# Quartz Crystal Deposits of Western Arkansas

*By* A. E. J. ENGEL

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# QUARTZ CRYSTAL DEPOSITS OF WESTERN ARKANSAS

By A. E. J. Engel

**ABSTRACT**

The quartz crystal deposits of western Arkansas constitute one of the few important domestic sources of quartz of grades satisfactory for optical and oscillator use. Eye-clear crystals have been mined at numerous localities in the district for many years, principally for jewelry and for mineral displays. In 1943 a total of 212,620 pounds of salable crystals, worth approximately $35,000, was mined. Of this, some 6,000 pounds, graded for optical and oscillator use and taken mainly from the Jessieville area, was sold for $20,000.

Most of the high-grade quartz has been obtained from deposits in the Blakely (Ordovician) and Crystal Mountain (Ordovician?) sandstones, but quartz crystal deposits occur throughout the Paleozoic shales, sandstones, and cherts exposed along the central belt of the Ouachita Mountains. These strata, more than 25,000 feet thick, have been deformed into complex, gently plunging folds that trend about east. Steeply dipping fractures closely related to the major folds controlled the deposition of most of the quartz.

Clear quartz ordinarily is confined to the terminal parts of simple crystals—specifically, crystals that have developed without disturbance or interference. These crystals in general are elongate parallel to their *c* axes and are bounded by relatively simple crystal forms. Deposition of silica during and subsequent to breakage resulted in the formation of complex crystals. These are characterized by abundant optical twinning and lineage structures and commonly are bounded by aggregates of the simpler crystal forms. The principal defects in all types of crystals are twinning, smokiness, cavities, solid inclusions, and fractures.

Several minerals are associated with the quartz, which usually constitutes 90 percent or more of the cavity fillings. Clay minerals, including dickite, are widespread. Calcite is a common associate, especially in the parts of the veins cutting limestone or dolomite, and adularia and chlorite are found in veins cutting certain shales. Carbonaceous material also is common.

The quartz deposits enclosed in shales, especially the Stanley (Pennsylvanian) and Womble (Ordovician) shales, occur as veins that consist largely of massive milky vein quartz and yield relatively few faced crystals. Deposits in sandstones include veins, sheeted zones, and stockworks, which, although they may contain much less quartz than the deposits in shale, yield a relatively high proportion of clear crystals in cavities or pockets. Many of the crystal pockets are distorted or crushed, and the veins commonly show complex fabrics.

Most of the deposits are cavity fillings, apparently deposited by rising hydrothermal solutions at relatively low temperatures and pressures. The constituents of the cavity fillings may have been derived principally either from magmatic sources or from underlying rocks, with definite additions from the rocks enclosing the cavities. The complex vein fabrics apparently resulted from intermittent regional deformation during the deposition of the quartz. These features and certain structural relations of the deposits suggest that they were formed in the final stages of the Ouachita orogeny, possibly in middle Pennsylvanian time.

Eight of the larger and more productive quartz crystal mines are described in detail. Described in tabular form are 63 quartz crystal mines, prospects, and deposits that have yielded small quantities of high-grade quartz.

## INTRODUCTION

To the geologist and mineralogist, the term "crystal" connotes bounding crystal forms, which is the usage followed in this paper. Thus employed, the term is much more selective than "crystal" as used by the physicist or chemist to denote the crystalline state of matter. Vein quartz masses that are devoid of faced crystals are here referred to as quartz deposits.

The quartz crystal deposits of western Arkansas are the commercially important parts of a large belt of genetically related quartz deposits in the Ouachita Mountains. These quartz deposits have been studied by Honess (1923) and, more recently, by Miser (1943, p. 94).

Honess' studies were restricted to Oklahoma, but Miser found the belt of quartz deposits, as exposed, to be some 30 to 40 miles wide, extending about 150 miles in a west-southwesterly direction from Little Rock, Ark., to Broken Bow, in northern McCurtain County, Okla. Miser also (1943, pp. 94–95) reported the existence of quartz veins, which undoubtedly are part of the belt, in eroded roots of the Ouachita Mountains to the southwest, both in southern Oklahoma and in Texas, as shown by samples from deep wells that penetrated beneath the overlapping Lower Cretaceous strata.

The investigation represented by this paper was concerned only with the crystal-bearing quartz deposits, inasmuch as Miser's studies indicated that in Arkansas only the faced crystals which grew in vein openings could be suitable for oscillator and optical use. Moreover, the quartz veins that contain crystals of possible value appear to be confined, in general, to the Arkansas segment of the quartz belt. Valuable crystals ordinarily are found in veins as far east as Paron, Ark., and at irregular but frequent intervals in quartz deposits as far west as Mount Ida, Ark. The deposits are mostly along or near the structural crest of the mountains, and they outline the quartz crystal district as shown on plate 25. Deposits of quartz containing a few crystals exist outside the area of plate 25, but these outlying deposits are widely scattered and the crystals found in them so far are of little value.

The studies summarized in this paper were begun in December 1942 as a part of the Nation-wide search, during World War II, for quartz suitable for piezoelectrical and optical use. The project was under the general supervision of H. D. Miser, whose earlier investigations were used as a springboard to a more detailed examination of the crystal deposits. His broad knowledge of the quartz deposits and

of the geology of the Ouachita Mountains has aided the author greatly. Ralph Wilpolt worked on the project during much of the field investigation, and John Albers and E. W. Heinrich gave valuable field assistance in the spring of 1943. Many of the production data incorporated in the report were obtained through C. W. Plumb and C. J. Coquoz, agents for the Metals Reserve Company, a subsidiary of the Reconstruction Finance Corporation. Facilities of the University of Missouri Department of Geology and the administration offices of the National Park Service at Hot Springs were utilized. Others who gave valuable assistance were H. M. Bannerman, C. S. Ross, W. T. Schaller, Earl Ingerson, T. P. Thayer, Ralph Van Alstine, and John Eric, all of the U. S. Geological Survey.

## HISTORY OF MINING

The existence of quartz crystals in the Ouachita Mountains has been known since the days of the Indians. According to Miser (1943, p. 92, and personal communication), De Soto's men found that the Indians had been chipping arrowheads from quartz crystals. Nearly 400 years later Schoolcraft (1819, p. 182) commented on the Arkansas quartz as follows:

> One of the most noted localities of this mineral [quartz] west of the Mississippi river is the Hot Springs of Ouachitta (Washitaw) in Arkansaw Territory. At this place numerous pieces of quartz have been found, very pure and transparent, and beautifully crystalized in six sided prisms, terminated by six sided pyramids.

As the popularity of Hot Springs as a resort grew in the latter half of the nineteenth century, tourists and collectors stimulated crystal mining by their increasing demand for quartz crystals. In 1859 Owen (1860, p. 25) recorded a wide sale of quartz crystals to visitors. The source of crystals at that time seems to have been the Crystal Mountains in Montgomery County, but by 1890 crystals were being mined also from deposits in Garland County and the western part of Saline County (Griswold, 1892).

Between 1906 and the late 1920's, fewer visitors came to the Hot Springs area, and as a result crystal mining in the district declined for lack of a nearby market. With the miners inactive, only a few noteworthy deposits were discovered (personal communications from older crystal miners). New paved highways in the 1920's, however, brought increasing numbers of travelers into Hot Springs and adjacent mountain areas, and crystal mining again became a popular part-time occupation of the local inhabitants.

Few restrictions or legal problems hindered the early miners, although most crystal deposits are on land owned by the Federal Government and by timber companies. As long as he left timber undamaged and saw to it that his openings did not become pitfalls for livestock, a miner was free to dig where he dropped his pick and "scratcher" (an iron rod, commonly 8 inches to 2 feet long and bent into a right angle several inches from the point, used to "scratch out" the crystals). Patented claims or leases rarely were obtained. In the fall of 1942, however, the critical need for oscillator quartz brought about a rapid expansion in prospecting and mining, with Federal agencies and private mining companies participating. Mining rights received more careful scrutiny, and free-for-all operations necessarily dwindled. As a part of the Federal program to stimulate domestic production of oscillator quartz, the Metals Reserve Company established a quartz-buying station in Hot Springs in June 1943. About 75 percent of the oscillator quartz mined in the district during 1943, amounting to more than 4,000 pounds, was tested at the station and classified according to the requirements of the National Bureau of Standards.

The Bureau of Standards classification is as follows:

For the purpose of inspecting, testing, and grading, all crystalline quartz is divided into two general classes by weight—the first being 200 grams and above, and the second less than 200 grams but not less than 100 grams.

I. Quartz crystals 200 grams and above in weight per piece.

*Grade 1.*—Grade 1 quartz shall be quartz which in the usable portion shall be free from all defects that can ordinarily be detected in an oil bath, using polarized light, and by moderate arc-lamp illumination.

It shall be divided into two classes: Oscillator and Optical.

Oscillator quartz shall be classified into faced and unfaced material and designated and divided into percentage limits of usability as follows:

| *Designation* | *Percentage limits* |
|---|---|
| 13 | 30–45 |
| 14 | 45–60 |
| 16 | 60–100 |

Optical quartz shall, in general, consist of crystals 500 grams and above in weight, and shall have the following percentage limits of usability: 45–60 and 60–100. It shall, in general, surpass oscillator quartz in quality, and in addition shall be, as far as practicable, free from strain and give good definition when used with monochromatic light. It need not be free from electrical twinning.

*Grade 2.*—Grade 2 quartz shall be oscillator quartz which in the usable portion shall be free from all defects that can ordinarily be detected in an oil bath, using polarized light, and by moderate arc-lamp illumination, except that when examined by moderate arc-lamp illumination the following inclusions are permitted in the usable portion:

1. Hard blue needles—all types.
2. Soft blue needles—all types.
3. Color.
4. Tyndall effect.
5. Scattered fine bubbles.

| *Designation* | *Percentage limits* |
|---|---|
| 23 | 30–45 |
| 24 | 45–60 |
| 26 | 60–100 |

*Grade 3.*—Grade 3 quartz shall be quartz selected from material which does not meet the specifications of Grade 2. It shall be classified as 45–100 percent usable and shall not appear to be less than 45 percent free from inclusions and cleavages when viewed in a bath, using polarized light from a mercury-vapor lamp and without the analyzer in position.

It shall be classified into faced and unfaced material, and designated and divided into percentage limits of usability as follows:

| *Designation* | *Percentage limits* |
|---|---|
| 30 | 0–45 |
| 34 | 45–100 |

Trimming:

(a) All 30 (0–45) Grade 3 crystals, weighing 500 grams or more, shall be sent through a trimming operation for salvaging usable material.

(b) Salvaged material resulting from the trimming operation shall be classified into Grades 1, 2, or 3.

II. Quartz crystals not less than 100 grams in weight but less than 200 grams.

1. Quartz not less than 100 grams but less than 200 grams in weight shall be separated into faced and unfaced material.

(a) Faced quartz shall be defined as quartz having a portion of one natural recognizable face, which portion shall be approximately ½ inch square.

(b) Unfaced quartz shall be packed for storage.

(c) The length of the crystal shall be estimated along the line through the crystal parallel to the optic axis.

(d) The diameter of a crystal shall be estimated along the shortest line through the crystal perpendicular to the optic axis.

(e) Quartz having a minimum diameter less than 1 inch shall be rejected.

2. *Grade 1.*—Grade 1 quartz shall be quartz which in the usable portion shall be free from all defects that can ordinarily be detected in an oil bath, using polarized light, and by moderate arc-lamp illumination.

It shall be divided into two classes:

(a) L-quartz whose length is not less than twice the diameter.

(b) S-quartz whose length is less than twice the diameter.

*Grade 2.*—Grade 2 quartz shall be quartz which in the usable portion shall be free from all defects that can ordinarily be detected in an oil bath, using polarized light and moderate arc-lamp illumination, except that when examined by moderate arc-lamp illumination the following inclusions are permitted in the usable portion:

1. Hard blue needles—all types.
2. Soft blue needles—all types.
3. Color.
4. Tyndall effect.

The percentage limits of usability shall be 45–100.

It shall be divided into two classes:

(a) L-quartz whose length is not less than twice the diameter.

(b) S-quartz whose length is less than twice the diameter.

Effective October 8, 1943, the classification of quartz under 200 grams was replaced by the following: "Eye-test quartz: Eye-test quartz shall be faced quartz under 200 grams and at least 2½ inches long by ¾ inch wide in which the usable portion shall be more than

75 percent 'eye clear' in ordinary daylight." This classification applied only to the Arkansas district, where elongate crystals commonly referred to as "candle quartz" are particularly abundant.

The Fisher Mountain, Miller Mountain, and McEarl deposits were worked by the Metals Reserve Company between January and September 1943 by open-pit and underground mining methods in a program calculated to test the potentialities of the district. The Diamond Drill Carbon Co., of New York, employing a power shovel and hand labor, ran open-cuts in 1943 and 1944 on five tracts of the Dierks Lumber & Coal Co.

## PRODUCTION AND USE OF CRYSTALS

It is almost impossible to evaluate the early production of quartz crystals because the value of all crystals except those sold for oscillators depends upon such factors as clarity, perfection of crystal faces, bizarre or distorted crystal habits, phantoms, variously shaped inclusions, smokiness, freak breaks or intergrowths, secondary growths, rare faces, etch patterns, and twinning. These and many other features may materially affect the sale price—upward to some buyers, downward to others.

Owen (1860, p. 25) estimated that crystals mined in Montgomery County and sold to visitors and jewelers brought about $1,000. Griswold (1892) estimated that, excluding the quartz cut for jewelry, sales of crystals amounted to about $5,000 in 1890. Miser (1942) commented on quartz crystal production as follows:

> Naturally the production has varied, the chief factor being the market for them [the crystals]—the visitors to Hot Springs and the travelers along the highways. The annual sales during the depression in the early thirties may not have exceeded $1,000 worth of crystals. * * * In 1941 the sales are estimated by me to have been about $12,000. The present curtailment of travel and other war conditions have resulted in decreased mining. My estimate is that at no time in recent years have more than 12 men been engaged either whole or part time in digging crystals.

In 1943 about 212,600 pounds of salable crystals, valued at an estimated $35,000, was mined in the Arkansas district. Nearly 6,000 pounds, or about 28 percent of this total, was sold for oscillators and brought about $20,000. Most of the crystals came from the deposits in the Blakely sandstone near Jessieville. The Dierks No. 4 mine (Blocker lead) ranked first in production, but a considerable yield came from the Diamond Drill Carbon Co. No. 4 and No. 5, Miller Mountain, and McEarl operations. Most of the oscillator quartz mined in the Crystal Mountains came from the Fisher Mountain mine.

The amount of oscillator quartz in each grade purchased by the Metals Reserve Company in the Arkansas district is shown in table 1. Table 2 gives the value and amount of oscillator quartz produced in

TABLE 1.—*Oscillator quartz crystals purchased by the Metals Reserve Company in the Arkansas district between February 1 and December 15, 1943, by grade*

[Data from files of Metals Reserve purchasing depot, Hot Springs, Ark.]

| Class and grade | Quantity purchased, tabulated by crystal size, in grams | | | | | | | | | | | | | | | | | | | | | | Total weight | | Percent of total weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Under 200 [1] | | 200–300 | | 300–500 | | 500–700 | | 700–1,000 | | 1,000–2,000 | | 2,000–3,000 | | 3,000–4,000 | | 4,000–5,000 | | 5,000–7,000 | | 7,000–10,000 | | | | |
| | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | |
| Class I: | | | | | | | | | | | | | | | | | | | | | | | | | |
| Grade 1: | | | | | | | | | | | | | | | | | | | | | | | | | |
| 30–45 percent [2] | | | 54 | 13 | 75 | 3½ | 27 | 5 | 21 | 12½ | 23 | 9 | 5 | 10 | 6 | 14 | | | | | | | 215 | 3 | 5.2 |
| 45–60 percent | | | 19 | 1 | 17 | 5½ | 8 | 12½ | 3 | 4 | 10 | 7 | | | | | | | | | | | 58 | 14 | 1.4 |
| 60–100 percent | | | 2 | 13½ | 7 | 3½ | 4 | 10 | 3 | 11 | 4 | 5 | | | | | | | | | | | 22 | 11 | .6 |
| Grade 2: | | | | | | | | | | | | | | | | | | | | | | | | | |
| 30–45 percent | | | 55 | 11½ | 33 | 6½ | 11 | 5 | 5 | 2 | 5 | 4 | | | | | | | | | | | 110 | 13 | 2.6 |
| 45–60 percent | | | 21 | 12 | 4 | 11 | 1 | 4 | 1 | 10 | 3 | 11 | | | | | | | | | | | 33 | 0 | .8 |
| 60–100 percent | | | 4 | 1 | 0 | 15 | 1 | 6 | 2 | 0 | | | | | | | | | | | | | 8 | 6 | .2 |
| Grade 3: 45–100 percent | | | 420 | 6½ | 441 | 4 | 243 | 10½ | 258 | 12 | 405 | 10½ | 183 | 14 | 103 | 7 | 28 | 8 | 50 | 4 | 19 | 3 | 2,154 | 15½ | 52.8 |
| Class II: | | | | | | | | | | | | | | | | | | | | | | | | | |
| Grade 1: | | | | | | | | | | | | | | | | | | | | | | | | | |
| Long | 21 | 7 | | | | | | | | | | | | | | | | | | | | | 21 | 7 | 3.3 |
| Short | 111 | 7 | | | | | | | | | | | | | | | | | | | | | 111 | 7 | |
| Grade 2: | | | | | | | | | | | | | | | | | | | | | | | | | |
| Long | 83 | 10 | | | | | | | | | | | | | | | | | | | | | 83 | 10 | 6.6 |
| Short | 186 | 9 | | | | | | | | | | | | | | | | | | | | | 186 | 9 | |
| Eye-test: 75–100 percent | 1,077 | 4½ | | | | | | | | | | | | | | | | | | | | | 1,077 | 4½ | 26.5 |
| Total | 1,480 | 5½ | 578 | 10½ | 580 | 1 | 298 | 5 | 296 | 3½ | 452 | 14½ | 189 | 8 | 110 | 5 | 28 | 8 | 50 | 4 | 19 | 3 | 4,084 | 4 | 100 |
| Percent of total weight | 36.4 | | 14.1 | | 14.3 | | 7.3 | | 7.2 | | 11.1 | | 4.6 | | 2.7 | | 0.7 | | 1.2 | | 0.4 | | 100 | | |

[1] 100–200 grams for crystals of class II, grades 1 and 2.
[2] Usability, in terms of percentage limits.

1943 from six of the larger deposits in Arkansas, showing the ratio of oscillator quartz to total crystals and rock mined. Tables 3–7, respectively, give statistics for the Miller Mountain, Fisher Mountain, and Dierks No. 4 (Blocker lead) mines, the Shaw tract, and deposits in the Womble and Stanley shales in the Jessieville-Beaudry area.

TABLE 2.—*Value and amount of oscillator quartz produced in 1943 from six of the larger deposits in Arkansas*

[Data in part from files of Metals Reserve Company, in part from author]

| Mine or prospect | Ground moved | Crystals mined | Oscillator quartz | |
|---|---|---|---|---|
| | | | Total mined | Value |
| | *Cubic yards* | *Pounds* | *Pounds* | *Dollars* |
| Dierks No. 4 (Blocker lead) | 9,000 | 100,000 | 2,100 | 10,185.00 |
| Diamond Drill Carbon Co. No. 4 | 9,100 | 16,000 | 760 | 4,400.00 |
| Miller Mountain | 3,260 | 18,000 | 994 | 1,760.00 |
| McEarl | 1,850 | 6,700 | 134 | 282.00 |
| Fisher Mountain | 16,000 | 30,000 | 206 | 407.59 |
| Diamond Drill Carbon Co. No. 5 | 10,000 | 22,000 | 560 | 1,575.00 |
| Total | 49,210 | 192,700 | 4,754 | 18,609.59 |

TABLE 3.—*Oscillator quartz mined at Miller Mountain, Ark., in 1943 and purchased by the Metals Reserve Company, by grade*

[Data from files of Metals Reserve Company]

| Class and grade | Quantity mined, tabulated by crystal size, in grams | | | | | | | | Total weight | | Percent of total weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Under 200 [1] | | 200–300 | | 300–500 | | 500–700 | | | | |
| | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | |
| Class I: | | | | | | | | | | | |
| Grade 1: 30–45 percent [2,3] | | | 7 | 9 | 1 | 6 | | | 8 | 15 | 1 |
| Grade 2: | | | | | | | | | | | |
| 30–45 percent | | | 18 | 5 | 10 | 4 | 1 | 7 | 30 | 0 | 3.5 |
| 45–60 percent | | | 9 | 15 | | 11 | | | 10 | 10 | 1.2 |
| 60–100 percent | | | 2 | 0 | | | | | 2 | 0 | .2 |
| Grade 3: 45–100 percent | | | 113 | 14 | 47 | 9 | 11 | 13 | 173 | 4 | 20.4 |
| Class II: | | | | | | | | | | | |
| Grade 1: Long and short | 57 | 4 | | | | | | | 57 | 4 | 6.7 |
| Grade 2: Long and short | 146 | 12 | | | | | | | 146 | 12 | 17.1 |
| Eye-test: 75–100 percent | 425 | 0 | | | | | | | 425 | 0 | 49.9 |
| Total | 629 | 0 | 151 | 11 | 59 | 14 | 13 | 4 | 853 | 13 | 100 |
| Percent of total weight | 73.7 | | 17.8 | | 7 | | 1.5 | | 100 | | |

[1] 100–200 grams for crystals of class II, grades 1 and 2.
[2] Usability, in terms of percentage limits.
[3] No crystals of class I, grade 1, 45–60 or 60–100 percent, mined in this area.

TABLE 4.—*Oscillator quartz mined at Fisher Mountain, Ark., in 1943 and purchased by the Metals Reserve Company, by grade*

[Data from files of Metals Reserve Company]

| Class and grade | Quantity mined, tabulated by crystal size, in grams | | | | | | | | | | Total weight | | Percent of total weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Under 200 [1] | | 200–300 | | 300–500 | | 500–700 | | 700–1,000 | | | | |
| | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | |
| Class I: | | | | | | | | | | | | | |
| Grade 1: 30–45 percent [2,3] | | | 3 | 2 | | | | | | | 3 | 2 | 1.5 |
| Grade 2: | | | | | | | | | | | | | |
| 30–45 percent | | | 9 | 7 | 2 | 6 | | | | | 11 | 13 | 5.7 |
| 45–60 percent | | | 2 | 7 | | | | | | | 2 | 7 | 1.2 |
| 60–100 percent | | | | 8 | | | | | 2 | 0 | 2 | 8 | 1.3 |
| Grade 3: 45–100 percent | | | 9 | 8 | 6 | 2 | 1 | 5 | | | 16 | 15 | 8.2 |
| Class II: | | | | | | | | | | | | | |
| Grade 1: Long and short | 13 | 14 | | | | | | | | | 13 | 14 | 6.7 |
| Grade 2: Long and short | 60 | 2½ | | | | | | | | | 60 | 2½ | 29.2 |
| Eye-test: 75–100 percent | 95 | 0 | | | | | | | | | 95 | 0 | 46.2 |
| Total | 169 | ½ | 25 | 0 | 8 | 8 | 1 | 5 | 2 | 0 | 205 | 13½ | 100 |
| Percent of total weight | 82.1 | | 12.1 | | 4.1 | | 0.7 | | 0.1 | | 100 | | |

[1] 100–200 grams for crystals of class II, grades 1 and 2.
[2] Usability, in terms of percentage limits.
[3] No crystals of class I, grade 1, 45–60 or 60–100 percent, mined in this area.

TABLE 5.—*Oscillator quartz mined at the Dierks No. 4 mine (Blocker lead), Ark., in 1943 and purchased by the Metals Reserve Company, by grade*

[Represents Blocker mining to Aug. 30, 1943; data from files of Metals Reserve Company]

| Class and grade | Quantity mined, tabulated by crystal size, in grams | | | | | | | | | | | | | | | | | | | | Total weight | | Percent of total weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 200–300 | | 300–500 | | 500–700 | | 700–1,000 | | 1,000–2,000 | | 2,000–3,000 | | 3,000–4,000 | | 4,000–5,000 | | 5,000–7,000 | | 7,000–10,000 | | | | |
| | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | |
| Class I: | | | | | | | | | | | | | | | | | | | | | | | |
| Grade 1: | | | | | | | | | | | | | | | | | | | | | | | |
| 30–45 percent [1] | 13 | 5 | 24 | 6 | 13 | 8 | 10 | 13 | 17 | 1 | 5 | 10 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 84 | 11 | 6.6 |
| 45–60 percent | 5 | 7 | 4 | 11 | 5 | 7 | ----- | ----- | 5 | 10 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 21 | 3 | 1.6 |
| 60–100 percent | 1 | 0 | ----- | 14 | 1 | 3 | 2 | 2 | 4 | 5 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 9 | 8 | .7 |
| Grade 2: | | | | | | | | | | | | | | | | | | | | | | | |
| 30–45 percent | 9 | 0 | 14 | 11 | 5 | 0 | 1 | 12 | 2 | 4 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 32 | 11 | 2.5 |
| 45–60 percent | 2 | 3 | ----- | 10½ | 1 | 4 | 1 | 10 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 5 | 11½ | .4 |
| 60–100 percent | ----- | 15 | ----- | 15 | 1 | 6 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 3 | 4 | .2 |
| Grade 3: 45–100 percent | 90 | 0 | 177 | 10 | 135 | 7 | 166 | 10 | 308 | 10 | 137 | 14 | 62 | 10 | 28 | 8 | 24 | 0 | 19 | 3 | 1,150 | 8 | 88 |
| Total | 121 | 14 | 223 | 13½ | 163 | 3 | 182 | 15 | 337 | 14 | 143 | 8 | 62 | 10 | 28 | 8 | 24 | 0 | 19 | 3 | 1,307 | 8½ | 100 |
| Percent of total weight | 9.3 | | 17.1 | | 12.5 | | 14 | | 25.8 | | 11 | | 4.8 | | 2.2 | | 1.8 | | 1.5 | | 100 | | |

[1] Usability, in terms of percentage limits.

TABLE 6.—*Oscillator quartz mined on the Shaw tract, western Arkansas, in 1943 and purchased by the Metals Reserve Company, by grade*

[Data from files of Metals Reserve Company]

| Class and grade | Quantity mined, tabulated by crystal size, in grams | | | | | | | | | | Total weight | | Percent of total weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Under 200 | | 200–300 | | 300–500 | | 500–700 | | 700–1,000 | | | | |
| | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | *Pounds* | *Ounces* | |
| Class I: | | | | | | | | | | | | | |
| Grade 1: | | | | | | | | | | | | | |
| 30–45 percent[1] | | | 3 | 11 | 8 | 1 | 1 | 7 | 2 | 2 | 15 | 5 | 29.2 |
| 45–60 percent | | | 4 | 0 | 4 | 3 | 2 | 3 | | | 10 | 6 | 19.8 |
| 60–100 percent | | | | 14 | | 12 | 1 | 2 | | | 2 | 12 | 5.3 |
| Grade 3:[2] 45–100 percent | | | 4 | 2 | 3 | 1 | 1 | 2 | | | 8 | .5 | 15.9 |
| Class II: | | | | | | | | | | | | | |
| Grade 1: Long and short | 15 | 3 | | | | | | | | | 15 | 3 | 29 |
| Grade 2: Long and short | | 7 | | | | | | | | | | 7 | .8 |
| Total | 15 | 10 | 12 | 11 | 16 | 1 | 5 | 14 | 2 | 2 | 52 | 6 | 100 |
| Percent of total weight | 29.8 | | 24.2 | | 30.7 | | 11.2 | | 4.1 | | 100 | | |

[1] Usability, in terms of percentage limits.
[2] No crystals of class I, grade 2, mined in this area.

TABLE 7.—*Oscillator quartz purchased by the Metals Reserve Company in 1943 from deposits in the Womble and Stanley shales in the Jessieville-Beaudry area, Ark., by grade*

[Data from files of the Metals Reserve Company]

| Class and grade | Quantity purchased, tabulated by crystal size, in grams | | | | | | | | | | | | | | | | | | | | Total weight | | Percent of total weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Under 200 [1] | | 200–300 | | 300–500 | | 500–700 | | 700–1,000 | | 1,000–2,000 | | 2,000–3,000 | | 3,000–4,000 | | 4,000–5,000 | | 7,000–10,000 | | | | |
| | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | *Lb.* | *Oz.* | |
| Class I: | | | | | | | | | | | | | | | | | | | | | | | |
| Grade 1: | | | | | | | | | | | | | | | | | | | | | | | |
| 30–45 percent [2] | | | 2 | 10 | 3 | 6 | 2 | 4 | | | | | | | | | | | | | 8 | 4 | 9.9 |
| 45–60 percent | | | 1 | 8 | | | | | | | | | | | | | | | | | 1 | 8 | 1.8 |
| 60–100 percent | | | | 7 | | | 1 | 3 | | | | | | | | | | | | | 1 | 10 | 2 |
| Grade 2: 30–45 percent [3] | | | | 7 | | | | | | | | | | | | | | | | | | 7 | .5 |
| Grade 3: 45–100 percent | | | 4 | 10½ | 3 | 5 | 7 | 8 | 6 | 9 | 11 | 0 | 4 | 12 | 13 | 12 | | | 14 | 2 | 65 | 10½ | 79.2 |
| Class II: | | | | | | | | | | | | | | | | | | | | | | | |
| Grade 1: Long and short | | 12 | | | | | | | | | | | | | | | | | | | | 12 | .9 |
| Grade 2: Long and short | 3 | 0 | | | | | | | | | | | | | | | | | | | 3 | 0 | 3.6 |
| Eye-test: 75–100 percent | 1 | 11½ | | | | | | | | | | | | | | | | | | | 1 | 11½ | 2.1 |
| Total | 5 | 7½ | 9 | 10½ | 6 | 11 | 10 | 15 | 6 | 9 | 11 | 0 | 4 | 12 | 13 | 12 | | | 14 | 2 | 82 | 15 | 100 |
| Percent of total weight | 6.6 | | 11.6 | | 8.1 | | 13.2 | | 7.9 | | 13.3 | | 5.7 | | 16.6 | | 0 | | 17 | | 100 | | |

[1] 100–200 grams for crystals of class II, grades 1 and 2.
[2] Usability in terms of percentage limits.
[3] No crystals of class I, grade 2, 45–60 or 60–100 percent, mined in this area.

## GEOLOGY

The Ouachita Mountains, in which the quartz crystal deposits occur, consist of mountain ridges, valleys, and broad lowlands, with local relief ranging from 100 to about 600 feet. Bedrock is a closely folded Paleozoic sedimentary series which structurally forms a broad anticlinorium, probably of late Paleozoic age. Enclosing the quartz deposits are these closely folded rocks, principally shales, sandstones, and cherts.

The rocks are cut by relatively few known faults. Many faults may exist, however, beneath the alluvial and colluvial cover that obscures much of the bedrock geology. Most, if not all, reconstructions of structural features based upon outcrops are as readily explained by various combinations of folds, of types known to exist, as by faults. Consequently, folds are inferred on the maps and in reconstructions.

All the rocks show evidences of the incipient regional metamorphism that accompanied the Ouachita deformation, presumably in the late Paleozoic; the sandstones and cherts are partly recrystallized and the argillaceous rocks show various stages of conversion into slates. In general, the older, more deeply buried rocks were more affected by metamorphism than the younger formations nearer the surface. Lamprophyre dikes, intruded in middle Cretaceous time (Glenn, 1912; Miser 1914, pp. 541–545), have been found in Saline, Garland, and eastern Montgomery Counties, but few such dikes are associated with quartz deposits.

### STRATIGRAPHY

#### GENERAL FEATURES

The geologic formations in the crystal-bearing part of western Arkansas, with their principal lithologic features, are described in the following section:

*Exposed sedimentary rock formations in the quartz crystal district of western Arkansas*

| | Feet |
|---|---|
| Carboniferous (Pennsylvanian): | |
| Atoka formation: Alternating sandstones and shales in about equal amounts. Sandstones, gray to buff, thin-bedded; shales, dark-gray to black, thin-bedded | 6,000 |
| Jackfork sandstone: Sandstone and smaller smaller amounts of shale. Sandstone, gray, fine- to coarse-grained, mostly quartzitic; shale, green to black, thin-bedded | 5,000–6,000 |
| Stanley shale: Mainly shale with much sandstone and conglomerate. Shale, fissile, yellow, brown, green, or black; sandstone, compact, quartzitic, fine-grained, greenish- or bluish-gray. Siliceous conglomerates containing pebbles of novaculite near base of formation | 5,000–6,000 |

| | Feet |
|---|---|
| Carboniferous (Pennsylvanian)—Continued | |
| Hot Springs sandstone: Hard gray quartzitic sandstone; some shale and conglomerate | 0–200 |
| Devonian(?) and Devonian: | |
| Arkansas novaculite: Upper member (Devonian?), massive gray novaculite; middle member (Devonian? and Devonian), thin-bedded dark novaculite and black shale; lower member (Devonian), massive white novaculite | 0–900 |
| Silurian: | |
| Missouri Mountain slate: Red, green, and black slate and shale | 0–300 |
| Ordovician: | |
| Polk Creek shale: Black, thin-bedded carbonaceous shale | 0–175 |
| Bigfork chert: Gray to black, even-bedded, highly fractured chert, some black shale, and a little black siliceous limestone | 500–700 |
| Womble shale: Black, green, and buff laminated shale, some blue to black limestone, and a little thin-bedded sandstone and black chert | 1,000 |
| Blakely sandstone: Sandstone, shale, and conglomerate. Sandstone, mostly buff to gray and siliceous, the rest bluish black and calcareous. Conglomerate consists of shale, limestone, and sandstone pebbles in a sandy or calcareous matrix | 0–500 |
| Mazarn shale: Black and green laminated shale containing thin layers of gray sandstone and lenses of dark-blue limestone | 1,000 |
| Ordovician (?): | |
| Crystal Mountain sandstone: Coarse-grained, massive, gray to brown sandstone, partly quartzitic or calcareous, containing a few thin shale and conglomerate layers near base and top | 550–850 |
| Cambrian: | |
| Collier shale: Laminated, bluish-black, soft graphitic shale, some limestone, and a few thin layers of black chert | 200 |

## PRINCIPAL QUARTZ-BEARING FORMATIONS

Although all the Paleozoic rocks in the district are cut by quartz veins containing some crystals, the chief producing deposits are in the Blakely and Crystal Mountain sandstones.

### CRYSTAL MOUNTAIN SANDSTONE (ORDOVICIAN?)

The Crystal Mountain sandstone is a massive quartzitic sandstone that forms the rugged Crystal Mountains in the west end of the quartz crystal district. The formation was described by Miser and Purdue (1929, pp. 24, 25) as follows:

> Besides sandstone the formation contains a thin basal conglomerate and a very subordinate quantity of shale. The sandstone is massive and coarse grained and is composed of well-rounded, translucent quartz grains, cemented together in some beds by calcium carbonate but in most beds by silica. The calcareous beds are brown and become rather friable on weathering, but the siliceous sandstone is light gray, is hard and dense, and breaks into large and small blocks that cover much of the surface. Joints in the sandstone are abundant, and they are so even and nearly parallel in many places that their surfaces may be mistaken for bedding planes. * * *
>
> The small quantity of shale interbedded with the sandstone is a black clay shale, but in places there are thin alternating layers of greenish color.

The shales occur principally near the base and top of the formation. Some zones in the sandstone contain discoidal to irregularly shaped fragments of shale ranging from microscopic to thumbnail size. The largest particles usually occur near shale interlayers. Where the more soluble constituents in the fragments have been leached, discoidal or irregularly shaped voids are left in the enclosing sandstone, in some instances containing a residue of buff or white clay. The shale fragments, or their casts, usually lie parallel or nearly parallel to the bedding. Discordances in the alinement of particles or casts seem to be due in part to obscure cross bedding or other depositional disturbances and in part to subsequent shearing of the sandstone during regional metamorphism.

In places intense shearing is indicated by many crushed and partly recrystallized quartz grains. Exposures of sandstone traversed by minute ruptures and gash fractures are numerous in the Crystal Mountains. Those grains that are marginal to small irregular fissures generally have been secondarily enlarged. Where milky vein fillings are present, the contact between vein and country rock may be transitional. A thin zone of sandstone bordering major joints commonly has been recrystallized to form a dense shell that weathers very smooth. This is in sharp contrast to the granular surface of the less altered adjacent sandstone.

Microscopic study shows that much of the Crystal Mountain sandstone consists almost entirely of quartz grains, mostly between 0.20 and 0.75 millimeter in diameter, with incipient to moderately sutured boundaries. A small percentage of the grains shows strain shadows in uniform zones and irregular patterns. Secondary growth of grains was noted in places, and in a few slides the grains were seen to be slightly crushed, forming a mortar structure. Sericite, ferroan calcite, limonite, and clayey material are very sparingly present.

The thickness of the Crystal Mountain sandstone in the central part of the Crystal Mountains is given as 850 feet by Miser and Purdue (1929, p. 24). At Fisher Mountain, along the northern flank of the Crystal Mountains, the formation appears to be about 550 feet thick.

In describing the stratigraphic relations of the Crystal Mountain sandstone, Miser and Purdue (1929, p. 25) state:

It is unconformably underlain by the Collier shale and is overlain by the Mazarn shale, of Lower Ordovician age, from which it is not separated by any indication of a stratigraphic break. * * * To the observer in the field it appears * * * that the Crystal Mountain sandstone and Mazarn shale belong to the same series—Lower Ordovician—though the reference of the sandstone to this series can not be definitely made on account of the absence of fossils in the sandstone.

### BLAKELY SANDSTONE (ORDOVICIAN)

The Blakely sandstone is the resistant component of many west-southwestward-trending ridges in the crystal district between Mountain Valley and Beaudry, in eastern Garland County, and Norman and Cedar Glades to the west. The Blakely sandstone lenses out westward, 5 miles southeast of Mount Ida in the Fisher Mountain area in Montgomery County.

Purdue and Miser (1923, p. 3) describe the Blakely sandstone in exposures near Mountain Valley as follows:

The formation consists of about 500 feet of interbedded shale and sandstone of which the shale forms probably 75 percent. Though the shale thus preponderates, the sandstone is resistant enough to form sharp, rugged ridges that in places attain an elevation of 600 feet above the valleys and that form some of the roughest topography in the district. The shale is black and argillaceous and much of it is ribboned, and it is therefore not unlike the Mazarn and Womble shales. The sandstone occurs in beds that are in most places only a few feet thick but at others measure as much as 40 feet; and one bed on Little Glazypeau Creek is 80 feet thick. It is made up of medium-sized quartz grains, firmly cemented together, in most beds by silica but in others by calcium carbonate. There are thus two kinds of sandstone, one quartzitic, the other calcareous. The quartzitic sandstone is light gray to bluish gray, laminated, extremely hard, and much jointed, and it disintegrates slowly on weathering. As a result of its resistance to weathering the crests of the ridges are generally covered with large quantities of angular boulders, which are piled in great heaps, suggesting numerous massive beds, though in fact most of the beds are thin and are separated by thick beds of shale. The calcareous sandstone is bluish black, and its limy material dissolves out on weathering, leaving a friable stone that ranges in color from gray to brown.

A conglomerate that is only a few inches thick and that consists of small rounded pebbles of black chert in a sandy matrix was observed at a few places at the base of the Blakely sandstone. Moreover, near the middle of the formation there is a conglomerate a few feet thick, which consists of small rounded pebbles of chert and limestone embedded in a sandy, calcareous bluish-black matrix. At one place near the top of the formation there is a conglomerate 18 inches thick, which consists of a black shale matrix with small pebbles of sandstone and numerous cavities that were once probably occupied by pebbles of limestone.

Layers of sandstone occur near the top of the shale that underlies the Blakely sandstone as well as near the base of the shale that overlies it, and the lower and upper contacts of the formation are therefore fixed arbitrarily except where they are marked by a characteristic bed, like the conglomerate at the base.

The Blakely sandstone toward the north and west across the crystal district is characterized by abrupt variations in over-all thickness as well as in the relative proportions of sandstone, shale, and conglomerate. As much as one-third of the formation, at several localities near Chance and on Miller Mountain, is composed of conglomerates. Fragments of shale, quartzite, limestone, and chert, of all sizes up to 3 feet in diameter, are embedded in a matrix ranging in composition from sandstone to dark-blue sandy limestone. Many zones within the sandstones of the Blakely also contain small discoidal or angular shale or shaly carbonate masses (less than 3 inches across), commonly highly weathered.

Most exposures of the Blakely sandstone, except the quartzitic phases of the formation, are much weathered. The shales alter to sticky clays, and the sandstones and conglomerates initially having a high carbonate content leach and form porous friable rocks. Red iron oxides are common. These are derived, in part at least, from secondary carbonates and sulfides.

Microscopic examination shows that the quartzitic sandstone consists almost entirely of quartz grains, most of which range from 0.18 to 0.80 millimeter in size. Sericite, carbonate, and clay minerals are sparse. Localized shearing, shattering, and recrystallization of the quartz are evident. Many quartz grains are deeply corroded into skeletal forms, and interpenetrating grain boundaries are incipient to well developed. Zones and irregular areas of strain shadows are present in a few grains in all sections except one, where undulatory extinction is common. Most grains contain lines or irregular groups of vacuoles.

The matrix of the conglomerate, when examined under the microscope, is seen to consist of various proportions of quartz and calcite and a few flakes of sericite. Commonly the carbonate has been leached, leaving a porous network of quartz grains and veinlets in which only a small part of each quartz grain touches one or more of its neighbors. Many grains are badly shattered, strained, and corroded, and their contacts are sutured or highly irregular. Groups of vacuoles, some of which seem to contain either liquid or solid matter, or both, and minute euhedral crystals of zircon and rutile are enclosed in the quartz grains.

Purdue and Miser (1923) estimated the thickness of the Blakely sandstone at 500 feet in the northwest corner of the Hot Springs quadrangle. The following sections, necessarily measured in areas of extreme deformation and incomplete exposures, indicate the approximate thickness of the formation to the north and west, in the heart of the crystal district.

*Section of Blakely sandstone measured on north slope of Miller Mountain*

| | Feet |
|---|---|
| Top of section. | |
| Buff to black, thinly laminated shale | 10 |
| Gray, massive quartzitic sandstone | 14 |
| Covered zone (sandy shale?) | 200 |
| Red argillaceous sandstone and conglomeratic sandstone | 70 |
| Conglomerate of subangular to rounded fragments of shale, limestone, chert, and sandstone in argillaceous and calcareous sandstone matrix | 50 |
| Alternating layers of argillaceous red sandstone and thinly laminated buff to pink shale | 40 |
| Thinly laminated buff to pink shale with intercalated thin beds and nodules of black chert | 7 |
| Coarsely crystalline siliceous, dark-gray to black limestone | 4 |
| Thinly laminated buff to pink shale and slabby beds of limestone containing nodules and lenses of black chert | 15 |
| Base of Blakely sandstone. | 410 |

*Section of Blakely sandstone at the McEarl mine, West Chance area*

| | Feet |
|---|---|
| Top of section. | |
| Buff to pink, thinly laminated shale | 10 |
| Massive, quartzitic, coarse-grained gray sandstone | 50 |
| Argillaceous red sandstone and conglomeratic red sandstone containing fragments of shale and sandstone. Sandy matrix locally calcareous | 74 |
| Argillaceous red sandstone, in part calcareous, and sandy shale | 20 |
| Base of Blakely sandstone. | 154 |

The Blakely sandstone 5½ miles southeast of Mount Ida, in the Fisher Mountain area, consists of alternating layers of thin-bedded slabby sandstones, siltstones, and thinly laminated shales ranging from a knife edge to 150 feet in thickness.

The contacts of the Blakely sandstone with the overlying and underlying shale formations are rarely exposed. In a mine shaft on the north slope of Miller Mountain a narrow zone which includes limestone and nodules of black chert marks the contact of the Blakely sandstone with the underlying shale, but no unconformity is apparent (pl. 37). In the Jessieville area, the basal beds of the Blakely are transitional from the overlying sandstones and conglomerates downward into the underlying Mazarn shale (pl. 36). Purdue and Miser (1923, p. 1) found a thin conglomerate at the base of the Blakely sandstone at a few places in the Hot Springs district; they suggested that the Blakely might be unconformable with the Mazarn shale below.

In the observed exposures, the top of the Blakely sandstone is sharply defined against, or abruptly transitional into, the overlying Womble shale; there is no evidence of an unconformity between the two formations.

In the Hot Springs district, graptolites (Purdue and Miser, 1923) of Beekmantown (Early Ordovician) age have been found near the middle of the Blakely sandstone.

## STRUCTURE

### STRUCTURAL FEATURES OF THE OUACHITA ANTICLINORIUM

The broad Ouachita anticlinorium is composed of at least three subsidiary anticlinoria, which rudely outline an interposed elongate, composite synclinorium (Miser, 1929, pls. 1, 2). The largest of these four structural units is the Crystal Mountain anticlinorium (Purdue and Miser, 1929, pp. 11–12), which topographically forms a chain of rugged hills and intervening lowlands along and near the crest of the Ouachita Range. The Crystal Mountain anticlinorium, together with the flanking folds in the Pennsylvanian strata to the north, encompasses the quartz crystal district.

Both the broad and the detailed structural features of the district are best revealed by the more competent sandstones and cherts, which are compressed into tight, gently plunging folds that strike slightly north or south of east and commonly are overturned so that both limbs dip north. The thick, intercalated shales are intensely crumpled and sheared. An interesting feature of the argillaceous rocks is that these units of Cambrian and Ordovician age exhibit a slaty cleavage ($S_2$), obscurely to moderately developed, which commonly dips much more gently than the bedding and the axial planes of isoclinal folds in the bedding. This relationship is especially marked in the central parts of the shaly rocks where no stiffening interlayers of sandstone or chert appear. It is least pronounced, and in some places even nonexistent, at and near the contacts of the argillaceous formations with adjoining formations of appreciable competency. Very gentle undulations or folds also appear in the slaty cleavage ($S_2$). The trends of these gentle folds in the cleavage are in some places parallel to trends of folds in the bedding, but in other places trends of undulations in the slaty cleavage ($S_2$) diverge as much as 45° from trends of folds in the bedding. In the younger argillaceous formations, such as the Stanley shale of Pennsylvanian age, bedding and cleavage are commonly parallel, even in the thickest argillaceous zones devoid of more competent interlayers.

The variation in the relations of the slaty cleavage and bedding in rocks of differing age is conceivably a corollary to the differing degrees of metamorphism found in these rocks—that is, a general decrease in the degree of recrystallization and reconstitution apparent in argillaceous rocks with decrease in age from Cambrian and Ordovician to Pennsylvanian.

Known faults of appreciable magnitude are rare in the district, despite the severe folding. Several faults of slight displacement occur in or near a few of the quartz deposits mapped, and a major thrust may exist on the north side of Fisher Mountain. There is no compelling field evidence indicating that any of these breaks have acted as major channels for silica-bearing fluids, and in many of the best-exposed areas of quartz mineralization no faults could be found.

Along the southwestern part of the district, in Montgomery County, the Crystal Mountains form the elongate core of the Crystal Mountain anticlinorium. The structural features of this region are typically developed in the vicinity of Fisher Mountain (pl. 26), which is on the north flank of the Crystal Mountains. The structure and lithology are clearly reflected in the topography of the area. East-west ridges with a local relief of 300 to 600 feet appear in the southern and western parts of the area. These ridges are underlain by the Crystal Mountain sandstone, which has been complexly folded. Most of the ridges are large anticlines on which subsidiary anticlines or structural terraces are superimposed; most of the intervening valleys accordingly are folded synclines. In form and orientation, the subsidiary folds resemble the larger folds. The south flanks of several of the anticlines are vertical or slightly overturned, the crests are sharp, and the north flanks dip gently to moderately to the north. Other folds are more nearly symmetrical. Individual folds, which can be traced for distances ranging from several hundred feet to several miles, interfinger with other folds or die out at the ends. The northern half of the area is essentially a broad, flat shale valley divided, east of Mount Ida, by a low east-west ridge of sandstones and shales of the Blakely sandstone.

In the vicinity of Chance (pl. 27), the folds that form the major structural features are in the Mazarn shale, Blakely sandstone, and Womble shale. The crumpled Mazarn shale is exposed in the eroded crests of major anticlines outlined by the Blakely sandstone, and the overlying younger Womble shale occupies the troughs of adjacent synclines. The two major anticlines in the area mapped have broad crenulate or furrowed crests formed by parallel-trending subsidiary folds. The noses of both large and subsidiary folds are rudely symmetrical, with the flanks of each fold dipping in opposite directions at different but moderate angles. Where each fold was traced eastward, however, its south flank was seen to steepen, pass through the vertical, and become distinctly overturned, commonly dipping to the northwest at moderate to gentle angles. Thus the south flank of the large anticline just northwest of Chance village is overturned through an angle of 170° and now dips about 10° NW. where it is crossed by the road to Jessieville.

The structural features and rocks in the Miller Mountain area (pl. 28) are very similar to those in the vicinity of Chance. Sandstones and conglomerates of the Blakely sandstone form three anticlinal ridges striking N. 60°–70° E. Smith Mountain, the southwesternmost of the three anticlines, consists of an isoclinal fold overturned to the southeast as much as 45°, so that both flanks dip to the northwest. The anticline plunges gently to the southwest and northeast, culminating at the northeast between the anticlines in Miller and Beard Mountains. The Beard Mountain anticline (pl. 44) is less closely compressed, both limbs dipping steeply away from the axis in most places. The south limb of Miller Mountain anticline is nearly vertical over much of its extent; the north limb dips 60°–80° N.

In the northern part of the crystal district most of the quartz deposits occur in irregular belts of Womble and Stanley shales; scattered deposits are in the Bigfork chert and Jackfork sandstone. This is true, also, in the eastern part of the district in Saline County, where the Ouachita anticlinorial arch, about 20 miles across, is relatively flat.

## FRACTURES CONTROLLING THE DEPOSITION OF QUARTZ

The major quartz crystal deposits are limited to fracture groups or systems closely related to the regional structure. Two general types of fractures, longitudinal and transverse, are apparent.

More than 85 percent of the crystal deposits occupy steeply dipping or vertical longitudinal fissures, which parallel or diverge only slightly from the trend of the folds in the Ouachita Mountains. This parallelism in the strike and, to a lesser degree, the dip of many crystal-bearing veins and of the axial planes of folds persists throughout most of the crystal district; thus the crystal deposits in the western and central parts of the district, from Mena to the area east of Jessieville, trend east and in general dip steeply to the north. These deposits are largely veins and sheeted zones. In the Paron area, where the folds trend southeastward, the veins likewise strike southeastward and dip steeply to the north or are vertical.

The transverse fractures, which strike approximately across the folds and dip nearly vertically, contain productive crystal deposits in the Chance area, in the Crystal Mountains, and—locally—elsewhere. The highly productive Diamond Drill Carbon Co. No. 4 mine near Chance (pl. 35) contains some veins of this type. In general, the fracture groups paralleling fold axes occur in all major rock types—sandstones, shales, and cherts—but are most conspicuous in sandstones along the crests of anticlines. In shales and slaty rocks, the general parallelism in the strike of veins and the trend of major folds is clear-cut, but divergences of minor folds from the strike of nearby veins exist in all these units. In the area of the Marler mine, for example, minor folds in the Womble shale have trends which diverge from the strike of most quartz-filled fissures. The transverse fissures are limited chiefly to the flanks of folds in sandstones and quartzites, although locally, as in the Chance area, both groups are abundant.

Discordances between fracture fillings and fold axes, though uncommon in sandstones in the central parts of the district, become increasingly apparent in the Crystal Mountains and elsewhere along the margins of the crystal-producing area. Veins strike diagonally across the trend of folds at angles up to 40° at Fisher Mountain and at several other deposits in the Crystal Mountains, and irregular fractures such as those forming the few stockworks in the district (McEarl, Diamond Drill Carbon Co. No. 4, and Collier Creek mines) increase in abundance north and south of the crystal-producing areas shown in plate 25. However, the general parallelism of fractures and major-fold axes persists, not only in the quartz crystal district, but throughout the area of major quartz deposits in Arkansas and in Oklahoma (Honess, 1923, pl. 1).

The bulk of the silica in the quartz deposits of the district fills the longitudinal fissures in a belt of country that coincides with and extends somewhat north of the major axis of the Ouachita anticlinorium. Although movements along these fissures appear to have been slight to moderate, geologic features discussed in succeeding sections of this paper indicate that many fissure openings persisted and were probably enlarged by recurrent openings of the fissures throughout the period of quartz deposition.

Near the margins of the main quartz belt, especially in the Chance and Miller Mountain areas and in the Crystal Mountains where some of the most productive crystal deposits occur, the quartz crystal-bearing fissures are in competent beds on the crests of anticlines. Many crystal pockets occur in fractures in sandstones adjacent to shale contacts and along thin brittle sandstones interbedded with shales. Slates and shales adjacent to these competent beds, although fractured, are relatively tight and barren (pl. 34).

Regarding the origin of the fractures, which have largely controlled the deposition of the quartz, Miser (1943, p. 101) says:

To account for the restriction of most of the quartz to this belt the suggestion is offered that the regional arching of the strata to form the anticlinorium of the Ouachita Mountains was a final stage in the deformation of the depositional geosyncline of these mountains. Such regional upwarping would have developed tensional fractures to serve as suitable sites for growth of the quartz, and continued upwarping during the period of quartz deposition would have produced brecciation and fractures that would be healed partly or wholly by later deposition of quartz.

Honess (1923, pt. 2, p. 41) also concluded that the fissures in Oklahoma that controlled quartz deposition are "tension joints, free from brecciated country rock, and are of the type known as gash veins in most cases at least."

There seems to be little doubt that many quartz-mineralized longitudinal fissures that tend to parallel axial planes of folds in the quartz crystal district were opened by tension. Many of these fissures in shales and slates—and quite a few in sandstones, quartzites, and cherts—obviously are not solution openings, and the quartz-vein materials are not reconverted wall-rock silica. Some quartz-filled fissures have matching walls, with sharp, clean contacts between the quartz and the wall rock (pl. 30). In many shales and slates, especially, key beds and laminae on opposite sides of the fissures can be matched. In some places the intersections of these key beds with fissure walls are at oblique and obtuse angles. The beds show offsets roughly proportional to the width of the fissure, if the opening movements are calculated as about normal to the plane of the fissure. These features apparently indicate a pulling apart of some fissure walls, locally as much as 20 feet or more, with the principal direction of movement at a high angle to the two greatest dimensions of the vein.

Relations of this type are by no means widespread, however, even in the longitudinal fissures that contain most of the quartz. Actual openings along some longitudinal fractures in sandstones may be very small, and where veins appear along these fractures the veins would seem best attributed to the reconversion of siliceous wall rock (pls. 34*A*, 34*B*).

Other longitudinal fractures in a strict sense are faults because opposite walls have moved mostly along or near the surfaces of plane, curved, or irregular fissures. These faulting movements are conclusively shown by matching offsets in distinctive beds and by features of the veins themselves (fig. 20). For example, some veins are sheared out and partly granulated by differential wall-rock movements during vein growth. Relative movements of wall rock essentially parallel to some veins, or at moderate if not low angles to the plane of the vein, have sheared off growing quartz crystals and inequidimensional grains initially elongate normal to the vein walls. In extreme examples of faulting movements, these crystals and grains have been rotated so that their longest axes (the *c* axis of the grain or crystal) now are parallel to the vein walls. Several interesting fabrics have been developed. In many veins, or parts of veins, the long axes of the crystals show no preferred orientation within the general plane of the vein; in other parts of veins, as in the vein near Angling Pinnacle shown in figure 20, strikingly lineated mats of crystals appear. In these mats the longest axes of the crystals are roughly parallel with one another and the vein walls—and presumably either normal to or parallel with the direction of maximum net slip of the faulted vein walls. Most of the faults are thrusts which seem to have evolved in conjunction with folding. The thrust planes are rudely parallel with the axial planes of the folds.

In the known veins that follow longitudinal fractures, clear-cut evidence of faulting during vein formation of the type just described is not widespread. The general process seems to have been a tensional opening of fissure walls during mineralization, but veins seemingly formed by recrystallization of wall rock, like those shown on plates 34*A* and 34*B*, and parts of veins formed by more conventional replacement phenomena (pl. 31) represent perhaps 15 percent of the total veins in sandstones and quartzites. Mashed and shattered vein fabrics and crystals commonly rehealed by later deposits of silica are the rule, although few show the lineations cited in the preceding paragraph. These features indicate clearly that most fissure walls during vein growth underwent differential movements other than simple tensional opening.

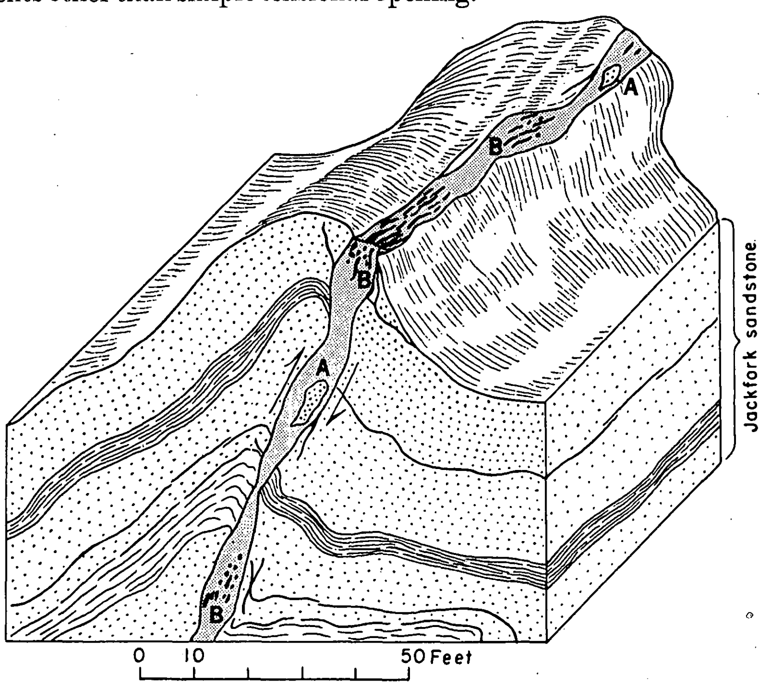


FIGURE 20.—Diagrammatic block sketch showing the features of a deformed vein localized along a thrust fault near Angling Pinnacle, Ark. (pl. 25). *A* indicates a sandstone inclusion appearing in the deformed vein; *B*, quartz crystals, many of which have been broken from crystal pockets and rotated until their *c* axes are alined rudely parallel to each other and to the walls of the vein. Rectorite folia wrap around some of the crystals.

Such evidence merely indicates types of movement or, conversely, of equilibrium of the fracture walls after the inception of the fracture. Even though most openings seem to have resulted through tension, with minor faulting and perhaps some solution phenomena, the initial rupture or discontinuity was not necessarily caused by tension or shear. At this point "one feels the need for the utmost generality of analysis" (Bridgeman, 1938, p. 528). On the basis of his extensive experiments, Bridgeman warns against any "intuitive demands" of our experience.

The ultimate cause of origin of the transverse fractures is likewise unknown although it can be readily presumed "intuitively (?)." These transverse fractures in general are even more uniform in orientation and more sharply defined than the longitudinal fractures. Clean straight walls with little or no associated breccia or gouge are the rule except where replacement or recrystallization of the wall rock into vein material has modified the vein "wall." However, many longitudinal fractures show what seem to be slightly to clearly warped surfaces and mildly diverging patterns with associated "horses" and other wall-rock fragments. There is no doubt that fissuring and pronounced openings are much less common along most transverse fracture sets than along the longitudinal fractures, and other relative offsets of opposing walls, in any direction, seem more uncommon. Inasmuch as vein formation has been dominantly a process of incomplete fissure filling, sets of transverse fractures tend to be barren or only slightly mineralized except in the Chance area, where transverse fissures, probably opened as much as 4 feet, are common.

The fact that transverse fractures cut across all folds, are straight, and are generally tight and unmineralized could imply that they are among the youngest of structural features associated with deformation. Superficially at least, they seem younger than the longitudinal fractures, which are warped and ordinarily mineralized. However, the incipient discontinuity now apparent as a transverse fracture might well be at least as old as the longitudinal fractures. If so, it has remained tight until the final stages of mineralization or later. The absence of warps in the fracture surface could be ascribed to the orientation of the plane of the fracture—parallel with the principal direction of movement during deformation. This orientation might permit continuing movements in the enveloping rocks with little change in the shape of the rupture surface. In support of this concept, Bridgeman (1938, p. 518) has noted that

> if the extension is uniform [of a cylinder parallel to its axis, which may be rudely analogous to folded rocks parallel to *B*] every cross section which was originally plane remains plane after the stretching [elongation]. That is, the deformation can be described from the large-scale point of view by saying that every line of particles which was originally parallel to the axis remains parallel,


CRYSTAL-STUDDED QUARTZITE SLAB TAKEN FROM A FISSURE VEIN ON FISHER MOUNTAIN, MONTGOMERY COUNTY, ARK.

The slab is oriented as it was lodged and encrusted in a nearly vertical fissure. Note that the rhombohedral faces are larger on the lower sides of many crystals, as at *A* and *B*. A few reversals in this crystal asymmetry appear, however, as at *C*. Tiny crystal encrustations occur on the uppermost prism face or faces of many of the larger crystals. The ruler is about 7 inches long.


QUARTZ VEINS (*A*, *B*, *C*, AND *D*) IN STANLEY SHALE (*S*), WESTERN ARKANSAS.

The veins are composed largely of coarse, milky, anhedral grains. Partly clear crystals in vugs or pockets occur locally, however, along the larger veins. The contact of vein and wall rock is exceptionally sharp except to the left of and below *D*. Very little disturbance of the shale (incipient slate) is apparent at this locality. Relations of the type shown are interpreted as largely favorable to the concept that the quartz filled open fissures in the rock. The vein-filled fractures strike slightly north of east; bedding and slaty cleavage are essentially parallel and dip gently to the north. The locality is the Diamond Drill Carbon Co. No. 3 cut (see table 10).

but extended uniformly, and every line of particles originally perpendicular to the axis remains perpendicular, but uniformly contracted. Lines of atoms thus remain lines of atoms, but their centers change in distance apart.

Bridgeman goes on, however, to describe the development of ruptures in experimentally deformed materials in another way that is perhaps even more analogous to the natural processes causing some transverse and longitudinal joints. The breaks were produced experimentally by Griggs (1936), who was investigating the compressive strength of limestone as affected by hydrostatic pressures that acted over the entire surface of the body and were superposed on the compressive load. Griggs found that if the experiments were halted by release of compressive load and then release of pressure before the occurrence of compressive rupture, but after appreciable solid flow had taken place, the specimen was ruptured into disks along planes perpendicular to the original direction of compression.

Bridgeman (1938, p. 527) concluded that

during release of compressive load and hydrostatic pressure there is an extension of the body reckoned from the configuration which it had reached by plastic flow under the maximum load. This extension is greatest, of course, in the direction of the axis of compression. As long as the pressure is high, this extension takes place stably, because the atoms are still in sufficiently close contact in all directions. But when the pressure is reduced far enough, the corresponding extension can no longer take place stably and the body ruptures across the planes on which the extension is greatest.

Analogies to nature are obvious in assuming either (1) the axial direction of the folded structures as parallel with the axis of the deformed cylinder or (2) the axial direction of the cylinder as representative of the *A* direction (rock transport) in the conventional coordinate system of structural petrology. The assumption that the cylinder axis is in effect the fold axis provides a possible explanation for the origin of the transverse joints. But the direction of fold axes *B*, in the Ouachita Mountains, is a direction of relatively little yielding, if not in effect an axis of compression. On this assumption the origin of the longitudinal joints may be explained.

In the Crystal Mountains the fractures and sheeted zones that diverge as much as 40° in strike from the strike of fold axes are in the northeast-southwest quadrants and cut across folds whose trend is about east. Ordinarily, a complementary set of diagonal fractures does not appear in the northwest-southeast quadrants. The diagonal fractures appear in sets several inches to tens of feet apart. Some are straight and uniform, with little brecciation of the associated slates of the wall rocks, but others, as on Fisher Mountain (pl. 40), are zones of slightly diverging fractures with many associated lenticles and slabs of wall rock. Relative spreading movements of the opposite walls of these fractures seem to have occurred where some veins about 3 feet wide have matching walls. The absence of cross-cutting key beds and the lack of other means of checking the amount and direction of offset complicate the task of analyzing the history of these fractures.

The orientation of the diagonal fractures and their interrelations with other structural features seemingly could be explained equally well by either of two hypotheses: (1) a genetic hypothesis of shear or (2) one involving extension and subsequent tension. The fractures may have been opened by shearing movements not intimately related to their origin.

## QUARTZ DEPOSITS

### FORM, SIZE, AND DISTRIBUTION

The quartz crystal deposits include single veins, systems or groups of veins, sheeted zones, stockworks, and various combinations of these types. Simple quartz-filled fissures in sandstones and cherts merge in many places into fracture systems containing much broken country rock. Some of these fracture systems in turn widen or merge into sheeted zones of closely spaced, nearly parallel fractures that are locally complicated by cross joints or brecciation. Most deposits enclosed in slates and shales are relatively simple veins or subparallel or alined groups of veins.

Single veins usually are characterized by abrupt bulges and equally abrupt thinnings or terminations. A veinlet of quartz only a fraction of an inch or several inches wide may swell into an irregularly rounded or lenslike pocket or vein mass 1 to 4 feet wide within a few feet along the strike or down dip (pls. 30 and 34). Slabby and irregularly shaped wall-rock inclusions are widespread in a few veins and present locally in others (pl. 29; see also fig. 21 and pls. 31 and 40). Single veins in shales range from 10 to 500 feet in length, 40 to 100 feet being most common. Their depth is in most instances equal to, and rarely as much as three times, their strike length where these dimensions can be checked. Veins range in width from paper-thin stringers to 30 feet.

The forms of veins vary greatly in the argillaceous rocks, but certain general types can be recognized. In the Stanley shale of the Paron area (pls. 30 and 31) many simple podlike or lens-shaped bodies of massive milky quartz commonly are 4 to 6 feet wide (pl. 31) and rarely attain widths of 18 to 20 feet (pl. 41). Strike lengths average 40 to 50 feet; characteristically these veins lens out abruptly. In the Jessieville area the veins are more uniform but somewhat narrower in both the Stanley and Womble shales than in these units near Paron;

tabular veins 1 to 3 feet wide and 50 to 100 feet long are common. Both pod-shaped and tabular veins, with a few commonly small crystal-bearing cavities, occur as far west as Mena, in Polk County. Veins to the west of Mena rarely produce salable crystals.

In sandstones a strike length of more than 100 feet is unusual for single veins; 30 to 50 feet is about average. Single veins in groups up to 200 feet apart have been worked in the Chance area (Brown, Dierks No. 3, Jackson-Masoner prospects).

Groups of veins composed of single veins in subparallel, intersecting fractures predominate throughout the district. The groups are characterized by slightly diverging fractures, which break the country rock into a series of lenticular or irregular slabs and ribbons. In general, fracture groups in the argillaceous rocks are characterized by a greater length-to-width ratio of quartz filling than those in sandstones. The individual veins in argillaceous rocks range in width from a knife edge to 20 feet, and vein groups attain widths as great as 75 feet. Fragments of argillaceous country rock usually compose less than half the volume of the fractured zone. Many ribbons of wall rock are less than half an inch wide, though in the larger veins the lenses of country rock vary in thickness up to several feet.

Vein groups with strike lengths from 30 to 200 feet are common in the sandstones, and a few scattered groups persist for 800 feet (Fisher Mountain). Widths of several inches to 6 feet are common, with the thickness of quartz filling ranging from a fraction of an inch to 3 feet. However, groups as much as 20 feet wide, composed of different proportions of sandstone or quartzite country rock and quartz, occur locally (fig. 21).

Groups of veins enclosed in all types of rocks found in the district commonly occur in subparallel or alined systems, either with single veins or with other vein groups. Various transitions between single veins and groups also exist in many places in the crystal district.

Parts of numerous quartz deposits in the Crystal Mountain sandstone are in sheeted zones. The sheeted fissures, a few inches to 2 feet apart, segment the country rock into flat slabs, lenses, and wedge-shaped fragments. Most fissures are thinly coated with quartz or "healed" by veinlets less than 6 inches wide, which are "frozen" to both walls. Locally, however, the vein quartz exceeds in volume the partitioning sheets and slabs of quartzitic wall rock (pls. 30 and 34). At places on Fisher Mountain the sheeted zone is cut by parallel transverse fractures, striking N. 25°–35° E., which dip steeply to the northwest and are spaced several inches to 18 inches apart. Where the resulting fracture system has been ideally developed (fig. 21 and pls. 29 and 40), the country rock is broken into rhombic blocks.

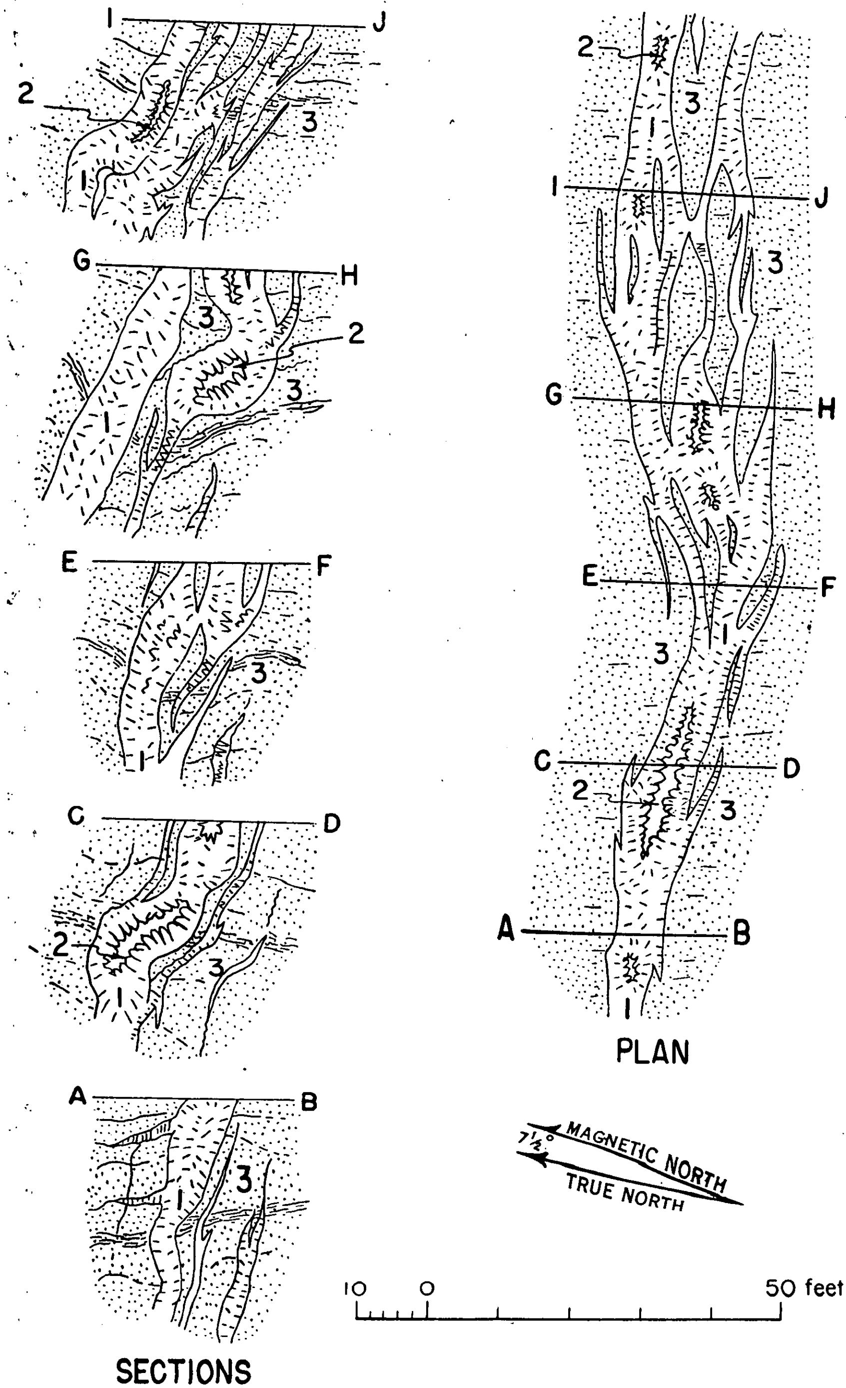


FIGURE 21.—Plan and sections of the quartz crystal-bearing vein zone at the Dierks No. 4 mine (Blocker lead), western Arkansas. 1, Massive, milky vein quartz; 2, comb or sack crystal pocket in quartz vein; 3, deeply weathered argillaceous Blakely sandstone.

Fracture systems in the quartzitic sandstones at Fisher Mountain, Collier Creek, the McEarl mine, and the Diamond Drill Carbon Co. No. 5 (pl. 40 and fig. 22) and other localities are further complicated by shears and fractures oriented at random. As a result, crystal-bearing stockworks are formed by veinlets and irregular masses of quartz that fill cavities and cement irregularly fractured country rock that occurs in conjunction with both the transverse and longitudinal veins. Consequently, the gross structure of the stockworks may trend either parallel with, or across, the strike of the regional structure.

Variations in the form and size of most veins are commonly abrupt and can be predicted to a limited degree. Most veins show abrupt variations in form and size within a single general-type wall rock, as well as in passing from one type of wall rock to another, and many veins show abrupt terminations at rock contacts.

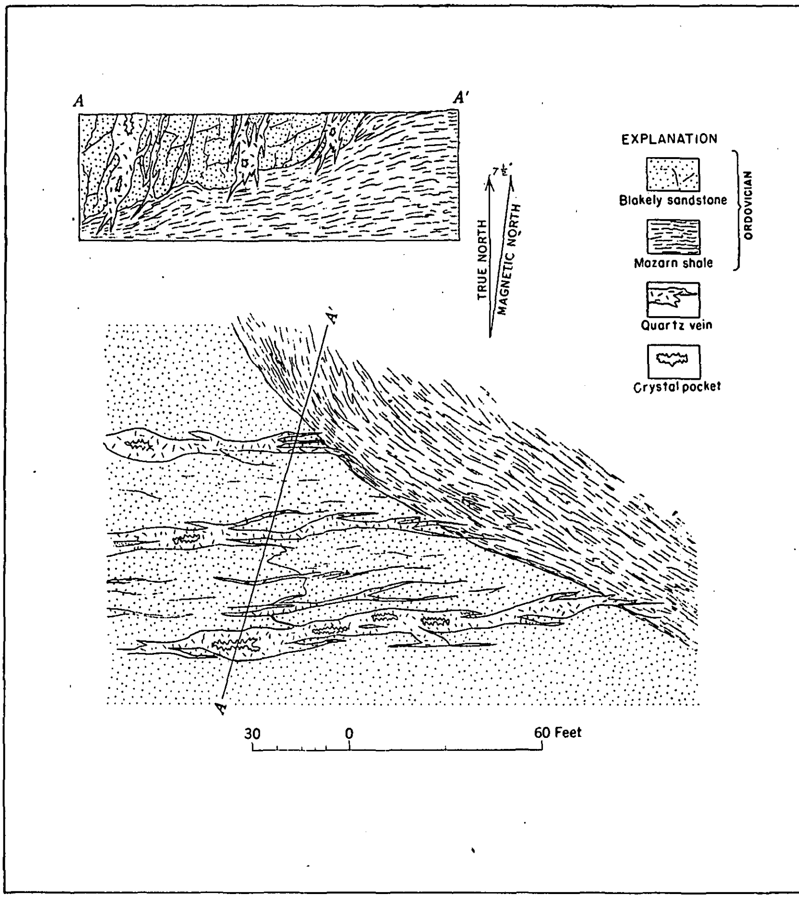


FIGURE 22.—Plan and section of quartz veins at the Diamond Drill Carbon Co. No. 5 mine, western Arkansas, showing the tendency of the veins to terminate abruptly in both lateral and vertical directions at shale contacts.

As a general rule, veins cutting the massive quartzose beds of the Crystal Mountain and Blakely sandstones either terminate abruptly or branch into thin discontinuous veinlets at contacts with argillaceous units. Of hundreds of veins examined in this study and prospected, only a few remain productive in both types of wall rock. Large crystal-bearing veins in sandstones that are barren, thinned, or terminated at or only a few feet beyond the contact of a quartzose bed appear throughout the Blakely sandstone in the Chance area, in the Crystal Mountain sandstone in the Crystal Mountains, and—to a more limited extent, perhaps—in the Blakely sandstone on and near Miller Mountain. Plate 34 shows veins confined to quartzose layers of the Crystal Mountain sandstone. The Diamond Drill Carbon No. 5 cut, west of Chance (pl. 35 and fig. 22), is another striking example, on a much larger scale. At this locality the veins were carefully followed laterally and downward in the argillaceous facies of the Blakely sandstone. In the sandstone, veins are as much as 12 feet wide and contain numerous crystals. At and just beyond the contact of the sandstone with the underlying Mazarn shale, the veins divide abruptly into thin irregular veinlets devoid of crystals. These veins are discontinuous and die out downward and laterally in the shale at distances of 5 to 15 feet from the sandstone contact.

There are, of course, many veins in shales and slates and some veins that crosscut alternating beds of sandstone and sandy shale or of shale and limestone. In general, veins become thin when passing from sandstone to sandy shale. Veins passing from shale to limestone may widen, but the volume of silica decreases at the expense of recrystallized calcite. Few of these veins produce valuable crystals in quantity.

Many thick veins in shales are known, but most of these occur at considerable distances from major sandstone beds.

Abrupt variations of veins in relatively uniform wall rock appear to be due to various causes. Few of these variations are predictable. Vein swellings appear at some intersections of sets of fractures, at highly brecciated or broken places along the major fracture that the vein tends to follow, at places where the vein stuff consists of reconverted or replaced wall rock, and at numerous places where the exact reasons for the swelling or, conversely, for a thinning cannot be explained by the present author.

Vein swellings at intersections of fractures, which are commonly slightly elongated parallel with the intersection, appear locally in the Crystal Mountain and the Jackfork sandstones and rarely in other sandstones. Most of these swellings are found where sets of longitudinal and transverse fractures intersect or where longitudinal fractures (faults?) are cut by gash veins that strike parallel with the longitudinal fracture and cross it along sinuously curved surfaces.

These elongate bulges, somewhat pod-shaped, have their longest axis near the horizontal, in contrast to those developed with their longest axis vertical along the vertical or steeply plunging intersections of sets of longitudinal and transverse fractures. Although the general orientation of these forms may be predicted in any given area, their distribution along the vein cannot be predicted with any assurance. Furthermore, these bulges are neither abundant nor are they the source of appreciable quantities of crystals.

Podlike swellings of much greater importance appear along the large veins in the West Chance area. These vein swellings are elongate in or near the horizontal, generally at slight or marked bends or "rolls" in the vein. The longest dimension of the pod and roll is nearly parallel with the gentle plunge of the immediately associated fold axis. Probably the best and most valuable pod of this type is at the Dierks No. 4 mine (Blocker lead). This large pod (now entirely mined out), about 8 by 15 by 75 feet, has produced thousands of crystals. The longest axis of this crystal-bearing pod was slightly sinuous but nearly parallel with the gentle westward plunge of the major and minor anticlinal axes in this area. These relationships are shown in plate 35 and in figure 21. Unfortunately, this vein and several others showing pods and rolls have not been explored enough to determine whether other features of this type occur in similar orientation, mutually parallel and accordant with the axis of the associated fold.

Perhaps other characteristic bulges or thinnings would become apparent in a pattern correlative with associated structural or lithologic features if more veins were carefully and extensively explored in all dimensions. The bulges so common along veins formed by reconversion of wall rock (pls. 34*A* and 34*B*) and by replacement are most unpredictable. No significant progress was made in attempts to predict the occurrence or form of these bulges, which generally contain valuable crystals.

## CLASSIFICATION OF OSCILLATOR-GRADE QUARTZ

More than 80 percent of the oscillator quartz crystals mined in Arkansas in 1943 was graded and priced according to the requirements of the National Bureau of Standards, given on pages 176–177. A statistical analysis of this quartz is given in tables 1 to 7. Quartz for oscillator plates must be essentially free from most imperfections, including twinning; hence, grades 1 and 2 are used chiefly. Grade 3 quartz has not yet proved economically useful.

## CRYSTAL FORMS

Quartz crystals representative of the district are chiefly in the hands of dealers. Those listed have particularly interesting displays.

Bauer, J. A., 435 Whittington Ave., Hot Springs, Ark. Crystals from Miller Mountain and scattered localities; clusters, principally from Fisher Mountain.

Blocker, John, Box 34, Cedar Glades, Ark., on the road west of Jessieville. Crystals from the Dierks No. 4 mine (Blocker lead).

Davis, J. L., 303 Ward Ave., Hot Springs, Ark. Clusters and crystals from different localities.

Lewis, John, Jr., Crystal Springs, Ark. Crystals and clusters from Fisher Mountain and many other localities.

Milholen, Garland, Crystal Springs, Ark., on U. S. Highway 270, about 2 miles west of Crystal Springs. Crystals and clusters from many localities.

Wiles, Oliver, Box 45, Crystal Springs Route, Hot Springs, Ark. Crystals and Clusters from Fisher Mountain, the Chance area, and other localities.

The crystal forms are relatively simple and uniform throughout the district. All six faces of the unit prism *m* (10$\bar{1}$0) are invariably present. The prisms are singly terminated by the positive rhombohedron *r* (10$\bar{1}$1) and the negative rhombohedron *z* (01$\bar{1}$1). Additional forms include the right (11$\bar{2}$1) or left (2$\bar{1}\bar{1}$1) trigonal pyramids *s*; less commonly the right (51$\bar{6}$1) or the left (6$\bar{1}\bar{5}$1) positive trapezohedrons *x*; and a steeper rhombohedron (30$\bar{3}$1 ?) *M*. (See fig. 23.)

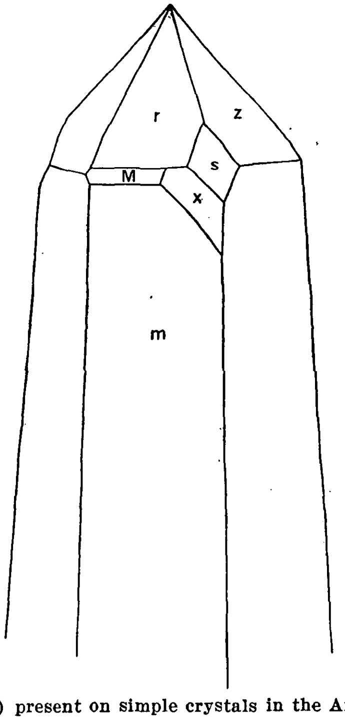


FIGURE 23.—Faces (forms) present on simple crystals in the Arkansas district. *m*, Prism (invariably all six prism faces are present); *r* and *z*, positive and negative rhombohedrons, respectively (invariably present); *s*, trigonal pyramid (locally common but absent on many crystals); *x*, trapezohedron (locally common); *M*, higher rhombohedron (rare to locally common).

### SIMPLE CRYSTALS

The term "simple" as used in this paper refers to crystals that have remained in the same position during their entire growth. In contrast, "complex" crystals show evidence of a more complicated development involving breakage and movement during growth.

Almost all simpler crystals are elongate parallel with the *c* (*Z*) axis. The maximum elongation or ratio of length (measured from base to apex) to width (measured between opposed prism faces) of crystals over 10 grams in weight is about 6 to 1. The more elongate crystals usually taper from the base toward the terminal rhombohedrons and, because of their shape, are called "candles." This type is especially abundant in the Crystal Mountains and at Miller Mountain. The maximum elongation of crystals under 10 grams may be as much as 10 to 1, with relatively slight tapers. These crystals, some of them needles, are most prevalent in the Crystal Mountains, particularly at the Collier Creek mine, where they occur in clusters aptly described by some miners and dealers as "pincushion quartz."

Distorted unit prisms having three alternate *m* faces greatly enlarged at the expense of the adjacent *m* faces are locally abundant, but in no observed crystals are the repressed faces omitted.

On many Arkansas crystals transverse striae on prism faces (Dana, 1932, p. 198) due to oscillatory combinations of prism and rhomb faces may be complicated by vicinal faces (Kalb, 1933, pp. 439–452) and on a few crystals striae cannot be detected readily. In most crystals the transverse striae are shallow, but they may be inset as much as a quarter of an inch.

Tabular simple crystals, composed of a series of crystals in parallel growth, or orientational-type twins, are found in some deposits. At the Willis mine and other deposits, especially in shales, the *c* axes of the tabular crystals may be parallel with, rather than normal to, the walls of the pocket.

The six terminating rhombohedral faces *r* and *z* are variously developed in crystals from Arkansas. Most simple crystals are singly terminated, being attached at the base. Doubly terminated simple crystals are chiefly the result of various types of seeded growth on other crystals and rarely of replacement or displacement of rock materials by growing crystals.

The symmetrical development of the rhombohedrons *r* and *z* is rare, possibly because movements of solutions result in unsymmetrical growth and greater development of rhombohedral faces on the stoss side of the crystal (pl. 29 and fig. 24). Crystals that appear to be terminated by equally developed *r* and *z* faces are usually penetration twins or other compound forms.

The trigonal pyramids *s*—right (1121) and left $(2\bar{1}\bar{1}\bar{1})$—as shown in figure 23, are present on at least one-fourth of the crystals examined from several localities within the district, but elsewhere they are rare or absent. At the John Brown prospect, fully half the crystal forms are modified, either by the right or left trigonal pyramid or by both. Crystals having both left- and right-handed forms are twinned. In the deposits examined, the right- and left-handed forms are about equal in number and are of average size. Rarely, all three pyramid faces are developed on one crystal; a smoky twinned form, modified by three right and two left *s* faces, was found at the John Brown prospect. Where there is a marked disparity in the size of the rhombohedrons *r* and *z*, the *s* face is almost invariably associated with the larger rhombohedrons. On wedge- or chisel-shaped crystals, the length of the face measured parallel with adjacent edges of *r* and *m* faces may be as much as 16 times the width. In some specimens one or more pyramid faces may have four sides of almost equal dimensions, so that all transitions in the shapes of *s* faces, from diamond- to square-shaped forms, occur. In rare instances the *s* face may exceed all but the largest rhombohedral (*r* or *z*) face in size. These pyramidal forms are called "diamond faces" by the miners and dealers.

The left positive trapezohedron $(6\bar{1}\bar{5}\bar{1})$ and the right positive trapezohedron $(5\bar{1}\bar{6}\bar{1})$ are rarely found except at a few localities, notably the John Brown prospect, where *x* is present on 3 percent of the counted crystals, and at Miller Mountain, where it occurs on 0.5 percent. The *x* face is usually accompanied by the corresponding trigonal pyramid (*s*). One twinned crystal of smoky quartz from the John Brown prospect has both right and left trigonal pyramids and right and left positive trapezohedrons *x*. The *x* faces commonly show etch or unequal growth pits even though the other faces show no evidence of these features.

The form *x* is invariably bordered (between *x* and *m*) by a narrow zone of weak reflection (?) which may be striated parallel with *r*/*m*.

On many crystals there are rhombohedral forms steeper than the primary rhombohedrons *r* and *z*. These have not been recognized heretofore in Arkansas, possibly because of the nature of their occurrence and their small size. Many crystals in the district taper abruptly by oscillatory combinations of the prism *m* with a steep rhomb ($30\bar{3}1$ ?). The higher rhombohedron ordinarily is difficult to detect because of the fineness of most oscillatory striae. Another form that also appears to be $30\bar{3}1$ is associated with the trapezohedron *x* (fig. 23), but clearly discernible forms of this type are rare; they are found most often in the deposits near Chance and at Miller Mountain and Crystal Bluff (pl. 25 and table 10).

### COMPLEX CRYSTALS

Although the shape and habit of the simple crystals are usually severe, recurrent breakage and regrowth have resulted in variously shaped and composite complex crystals. The portions formed subsequent to breakage are characterized by widespread optical twinning and lineage structures (Buerger, 1934) and are bounded by aggregations of the simple crystal faces. Miser (1943, p. 99) remarked:

> Many stages in the further growth of fractured crystals may be noted. These range from fractured surfaces in which little quartz has been added, to surfaces that are nearly or completely obliterated by further growth. The new growth on such surfaces has the same crystallographic orientation as that of the original crystal. Some have been bent into curved shapes through fracturing and subsequent healing of the fractures by new quartz. Crystals displaying all the features just enumerated have been observed at many localities in western Arkansas.

Most breakage during the growth of candle crystals evidently occurred in that part of the crystal which at the time of deformation contained the most imperfections. Because this part was usually at the base of the crystal, the initial elongate shapes of many crystals were retained after breakage. Commonly the break occurs parallel to *r* or less often *z*, or along irregular surfaces at small angles to the basal plane. Under relatively slight deformation these crystals show little other alteration of their external form, although internal imperfections such as tiny cracks or veils are introduced or exaggerated. With subsequent growth the broken crystals tend to develop a second termination, and most of the doubly terminated crystals in the Arkansas district probably originated in this fashion (fig. 27). The new faces developed on breaks tend to be the common forms whose planes are nearest that of the break. When a crystal fractures along a plane parallel with *r* or *z*, the new termination consists of the most concordant rhombohedral face, greatly developed, and five incipient ones. Ten to twenty-five percent of the simple crystals in many deposits cleave most readily parallel with a rhombohedral face, and consequently complex forms having abnormal rhombohedral faces are particularly common. With continued additions of silica, the incipient rhomb faces enlarge, and the initially large face diminishes in relative size. These terminations are opposite the tapered end of the crystal and may thus be distinguished from primary terminations distorted by growth in solution currents. They are further characterized by an abnormal development of vicinal faces. Where the original break is very irregular, secondary growth is especially likely to be established at numerous independent centers of nucleation which enlarge into lineage groups bounded by aggregates of appropriate faces. This process produces prisms terminated at one end by the original six rhombohedral faces and at the other end by a multitude of rhombohedral forms.

Breakage during the growth of the more equidimensional simple crystals commonly results in the more diverse shapes of the complex crystals. In addition to the rhombohedral cleaving and to the numerous irregular fractures at relatively small angles to the basal plane, many compound breaks may diverge at small angles from *m*. Where the original width of the simple crystal almost equals its length, resulting fragments are commonly elongate parallel with the break; upon regrowth each fragment tends to develop complete bounding surfaces. Many breaks are highly irregular, and because the addition of silica invariably occurs at numerous independent points of growth, crystal lineages and aggregates of faces are formed. Another factor of significance in the growth of aggregate forms may be breakage accompanied by granulation, or intermixing of splintered quartz crystals and heterogeneous vein matter and wall rock, so that the slabs and chips of crystals are enveloped in a porous aggregate of crystal shards, sand, and clay. The smaller quartz fragments tend to recrystallize as an integral part of the broken crystal, locally enlarging it, whereas the clay or other foreign matter tends to impede crystal growth.

## TWINNING

Optical twinning (Brazil twinning, chiral type) is present in various amounts and areas in quartz from all the localities given in table 10, and electrical twinning (Dauphiné twinning, orientational type) is locally abundant although seemingly less common at many deposits. The Japanese twin (twinning plane $11\bar{2}2$) is extremely rare. Of the four specimens from the district that show twinning of the Japanese type, three are known definitely to have come from Fisher Mountain and the fourth may have come from the same locality.

The proportions of eye-clear quartz more than 60-percent optically twinned, as compared with eye-clear quartz less than 60-percent optically twinned, are given in table 8. They are from the larger producing mines or areas. This compilation, studied in conjunction with details of tables 1 to 7, inclusive, and with other data given, suggests the following possible relationships:

Apparently the ratio of highly twinned to less twinned quartz varies widely between localities in dissimilar country rocks but is fairly constant within a single deposit or group of closely related deposits in comparable host rocks. For example, three deposits which fall within an area of 3 square miles produce 142 of the crystals reported from "veins in Womble shale northeast of Jessieville."

TABLE 8.—*Comparison of eye-clear Arkansas quartz 60-percent optically twinned with that less than 60-percent optically twinned*

| Locality in which found | Percentage, by weight, more than 60-percent optically twinned | Host rock | Percentage, by weight, less than 60-percent optically twinned | Specimens examined | |
|---|---|---|---|---|---|
| | | | | Weight | Number |
| | | | | *Pounds* | |
| Fisher Mountain | 45 | Crystal Mountain sandstone (massive phase). | 55 | 50 | 125 |
| Miller Mountain | 77 | Blakely sandstone (argillaceous phase). | 23 | 225 | 500 |
| McEarl mine | 28 | Blakely sandstone (massive phase). | 72 | 21 | 50 |
| Dierks No. 4 mine (Blocker lead). | 86 | Blakely sandstone (argillaceous phase). | 14 | 1,300 | 800 |
| E. C. Shaw area | 23 | do | 77 | 40 | [1] 100 |
| Veins in Womble shale northeast of Jessieville, Ark. | 85 | Womble shale | 15 | 100 | 150 |

[1] Largely unfaced.

At these deposits the shale environment was approximately similar. Of the eye-clear quartz that was more than 60-percent optically twinned, the percentages in each deposit varied as follows:

| *Deposit* | *Number of crystals examined* | *Percentage, by weight, more than 60-percent optically twinned* |
|---|---|---|
| 1 | 47 | 86 |
| 2 | 36 | 78 |
| 3 | 59 | 91 |

Crystals from deposit 2 were slightly larger in average size than those from deposits 1 and 3. The lack of large quantities of crystals obviously qualifies the interpretation, but the suggestion is that there are larger percentages of highly twinned quartz (using 60 percent as a break) in these deposits than in all but one deposit in sandstone (Dierks No. 4 mine). A greater disparity in percentages of twinning in specimens is apparent where deposits in purer massive sandstones are contrasted with those in the Womble shale. This contrast is aided by use of a breakdown of figures on optical twinning in crystals from open-cuts FC 1, FC 2, and FC 4 on Fisher Mountain (pl. 39), where the host rock is massive, moderately clean Crystal Mountain sandstone.

| *Open-cut* | *Number of crystals examined* | *Percentage, by weight, more than 60-percent optically twinned* |
|---|---|---|
| FC 1 | 18 | 51 |
| FC 2 | 23 | 39 |
| FC 4 | 45 | 45 |

These three cuts are separated by a minimum distance of about 200 feet (pl. 39). The general degree of twinning seems to be roughly the same in crystals from all the cuts and much lower than that recorded from the deposits in the Womble shale.

The wall rock in all three cuts is massive Crystal Mountain sandstone, relatively free of argillaceous material. The only other deposit in similar wall rock from which significant data could be obtained is the McEarl mine. There intensive twinning seems to be even less common, although only 50 crystals, weighing 21 pounds, were studied.

The data from the E. C. Shaw area and the Dierks No. 4 mine are of considerable interest in that these deposits are very close together (pl. 35) and both in the Blakely sandstone, yet they suggest, superficially at least, a pronounced exception to the trend here implied. Actually, however, all the specimens from the Dierks No. 4 mine were crystals found essentially in place in veins in a highly argillaceous facies near the base of the Blakely sandstone (pl. 32). Most of the specimens obtained from the E. C. Shaw area were unfaced colluvial quartz fragments found in the residual soil. These fragments were almost wholly eye-clear when found and obviously had been subjected to a selective natural cobbing or "beneficiation" by processes of weathering and rock creep. Basal and marginal parts of the original crystals were broken off. In crystals from the Dierks No. 4 mine and from many other localities, much if not most of the optical twinning occurs in the outermost parts, which have largely been removed from the Shaw specimens. In addition, the specimens from the Shaw property probably grew in deposits stratigraphically higher in the Blakely than the deposits at the Dierks No. 4 mine, which would imply a wall-rock environment of more massive pure sandstone, somewhat comparable to that at the McEarl mine.

Quartz from a single locality varies in the complexity of the intergrowths of right- and left-handed modifications, but these differences in complexity are greater in typical specimens from separate localities. The formation of complex crystals due to fracturing and regrowth of simple ones commonly results in an intricate intergrowth of the two modifications, a result which is economically unfavorable because it allows only small amounts of untwinned quartz to be cut from each specimen. The formation of both right- and left-handed modifications is aided by such favorable sites for independent nucleation as the highly irregular surfaces and splintered faces. Alternating fine lamellae of right- and left-handed quartz also composed many of the simple crystals that were tested, particularly those from the deposits in argillaceous facies of the Blakely sandstone on Miller Mountain and near Chance. However, many twinned crystals from deposits examined in the quartzitic sandstones and in shales contained appreciable portions of untwinned quartz sandwiched between twinned portions.

*Electrical (Dauphiné)* twins were recognized by the writer by visual inspection of features of the crystal faces and later verified by etching in hydrofluoric acid. In numerous localities the contrasting sheen of interpenetrating *r* and *z* faces may be related to sutures on *m*, as found on the ideal electrical twins, and in a few instances vicinal faces (Kalb, 1933, pp. 439–453) somewhat similar to Kalb's type 1 are present. These criteria are not widely applicable because (1) identical sutures on *m* may be due to parallel crystal growth, (2) conclusions made from the study of vicinal faces are not always reliable, and (3) the luster of the positive and negative rhombohedral faces may be similar prior to etching. Hydrofluoric acid etch tests on a limited number of quartz sections cut along the *ZY* plane (Cady and Van Dyke, 1942) suggest that, as with optical twinning, the character and extent of electrical twinning may be fairly constant within a single deposit but may vary widely between one locality and another.

In general, those crystals that show abundant Dauphiné twinning tend to have less optical twinning; conversely, crystals riddled with optical twinning have limited Dauphiné twinning. An apparent exception is the crystals from the Dierks No. 4 mine, in which both Dauphiné and optical (Brazil) twinning are very abundant.

Whether specimens such as those from the McEarl mine and the E. C. Shaw area, in which optical twinning is not abundant, show extensive electrical twinning has not been determined.

## COLOR

The smoky color in crystals ranges from an almost imperceptible tint, which usually imparts a faint oily sheen to the crystals, to shades of deep brown or almost black (table 10). Variations in the intensity of the smoky color are apparent within single crystals, usually in zonal growths that grade into colorless or milky quartz near the base of the crystal.

Smoky crystals ordinarily are limited to particular veins in a deposit, but locally they appear in one or more pockets of colorless crystals in a vein filled mostly with such colorless crystals. The colorless crystals associated with the smoky ones can be smoked by exposure to X-ray irradiations, and both the synthetic and naturally smoky crystals can be decolorized by heat. The decolorization is a time-temperature reaction (Holden, 1925). Tests have shown that most of the naturally smoky crystals from Arkansas lose some or all of their color if subjected to temperatures of 215° to 220° C. for 80 to 100 hours. Higher temperatures produce decolorization in much less time, and crystals heated to 375° C. or higher lose their smoky color in less than an hour.

The behavior of these crystals suggests that the smoky color may be attributed to certain imperfections in the crystal lattice, although quantities of some impurity might have been a cause, perhaps in an indirect way (Mott and Gurney, 1940, p. 275). Holden (1925, p. 249) concluded that the smoky color was due to particles of free silicon of atomic dimensions and was induced in the crystals by radiations during crystal growth.

If the smoky quartz is primary, as Holden concluded, the temperature producing decolorization may represent a maximum (225° C. ±) during the growth of the Arkansas crystals, but too little is known of either the precise cause of naturally smoky quartz or the past growth of the Arkansas crystals to justify this hypothesis as more than an alternative. Possibly the smoky color was induced in many favorable crystals as a secondary feature during the cooling of the crystals or at a subsequent period. The most susceptible crystals might have retained the color while others lost it or remained uncolored. Certainly the author's laboratory studies using X-rays indicate that individual crystals respond quite differently to irradiation and that some tend to lose part of the imparted smoky color with the passage of time.

## CAVITIES AND INCLUSIONS

Cavities or vacuoles within crystals and vein quartz vary appreciably in shape and size. The commonest types in the order of their abundance are (1) highly irregular cavities, (2) tubular or needle-shaped cavities, and (3) negative cavities or skeletal crystals.

Irregular to spherical cavities are oriented at random or form numerous patterns in crystals. These cavities range from those barely discernible under the microscope at a magnification of 450 to about 0.002 millimeter—rarely 2 centimeters—in diameter. Groups of these cavities may form curved sheets or veils, or they may be distributed along planes parallel with crystal faces. Some cavities may be alined in elongate groups or chains. Chains of cavities may be subparallel or intersecting, and in some specimens of vein quartz they cross grain boundaries. In other chains the cavities are elongate normal to the trend of the chain. Many cavities have sharp, well-defined walls; others are bordered by serrate edges or by zones of frothy quartz. Some cavities contain liquid inclusions and tiny gas bubbles that move about in the liquid as the crystal is turned. In other cavities solid particles are immersed in liquids or gases. Rarely, all three phases—gas, liquid, and solid—are present in a single cavity.

Tubular or needle-shaped cavities in quartz crystals and quartz grains range in size from those with microscopic dimensions to tubes 4 inches long and one-sixteenth inch in diameter. Many are nearly parallel with rhombohedral planes in the crystals, forming V-shaped or inverted "pine tree" patterns. Others are distributed in random or variously radiating patterns. In some crystals, rod-shaped or T-shaped tubular cavities form chains that resemble a single broken


QUARTZ VEIN IN THE STANLEY SHALE EXPOSED ALONG ARKANSAS HIGHWAY 9.

This vein is about 45 miles east of those shown in plate 30. Note the irregular and disturbed wall contacts between wall rock and vein, the inclusion at *A*, and the branch veins *B* and *C*, which were not present in plate 30. Along this vein, zones of silica as much as one-half inch or, rarely, several inches wide contain ghost structures of slaty cleavage and bedding as well as appreciable quantities of chlorite, sericite, and carbonaceous matter. These features are interpreted as evidence of minor replacement of wall rock by silica. Unequivocal evidence of fissuring in the shale is also apparent at the outcrop, however, in the offsets of distinctive beds and laminae on either side of the principal and branch veins.

PILE OF SOME OF THE LARGER CRYSTALS TAKEN FROM THE DIERKS NO. 4 MINE (BLOCKER LEAD), WESTERN ARKANSAS.

Most crystals of this size are veiled or milky, although others contain quartz of oscillator quality in their terminal parts. The hammer handle is about 1 foot long.

tube. Tubular cavities were found in crystals from several widely scattered deposits, and at Fisher Mountain they constitute one of the major defects in the crystals.

Negative crystal cavities, outlined by well-defined crystal faces, are abundant locally in crystals and vein quartz. Gradations in form seem to exist, however, between "euhedral" negative crystals and irregular cavities. Examples of negative crystals and closely related cavities whose form has been controlled by crystallographic planes are especially numerous at the F. Barber, O. Wiles, and Pigeon Roost Mountain prospects (table 10). Most of the quartz at these localities contains cavities, and many crystals are "honeycombed" by irregularly flattened cavities roughly parallel with crystal faces. Internally, these honeycombed crystals resemble skeleton forms. The enclosed cavities may be microscopic in size or as much as 3 inches in their greatest dimension, and in their outer zones some have slotlike openings on crystal faces. Tongues of quartz, generally coinciding with hexagonal crystallographic planes, form partial septa or ribs in many cavities, and some of the cavities are irregularly connected. Clay is only rarely enclosed in the crystals, though at many places it lines cavities that open on crystal faces. Most closed cavities contain liquid and gas inclusions. Some crystal intergrowths from the F. Barber prospect contained flattened gas bubbles of thumb-nail size which moved more than an inch through liquid inclusions about six to ten times the volume of the bubbles. When these crystals were subjected to successively lower temperatures the cavities burst at slightly below 0° C., suggesting that the enclosed liquid was principally water.

Most cavities probably were formed contemporaneously with the deposition of the quartz surrounding them, but some of the smaller tubular cavities may have resulted from exsolution and many chains of cavities, tubular cavities, and negative crystals may have been formed by solution (Judd, 1886, p. 82). Chains of cavities crossing grain boundaries without offset probably were formed after the enveloping quartz (Ferguson and Gannett, 1932, pp. 41–44). The crystals containing cavities that are filled or partly filled with liquid (called "water crystals" in the district) are clearly examples of skeletal crystal growth (Bain, 1925; Sosman, 1927, pp. 513–514). Pitted surfaces similar to those produced by etching quartz appear on some of the "water crystals" within the cavities and on various crystal faces. These pits seem to have evolved during the growth of the crystal and represent gaps in the lattice where quartz was not deposited.

In the comparatively clear crystals, the cavities with fluid inclusions that probably developed during crystal growth offer a possible means of measuring the temperatures that prevailed in the veins during their

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formation. Almost a century ago, Sorby (1858, pp. 453–500) noted that cavities of this type, if heated to the point where the trapped liquid once again just filled the cavity—that is, to the point where the associated bubble disappeared—would presumably yield results from which could be calculated the prevailing temperature during crystal growth.

Data for these calculations require either knowledge or assumption of the depth to which the deposits were buried during mineralization. Other assumptions must be made, specifically (1) that the cavity has not changed volume owing to deposition of materials from the trapped fluids, recrystallization of the crystal, or other causes and (2) that there has been no loss from, or addition to, the contents of the cavity. Arkansas crystals containing inclusions were heated on a thermal stage under the microscope. The temperatures at which the bubbles in the cavities disappeared are recorded in table 9.

TABLE 9.—*Results of independent heating of six cavities in three Arkansas quartz crystals*

[Temperature values corrected for lithostatic load of 1 mile]

| Source of crystal | Crystal length | Crystal thickness | Temperature at which bubble disappeared (° C.) | |
|---|---|---|---|---|
| | | | Cavity 1 | Cavity 2 |
| | *Inches* | *Inches* | | |
| Fisher Mountain | 2 | ½ | 130–155 | 160–175 |
| Miller Mountain | 1¾ | ½ | 125–160 | 145–165 |
| Dierks No. 4 mine | 10 | 3 | 120–155 | 160–175 |

Although the results seem to agree fairly well and are in accord with temperatures commonly assumed for deposits of this general type, much careful study seems necessary before the accuracy of such measurements can be established. Limitations of time and apparatus prevented readings on many cavities in large crystals to determine, for example, if cavities along or near one crystallographic growth line gave about equivalent temperatures (one way to check the validity of the technique) or if readings on cavities from the core to the margin of the crystal indicated appreciable orderly changes or fluctuations in temperature. Other possibilities suggest themselves, especially a study of cavities in crystals from widely separated deposits to ascertain if some zonal temperature pattern evolved for the district.

Solid inclusions in crystals and grains consist chiefly of carbonaceous material, sand, clayey aggregates, and associated vein minerals (table 10). Solid inclusions show distribution patterns similar to those of cavities and usually are associated with them. Many inclusions are alined in crystallographic directions and seem to be contemporaneous with the enclosing quartz; others localized along veins and flaws were probably introduced by solutions subsequent to the deposition of the quartz.

Black carbonaceous flakes and fuzzy aggregates are the most widely distributed type of inclusion (table 10), and where abundant they may impart a dark-blue or smoky cast to the quartz. In quartz crystals they commonly form phantoms, but they may be localized along breaks or other defects. Most of these particles are 0.001 to 0.5 millimeter across, but clots several millimeters across have been found.

Aggregates of clay, silt, and sand are especially numerous in crystals at the Cruse Anderson and J. W. Ellison prospects (pl. 43) and at the McEarl mine and Diamond Drill Carbon Co. No. 4 mine (pls. 27 and 35; table 10). The more siliceous aggregates may be in part oriented with and joined to the enveloping crystal. Microscopic study of the specimens shows that the foreign materials tend to be localized near grain boundaries or clotted in irregular zones of frothy quartz.

In some places "sand crystals" have formed in the loose porous wall rock. These evolve where host-rock grains are enveloped in silica that presumably was introduced by solutions encroaching upon them from nearby fractures. The invading silica tends to crystallize in a common space lattice over areas of several square inches or more, which often are bounded by the ordinary crystal forms of quartz. In effect, the area of cement in crystallographic continuity becomes a crystal enveloping the host-rock sand grains. In some sand crystals the enveloped sand grains are little altered, but in many others the stages appear in the "reorientation" of the grains' lattice into crystallographic continuity with that of the "cement." Presumably the process involves solution and recrystallization of the grain in the orientation of the enveloping silica. Consequently, there are some crystals in which both cement and many enveloped host-rock grains have merged into a single subhedral to euhedral crystal several inches in length and an inch or more in thickness. Where this has occurred the coatings of iron oxide, clay, or carbonaceous matter on the former host-rock grains generally remain in their original position to outline the preexisting sandstone pattern. These ghostlike outlines constitute the principal evidence of the reconversion process in its final stages, a process which seems to have occurred in a nearly stress-free wet environment.

In many crystals that grew in open pockets, subhedral to euhedral quartz grains were common inclusions. They range in diameter from 0.001 to 0.1 millimeter and diverge in optical orientation from the enveloping quartz crystal. Usually present in linear groups or in zones that parallel successive growths of the host crystal, they probably originated as encrustations which were enveloped by successive generations of quartz.

Brookite ($TiO_2$) crystals, in swordlike blades with flattened diamond-shaped cross sections and partly enclosed in quartz crystals, were found at Miller Mountain. The brookite blades are longitudinally striated prisms projecting inward from the surfaces of the quartz crystals at various angles. Amber to brown in color, the crystals range from one sixty-fourth to one-sixteenth inch in thickness, from one-eighth to three-eighths inch in width, and from a fraction of an inch to 1½ inches in length. They transmit light on thin edges. The brookite-bearing quartz crystals were found in only one vein zone on the north side of the mountain. Neither brookite nor other titanium-bearing minerals are known elsewhere in the district. The titanium may have been transported by the solutions that deposited the quartz. If so, one may ask why the brookite seems restricted to only one vein zone on Miller Mountain. The paragenetic relations seem most easily explained by postulating contemporaneous intergrowth of the brookite and quartz. The relations, however, do not necessarily preclude a prequartz or postquartz origin for the brookite. Perhaps the least acceptable of the paragenetic concepts is that postquartz brookite blades have penetrated and replaced the quartz, but abundant brookite that is clearly postquartz in age occurs with other titanium minerals and with quartz unrelated in age or origin to the crystal deposits at Magnet Cove, Ark. (Williams, 1891, pp. 322–324; Ross, 1941, pp. 23–26). The Magnet Cove area is about 25 miles southeast of Miller Mountain.

## FRACTURES AND CLEAVAGES

In Arkansas quartz, fractures are more numerous than cleavages and partings. The fractures are found in the basal portions of all crystals. Some occur singly, although branching short fractures and conchoidal to irregular ones form many compound breaks in the quartz. Where they show uniform over-all trends parallel with crystal faces, compound fractures may resemble cleavages.

Many breaks in the Arkansas quartz are parallel with the structural planes in the crystal lattice that offer the best possibilities for cleavage (Fairbairn, 1939, pp. 359–364). Cleavage parallel with *r* or, less commonly, with *z* prevails. About one-quarter of the crystals in many localities (table 10) have an *r* or *z* cleavage clearly developed, and most crystals can be cleaved readily along the *r* plane.

In highly deformed deposits, distinctive rhombohedral checkmarks that appear in a few crystals and grains are produced largely by intersecting *r* or *z* cleavages usually of microscopic dimensions. Consequently, breaks that appear simple are seen under magnification to consist of numerous smaller breaks, intersecting or grouped in various patterns. The curved corrugations so common on surfaces broken at high angles to *m* also appear due largely to *r* and *z* cleavages. Many breaks that appear parallel with a prism face *m* when magnified seem to be composed of minute alternating *r* and *z* cleavages (Mallard, 1890, p. 62). Although well-defined cleavage parallel with *m* is rarely found in the district, other breaks so oriented are due at least in part to fracturing.

Some twinned crystals, when cobbed with a hammer to eliminate intensely twinned areas, appear to have developed a parting along the twin boundary that is parallel with *r*. The same sort of parting into quartz plates whose boundaries conform to twin contacts has been observed in naturally deformed crystal mats. Presumably, in these crystals, the twin contacts are surfaces of least tensile and shearing strength.

## TEXTURES

A wide range of textures occurs in the deposits. Grouped in the order of their abundance, the chief primary kinds of quartz based on texture are (1) massive, milky, subhedral to granular, coarsely crystalline quartz; (2) anhedral to euhedral, milky comb quartz; and (3) partly clear or milky crystals in vugs or pockets. All gradations in texture may be found in a single quartz vein. Massive, milky euhedral quartz is traceable into tight comb quartz, which in turn opens into vugs or pockets where the space available permitted the incomplete development of crystal faces.

Massive milky quartz, whose grains may be microscopic or at least 3 feet in their largest dimension, predominates in most deposits. Microcrystalline aggregates are extremely rare. The grain size ordinarily is roughly proportional to the width of any single segment of the quartz vein, but there are numerous exceptions.

Comb quartz predominates in most partly filled fissures, in narrow vein fillings, and in narrow segments of compound veins. The widest single vein of comb quartz observed measured about 3 feet. However, quartz cavity fillings more than 12 inches thick commonly contain irregular areas of randomly oriented grains. In most of these wider, unsegmented cavity fillings, the comb quartz constitutes only a small part of the cavity filling. Nearly parallel sheetlike or lens-shaped combs several inches or rarely a foot in width appear in certain compound veins, partly separated by ribbons of shale, carbonaceous quartz, or areas of massive quartz.

The word "pocket" is applied in this report, in accordance with the crystal miners' usage, to all types of vugs and crystal-bearing cavities that result from incomplete or imperfect fissure filling or from solution cavity filling. Comb pockets, lined by opposed crystals oriented approximately normal to the vein walls, are the commonest type of primary pocket (fig. 24).

Most of these pockets are incompletely filled fissures, formed by relative movements of fractured country rock, as described in a preceding section of this paper. A small number of pockets, especially in sandstones and cherts, are interpreted as solution cavities. Numerous others, totaling 10 to 20 percent of the pockets in all sandstones and quartzites, are interpreted as having been formed partly by relative movements of opposing fracture walls and partly by solution and recrystallization processes.

In the comb pockets, many of the simple crystals projecting inward from the walls clearly reveal an asymmetry of form, as shown in figure 24 and plate 29. This asymmetry is most apparent in the abnormal development or enlargement of one (or two or three) rhombohedral faces on one side of the crystal and a marked repression of the rhombohedral faces on the opposite side (these "sides" of the crystals generally are about at right angles to the greatest diameter of the asymmetrical prism). Arkansas crystals thus distorted are not chaotically oriented in the pocket. They project outward, as shown in plate 29 and figure 24, and in a majority of crystals the smaller rhombohedral faces and the "uncentered" apex are on the upper side of the crystal as it appears in the vein. The author studied more than a thousand of these asymmetrical crystals in place in more than 75 veins scattered over an area exceeding 1,000 square miles. In 68 veins, three-fourths or more of the asymmetrical crystals were so oriented that the sides of the enlarged rhombohedral faces were downward, or within 35° of downward. Essentially similar orientations exist in scattered asymmetrical quartz crystals genetically associated with the mercury, antimony, and lead-zinc mineralized areas (Miser, 1943 pp. 114–117; Reed and Wells, 1938) marginal to the quartz crystal district.

The crystal asymmetry also is shown by unequal thicknesses of growth bands or zones that parallel crystallographic forms in the crystals and by unequal diameters of the prisms.

Newhouse (1941, p. 619) concluded that "on these [quartz] crystals the smaller *r* faces and the smaller *z* faces have received the most abundant additions of material, and if the crystal grew in a free, unimpeded current they are on the stoss side."

In a discussion of Newhouse's paper, Bandy (1942) described relations of asymmetrical crystals at Llallagua in Bolivia, which seemingly conflict with the interpretation of Newhouse. In the Llallagua mine and in other Bolivian deposits, the sides of the repressed rhombohedrons, which were usually encrusted with other minerals, are upward in the vein. The opposite, lower sides of the quartz crystals, which exhibit the enlarged rhombohedral faces, seemed to Bandy to represent the stoss, solutionward side—an interpretation certainly more consistent with independent data bearing on the hypogene origin of the Bolivian deposits.

In connection with the geologic features of the Arkansas quartz crystal deposits, the questions raised by Bandy seem quite pertinent. In the comb-crystal pockets in this district, as in Llallagua and other localities in Bolivia, the smaller rhombohedral faces and the partial encrustations ordinarily appear on the upper sides of the crystals in the veins. To interpret these upper sides of the crystals as facing upstream means, of course, to postulate descending mineralizing solutions, both in Arkansas and in Bolivia, but this postulate is out of harmony with other geologic features presented later in this paper.

Actually, there are reasons to doubt whether the asymmetry of crystals is any indication of unequal growth in silica-depositing solutions moving with perceptible current along the fissures. If it is assumed, however, that movements of solutions were a factor in causing crystal distortion, then certain Arkansas quartz crystals may provide answers to some of the questions and explanations for the seeming contradictions raised by the separate studies of Newhouse and Bandy.

Newhouse (1941, p. 619) concluded after experimentation that "crystal growth distortion" develops because "the nutrient material is added more rapidly on the stoss side of the crystal" and, further, that "the faces grow more rapidly on that [stoss] side."

For the isometric crystal forms in Newhouse's experiments, and for such commonly cubic vein minerals as galena, it seems easy to determine on any asymmetric crystal whether the nutrient material has been added more rapidly in specific zones parallel with certain crystal faces and whether these faces grew more rapidly in total area. The problem becomes more complex, however, if quartz is considered. Because of the geometrical relations of the bounding prisms and rhombohedrons of quartz, a greater volume of nutrient material (silica) may be added on one side of the crystal, whereas simultaneously silica is added more rapidly in a restricted area on the opposite side of the crystal. These relationships are illustrated quite clearly by several naturally zoned crystals from an Arkansas vein (fig. 24). The Arkansas crystals are sectioned parallel with and normal to *c* (*Z*).

The fastest growth in these and most other Arkansas crystals occurs essentially along their *c* axes, as indicated by the greater thickness of the growth zones that lie parallel with rhombohedral faces (fig. 24). In these rhombohedral zones, the maximum amount of crystal growth has been in a direction measured normal to the smaller rhombohedral faces. The growth zones paralleling the small rhombohedral faces almost invariably are the thickest zones on the asymmetrical crystals. However, the total quantity of silica deposited parallel to these smaller rhombohedral faces is generally less than that deposited on the large rhombohedral faces on the opposite side, and in some crystals it is much less.

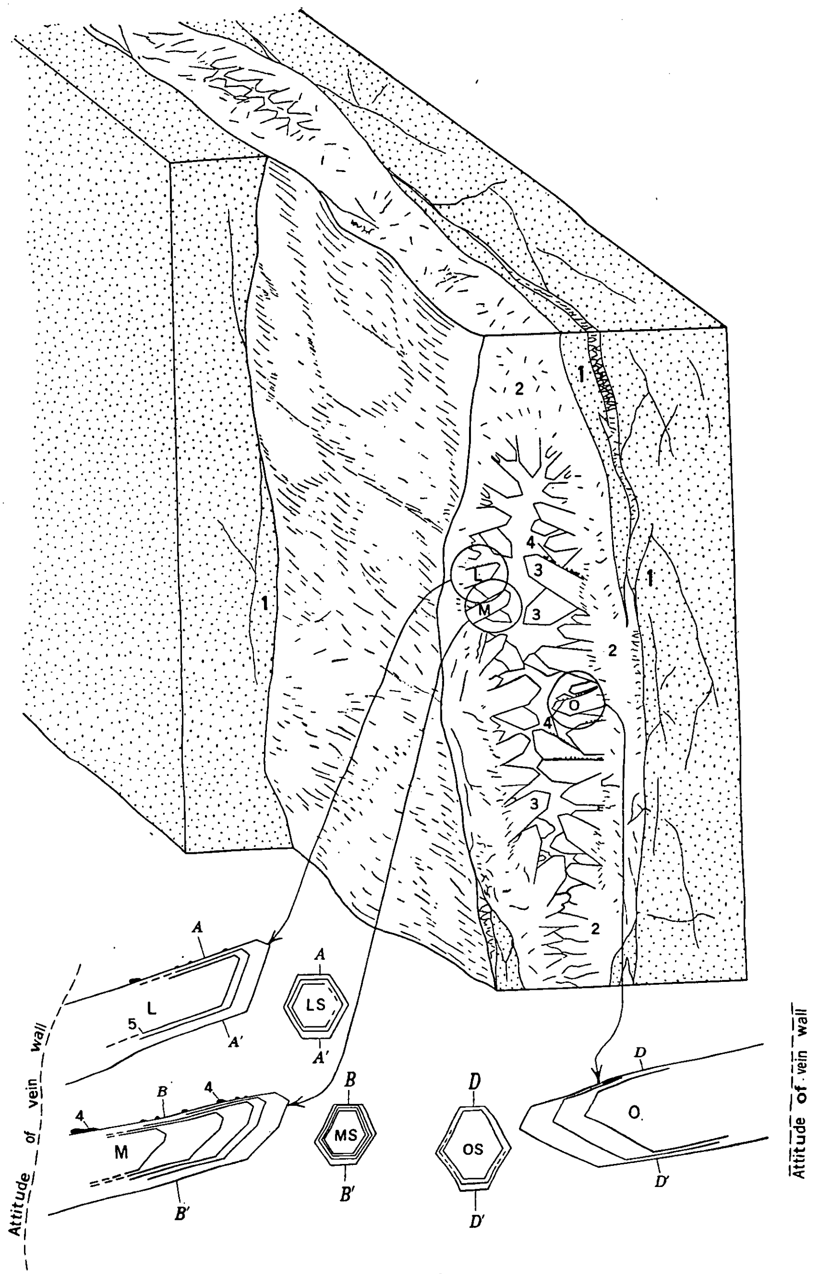


FIGURE 24.—Comb crystal pocket in a quartz vein.

Examination of the prismatic areas of these crystals shows that growth zones are thickest on the lower sides, the maximum amount of growth having been downward from the lower prism face. As the total area of the three upper prism faces roughly equals that of the three lower faces, the lower prisms obviously have received more generous additions of silica than the upper prisms.

Thus, even though the maximum rate of growth of each crystal is normal to the smaller rhombohedral faces, a greater volume of silica accumulates on the opposite (lower) side. We might assume that, because the specific zones parallel with the smallest rhombohedral faces are thickest, the same side of the crystal (upper side) has faced upstream. However, this would be perhaps a confusion of cause and effect, for, if a marked disparity in size develops or exists between the rhombohedral faces on opposite sides, it becomes a geometrical necessity that the fastest rate of growth be normal to the smaller rhombohedrons. If not, either the faces become more nearly equal in size or the small rhombohedron is repressed entirely. The complete repression of one or more rhombohedral faces on a single crystal has never been observed in Arkansas crystals, to the author's knowledge, and is generally rare in quartz. The smallest rhombohedral face on asymmetric crystals from Arkansas, however, commonly has less than one-tenth the surface area of the largest rhombohedral face and may be of pinhead size on crystals weighing 50 grams or more.

Zonation of the general type shown in figure 24 is fairly common in the Arkansas crystals sectioned, but other naturally zoned asymmetric crystals from Arkansas show deviations toward types more comparable to those figured by Newhouse (1941, p. 624), Armstrong (1943, fig. 1), and Johnston and Butler (1946, figs. 24, 25). In many of these types it is more difficult to determine which side of the crystal received a greater precipitation of silica at a given time or received it throughout growth.

For example, some zoned Arkansas crystals closely resemble one from Sonora, Mexico, sectioned by Newhouse, in which a well-defined

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EXPLANATION OF FIGURE 24

Block diagram of a comb crystal pocket in a quartz vein at the John Brown prospect, western Arkansas, and sections of three smoky quartz crystals showing unusually complete smoky phantoms or growth zones. The enlarged rhombohedral faces are on the downward sides of most of the crystals; encrustations occur on the upper sides. The clear quartz is principally at the terminal parts of the less confined crystals. The remaining area around the crystals commonly is filled with halloysitic red clay. Crystal sections *L, M,* and *O* are cut parallel to *c* (*Z*). Crystal sections *LS, MS,* and *OS,* cut normal to *c* along lines *A–A′*, *B–B′*, and *D–D′*, indicate that the greatest diameter of the prism of each crystal is roughly parallel to the plane of the sections above. 1, Sandstone wall rock; 2, milky vein quartz; 3, clear quartz; 4, encrustations on crystals; 5, smoky growth lines or phantoms.

prismatic growth zone is thickest on the same side of the crystal as the smaller rhombohedral face. In crystals of this type the maximum rate of growth in the prismatic zones has been on the same side as in the rhombohedral zones. Johnston and Butler figure several Brazilian zoned crystals for which the same interpretation may be made. Unfortunately, the exact geological setting and orientations of these crystals figured by Newhouse and by Johnston and Butler are unknown.

The geologic environment of the Japanese-type twin crystal experimentally enlarged by Spezia and described by Armstrong (1943) also is unknown. The fact that the orientation of this twin with respect to any solution flow was probably different in nature from that in Spezia's experiment complicates any analysis of its asymmetric features. The outer, experimentally produced zonation in this twin seems to represent a reversal in trend of asymmetry from that in the natural crystal. No highly developed asymmetry has developed, however, in either the natural or the experimental environment.

Obviously, well-defined discordances in growth habits appear within these few crystals from Arkansas, Brazil, and Mexico and in Spezia's twin crystal. Even within uniformly oriented crystals in similar types of fissures in Arkansas, striking discordances exist between the types of zonation and in the superficial asymmetry of crystal form.

In most quartz deposits in Arkansas, unfortunately, visible growth zones are too uncommon or too imperfect to evaluate adequately the factors controlling these discordances, and similar impediments to observation exist in most other quartz crystal deposits. Until the growth habits of quartz are better known, some technique is required for bringing out growth zonation in appropriate crystals where it is initially invisible or poorly defined. Irradiation of sections of oriented crystal offers a method of defining growth lines and zones, and this and other approaches to the problem are under study by the author. Additional information on the growth habits of quartz should result, also, from laboratory efforts to grow crystals.

Of the more asymmetric Arkansas crystals that have grown in narrow, straight, nearly vertical fissures, one striking feature is the orientation of the very large rhombohedral face with respect to the plane of the fissure. Generally the *c* axes of such crystals are inclined upward as much as 20° or more from the horizontal. Crystal *L* in figure 24 is an example, and the two largest crystals in the group illustrated by Newhouse (1941, p. 627, fig. 7) are of this type. The large rhombohedral face of these crystals (usually *r*) commonly is roughly parallel with, or diverges only slightly from, the plane of of the fissure. One reason for this crystal development may exist in the generalization by Newhouse that "if the slant of a face is such as to permit a large amount of current to sweep by at nearly maximum speed, this face grows very rapidly in comparison with other faces of that form." The same result, however, could be produced in a relatively quiet solution if a concentration gradient existed along which the solution was most impoverished in silica at and near the walls of the pocket.

Certain other noteworthy relationships exist among encrustations, etch patterns, and crystals. As will be shown later, the incomplete encrustations that generally occur on the upper sides of Arkansas crystals show no special preference for the asymmetrical crystal forms. Upper-side encrustations may appear on crystals of varying degrees of asymmetry as well as on those crystals having asymmetries in the opposite sense to the majority—that is, having enlarged rhombohedral faces upward. If, however, the asymmetrical crystal forms are indications of the direction of movement of the silica-depositing solutions, that direction would seem to be essentially upward, rather than downward or lateral.

Several problems are posed by assuming that these distorted forms are caused by crystal growth in currents. The crystal pockets in many veins are separated from each other by several feet or by tens of feet of solid, massive vein quartz which has no openings of sufficient size and frequency to allow uniform solution currents to persist along the vein. In effect, the crystal pockets represent incomplete fissure fillings. It has been suggested that these pockets or vugs may actually exist as such because this part of the vein has been sealed off from the vein-forming solutions. If solution currents are inferred to produce crystal asymmetry, the conclusion must be either (1) that the asymmetrical crystals in what are now the pockets approached their present form and size before the rest of the vein became filled to capacity with massive quartz or (2) that currents were able to persist in a uniform direction and at a sufficient speed through the massive quartz-filled, or nearly filled, vein or through the pores of the enclosing wall rock. Either explanation is difficult to accept. Of course, some 5 to 20 percent of the asymmetrical crystals show random orientations in even the most uniform pockets. These crystals are in general no larger than similar crystals more uniformly oriented, and there is no proof to indicate that they formed later, after currents had diminished in intensity or altered their direction.

Perhaps the kind or rate of movement of the currents had less influence on asymmetry than is now assumed. It is conceivable that crystals owe their asymmetry wholly or partly to concentration gradients, to diffusion, or to some other more obscure and elusive processes operative in a more static solution.

The incipient stage in the formation of many comb pockets seems to be indicated by fissures, opened to various widths, in which the wall rock has become partly or completely lined with small crystals. Examples of this early stage are well exposed at the John Brown prospect in the Blakely sandstone and at the Monroe-Robbins mine in the Crystal Mountain sandstone. This incipient stage in the formation of euhedral crystals along shale or limestone walls is rarely found. The first stage of vein development in these rocks characteristically seems to have been a rapid deposition of considerable silica in the form of anhedral to subhedral milky grains. The milkiness is produced largely by innumerable cracks and voids in which liquid, gas, and some solid phases of the solution are trapped. The lack of well-formed crystals seems attributable to the many closely spaced centers of nucleation from which numerous individuals grew and mutually impinged with great rapidity. The impingement during rapid growth presumably eliminated opportunities for faced crystals and set up stresses that further militated against development or preservation of clear quartz.

In the sandstones and quartzites, the centers of crystallization may not have been as close as in the shales, or, if the centers were as close, growth was slower and possibly many infant quartz individuals were resorbed into the system to provide nutrition for larger or more favorably situated neighbors. The growth of larger crystals in an essentially saturated system at the expense of the smaller crystals is a well-known process which may well have operated during crystal growth. The fissure-filling solutions could have been, in effect, "supersaturated" in terms of the largest crystals and slightly "undersaturated" in respect to the smallest quartz individuals.

At the Monroe-Wheeler mine, the growth of crystals halted before many crystals touched at their bases, sides, or protruding apical ends. Some data suggest that crystal plates of this type may have been formed very late in the sequence of silica deposition or were formed in fissures relatively distant from major feeder channels, but at scattered places at the Monroe-Wheeler mine, and at other localities such as the Diamond Drill Carbon Co. No. 4 cut, the Crystal Mountains, and the McEarl mine, some other process of importance may have been operating. At these mines and areas are examples of what clearly seem to be all stages in the conversion of wall-rock sand grains to crystals through solution, coalescence, and recrystallization.

In other incipient veins, additions of silica continuously made to the initially formed grains and crystals, and perhaps the development of new centers of crystallization, have caused the grains to enlarge and mutually interlock so as to form a mat of subhedral milky or turbid quartz. This mat is frozen to, or partly coalesced with, the host rock:

the surviving crystals project into the available fissure openings. Mats of this type (called "plates" by the miners), as much as 8 feet across and completely covered with crystals, characterize some deposits on Fisher Mountain. Smaller mats are commonly associated with the less deformed fissures in many sandstones or argillaceous sandstones. The basal milky mats of impinging grains which are sealed to the host rock commonly are as much as several inches or a foot in thickness, and protruding crystals generally are less than 3 inches long (pl. 29), though some may be as much as 3 feet.

In many quartz deposits throughout the Arkansas crystal area, particularly in shale and slate deposits, fissure filling has progressed to the stage where the remaining pockets are lenslike to irregular in shape and are terminated in any direction along the vein by complete intergrowth of opposing grains and crystals. Still further increments of silica leave only tiny cavities bounded chiefly by parts of abutting crystal faces at irregular intervals through the massive milky quartz. These small cavities, which rarely contain well-formed crystals, are called "sign pockets" by many miners, who regard them as a "sign" or indication of productive crystal pockets "just beyond." However, sign pockets in some veins clearly constitute the sole remnants of crystal occurrences earlier in the history of the deposits and do not indicate potential crystal production in the vein, as many an optimistic miner has learned after vainly hacking and digging along many feet of vein rich in sign pockets but barren of crystals.

The more random orientation of quartz in larger veins is manifest in pockets of irregular rounded form, in which the component crystals project at various angles into the cavity. Because of their random fabric and sackform shape, they are called "sack pockets." There exists an almost complete transition between such pockets and comb pockets. Random or diverse crystal orientation is commonly apparent where the silica-depositing solutions were not confined to uniform restricted channelways. These pockets are therefore more common in the wider veins, especially in shales.

## MINERALS ASSOCIATED WITH THE QUARTZ

The minerals, other than quartz, in the deposits are listed and their paragenesis indicated in the accompanying diagram (fig. 25).

Adularia ($KAlSi_3O_8$) is a component of many quartz deposits in shale and is sparingly present in several fissure fillings in argillaceous sandstone (pls. 33*A* and 33*B*). Crystal pockets, especially at Hamilton Hill and Little Utley Mountain, are lined with adularia crystals as much as half an inch across, and, rarely, adularia is included in the quartz crystals. More commonly, adularia is intergrown with massive vein quartz, particularly in the margins of veins adjacent to argillaceous wall rock (pl. 33*B*). The columnar structure of quartz is

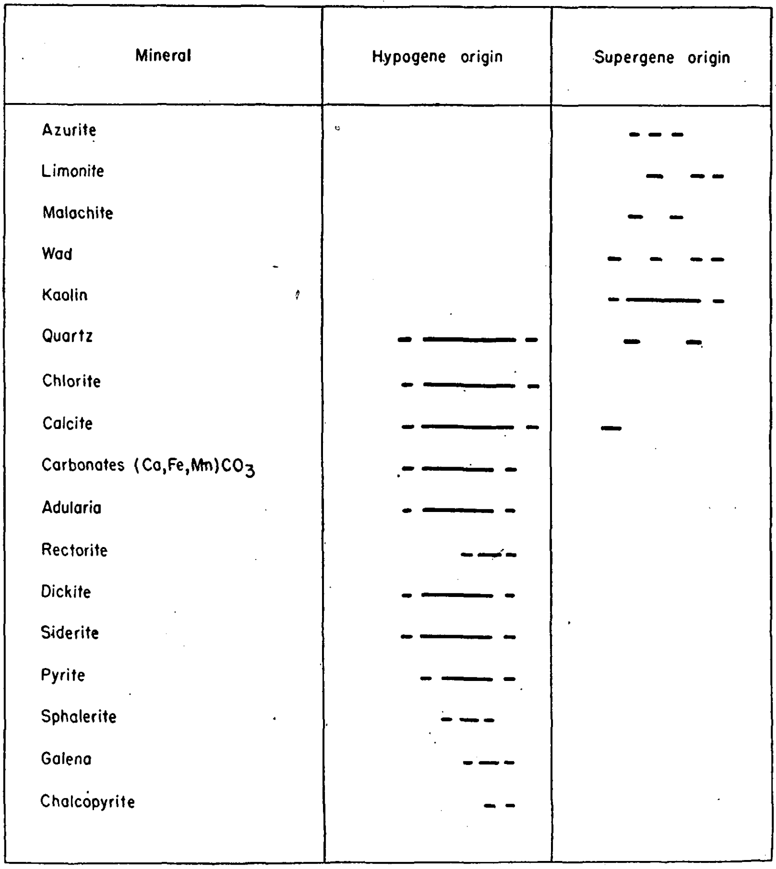


FIGURE 25.—Minerals and their approximate paragenesis in the Arkansas quartz crystal deposits.

emphasized in many intergrowths by the adularia, which forms narrow, transverse laths between the elongate grains of quartz (pl. 33*A*). Argillaceous wall-rock inclusions in veins may be rimmed by irregular or elongate grains of adularia, whereas most of the vein filling contains almost none.

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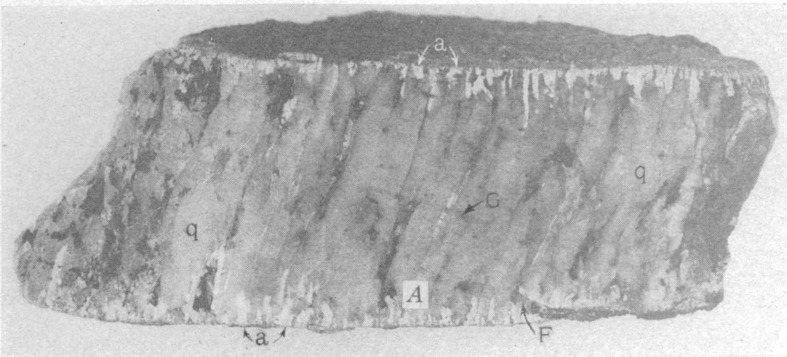
## EXPLANATION OF PLATE 33

*A*, Quartz (*q*) and adularia (*a*) vein intergrowth developed in sandy shale on Miller Mountain, Garland County, Ark. The adularia is present only where the vein is enclosed in argillaceous rocks and is absent along the vein continuation in clear sandstone. The distortion in the well-defined columnar structure of the vein was probably imparted by relative upward movement of the left wall of the vein during mineralization. The faint zones trending diagonally across the vein at *F* and *G* are relict gash fractures formed by movements of the vein walls and subsequently rehealed by additions of silica.

*B*, Quartz vein containing brecciated fragments of shaly wall rocks (*s*) rimmed with adularia (*a*). Constituents for the adularia have been derived in part at least from the shales. These relationships are typical of many veins in argillaceous rocks in the Arkansas quartz crystal district.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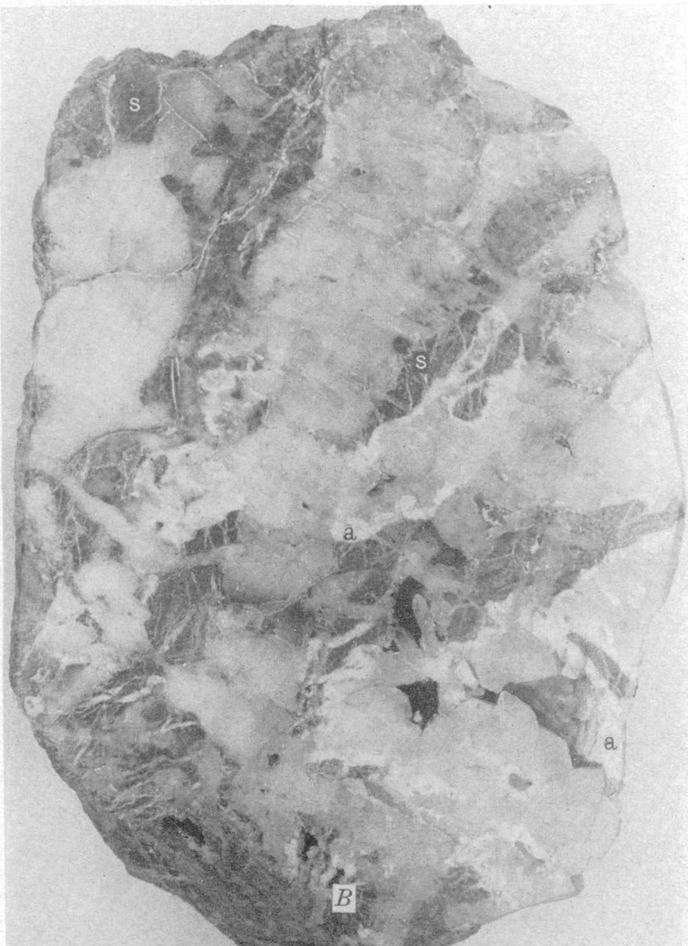
F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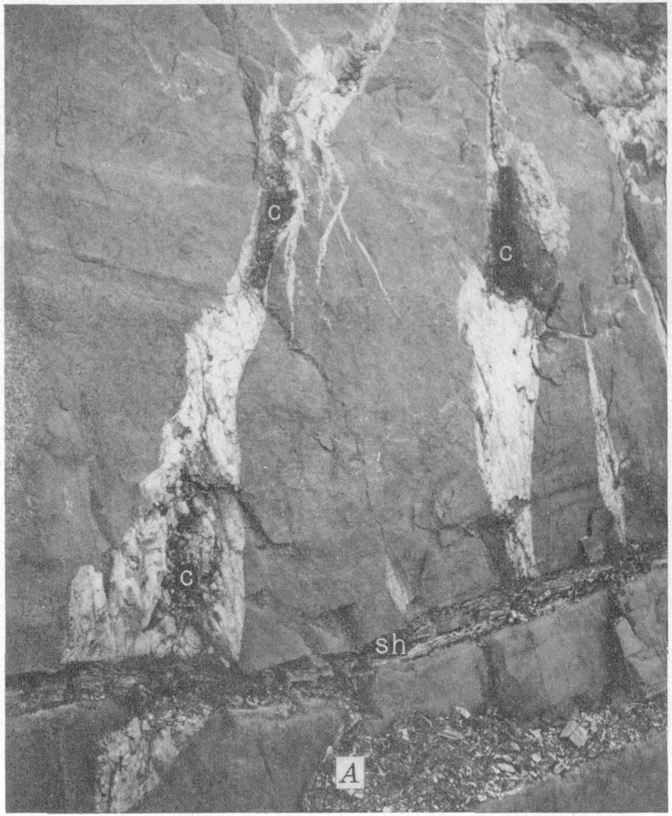



QUARTZ VEINS IN THE CRYSTAL MOUNTAIN SANDSTONE (QUARTZITE).

Lamellar, rhombohedral, and massive vein calcite ($CaCO_3$) and, more commonly, cavities indicating the former presence of calcite occur in many deposits. Calcite is a relatively abundant vein constituent in carbonate-bearing sediments and is scarce or absent in carbonate-free environments. Where the quartz veins transect limestones, massive white, coarsely crystalline calcite is always present with the quartz in various proportions.

Rhombs of calcite are found alined in single or successive growth zones within clear quartz crystals from a few localities (table 10), and cavities left by solution of these rhombs are particularly abundant in vein quartz and crystals mined near Chance, Ark. Lamellar calcite or molds thereof are most common in quartz deposits in the Bigfork chert and the upper part of the Womble shale. The lamellar forms range from minute blades to plates several inches long and a quarter of an inch thick.

Pale-to medium-green chlorite [$(Mg,Fe)_5(Al,Fe''')_2Si_{13}O_{10}(OH)_8$] is a relatively common constituent of the quartz veins in the Stanley shale and is sparingly present in veins enclosed in other shales. Vermicular and granular aggregates of chlorite form phantoms and irregularly shaped inclusions in crystals and in masses of vein quartz. The chlorite is most abundant in quartz adjacent to fragments of silty wall rock. Selective encrustations (Frondel, 1934, pp. 318–320, 323–329) of chlorite are occasionally found on the three positive rhombohedrons *r* of Arkansas quartz. More commonly, enlarged adjacent *r z r* forms and parts of the adjoining three prism faces *m* on the down side of the crystal, or irregular areas on crystal faces, are encrusted with chlorite.

Dickite [$Al_4(Si_4O_{10})_3(OH)_{12}{\cdot}3H_2O$] is widely distributed (Miser, 1943, pp. 97–98) as coarsely crystalline (grains as much as 1.5 millimeters in diameter) or fine-grained aggregates in quartz crystal pockets and as coatings along fractures in massive quartz. It forms inclusions in quartz crystals, especially in deposits located along the margins of the district.

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EXPLANATION OF PLATE 34

Veins exposed on Arkansas Highway 6, about 6 miles west of Crystal Springs. *B* is a close-up of the area at and below the lower left-hand corner of *A*. Note the abrupt terminations of the veins at the contacts of the intercalated shaly zones (*sh*) and the resumption of the vein in quartzite on the opposite side of the shale. At this locality the vein walls clearly do not match in outline and are not offset, and the veins cannot be interpreted as simple fissure fillings. From the features in this area, and by analogy with other localities of this type where "sand crystals" and the coalescence of wall-rock grains into vein stuff are very apparent, these veins are interpreted as, in large part, products of the recrystallization of wall rock. The presence of crystal-bearing cavities (*c*) and the absence of the clay and iron oxides of the wall rock in or along the veins suggest that the system was an open one from which solutions undoubtedly carried some iron, argillaceous matter, and probably silica. In this outcrop no criteria were found to indicate whether any silica was introduced.

Rectorite [$(Al_2O_3 \cdot 2SiO_2 \cdot H_2O)$] occurs (Brackett and Williams, 1891) with quartz in the Jackfork sandstone, especially near Angling and Smith Pinnacles, along the Saline-Garland County line. The two minerals usually occur together in highly deformed veins. The quartz commonly shows ragged, irregular contacts with the rectorite folia and is partly enveloped in them.

## WALL-ROCK ALTERATION AND REPLACEMENT

Most of the rocks enclosing the quartz deposits show little alteration or replacement by the mineralizing processes. The replacement of shales by quartz or the recrystallization of sandy quartzitic and cherty wall rock into white vein quartz or crystals, as briefly mentioned in preceding pages, can be demonstrated with assurance at only 20 or 30 localities out of more than a thousand examined. The extent to which these processes are important at any deposit, or should be extrapolated to other deposits where criteria are lacking, is a critical problem. Certain well-defined limitations in the scale of either replacement or reconversion of wall rock into vein matter are imposed by deposits where opposite walls are sharp, clean, and matching in outline and where there are clear-cut offsets of key beds that lie at oblique and acute angles to the vein. Deposits with these features are clearly in the majority. There remain, however, many localities where no clear-cut criteria were found to evaluate adequately the importance of fissure filling as compared with replacement, recrystallization, or other reconversion of wall rock. In addition, a combination of these processes seems indicated for at least a hundred localities and possibly for many more.

Some veins in cherts, sandstones, and quartzites definitely have been enlarged 5 to 10 percent of their total volume by recrystallization of narrow selvages of wall rock. Notable examples, some of which have been cited before, include deposits in (1) the Blakely sandstone at Miller Mountain and the McEarl, Dierks No. 4, Diamond Drill Carbon Co. No. 4, J. W. Ellison, and W. T. Beard mines; (2) the Crystal Mountain sandstone at the Fisher Mountain mine and (3) at many minor localities scattered through the Crystal Mountains to the east, west, and south of Fisher Mountain; and (4) the Bigfork chert at the Floyd Graves mine, Big Utley Mountain, and Chalybeates Springs. Locally, examples are known of extensive replacement, recrystallization, and related reconversion of wall rock into quartz veins and crystals. Criteria like those illustrated in plates 34*A* and 34*B* are apparent at scattered localities in the Crystal Mountain sandstone in the Crystal Mountains and in the Blakely and Jackfork sandstones. At these localities veins ordinarily are confined to sandy or quartzitic beds intercalated with shales. The shaly layers are contiguous and not much deformed across the abrupt "termination" of the quartz vein (pls. 34*A* and 34*B*). Although fractures in the sandy wall rock seem to have controlled the location of these veins, there could have been little opening of the fractures or displacements along them, for such movements would be indicated in disturbances in the intercalated shales. Some veins of this type swell abruptly to widths of one or, locally, several feet, and the opposing vein walls cannot be matched.

In some of these veins intermediate stages may be seen in the process by which wall rock is converted to vein quartz and crystals, ranging from slight recrystallization or silicification of the wall rock to the envelopment of quartz grains which then coalesce with the introduced silica and assume a common crystallographic orientation with it. Some of the carbonaceous and argillaceous matter or other impurities in and between the wall-rock grains have been expelled to the perimeters of the larger white grains and crystals that have evolved into "vein." In some places these impurities are transported tens to hundreds of feet or more, presumably by circulating waters which facilitated the conversion process. The presence of pockets or vugs in some of these veins seems clear-cut evidence that some constituents were redistributed or removed.

The evolution of "sand crystals" can be clearly seen at the McEarl mine, the Diamond Drill Carbon Co. No. 4 cut, and the Ellison mine. These deposits show the several stages in the conversion of porous sandy wall rock to partly clear crystals.

Alteration of shale and slate wall rock during vein formation seems to be confined largely to thin fragments or finely broken aggregates within the mineralized fissures and to narrow zones and ribbons of host rock along fissure walls. Many scattered examples appear where silica, presumably carried by water, has permeated the more porous shaly or silty fragments and either partly or wholly silicified or recrystallized them. In other deposits the more exposed argillaceous materials, soaked by the solutions, were leached of large quantities of carbonaceous material and smaller amounts of potash, magnesia, and perhaps alumina. The altered fragments are pale-gray to buff kaolinitic or halloysitic aggregates. The presence of quartz pseudomorphs of slaty and shaly textures, with the outlines of the original argillaceous fragment still clearly visible, seems to be unmistakable evidence of replacement. These ghost textures of shale, which appear as ribbonlike and platy to angular bodies in the quartz veins, are commonly pale to bluish gray. Some still contain traces, or even several percent, of carbonaceous and argillaceous matter. Many contain grains of adularia, chlorite, dickite, and sericite or are rimmed by these minerals (pl. 33*B*).

Where fractures cut the limestone beds that are interlayered with the shales and cherts, zones of limestone as much as a few inches wide commonly are recrystallized into coarse-grained white calcite, which then becomes the major component of the vein. A small amount of calcite has been dissolved from the fractured calcareous cherts and sandstones by vein-forming solutions, converting them into porous, friable masses. Some of these porous quartzose aggregates become vein quartz and crystals.

## RELATIONSHIP BETWEEN VEIN MINERALS AND TYPE OF WALL ROCK

The differences in the physical and chemical properties of the wall rocks are well indicated in the enclosed quartz. In general along the north and south margins of the district, but more locally throughout the district, the vein quartz and crystals occur mostly in sandstones and quartzites (pl. 34 and fig. 22). Because of their greater strength and brittleness, these quartzose rocks seem to have developed fractures which, in places, considerably facilitated the evolution and maintenance of open fissures. These fractures, some of which evolved into fissures, obviously localized most of the quartz deposits of all types. Even the few deposits that seem to have formed largely by replacement or reconversion of siliceous wall rock apparently began along fractures or breccia zones.

In the central part of the quartz belt, deformative stresses also caused more fractures and some open fissures in the argillaceous rocks. In these wall rocks in the central part of the district, one factor favoring the incidence of fractures and fissures was the more advanced degree of recrystallization and reconstitution (metamorphism) of shales in the central Ouachita belt. However, the area of greatest metamorphism of shales—to slates—in the Ouachita Mountains is not entirely matched by the area of most abundant quartz veins in these rocks.

The fractures and fissures in argillaceous rocks presented greater physical and chemical variations to silica-bearing solutions than channelways in massive sandstones, largely because the argillaceous rocks are lithologically more heterogeneous than thick sandstone units. These variations undoubtedly caused contamination of the solutions by various impurities, resulting in abrupt changes in the physical and chemical environment in which the quartz was being formed. This impeded the development of clear quartz and facilitated the development of milky quartz, which would seem to explain the great volume of milky quartz formed in fissures in shales containing only small amounts of clear quartz. A noteworthy corollary is that veins in shale, impure cherts, or other nonuniform lithologies tend to contain a much higher proportion of (1) milky vein quartz to crystals and (2) cloudy crystals to partly clear ones than deposits in massive, more nearly homogeneous sandstones, quartzites, and argillaceous sandstones.

The type of wall rock enclosing the deposit also has exerted a marked influence on the kinds of minerals and amorphous materials other than quartz in the veins. The restriction of adularia (pl. 33) and, more locally, chlorite mainly to cavity fillings in the shales seems to warrant the conclusion that the formation of these minerals was dependent upon favorable wall rocks as a source of potash and magnesia. Significantly, chlorite is especially abundant in the tuffaceous Stanley shale, which has a higher magnesia content than the other shales of the district. Adularia is present in veins in all the shales, being particularly abundant in veins that cut zones of the Womble shale. The chlorite and adularia in cavity fillings are limited chiefly to narrow areas adjacent to altered argillaceous wall rock.

The association of vein calcite and crystals with quartz deposits, principally in calcareous beds, indicates that the chemical nature of the wall rock controlled the formation of calcite in the deposits. All transitions from dark, fine-grained limestone to white, coarsely crystalline vein calcite are observable along quartz veins cutting limestone, and in some brecciated or tightly fractured limestones, this recrystallized carbonate wall rock may form most of the vein. Veins traced a few feet beyond limy beds show a marked impoverishment in calcite and an equally abrupt increase in quartz. The occurrence of lamellar calcite (which is assumed to be the high-temperature form) with quartz, chiefly in deposits in the Bigfork chert and the upper part of the Womble shale, may be largely attributable to some stratigraphic control exerted by these chert and shale zones. The zones are distinct from other wall rocks in the district in that they contain chert, calcite, and pyrite as abundant constituents.

These relationships show conclusively that some or all of the major elements for certain vein minerals were derived from the adjoining wall rocks and incorporated into the veins to produce contrasting assemblages and features in the veins in the different wall rocks. In the crystal district the vein associations for a given wall rock, if present, are remarkably consistent. Many veins, perhaps a majority in all types of wall rocks, consist largely of quartz.

At a few places where quartz veins cross lithologic contacts, there is sufficient carry-over of certain wall-rock material in one direction from one wall-rock type into another to suggest a direction either of movement for vein-forming solutions or of diffusion of vein-forming constituents in the solutions. One of the best examples of unidirectional carry-over observed was on Miller Mountain (at MA 1 on pl. 36). There a vein cuts directly across a sequence of thin flaggy limestone and thicker shale and sandstone beds. Where the vein cuts limestone, calcite is the dominant vein mineral, with subordinate quartz. As the vein passes from the limestone bed into the shale, calcite diminishes abruptly in total volume and quartz increases to become the major vein mineral. Some calcite appears in the vein in the lower part of the shale, however, and extends up as far as the dashed line in figure 26. Adularia appears rather abruptly in the vein at or near the base of the shale zone and remains a common constituent of the vein throughout the shale. In addition, small quantities of adularia appear to be "carried over" for some distance into the vein in the sandstone, just as calcite appears to have been carried into the shale environment. The extent of the upward persistence or carry-over of adularia into the relatively clean sandstone overlying the shale also is indicated in figure 26.

Only a few veins on Miller Mountain were well enough exposed by mining operations to obtain measurements of carry-over. In these

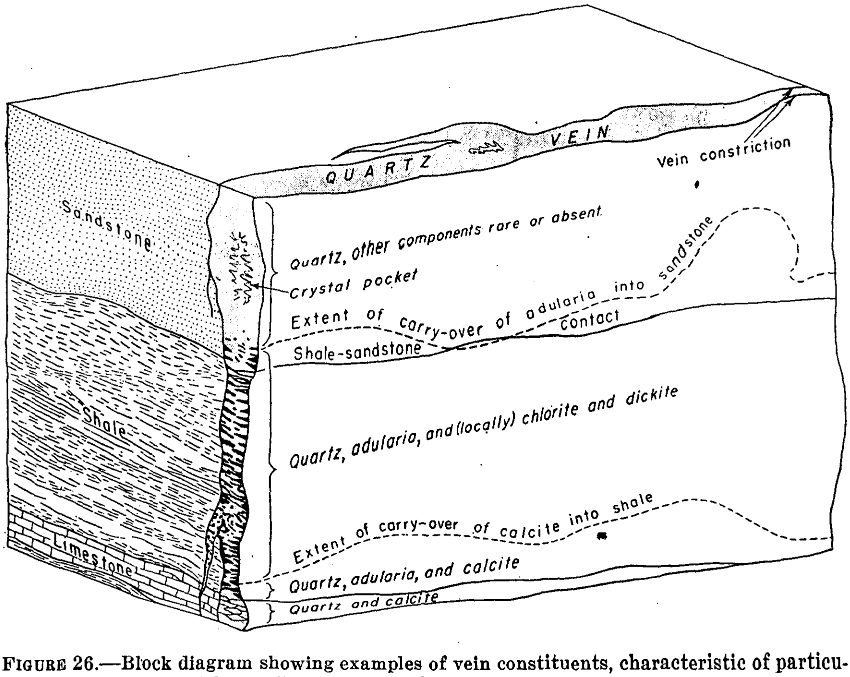


FIGURE 26.—Block diagram showing examples of vein constituents, characteristic of particular wall rocks, which are "carried over" into the vein in an adjacent alien wall rock. The carry-over of the constituents is dominantly upward for various distances at different points along the vein. The vein in the diagram has a maximum width of 9 inches and is shown exposed for 15 feet along the strike. The locality is Miller Mountain, at MA 1 on plate 36.

veins, a vertical component suggesting upward movement of constituents was dominant. However, several examples of apparent lateral and even downward components were found. Efforts to compare these data with the possible direction of movement of silica-depositing solutions as suggested by asymmetrical crystals were handicapped by the scarcity of pockets of simple crystals in this vein. Accordingly, not enough data are at hand to provide a conclusive answer. The two features do not always point to a common direction from which to attribute the flow of vein-forming solutions, although, in both features, a general upward direction is implied. One way to reconcile the known discrepancies without abandoning the hypothesis of currents is to assume that the phenomenon of carry-over is a more sensitive indicator of the currents in solutions than asymmetric crystal fabrics.

### SECONDARY FEATURES RELATED TO DEFORMATION

Nearly all the quartz deposits in the district show marked effects of deformation during and following silica deposition. The value of a deposit as a source of oscillator- and optical-grade quartz is generally in inverse proportion to the severity of deformation, although quartz crystal as a curio specimen often is improved by deformation and regrowth. Commenting on these features of the deposits, Miser (1943, p. 99) says:

> Some veins in laminated sandstone have been offset by shearing along the laminae; some have been cut by faults and thus display slickensides; and some have been formed in two sets, the later one crossing the earlier one. In addition, some veins have been crushed into coarse and fine breccia in whose spaces a later generation of quartz grew. Quartz crystals by the hundreds have been noted that have been broken away from their attachment and have grown by the addition of further quartz to the fractured surfaces. In fact the crystal clusters at some places have been so greatly fractured that clusters do not remain; all the crystals at such places are doubly and singly terminated and lie loose in the clay.

Crystal pockets, the source of clear quartz, were sites especially susceptible to breakage and subsequent deposition of silica. Those greatly altered are here termed "crush pockets," and the various types of deformation are illustrated in their complex crystal fabrics.

Where opposing crystals were interlaced in elongate pockets and fissures, the slightest differential movements have sheared the confined crystals from their roots and "veiled" or distorted numerous others (fig. 27). Simultaneously, new cavities and fissures have been opened. The loosened or "erratic" crystals then lodged in random fashion in the new fissures, into which they became cemented by continued deposition of silica and surrounded by a new generation of comb crystals. At the Monroe-Robbins mine, most of the erratic crystals are milky, and

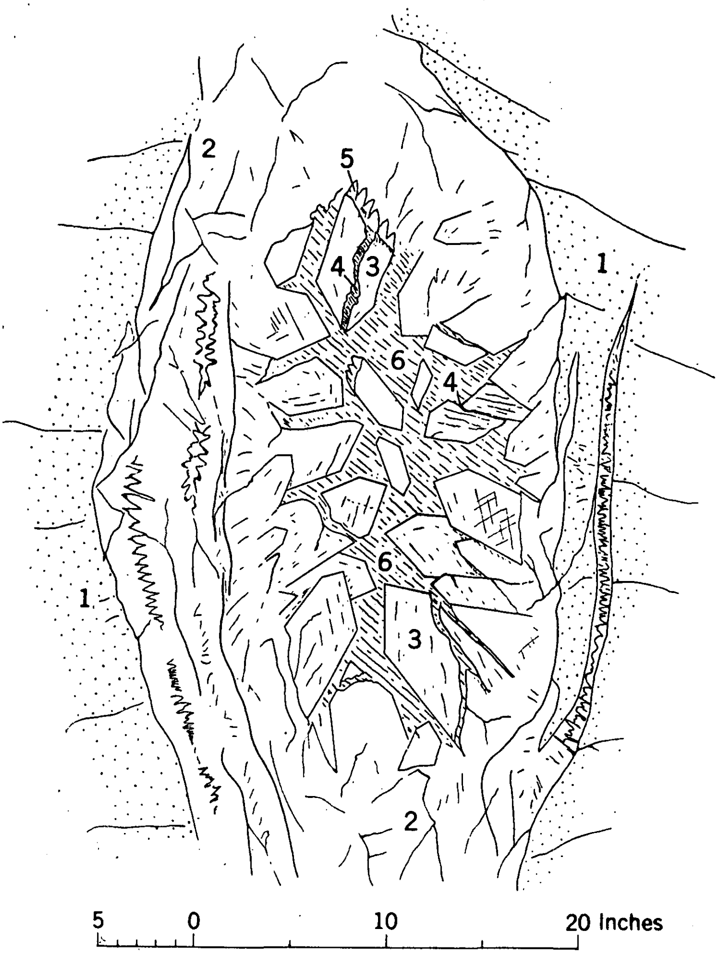


FIGURE 27.—Slightly deformed quartz crystal pocket at the Diamond Drill Carbon Co. No. 5 cut, western Arkansas. 1, Deeply weathered argillaceous Blakely sandstone; 2, massive, milky vein quartz; 3, fractured quartz crystal; 4, healed fracture; 5, part of a crystal grown subsequent to fracture; 6, red clay filling around crystals.

they lie among the small, clear later crystals like "down" timber among second-growth saplings.

In veins on Deckard Mountain and east of Smith Pinnacle, crystals have been broken or successively distorted and rotated by differential movements of fissure walls until their axes lie essentially parallel with the cavity wall. Some of the fissures are clogged with aggregates of closely packed crystals that are "frozen" together in subparallel and swirled patterns. A large number of individual crystals appear to be bent or warped because of slight offsets along cleavages, or fractures, accompanied by rehealing.

Where movements resulted in the constriction of a crystal-lined cavity, the flattened, distorted crystals lie matted in a crisscross pattern. In the more severely crushed pockets, crystal fragments, brecciated vein matter, and wall rock form a porous rubble. The complex products are distorted crystal mats typified by those of the Fairchild prospect and other deposits, particularly in the shales.

In veins where extensive deformation has occurred during crystal formation, minute chips of vein quartz or wall rock have piled up, sometimes to the angle of repose, as encrustations on the upper side (Bandy, 1942, p. 330) of the crystals (fig. 24). Many of the encrusting fragments are modified or enlarged only slightly and can be traced to their source in the crushed fillings above. Significantly, the incomplete encrustations generally occurring on the upper sides of crystals show no preference for the asymmetrical crystal forms. Crystals of quite different degrees and types of asymmetry, as well as crystals with enlarged rhombohedral faces upward, may be encrusted on their upper sides. Other encrustations appear to be localized by diverse controls, among which may have been certain vectorial properties of crystals (Frondel, 1934). Most overgrowths or encrustations, so prevalent on the Arkansas crystals, seem to owe their origin largely to migration, by gravity, of particles precipitating from the solutions or loosened from superposed parts of the cavity at various stages during cavity filling, rather than to a more copious nutrition on the stoss side (Newhouse, 1941, p. 620). On the larger crystals these particles are commonly recrystallized, enlarged, or enveloped by subsequent additions of silica.

## SUMMARY OF ORIGIN

The quartz-crystal deposits of the district are chiefly cavity fillings. Replacement and recrystallization of wall rock can be shown to be important processes in the formation of a few deposits and in many others are presumably processes subsidiary to cavity filling.

Vein formation is assumed to have occurred during the flooding of fractured and fissured wall rocks by water solutions of alkali silicates in which quartz was the primary phase. That water is the vehicle of transportation and medium of diffusion of vein-forming constituents is borne out by these facts: (1) Fissure-filling was a dominant process; (2) aqueous solutions are trapped in the water crystals; and (3) highly hydrous and hydroxal-bearing minerals are common, as are other relatively low temperature and pressure features.

The relative abundance of clear crystals found in many veins, as well as the absence of colloform structures, suggests that much of the quartz grew, molecule by molecule, from the aqueous solutions during fairly constant physiochemical conditions. Comparatively slow crystal growth under uniform conditions may have occurred, especially in many sandstone environments. More rapid deposition and growth of quartz under less stable conditions are implied for many shaly and cherty environments, which are physically and chemically more heterogeneous.

The association of dickite, platy calcite, chlorite, and adularia, all contemporaneous with the quartz, certainly suggests hydrothermal solutions as an agent of transport. (A magmatic source is not necessarily implied in the term "hydrothermal.")

The existence of dominantly rising currents in the solutions is perhaps suggested by the growth distortion of many crystals and by the unidirectional carry-over of constituents from one characteristic vein environment to another. Other features of the deposits that seem to point to a hypogene origin include their appreciable vertical range, their general lack of relation to relict topography, and their persistence in the most deeply dissected rocks.

In addition, the age and location of the deposits do not imply a supergene origin. The deposits certainly are older than the Lower Cretaceous sedimentary rocks of the coastal plain containing detrital vein quartz. On the basis of regional studies, Miser (1943, pp. 98–99) suggests a middle Pennsylvanian age. The possibility seems remote that supergene quartz deposits, formed at or very near the surface, could persist along the crest of a mountain range which, because the voluminous sediments of Mesozoic and Cenozoic age to the south definitely were derived from it, is known to have been strongly positive.

Lateral secretion on a scale of inches or even tens of feet is implied by the consistent association and restriction of characteristic vein minerals to veins in or near chemically favorable wall rocks. However, widespread lateral movement of vein solutions or constituents seems unlikely. The wall rocks were deformed before mineralization into close folds with steep axial planes. The fractures and fissures that seem to represent the major channelways and loci of solutions are likewise steep in dip or vertical. There are no obvious flat-lying or gently dipping channelways or permeable zones. If the growth fabrics of quartz crystals and the unidirectional carry-over of vein minerals from one characteristic environment into an alien one are features that reflect movements of vein-forming solutions, then the dominant direction was upward.

To many geologists, the features of these deposits are generally characteristic of epithermal deposits as defined by Lindgren (1933, p. 210). This means an environment in which the temperature "is relatively low, perhaps from 50° to 200° C., and the pressure will scarcely exceed 100 atmospheres."

In an attempt to arrive at some quantitative temperature range that may be assumed to have prevailed during mineralization, thermal tests were run on smoky crystals and on fluid inclusions in crystals, as described in a preceding section. A maximum temperature of 200° to 225° C. during mineralization is suggested by these tests. Evidence derived from thermal tests of fluid inclusions suggests a minimum of 120° C. These temperatures, though useful at least as a target, are in the author's opinion hardly conclusive, largely because of previously discussed assumptions inherent in the studies.

The depth of burial and the vertical range of the deposits can be bracketed only within very broad limits. All the sedimentary formations from the Crystal Mountain sandstone (Ordovician ?) up through the Jackfork sandstone (lower Pennsylvanian) enclose quartz crystal deposits of undoubted affinity. Possibly quartz veins in the lower part of the Atoka formation, of Pennsylvanian age (Miser, 1934, p. 978), also are a part of the silica mineralization.

The maximum possible depth of burial of the quartz veins in the youngest host rocks offers perhaps the most conclusive value for the depth of origin of some veins. This figure may be obtained by totaling the thickness of the post-Jackfork, the lower Atoka, sediments that probably extended across the present Ouachita Mountains (Miser, 1934, pp. 979–981) before major uplift and erosion of parts of the range began. These sediments definitely include 6,000 to 8,000 feet of the Atoka formation. They also may have included up to 4,500 feet of post-Atoka sedimentary rocks now found in the Arkansas valley, although they are unknown in the Ouachita Mountain area (Miser, 1934, pp. 980–981). Probably 8,000 feet is a reasonable estimate of the maximum cover existing over the veins in the upper part of the Jackfork sandstone during their formation.

The initial cover on the Crystal Mountain sandstone, the oldest formation with typical quartz veins, must have totaled between 20,000 and 30,000 feet (Miser and Purdue, 1929, pl. 4). Prequartz and synquartz erosion of this central, higher part of the range undoubtedly removed a sizable fraction of the cover, but to bring the site of these deposits within a mile of the surface implies the cutting of at least valleys or canyons through a minimum of 15,000 feet of sediments, including 5,000 to 6,000 feet of Jackfork sandstone. Unless the bulk of this erosion of the rock column in the Ouachita Mountains occurred before and during the quartz mineralization, the deposits were emplaced at depths commonly thought of as mesothermal (Lindgren, 1933, p. 210) or leptothermal (Graton, 1933, pp. 536–540). A resultant corollary is that, if one assumes—as is generally done—an epithermal environment and a middle Pennsylvanian age for these deposits and nearby antimony and quicksilver deposits (Miser, 1943, pp. 114–117; Reed and Wells, 1938, pp. 51–53), most erosion of this part of the Ouachita Mountains had to take place between late early Pennsylvanian and late middle Pennsylvanian time. This would have been between the last known deposition in the Ouachita geosyncline and the assumed time of mineralization. These considerations certainly do not favor a conclusive answer to the question of depth environment or, for that matter, the age of the Ouachita mineral deposits.

The quartz deposits and their associated minerals may well have been derived from a composite source: (1) wall rocks immediately adjacent to the present deposit, (2) rocks in and adjacent to deep-seated channel walls traversed by rising fluids, and (3) a subjacent magma.

Miser (1943) concluded the deposits were probably of hydrothermal origin, formed by solutions that had their source in a magma, but that these solutions

> probably deposited a part of their load enroute and picked up some substances before reaching the present enclosed rocks, which were then, of course, deeply buried; in fact a part of the substances in the quartz veins may have been derived from the rocks traversed by the solutions or from rocks enclosing the veins—quartz from the sandstones, calcite from the limestones, and potash and alumina for the adularia from the slates.

This conception is almost entirely in accord with the data presented in the present report and is in general agreement with the author's ideas.

The postulated magma source is of course open to question. Although magmas as the source of appropriate water and vein components often are invoked a priori, there is no direct evidence in the crystal district for this assumption. Metal sulfides and fugitive constituents which commonly are believed to be characteristic of certain magmatic solutions are rare in the district. In all the thousand or more veins examined during this study in an area of some 1,500 square miles, not 500 pounds of metal sulfides was observed. The rare local occurrences of pyrite, chalcopyrite, galena, and sphalerite could easily represent derivatives from the enclosing wall rocks or from almost any preexisting rocks that through-going solutions may have permeated.

The major vein component, quartz, is certainly derived, in part at least, from the wall rocks at and near the present veins. The other common vein minerals—adularia, chlorite, calcite, and dickite—occur in relations that indicate a wall-rock source for at least some of their elemental constituents. Most of the silica, and probably alkalis, undoubtedly were carried into the fissures they now fill from a source or sources at least hundreds or thousands of feet away. However, no matter what its origin, any water with sufficient mechanical, thermal, and chemical energies may have effected this redistribution. Meteoric waters could have penetrated downward through the widely fractured rocks enclosing the quartz deposits to even greater depths and acquired the appropriate energies to become resurgent mineralizers. Other alternatives consistent with the data are that the solutions responsible for the mineralization represented (1) commingled meteroic waters and magnetic waters largely stripped of obvious magmatic or deep-seated components, (2) connate waters driven upward toward the surface by rising temperatures and pressures during metamorphism, or (3) various combinations of magmatic and connate, or meteoric and connate, waters.

Possibly the small deposits of antimony, lead, copper, zinc, and mercury that occur largely in the southern margin of the exposed Ouachitas and at other scattered points are, as Miser suggests (1943, pp. 114–117), related in origin and time to the quartz crystal deposits, although the area in which deposits are distributed does not clearly overlap that of the quartz vein and crystal province. Quartz occurs as a gangue mineral with the metals, but this quartz cannot be traced into, or conclusively associated with, that in the crystal district. The relationship is suggestive, however, as Miser has pointed out.

Studies of the non-crystal-bearing quartz veins and sulfide deposits of the Ouachita Mountains in Oklahoma led Honess (1923, p. 41) to conclude:

> The sulphide veins usually carry not more than 50 per cent of quartz and other gangue minerals. The large quartz veins are practically all quartz. The former are prominently brecciated; the latter are tension joints, free from brecciated country rock, and are of the type known as gash veins, in most cases at least. The writer is of the opinion, therefore, that the gash veins are relatively shallow, and that the brecciated fault zones are deep and are the channels through which deep seated magmatic waters circulated in finding their way to the surface. The writer does not wish to infer that the quartz of the gash veins is not also magmatic. It is considered hydrothermal quartz and is thought to come from alkaline silicate water migrating to the surface through granitic rocks. The quartz must have been precipitated from the hot alkaline solutions by the carbon in the richly graphitic and carbonaceous slates and shales of the Collier, Womble, and Stanley especially. It is thought that the sulphides came from still deeper sources than the sheer quartz pegmatites and, also, were precipitated from thermal solutions. Nothing is known of the relative ages of the two types of veins.

Whatever the ultimate source of these solutions, their selective invasion into the wall rocks adjacent to the fractures and fissures which localized the deposits permitted chemical elements to be removed from the wall rock and incorporated in the cavity fillings. Solutions permeating and leaching the shales and slates of the district were enriched with potash, magnesia, and possibly silica and alumina. That these introduced solutions were originally poor in potash and magnesia is demonstrated by the absence of these elements from cavity fillings in other than argillaceous host rocks. As a result, a marked concentration gradient was set up in the solutions between the soaked wall rock and the cavity. It is suggested that potash, magnesia, and alumina migrated by slow lateral diffusion outward, in solution, toward the cavity. Their addition to the general system resulted in the immediate formation of adularia and chlorite with the quartz in the fissures.

There was widespread movement of carbonaceous substances, derived from the black shales and shale clots in sandstones, into the cavity fillings. The carbonaceous material was introduced into the quartz as aggregates of fine flakes and seems to have been transported by the solutions, at least locally, as a colloidal fraction or as discrete particles.

The principal wall-rock sources of silica were the porous sandstones and cherts, although small amounts of silica appear to have been removed from the shales and slates. Some silica seems to have been dissolved from the smaller, more soluble grains in these beds and deposited on the relatively large quartz grains and crystals of the cavity fillings. Considerable silica seems to have been abstracted locally from the wall rocks in this fashion and incorporated into the cavity fillings. Siliceous wall rock also has been converted to vein material by the coalescence of the grains into larger quartz individuals without appreciable migration of the silica. Even in the areas of greatest solution and recrystallization, however, the local supply of quartz has been augmented by silica introduced or more widely redistributed by the solutions.

Some alumina also may have been derived from the aluminous wall rocks and converted into the dickite crystals of the cavity fillings.

Presumably growth and continued preservation of oscillator-grade quartz in the deposits were possible for relatively few quartz individuals. The initial solutions, rising toward the surface into zones of diminishing pressures and temperatures, were undoubtedly contaminated by crushed host rock and by any connate solutions that may have persisted in the sediments. This contamination probably facilitated the nucleation and deposition of silica but caused numerous grains and crystals to be clouded by various impurities and physical imperfections. As the channelways were cleansed and warmed by ascending solutions, the physiochemical system may have become more stabilized. If so, the resulting slower, more regular precipitation from relatively constant solutions in uniform circulation enhanced the opportunities for more perfect unit-crystal growth. Even then the formation of clear quartz was confined almost entirely to the unstressed, terminal parts of crystals. Pressures, differentially applied to crystals as a result of their mutual interference during growth, caused physical imperfections and consequent milkiness.

Each succeeding deformation during vein formation must have introduced hydrodynamic variations within the solution-filled fissures. New cavities were formed and preexisting ones broken or crushed. Many crystals and areas of massive vein quartz were strained and fractured. During periods of instability the physiochemical system probably varied from place to place. Fragments of wall-rock and vein materials fell through, or were carried along by, the moving solutions and were lodged against growing cavity fillings. In general, more opportunities existed in shales than in sandstones for the contamination of solutions and the incorporation of impurities in the growing quartz.

## AGE OF THE QUARTZ DEPOSITS

The available evidence, already recorded in large part by Miser (1943, pp. 98–100), indicates that the quartz crystal and associated mineralization took place between early Pennsylvanian and early Cretaceous time and that it is not related to the Cretaceous igneous activity in Arkansas. That the deposits were formed during the final stages of the Ouachita orogeny is suggested by the control of the quartz deposition by fractures related to the folding of the Paleozoic rocks, the recurrent deformation during quartz formation, and the localization of the major quartz deposits in zones of greatest metamorphism (Miser, 1943, pp. 102–107) in the orogeny. The conclusion of recent workers (Honess, 1923, p. 259; Morgan, 1924, pp. 19–21; Powers, 1928, pp. 1047–1049; Miser, 1934, pp. 1007–1009; Harlton, 1938, pp. 861–864) who have studied the geology of the Arkansas-Oklahoma area is that the Ouachita deformation occurred in middle Pennsylvanian time. A late middle Pennsylvanian age therefore seems indicated for the quartz crystal deposits.

## SUGGESTIONS TO PROSPECTORS

The outlines of the crystal district, as indicated by the distribution of localities in plate 25, of necessity are arbitrary. Numerous quartz veins and a few scattered crystal occurrences are known outside this area. However, the prospecting of localities within the district, adjacent to or structurally analogous to those known to contain crystals, will probably be far more productive than random search for new deposits elsewhere in the Ouachita Mountains.

So far, the richest finds of oscillator quartz have been in deposits in the Blakely sandstone, where many deposits may yet be discovered. In both the Blakely and Crystal Mountain sandstones, crystal deposits seem to be localized along longitudinal or nearly longitudinal fissures on the crests and noses of folds. However, the quartz in such fissures may be accompanied by stockworks and transverse veins along the flanks of the folds. The anticlines of the Blakely sandstone along the strike in both directions from the Chance and Miller Mountain areas are especially promising. In these areas and in the Crystal Mountains to the southwest, the productive crystal deposits occur largely in the relatively massive sandstone or argillaceous sandstone.

Productive crystal deposits occur in the thick shales to the north and east of the Miller Mountain, Chance, and Crystal Mountain areas, but these deposits generally contain greater proportions of massive milky vein quartz to crystals, as well as of complex to simple crystals. The veins in shale most likely to yield oscillator quartz are those in the Womble shale, north and northeast of Jessieville and north of Beaudry, but many quartz exposures in the Stanley shale, particularly in the Paron area, consist almost entirely of massive milky quartz. Other exposures, surficially unproductive, probably contain low-grade crystal deposits at depth. Crystal occurrences in the cherts and in the Jackfork sandstone, although subject to the same broad structural controls indicated for the other deposits of the district, are probably the least predictable. This is largely because of the sharply contrasting types of beds within these formations and, in the case of the Jackfork sandstone, because of the limitation of its exposures to the periphery of the major quartz belt.

Some of the more important features of the various deposits and of the associated quartz crystals are given in table 10; from these features may be derived certain generalizations pertaining to the nature of the crystals found in most types of rocks in the district.

Inasmuch as the quartz deposits are characterized by abrupt variations in thickness, in lateral and vertical extent, and in the position of crystal-bearing pockets, it is difficult or impossible to block out crystal reserves. Drill holes can indicate the persistence of quartz deposits at depth, but they reveal little about the crystal content; the presence of vein quartz by no means guarantees the presence of crystals. Adits driven to intersect the vein at depth may strike areas of pinched-out veins and miss a crystal pocket by only inches or feet. The only known way to ascertain the productivity of a deposit is to follow and selectively mine it as economically and efficiently as possible. This procedure requires much care, because methods of handling large amounts of ground rapidly and efficiently are likely to crush random crystals.

## QUARTZ CRYSTAL MINES AND PROSPECTS

Eight of the larger and more productive mines and prospects that exhibit features characteristic of the Arkansas quartz crystal occurrences are described in some detail in the following paragraphs.

### McEARL MINE

The McEarl mine is in the NE¼SW¼ sec. 1, T. 1 S., R. 20 W., 1½ miles west of Chance (Blue Springs) and Arkansas Highway 7 (pl. 35). For several years prior to 1943 small surficial pockets of crystals were worked here, and in the early spring of 1943 about 50 pounds of eye-clear quartz was mined from several pits. The property was purchased in May 1943 by the Metals Reserve Company, which prospected the property until September. During this period two shallow adits were driven almost across the ridge from the southeast, and a series of open-cuts and trenches was dug.

About 4,000 pounds of crystals is said to have been mined prior to May 1943, and about 6,700 pounds of crystals, including 134 pounds of oscillator quartz, was mined by the Metals Reserve Company (table 2).

The Blakely sandstone forms the quartz-bearing ridge that extends across the McEarl property, and adits MA 1 and MA 2 (pl. 35) cut almost the entire thickness, which is here about 150 feet. The upper half of the formation is massive quartzitic sandstone exposed in a belt along the north flank of the anticline west of Chance (pls. 27 and 35). The sandstone strata dip about 35°–75° NW. and grade abruptly into the overlying Womble shale. Friable, deeply oxidized argillaceous sandstones, in part conglomeratic, and sandy shales comprise the lower half, which grades into the underlying Mazarn shale. Veins occur only in the sandstone, both the Womble and Mazarn shales apparently being barren.

The quartz deposits are principally irregular composite veins. Single veins intersect or merge into stockworks in the more highly fractured sandstones. A wide variation in strike is apparent in the veins; most of the dips are steep to vertical. Only a few of the quartz fillings can be traced far without an abrupt change in strike or dimension. Maximum vein widths of 2 to 3 feet are common at intersections. The stockworks are characterized by extreme variations in the proportion of cavity filling and host rock. The largest stockwork explored, at least 50 by 50 by 20 feet, consists of approximately 90 percent host rock and 10 percent quartz and clay.

Many thin irregular zones of sandstone adjacent to fissures are recrystallized, and sand crystals are abundant locally.

Most of the pits and trenches on the south slope of the ridge are located in residual mantle. Several of the cuts have exposed small concentrations of crystals, which are remnants of eroded deposits or small aggregates severed from their source by the extensive rock creep. Several of these crystal concentrations seem to have moved 50 feet or more from the site of the hypogene "parent" vein, which is still in place. Accordingly, these crystal concentrations exhibit no downward vein projections.

### DIAMOND DRILL CARBON CO. NO. 4 MINE

The Diamond Drill Carbon Co. No. 4 mine is in the NE¼SW¼-SW¼ sec. 1, T. 1 S., R. 20 W., about 1,000 feet southwest of the McEarl mine (pls. 27 and 35).

Prior to the spring of 1943 very little prospecting had been done, but about 1,000 pounds of crystals had been mined from the residual mantle. The Diamond Drill Carbon Co. began the No. 4 open-cut in March 1943, found crystals very close to the surface, but by August had practically exhausted the high-grade crystal pockets. Approximately 9,100 cubic yards of ground yielded approximately 8 tons of crystals, including about 760 pounds of oscillator quartz valued at about $4,400.

The geology of the deposit is similar to that of the adjacent McEarl mine. The cut extends across the entire surface width of the Blakely sandstone, which at this place dips 35°–40° NW.

The quartz deposit is a series of intersecting composite veins, which form a stockwork in the fractured massive sandstone. Most of the crystals mined were from two irregular zones, each as much as 10 feet wide, separated by a relatively barren area 10 to 18 feet wide. Many veins in both zones dip steeply, and their strike diverges less than 20° from that of the bedding. Only a few of the veins are simple fissure fillings in which the vein quartz is frozen to sharply defined wall rock. The silica that composes crystals and vein quartz appears to have been in part introduced, and in part derived, by relatively widespread wall-rock recrystallization. Specimens showing all transitions in the process of conversion of wall rock to "vein" are apparent, with many composite veins containing relict outlines of sand grains and irregular segregations of impurities. Because many crystals mined at a depth of 15 to 25 feet near the base of the exposed crystal zone contain numerous inclusions of carbonaceous material and sand grains, they are valueless for piezoelectric or optical uses.

### DIERKS NO. 4 MINE (BLOCKER LEAD)

The Dierks No. 4 mine is in the West Chance area, 2 miles west of the village of Chance (Blue Springs) in the west center W½ sec. 12, T. 1 S., R. 20 W. (pls. 27 and 35).

Although this mine eventually became one of the biggest crystal producers in the district, it was worked very little before 1943. Apparently the early diggers were discouraged by the bulk of surficial massive white vein quartz. Consequently, the main vein zone was not adequately explored until the spring of 1943. At this time the milky vein-quartz "capping" was penetrated by several local miners, who attained a sizable production of both ornamental and oscillator quartz. Operations were entirely by hand, the workings consisting of numerous open holes closely spaced along the strike of the veins. Pockets in a zone 10 to 50 feet wide and 800 feet long, striking about N. 85° E., were prospected to a maximum depth of 20 feet. In 4 months the miners obtained about 50 tons of crystals, of which 2,100 pounds was of oscillator grade. Table 5 shows the several grades represented in most of this output.

In August 1943 the local miners stopped working the productive zone because of claims litigation. In January 1944 the Diamond Drill Carbon Co. set up operations there, exploring the vein with open-cuts as much as 40 feet deep (pl. 35). During the next 4 months this company mined 60 tons of crystals and more than 2,500 pounds of eye-clear quartz, the most outstanding production in volume and in average crystal size (pl. 32) from any single deposit in the district. In the mining operations about 47,000 tons of ground was moved.

The country rock is the argillaceous sandstone facies of the Blakely sandstone. The veins constituting the Blocker lead fill longitudinal fissures along the nose of an asymmetric anticline. The nose, plunging gently toward the west, is best defined by the massive sandstones that crop out in a rude "U" at the base (the southwest end), where the deposit is located (pl. 35). Erosion has exposed the Mazarn shale along the crest of the anticline east of the property, and the contact with the shale is inferred to underlie the property at depths of 40 to 60 feet.

The crystal-bearing veins that together form the Blocker lead have known widths up to 10 feet, and the vein zone, including as much as 50 percent of slabby or brecciated host rock, swells to widths of 30 to 50 feet. Although the over-all strike of the zone is about N. 85° E., single veins vary as much as 12°. Most veins dip steeply or vertically, but locally gentle dips occur along "rolls" that are nearly horizontal, lacking appreciable plunge.

Pockets, initially of the comb and sack types, are badly crushed. They consist of jumbled masses of fractured complex crystals, vein quartz, and decomposed wall rock. Pockets mined to date have measured as much as 4 by 10 by 30 feet and have contained mostly large crystals (pl. 32), the largest weighing as much as 600 pounds.

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The acceptable oscillator crystals (mine-run) average between 500 and 1,000 grams in weight, more than in any other known Arkansas deposit. Many crystals between 20 and 40 pounds contain 10 to 30 percent oscillator quartz. The largest single piece of oscillator quartz mined weighed 18 pounds after cobbing. However, more than 88 percent of the eye-clear quartz shows appreciable optical twinning (table 5). Etch tests also indicate widespread electrical twinning.

No associated primary minerals have been found in the exposed deposits, which are deeply weathered, but many crystals and fragments of vein quartz contain rhombohedral casts of calcite. Clots of kaolin and dark-red halloysitic clays fill fissures throughout the deposits. Crystal and vein quartz with carbonaceous inclusions occur locally.

### MILLER MOUNTAIN MINE

The term "Miller Mountain mine" refers to the crystal diggings, some of which are underground, in the southern part of sec. 2, T. 1 S., R. 21 W., 8½ miles by airline and 10 miles by road west of Jessieville, Ark. The Cedar Glades road skirts the mountain on the north. The principal productive deposits are on the C. H. Miller tract, which is in the SE¼SW¼ sec. 2; the H. E. Bauer tract, which is in the SW¼SE¼ sec. 2; and the Dierks Lumber and Coal Co. tract, which is in the E½SE¼ sec. 2 (pl. 36).

Most of the prospecting and mining prior to 1943 was of a desultory nature and was confined to shallow pits and trenches dug by property owners or other local inhabitants, principally between 1890 and 1910 and between 1928 and 1942 (pl. 36). In the winter of 1942–43, the Metals Reserve Company leased the Miller and Bauer tracts, and the Diamond Drill Carbon Co., of New York, took an option on the Dierks land. The Metals Reserve Company operations, which were discontinued in September 1943, included about 830 feet of underground workings and a series of open-cuts and trenches (pl. 37). During February 1943, the Diamond Drill Carbon Co. prospected the south mountain slope on Dierks Lumber and Coal Co. land by means of several open-cuts (pl. 36) but did not find any valuable quartz crystals.

The quartz crystal production, prior to 1943, in the area of the various workings described, is unknown, but it probably exceeded 10 tons of salable crystals, most of which was sold to tourists and mineral collectors. In the summer of 1943, the Metals Reserve Company mined approximately 8 tons of crystals including 854 pounds of oscillator grade (tables 2 and 3), almost entirely from the north area shown in plate 37, on the north slope of the mountain. After the termination of the lease by the Metals Reserve Company, mining was resumed by the owners, who, up to December 15, 1943, had mined approximately 2,000 pounds of crystals, including 140 pounds of oscillator grade. Crystals from Miller Mountain are uniformly small (73.6 percent are under 200 grams), although a high proportion have areas of eye-clear quartz. However, examination in the "inspectroscope" with polarized light indicates that more than 80 percent of the eye-clear crystals are optically twinned. Many of the crystals below oscillator grade can be sold as mineral specimens.

The country rock at the Miller Mountain mine is the argillaceous sandstone and conglomerate facies of the Blakely sandstone. The deposits are localized along the crest of the Miller Mountain anticline, on the crest and upper slopes of the ridge. The wall rock is highly fractured and deformed, but several more competent sandstone beds are exposed well down the north and south flanks of the ridge and serve as the best guides to general structure (pl. 36). The extreme nature of the deformation in the less competent facies is well exposed underground, where the more brittle strata are complexly broken and milled into the adjacent plastic shaly sandstones, forming tectonic breccias.

Well-developed fractures and fissures, in general dipping steeply or vertically, strike slightly north of east. The largest fault observed underground is a normal fault with a displacement of only 4 feet. The extreme alteration of the rock, however, could readily obscure faults of much greater magnitude.

The crystal-bearing veins on the north slope of the ridge are in the deeply oxidized argillaceous sandstone that here forms the lower portion of the Blakely sandstone. The veins split into barren milky stringers or pinch out downward near the contact with the underlying Mazarn shale.

The principal mine workings on the north slope of the ridge follow two subparallel vein zones as much as 30 feet wide (pl. 37). Along both veins the proportion of crystals to milky vein quartz is particularly high, locally reaching a ratio of 1 to 1. The east drift and a raise (vertical section *E–E′* and *H–H′*, pl. 37) from MA 4 (pl. 36), which is 16 feet below the surface, followed a shattered comb pocket in the Bauer lead almost continuously for 60 feet along the strike (see also fig. 28). The pocket merged downward into milky vein quartz 8 to 15 feet above the Mazarn shale. On the Miller tract (SE¼SW¼ sec. 2), the argillaceous sandstone is less deeply dissected, and the contact with the Mazarn shale is 40 to 80 feet below the surface. Crystals persist in the veins to depths as great as 40 feet.

### HAMILTON HILL MINE

The term "Hamilton Hill mine" refers to the crystal diggings in the SE¼ sec. 14 and the SW¼ sec. 13, T. 1 N., R. 19 W., 5 miles north-

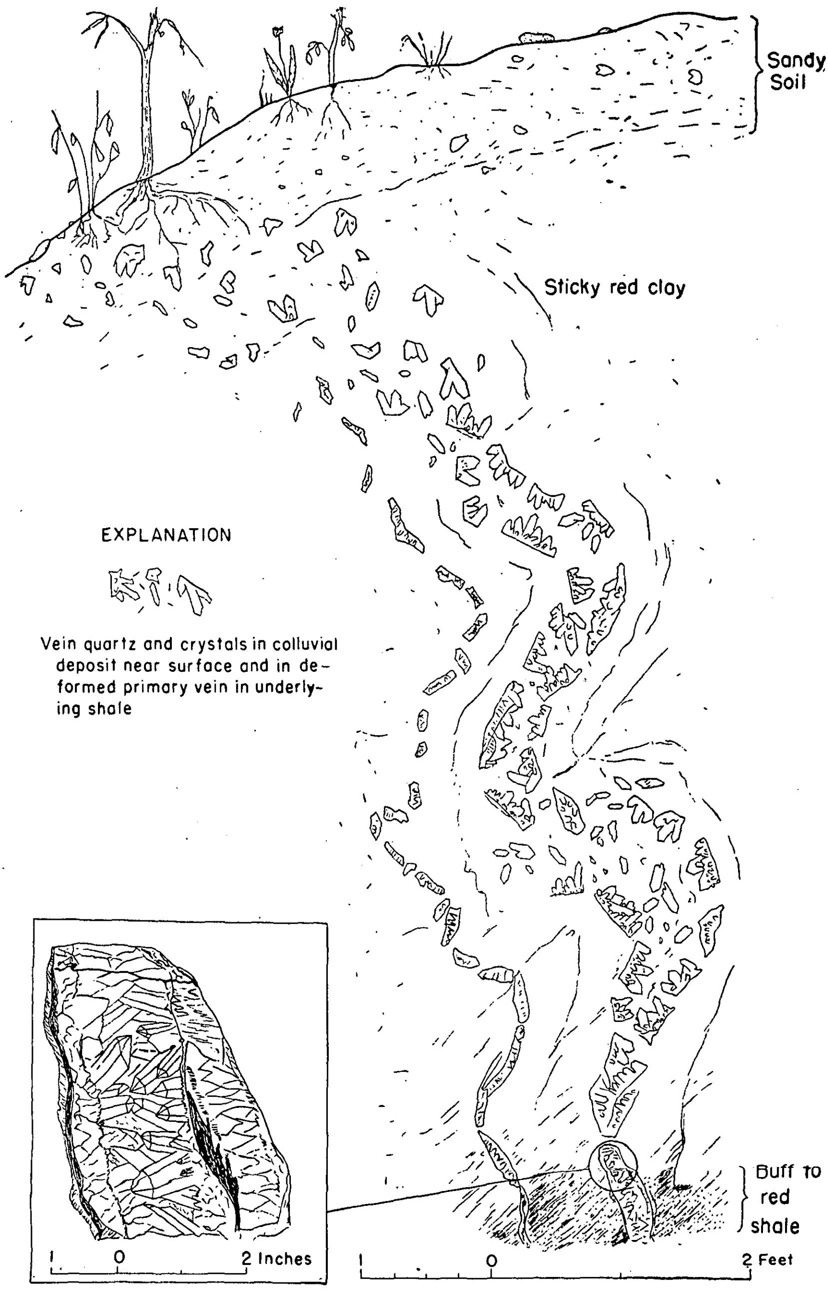


FIGURE 28.—Sketch of a deformed and partly dispersed comb crystal pocket in a quartz vein on the north slope of Miller Mountain, Garland County, Ark. This exposure is on the east wall of the shaft leading to the underground level labeled MA 3 (pl. 36). The fractured and dispersed form of the vein is interpreted as in part the result of orogenic deformation during the growth of the quartz (see also fig. 27) and in part due to weathering processes. Thus the upper third of the vein is interpreted as dispersed largely by volume changes and creep of the soil mantle as it has evolved from the buff to red sandy shale visible in place at the base of the drawing.

east of Jessieville, Ark., on the property of the Dierks Lumber and Coal Co. (pl. 38). Quartz crystal mining was begun at Hamilton Hill shortly after the Civil War by William Hamilton and John Neal. Hamilton worked the deposits for about 25 years and did most of the development work. The mine workings consist mainly of three short adits, no more than 30 feet long, which were caved in 1945; two caved vertical shafts said to have been sunk to depths of 30 and 40 feet, respectively; and numerous small surface pits. In the summer of 1943, a few shallow surface pits were dug by John Ridgeway and George Clemmons.

The crystal production at Hamilton Hill is reputedly greater than that from any of the older mines in the vicinity of Jessieville. A relatively high percentage of eye-clear crystals weighing more than 100 grams is said to have been obtained. In addition, much display material of particular interest to collectors and mineralogists has been found. Quartz exposures at the mine are limited to several pits on the upper east ridge and on the hill slope to the west, along what are readily inferred to be nearly parallel veins or vein zones in the Womble shale.

Forest growth and a thin mantle of soil and rock almost completely cover the area. In exposures along Angling Creek to the north and to the southwest of the most westerly pits, black shales and some limestone and chert are deformed into small complex folds that commonly strike southeast or a little north of east. A well-defined slaty cleavage forms flat folds whose gentle flanks dip predominantly to the north and to the south. In the scattered outcrops are many fractures which strike S. 60°–75° E. and dip almost vertically. These fractures commonly are sharp and show little displacement, but some have crumpled and sheared walls and appear to be small faults, with displacements of several inches or a foot, nearly parallel to the plane of rupture. These two types of fractures, presumably transitional, appear to contain most of the quartz deposits in the area.

Each prospected vein or group of slightly diverging veins seems to be separated from nearby veins by irregular segments of shale 15 to 25 feet wide. The veins mined in the east workings apparently are separated from the more productive deposits on the west slope by 100 to 200 feet of barren ground. Exposed veins are nearly vertical and strike about N. 76° W. Vein widths are variable but are not greater than 8 feet, and the amount of fracturing seems to vary considerably along each vein. Some pockets are badly crushed, whereas others retain a primary comb structure and have relatively unmarred clusters. Adularia and calcite are abundant in the crystal pockets, along the massive parts of one vein zone in the center of the west workings and at the most northerly mined vein in the east diggings. Minute rhombs of calcite, and, uncommonly, adularia form inclusions in layers parallel to crystallographic planes in crystals from these veins. Carbonaceous and frothy quartz phantoms, most commonly formed parallel to rhombohedral faces, characterize many crystals from the northern vein at the west diggings.

### FISHER MOUNTAIN MINE

The term "Fisher Mountain mine" refers to diggings in the S½SE¼SE¼ sec. 4, the S½SW¼SW¼ sec. 3, and a small area immediately adjacent to the section line in the NW¼NW¼ sec. 10, T. 3 S., R. 24 W., on the ridge known as Fisher Mountain (pl. 39). All the deposits are in the Ouachita National Forest. Most mining has been done on a 40-acre area in section 4.

Prospecting and mining were probably begun by the Indians, according to William Fisher, and were continued by white settlers intermittently up to 1942. Diggings consisted of shallow prospect pits and trenches. The Metals Reserve Company leased the property in the spring of 1943 and subsequently drove three adits totaling 260 feet, two on the north slope of the mountain and one on the south slope, across the strike of the quartz veins. Surface operations included four open-cuts, FC 1 to FC 4 on plates 39 and 40, the most important being cut FC 4 (pl. 39). The Metals Reserve Company stopped mining in September 1943, and the leases were allowed to lapse.

The Metals Reserve Company handled about 32,000 tons of ground, more than four-fifths of it from cut FC 4. Of some 15 tons of crystals mined, 206 pounds passed the National Bureau of Standards specifications for oscillator quartz (table 4), and perhaps half the remainder was sold as museum or curio quartz. Local miners have estimated previous production, most of which was bought for curio or museum specimens, as somewhat greater than the Metals Reserve Company totals.

Most of the quartz occurs apparently along the crest of an anticline overturned to the south (pls. 26 and 39), in fractures that strike N. 55°–85° E. and dip 50°–80° NW., in Crystal Mountain sandstone. These fractures trend at angles of 20° to 40° to the trace of the axis of the fold, and, inasmuch as they occur along the crest of the anticline, the dip is almost normal to the bedding. They commonly occur in 2- to 10-foot zones spaced as much as 50 feet apart. Where they coalesce, they form sheeted zones of the types mined in cut FC 4 (pl. 39).

A set of remarkably uniform, well-defined vertical fractures, which are well exposed in outcrops 700 feet to 1,200 feet southeast of open-cut FC 4 (pl. 39), strike N. 20°–35° E. across the main fissures. These fractures are 3 inches to 2 feet apart and occur chiefly along the crest and the south flank of the anticline. Many of the fractures are barren of vein quartz, and the quartz veinlets in others are thin discontinuous shoots branching from the major veins. Random shears and fractures partly obscure the fracture sets, however, particularly along the north side of the mountain crest. The most productive vein zone, mined in open-cut FC 1, is 10 feet in maximum width and contains up to 80 percent inclusions of the host rock or slabby portions of it. The largest clusters of crystals produced in the Arkansas district prior to the Metals Reserve Company operations were mined by John and Garfield Lewis at the southwest end of this zone, at what is now open-cut FC 1.

More than three-quarters of the crystals mined by the Metals Reserve Company were from the southwest part of the sheeted zone in open-cut FC 4. There crystals occur in comb and crush pockets, randomly spaced and irregular in size. The average pocket, measuring perhaps ¾ by 2 by 3 feet, may connect with other pockets or plates extending continuously as much as 10 feet down dip and along the strike.

### WILLIS MINE

The Willis mine is in the NE¼SW¼ sec. 22, T. 2 N., R. 17 W., 3 miles northwest of Paron, Ark. (pl. 41). The mine was worked intermittently for 40 years prior to 1942 by the owner, J. T. Willis, and by contracting miners. The single cut, up to 25 feet deep, has been opened entirely by hand. Miser (1942) reports a crystal production of about 200 tons over a period of 1½ years in the late 1930's. Many of the crystals are exceptionally large, the largest single crystal or "point" weighing 330 pounds and the largest cluster 750 pounds. Although most of the crystals have been bought by collectors or used for decorative purposes, some clear quartz is said to have been sold for optical use.

The enclosing rock, Stanley shale, consists of shales, siltstones, and sandstones ranging from buff or green to black. In the mine opening, sericitized and chloritized siltstones comprise two-thirds of the enclosing rock. The beds strike southeast and dip to the northeast in conformity with the larger structural features of the Paron area.

The quartz deposits are a series of wide lenticular fissure fillings that strike about N. 45°–60° W. and dip steeply or vertically. At least three and possibly five veins are exposed on the property, and numerous others occur on adjacent tracts. The vein that is exposed in the mining cut may be traced for 120 feet, and it ranges from 6 to 13 feet in width. In May 1943, no crystal pockets were exposed, and the quartz in place was massive and milky. However, numerous rejected crystals were found scattered over the dumps. Small amounts of chlorite are intergrown with some of the quartz locally, particularly adjacent to the country-rock contacts. Inclusions of host rock are not abundant in the quartz.

The small knoll about 400 feet northwest of the mining cut contains two quartz exposures. The more westerly exposure appears to be a zone, about 40 feet wide, of massive, milky vein quartz and numerous country-rock partitions. About 200 feet to the northeast is a similar but narrower zone. One or both of these deposits may be a continuation of the mined veins, although the absence of intervening quartz exposures or areas of float is unfavorable to this assumption. Other exposures of vein quartz were seen about 450 feet southeast and 375 feet north of the mine.

## MARLER MINE

The Marler mine is in the SW¼SW¼ sec. 17, T. 1 N., R. 17 W., three-quarters of a mile north of U. S. Highway 270, on land belonging to the Gurdon Lumber Co. (pl. 42). The prospect and mine pits on the three low knolls, 600 to 700 feet apart, were dug between 1935 and 1943 by Will Marler, of Lonsdale. About 6 tons of crystals has been mined from the pits on the western knoll, most of it sold as decorative or museum material for about $2,500. In the early spring of 1943, about 50 pounds of eye-clear quartz—all that remained of an apparently high yield—was sold for oscillator cutting.

The veins occur in buff and black Womble shale that includes thin slabby beds of siltstone and black limestone. Slaty cleavage obscures the bedding in a few outcrops but is commonly less conspicuous than the bedding. The quartz deposits fill uniformly oriented short fissures that strike N. 65°–75° E. and dip steeply. There is no apparent relation between these fractures and the poorly exposed local plications of the strata.

The western pits are in a zone, at least 30 feet wide and 150 feet long, of fractured vein quartz and host-rock fragments. Narrow zones of silicification or selective replacement of slate and siltstone are common. The quartz replacing the slate exhibits structures relict after the original cleavage and bedding. Vestigial carbonaceous matter imparts a blue or gray color to the quartz, which is cut by veinlets of later white quartz. Many of the siltstone beds impregnated by the silica are now quartzitic. Exposures of quartz are confined to the crest of the west knoll, and the veins appear to pinch abruptly along the strike. Closely spaced crystal pockets within the zone have been worked out to a maximum depth of 18 feet, but the vein apparently continues to a greater depth. The largest crystal mined weighed 40 pounds, and the largest crystal of eye-clear quartz weighed 11 pounds. A lamprophyre (monchiquite) dike intruded along the northern margin of the vein is weathered to a deep-green clay containing flakes of biotite and subhedral to euhedral crystals of augite. Both vein quartz and crystals adjacent to or partly enveloped by the dike are thoroughly shattered and exfoliated, with development of an onionlike structure. These effects seem to have been caused by sudden heating of the quartz by the lamprophyre during its intrusion.

The superficial pits in the poorly exposed veins on the knolls to the east are barren of crystals. Similar quartz deposits, whose surface exposures are characterized by massive, fractured milky quartz, crop out in areas adjacent to that shown on plate 42.

### OTHER MINES AND PROSPECTS

Fifty-five quartz crystal mines, prospects, and deposits in the district, of either particular economic or genetic interest, that have yielded small quantities of high-grade quartz are briefly described in table 10. Maps of four of these areas—the Ellison-Dierks and W. T. Beard areas in Garland County and the Monroe-Robbins and Howard-Sheffield areas in Montgomery County—are given on plates 43–45 and figure 29.

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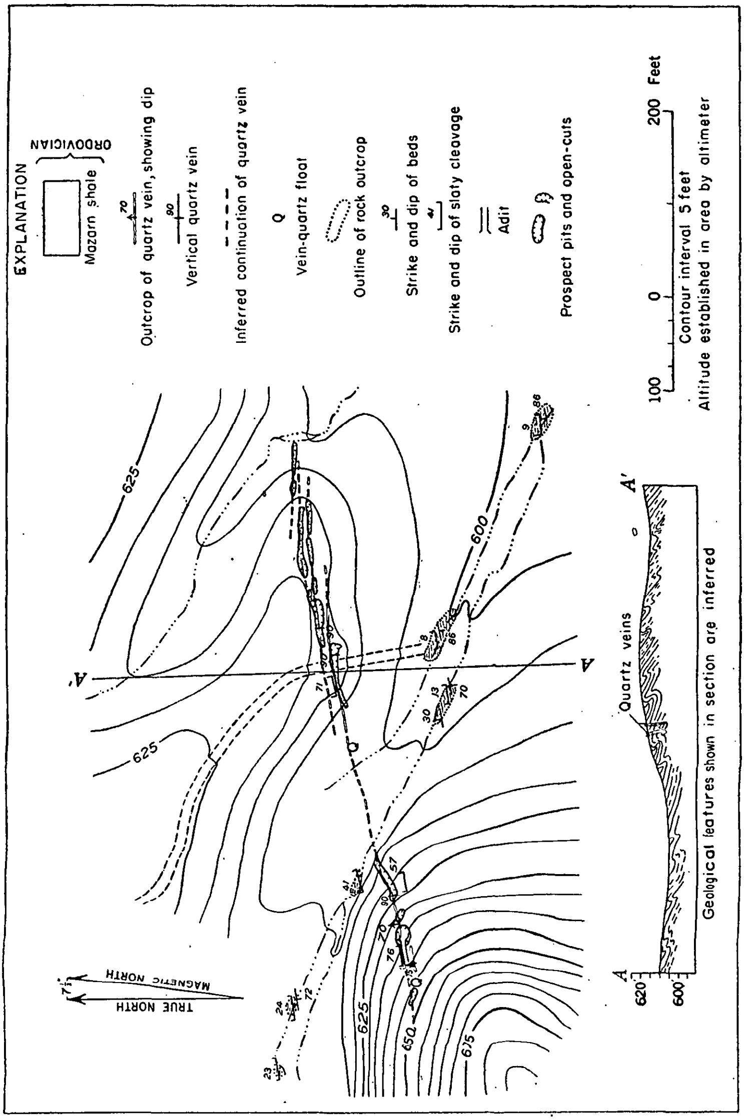


FIGURE 29.—Geologic map and section of the Howard-Sheffield quartz crystal mine, SW¼ SW½ sec. 4, T. 2 S., R. 24 W., Montgomery County, Ark.

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