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The Calcite Veins of the Livingston Formation

John Moore Conrow

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THE CALCITE VEINS
OF THE
LIVINGSTON FORMATION

by
JOHN MOORE CONROW

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

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THE CALCITE VEINS OF THE LIVINGSTON FORMATION

Introduction

An interesting group of calcite veins occur near Livingston, Montana in a zone about eight miles wide and forty miles long in the edge of the plains region of Montana in front of the main ranges. The zone extends from the Boulder River south of Big Timber, through Springdale and Hunters Hot Springs, to Potter's Basin just north of Wilsall in Park County. The group of veins is particularly interesting because they cut relatively flat lying strata, because they suggest a structural relationship to one another, and because they are nearly pure calcite. They present a problem as to structural control of vein systems, and as to origin.

The present investigation, as originally planned, was undertaken to determine the position of the calcite veins by plotting them on a base map of the district. In addition, it was planned to determine the mineralogy and origin of the veins and their structural and stratigraphical relationship to the rocks of the Livingston formation which they cut.

Subsequent work on the problem has proven it to be of greater magnitude than was at first anticipated; and this together with the inaccessibility of the area for field mapping during the winter months resulted in only a beginning of the plotting of the veins on a base map. Mineralogical and microscopic studies of the vein material have been made.

The calcite veins were described in an earlier report by Weed in 1905. The reference is not of value except that it gives the location of the veins as being near Hunters Hot Springs. Weed describes the veins as composed of gypsum and
stilbite. It is difficult to understand how a geologist of Weed's training and known ability could have made such an error. It is possible that he may have taken samples of the material to study at a later date and have gotten them mixed with samples from another locality. In my examination of the vein material, I found no gypsum and stilbite occurs only in microscopic quantities. The veins are nearly pure calcite.

Geography

The area in which the calcite veins occur is one of gently rolling hills and long ridges lying on either side of the Yellowstone and Shields River valleys to the north of Livingston, Montana. The area is bounded on the north and west sides by the Crazy Mountains and the Bridge Range, and on the south by the Absaroka Range.

On the north side of the Yellowstone river, fourteen miles north of Livingston and four miles west of Hunters Hot Springs, an escarpment known as Sheep Mountain rises to a height of 1000 feet above the valley floor. This mountain is an abrupt sandstone cliff capped by an andesite sill. Ten miles to the north of Sheep Mountain are the Crazy Mountains with an elevation of 11,000 feet. Between Sheep Mountain and Yellowstone River is a tract of low rounded hills which rise gradually to a long, high, flat-topped, gravel-covered ridge just west of Springdale. The ridge forms a part of a gentle fold known as the Livingston anticline. This structure has a general northwesterly trend and the hot springs fissures at Hunters Hot Springs occur on the northeast limb of this anticline.

Southeast of Yellowstone River, the ridges and hills caused by the Livingston anticline are encountered again, and
they extend from Springdale to the Boulder River.

The southern end of Sheep Mountain slopes downward to another tract of low, gently rolling hills which extends south to Livingston and north to Wilsall. In the vicinity of Wilsall, on the east side of Shields River, the rounded hills are replaced by a series of benches which slope toward Wilsall from the Crazy Mountains.

On the south side of Yellowstone River, between Livingston and Elton, the valley is flanked by high erosional terraces, capped with river gravels. These terraces are evidence of two earlier stages of erosion which existed during the early history of Yellowstone Valley.

Yellowstone River, which rises in Yellowstone National Park, Shields River, which rises in the Crazy Mountains, and Boulder River, which rises in the Absaroka range, drain the entire area. Intermittent streams are numerous. Several larger creeks, such as Rock Creek and Fall Creek in the Shields Valley, Duck Creek north of Hunters Hot Springs, Dog Creek west of the springs, and Mendenhall Creek south of Springdale, flow continuously throughout the year.

General Geology of the District

The area in which the calcite veins occur is underlain essentially by sedimentary rocks and volcanic debris of the Livingston formation. Other rocks which crop out in the region are the basic dikes of the Crazy Mountains, the andesites of Sheep Mountain, and the basic andesitic breccia and lava flows of the Boulder River country. These rocks are of upper Cretaceous age.

The Livingston formation consists of 12,000 feet of
conglomerates, sandstones, and shales, with local areas of volcanic agglomerates and breccia near the base. The series rests upon the Eagle sandstone of middle Cretaceous age. The upper strata of the Livingston formation consist of light earth colored and white sandstone beds separated by bands of gray and purple clays and shales. Associated with the shales are thin lines of empire limestone. The lower strata of the Livingston consist of beds of coarse, dark-colored sandstones alternating with thin beds of dark gray, brown, and purple shales. Many of the sandstone members of the lower portion of the Livingston seem to be formed of the disintegrated but unaltered minerals of a basic igneous rock. Hence their dark color in contrast to the light colored sandstones of the upper strata. These lower members might truly be called arkose.

The sedimentary rocks of the Crazy Mountains greatly resemble the rocks of the Livingston and are grouped with them. These sediments have been intruded by a great number of dikes and sills which form a resistant framework of the range. The material which forms these intrusives is a basic andesite.

The Sheep Mountain escarpment, facing the Yellowstone south of the Crazy Mountains, is an abrupt sandstone cliff, capped by a fifty-foot sill of basic porphyritic andesite, which rises to a height of 1000 feet above the floor of the valley. This sill, and the dikes and sills of the Crazy Mountains, are probably late Cretaceous or early Tertiary in age and may be genetically related.

In the region drained by the Boulder River is a rather extensive area of volcanic agglomerate. It extends from Mendenhall Creek, one-half mile south of Springdale, southward
to the Boulder River. This agglomerate consists of a dark, fine-grained, basic lava, enclosing rounded boulders of a coarsely crystalline igneous rock, having approximately the composition of an andesite. The boulders appear to have been derived from an earlier lava flow.

The Livingston formation and its associated rocks are underlain by middle and lower Cretaceous formations, the Jurassic formation, and the Paleozoic series of Montana. These formations include the Carboniferous and Jurassic limestones which may be of considerable importance in connection with the calcite veins. The entire series in the area in which the calcite veins occur has a regional dip of about eight degrees to the north away from the Absaroka range. The total thickness of the series from the base of the Cambrian to the top of the Livingston formation is 16,500 feet.

In some areas, the structure of the Livingston formation is quite simple and in others, it is quite complicated. As has been previously stated, the strata have a general northerly dip. Between Livingston and Wilsall, the beds conform to this general dip, and are relatively continuous and undisturbed on either side of the Shields River. This is not the case in the group of hills lying between Sheep Mountain and Springdale. The strata in this area have been so badly faulted that it is difficult to trace any one member for more than a hundred yards. A great deal of very detailed mapping would be necessary in determining the small scale structure. The region is traversed by a major fold known as the Livingston anticline, which comes in from the Boulder River country. Its general strike is northwest. The crest of the anticline passes one mile to the south of Springdale. As it continues westward, it crosses
Fig. 1.-- Slickenside from the wall of one of the calcite veins $\times \frac{1}{2}$

Fig. 2.-- Banded calcite from the calcite mine on Mendenhall Creek $\times \frac{1}{4}$
cellent example of the banding is shown in Figure 2. This specimen is 10 inches in width and was taken from the wall of a three foot vein of calcite on Mendenhall Creek south of Springdale. The specimen shows the calcite to have been deposited in successive layers or bands from the walls inward towards the center of the fissure. It also shows a considerable variation in the width of the successive bands indicating that the amount of calcium carbonate carried in solution by the mineralized solutions was not constant but varied considerably from time to time.

The banded structure of the calcite in some of the veins seems to give a hint as to the condition of the fault fissures at the time the calcite was being deposited. It has been suggested by others who have examined the calcite veins that the original fissure openings were not more than a few inches in width and that the present width of from four to six feet attained in some of the veins is due to the spreading of the fissure walls by the force of growing crystals of calcite. The exponents of this theory maintain that it is unlikely that a fissure several feet in width would remain open for any length of time. There seems to be no good reason for such a statement.

Although no open fissures of the magnitude of those in which the calcite occurs are known to exist at the present time, such fissures are entirely within the realm of possibility. If the fault walls were curved surfaces, the movement of one wall past the other would open fissures which might very well be of considerable width and length and such fissures would remain open indefinitely.

It seems more likely that the calcite was deposited in open fissures than that the fissures were open by the force
of crystal growth as the calcite was deposited. The evidence presented by the banded calcite of Figure 2 supports this theory. Each of the bands is composed entirely of perfect crystals of calcite standing perpendicular to the walls of the vein. The inner terminations of the crystals are well formed and the crystals do not appear to have been interfered with during their growth. This would not be the case if the crystals growing inward from the two walls of the fissure were pressing each other for room in which to grow. They would be deformed, there would be some interlocking, and the crystals would be shattered as the walls of the fissure were spread apart. Consequently the fissures must have been of the same width when the first calcite was deposited as they are now because the deposition of calcite, so far as could be discovered, went on without interruption.

Following the deposition of the calcite, there may have been a further widening of the fissures by post-mineral movements. There is considerable evidence in some of the veins that there was some movement along the fault planes after the calcite was deposited. Locally the calcite has been brecciated, and along the planes of slippage it has been pulverized to a calcite fault gouge. Near the surface the fragments of shattered calcite have been cemented together by calcite crystals, apparently deposited by downward percolating surface waters. This calcite breccia presents a "rosette" structure which is probably what Weed describes as being made up of crystals of gypsum surrounded by stilbite.

The vein calcite is all of the crystalline variety except where it has been crushed by post mineral faulting. The variety of calcite known as dogtooth spar is quite common and
very good crystals of it may be obtained from the veins. Most of the calcite which comes from the mines is in the form of blocky cleavage pieces. Some of it is quite clear and of nearly optical quality, but the greater part of it is milky white or yellow to light brown in color. The yellow and brown calcite is probably colored by a very small amount of iron oxide which it contains. The calcite is of a very high degree of purity, the iron oxide being the only impurity found combined with it. Pyrite, stilbite, and silica are locally associated with the calcite in the veins, but they are sparsely and locally distributed, and microscopic in quantity with the exception of the silica.

The silica which occurs in the calcite veins is in the form of crypto-crystalline quartz. At least two generations of silica are in the veins. The first generation preceded the calcite and is found lining the walls of the fissures. The second generation of silica occurs towards the center of the veins and is found enclosing the fragments of the calcite which was shattered by the post-calcite faulting. Figure 3 shows a specimen of this silica with casts of calcite rhombs around which it formed. The calcite has been dissolved out by surface waters. Figure 4 is a micro-photograph of a thin section of a portion of the specimen of Figure 3. Both photographs show the porous structure of the silica caused by the leaching of the enclosed calcite fragments. The presence of the silica is difficult to detect with the unaided eye except where the material has been subjected to the solvent action of surface waters. It differs little in general appearance from the calcite with which it is associated, and the two cannot be distinguished in the fresh material which comes from the mines.
Plate 2

Fig. 3.-- Casts of calcite rhombs in a matrix of silica x ½

Fig. 4.-- Thin section of the silica of Fig. 3. showing porous structure due to leaching of the calcite by surface waters x 160
except by hardness. However, under the microscope, it is readily detected.

Associated with the silica in scattered portions of the veins is a very small amount of pyrite. The pyrite occurs as minute crystals, invisible to the unaided eye, and so infrequent that they are of no consequence in so far as the mineral composition of the veins is concerned. They may, however, be of some consequence in determining the origin of the waters which deposited the calcite as will be discussed in a later portion of this paper. Figure 5 is a microphotograph of two of these crystals of pyrite in a groundmass of silica. All of the pyrite which has been observed has been associated with the silica rather than with the calcite. Whether or not this is of any particular significance has not been determined.

The third mineral which is associated with the calcite is stilbite. Like the pyrite, it is not visible to the unaided eye in a hand specimen and was discovered in thin sections under a microscope. The crystals of stilbite are microscopic in size, and although more plentiful than those of pyrite, are of no quantitative importance. Figure 6 shows stilbite from a vein near Hunters Hot Springs. Figure 7 shows crystals of stilbite associated with irregular masses of silica from the vein of calcite which is being worked on Mendenhall Creek southeast of Springdale.

Stilbite is a common mineral in hot springs deposits and is often found associated with calcite.

Origin of the Calcite Veins

In foregoing pages, the calcite veins have been frequently
Fig. 5. -- Thin section showing two crystals of pyrite in a matrix of silica x 160

Fig. 6. -- Stilbite from a calcite vein near Hunters Hot Springs x 65
referred to as hot springs deposits.

There is little or no doubt that the deposits are of hydrothermal origin. Hot springs are numerous throughout the area, although the only ones of any importance at present are at Hunters Hot Springs, and their presence immediately suggests that the fissures in which the calcite formed were once occupied by similar springs. The wall rock of the veins has been hydrothermally altered and impregnated with calcite and fragments of the wall rock which are included in the veins have been so highly altered that it is not possible to determine their original character in many instances. Figure 8 shows two of these fragments in the calcite. The original minerals of the rock have been completely altered and the rock, which was originally an arkosic sandstone, now has a jaspy appearance. Other bits of evidence supporting the theory of hot springs origin are the banded character of the calcite showing that it was deposited in layers on the walls of the fissure and the presence of stilbite which is known to be a common mineral in hot springs deposits.

The hot water which deposited the calcite could have been either of magmatic origin, or it could be artesian water from a deeply buried water bearing formation, or it might be a combination of the two, that is, from an intrusion of igneous material into an aquifer. In the last case the aquifer would supply the water which would be heated by the intrusive.

The Livingston formation is underlain by two formations which are known to be good water carriers. The uppermost of these is the Dakota sandstone which lies at a depth of approximately 4500 feet below the present land surface in the vicinity of Hunters Hot Springs. The second aquifer is the
Fig. 7. -- Stilbite and silica from a calcite vein near Hunters Hot Springs x 65

Fig. 8. -- Fragments of fault breccia included in the calcite x $\frac{1}{2}$
top of the Madison limestone. Either of these formations could supply the water for the hot springs. The fact that the water is hot does not preclude either of these as a possible source. A study of the temperature gradients in oil wells which have been drilled in Montana shows that the temperatures of the earth increases one degree Fahrenheit for each 50 to 100 feet increase in depth. If this temperature increase is constant, it is quite possible that the water at a depth of 4500 feet may be quite hot. If this temperature gradient is correct, it would be possible for either the Madison limestone or the Dakota sandstone to supply the water for the hot springs. However, because the amount of calcium carbonate which the waters of the Dakota sandstone would be able to acquire is decidedly limited by the very small amount of limestone which occurs in the formations overlying it, the field is narrowed down to the Madison limestone.

The Madison limestone crops out as a long, high ridge, known as Wineglass Mountain, five miles south of Livingston. From Wineglass Mountain, the limestone dips in the direction of Livingston and passes under the Livingston formation. The outcrop of the Madison limestone on Wineglass Mountain is 3000 feet higher than the elevation of the land surface in the vicinity of Hunters Hot Springs. Hence the head on the water is adequate to send it to the surface to form springs.

Opposed to the theory of artesian origin of the water which deposited the calcite is the theory of igneous origin. Evidence of recent igneous activity in the district is plentiful. Lava flows were found associated with the Livingston formation in the region drained by the Boulder River south of Springdale and to the north are the dikes and sills
of the Crazy Mountains and Sheep Mountain. These dikes and sills were injected into the upper part of the Livingston formation and hence can be no older than the Late Cretaceous sediments, and they are probably early or middle Tertiary in age. As the calcite veins cut the same formations which are intruded by the igneous rocks, a possible correlation between the veins and the igneous activity is suggested. Thus far it has not been possible to accurately correlate the age of the calcite veins with that of the igneous intrusions but their age is approximately the same. Should subsequent investigations prove the calcite to be older than the andesite, the theory of igneous origin of the spring waters may have to be abandoned. The presence of springs in the regions at the present time indicates, however, that the calcite will prove to be the younger of the two.

Although sufficient evidence has not been obtained as yet to make it possible to make any definite statement as to the origin of the waters which deposited the calcite, the theory of a magmatic origin seems most likely to the writer. The numerous igneous intrusions in the district clearly indicate the presence of a deep-seated igneous body. Geologically, this body is quite recent and should be capable of supplying the waters for the hot springs. The presence of pyrite in the calcite veins and of hydrogen sulphide gas in the waters of Hunters Hot Springs also lends support to this theory. Sulphide gases are among the more common associates of igneous bodies. It is true that they could be derived from other sources. Hydrogen sulphide is not uncommon in coal-bearing rocks in some localities and it is possible that the sulphide gas is coming from the coal-bearing Eagle
sandstone upon which the Livingston formation rests.

The calcium carbonate which was deposited in the fissures as the mineral calcite may have been derived from any of the Paleozoic or Mesozoic limestone formations or from several of them. Limestones compose the greater part of the pre-Cretaceous rocks of the district. Which of these formations supplied the calcium carbonate, it would be difficult to determine. For the present it is sufficient to say that the known limestone formations underlying the Livingston are quite adequate to have supplied the material of the veins. The same is true of the silica. It may have been derived from almost any of the underlying formations or from the rocks of the Livingston formation itself.
Economic Importance of the Calcite Veins

The calcite veins in the vicinity of Springdale have become of some economic importance during the past few years. The calcite is being mined, crushed, and sold as a stock and poultry food. The Ray of Hope properties near Hunters Hot Springs are no longer being operated and the plant there has been torn down. The Springdale Calcite Products Company is still shipping several carloads of calcite each week. The mine is located on a vein which crops out on Mendenhall Creek, three miles south of Springdale.

The calcite marketed is of a high degree of purity, generally containing more than 99% calcium carbonate. In this report the minerals which occur as impurities in the calcite have been stressed because of their interest from a purely scientific viewpoint. Quantitatively these minerals are insignificant, and their effect upon the grade of the calcite is negligible. Likewise, the photographs in this report are by no means representative of the mass of the calcite, since they are picked specimens, chosen to illustrate some particular phase of the problem. An erroneous impression that the vein material as a whole is of this nature must not be had.

As a small scale operation the industry seems to be thriving and should continue to do so. The market for the calcite is not large but it is consistent and permits profitable operations for one or two small companies. An increase in production or in the number of producing companies would soon flood the market and make profitable operation impossible for all concerned.
Bibliography: