range in length from about 15 to 50 meters (Figure 1)

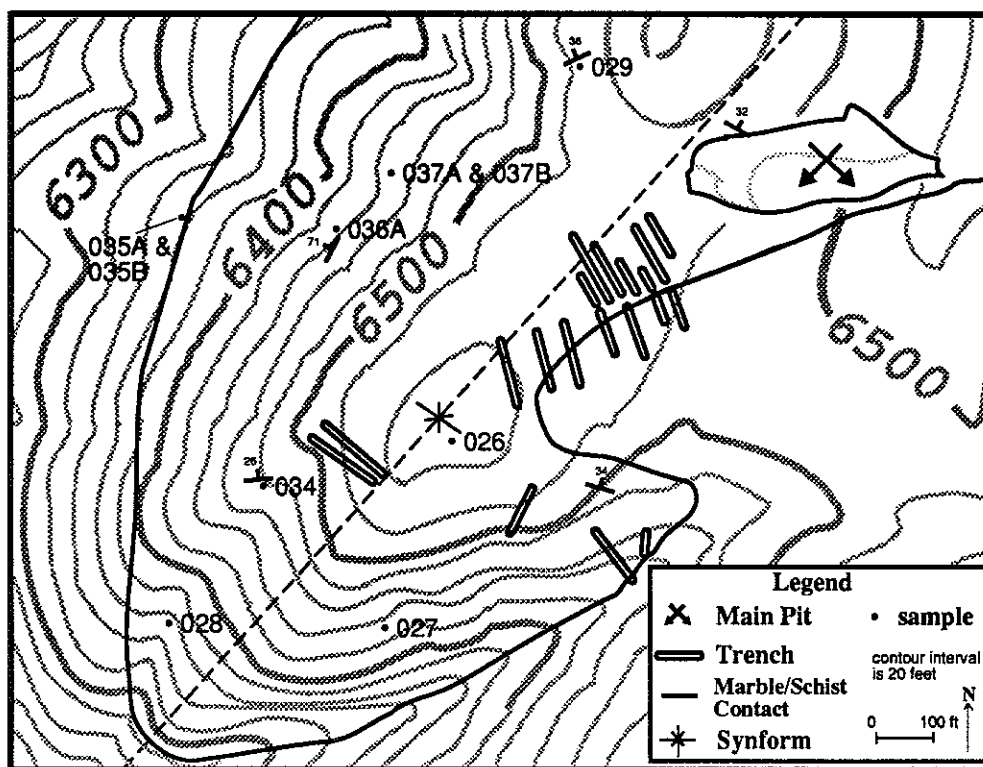


Figure 1: Topographic sketch map of Regal-Keystone Mine study area with pit and trenches (adapted from James, 1990).

both the unaltered marble and talc rock. However, the Sweetwater mine contains the only large amounts of apatite found in the specimens collected.

ICAP

Major and trace element data for thirty-three talc and carbonate specimens was collected using Beloit College's Inductively Coupled Argon Plasma spectrometer. Initial attempts to obtain major element data with the ICAP proved unsuccessful due to improper calibration of the machine. However, the trace element data obtained were very accurate. The abundance of all the trace elements analyzed was low but aid significantly in understanding the chemistry and origin of the metasomatic fluids involved in the talcification process. Many of the trace elements analyzed showed obvious changes in concentrations between the marble and talc specimens (Figure 4). The addition of Zr, Ce, and V to the marble in the process of making talc must have occurred, either by contamination from the interlayered gneiss or primary fluids, since the increase is beyond that which might be expected from a concentration during a volume change following complete metasomatic alteration. The densities of dolomite and talc are very similar (2.85 g/cm³ and 2.7-2.8 g/cm³ respectively). This similarity in densities limits the concentration of trace elements possible during metasomatism. The concentration of Be in both the marble and talc specimens remained relatively constant in the mines and prospects sampled. This data represent the best chemical confirmation that no large volume change occurred between the marble and talc during metasomatism. The lack of expansion fractures or voids during petrographic analysis of the partially altered marbles has also confirmed that a large volume modification as a result of the metasomatic process did not transpire.

A series of Archean gneisses is commonly found interlayered with the Archean marble of the Ruby Range (Anderson and others, 1990). The dark-green chloritic-talcs found in close proximity to many talcified marbles is thought to be the altered remnants of the interlayered gneiss. The American Chemet Mine has several of these altered gneiss units present. Chemical analysis of the altered gneiss reveals high trace element concentrations (Figure 4 AC-16). Pure talc samples from the American Chemet Mine similarly exhibit a relatively high concentration of some trace elements compared to the pure talcs specimens from the Ruby Range (Figure 4 AC-Avg). One explanation for the high trace element concentrations in the talc of the American Chemet Mine is the presence of the altered gneiss.

CONCLUSION

The composition of the fluids are important if the metamorphic history of the area is to be attained. Without major element data, it is difficult to ascertain the exact composition and mass-transfer capabilities of the system. However, the trace element data suggest several important possibilities that must be considered. First, the F and Cl concentrations in the talc are low enough to challenge whether the metasomatic fluids were saline, which is the predominate theory (Anderson and others, 1990). Second, the comparison of trace element concentration between the talc and the unaltered marble indicates a substantial difference, thus reflecting the trace element chemistry of the fluids. The high concentration of Cr, Ce, and Zr in talc specimens from the American Chemet Mine suggests a plausible contribution from the altered gneiss closely associated with the talc. The consistent concentration of Be throughout the Ruby Range in both marble and talc samples is chemical evidence that no large volume change occurred during the talcification process.

REFERENCES

- Anderson, Dale L., Mogk, David W., Childs, John F., 1990, Petrogenesis and Timing of Talc Formation in the Ruby Range, Southwestern Montana: *Economic Geology*, v.85, p.585-600
- Berg, Richard B., 1979, Talc and Chlorite Deposits in Montana: *Montana Bureau of Mines and Geology, Memoir 45*
- Garihan, J.M., 1973, *Geology and Talc Deposits of the Central Ruby Range, Madison County, Montana: Unpublished Ph.D. dissert. Pennsylvania State Univ., 209p.*

Open Pit Mine:

The open pit mine is divided into two areas with a lower pit, depth approximately 10 meters, residing within an upper pit having a depth of 5 to 10 meters. Dolomitic and calcitic marble, talc with varying accessory minerals, as well as amphibolite units are present in the pits (Figure 2). The northern wall of the mine is dominated by massive, marble lithologies, and the southern wall is dominated by the talc body. The talc and marble units are in direct contact with each other; the change in lithology is abrupt and does not appear to be bounded by faults. Talc pods and veins of varying size (1 mm to several centimeters) are present in the massive marble unit of the northern wall of the mine. An amphibolite unit outcrops at the surface at the eastern end of the pit and is visible in cross sectional view in the northern wall of the lower pit. Small, bedded dolomitic marble blocks are also located within the talc body of the lower pit's northern wall in close proximity with the amphibolite unit (Figure 3).

Trenches and Nose:

Trenches to the southwest of the mine reveal a variety of lithologies: calcitic and dolomitic marble, talc, amphibolite, schist, and quartz dominated units. As exposed in the trenches, marble is the dominate lithology to the north and west within the core of the fold, and schist is the dominate unit to the south and east. Unlike the massive marble in the upper pit of the mine, the marble units in the trenches generally are thinly bedded, and some are highly weathered. Large-scale lenses of talc crosscut much of the marble and outcrop in many of the trenches. Talc also crosscuts the schist unit (trenches 3, 5, 9). Pegmatites or quartz-rich rocks are rare and outcrop in small amounts within the schist unit (trenches 13 and 14). The gneiss unit, also rare and in small amounts, is present only in trench 13 and is located possibly within the marble lithology. The nose of the fold predominantly consists of dolomitic marble; however, the marble unit changes in composition abruptly from dolomitic to calcitic marble, even along strike.

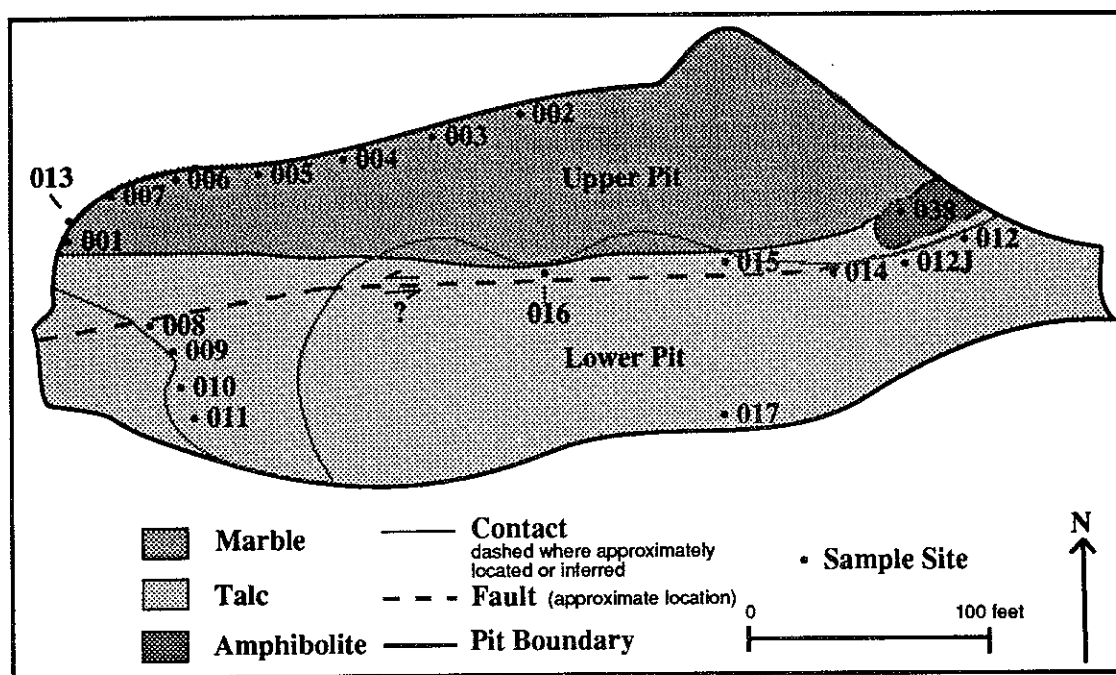


Figure 2: Sketch map of Regal-Keystone open-pit mine, with upper and lower pits. Black dots indicate sample sites.

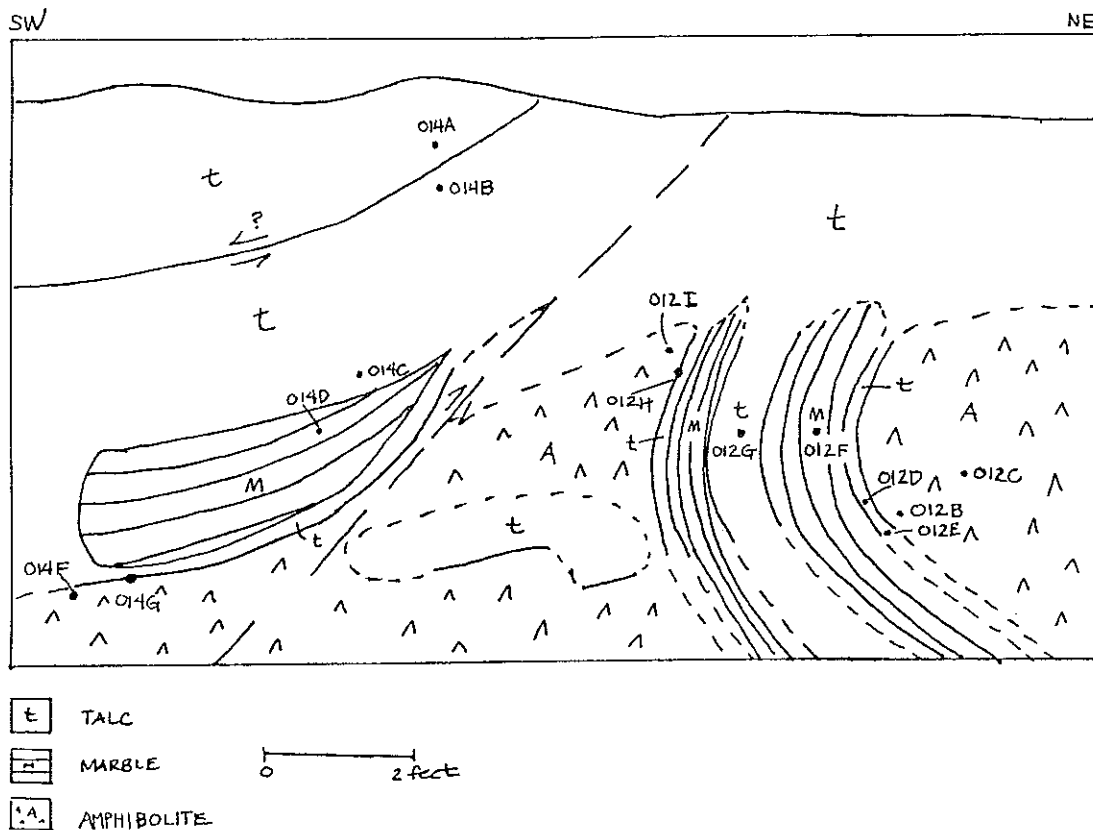


Figure 3: Cross sectional view of northern wall of lower pit at stations 12 and 14. Talc, marble and amphibolite units are present.

Petrographic Analysis:

Methods:

Petrographic analysis of thin sections made from a variety of rock types in the study area of the Regal-Keystone talc mine was conducted to identify main and accessory minerals and mineral texture interrelationships. Thin section samples included talc from both the mine and trenches; marble from the mine, trenches, and nose; amphibolite from the mine and trenches; schist from trenches 13 and 15; and pegmatite from trench 13.

Results:

The talc samples show a high occurrence of phyllosilicate minerals. Chlorite is present in all the talc thin section samples, and many samples contain phlogopite. Carbonate and small occurrences of graphite, apatite, and tourmaline are also common in the talc, and two samples contain olivine or serpentine. Textures in talc samples indicate that talc is replacing both chlorite (001Ab, 008B, 010B, 014B, 017A, 019A, 021C), phlogopite (014G) and carbonate (001Ab, 008B, 010B, 012D, 014G). Some samples, however, show chlorite growing into talc (010b, 011A, 014A). Phlogopite is typically intergrown or in contact with chlorite.

All of the marble samples contain at least a small percentage of phyllosilicate minerals. Chlorite is the dominate sheet silicate mineral in the marbles, but phlogopite is also present in some samples. Many of the marble samples also contain a small percentage of talc, and all marbles containing talc also contain phyllosilicates, commonly chlorite. Other accessory minerals present in the marbles

include apatite, garnet, olivine, titanite, pyroxene, and graphite. The majority of the marble samples across the study area are dolomitic rather than calcitic, as determined in the field from HCl tests; the calcitic marbles include samples 005A, 007A, 028, 029, 034, and 037. Future staining of rocks and thin sections and analysis of samples on the cathodoluminoscope should help distinguish dolomite from calcite in more detail.

Isotopic Analysis:

Methods:

Oxygen ($\delta^{18}\text{O}$) and carbon ($\delta^{13}\text{C}$) isotope analyses of carbonates located at the Regal-Keystone Mine, American Chemit Mine, and several other locations across the Ruby Range were performed at a stable isotope laboratory at Dartmouth College. Oxygen and carbon analyses were conducted on isolated CO_2 gas emitted from both dolomitic ($\text{CaMg}(\text{CO}_3)_2$) and calcitic (CaCO_3) marbles. At least 20 mg of pure carbonate is combined with 3 ml of 100% phosphoric acid (H_3PO_4) in a closed, vacuum sealed vessel and equilibrated at 25°C . The sample vessel is connected to a vacuum sealed line where the resulting CO_2 gas is separated from any other products of the carbonate-phosphoric reaction by a series of nitric acid and ethanol slush freezes. The sample of CO_2 is then entered into a mass spectrometer where it is compared with a standard CO_2 gas ($\delta^{13}\text{C}/^{12}\text{C}$: PDB - 3.463; $\delta^{18}\text{O}/^{16}\text{O}$: PDB- CO_2 -18.522; PDB - 8.462; V.SMOW-SLAP + 22.186), which determines the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values. Doubles of each sample were run in order to test the accuracy of the carbon and oxygen isotope results.

Results:

Isotope analysis of CO_2 gas from carbonates show a wide range of $\delta^{18}\text{O}$ values (9.57 - 30.36‰) and a narrow range of $\delta^{13}\text{C}$ values (-3.79 - 1.21‰) (Figure 4). $\delta^{18}\text{O}$ values are greatest at the nose and north wall of the upper pit, and $\delta^{18}\text{O}$ values are lower in the north wall of the lower pit, in the trenches, and in the the American Chemit Mine. Regional marbles showed the same wide range of $\delta^{18}\text{O}$ values, from 11.6 - 22.6‰ (Figure 5), as the Regal-Keystone rocks.

Carbonate Oxygen and Carbon Isotope Values

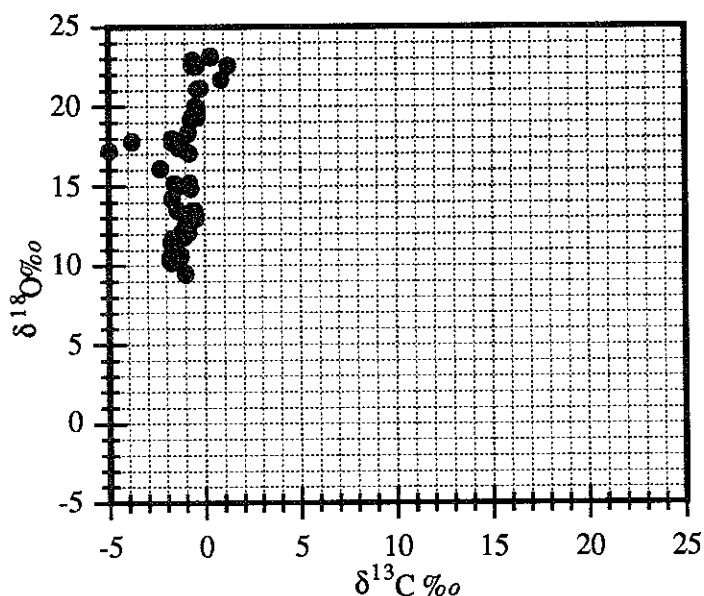


Figure 4: $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values of carbonates in Regal-Keystone Mine, American Chemit Mine, and across Ruby Range region. Black dots indicate samples and their doubles.

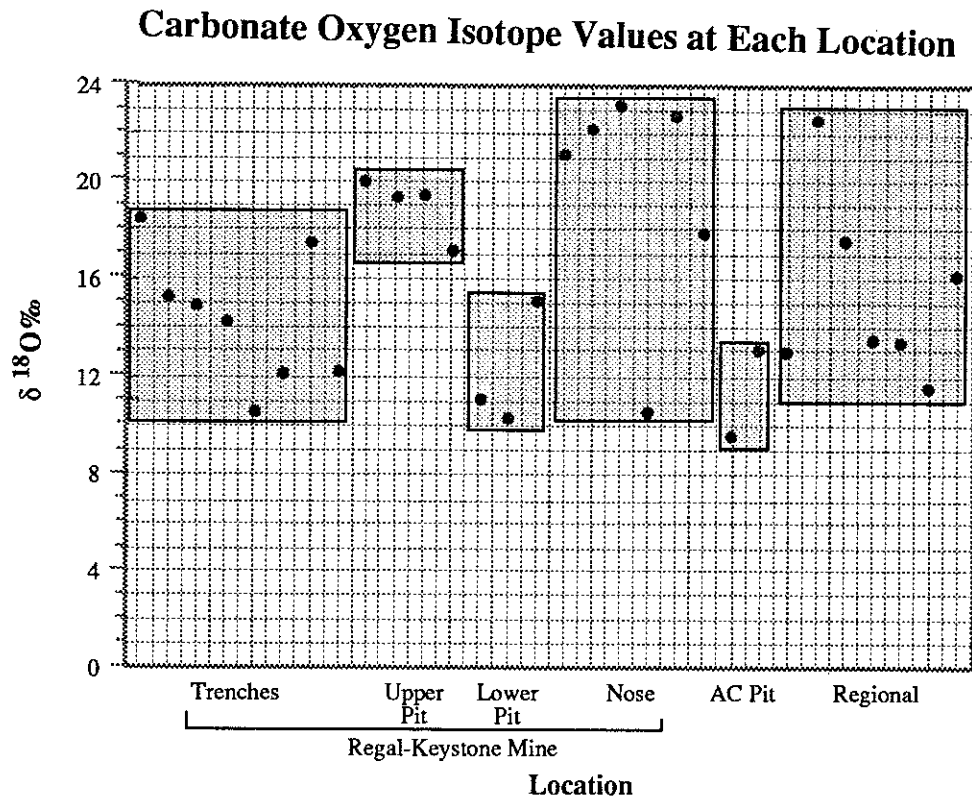


Figure 5: $\delta^{18}\text{O}$ values at various locations at the Regal-Keystone Mine, American Chemit Mine (AC), and Ruby Range region. Shaded areas distinguish different locations, and black dots indicate specific samples at each area.

Discussion:

The dominate process of talc formation in the Ruby Range is the metasomatic replacement of dolomite by talc. Previous studies link talc formation to a retrograde event following the metamorphism of the dolomitic marble, and they suggest hydrothermal fluids to be the agent of this process (Berg, 1979; Anderson *et al.*, 1990; James, 1990). Additionally, chlorite deposits in the Ruby Range are documented as associated with talc deposits, however not all talc deposits are associated with chlorite deposits (Berg, 1979).

Textural relationships between talc and carbonate, observed under the petrographic microscope, support replacement of dolomite by talc. Because chlorite is associated with talc, its occurrence in both the talc and carbonate samples is not surprising. Since some textural relationships show talc replacing chlorite and others show chlorite replacing talc, their time of formation may be simultaneous. Indeed, Berg (1979) believes the time of chlorite and talc formation to be concurrent because of the close association of the two types of deposits. Trace graphite occurrence in both talc and carbonate samples is also not surprising since graphite is a common accessory mineral of marble across the Ruby Range (James, 1990). James (1990) suggests the origin of graphite to result from the fluid mobilization of carbon of originally organic detritus which was later redeposited as graphite under elevated temperatures associated with regional metamorphism.

Since the passage of fluid through a rock unit can change the isotopic characteristic of the rock toward those of the fluid, oxygen and carbon stable isotope results reflect the state of equilibrium between the rock and the fluid (Hoefs, 1987). Thus, the wide range of $\delta^{18}\text{O}$ values of marbles in this study indicate the pervasiveness of the fluid that passed through the Regal-Keystone Mine area. Rocks with higher $\delta^{18}\text{O}$ values will have had less interaction with the fluid than those with lower $\delta^{18}\text{O}$ values. $\delta^{18}\text{O}$ values of 20‰ or greater are normal for metamorphosed carbonates unaffected by a fluid.

The marble samples in the lower pit of the mine and in the trenches showed $\delta^{18}\text{O}$ below 20‰, indicating a high degree of interaction with a fluid. Marble samples in the north wall of the upper pit and many located in the nose have higher $\delta^{18}\text{O}$ values, many near and above 20‰, suggesting low to no interaction with a fluid. Although small talc pods are present in the marble of the upper pit, its massiveness may have prevented pervasive fluid flow through the unit. The marbles in the trenches and lower pit, however, are thinly bedded, and the marble samples from the lower pit are units completely surrounded by the massive talc unit. Thus, the structure of the marble in these localities is more conducive to pervasive fluid flow, explaining its lower $\delta^{18}\text{O}$ values. Hoefs (1987) explains that fluid flow can be channelized, due to rock structure and degree of permeability which would result in a heterogenetic isotope signature within the rock. Low $\delta^{18}\text{O}$ values in the American Chemit Mine are also expected since fluid must have flowed through the mine area in order to form the talc deposit. The regional marbles were collected away from known talc deposits in order to have samples not associated with the talc formation. Thus, high $\delta^{18}\text{O}$ results were expected. Only one regional sample, however, showed a high $\delta^{18}\text{O}$ value (22.6‰) while the others showed $\delta^{18}\text{O}$ results below 20‰. These low results may indicate that fluid flow, although channelized, is regional.

Insignificant change in carbon isotope values suggest that carbon, unlike oxygen, is not a large constituent of the fluid involved with talc metasomatism. Thus, variations of $\delta^{13}\text{C}$ values may reflect differences in the organic content originally in the rock prior to metamorphism. Further analysis of carbon stable isotope values in graphite in regional and American Chemit marbles will be compared with the carbon stable isotope values of the carbonate in these same rocks in order to interpret the geothermometry of the retrograde event.

References Cited:

- Anderson, D. L., D. W. Mock, J. F. Childs. 1990. Petrogenesis and timing of talc formation in the Ruby Range, Southwestern Montana. *Economic Geology*. 85, 585-600.
- Berg, R. B. 1979. Talc and chlorite deposits in Montana. *Montana Bureau of Mines and Geology, Memoir 45*.
- James, H. L. 1990. Precambrian geology and bedded iron deposits of the southwestern Ruby Range, Montana. *U.S. Geological Survey Professional Paper 1495*.
- Olson, R. H. 1976. The Geology of Montana Talc Deposits. *In Eleventh Industrial Minerals Forum, Special Publication 74. Directed by Groff, S.L. Montana College of Mineral Science and Technology, Butte, Montana, 99-143.*

A COMPARATIVE ANALYSIS OF TALC DEPOSITS IN THE RUBY RANGE, MONTANA

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Most geologists agree that continental growth occurred during the Archean, but much debate remains about the nature of the tectonic systems that facilitated the thickening of this crustal material (Windley, 1984). Many small remnants of Archean rocks, Archean terrains, occur scattered throughout the globe, primarily in the heart of mobile belts. These terrains contain clues about the Earth's early evolution and continental growth. The Archean basement of southwestern Montana, part of the northernmost Wyoming Province, is exposed in foreland block uplifts and contains a variety of metamorphic and structural styles that reflects the early continental growth of North America (Mogk and Henry, 1988). Late Archean basement rocks to the west of the Beartooth Mountains, including those rocks in the Ruby Range, southwest of Dillon, Montana, are dominated by high-grade quartzofeldspathic gneisses and supracrustal metasedimentary sequences, mainly schists, quartzites, and marbles (Mogk and Henry, 1988). A working model by Mogk and Henry (1988) calls for deposition of coarse clastic and platform-type sediments in a rift-bounded basin, followed by collapse of the basin, deep burial of sediments by means of tectonic thickening, isoclinal folding and nappe emplacement. In the Ruby Range this resulted in amphibolite- to granulite-grade metamorphism, with peak metamorphic conditions at 700°-750° C and 6-8 kbars (Dahl, 1979) at approximately 2.7 Ga (James and Hedge, 1980).

Talc deposits in the Ruby Range occur within dolomitic marble units of the Archean terrain. These talc deposits yield a high grade of relatively pure talc that is of economic interest. Ore reserves are estimated to be on the order of 10⁶ tons (Anderson et al., 1990). Talcification of dolomitic marbles requires the metasomatic introduction of SiO₂, Mg⁺², and H₂O, and the removal of large amounts of Ca⁺² and CO₂. A Proterozoic retrograde regional thermal event overprinted granulite to amphibolite grade mineral assemblages with greenschist-grade assemblages. Previous workers (Olson, 1976; Berg, 1979; and Karasevich et al., 1981) have suggested that the talc formed by fluid movement along northwest trending faults active during this event. Based on Rb-Sr whole-rock analysis and K-Ar analysis of biotite this event has been dated at 1.6 Ga (Giletti, 1966). It has also been suggested that the emplacement of diabase dikes about 1.455 Ga, may have been accompanied by another metamorphic cycle of low intensity and that these dikes could have served as the source of heat and/or fluids for talc formation (James, 1990; and Anderson et al., 1990). The ultimate goal of this project is to determine the origin and subsequent evolution of the talc deposits that occur in the Ruby Range and other Precambrian terrains of southwestern Montana.

The purpose of my study is to characterize, on a regional scale, the petrographic and petrochemical nature of the Ruby Range talc deposits. Hence, seven known deposits were selected for study on the basis of geographic distribution, size, extent of outcrop, and accessibility. Of the seven localities, the Regal-Keystone Mine, is being studied in detail by Amy Larson and her work will serve as a basis for my regional comparisons.

In the summer of 1990, three weeks were spent collecting approximately 250 samples from the seven talc prospects (see Fig. 1 of Cheney and Brady, in this volume). An average of five samples from each deposit, 36 in all, were selected for thin-section study. These samples range, at each locality, from pure marble through talc plus carbonate rocks, to relatively pure talc rocks. Initial petrographic results are generally consistent with those of Anderson et al. (1990). Of particular significance is that the talc texturally postdates the carbonate, and the dominant mineral assemblage of talc bearing marbles is talc-dolomite-chlorite ± calcite with accessory graphite and pyrite.

As defined by Hoefs (1987), stable oxygen and carbon isotopic studies can constrain the nature of fluids and help determine peak metamorphic conditions. Isotopes may be used as a "tracers" in a rock's history; generally, certain types of rocks have a specific isotopic "signature". Because the dolomite should have a specific isotopic signature, any deviation from that signature will reflect the chemical influence of the talc forming fluids. Comparing isotopic data from deposit to deposit may provide conclusions about the overall nature of the infiltrating fluid and its effects on the country rock.

Three to four samples from each deposit, twenty-three in all, were selected for carbon and oxygen isotope analyses. These samples represent several textural types that include: 1) medium-grained "pure"