Optical Calcite Deposits in Park and Sweet Grass Counties, Montana

GEOLOGICAL SURVEY BULLETIN 1042-M

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By W. C. STOLL *and* FRANK C. ARMSTRONG

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A report on Montana deposits that provided essential optical material during the early years of World War II

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By W. C. Stoll and Frank C. Armstrong

ABSTRACT

The calcite deposits of Park and Sweet Grass Counties, Mont., although mined locally for chicken grits, had yielded only slightly more than 600 pounds of optical spar and mineral specimens before World War II.

During 1942 and 1943 the deposits were exploited extensively to obtain calcite for use in a new antiaircraft sight developed by the Polaroid Corporation. Records were not kept of the first production after the beginning of World War II, but it probably amounted to less than 1,000 pounds of acceptable optical calcite. Available records indicate that Calcite Operators, Inc., and Metals Reserve Company produced 9,217.5 pounds of optical material during the period of intensive mining.

By the summer of 1944 the Polaroid Corporation had developed a synthetic substitute for optical calcite. The substitute was nearly as good as the calcite and could be mass produced. Mining of optical calcite ceased, therefore, in August 1944.

Most of the optical calcite has been obtained from veins cutting sedimentary rocks of the Livingston formation, but some also has been obtained from veins in the Livingston igneous series of Parsons (1942). Sedimentary rocks of the Livingston formation are composed of andesitic sandstone, tuff, shale, conglomerate, and local intercalations of volcanic breccia and agglomerate. The Livingston igneous series of Parsons (1942) is made up of andesitic tuff, breccia, agglomerate, tuffaceous sandstone, volcanic conglomerate, and a few thin flows of andesite and basalt. Both the sedimentary rocks of the Livingston formation and the Livingston igneous series of Parsons (1942) are believed to be the stratigraphic equivalents of a number of Upper Cretaceous and lower Tertiary formations in areas nearby. In the calcite-producing area the Livingston formation has been folded into a broad, flat, synclinal trough trending about north. To the northeast, west, southwest, and south the Livingston formation has been turned up along the fronts of the surrounding mountains.

The calcite veins occupy faults that trend northwestward and dip steeply either southwestward or northeastward. The calcite occurs as thick massive veins, as systems of branching smaller veins, or as stockworks of veinlets. A few veins also contain stilbite, and one occurrence each of laumontite and chalcedony was found. Some of the larger veins have been traced several thousand feet on the

surface and may have a maximum thickness of 20 feet. A thick vein about 100 feet below the surface on the bottom level of the Wade property is the deepest worked calcite vein in the area. Veins that cut both shale and sandstone tend to be thicker in the sandstone; and the steeply dipping parts of veins are generally thicker than the flatter parts. Many veins are conspicuously banded parallel to their walls, and the individual bands exhibit comb structure. The bands resulted from repeated movement on faults followed by deposition of calcite in the openings formed by the movement.

Vugs created by incomplete filling of fissures have been the source of all optical calcite mined. The largest vug of record measured 70 feet long, 30 feet wide, and 3 feet thick. Most of the productive vugs were tabular in shape and had volumes of several tens to hundreds of cubic feet. Most of the usable material came from the clear crystal tips, though some came from the "root" material nearer the vein walls. In productive vugs crystals 3 to 8 inches across were the most numerous. The two most common crystal forms in all vugs were rhombohedrons and scalenohedrons. All crystal faces had been strongly etched by ground water. The principal defects causing rejection of crystals were excess opaqueness, twinning, and incipient cleavage fractures within the crystal.

The calcite veins were deposited in open fractures by rising hydrothermal solutions of low temperature and pressure. The veins appear genetically related to the local igneous activity, and may have been deposited during an earlier hypogene period of carbonate mineralization by ancient hot springs similar to the present ones in the area.

All known optical calcite deposits in the counties are described here, including several other large veins that have not been exploited.

INTRODUCTION

The presence of calcite veins in south-central Montana has been known for many years, but the veins were of little economic importance until World War II when the invention of an optical ring sight for anti-aircraft artillery required the production of an unprecedented amount of transparent calcite. During 1943 and 1944, mining by private and government organizations proved that many of the calcite deposits contain substantial amounts of suitable material—mainly as crystals lining the walls of vugs. Mining techniques were developed and the military demand for optical calcite was temporarily satisfied, principally by the Montana mines.

Geographic features.—The calcite veins of the north and central parts of Park County and the central part of Sweet Grass County are within a northwestward-trending area about 50 miles long and 20 miles wide. This area includes some of the valley of the Yellowstone River, the master stream of the area, and the valleys of the Shields and Boulder Rivers, the major tributaries. The broad, rolling grasslands are used mainly for the grazing of cattle and sheep; the wider valley bottoms are partly cultivated. Thinly to densely wooded mountains enclose the valley lands on three sides. The veins crop out in the valleys and in a hilly tract near the headwaters of Upper and Lower

Deer Creeks in the foothills of the Beartooth Mountains. Plate 23 is a map of the calcite-bearing area.

The largest cities in the area, Livingston and Big Timber, are on the banks of the Yellowstone River. The main line of the Northern Pacific Railway passes through both places, and from Livingston a branch line runs north, up the Shields River valley through the small settlements of Grannis, Clyde Park, and Wilsall. Another branch runs 50 miles south to Yellowstone National Park. Small villages and many ranches lie near the streams and are connected to main highways by paved or graded Federal and State roads along the main rivers and by a system of dirt roads in the hinterland.

Field work and acknowledgments.—The field work for this report was done by the writers between November 18 and December 5, 1943, and during two weeks in May and five weeks in August and September 1944. The earlier work was done to determine the amount of optical calcite that could be produced by systematic mining of the deposits near Clyde Park and Wilsall. During the 1944 field work many mines were in operation, and the deposits were studied in detail underground. Field work included the examination and detailed mapping of veins and host rocks, and the assembling of data on production, excavation, and the economic value of the deposits. Large-scale planetable maps were made of selected surface areas, and compass and tape maps were made of the underground workings. Many veins other than those mined were visited and their location plotted in order to obtain a better knowledge of the geographic and geologic relations of the vein systems. Areal geologic mapping was not attempted.

Land owners and personnel of mining organizations gave the fullest cooperation. Leo J. Coady, contractor, and Eric G. Ericson, mining engineer for Metals Reserve Company, provided maps, stope surveys, production data, and other necessary material. Information on local history, production, and location of outcrops was given by R. D. Hoffman and A. L. Anderson, manager and foreman, respectively, for Calcite Operators, Inc., W. H. Wade and J. B. Killorn, property owners, and Edwin Over, prospector and operator. Valuable data also were given by E. W. Newman and D. B. Hoiekvam of the United States Bureau of Mines.

Previous work.—The first known geologic examination of Montana calcite deposits was made in Sweet Grass County in 1916 by C. S. Lind of the Bureau of Mines. Brief accounts of his work are given by Parsons (1918) and Hughes (1931, p. 11). The next known investigation was made in 1942 or 1943 by Dr. Harry Berman of Harvard University, but a report on his examination is not available. In 1943, deposits near Clyde Park were inspected briefly by Harold L. James, Adolph Knopf, and James Gilluly, all of the Geological Survey, and by E. W. Newman of the Bureau of Mines. Their brief, unpublished memoranda have been studied by the writers.

Use of the calcite.—The great demand for optical calcite during World War II was one result of the invention by Edwin H. Land, president of Polaroid Corporation, Cambridge, Mass., of a military gunsight that requires a circular basal plate of transparent calcite about seven-eighths of an inch in diameter and one-eighth inch thick. The sight, known as the Polaroid optical ring sight, was used by the Navy on manually operated anti-aircraft guns during the war; in industry the sight is used as a view finder on television field cameras. The deposits were mined solely to obtain material for the manufacture of military sights.

HISTORY, MINING, AND PRODUCTION

The first calcite deposit developed in Montana was apparently on the Cartwright Crystal Spar group (pl. 23, no. 10) near Greycliff and Big Timber in Sweet Grass County. The deposit was discovered by W. E. Burch about 1907, and a 75-foot shaft was sunk. About 600 pounds of optical grade material, from the 30 or 40 tons of calcite taken out, are reported to have been shipped to Germany.

A second vein a mile northeast of the first (pl. 23, no. 11) was opened by R. H. Cartwright and samples of unknown quality were sent to Philadelphia and London. A third deposit was discovered on the Boulder property southwest of Big Timber (pl. 23, no. 33).

The Crystal Spar group was worked again about 1915. Optical spar and material for mineral specimens and chicken grits were sold. This property was visited in 1916 by C. S. Lind of the Bureau of Mines (Parsons, 1918; Hughes, 1931, p. 11).

About 1929, veins near Hunter Hot Springs (pl. 23) and on the Smith (Scott?) property south of Carney (pl. 23, no. 29) supported a small mining operation that supplied calcite for making chicken grits to a grinding mill near Springdale.

Material needed during World War II for manufacture of the anti-aircraft ring sight did not have to be first-grade optical spar.[1] Color and a few inclusions were permissible, but crystals with cracks along cleavage planes, or with lamellar twinning or twinning on the rhombohedron, were not acceptable. There was no objection to basal twinning. The first specifications required individual pieces large enough to yield circular discs, cut normal to the *c* axis, at least

[1] According to H. H. Hughes (1931, p. 4), the specifications for optical spar are as follows: Crystals or cleavage fragments must be at least 1 inch long and at least one-half inch thick. Smaller pieces are rarely acceptable. They must be colorless and absolutely transparent, completely free of cloudy inclusions, cavities, or foreign particles. The material must not show any internal iridescence or rainbow colors due to incipient cracks along cleavage planes. Twin lamellae invisible to the naked eye may make some pieces unsuitable for optical use.

1⅛ inches in diameter; later the required size was reduced to seven-eighths of an inch. Material meeting only the minimum requirements is not first-grade optical spar. Some first-grade material, suitable for use in polarizing microscopes and other scientific apparatus, was produced in Montana during 1943–44, but the quantity is not known. The terms "optical calcite" and "optical spar," unless otherwise explained, are used here to designate material accepted by the Metals Reserve Company in Montana for the manufacture of ring sights.

Because large quantities of calcite of this grade were needed, the manufacturer began a search for workable deposits. Polaroid Corporation's consultant, Dr. Harry Berman of Harvard University, selected deposits near Clyde Park, Mont., and in California[2] for exploitation.

In October or November 1942, A. H. Hansen of Clyde Park, with a crew of four men, started surface mining on a vein on land belonging to W. H. Wade, in sec. 7, T. 1 N., R. 9 E. (pl. 23, no. 4), under an agreement to supply suitable calcite at cost to the manufacturer. During that winter a shaft was sunk and about 12,000 pounds of crude calcite was recovered from a large vug known locally as the "Hansen vug." The material was shipped to Polaroid Corporation, which accepted less than a thousand pounds of it.

In May or June 1943, Calcite Operators, Inc., a New York corporation organized to mine optical spar deposits in California and Montana, began mining on the Wade property. An affiliated company, Crystal Cutters, Inc., established an office and shop in Clyde Park, Mont., for the purpose of trimming and packing the mine-run material for shipment. The president of Calcite Operators, Inc., was Arnold Hoffman of New York. The supervision of mining and trimming was assumed by Robert D. Hoffman and S. R. DuBravac. About 40 men were employed during the peak of the operation.

During 1943 the company sank three shafts and drove a 70-foot adit and a 400-foot drift in the west area of the Wade property, on the vein formerly worked by Hansen. Additional optical calcite was recovered from the Hansen vug and from other parts of the deposit. Prospecting and mining were carried on concurrently at the Francis (pl. 23, no. 2) and Killorn (pl. 23, no. 5) properties, near Clyde Park, and at the Briebach property (pl. 23, no. 8), west of Wilsall. Several other veins also were prospected. A little mining was done in shallow shafts in the east and southeast areas (pl. 23, nos. 5 and 6) of the Wade property during October and November. Operations by Calcite Operators, Inc., were terminated in November 1943. A rough estimate of the quantities of optical calcite accepted by the manufacturer

[2] Durell, C., and Bell, G. L., 1944, Calcite mines in northeast San Diego County, California: U. S. Dept. Interior press release, Nov. 30, 1944, 2 p., 1 map.

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between January and October 1943 is given in table 1. After October an additional shipment was made by Calcite Operators, Inc., but the quantity accepted is not known.

TABLE 1.—*Optical calcite produced from January to October 1943* [1]

	Pounds
Wade property:	
West area:	
Hansen vug	1, 190
Shaft no. 5	24
Other underground workings	646
Opencut and connecting shaft	20
East area, shaft no. 1	238
Francis property	12
Briebach property	119
Killorn property, sec. 18, T. 1 N., R. 9 E.	2
Total	2, 251

[1] Estimates of operators. Published by permission of the owners.

The estimated volume and tonnage of excavation made by A. H. Hansen and Calcite Operators, Inc., on the Wade property are given in table 2.

TABLE 2.—*Excavation on Wade property as of December 5, 1943* [1]

Location	Total tons	Wall rock		Vein	
		Tons	Percent	Tons	Percent
West area:					
Drift, adit, and crosscut	1, 570. 0	1, 190. 0		380. 0	
Main shaft	296. 0	296. 0	45	----------	55
Stopes and shafts on vein	3, 150. 0	790. 0		2, 360. 0	
Shaft no. 5	186. 5	186. 5	60	----------	40
Drift	157. 5	19. 9		137. 6	
East area, shaft no. 1:					
Incline	120. 0	48. 0	27	72. 0	73
Stope	71. 0	3. 0		68. 0	
Total	5, 551. 0	2, 533. 4	45. 6	3, 017. 6	54. 4

[1] Excavation approximated. Tonnage factor: 12 cubic feet per ton. Published by permission of J. H. Wade, owner.

From December 1943 until the end of August 1944, exploration, development, and mining of optical calcite deposits were carried on by the Metals Reserve Company, a subsidiary of the Reconstruction Finance Corporation. Leo J. Coady was in charge of the operation. From 65 to 125 persons were employed. All mining was done near

Clyde Park on properties belonging to W. H. Wade, J. B. Killorn, and Marie Francis. Accounts of the operation have been given by Coady (written communication) and Newman (1945).

Surface prospecting was done by hand or machine drilling and by removing overburden where the veins were concealed. Almost all productive veins crop out prominently, so there was little overburden to remove. Angledozers were used to excavate trenches as much as 20 feet deep alongside the veins. The exposed parts of the veins were then mined with pick and shovel and light blasting. Very little optical calcite was produced from surface cuts. Shafts were sunk on the wider vein outcrops to depths of 25 to 100 feet, and the veins were explored by drifting. Exploration and development raises were driven at irregular intervals, and the vein walls were prospected by drill holes and a few short crosscuts. Where vugs were thought to be present, the drifts and raises were blasted lightly in order not to damage the crystals. Where vugs were exposed, the crystals lining the walls were chipped off by small pneumatic chippers equipped with pointed or chisel-type bits. The detached material was cobbed and the crystals put in sacks and boxes for transport to a trimming plant.

In the few vugs sufficiently thick to mine without additional excavation, scaffolding and working platforms were erected. To provide working room in narrower vugs, the vein material on either side of the vug was lightly blasted after the crystals lining the vug had been removed. A modified type of shrinkage stoping was used, and the broken nonoptical calcite vein material periodically was drawn from chutes in order to keep the top of the backfill at a proper level for working. The stopes follow the vugs and are therefore highly irregular. Shafts and drifts were timbered, but only a few stulls were needed in the stopes.

The Metals Reserve Company sank 672 feet of shafts and drove 996 feet of raises and 2,624 feet of drifts and crosscuts. Stoping totaled 52,382 cubic feet. The total underground and surface excavation measured 416,767 cubic feet, equivalent to 12,019 tons of vein material and 17,758 tons of wall rock. Table 3 gives complete data on development footage and tonnage excavated at each mine and for the operation as a whole. In table 3 the division of the material mined into wall rock and vein material is based on an estimate of the amount of each in every working place examined. The estimate in turn is based on detailed geologic mapping and data supplied by the operators. The figures thus arrived at are believed to be correct within 10 percent. The total production of crude vug calcite was 515,403 pounds, or 2.14 percent of the vein material mined (table 4).

The crude vug calcite was trucked to a trimming plant at Clyde Park. After preliminary sorting and the rejection of obviously worthless material, the crystals were cleaned in a bath of dilute hydrochloric acid and washed with water. The cleaned crystals were then moved to inspection tables and examined with the aid of electric lamps. The flawed or nontransparent parts of each crystal were carefully trimmed away with chisels and chipping hammers, and the acceptable pieces stored for shipment. From 515,403 pounds of crude vug calcite produced at the government-operated mines, only 4,876½ pounds of material seven-eighths of an inch in diameter and larger was saved for shipment. The recovery of optical calcite from crude vug calcite was thus 0.946 percent. An additional 1,072⅝ pounds was purchased from private operators. Shipments to the manufacturer totalled 5,949⅛ pounds, of which 69.8 percent finally was accepted as usable material. A total of 1,017⅜ pounds of material ranging from ½ to ⅞ inch in diameter was produced but is not included in the above figures because it was not sold to Polaroid Corporation but put in storage in Bethlehem, Pa.

The production and grade of each deposit mined by the Government and the totals and averages are given in table 4. The costs of operation by the Metals Reserve Company are given in table 5.

During the spring and summer of 1944 an exploration project was carried on by the Bureau of Mines on the Cartwright Crystal Spar group (pl. 23, no. 10) in Sweet Grass County. The vein was mined and 43⅝ pounds of optical calcite was produced and sold to the Metals Reserve Company. Shallow shafts were sunk on the Calcium (pl. 23, no. 11) and Boulder (pl. 23, no. 33) claims but no optical spar was found.

Of the several private mining operations carried on the largest was on the Bodine property near Clyde Park (pl. 23, no. 9). One thousand pounds of acceptable optical spar were produced from this mine by Elmer Boyce, A. H. Hansen, and Edwin Over. Small quantities also were produced at the Briebach (pl. 23, no. 8) and Scott properties. A diligent search by the authors failed to establish definitely the location of the Scott property, but it seems likely that the so-called Scott property is the Smith property (pl. 23, no. 29). Independent producers were paid $7.50 per pound by the Metals Reserve Company for material accepted at Clyde Park.

By August 1944 the Polaroid Corporation had developed a gun sight employing a synthetic substitute for calcite. The new sight was very nearly as good as the one requiring calcite and had the advantage that no strategic or hard-to-get materials were used in its manufacture. Because optical calcite was not being produced in sufficient quantity to satisfy the increased demands of the armed forces, it was decided

TABLE 3.—*Data on development, excavation, and tonnage of Metals Reserve Company's optical calcite mining operations* [1]

Workings	Development (total linear feet)—				Excavation [2] Vein material (tons)—					
	Shafts	Raises	Drifts and crosscuts	Total	Shafts	Raises	Drifts and crosscuts	Stopes	Surface excavation	Total
Wade No. 1	[3] 42	162	307	511	75.6	430.8	429.8	489.6	[6] 1.6	1,427.4
Wade No. 2	[7] 69	260	422	751	306.4	691.5	1,041.3	1,840.8		3,880.0
Wade No. 3			43	43						
Wade No. 4	61	7	77	145	72.5	18.6	64.8			155.9
Wade No. 5	[11] 5	109	206	320	6.3	326.4	[13] 257.3	412.7		1,002.7
Killorn No. 6	46	104	520	670	89.8	276.7	611.9	673.1	[6] 20.4	1,671.9
Killorn No. 7	70	126	[16] 286	482	77.7	334.9	383.7	220.2	[6] 55.4	1,071.9
Killorn No. 8	47			47	45.5					45.5
Killorn No. 9		31	332	363			[19] 491.8			491.8
Killorn No. 10		69	100	169		183.6	224.0	70.8		478.4
Wade No. 11	[21] 33		57	90	14.8		8.4			23.2
Wade No. 12	58	24	73	155	117.0	63.9	72.8	53.3		307.0
Wade No. 13	37	82	108	227	72.6	218.0	60.5	98.0		449.1
Wade No. 14	50	9	46	105	126.0	23.9	80.7	14.6	[6] 8.9	254.1
Killorn No. 15	31		7	38	33.4		5.8		[6] 106.3	145.5
Wade No. 16	12			12	21.6				[6] 50.2	71.8
Francis No. 17	[25] 29	13	32	74	41.8	34.6	31.3	107.9		215.6
Francis No. 18	11			11	3.9				[6] 40.9	44.8
Francis No. 19	30		2	32	70.2		3.6		[6] 71.7	145.5
Francis No. 20	41		6	47	14.7		1.7		[6] 120.3	136.7
Total, Wade workings	367	653	1,339	2,359	812.8	1,773.1	2,015.6	2,909.0	[6] 60.7	7,571.2
Total, Killorn workings	194	330	1,245	1,769	246.4	795.2	1,717.2	964.1	[6] 182.1	3,905.0
Total, Francis workings	111	13	40	164	130.6	34.6	36.6	107.9	[6] 232.9	542.6
Total, optical-calcite-producing deposits	551	965	2,190	3,706	1,055.4	2,602.9	3,265.6	3,981.0	[6] 363.1	11,268.0
Total, all deposits	672	996	[28] 2,624	4,292	1,189.8	2,602.9	3,769.4	3,981.0	[6] 475.7	12,018.8

Footnotes at end of table, p. 441.

TABLE 3.—*Data on development, excavation, and tonnage of Metals Reserve Company's optical calcite mining operations* [1]—Continued

Workings	Excavation [2]—Continued											
	Wall rock (tons)—						Total tons—					
	Shafts	Raises	Drifts and crosscuts	Stopes	Surface excavation	Total	Shafts	Raises	Drifts and crosscuts	Stopes	Surface excavation	Total
Wade No. 1	75.6	22.8	429.8	25.8	[4] 1,430.0 [6] 30.8	2,014.8	[5] 151.2	453.6	[5] 859.6	515.4	[4] 1,430.0 [6] 32.4	3,442.2
Wade No. 2	16.1	36.5	167.2	97.2	[4] 243.7	560.7	[8] 322.5	728.0	[9] 1,208.5	1,938.0	[4] 243.7	4,440.7
Wade No. 3			120.4		[4] 25.3	145.7			120.4		[4] 25.3	145.7
Wade No. 4	168.9	1.0	150.8			320.7	[10] 241.4	19.6	215.6			476.6
Wade No. 5	11.7	17.2	319.5	21.6		370.0	18.0	[13] 343.6	576.8	434.3		1,372.7
Killorn No. 6	89.8	14.5	844.1	35.4	[4] 250.3 [6] 47.6	1,281.7	[14] 179.6	291.2	1,456.0	708.5	[4] 250.3 [15] 68.0	2,953.6
Killorn No. 7	181.4	17.9	417.1	11.6	[6] 1,053.9	1,681.9	[17] 259.1	352.8	800.8	231.8	[6] 1,109.3	2,753.8
Killorn No. 8	136.3					136.3	[18] 181.8					181.8
Killorn No. 9		86.8	486.5		[4] 979.4	1,552.7		86.8	[20] 978.3		[4] 979.4	2,044.5
Killorn No. 10		9.6	56.0	3.8		69.4		193.2	280.0	74.6		547.8
Wade No. 11	134.4		159.2			293.6	[22] 149.2		[23] 167.6			316.8
Wade No. 12	91.8	3.3	131.6	2.8		229.5	208.8	67.2	204.4	56.1		536.5
Wade No. 13	72.6	11.6	241.9	5.2		331.3	[24] 145.2	229.6	302.4	103.2		780.4
Wade No. 14	54.0	1.3	48.1	0.8	[6] 170.4	274.6	180.0	25.2	128.8	15.4	[6] 179.3	528.7
Killorn No. 15	78.2		13.8		[6] 2,020.1	2,112.1	111.6		19.6		[6] 2,126.4	2,257.6
Wade No. 16	21.6				[6] 954.0	975.6	43.2				[6] 1,004.2	1,047.4
Francis No. 17	62.6	1.8	58.3	5.8	[6] 631.4	759.9	104.4	36.4	89.6	113.7	[6] 631.4	975.5
Francis No. 18	35.7				[6] 776.1	811.8	39.6				[6] 817.0	856.6
Francis No. 19	37.8		2.0		[6] 1,361.6	1,401.4	108.0		5.6		[6] 1,433.3	1,546.9
Francis No. 20	132.9		15.1		[6] 2,286.2	2,434.2	147.6		16.8		[6] 2,406.5	2,570.9
Total, Wade workings	646.7	93.7	1,768.5	153.4	[4] 1,699.0 [6] 1,155.2	5,516.5	1,459.5	1,866.8	3,784.1	3,062.4	[4] 1,699.0 [6] 1,215.9	13,087.7
Total, Killorn workings	485.7	128.8	1,817.5	50.8	[4] 1,229.7 [6] 3,121.6	6,834.1	732.1	924.0	3,534.7	1,014.9	[4] 1,229.7 [6] 3,303.7	10,739.1

Total, Francis workings	269.0	1.8	75.4	5.8	[6] 5,055.3	5,407.3	399.6	36.4	112.0	113.7	[6] 5,288.2	5,949.9
Total, optical-calcite-producing deposits	1,057.2	137.5	2,893.3	210.0	[4] 1,924.0 [6] 7,194.4	13,416.4	2,112.6	2,740.4	6,158.9	4,191.0	[4] 1,924.0 [6] 7,557.5	24,684.4
Total, all deposits	1,401.4	224.3	3,661.4	210.0	[4] 2,928.7 [6] 9,332.1	17,757.9	[27] 2,591.2	[28] 2,827.2	[29] 7,430.8	[30] 4,191.0	[4] 2,928.7 [6] 9,807.8	29,776.7

[1] Sources: field work, Metals Reserve Co. records, talks with operators.
[2] Tonnage factors: rock in place, 12.5 cu ft per ton; bulldozer excavations, 16.0 cu ft per ton.
[3] Shaft 31 ft deep when Metals Reserve Co. began work.
[4] Construction.
[5] Assumed 50 percent vein material.
[6] Prospecting and development.
[7] Shaft 12 ft deep when Metals Reserve Co. began work.
[8] Includes enlarging (926 cu ft).
[9] Includes enlarging (336 cu ft).
[10] Includes enlarging (272 cu ft).
[11] Shaft 40 ft deep when Metals Reserve Co. began work.
[12] Predominantly gouge and breccia.
[13] Includes enlarging (420 cu ft).
[14] Includes enlarging (176 cu ft).
[15] 850 cu ft excavation on vein for hoist house. Drilled and blasted. Similar to underground work.
[16] Includes footage of May 1944 in 2-DSE (46±ft) which Metals Reserve Co. omitted.
[17] Includes enlarging (88 cu ft).
[18] Includes enlarging (158 cu ft).
[19] Predominantly fault material, very little calcite.
[20] Includes enlarging (386 cu ft) and 222 cu ft at portal of tunnel.
[21] Shaft 12 ft deep when Metals Reserve Co. began work.
[22] Includes enlarging (380 cu ft).
[23] Includes enlarging (100 cu ft).
[24] Includes enlarging (150 cu ft).
[25] Shaft 15 ft deep when Metals Reserve Co. began work.
[26] Includes footage of May 1944 in Killorn No. 7 2-DSE (46±ft) which Metals Reserve Co. omitted. Company's footage, 2,578 linear feet.
[27] Includes enlarging (2,150 cu ft).
[28] Includes enlarging (480 cu ft).
[29] Includes 822 cu ft of enlarging and 222 cu ft at Killorn No. 9 tunnel site.
[30] 90 cu ft in excess of Metals Reserve Co. figure. July 1944 excavation from Killorn No. 6-4 stope southeast omitted by Company.

TABLE 4.—*Data on production and grade of optical calcite of Metals Reserve Company's mining operations* [1]

Workings	Vein material (percent of total excavation)	Production: Crude vug calcite (pounds)	Production: Optical calcite (pounds)	Grade: Optical calcite recovered from crude vug calcite (percent)	Calcite in vein material: Crude vug calcite: Percent	Calcite in vein material: Crude vug calcite: Pound per ton	Calcite in vein material: Optical calcite: Percent	Calcite in vein material: Optical calcite: Pound per ton	Calcite in total material excavated: Crude vug calcite: Percent	Calcite in total material excavated: Crude vug calcite: Pound per ton	Calcite in total material excavated: Optical calcite: Percent	Calcite in total material excavated: Optical calcite: Pound per ton
Wade No. 1	70.9	25,981	892¼	3.43	0.91	18.20	0.031	0.625	0.646	12.91	0.022	0.443
Wade No. 2	92.45	232,133	1,798	.77	2.99	59.83	.023	.463	2.77	55.31	.021	.428
Wade No. 3 [2]												
Wade No. 4	32.71	652	8½	1.3	2.09	4.18	.003	.055	.068	1.37	.001	.018
Wade No. 5	73.05	6,169	256⅞	4.16	.307	6.15	.013	.256	.024	4.49	.009	.187
Killorn No. 6	61.85	127,319	227½	.179	3.81	76.15	.068	.136	2.35	47.10	.004	.084
Killorn No. 7	38.92	78,199	768⅜	.98	3.65	72.95	.036	.717	1.42	28.40	.014	.279
Killorn No. 8	25.03											
Killorn No. 9	46.17											
Killorn No. 10	87.33	[3] 12,430	112⅛	[4] .91	[5] 1.00	[5] 19.92	[5] .012	[5] .234	[6] .221	[6] 4.43	[6] .010	[6] .205
			[4] 113⅜									
Wade No. 11	7.32											
Wade No. 12	57.22	7,650	108⅝	1.42	1.25	24.92	.018	.354	.71	14.26	.010	.202
Wade No. 13	57.55	[7] 19,710	396¼	[8] 2.29	[9] 1.89	[9] 37.84	[9] .044	[9] .882	[10] .539	[10] 10.78	[10] .025	[10] .508
			[8] 451¾									
Wade No. 14	48.06	780	1⅜	.18	.153	3.069	<.001	.005	.074	1.48	<.001	.003
Killorn No. 15	6.44	(11)	1¼	(11)	(12)	(12)	<.001	.009	(12)	(12)	<.001	.001
Wade No. 16	6.86	(13)	55½	(13)	(14)	(14)	.039	.773	(14)	(14)	.003	.053
Francis No. 17	22.10	2,020	85⅝	4.24	.468	9.369	.020	.397	.104	2.071	.004	.088
Francis No. 18	5.23											
Francis No. 19	9.41	200			.069	1.375			.006	.129		
Francis No. 20	5.32	2,160	39⅜	1.82	.790	15.80	.014	.288	.042	.840	.001	.015
All Wade deposits	66.48	293,075	[15] 3,642¼	1.24	1.935	38.71	.024	.481	1.286	25.73	.016	.320
			[15, 16] 4,441⅛	[16] 1.52			[16] .029	[16] .587			[16] .019	[16] .390
All Killorn deposits	41.06	217,948	1,109¼	.509	2.79	55.81	.014	.284	1.46	22.92	.006	.117
			[16] 1,301¾	[16] .597			[16] .017	[16] .333			[16] .007	[16] .137

All Francis deposits	9.12	4,380	125	2.85	.403	8.07	.011	.230	.037	.736	.001	.021
			[16] 151	[16] 3.45			[16] .014	[16] .278			[16] .001	[16] .025
All optical-calcite-producing deposits	49.51	515,203	[15] 4,876½	.94	2.29	45.72	.022	.433	1.13	22.64	.011	.214
			[15, 16] 5,893⅞	[16] 1.14			[16] .026	[16] .523			[16] .013	[16] .259
All deposits	44.77	515,403	[15] 4,876½	.946	2.14	42.88	.020	.406	.96	19.20	.009	.182
			[15, 16] 5,893⅞	[16] 1.14			[16] .024	[16] .490			[16] .011	[16] .220
Grade based on acceptance by Polaroid Corporation [17]		515,403	3,403.797	.660			.014	.283			.006	.127

[1] Sources: Metals Reserve Co. records, talks with operators, and field work.
[2] Driven on small vein but primarily for powder storage space.
[3] Includes crude from Killorn No. 15. Separate amounts not determinable.
[4] 1¼ lb optical from Killorn No. 15 included in computing crude and optical.
[5] Total tons vein material from Killorn Nos. 10 and 15 used in computing crude and optical.
[6] Total tons from Killorn Nos. 10 and 15 used in computing crude and optical.
[7] Includes crude from Wade No. 16. Separate amounts not determinable.
[8] 55½ lb optical from Wade No. 16 included in computing crude and optical.
[9] Total tons vein material from Wade Nos. 13 and 16 used in computing crude and optical.
[10] Total tons from Wade Nos. 13 and 16 used in computing crude and optical.
[11] Reported with Killorn No. 10.
[12] For grades involving crude see Killorn No. 10.
[13] Reported with Wade No. 13.
[14] For grades involving crude see Wade No. 13.
[15] Includes 98¼ lb from "Wade Resort" (source unknown), and 26⅝ lb unaccounted for balance.
[16] Includes ½ inch to ⅞ inch material.
[17] Polaroid Corporation accepted only 69.8 percent of all calcite shipped.

TABLE 5.—*Cost of producing optical calcite, Metals Reserve Company projects* [1]

Units	Total cost	Cost per ton of vein material mined	Cost per pound of optical calcite accepted by Metals Reserve Co. at Clyde Park, Mont.		Cost per pound of optical calcite accepted by Polaroid Corp., Cambridge, Mass.[2]
			Calcite ½ to ⅞ inch in diameter [3]	Calcite ⅞-inch diameter and larger	
MINING AND TRIMMING					
Labor and salaries	$133,349.87	$11.095	$22.625	$27.345	$39.177
Supplies and services	[4] 24,299.72	2.022	4.123	4.983	7.139
Rental, machinery, and equipment	3,606.51	.300	.612	.739	1.060
Transportation, supplies, and equipment	841.57	.070	.143	.173	.247
Contractors' fees	8,300.00	.690	1.408	1.702	2.438
Taxes, payroll	4,910.74	.409	.833	1.007	1.443
Insurance, Workman's Compensation	9,351.30	.778	1.587	1.918	2.747
Total	184,659.71	15.364	31.331	37.867	54.251
GENERAL					
Transportation, local	2,286.14	.190	.388	.469	.672
Supervisory services and expenses	1,919.74	.160	.326	.394	.564
Royalties	2,947.00	.245	.500	.604	.866
Insurance, general	230.88	.019	.039	.047	.068
Taxes, general	42.50	.004	.007	.009	.012
Repairs	621.19	.052	.105	.127	.182
Miscellaneous [5]	10,325.84	.859	1.752	2.118	3.034
Total	$18,373.29	$1.529	$3.117	$3.768	$5.398
Grand total (net)	$203,033.00	$16.893	$34.448	$41.635	$59.649

[1] Production by independent operators and cost of purchase of independently produced calcite are excluded from calculations. Unit costs computed from cost data supplied by Metals Reserve Co.

[2] Polaroid Corp. accepted only 69.8 percent of the material shipped by Metals Reserve Co., or 3,403.797 lb. No ½ to ⅞ inch material was shipped to Polaroid Corp.

[3] 5,893⅞ lb. accepted by Metals Reserve Co. including 1,017⅜ lb. ½ to ⅞ inch in diameter which was shipped to Lawrence Warehouse Co., Bethlehem, Pa.

[4] $841.40 gasoline tax refund and earned discount deducted from Metals Reserve Co. figure.

[5] Includes rental, express charges, office and legal expense, Reconstruction Finance Corp. salaries and travel expense, and expenses preliminary to operations.

to standardize the substitute sight and mass produce it. Accordingly, all production and purchasing by the Metals Reserve Company was stopped on August 31. Coady's summary (written communication) of total production in Park and Sweet Grass Counties for the period December 1943 to August 1944 is given in table 6.

GEOLOGY

Plate 23 is a geologic map of the calcite-producing area of Park and Sweet Grass Counties, Mont. The map is modified and enlarged from the Geologic Map of Montana, compiled by D. A. Andrews, G. S. Lambert, and G. W. Stose (1944). The area is at the east front of the Rocky Mountains in Montana and at the west edge of the

TABLE 6.—*Summary of optical calcite produced and accepted from December 24, 1943, to August 31, 1944, Park and Sweet Grass Counties, Mont.*[1]

Operation	Crude vug calcite submitted (pounds)	Accepted as optical calcite	
		Pounds	Percent
Metals Reserve Company:			
Wade property	293, 075	4, 441⅛	1. 52
Killorn property	217, 948	1, 301¾	0. 60
Francis property	4, 380	151	3. 45
Total	515, 403	5, 893⅞	1. 14
Independent:			
Bodine property	5, 540	1, 000	18. 05
Briebach property	341	17⅞	7. 42
Cartwright property [2]	955	43⅜	4. 54
Scott (Smith?) property [3]	47	11⅜	24. 20
Total	6, 738	1, 072⅝	15. 81
Grand total	522, 186	[4] 6,966½	1. 33

[1] Submitted to and accepted by Metals Reserve Company at Clyde Park, Mont. Published with permission of the property owners.
[2] Operated by the U. S. Bureau of Mines.
[3] Authors' insertion.
[4] Includes 1,017⅜ pounds of material from ½ to ⅞ inch in diameter. The balance is ⅞ inch and larger.

Great Plains. It is drained by the Yellowstone River and two major tributaries, the Shields and Boulder Rivers. The Beartooth and Gallatin Ranges border the area on the south and southwest, the Bridger Range on the west, and the Crazy Mountains on the north and east. The foothills of the Beartooth and Gallatin Ranges rise immediately south and west of the Yellowstone River, at the south border of the map area. Calcite veins are exposed in the broad Shields and Yellowstone river valleys north and east of Livingston, in the hilly country near the headwaters of the Upper and Lower Deer Creek drainage basin south of Big Timber, and the Fryer Creek drainage basin south of Carney. The Shields and Yellowstone valleys are rolling, open benchlands, rising gently toward the enclosing mountains. In places the principal streams are incised to depths of 100 to 400 feet below valley level. The minor tributaries have cut canyons or narrow valleys below the level of the benchlands, particularly near the mountains.

The earliest geologic work in the region includes that of Hayden (1872, 1873) and Lindgren (1886). A report on the Laramie and Livingston formations and a geologic map of an area near Livingston, by W. H. Weed, was published in 1893. The Livingston and Little Belt Mountains one-degree quadrangles were subsequently mapped by Iddings and Weed (1894) and by Weed (1899). They include most of the area shown in plate 23. Geologic reports on the region around Livingston were written by Stone (1909), Calvert (1912), Stone and Calvert (1910), Wolff (1938), and Parsons (1942).

The valley and hill country is underlain by the Livingston formation which includes the Livingston igneous series of Parsons (1942). For ease of discussion the Livingston formation is described in two parts—the sedimentary rocks and the igneous rocks, a separation suggested by Parsons. The sedimentary rocks are in a broad, flat synclinal trough trending about north and bordered on the south and west by older, highly folded and faulted rocks which form the Beartooth, Gallatin, and Bridger Ranges. In the mountains the oldest rocks are Archean-type granite, gneiss, and schist, and sedimentary rocks of the Belt series of Precambrian age. The Precambrian rocks form the cores of some of the ranges, and are overlain and flanked by a thick sequence of Paleozoic and Mesozoic age. Folded, upturned beds of Cretaceous age form the foothills and lower slopes. In the south part of the map area (pl. 23) the lower slopes of the Beartooth Mountains are underlain by the Kootenai formation of Early Cretaceous age, the Colorado shale of Early and Late Cretaceous age, and the Eagle sandstone of Late Cretaceous age. These strata are folded parallel to the trend of the mountain front and are overlain by the Livingston formation, which is gently upturned.

The sedimentary rocks of the Livingston formation, which underlie most of the Shields and Yellowstone river valleys within the map area, are composed of andesitic sandstone (which some geologists might call a graywacke), tuff, shale, conglomerate, and local intercalations of volcanic breccia and agglomerate. Most of the calcite veins were found in andesitic sandstone, a clastic rock composed of sericitic feldspar grains, andesitic rock fragments, quartz, augite, calcite grains, and fine-grained interstitial cement. The larger grains are 1 to 2 millimeters across. Next to the mountains, the Livingston strata are moderately to steeply upturned. Open folds are readily discernable in the beds in the northern part of the synclinal trough, but in the south folding is barely perceptible throughout wide areas.

The stratigraphy as originally worked out by Weed (1893) distinguished the Livingston as a new and distinct formation 7,000 feet thick, unconformably overlying coal-bearing sandstone of supposed Laramie age, and in turn unconformably overlain by Fort Union strata exposed in the Crazy Mountains. On the basis of later work, Stone and Calvert (1910, p. 757) and Calvert (1912, p. 387) decided that the coal-bearing sandstone of Weed conformably underlies sedimentary rocks of the Livingston formation, is of early Montana age, and is correlative with the Eagle sandstone—the basal formation of the Montana group. Stone and Calvert concluded that in the area shown on plate 23 the Livingston formation occupies the same stratigraphic position as several Upper Cretaceous and lower Tertiary formations nearby and that these formations grade laterally into the Livingston formation, and in so doing lose their distinctive lithologic identities.

In the area in which abundant calcite veins crop out the Livingston formation is believed to be equivalent to the following formations: the Eagle sandstone (excluding the Virgelle sandstone member), Clagget shale, Judith River formation, Bearpaw shale and Lennep sandstone of the Montana group of Late Cretaceous age; the Lance formation of Late Cretaceous age, and the Lebo shale member of the Fort Union formation of Paleocene age. Other changes of the stratigraphy from that described by Weed were also made, and are incorporated in the geologic map (pl. 23).

The Livingston igneous series of Parson (1942) underlies the southeast part of the map area. Weed mapped (1893, pl. 1, p. 26) this area as Livingston agglomeratic rocks that occur stratigraphically between the lower and upper beds of the Livingston sedimentary sequence. Near Nye, Mont., Vhay (1939, p. 434) found that the formations of the lower part of the Montana group grade upward into a pyroclastic facies of the Livingston formation. Parsons (1942, p. 1182) states that his Livingston igneous series, which he indicated as Late Cretaceous in age, rests with a slight angular unconformity on the Eagle, Claggett, and Judith River formations of Late Cretaceous age and is conformably overlain by the Hell Creek formation in the drainage areas of Upper and Lower Deer Creeks north and west of Nye. Most of the igneous rocks are pyroclastic. The series includes andesitic tuff, breccia, agglomerate, tuffaceous sandstone, volcanic conglomerate, and a few thin flows of andesite and basalt which were extruded from many small volcanic vents. Pipes, dikes, and laccoliths of dacite, andesite, and diorite cut the sediments nearby and some of the pyroclastic rocks. The series is 2,000 feet thick in the Upper and Lower Deer Creek headwaters region but to the north and west at the Yellowstone River the series thins to about 50 feet.

The calcite veins on the Cartwright Crystal Spar and Calcium groups, Boulder, and other properties described here are found in igneous rocks of the Livingston. Several specimens of andesitic rock were collected by the writers and examined petrographically by C. S. Ross of the Geological Survey. A section of andesite from the Cartwright Crystal Spar group contains plagioclase that has been partly replaced by a colorless isotropic material of low refractive index that is probably allophane. A brown clay, probably either beidellite or saponite, occurs throughout the section. Augite and magnetite are present, the latter partly altered to limonite. A second section of coarse feldspathic rock from the same locality is highly altered, possibly to a clay mineral. Pale green patches in the rock appear to be unusually pale celadonite, an igneous rock alteration product structurally similar to glauconite. The paleness and slightly low index of refraction of the mineral probably mean that it is low in iron content and high in magnesium.

Andesitic rock from the Cartwright Calcium group is highly altered and contains allophane. Augite and hornblende are largely altered to magnetite. Bright green areas show the partial alteration of biotite to chlorite. Porphyry from the Boulder property contains many closely spaced plagioclase phenocrysts in a fine-grained andesitic groundmass. Brown, micaceous nontronite fills cavities in the rock.

Granite, diorite, gabbro, and peridotite composing stocks, laccoliths, sills, and a multitude of radiating basic and acidic dikes intrude the Livingston formation in the southern part of the Crazy Mountains. Outlying sills, such as Sheep Mountain (pl. 23), and dikes rise as buttes and ridges above the sedimentary rocks in the Shields and Yellowstone valleys. A large dike a few miles southwest of Clyde Park was mapped by Iddings and Weed (1893) as basic porphyrite or andesite (pl. 24).

An andesite porphyry dike crossing the Bodine calcite property south of Clyde Park contains abundant red-brown biotite and another micaceous mineral, perhaps nontronite.

OPTICAL CALCITE DEPOSITS

Areal distribution.—The geology of the calcite region and the distribution of the deposits examined are shown in plate 23. The deposits are veins of hydrothermal origin that occupy northwestward-trending faults cutting the clastic sedimentary rocks of the Livingston formation and the associated extrusive and intrusive andesitic rocks. Fifty-six veins were mapped (pl. 23), but in the opinion of the writers they represent only one-third to one-half of the total number present. Most of the veins occur in groups, separated by broad tracts that contain a few isolated veins. The main groups or vein systems crop out near Clyde Park; west and southwest of Hunter Hot Springs; southeast of Grannis; and on the upper reaches of Willow Creek northwest of Livingston.

Vein outcrops.—The calcite veins are in general more resistant than the wall rocks. The largest veins crop out boldly, forming long, low, interrupted ridges (pl. 25). Smaller veins may stand only a few inches above the surrounding surface, but they are conspicuous because of the contrast in color between the white calcite and the drab country rock and vegetation. Throughout the area residual soil is scanty. Veins on steep hillsides may be covered with slide debris, but generally the veins are visible at the surface. Where calcite can not be found in soil along the projection of a vein it can be assumed safely that the fault, if present, is not filled with calcite at that point. A short distance down the dip, however, the fault could be filled with calcite.

Although many of the veins are notably vuggy, as proved by underground development, only a dozen or so vugs were observed at the surface in all the veins examined. A near-surface vug is shown in plate 26. In some veins that crop out as wide bands of solid calcite, many vugs were found within 25 or 50 feet of the surface. The lack of vugs exposed at the surface may be explained by the fact that a vuggy calcite vein would be destroyed by erosion more rapidly than a vein of solid calcite. Furthermore, according to Emmons' hypothesis (1940, pp. 123–125), in an area where the vein (solid calcite) is more resistent than the country rock and has a wide range of thickness, the thicker parts of the vein will survive in outcrop for a longer period than the narrower parts. From this Emmons deduced that a thick vein outcrop generally represents a relatively thick part of the vein and that the vein will narrow with depth. This reasoning can be extended to the outcrops of calcite veins to suggest that narrow and vuggy parts of the veins have been eroded relatively quickly and that thick solid calcite veins will become either narrower or more vuggy with depth. In some veins the wide outcrops have protected and preserved the vugs that lie beneath. Because optical calcite is found in the vugs, relations of this kind may be of some commercial importance, although it is apparent that other factors such as the thickness of the vein, the amount of faulting in the vein, and the presence or absence of banding must be considered in judging outcrops.

Mineralogy.—The veins are composed principally of calcite and minor quantities of chalcedony and the zeolites, stilbite, and laumontite. The calcite is of two principal varieties and ages: vein calcite which makes up the great bulk of all the deposits, and vug calcite of a later age which has grown in vugs in the veins or in fractures which cut the older calcite.

Most vein calcite is white but some is yellowish-brown or brownish-orange. A small proportion of it is clear or semiclear. White calcite from different sources may differ considerably in translucency. Some of it is only slightly milky, and some is densely white and completely opaque in the hand specimen. Material of the latter type is known locally as "bony" calcite because it has the general appearance of bleached bones. In some deposits, such as those near Clyde Park, calcite occurs as massive fissure-fillings of cleaved, equant, interlocking anhedra ranging from a quarter of an inch to 12 inches across. The average diameter is perhaps 2 inches. In other veins the calcite fillings are banded due to vein growth by accretion, and some of the calcite crystals composing the bands may be elongate or platy. Overgrowths of small white platy crystals were seen at the Cartwright Crystal Spar group.

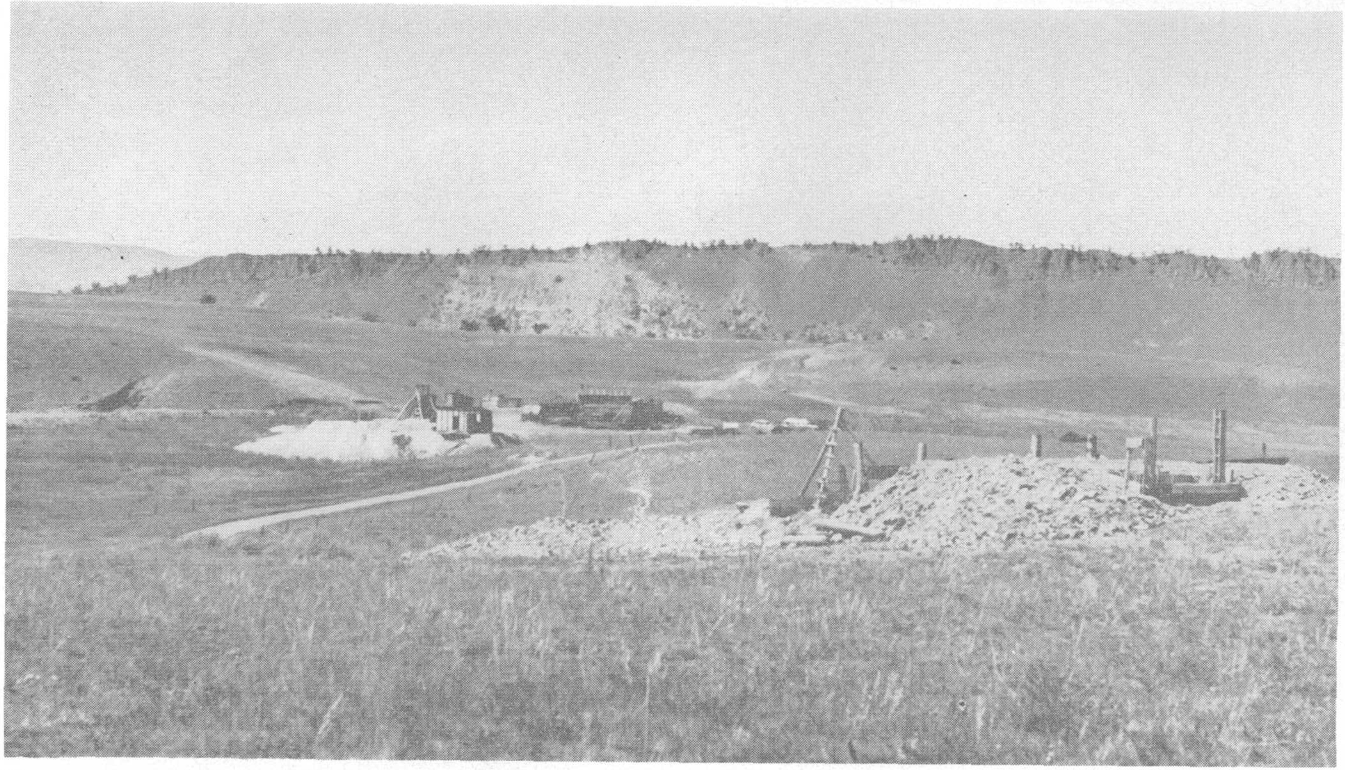
Vug calcite is the crude material from which optical calcite is obtained, but of all the vug crystals mined only about 1 percent met the specifications for optical use. Most were rejected because of milkiness or twinning Most crystals occur typically as drusy linings on the walls of vugs, but some have been detached and are embedded in the mud which fills some near-surface vugs. The crystals are rhombohedrons and scalenohedrons. Some vugs appear to contain a preponderance of crystals of one form or the other, but rhombohedrons are perhaps the more abundant. Most of the rhombohedrons are fundamental forms; that is, neither acute nor obtuse. A few penetration twins were seen. Twinning lamellae parallel to $\{01\bar{1}2\}$ are very common. On the crystal surfaces parting planes due to twinning have been etched by the dissolving action of ground waters. With few exceptions the crystals terminate only at one end, and only the terminations ordinarily show well-developed crystal faces. One doubly terminated scalenohedral crystal was seen.

Vug crystals differ widely in clearness, color, and size. Most are transparent, semitransparent, or highly translucent, some are slightly translucent to milky. Clear crystals are ordinarily colorless, but in some deposits they are yellowish or brownish. The tips of many crystals are clear, whereas the roots of the same crystals are more or less cloudy. Differences in transparency within a single crystal or cleavage piece are common, and the demarcation between the clear and the cloudy parts may be quite sharp. The vug crystals range from a fraction of an inch to 12 inches in diameter. In the productive vugs, crystals from 3 to 8 inches across were most numerous. The largest crystal removed during the operations in 1943 and 1944 weighed 330 pounds and yielded 32 pounds of optical-grade material. It came from no. 2 shaft on the Wade property.

Joint surfaces throughout the calcite area commonly are covered with a white, earthy coating or thin botryoidal crust of fine-grained calcite.

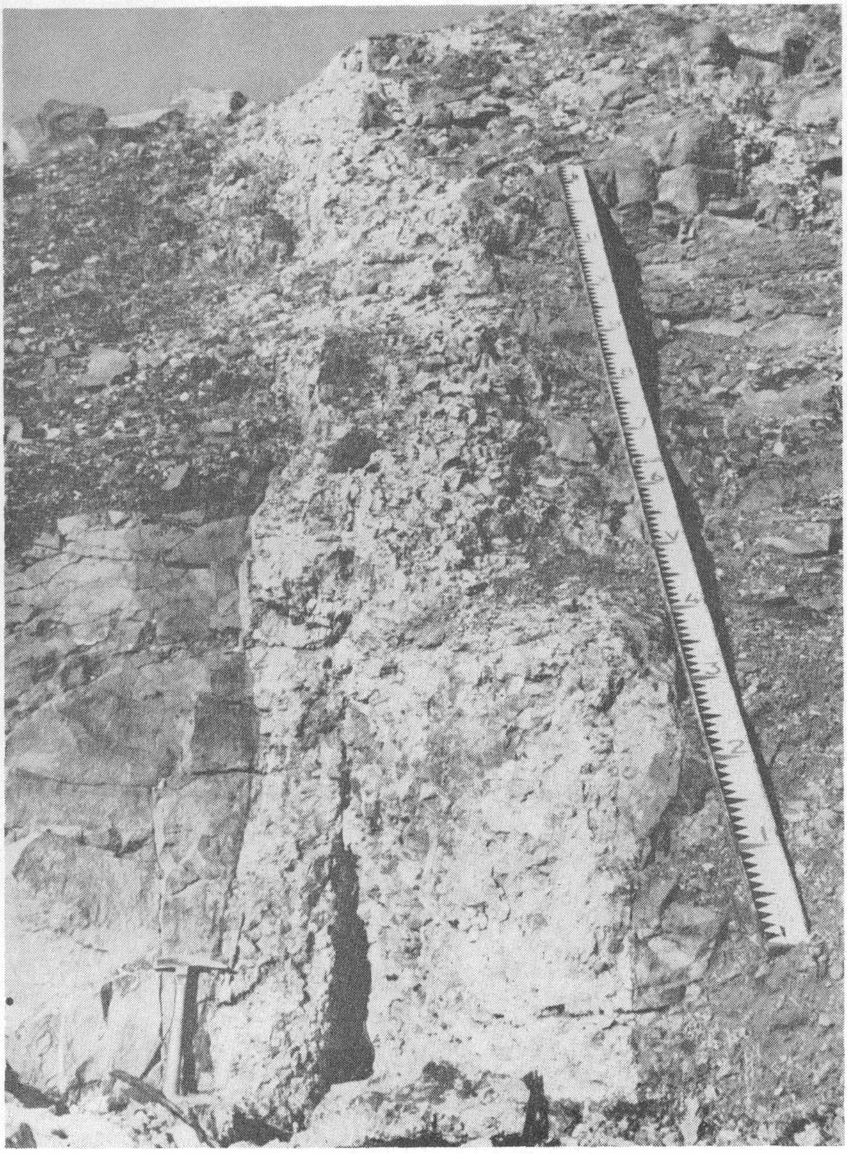
At the Killorn property in sec. 18, T. 1 N., R. 9 E., a hard, thin, white botryoidal layer of chalcedony coats the calcite.

Stilbite is most abundant at the Briebach property and in veins near Hunter Hot Springs. It forms narrow veinlets in and crystal coatings on calcite. The veinlets follow the walls of the calcite veins or cut across the wall rock and the vein filling. The crystals include

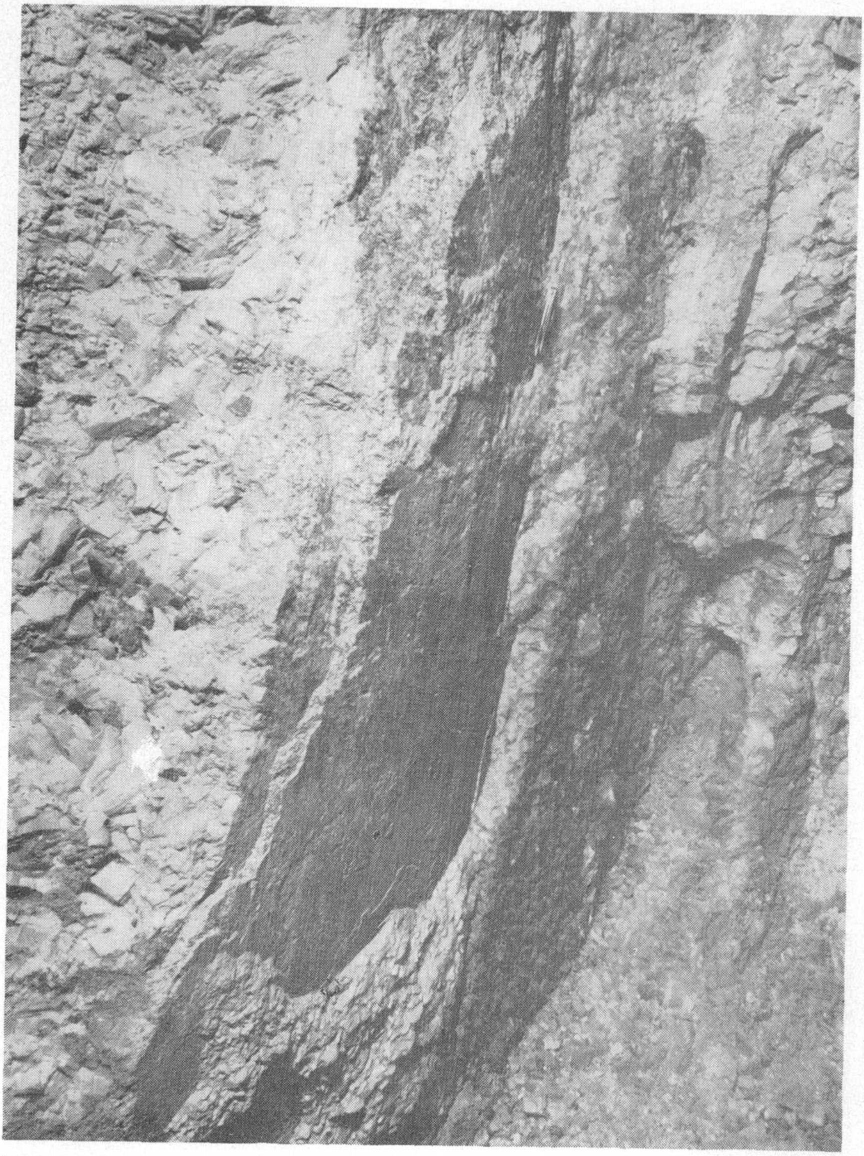


View looking north from Killorn property, sec. 8, T. 1 N., R. 9 E. No. 8 shaft is in foreground. Tripod headframe of No. 7 shaft is visible beyond. No. 2 shaft is in middle distance. The ridge in the distance is made up of Tertiary igneous rock intruded into the Livingston formation.

Outcrop of large calcite vein near Hunter Hot Springs, Mont., as observed from the northwest.



Calcite vein outcrop showing near-surface vug. Location in pit 5 feet southeast of Killorn No. 6 shaft.



Fault cutting a vein of white calcite near the bottom of chute No. 5, southeast drift, Wade No. 2 workings. Knife lies on fault surface. Slickensides on fault indicate dip-slip movement. To the right of the knife small crystals of clear calcite have been deposited on the fault surfaces.

Partly stoped central vug in calcite vein. Located in southeast end of stope above No. 8 chute, northwest drift, Killorn No. 6 workings. The vug is lined with crystals of clear calcite which are coated with mud washed in from the surface. Part of the left side of the vug has been mined, and the vein footwall shows in the lower left corner. Coarse, cleaved, white calcite lies between the footwall and the vug. The vug surface at right is intact; the crystals were too small to be used. The view covers a vertical distance of about 4 feet.

Calcite vein with vug, located in back of southeast drift about 30 feet from end, Killorn No. 6 workings. The vein is 5 to 10 inches wide and cuts unweathered andesitic sandstone. The vug near the center of the photo contains crystals of clear and semiclear calcite. The surrounding calcite is white. Note cleavage in white vein filling in the lower part of the picture.

both glassy and pearly white varieties and most of them are less than one-half inch long.

Small quantities of pale pink laumontite occur with calcite in narrow joint fillings on the G. L. Miller property.

Types of veins.—The calcite veins throughout the area are similar in general appearance and structure but have different degrees of development of internal structures. Some veins are massive whereas others are internally banded and have comb structure. Some massive veins have comb structure locally, but few are internally banded. A small amount of optical calcite was obtained from a banded vein on the Cartwright Crystal Spar group, but two other attempts at mining the banded veins failed to produce optical grade material. Almost all optical spar came from massive-type veins like, for example, those of the Wade and Killorn deposits near Clyde Park. The greater production from this type than from the banded veins may be due almost entirely to more intensive exploration, for relatively few workings have been driven in banded veins. On the other hand, almost all workings on massive veins produced at least a few pounds of optical calcite. The writers believe that the massive veins probably contain considerably more clear calcite than the banded veins, but the geological reasons for this are not known. One explanation may be that fissures now containing banded calcite were more nearly completely filled than fissures now containing massive calcite, and the later-stage deposition of clear calcite may have been largely inhibited thereby.

Structure.—The calcite veins follow normal faults in which the movement was mainly dip-slip but in which some horizontal movement also occurred. Faulting, recorded by numerous slickensides, striations, and tension breaks, occurred before, during, and after mineralization.

Most of the veins are in groups, each group consisting of several subparallel zones. A zone consists of two or more large subparallel veins, commonly in end-to-end position, and of subparallel smaller veins. Where one vein pinches out in a zone, other veins in echelon and offset a few feet continue the zone. In most zones the veins are consistently offset to the left as viewed along the outcrop. At the Cartwright Crystal Spar group, however, the offset is to the right. In other zones the echelon pattern is not well defined.

Most of the vein zones are a few hundred to several thousand feet long. One zone, near the Boulder River in Sweet Grass County, was traced for 8,000 feet by engineers of the Bureau of Mines. Other carefully traced veins range in length from less than 50 to as much as 500 feet. They have been mined to a maximum depth of about 100 feet, and it is probable that their dip length is roughly comparable to

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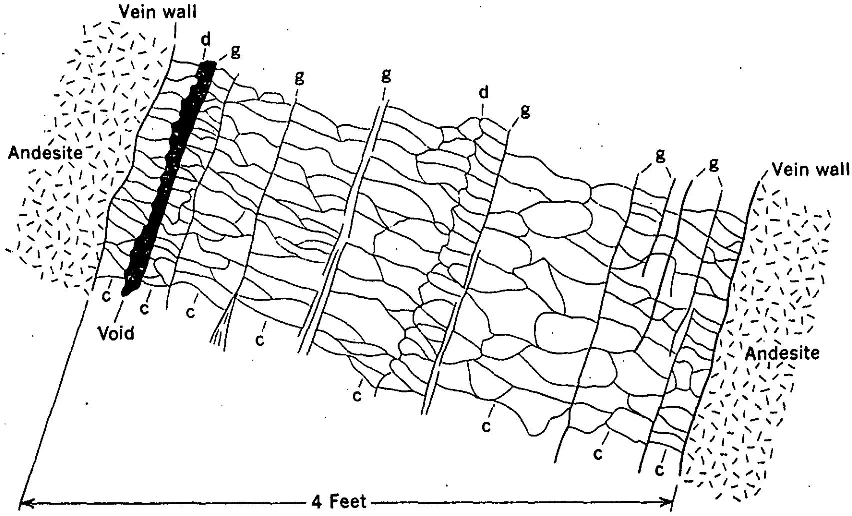
their strike length. The zones and component veins strike northwestward and dip vertically or steeply either to the northeast or southwest. A few veins strike slightly east of north.

Most commonly the veins are massive or banded fissure-fillings of calcite from less than 1 foot to 20 feet thick. Locally the veins may be crowded with angular inclusions of wall rock, or may contain large wedge-shaped horses. At other places the deposits are lodelike in that they are composed of stockworks of interlacing veinlets or several parallel closely spaced veins, stringers, and nonmineralized shear fractures. Where the faults are barren they are in zones of gouge and brecciated wall rock. Some veins are mainly gouge- or breccia-filled fractures containing only scattered lenses of calcite. Other fissures contain a continuous calcite filling of varying thickness from end to end. Along the strike the veins die out as thin, slightly mineralized fissures or as a series of parallel slip surfaces.

Short spur veins branch from the main fissures. Some of the branch veins rejoin the main fracture farther along the strike, others taper out in the wall rock. The latter probably are filled tension cracks caused by movement along the adjoining main fracture. The adjacent ends of two in echelon veins may be linked by a narrow cross vein. Outlying, parallel, subsidiary veins occur at some places within a few rods of a larger vein. Vein walls are locally sheeted, and calcite stringers follow sheeting, joints, and open bedding planes near the main fissures.

Many calcite-filled fissures are conspicuously banded parallel to the walls. Individual bands range from an inch to a foot in thickness, and a single vein may consist of as many as 10 or 12 bands. Each band is a layer of interlocking calcite crystals which grew inward from the walls of the fissure during successive stages of deposition. Some bands show comb structure; that is, the individual crystals are finger-shaped and oriented with their long dimensions normal to the walls (fig. 48). Adjacent calcite layers may differ in width, texture, color, and clearness. This type of banding is well developed in the Cartwright Crystal Spar vein, in veins on upper Willow Creek near Livingston, and in veins at other places. It is absent or poorly developed in veins on the Wade and Killorn properties near Clyde Park. The fill material of veins near Clyde Park is an aggregate of coarse interlocking calcite anhedra of nearly uniform size. Comb structure is rare, and the absence of crystal banding indicates that the vein filling occurred during a single uninterrupted period of deposition. Banding due to shearing is quite common. Shear surfaces in the veins appear as thin seams of granulated calcite. Narrow openings may be filled with mud washed in from the surface or they may be lined with minute calcite crystals.



EXPLANATION
c - Comb of calcite crystals
d - Drusy surface
g - Slip surface marked by granulated calcite. Some narrow openings along these surfaces contain later calcite druses

FIGURE 48.—Cross section of vein showing banding and comb structure, Cartwright Crystal Spar group.

During the main period of mineralization white calcite completely filled some fissures, but only partially filled others. The unfilled parts in early white calcite veins are called here primary vugs. At the same time, white calcite was deposited also in all accessible fractures subsidiary to the main fissures, such as tension cracks, joints, and sheeting planes. Later, transparent calcite was deposited in all available types of openings, but most of it in primary vugs. Renewed faulting after most of the veins had formed created more openings in the white calcite veins and clear calcite was deposited in these openings. Narrow open spaces are lined with calcite druses (pl. 27). Less common types of cavities resulting from renewed faulting are fractures along flat bedding planes and along previously tight parts of faults; in both of these types clear calcite was deposited directly on sandstone walls. Such vugs were seen in the Killorn no. 6 and no. 7 workings. Many openings were filled completely by clear calcite, but in others no clear calcite was deposited. A vug of the latter type, its surface consisting of drusy white calcite, was found at the head of Killorn no. 6 shaft.

Most vugs, in veinlets as well as in large veins, are near the middle of the vein because calcite was deposited about equally on opposite walls of the fissure. Where vein filling has been deposited asymetrically, the vugs lie closer to one wall than the other. Most central vugs are lenticular, their long axes lying roughly parallel to the vein, but others are equidimensional or elongate. Here and there vugs are bridged by masses of calcite that have grown inward from either wall. Many of the larger vugs are connected by narrow crevices that may be almost completely filled narrow parts of the original openings. It is reported that the Hansen vug, near Main Shaft, west area, Wade property (pl. 30) was 3 feet wide and extended 70 feet along the strike and 30 feet down the dip of the vein. Near no. 2 shaft on the Wade property, a vug in the vein measured 7 feet wide, 15 feet long, and 4 feet high. Many central vugs of comparable dimensions to the one near no. 2 shaft are reported to have been found. Other vugs, from less than a cubic inch to several cubic feet in volume, may be at any position in a vein. The positions of some seem attributable to irregularities in the fissures that were only partly filled; for others there is no apparent reason for their positions. A few small vugs extend across the vein rather than parallel it. Plates 28 and 29 are photographs of veins and veinlets with central vugs.

Unequal deposition of clear calcite on opposite walls of cavities has occurred in places. Plate 28 illustrates a partly stoped vug in which one surface has been left intact because the crystals are too small, while the other surface, presumably lined with adequately sized crystals, has been partly mined. In another vug the hanging wall was encrusted by clear and semiclear calcite a foot or more thick, whereas the thickness of a similar crust on the opposite wall was less than 6 inches. It has been shown experimentally (Newhouse, 1941; Armstrong, 1943; Garrels, 1951) that deposition is greater on the "upstream" sides of crystals; that is, the sides that face the direction from which the mineralizing solutions come. Stoiber (1946) attributed unequal deposition on the walls of cavities and on irregularities in the walls of fissures to the same phenomenon. Engel (1946, p. 612; 1948, p. 656–657) made field observations that seem to support the foregoing experimental evidence and suggested a possible way to reconcile Bandy's (1942) and Newhouse's diametrically opposed interpretations of asymmetry of crystals. In a later paper, however, Engel (1951, p. 225) doubts that direction of flow of mineralizing solutions is the sole or even principal cause for asymmetry of crystals and veins. Although asymmetry of the filling of fissures and inequalities of size among crystals in the same cavity may be related to the direction of flow of mineralizing solutions, and indirectly reflect irregularities in the conduits through which the solutions flowed, agreement is not possible at present concerning the cause of asymmetry observed in the calcite veins.

The presence of numerous vugs in a vein causes planes of weakness. Hence strike faults generally pass through the vugs. Similarly minor slip planes ordinarily coincide with the surfaces of discontinuity between bands in a banded vein. A few faults cut across the vein structure. Narrow open spaces caused by faulting during mineralization are lined with calcite druses (pl. 27). R. D. Hoffman of Calcite Operators, Inc., reported that a section of vein mined in the old Wade workings contained four overlapping parallel vugs. The writers saw similar features elsewhere. Such groups of overlapping parallel tabular vugs probably were produced by movement along parallel strike faults in the veins; it does not seem reasonable to regard them as spaces remaining after a single continuous process of fissure filling.

A correlation between thick veins and steep vein dips was noted in a few mines, but at most places conclusive evidence of this relation is lacking. Thick vein filling on the steep parts of veins suggests that the original openings in irregular high angle fissures were caused by normal faulting. Where veins cross beds of shale and sandstone, most veins tend to widen in the sandstone and to narrow where one or both walls are shale. At the Bodine mine, the vein changes course slightly where it crosses a contact of porphyry and sandstone. The largest and most productive vug was found near the bend and in the porphyry.

The walls of most vugs are composed of white calcite on which drusy crusts of clear and semiclear crystals have been deposited. In all openings the deposition of clear calcite proceeded by growth of the crystals from the walls inward. The calcite crust on which the crystals grew ranges from a fraction of an inch to more than a foot thick. Faint banding, probably indicating interruptions during the period of growth, is present in some clear calcite crystals. Changes in the conditions of deposition during the formation of a single crystal may be indicated by gradation from milky or semiclear calcite at the base of the crust to clear calcite on the inner drusy surface. Only the inward termination of the crystals show well-developed crystal faces. The terminations were the source of the greater part of the optical calcite produced, although, according to E. G. Ericson, perhaps 20 percent of production was derived from "root material"—that is, solidly intergrown clear calcite from which the well-formed crystal terminations projected. Clear cleavage rhombs were recovered from this massive crust after the terminations had been broken off. In all parts of the crust except the few inches including the inner drusy surface, conditions of interference between growing crystals prevailed and may have been a contributing cause of twinning and cleaving of the calcite. However, lamellar twinning is common also in the projecting crystal terminations. It seems likely that twinning and cleaving is due in part to the shock and friction incident to faulting.

Cavities that were filled with transparent calcite after the main period of vein formation are commercially the most important structural features of the veins. The quality of vug crystals, determined by the presence of milkiness, twinning, and cleaving, varies widely among different vugs. A consistent relation between quality and geologic features was not discernible.

The specifications for optical calcite imposed severe limitations on the quantity that could be produced. The necessity that the crystal be clear indicated that vugs and other cavities should be sought, but the presence of developed cleavage and twinning in the crystals from any single cavity could not be foreseen. The size specification and the urgent need for quantity production required the seeking of cavities of sufficient size to accommodate the growth of abundant and relatively large crystals.

The width of the cavities, the available supply of solution, the time of uninterrupted growth, and the local irregularities in size and shape of the openings determined the size attained by individual crystals. The limiting factor upon crystal size was, however, the amount of space available for growth. Wide cavities contain both large and small crystals, but narrow cavities contain only small crystals. Gunsight material of sufficient size could be obtained from clear, unflawed crystals weighing less than a pound and measuring about 2 inches in length and diameter. These dimensions set a theoretical minimum size of cavity necessary to accommodate optical calcite crystals. However, because only the tips of crystals usually were of suitable quality, it was necessary to find larger crystals and wider vugs than would have been necessary if the crystals had been of good quality throughout. That mineralized primary vugs still contained voids indicated that the theoretical limitation of crystal size by cavity width was not exercised in full. It is doubtful, therefore, that a constant or nearly constant ratio exists between average crystal size and cavity width.

In the field a rough general correlation was observed among large vein thicknesses, large and thick vugs, relatively large crystals, abundant crystals, and relatively large output of optical calcite. Complete statistical data, by which such a correlation might be given a quantitative value, are lacking, however. Little calcite was produced from veins less than 2½ feet wide; most came from veins at least 4 feet wide.

Origin.—The veins are believed to have originated by deposition of calcite and associated minerals from warm solutions rising in the faults. Replacement appears to have played little, if any, part. The theory of hydrothermal origin is supported by the presence of chalcedony and zeolites in some of the veins, and by the persistence of the veins below the present water table. In a brief study Kalb (1928) related the crystal habit of calcite to its manner of deposition, stating that rhombohedrons and scalenohedrons are characteristically of hydrothermal origin. These are the two most common crystal forms in the Montana calcite deposits.

The springs at White Sulphur Springs, Mont., about 36 miles north of the calcite-vein area, discharge about 500 gallons of water per minute (gpm) at a temperature of 95° to 125° F. (Stearns, Stearns, and Waring, 1937, p. 153). The most abundant dissolved constituents in the warm waters are sodium carbonate, sodium sulfate, sodium chloride, and calcium carbonate, in that order (Weed, 1899, p. 8; Fitch, 1927, p. 469). The waters of Hunter Hot Springs, halfway between Livingston and Big Timber, Mont. (pl. 1), discharge about 1,500 gpm at a temperature of 148° to 168° F. (Stearns, Stearns, and Waring, 1937, p. 155). The principal anions in the water are sulfate, carbonate, and chlorine, in that order; the principal cations are sodium, magnesium, and calcium, also in order (Crook, 1899, p. 320; Weed, 1905, p. 604; Fitch, 1927, p. 466). Hunter Hot Springs and White Sulphur Springs discharge water of moderately low salinity, and may be classed as springs of "mixed type" (Clarke, 1924, p. 194). The waters of both springs contain small amounts of silica. Concerning Hunter Hot Springs, Weed (1904, p. 75), who apparently identified calcite as gypsum, states "the hot waters are now depositing gypsum and the old hot spring fissures are filled by a mass of gypsum and stilbite." He considered (1905, p. 604) the stilbite, though contemporaneous with the gypsum, to be "mainly the product of the later or dying stages of hot-spring activity," and says "it is probable that the spring water [presumably from a different individual spring from that referred to above] is now depositing [stilbite], and not gypsum, but this could not be verified."

These springs conceivably represent the dying phase of hypogene carbonate mineralization which once affected a much wider area. The pinching-out of several calcite veins at short distances below the surface is attributable to structural reasons rather than to lack of supply of solution at these depths. No source of abundant carbonate solutions is apparent on the surface.

Parsons (1942, p. 1182) mentions "hydrothermal fissure veins" consisting "essentially of calcite and a fine-grained mixture of sericite and quartz with a little pyrite," near the center of the Iron Mountain laccolith, 15 miles south of Big Timber and a few miles south of the Cartwright Crystal Spar property. The laccolith, composed of fine-grained rock ranging from augite diorite to hornblende monzonite, shows the greatest alteration near the veins. Parsons believes that the more intense alteration near the veins is the result of hydrothermal action and that the alteration suggests the location of the pipe which fed the laccolith. Although the writers did not see hydrothermal alteration, such as that described by Parsons, in the wall rock of any of the veins examined by them, Parsons' observations suggest a hydrothermal origin also for the other calcite veins in the area.

The later solutions that deposited transparent calcite are thought to have been hydrothermal, but clear calcite may have been deposited by descending surface waters charged with calcium carbonate leached from upper parts of the veins. Vugs are the principal channels for descending waters; the dissolving effect of such waters is indicated by the etching and rounding of the vug crystals. There is no evidence that calcite is being deposited now from surface waters. Gradations between milky and clear calcite within a single crystal would appear to indicate continuous and gradual change in conditions of deposition, rather than interrupted deposition by waters from different sources. Furthermore, it seems unlikely that supergene solutions, which deposit their dissolved matter under the more or less fixed pressure and temperature conditions of the atmosphere, would undergo such changes within the space and time of growth of a single crystal.

The color and comparative opaqueness of white vein calcite may be caused by the presence of innumerable submicroscopic, gas-filled vacuoles. If so, the change from deposition of white vein calcite to deposition of transparent calcite may have been preceded or accompanied by a general reduction of solution temperature and pressure that released gaseous carbon dioxide from solution. Hypogene solutions rising toward the earth's surface undergo a reduction in pressure and temperature, but supergene solutions do not ordinarily undergo such changes.

Fries (1948, p. 143) concluded that the optical calcite veins in Mexico were deposited "by ascending hot water rather than by descending cold surface water." Kelley's (1940, p. 365–367) conclusion that an Iceland spar deposit in Taos County, N. Mex., is of hydrothermal origin was based largely on the observed presence of chalcopyrite veinlets in the calcite, and on additions of nickel, barium, bismuth, chromium, and molybdenum to the wall rock as shown by a comparison of spectographic analyses of altered and unaltered wall rock. Metallic minerals were not seen in the Montana deposits. Although the sandstone and shale of the Livingston formation are not visibly altered next to the veins, it is possible that spectrographic analysis of the wall rocks would reveal that metallic elements have been added to the wall rocks in minor quantities. The widespread alteration of the intrusive and extrusive andesitic rocks, as at the Cartwright properties, was probably caused by late magmatic rather than by vein-forming processes.

Wall-rock alteration and deposition of much of the calcium carbonate in the Iceland deposits are believed by H. H. Eiriksson (1920) to have been effected by heated ascending waters.

Kelley (1940) noted that most Iceland spar deposits on which geologic data are available are in basaltic rocks. Such is true of the deposit near Helgustadir, Iceland (Eiriksson, 1920), and possibly of deposits near Cedarville, Calif., and Pyramid Lake, Nev. (Hughes, 1931, p. 12–13). Calcite deposits in the Kenhardt district, Cape Province, South Africa, occur in diabase (Hughes, 1931, p. 10). Fries (1948, p. 138) found optical calcite deposits in Mexico in basalt, rhyolite, latite, breccia, and andesitic rocks and stated that "extrusive volcanic rocks, particularly those of moderately basic composition such as andesite and basalt . . . are more favorable to the occurrence of commercial deposits than others." Calcite veins in Malheur County, Oreg., examined by Stoll in 1944, contain stilbite and cut across flat-dipping basalt flows and beds of tuff and volcanic breccia. Optical spar has not been produced from them. Zeolites are also present in both the Iceland and Montana deposits.

The New Mexico deposit described by Kelley (1940) is in hornblende schist. J. H. Johnson (1940, p. 152) in describing the same deposit infers an origin connected with Tertiary vulcanism from examination of the abundant basic lava flows in the Rio Grande valley. Kelley noted that the minor elements introduced into the wall rocks of the deposit include the siderophile elements, chromium and nickel, and an element generally of granitic affiliations, molybdenum.

From available information it appears that calcite deposits are generally found in regions containing volcanic rocks, particularly basalts. In individual occurrences, it seems also that a genetic connection between certain kinds of vulcanism and the formation of calcite deposits may be inferred. The igneous rocks in the Montana calcite area are largely andesitic rather than basaltic in composition, but the general occurrence of calcite deposits in volcanic areas, and the Iron Mountain calcite occurrence previously mentioned, provide evidence for the conclusion that the Montana deposits are related in origin to some of the andesites and other intermediate igneous rocks in the area.

MINES AND PROSPECTS

WADE AND KILLORN PROPERTIES, SECS. 7 AND 8, T. 1 N., R. 9 E.

The greatest quantity of optical calcite produced by Calcite Operators, Inc., and subsequently by Metals Reserve Company came from the Wade property in sec. 7, T. 1 N., R. 9 E., and from the adjoining Killorn property in sec. 8. This producing area is shown in plate 30.

The underlying rocks are low-dipping interbedded andesitic sandstone, siltstone, and shale of the Livingston formation. The sandstone is the most abundant. The beds are transected by two, and in places three, sets of vertical or nearly vertical joints. The most prominent set of joints has an average strike of N. 34° W., nearly parallel to the average strike of the calcite veins. A second set has an average strike of N. 28° E. and the third set, weakly developed and absent in places, strikes N. 79° E. Most of the joints are vertical but a few dip at 70° to 85°. Locally, small calcite veinlets follow joints and bedding planes, but the economically important calcite veins lie in northwestward trending, steeply dipping faults. A few minor cross faults probably existed before mineralization. Three principal vein zones, each composed of several veins in echelon, are shown on plate 30.

West area.—A single vein zone having an average strike of N. 39° W., and dipping steeply southwest, crosses the west area in sec. 7, on property belonging to W. H. Wade (pl. 31). Within the limits of the area the zone is about 650 feet long, but it extends interruptedly 1,000 feet farther to the southeast (pl. 30). Outcrops are few, having been largely covered with waste from mining. The zone has several veins in echelon ranging in length from less than 100 feet to 300 feet, and in thickness from a few inches to more than 6 feet. Individual veins strike from N. 30° W., to N. 45° W., and bend slightly at some points. They dip southwest at angles of 60° to nearly vertical. The veins occupy faults, probably of normal displacement, which cut the gently dipping andesitic sandstone and shale. A few follow northwest-trending joints which at some places may have controlled the attitude of the later faults. Calcite was the only vein mineral seen in the west area.

Most of the optical material produced by Calcite Operators, Inc., came from the west area. An estimate of this production has been given in table 1. In 1943, A. H. Hansen and his successor, Calcite Operators, Inc., sank four shafts from 40 to 65 feet deep, and drove a 70-foot adit, a 25-foot cross cut, and 400 feet of drift on the most northwesterly veins of the zone. From these workings an estimated 1,856 pounds of optical calcite was produced and accepted for use by Polaroid Corporation. Most of it came from the Hansen vug.

On an adjacent vein lying to the southeast, no. 5 shaft was sunk 40 feet, and 50 feet of drift was driven. An estimated 24 pounds of optical material was accepted from this working.

In 1944, the Metals Reserve Company drove the northwest drift from the bottom of no. 5 shaft to connect with the older workings, and the vein was mined from January 8 to June 30. Production amounted to 256⅞ pounds of optical calcite, trimmed from 6,169 pounds of crude material. The average grade of the vein was 0.256 pounds of optical calcite per ton of vein material mined. The detailed geology of the workings and the quantities produced at each place worked by Metals Reserve Company are shown in plate 31.

In the underground workings (pl. 31), as at the surface, two veins that contain isolated lenses of calcite are exposed and are offset a few feet in echelon. The northwest vein is exposed for a length of 400 feet and the southeast vein for 260 feet. Between calcite lenses the veins are well-defined sinuous zones of sandstone breccia, sandy gouge, and interlacing calcite stringers. In the northwest end of the drift, the old workings, the fault occupied by the calcite consists of a series of closely spaced parallel slip surfaces between which the country rock is cracked and shattered. This diffused structure probably indicates that the fault dies out within a short distance to the northwest. At the southeast end of the workings the vein and fault are more strongly defined. The calcite bodies are tabular or lenticular, as much as 70 to 80 feet long, and 1½ to 7 feet wide. The coarsely crystalline white calcite, of which the lenses are larely composed, is crowded with angular breccia fragments of sandstone and sandstone horses several feet in length. Small clear crystals are present in minor faults, cracks, and joints near the vein. Fault striae and mullion structure on the vein walls and within the vein indicate several periods and directions of fault movement. Several narrow veins branch from the main fractures.

Almost all optical calcite was obtained from stopes above the adit level. The Hansen vug lay near the middle of a calcite lens 6 feet thick. It was reported to have been 3 feet across, 30 feet deep and 70 feet long. Here and there the cavity was bridged with calcite. Clear, untwinned, and uncleaved crystals, weighing as much as 10 pounds each, were extracted from the walls of the vug and from sandy vug-filling in which detached crystals were imbedded. Crystals of perfect form were found that weighed as much as 5 or 6 pounds. Where the vug was, the vein dipped steeply, reportedly 80° to 90° southwest. Beneath the vug, in the drift, the vein dips 67° southwest and is barren. The Hansen vug was largely mined underhand from the surface. Other vugs, yielding a smaller production, were mined upward from the drift.

The Metals Reserve Company mined three stopes a few yards northwest of no. 5 shaft. The upper parts of the stopes are in shale and shaly sandstone, and the lower parts, from which all the production came, are in sandstone. In the back of the stope above no. 5–6 raise, a 12-inch calcite vein, without vugs, is between shale walls. All optical calcite here was obtained from small vugs in the lower part of the stope and from the floor of the drift directly beneath. The stope, which is entered by nos. 5–5 and 5–4 raises, is on a hanging-wall split of the vein. The optical calcite was obtained from crystals lying loose in the mud-filled vug. In the back of the stope, the vein was 5 to 6 feet wide and composed largely of fault breccia and gouge. A stope on the foot-wall split at no. 5–3 raise yielded optical calcite from a vuggy vein 6 to 7 feet wide. Farther up the stope the vein splits into a number of stringers.

East Area.—The east area is crossed by a vein zone 900 feet long that trends N. 21° W. and consists of 5 veins from 25 to 330 feet long. The veins range in strike from N. 6° W. to N. 26° W., and dip southwest at angles of 60° to 70°. The maximum vein thickness was 10 feet in the back of a stope below the collar of no. 1 shaft. In 1943 the largest vein was opened by Calcite Operators, Inc., in a few surface cuts, no. 11 shaft, and no. 1 shaft. No. 1 shaft was sunk to a depth of 30 feet. An estimated 238 pounds of optical calcite was accepted by the Polaroid Corporation from crude material mined in the shaft and a small connecting stope. Crystals weighing from 1 to 7 pounds were the best material. Some scalenohedrons weighing a maximum of 50 pounds yielded small amounts of optical spar.

Between December 24, 1943, and July 31, 1944, the Metals Reserve Company deepened nos. 1 and 11 shafts and drove drifts and stopes. A total of 892¼ pounds of optical material was obtained from the largest vein, in stopes connecting with no. 1 shaft. The average grade was 0.625 pounds of optical calcite per ton of vein excavated. From a production of 25,981 pounds of crude vug calcite the recovery of optical material was 3.43 percent. No. 4 shaft yielded only 8½ pounds; no. 11 shaft yielded none.

Plate 32 shows the detailed geology of the east area. The geology of the small underground workings driven by Calcite Operators, Inc., is shown on plate 32 in the map of the upper stope and the cross section of no. 1 shaft. The more extensive workings made later by the Metals Reserve Company had been filled at the time of examination, and therefore were not mapped by the writers. The vertical longitudinal projection and plan of the underground workings were supplied by Eric G. Ericson, engineer for the Metals Reserve Company.

In outcrop the veins are solid white calcite, sandstone and shale breccia cemented by calcite, or stockworks of calcite veinlets ramifying through shattered wall rock—principally andesitic sandstone. At several places along the veins, shale forms one wall and sandstone the other. Very little clear calcite was seen in the outcrops.

The upper part of no. 1 shaft is a wide vuggy lens of calcite that contains breccia fragments of sandstone and shale. Abundant fault striae indicate movement in a direction about halfway between the dip and strike directions of the vein. The upper part of the shaft is reported to have followed a vug from 2 to 5 feet wide which extended 9 feet along the strike and 30 feet down the dip of the vein. The vugs observed were as much as 30 cubic feet in volume, and larger vugs were reported in the backfilled part of the vein.

Two small vugs were discovered in no. 11 shaft, but the vein was barren in the drift at the bottom. No calcite of optical grade was produced. According to Mr. Ericson, the vein in no. 4 shaft dips 65° to the southwest, and was followed to a depth of 60 feet before it pinched out. A little optical material was taken from small vugs 35 feet below the collar of the shaft, but the vein was composed primarily of slightly mineralized fault material.

Southeast area.—A surface map of the southeast area is shown in plate 33. It includes small parts of sec. 7, belonging to W. H. Wade, and sec. 8, belonging to J. B. Killorn. Optical calcite was derived from a strong zone of veins 1,400 feet long that trends N. 53° W. The first work in this area was done by Calcite Operators, Inc., which sank no. 2 shaft to a depth of 30 feet, but no optical calcite was produced. The Metals Reserve Company continued development and between December 24, 1943, and August 31, 1944, shafts 2, 6, 7, and 8 were sunk to depths of 40 to 85 feet, and more than 1,000 feet of drifts were driven on the vein. Many productive vugs were found and stoped. No. 2 shaft and connecting workings were the source of 232,133 pounds of crude vug calcite. The recovery of optical calcite was 0.77 percent, or 1,798 pounds, and constituted 0.463 pounds per ton of vein material excavated. No. 6 working yielded 127,319 pounds of crude calcite, from which 227½ pounds of optical calcite, or 0.179 percent, was recovered. The grade of the deposit was 0.136 pounds of optical material per ton of vein material mined. No. 7 workings had a production of 78,199 pounds of crude calcite from which 768⅜ pounds, 0.98 percent, of optical calcite were recovered. The vein averaged 0.717 pounds of optical material per ton. No optical calcite was obtained from no. 8 shaft.

Five large calcite veins in echelon, each offset a few feet to the left from the next, crop out conspicuously and make up the vein zone. Several short spur veins branch from the main veins. The large veins, from 80 to 430 feet long and from a few inches to 9 feet thick, strike northwestward and dip steeply southwest except for a few local reversals of dip. Near the northwest end of the zone, the main veins curve gently to the west. The spur veins are massive calcite or cemented breccia near their junctions with the large veins, but toward their outer ends they change to stockworks of irregular, narrow stringers. The outcrops of the main veins are massive white calcite, stringer lodes, or sandstone breccia cemented by calcite.

Two vugs were visible at the surface; one, extending downward in no. 2 shaft, contained clear crystals as much as 12 inches in diameter and they showed much lamellar twinning; the other, near the collar of no. 6 shaft, contained only milky calcite.

Several subordinate, outlying veins are nearly parallel to the main zone. They are narrow, relatively short, and occupy joints, or minor faults controlled by joints. Clear calcite is present in some of the veins but no usable optical calcite was recovered because the fissures were too small to permit the growth of sufficiently large crystals.

The veins underground are sinuous and pinch and swell and in some places attain a thickness of 15 feet (pl. 34). Gougy, pinched-out areas are few and small. Some of the echelon offsets observed at the surface are lacking underground. For example, between no. 2 and no. 6 shafts the vein is continuous, but at the surface it is discontinuous. Near the end of the drift southeast of no. 6 shaft, two veins that are offset on the surface are linked by a narrow cross vein underground. Many productive vugs were found in no. 2, no. 6, and no. 7 workings. Some vugs contained clear calcite crystals projecting inward from surfaces of white vein calcite, but in other vugs, chiefly in no. 6 and no. 7 workings, the clear crystals were attached to the sandstone walls.

The wall rock is andesitic sandstone interbedded with thinner layers of shale. In some places shale forms one of the vein walls and sandstone the other. The veins follow normal, dip-slip faults; the direction of principal movement is indicated by fault striae and subsidiary tension breaks. Some strike-slip movement is indicated by horizontal striations on the vein walls. Movement has occurred at all stages of the vein-forming process. The veins generally narrow where they cross shale beds or where their dip flattens. At most places where they are exposed below the floor of the drift the veins maintain good thicknesses.

WADE PROPERTY, SW¼ SEC. 7, T. 1 N., R. 9 E.

In 1943, Calcite Operators, Inc., prospected two small veins cropping out in the SW¼ sec. 7, T. 1 N., R. 9 E., and in the adjoining section of the next range to the west, owned by J. B. Killorn. During July and August 1944 one of the veins was mined by the Metals Reserve Company. No. 14 shaft was sunk vertically to a depth of 42 feet and drifts were run a few yards to the northwest and southeast. Only 1⅜ pounds of optical calcite was recovered. The surface and underground workings are shown in plate 35. The vein lies in a vertical fault, the southwest wall of which has moved relatively downward. The walls are interbedded shale, siltstone, and sandstone in about equal proportions. The maximum vein thickness is

6½ feet. Veins consist of both white and orange-brown calcite in which breccia fragments and large horses of wall rock are common. The productive vug found underground, a few feet in length and depth and about a foot thick, was between walls of sandstone and siltstone.

WADE PROPERTY, S½ SEC. 6, T. 1 N., R. 9 E.

A calcite deposit owned by W. H. Wade in sec. 6, T. 1 N., R. 9 E., a few thousand feet north of the main workings in sec. 7, was prospected in 1943 by Calcite Operators, Inc., and was developed and mined from May to August 1944 by the Metals Reserve Company. No. 12 shaft was sunk 56 feet and no. 13 shaft, 37 feet, on different veins. A small amount of stoping was done and 108⅝ and 396¼ pounds of optical calcite were produced from the workings of no. 12 and no. 13 shafts, respectively. The 5½ pounds of optical calcite produced from the opencut near no. 16 shaft is included in the total from no. 16 shaft.

A zone of calcite veins and stringers striking N. 45° W., is traceable for about 360 feet on the surface (pl. 36). One vug, 8 inches across, was visible at the surface and was later stoped. The veins dip steeply southwest and cut across flat-dipping sandstone and shale beds. Purple shale forms the footwall near the bottom of no. 13 shaft. Underground the veins attain a maximum thickness of 5 feet but most are 1 to 3 feet thick. In places they pinch out to seams of gouge or break up into stringer lodes. The veins narrow especially where shale forms the walls or where the dip flattens slightly (pl. 36, sections in nos. 12 and 13 shafts). Tension breaks and striae indicate that the southwest wall of the vein moved down and to the southeast relative to the northeast wall.

KILLORN PROPERTY, N½ SEC. 18, T. 1 N., R. 9 E.

A vein in the N½ sec. 18, T. 1 N., R. 9 E., belonging to J. B. Killorn, was prospected in 1943 by Calcite Operators, Inc. A 50-foot shaft (no. 10) was sunk, a few feet of drift were driven, and several shallow prospect holes were dug, but only a few pounds of optical calcite were produced. Exploitation of the property was continued by the Metals Reserve Company from June to August 1944, and an additional 112⅛ pounds of optical calcite were recovered. During Government operation, short drifts were driven from no. 10 shaft and the vein was stoped overhand. No. 15 shaft was sunk and no. 9 tunnel was driven from the surface. No. 9–3 raise was driven from the end of no. 9 tunnel to connect with the bottom of no. 10 shaft. The surface and underground workings, and geology are shown in plate 37.

A single vein zone, striking N. 42° W. and dipping steeply northeast, crosses the property. The zone has a length of 1,640 feet but only the middle 1,040 feet are shown on the surface map (pl. 37). On the surface the maximum thickness of calcite is 7 feet. The country rocks are interbedded andesitic sandstone, shale, and siltstone that dip gently northwest and are cut by two sets of joints, the most prominent of which strikes nearly parallel to the veins. The veins are coarse, massive, white calcite, calcite-cemented breccia of sandstone and shale, and networks of interlacing calcite veinlets. Small amounts of chalcedony and stilbite occur with the calcite. Chalcedony forms opaque white botryoidal coatings on calcite, and stilbite forms overgrowths of groups of tiny, transparent, colorless plates on calcite. Small pockets of clear calcite were found in the outcrop near no. 10 shaft during prospecting. Most of the pockets lie along the footwall of the vein which is brecciated or lodelike in structure. Crystals weighing as much as 10 pounds were found; most of them were milky and twinned.

In the stopes near the foot of no. 10 shaft, the vein is from 1 to 3 feet thick and contains many ordinary drusy cavities as much as 12 inches long. A small part of the vein calcite at this locality is brownish orange. At one place clear and semiclear crystals as much as 2 inches across, some of which are brownish orange, form a drusy coating on an opening that follows a flat bedding plane between sandstone and shale layers.

In no. 9 tunnel the vein has an average thickness of about 5 feet and is composed almost entirely of gouge and brecciated sandstone and shale containing a few calcite stringers. Calcite bands appear in the vein at both ends of the drift. Intense movement has been repeated several times; both dip- and strike-slip movement occurred; the hanging wall apparently moved downward and to the southeast relative to the northeast wall.

GIBSON PROPERTY

In sec. 17, T. 1 N., R. 9 E., on the Gibson property, a calcite vein cuts flat-bedded andesitic sandstone. The vein strikes N. 22° W., dips steeply, is 6 to 48 inches thick, and is traceable on the surface for about 550 feet. It was opened by a single pit, 10 to 12 feet deep, that exposed a small vug. Clear calcite is present in the outcrop near the southeast end of the vein.

FRANCIS PROPERTY

The Francis property, owned by Marie Francis, is in sec. 35, T. 1 N., R. 9 E., 2 miles southwest of Chadborn and 7 miles south of Clyde Park. In 1943 the veins were prospected by Calcite Operators, Inc. Several prospect cuts were dug on the outcrops and an 18-foot shaft (no. 17) and a 20-foot drift were driven. A number of vugs in the underground workings yielded much clear, colorless calcite. Clear rhombohedral crystals weighing from 10 to 20 pounds each and individual scalenohedral crystals weighing a maximum of 16 pounds were reportedly taken out, but a great part of the material was twinned and could not be used. An estimated 12 pounds of optical calcite was produced from no. 17 shaft, all of which is reported to have come from scalenohedral crystals.

During July and August 1944 the Francis property was prospected and mined by the Metals Reserve Company. A few opencuts were excavated, no. 17 shaft was deepened, and three new shafts were sunk to depths of 10 to 38 feet. From no. 17 shaft an additional 85⅝ pounds of optical calcite were recovered; and from no. 20 shaft, 39⅝ pounds. No optical calcite came from shafts nos. 18 and 19.

The principal veins are in a zone that is 2,200 feet long and strikes N. 40° W. The veins are 30 to 400 feet long and from less than an inch to about 6 feet thick. Smaller outlying veins were not mined. About 2,100 feet N. 73° E. of no. 17 shaft there is a calcite vein (not shown on pl. 38) 1 to 2 feet thick that trends N. 46° W. for a distance of about 200 feet. The country rocks are low-dipping strata of shale and andesitic sandstone. Shale is more abundant than on calcite properties nearby. The geology and workings are shown in plate 38.

In no. 17 shaft and in the small stope near the bottom, the vein averages about 2½ feet in thickness and dips 82° southwest. Most of the wall rock is shale. A gouge seam, containing clear but fractured crystals, follows the northeast wall. The vugs, which reportedly transect the vein rather than parallel it, may be partially filled tension openings caused by faulting.

In no. 19 shaft the vein consists of sheeted shale and sandstone cut by narrow calcite stringers, a band of massive calcite, and streaks of gouge and breccia. Near the bottom of the shaft the calcite band pinches out. About 5,000 pounds of crystals, some more than 8 inches in diameter, were removed but none yielded acceptable optical material.

No. 20 shaft was inaccessible to the writers, but it is said that the vein pinches in the lower part of the shaft. Some optical calcite was obtained from an opencut within 15 feet of either side of the shaft.

BODINE MINE

A calcite deposit owned by Howard Bodine is in the SW¼ sec. 11, T. 1 N., R. 9 E., about 3 miles south-southeast of Clyde Park, in Park County. The vein crosses a narrow, steep promontory on the southwest bank of the Shields River.

In February 1944 the calcite deposit was leased to Elmer Boyce of Wallace, Idaho, and he and A. H. Hansen of Clyde Park mined between 800 and 900 pounds of optical calcite from a single large vug in the vein. Edwin Over later joined partnership with the lessees. From March to May smaller vugs were mined and an additional 100 pounds of optical material were produced. During the summer a 40-foot drift was driven on the vein a few feet above the level of the river and two small vugs were found which yielded a few pounds of optical calcite. The mining ceased in August. Total production amounted to 1,000 pounds of optical calcite which was sold to the Metals Reserve Company at $7.50 per pound. A few hundred pounds of optical-grade crystals of substandard size also were produced.

The calcite deposit is in andesitic sandstone, siltstone, and shale of the Livingston formation and in a vertical dike of andesite porphyry that intrudes the Livingston. The geology of the property is shown in plate 39. The deposit cuts across the northeast end of the promontory, the southeast flank of which is composed of sedimentary rocks similar to the rocks underlying the Wade property 3 miles to the west. The beds strike from N. 7° E. to N. 75° E. and dip 9° to 33° to the northwest. On three sides of the promontory are flood-plain gravels of the Shields River. The andesite porphyry dike that crops out on the top and northwest side of the promontory is a massive to jointed, light-brown, white-spotted rock. The light-brown groundmass is a mixture of hornblende and plagioclase. The phenocrysts consist of laths and anhedra of white plagioclase and needles of hornblende a quarter of an inch in maximum length. Biotite, and possibly, nontronite are present also.

The vein zone consists of branching veins and closely spaced stringers lying on either side of the main calcite vein which occupies a fault. Abundant slickensides and mullion structures indicate dominantly dip-slip movement, but it was not possible to determine whether the movement was normal or reverse. The offset of the porphyry-sandstone contact suggests that the movement was normal. The main vein strikes N. 40° W., nearly at right angles to the contact of the porphyry and sedimentary rocks, and dips 60° to 80° SW. It is a few inches to about 4 feet thick, is traceable on the surface for 135 feet, and has been followed downdip for 65 feet. The main vein bends slightly where it crosses the contact between the dike and sedimentary rocks. The vein is coarse white calcite in which there are numerous vugs whose walls are lined with clear, colorless calcite crystals.

The northwest part of the main vein is wholly in porphyry, and the southeast part is wholly in sandstone. Where the main vein crosses the sandstone-porphyry contact on the surface, it is flanked by porphyry on the northeast and by sandstone on the southwest. At the same point on the vein but farther down the dip, both walls of the vein are porphyry; this fact indicates that the sandstone southwest of the main vein forms only a thin surface capping over the dike (pl. 39, vertical longitudinal projection). The large vug that yielded the major part of the optical calcite was found near the porphyry-sandstone contact a few feet below the sandstone capping. Between one-quarter and one-third of the crystals removed from this vug were of excellent quality. The recovery of acceptable material was exceptionally high because there was little lamellar twinning. In the porphyry the vein is stronger and better defined than in the sandstone where it resembles a stringer lode more than a filled fissure. Moreover, the vugs are smaller in the sandstone and the vug crystals are small and highly twinned. The porphyry seems to be the more favorable rock for the occurrence of optical calcite, although the contiguity of the two rock types, rather than simply the presence of the porphyry, may be the significant factor.

Mining on the Bodine vein is pretty well limited to the part above the level of the river. Most of this ground has been mined or thoroughly explored, and it is unlikely that much more optical calcite can be found.

MILLER PROPERTY

Sec. 11, T. 2 N., R. 8 E., owned by G. L. Miller, contains a few small veins and veinlets of calcite cutting andesitic sandstone. The largest vein is 10 to 16 inches thick, strikes N. 12° W., and dips steeply to the northeast. It is traceable on the surface for about 50 feet, and appears to consist entirely of "bony" calcite. The vein has been prospected by a pit 4 feet deep. The surrounding sandstone beds strike N. 40° E. and dip 43° to the northwest.

A few narrow white calcite veinlets, ½ to 2 inches wide, follow joints in the sandstone. Some of them contain small quantities of pink laumontite. Stilbite may be present also.

GROSSFIELD PROPERTY

In sec. 9, T. 2 N., R. 8 E., on property owned by a Mr. Grossfield, a line of calcite outcrops can be traced for several hundred feet. A calcite vein 6 to 8 inches thick that strikes N. 11° W. and dips 72° to the southwest is in a breccia zone 4 feet wide. The wall rock is andesitic sandstone. A 9-foot pit and a 17-foot adit have been driven on the vein.

PULLIS PROPERTY

A calcite vein owned by E. J. Pullis crops out south of the Pullis ranchhouse, in sec. 21, T. 4 N., R. 8 E., about 7 miles northwest of Wilsall in Park County. A shaft 20 feet deep was sunk on the vein in the fall of 1943 by Calcite Operators, Inc. The amount of optical calcite produced is not known.

The vein is exposed for a few feet on either side of the shaft, but its extension along the strike is covered by soil. At the shaft head the vein is 4 feet thick, strikes N. 11° E., and dips vertically. The country rock is gray medium-grained andesitic arkose. In contrast to the white calcite that forms the vein filling of other deposits in the Clyde Park and Wilsall areas, the vein material in the outcrop and on the dump at the Pullis property is mainly clear and semiclear coarse calcite. Stilbite is present in minor quantities. The Pullis vein appears to be a good optical calcite prospect.

BRIEBACH PROPERTY

The Briebach property, worked by Calcite Operators, Inc., during the summer and fall of 1943, is 7 miles west of Wilsall, in secs. 30 and 31, T. 3 N., R. 8 E., and can be reached by a country road extending west from Wilsall. Calcite Operators reportedly produced 119 pounds of optical calcite. Later operators sold about 18 pounds to the Metals Reserve Company. The workings consist of several prospect pits, 4 small opencuts, 9 shafts from 18 to 37 feet deep, and a few short drifts. Four vein zones and several small subsidiary veins are exposed. The vein zones strike from N. 9° W. to N. 25° W. and dip vertically or steeply to the northeast or southwest. The principal vein zone, on which the main shaft is located, is about 1,800 feet long, trends N. 25° W., and dips steeply northeast. Most of the veins are thin; the greatest thickness observed was 4.3 feet. The veins, like those in the Clyde Park area, are in echelon and have branch veins and local variations of dip and strike. The country rock is andesitic sandstone and shale. Uncommon, smooth-surfaced, hard, slightly flattened spheres of sandstone 4 to 5 inches in diameter were exposed in the sandstone of the main shaft. The beds dip gently north and northeast. Plate 40 is a sketch map of the Briebach property.

The vein minerals are calcite and stilbite. Most of the vein-forming calcite is coarsely crystalline and white, but a deep brownish-orange calcite was taken from the workings on the east side of the mapped area (pl. 40). Much clear vug calcite has been mined on the Briebach property, but most of it, particularly from the east workings, was unacceptable because of lamellar twinning. Almost all optical material came from the main shaft and opencut in the west workings. Stilbite is more abundant than on other properties examined, and forms coatings of white or glossy tabular crystals on the calcite. At one place, through a distance of several feet, a sharply defined selvage of stilbite is at the edge of the vein, between the wall rock and the calcite.

Another vein crops out about a mile east of the main workings.

It strikes N. 38° W. and dips 82° to the southwest. The greatest thickness observed was 6 feet; the vein seems fairly continuous for 300 to 400 feet along the strike.

WILLOW CREEK AREA

In the area drained by the middle and south forks of Willow Creek, about 9 miles northwest of Livingston, is a series of large calcite veins cutting andesitic sandstones of the Livingston formation. The veins appear on the areal map (pl. 23) as nos. 15, 16, 17, 18, 19, 20, 21, 46, and 54. Vein no. 15 strikes N. 22° W. and dips 70° to the northeast. It is traceable for 750 feet and throughout this length is 8 to 15 feet thick. Vein no. 16 strikes N. 25° W. and dips steeply; it is 6 to 20 feet thick and is traceable for about 1,000 feet. Vein no. 17 strikes N. 37° W. to N. 59° W. and can be followed for about 400 feet along the strike. Thicknesses range from 2 to 8 feet. Vein no. 18 strikes N. 29° W. and is 6 to 20 feet thick. Discontinuous exposures of what appears to be the same vein or vein zone are traceable for several thousand feet. Some of the outcrops are vuggy and may contain optical calcite; large clear crystals were present. Vein no. 19, which is 5 to 10 feet thick, trends N. 14° E. over a strike length of about 500 feet. Vein no. 20 is 300 feet long, 7 to 10 feet thick, and strikes N. 33° W. A shallow pit has been excavated on the vein and some optical calcite is reported to have been taken from it in 1914. Clear calcite was seen. Vein no. 21, which strikes N. 29° W. and dips vertically, is 100 feet long and 3 to 8 feet thick. Vein no. 46 strikes N. 18° W. to N. 40° W. and is 6 to 12 feet thick. It crops out discontinuously for more than 2,000 feet. Vein no. 54, striking N. 31° W., forms a series of outcrops for several hundred feet. Thicknesses range from 1 to 3 feet. A parallel zone of calcite stringers crops out 200 feet to the southwest of vein no. 54.

Most of the Willow Creek veins show banding and comb structure similar to that of the vein on the Cartwright Crystal Spar group in Sweet Grass County. Most of the calcite is white, but some is semiclear, some is brownish, and some forms clear crystals. Only a few prospect pits were seen.

Vein no. 22, on the Meigs property in sec. 27, T. 1 S., R. 9 E., strikes N. 39° W. to N. 44° W. It can be followed for about 2,000 feet and is 3 to 8 feet thick where exposed. Two short, narrow veins, nos. 40 and 41, crop out on the North Fork of Willow Creek.

AREA NEAR GRANNIS

A system of calcite veins is exposed in secs. 14, 15, and 23, T. 1 S., R. 10 E., a few miles southeast of Grannis, on property owned by Ralph Palmer and Mrs. R. J. Abraham. On plate 23 the principal veins of the group are numbered 42, 43, 44, and 45. Vein no. 42, on the Palmer property, strikes N. 25° W. and is traceable for about 700 feet. The outcrop forms a low ridge above the gently rolling grazing land. Vein no. 43, 2 to 7 feet thick, strikes N. 40° W. to N. 74° W. and can be traced about 800 feet. Vein no. 44 trends N. 58° W. to N. 61° W. and is traceable for 200 feet. Vein no. 45 splits into two veins, one of which strikes about N. 22° W. and the other N. 65° W. Each branch is discontinuously traceable for 1,000 feet or more. The vein thicknesses range from a few inches to 7 feet. Several small veins crop out near vein no. 45. All veins in the area near Grannis dip almost vertically.

Vein no. 39, about 2 miles west-northwest of Grannis, strikes N. 27° W. and is traceable for about 200 feet; it has an average thickness of 1½ feet.

AREA NORTH OF ELTON

From 1 to 3 miles north and northeast of Elton, on the north side of the Yellowstone River, a system of veins crops out in an area about 2 miles wide and 4 miles long. Part of the area is known as the Cassidy, or Windsor, property. The veins are designated on plate 23 as numbers 23, 24, 25, 26, 35, 36, 37, and 38—the last four of which are on the Cassidy property.

Vein no. 23 strikes N. 69° W. to N. 72° W., is 3 to 6 feet thick, and can be traced for about 1,000 feet. Vein no. 24 crops out discontinuously for 1¼ miles, strikes N. 51° W., and is 10 to 20 feet thick. Veins nos. 25 and 26 are small. No. 35 strikes N. 20° W. and can be followed for several hundred feet. Vein no. 36 strikes N. 70° W. and dips vertically. It is 1 to 4 feet thick, several hundred feet long, and contains a little clear calcite and stilbite. Vein no. 37 crosses a buffalo wallow, strikes N. 18° W. to N. 24° W., dips about vertically, and can be traced for about 1,000 feet with minor offsets. Most of the calcite is "bony" but a little clear material was seen. The vein contains a little stilbite also. Vein no. 38 crops out discontinuously for 500 feet and strikes N. 48° W. to N. 64° W.

HUNTER HOT SPRINGS AREA

A group of northwest-trending veins crosses the road immediately west of Hunter Hot Springs. On the areal map (pl. 23) the veins are numbered 47, 48, 49, 50, 51, and 52. The country rock is andesitic sandstone. The largest vein, no. 47, strikes N. 64°–79° W. and dips vertically to 65° NE. Plate 25 is a photograph of part of the outcrop. The vein is traceable with interruptions and offsets for a distance of 3,800 feet. Thicknesses range from 1 to 8 feet. The vein is composed largely of "bony" calcite, although there is a little brownish semi-clear calcite present also. In places the vein is crudely banded, the various bands differing mainly in the coarseness of the constituent crystals. Calcite anhedra from ⅛ inch to 2 inches across are most common. White stilbite is abundant and may make up as much as 0.25 to 0.5 percent of the vein matter. Stilbite occurs as veinlets ¼ to ½ inch thick that follow the vein contacts or cut across the calcite and the adjacent wall rock. The vein splits in places and contains many wedges and breccia inclusions of sandstone. Several pits have been dug on the outcrop, but no optical calcite is known to have been produced. Veins nearby are shorter but of similar thickness and general appearance. Weed (1904, p. 74, 1905, p. 601) reported gypsum and stilbite veins at Hunter Hot Springs. The writers did not recognize gypsum in the veins examined by them; an additional field examination of the veins in the immediate vicinity of Hunter Hot Springs by E. D. Jackson of the U. S. Geological Survey disclosed only coarse calcite and stilbite.

CARTWRIGHT CRYSTAL SPAR GROUP

The Cartwright Crystal Spar group, comprising 3 mining claims, is in the S½ sec. 7, T. 2 S., R. 15 E., in Sweet Grass County, about 11½ miles south-southeast of the town of Big Timber. The property is said to have been operated first by W. E. Burch of Pony, Mont., in 1907. Reportedly, 600 pounds of calcite crystals were sold to a German firm. In 1915, Robert Cartwright and Prof. J. P. Rowe of Missoula, Mont., mined some material for the University of Montana. Subsequently, sales of optical material are said to have been made to the Spencer Lens Company, and specimens and chicken grits were sold to other concerns. By 1944, when the property was held by Cartwright and four partners, the deposit reportedly had yielded about 300 pounds of optical calcite. During the spring and summer of 1944 the property was further developed and mined as a war project by the U. S. Bureau of Mines. Donald B. Hoiekvam supervised the operation. Development work by the Bureau comprised 128 feet of adit, 22 feet of winze, 55 feet of raises, and 229 feet of drifting on the vein. From 955 pounds of crude crystals submitted to Metals Reserve Company for inspection, 43⅜ pounds of acceptable optical calcite were recovered.

The Crystal Spar claims are on part of a strong vein zone striking N. 52° W. which is traceable interruptedly for about 3,000 feet. Plate 41 shows a small section of the zone on Crystal Spar nos. 1 and 2 claims, where all of the mining has been done. At least three veins, offset a short distance in echelon, are shown on the surface map. The underground workings (pl. 41) expose two of the veins. They dip vertically, or steeply northeast, and range in thickness from less than 1 foot to 9 feet. The country rock is pale-purple, green, or brown andesitic agglomerate and andesite. Examination of thin sections of these rocks by C. S. Ross of the Geological Survey revealed the probable presence of allophane, celadonite, and beidellite or saponite.

The veins occur in dip-slip faults and consist largely of calcite fillings that pinch and swell along the strike and dip. Locally the "solid" vein breaks up into stockworks of stringers or pinches out entirely into a band of gouge or intensely shattered andesite. Breccia fragments of wall rock are uncommon in the calcite. At most places the vein fillings of calcite are conspicuously banded parallel to the walls. Typical banding is illustrated in figure 48. Individual bands consist of interlocking finger-shaped calcite crystals of about equal size that have their long axes normal to the vein walls; less commonly the crystals are platy or equant. Some bands are wide, others narrow, and adjacent bands may be composed of crystals of different average size. In some bands the calcite is white; in others it is dominantly dark and glassy, pale brownish yellow, or colorless and clear. Each band is a comb of crystals of a single generation adhering to the inner surface of an adjoining comb of an earlier generation. The vein, therefore, seems to have grown by the accretion of combs from the walls inward. The surface between calcite combs may be drusy, but more commonly it is marked by a smooth, thin seam of granulated calcite formed by intramineral faulting along the planes of weakness between combs. Openings in such slip planes may contain druses of yet another generation of calcite. Irregular fractures have also formed in the vein, and where small openings resulted they have been filled with sandy mud washed in from the surface.

All optical calcite produced by the Bureau of Mines was found as loose crystals embedded in mud-filled crevices parallel to the vein on either wall or in the middle (fig. 49). The filled cavities are probably vugs which have become filled with debris washed in by surface waters. They are a maximum of 3 feet wide and are filled solidly with sandy brown mud containing pieces of calcite ranging from small fragments to irregular lumps 12 inches in diameter. As the cavity was filled, the embedded crystals were probably detached from the walls of the vug by the dissolving action of the percolating waters and possibly by the impact of falling rock fragments. Fault shocks may have contributed to the loosening of some crystals. About 350 tons of mud was mined to obtain 43⅜ pounds of optical calcite. It is probable that more optical material could be recovered from mud-filled cavities.

CARTWRIGHT CALCIUM GROUP

The Cartwright no. 2 vein, or North vein, is in secs. 5, 6, and 8, T. 2 S., R. 15 E., about a mile north-northeast of the Crystal Spar group. The road from Big Timber to the latter property crosses one

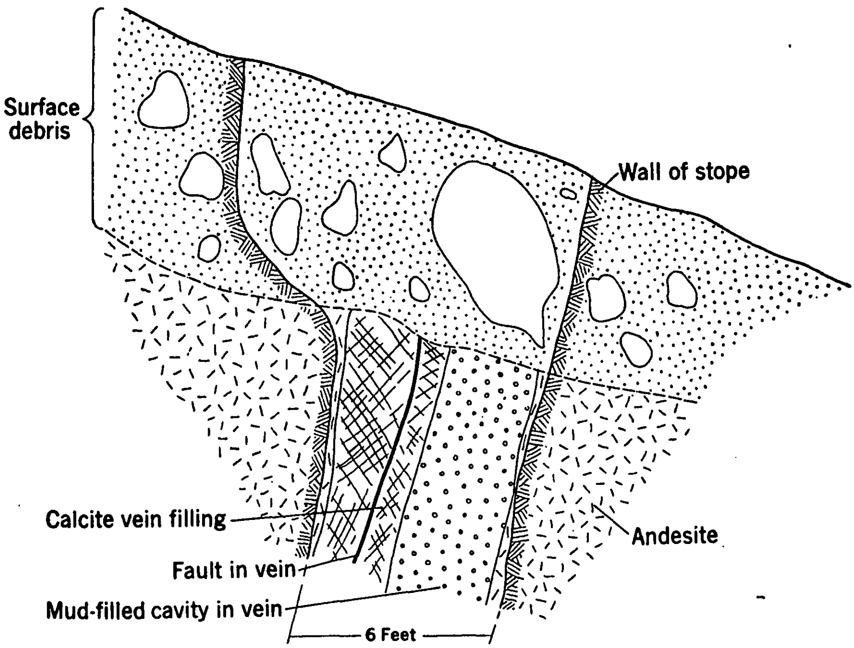


FIGURE 49.—Cross-section of vein showing mud-filled cavity at top of stope above Bureau of Mines drift, Cartwright Crystal Spar group.

of the three claims, known as the Calcium group, that have been located on the vein. The vein has been opened by several shallow trenches and by a 35-foot shaft sunk by the Bureau of Mines in 1944 on Calcium no. 2 claim. It is not known that any optical calcite was produced.

The vein strikes N. 45° W. and dips 80° southwest. It is 2 to 6 feet thick and is traceable for about 2,000 feet. The vein is composed of coarse, cleaved, milky to semiclear calcite. In one cut a spherical mass of calcite about 6 inches in diameter was found. On being broken open the mass was seen to consist of elongate calcite crystals arranged radially like spokes of a wheel about a central point. Arranged concentrically around the "hub" were white and brown bands that uninterruptedly crossed crystal boundaries. The brown bands are probably ferruginous. The country rock is andesite that is partly altered to allophane and chlorite.

BOULDER PROPERTY

The Boulder, or Boot, property is in secs. 7, 8, and 17, T. 1 S., R. 14 E., Sweet Grass County, 6½ miles south-southwest of Big Timber and accessible by road up the Boulder River. The property comprises Boulder no. 1 to no. 6 claims, which are on a conspicuous zone of calcite veins having an average strike of N. 56° W. The veins are traceable for 8,000 feet according to maps made by the U. S. Bureau of Mines. They are opened by a number of shallow cuts on claim nos. 1, 2, and 3. In 1944 the Bureau of Mines sank a 55-foot shaft on the vein on no. 2 claim in sec. 17. A vug reportedly was discovered, but no optical calcite was produced.

On Boulder no. 2 claim the vein is as much as 8 feet thick. At many points it is crudely banded, the individual bands differing in crystal size or in color. Most of the vein calcite is white, although some is honey brown, or colorless and clear. The wall rock is gray-green porphyritic andesite, and nontronite locally fills cavities in it.

SMITH (SCOTT?) PROPERTY

A group of veins trending N. 14° W. and dipping steeply lies 4 miles south of Carney in Sweet Grass County. The veins include one that crops out on the Smith property and is reported to have been mined at one time for chicken grits. The veins range in thickness from 1 to 10 feet, and are discontinuously traceable for 300 to 1,500 feet. As mentioned earlier, it is believed that this is the property referred to as the Scott property from which 11⅝ pounds of optical calcite was produced and sold to Metals Reserve Company.

AYRES PROPERTY

A vein on the Ayres property, in sec. 35, T. 1 S., R. 14 E., strikes N. 54° W., is 3 to 6 feet thick, and about 800 feet long.

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