INVESTIGATION OF THE SOURCES OF QUARTZ GRAINS OF THE BLISS FORMATION (CAMBRO-ORDOVICIAN), SILVER CITY AREA, NEW MEXICO

A Thesis

Presented to

the Faculty of the Department of Geology

University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

James W. Alewine

January, 1966

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ILLUSTRATIONS

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ABSTRACT

The Cambro-Ordovician Bliss Formation of the Silver City area, New Mexico is composed of approximately 190 feet of arkose, orthoquartzite, hematitic sandstone and glauconitic, arenaceous carbonate, resting nonconformably upon Precambrian granitic and metamorphic rocks, which are believed to be the source of most of the quartz grains in the Bliss. Three classes of quartz grains are distinguished: (1) polycrystalline (2) undulatory (monocrystalline strained) (3) nonundulatory (monocrystalline unstrained).

The purpose of this investigation was: (1) to determine whether or not clastic quartz grains can be related to their source rocks, and (2) to examine some current ideas concerning quartz grains, such as the hypothesis that undulatory grains are preferentially destroyed during transportation.

Sixty-eight samples of basement rocks, their outcrop detritus, and sedimentary rocks were collected from outcrops over a distance of 17 miles, and 102 thin sections of these samples were studied. Quartz grain size parameters were determined from sieve analyses and from thin section measurements. Ten parameters were tabulated for each of 5,964 quartz grains. Size, extinction type, abundance of bubble trains, roundness, inclusions, and polycrystallinity were found to be the most significant.

Polycrystalline quartz grains are rare in the Bliss (5.0 to

0.4 percent), but relative proportions of these grains in the various members permitted local correlation. Survival of these grains is attributed mainly to the interlocking nature of individual crystal boundaries. Stretched, sutured polycrystalline grains, presumed to be metamorphic, are virtually absent.

Orthoquartzites of the Bliss, in the fine sand size, have an average percentage (29.3) of nonundulatory quartz grains which is less than that of the local granite (39.0 percent), and is much less than that of the metamorphic rocks (67.0 percent). Percentages of relatively stable nonundulatory quartz grains are therefore not an index of sandstone maturity in this area.

Faulting of undetermined but "substantial" displacement within 100 feet of two sample sites did not significantly alter the percentage of nonundulatory quartz grains.

Although the average width/length ratio of quartz grains in the Bliss (0.66) is almost identical with those of the schist (0.64) and metaquartzite (0.65) and is quite unlike that of the granite (0.48), a preponderance of evidence points to a granitic origin for most Bliss quartz grains. It is apparent that form can not be relied upon to determine provenance in this area.

In the local metaquartzite, interstitial growth of muscovite, subsequently altered in part to sillimanite, resulted in peripheral penetration of adjacent quartz grains by these crystals. This suggests that sedimentary quartz grains which have peripheral concentrations of acicular or irregular inclusions have been derived from a metamorphic source.

After taking into account the size of the quartz grains and postdepositional history, percentages of nonundulatory quartz in the Bliss indicate a granitic rather than a metamorphic source for most of the quartz grains in this sedimentary unit. This conclusion is supported by evidence such as the presence of granite pebbles in the basal arkose; types of polycrystalline quartz grains; percentage of quartz grains without bubble trains; inclusions, and heavy minerals.

INTRODUCTION

Purpose

In the vicinity of Silver City, Grant County, New Mexico, the Bliss Formation is composed of a thin basal arkose and discontinuous pebble conglomerate, overlain by orthoquartzite, siltstone, hematitic sandstone (which locally becomes sandy hematite), and glauconitic, arenaceous carbonate. This Cambro-Ordovician marine lithostratigraphic unit is in nonconformable contact with underlying Precambrian granitic and metamorphic rocks which are thought to be the ultimate source of most of the clastic quartz grains in the Bliss. It was hopefully anticipated that the lateral and vertical variations in the internal character of these quartz grains would make it possible to trace the history of the grains from the time of their release from the source rocks to their incorporation in the Bliss Formation, possibly through more than one sedimentary cycle. The usefulness of clastic quartz grains for this purpose was first suggested by Sorby (1858), repeated by Krynine (1946), and substantially modified by Blatt and Christie (1963) and Blatt (1963). The Blatt hypotheses (based on averages obtained from a geographically and stratigraphically diverse group of samples) with which this project is concerned are as follows:

1. Polycrystalline and undulatory quartz grains are derived in abundance from both plutonic igneous and metamorphic rocks.

Excepting finely polycrystalline quartz, which does appear to be derived largely from metamorphic rocks, distinction between igneous and metamorphic source areas on this basis has little or no justification.

2. Chert, polycrystalline quartz, monocrystalline undulatory quartz and monocrystalline nonundulatory quartz have greater stability, in that order, during weathering and transport. Therefore, the amount of nonundulatory, monocrystalline quartz grains present among the total quartz may be a useful refinement of the estimate of mineralogic maturity. (Volcanic quartz grains, being largely nonundulatory, could produce misleading results if present in abundance; but volcanic rock fragments and idiomorphic, partially resorbed, fractured quartz grains should indicate this source).

3. Relative proportions of polycrystalline, undulatory, and nonundulatory quartz grains in a sedimentary rock may be useful for correlation purposes.

Location and Accessibility

The project area (Figs. 1 and 2) located near Silver City in Grant County, southwestern New Mexico, extends for approximately 17 miles along the outcrop of the Bliss Formation. Except for the Lone Mountain locality (E), the thesis area is confined to the Silver City Range, west of Silver City. This mountain range, which lies along the Continental Divide, is essentially a northeast-tilted horst.

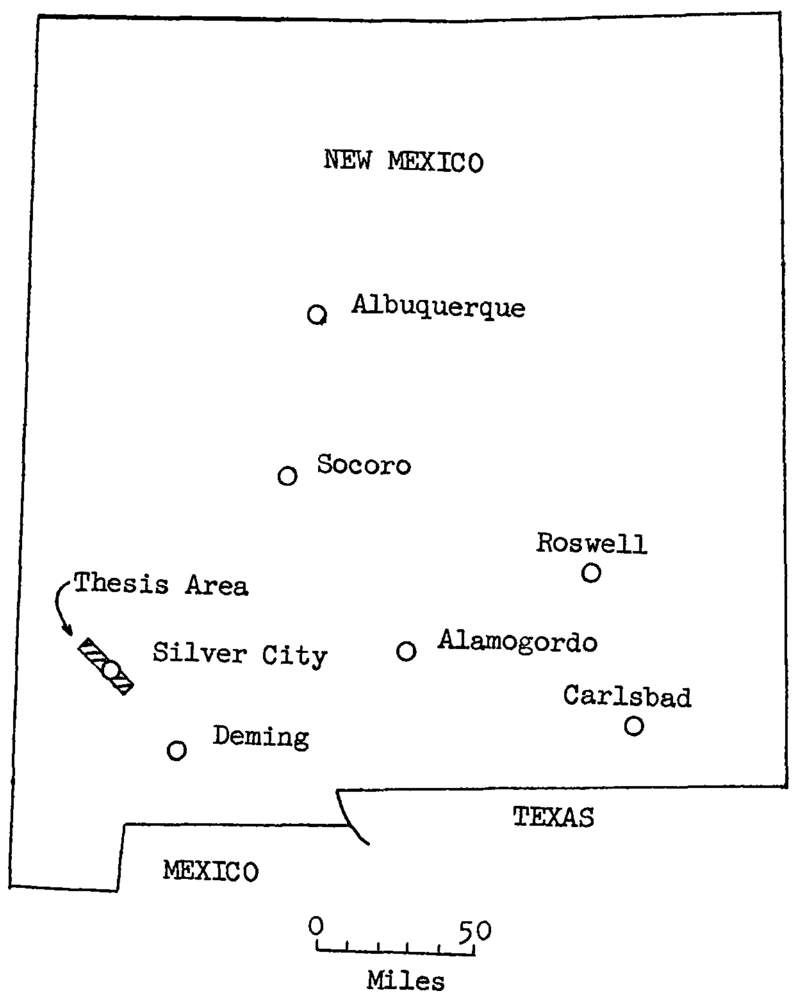


Figure 1.--Index Map of New Mexico

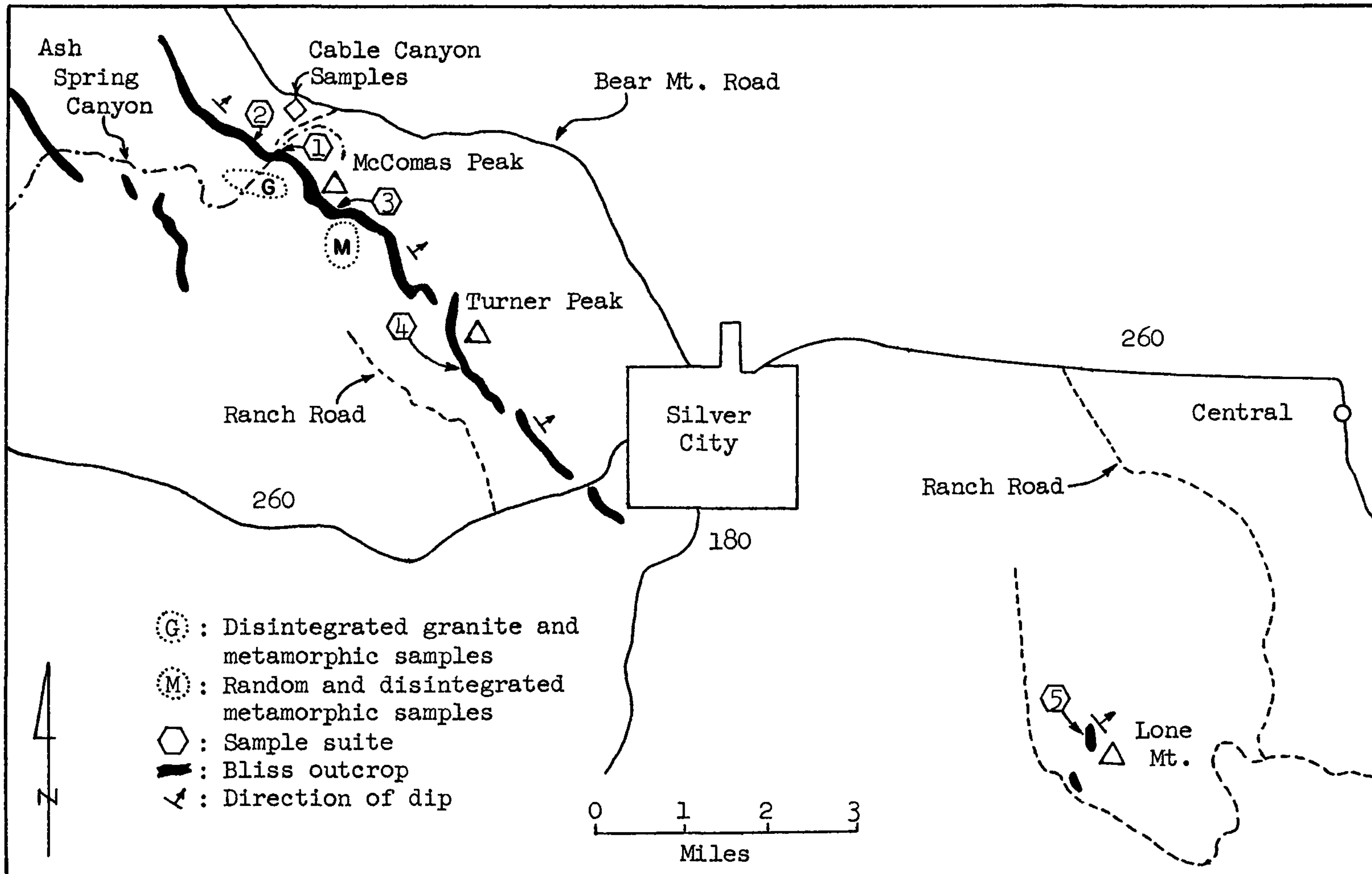


Figure 2.--Sample Locations, Silver City Area, New Mexico

Bliss outcrops after Paige (1916).

Topography is rugged and reaches an elevation of 7,681 feet above sea level at McComas Peak (sample locality C). The majority of samples were collected along the steeper southwestern flank of this fault block.

Localities A (Ash Spring Canyon), D (Turner Peak), E (Lone Mountain), and Cable Canyon (northwest of Ash Spring Canyon) can be approached by ranch roads. Localities B (west of Ash Spring Canyon), C (McComas Peak) and the random sample localities are accessible only by foot. The locations are shown on Figure 2 and described in Appendix 1.

Methods of Study

Samples.--The samples for this project were collected in July, 1963, and in April, 1964. Disintegrated primary rock samples were collected at two outcrops of granite and one outcrop of metaquartzite in the Ash Spring Canyon area and at two outcrops of partially interlayered schist and metaquartzite in the McComas Peak area. Each sample consisted of approximately two pounds of essentially untransported detritus. Undisintegrated samples of igneous, metamorphic and sedimentary rock were generally composed of three fragments, each of which were approximately eight cubic inches in volume. Five localities (A, B, C, D and E) were sampled in detail (Fig. 3) and additional undisintegrated metamorphic and vein quartz samples were collected at random in the McComas Peak area. Two undisintegrated

		Member	Thickness (Feet)	Samples (Feet above base)
CAMBRO-ORDOVICIAN	Bliss Formation	Upper glauconite	63	Not sampled
		Middle calcareous sandstone	16	● 10
		Middle quartzite	20	● 20 ● 10 ● 1
		Thin-bedded glauconite	85	● 20
		Lower hematitic sandstone	2	● 1
		Lower quartzite	11	● 11 ● 5 ● 1
PRE-	CAMBRIAN	Granite and metamorphic rocks		● One foot below contact

Figure 3.--Distribution of Samples at Localities A, B, C, D and E

Thickness data after Lewis (1961).

samples of the Cable Canyon Formation (Montoya Group) were collected north of the Ash Spring Canyon locality. The vertical position of each sample relative to the base of the member concerned was determined by Brunton compass (clinometer) and eye-height.

Laboratory Procedure.--Each disintegrated sample (150 grams) was boiled for 20 minutes in a five percent solution of oxalic acid in order to remove iron stains (Leith, 1950). The dried samples were sieved for 15 minutes in a Ro-Tap utilizing one phi sieve intervals from -2ϕ to $+4\phi$. Silt-sized grains were not graded further. The various size fractions were then weighed, set in plastic, and thin sectioned. The range of screen sizes was adequate for all samples except the metaquartzite, which contained polycrystalline grains coarser than -2ϕ. As screens of -3ϕ and -4ϕ were not available, grids of the appropriate sizes were constructed on cardboard and used to determine the longest dimension of the remaining grains.

Size distributions of quartz grains were obtained by multiplying the weight of each size fraction by the percentage of quartz in that size, as determined by thin section grain counts. The results were plotted on arithmetic probability graph paper, and size parameters were calculated using the formulae of Folk (1961).

Undisintegrated samples of all rocks were examined under a binocular microscope, and in thin section using a polarizing microscope. Sawed sections of carbonate-bearing sedimentary rocks were etched with 10 percent hydrochloric acid and examined with a binocular microscope to determine the percentages of calcite and dolomite.

One hundred randomly chosen quartz grains were examined in each thin section, if that many were present; if not, counting was continued until all grains were included. All thin sections of undisintegrated rocks, except two granite samples, contained at least 100 quartz grains. The coarser size fractions of the disintegrated samples (+2ϕ and larger) were deficient in quartz grains. Due to this factor and the abundance of mica in the schists, the range of grains counted per slide was very large, from 11 to 410, with the average of 167.

The following parameters of each quartz grain (in thin section) were examined:

1. Size--maximum length was measured to determine phi value. Average width was estimated and approximate area in square millimeters was calculated.

2. Extinction type--(undulatory or nonundulatory) was noted.

3. Crystallinity--(polycrystalline or monocrystalline) was noted.

4. Form--width/length ratios were determined.

5. Roundness--Folk's (1961) modification of Powers' (1953) scale was used.

6. Overgrowths--presence was noted (Fig. 4).

7. Polygonization--polygonized grains were classified as undulatory.

8. Vacuoles--abundance was noted.

9. Bubble trains--the number of linear zones of liquid (and/or gas) inclusions was recorded.

10. Inclusions--were identified when possible.

Various combinations of these parameters were then plotted on arithmetic graph paper.

A total of 102 thin sections of the following rock types were examined in the course of this study: disintegrated basement (39); undisintegrated basement (16); sedimentary (Bliss 44, Cable Canyon two); vein quartz (one).

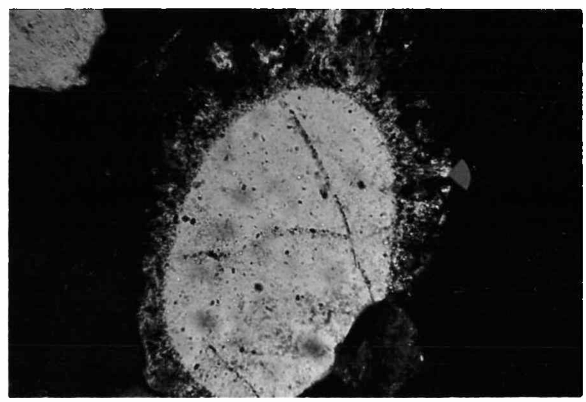
Sample descriptions of undisintegrated rocks as presented in appendices 2 and 3 include additional data.

Definitions

The terms employed in this investigation are defined as follows:

Orthoquartzite: 90 percent or more quartz and chert and less than 10 percent feldspar and polymineralic rock fragments; based on the mineralogy of the gravel, sand, and coarse silt-sized fractions.

Arkose: less than 90 percent quartz and chert and more feldspar than polymineralic rock fragments; based on the mineralogy



1 mm

Figure 4.--Rare Occurrance of a Chert Overgrowth on Monocrystalline Quartz Grain

Sample 70 (middle calcareous sandstone). Crossed nicols.

of the gravel, sand, and coarse silt-sized fractions.

Nonundulatory: extinction is complete with less than one degree rotation of the flat microscope stage.

Undulatory: extinction position varies in different parts of the grain.

Deformation lamellae: thin, closely spaced, subplanar structures in quartz grains. These structures commonly contain brownish inclusions and differ slightly in refractive index from the host quartz grains. Orientation of the lamellae is generally normal to the *c*-axis and to zones of undulatory extinction in the host grain (Fig. 5).

Polygonized structure: a single quartz grain with apparent irregular polygonal subdivisions which have slightly divergent optical orientations (Fig. 6). This phenomenon is believed to represent an early stage in the recrystallization of undulatory quartz grains.

Polycrystalline: two or more quartz crystals which constitute a single grain, neither of which comprises 90 percent or more of the grain area in thin section.

Monocrystalline: 90 percent or more of the grain area in thin section is composed of a single crystal.

Rock fragment: a polymineralic grain in which no mineral constitutes 90 percent or more of the fragment.

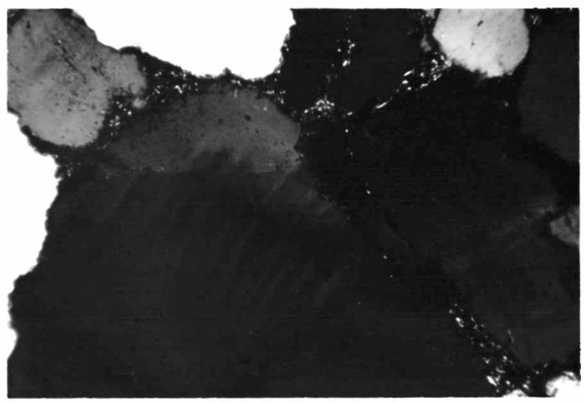


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Figure 5.--Deformation Lamellae

Sample 60 (lower quartzite). Crossed nicols. Note orientation normal to extinction band which approximately parallels c-axis.

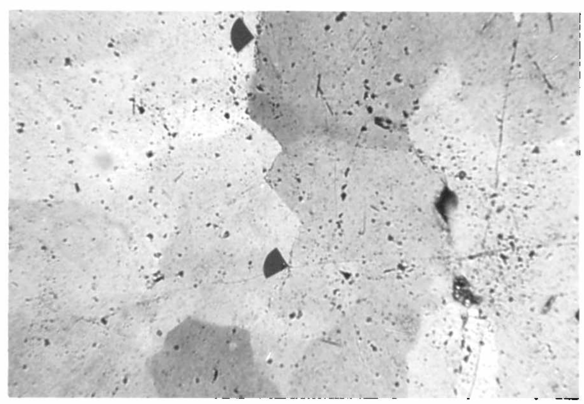

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Figure 6.--Polygonized Structure in Quartz Grain

Sample 60 (lower quartzite). Crossed nicols. Note bubble trains along polygonal boundary, which indicate that fracturing is sometimes involved in the polygonization process (Blatt, oral communication).

Bubble trains: planar concentrations of water (or other liquid and/or gas) bubbles (Fig. 7). They probably result from the trapping of liquid during the process of fracture healing (by secondary deposition of quartz).

Phi (ϕ): a logarithmic transformation of the Wentworth grain size scale in which -1ϕ equals 2 millimeters; 0ϕ equals 1 millimeter, +1ϕ equals 0.5 millimeter, etc.

Folk's (1961) roundness scale: Powers' roundness images (1953) are assigned numbers as follows: 0-1, very angular; 1-2, angular; 2-3, subangular; 3-4, subround; 4-5, round; 5-6, very round.

Roundness sorting (σ_ρ): standard deviation of roundness (using Folk's scale).

Previous Work

Bliss Formation.--The stratigraphy of the Bliss Formation has been described by many geologists, beginning with Richardson (1904), who named the formation. The type section is located in the Franklin Mountains, near Fort Bliss, Texas. Here the Bliss is a sandstone approximately 250 feet in thickness, which accounts for the common reference to the Bliss as a sandstone. Elsewhere (as at Silver City) other lithofacies may predominate.

Paige (1916) mapped the Silver City area as part of a reconnaissance survey for the United States Geological Survey. Kelley's

1 mm

Figure 7.--Bubble Trains Crossing Quartz
Grain Boundaries

Sample 17 (lower quartzite). Crossed nicols. This is evidence of postdepositional brittle fracture.

(1951) paper on hematite in the Bliss Formation described the stratigraphy in general, and included a comprehensive list of workers who had previously published stratigraphic data on this formation, mainly in New Mexico. More recent work has been done by Flower (1953), Lewis (1961), Pratt and Jones (1961) and Kottlowski (1963). The Silver City area has also been studied for the past several years by University of Houston geology students during their undergraduate summer field camp.

Quartz Grain Parameters.--Since the earliest reported observation of internal features in quartz (Sorby, 1877), petrographers have, in addition to seeking an explanation for these features, attempted to relate them to particular types of igneous and metamorphic source rocks. The parameters commonly employed in this effort have been extinction type (undulatory and nonundulatory), polycrystallinity, inclusions, and the numerical value of flat stage rotation (expressed in degrees) required to produce extinction. Also, grain shape has often been used in conjunction with the internal features as an indicator of provenance. Since Blatt and Christie (1963) have comprehensively summarized work previously done on the internal characteristics of quartz, discussion of work done prior to 1963 will be minimized in the following sections.

Acknowledgements

The writer is indebted to Dr. Harvey Blatt and Dr. Robert

Greenwood, for suggesting the thesis problem, and for supervising the research. I am also grateful to Dr. Max F. Carman for his help with problems concerning metamorphic petrography; to Dr. Walter Sadlick for critically reading the manuscript; and to Dr. Wayne Wentworth of the Chemistry Department for serving on the thesis committee.

STRATIGRAPHY

General

In the Silver City area, rocks of every geologic system are present (except Permian, Triassic, and Jurassic) including Precambrian metamorphic rocks, which are intruded by granite; Paleozoic and Mesozoic marine sandstones, limestones, and shales; and Cenozoic igneous intrusives, extrusives, pyroclastics, and continental sediments. In this study only the Precambrian basement rocks, the Cambro-Ordovician Bliss Formation, and the Ordovician Cable Canyon Formation were sampled.

Precambrian Basement Rocks

Granite is probably the dominant basement rock in the study area, since it underlies three (A, B, and E) of the five major sample localities. However, basement rock is not exposed in at least one-third of the project area, and metamorphic rocks may have a wider distribution than is apparent from the areas sampled. Available data are inadequate for a reliable estimate of the relative percentages of igneous and metamorphic basement rocks in the potential source areas for the Bliss near Silver City (Fig. 8).

The metamorphic rocks occurring in the McComas Peak area (locality C and random samples) are mainly metaquartzites and quartz-sillimanite-muscovite-biotite schists. Meta-arkose was observed at Turner Peak (locality D). Minor amphibolite float is present and is

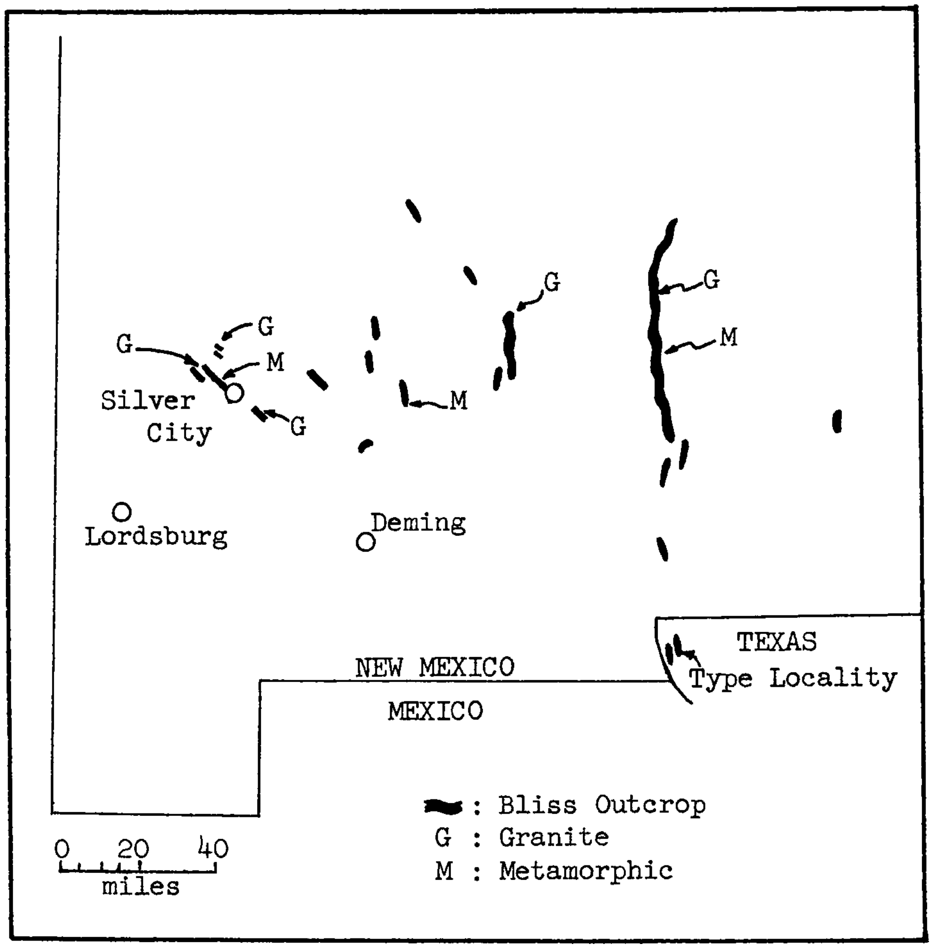

Figure 8.--Outcrop Map of the Bliss Formation Showing Type of Basement Rock at Some Localities in Southwest New Mexico

Bliss outcrops after Kelley (1951).

possibly derived from metamorphosed (?) basic dikes which occur locally.

Except for occasional channels with less than three feet of relief, the erosional surface on the Precambrian rocks very nearly achieves the ideal peneplane (Fig. 9). In the McComas Peak area, the contact between the Bliss Formation and the underlying meta - morphic rocks is discordant (Fig. 10).

Bliss Formation

Lithology.--Figure 11 illustrates the stratigraphic subdivisions of the Cambrian and Ordovician systems in the Silver City area. The Kelley and Silver (1952) classification of the Montoya Group, with which most geologists agree, was used in this study. Their classification of the El Paso Group and local nomenclature of Bliss members as reported by Lewis (1961) were also utilized. Pratt and Jones (1961), Lewis (1961) and Greenwood (oral communication) were the sources of thickness data for the Montoya, Bliss and El Paso units respectively.

The Bliss Formation is approximately 190 feet thick in the area studied and thickens in a south-southwestward direction. A thin pebble conglomerate, commonly present at the base of the Bliss, has subangular to well rounded pebbles which may attain 40 millimeters in longest dimension. Although the smaller pebbles have high sphericity, the larger ones are usually ellipsoidal. Pebbles

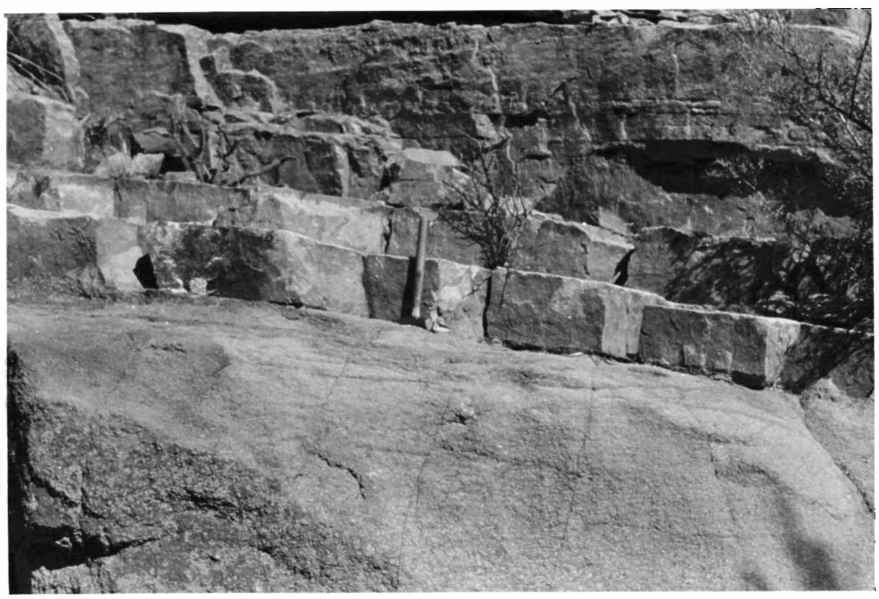

Figure 9.--Contact between Precambrian Granite and the Lower Quartzite Member of the Bliss Formation in Ash Spring Canyon

Note extremely even granite surface.

Figure 10.--Precambrian Metaquartzite and Schist in Contact with the Lower Quartzite Member of the Bliss Formation in McComas Peak Area

Note angularity of contact (red arrows). Fault with small displacement occurs at right (orange arrow) in photograph.

<table>
<tr><th>SYSTEM</th><th>Series</th><th>Group or Formation</th><th>Formation or Member</th><th>Approximate Thickness (Feet)</th><th>Lithology</th></tr>
<tr><td rowspan="4">UPPER ORDOVICIAN</td><td rowspan="4">Cincinnatian</td><td rowspan="4">Montoya Group</td><td>Cutter</td><td>207</td><td>Dolomite</td></tr>
<tr><td>Aleman</td><td>77</td><td>Cherty dolomite</td></tr>
<tr><td>Upham</td><td>52</td><td>Dolomite</td></tr>
<tr><td>Cable Canyon sandstone</td><td>16</td><td>Sandy dolomite</td></tr>
<tr><td rowspan="2">LOWER ORDOV-ICIAN</td><td rowspan="2">Canad-ian</td><td rowspan="2">El Paso Group</td><td>Bat Cave</td><td rowspan="2">600</td><td>Dolomitic limestone</td></tr>
<tr><td>Sierrite</td><td>Cherty limestone</td></tr>
<tr><td rowspan="6">UPPER CAMBRIAN</td><td rowspan="6">Croxian</td><td rowspan="6">Bliss Formation</td><td>Upper glauconite</td><td>63</td><td>Glauconitic dolomite</td></tr>
<tr><td>Middle calcareous sandstone</td><td>16</td><td>Dolomitic sandstone</td></tr>
<tr><td>Middle quartzite</td><td>20</td><td>Orthoquartzite</td></tr>
<tr><td>Thin-bedded glauconite</td><td>85</td><td>Sandy, glauconitic dolomite</td></tr>
<tr><td>Lower hematitic sandstone</td><td>2</td><td>Hematitic sandstone</td></tr>
<tr><td>Lower quartzite</td><td>11</td><td>Orthoquartzite</td></tr>
<tr><td colspan="3">Precambrian</td><td colspan="3">Igneous and metamorphic rocks</td></tr>
</table>

Figure 11.--Stratigraphic Nomenclature in the Silver City Area

After Kelley and Silver (1952), Pratt and Jones (1961), and Lewis (1961).

observed in the study area are exclusively vein quartz and granite, but pebbles of pegmatite, quartzite, gneiss, and schist have been reported elsewhere (Kelley, 1951).

Several sections of the Bliss Formation were measured in detail in the area by Lewis (1961) and some of his data are used in the following general description of the various members.

The lower quartzite member, which averages approximately 11 feet in thickness, is a pink to brownish gray orthoquartzite (except for an eight-to ten-inch arkose and discontinuous pebble conglomerate at its base). Some beds are rather massive; others are thin and cross-bedded. A one-to two-foot zone containing numerous vertical worm tubes is characteristic of the top of this member.

Thickness of the lower hematitic sandstone is about two feet (zero at the Lone Mountain site). The brownish red color is due to the hematite content, which predominates in some samples, resulting in a sandy hematite rather than a hematitic sandstone (Figs. 12 and 13). Bedding is thin to irregular.

An abundance of glauconite apparently inspired the name "thin-bedded glauconite", which was applied to the next higher member. However, this thin-bedded, light gray-green unit, with an average thickness of 85 feet, is predominately dolomite. Arenaceous zones occur mainly near the base and top. The only fossils observed were phosphatic brachiopod shell fragments.

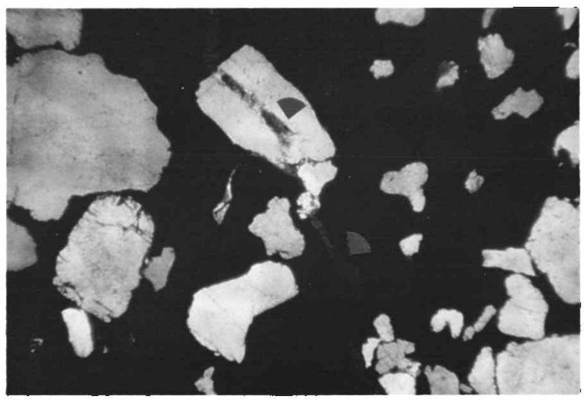

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Figure 12.--Glauconite (?) "Ribbon" Penetrates Quartz Grain

Sample 35 (lower hematitic sandstone). Uncrossed nicols. Glauconite (?) apparently fills a fracture which was only partially open across the quartz grain and replaces quartz in part. Black area is hematite.

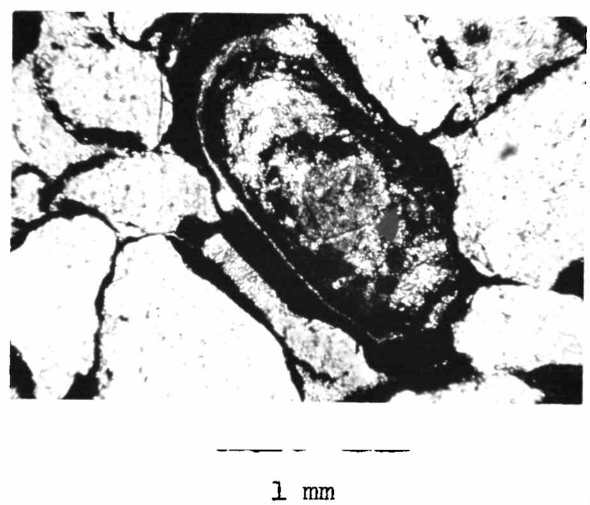


Figure 13.--Glauconite (?) Crystal Nucleates Hematite Oölith

Sample 19 (lower hematitic sandstone). Uncrossed nicols. Note additional disseminated glauconite (?) adjacent to nucleus. Black area is hematite. Light gray grains are quartz.

The middle calcareous sandstone, approximately 16 feet thick, is a brownish gray, cross-bedded calcareous sandstone. In some samples, however, carbonate (dolomite) predominates. Phosphatic brachiopod shell fragments are abundant in some thin sections.

The uppermost member of the Bliss Formation--the upper glauconite--was not sampled. This unit (average thickness 63 feet) is similar to the thin-bedded glauconite member, but contains less glauconite.

The contact between the Bliss Formation and the cherty limestone and dolomite of the El Paso Group (Early Ordovician) is gradational. The El Paso is disconformably overlain by the sandy Cable Canyon Formation of the Montoya Group (Late Ordovician), from which were taken two samples for comparison with Bliss and basement rocks.

Age.--The age of the Bliss Formation was first regarded as Cambrian on the basis of inconclusive faunal evidence (Flower, 1953). Flower, however, concluded that the upper part of the Bliss is Early Ordovician in age, and the basal Bliss may be as old as Late Cambrian. Kottlowski (1963) reported the common occurrence of Early Ordovician fossils in the upper part of the Bliss in many areas, including the type locality in the Franklin Mountains, where the basal 160 feet are unfossiliferous and the upper 80 feet contain Early Ordovician fossils.

Depositional Environment.--The presence of worm borings, marine fossils (mainly fragments of phosphatic brachiopod shells), glauconite, oölitic hematite, orthoquartzite, and limestone (with intraclasts), suggests that the Bliss Formation in the Silver City area was deposited in a warm, clear, relatively shallow (probably less than 200 feet), well-aerated, moderately agitated marine environment. The intraclastic carbonate zones are probably a product of storms, which rip up consolidated or semiconsolidated sediment and redeposit it near the original site of deposition.

QUARTZ GRAIN PARAMETERS

Size

Friedman's (1962) graphs were used to convert thin section mean and modal sizes to sieve size in this investigation. Silt-sized quartz grains were included in this study of disintegrated primary rock debris, but not in the undisintegrated samples. All quartz grains in undisintegrated igneous and metamorphic samples were regarded as monocrystalline, since by definition, polycrystalline quartz grains can only exist in clastic rocks.

Size is directly related to the abundance of several of the internal features of quartz grains, and for this reason this parameter will be discussed mainly in conjunction with other aspects of quartz.

From his studies of primary rock detritus, Blatt (1963) concluded that newly released monocrystalline quartz grains derived from plutonic igneous rocks fall mainly within the medium and coarse sand size range (+2.00ϕ to 0.00ϕ), while those from schists and gneises are usually very fine to fine (+4.00ϕ to +2.00ϕ). Thus sedimentary monocrystalline quartz grains with sizes larger than +2.00ϕ were considered to be derived primarily from plutonic igneous rocks. The average size of monocrystalline quartz grains from two samples of disintegrated granite (Silver City area) was 0.30ϕ which is well within the medium to coarse sand size range. However, the mean size of quartz grains in five undisintegrated schists was +1.76ø, which also falls within the medium to coarse range. The *t*-test indicates a 95 percent probability that this mean lies between 1.42ø and 2.10ø. In the latter case it would, of course, fall within the expected range, but it does point to the need for caution in using grain size as evidence of ultimate source.

Polycrystalline Quartz

Blatt (1963) observed that plutonic igneous polycrystalline quartz grains were generally composed of fewer individual crystals than those derived from gneisses and suggested that the number of crystals in thin sectioned polycrystalline grains might be useful as a provenance indicator. Since polycrystalline quartz grains were rare in the Bliss Formation, this line of investigation was not pursued in the present study.

Blatt and Christie (1963) concluded from their examination of 163 thin sections of igneous, metamorphic and clastic rocks that abundance of polycrystalline quartz grains cannot be relied upon to distinguish between plutonic igneous and metamorphic sources. They do, however, consider large concentrations of polycrystalline quartz to be indicative of proximate derivation from a primary source rather than from older sandstones. It was also noted that the relationship between abundance of polycrystalline quartz grains and mineralogic maturity is inverse, presumably due to fracturing along the boundaries of these grains as a result of sedimentary processes.

Conolly (1965) regarded abundance of polycrystalline quartz grains as quite useful in the determination of provenance, provided allowance is made for quartz grain size, and the mineralogy and texture of the other constituents of the sandstones are known, which makes it possible to determine whether the variation in polycrystalline quartz percentages is a result of changes in source, transportation, or distribution.

The influence of grain size on the distribution of polycrystalline quartz is illustrated in Figure 14.

The apparent rapidity with which polycrystalline quartz grains may be eliminated from the sedimentary cycle is illustrated in the Silver City area by the lower quartzite member of the Bliss Formation. Sample 5, a lower quartzite arkose, was collected one foot above the base of the Bliss Formation. The mineralogic immaturity of this sample is indicated by the feldspar content (21.0 percent as compared with 2.0 percent for the total Bliss). Also, the average quartz grain size (+0.85ϕ) is larger than that of the lower quartzite (+1.51ϕ) and the total Bliss +1.37ϕ. From these considerations, a relatively greater concentration of polycrystalline quartz grains would be expected in sample 5, but there is no significant difference. Average percentages of polycrystalline quartz in sample 5, the lower quartzite and total Bliss, were 2.0, 1.0 and 1.9 respectively.

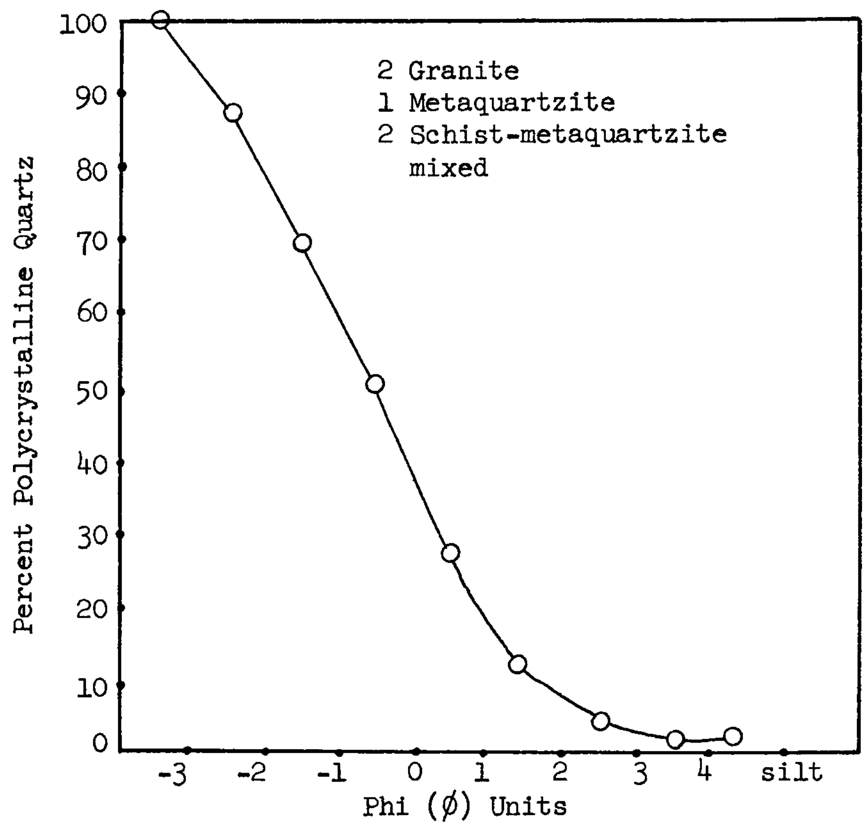


Figure 14.--Relationship between Size of Quartz and Abundance of Polycrystalline Quartz Grains

Disintegrated, untransported granitic quartz of this area contains an average of 34 percent polycrystalline grains in the approximate size range of sample 5 (this percentage is even higher in larger sizes). An appreciable number of these polycrystalline quartz grains should still be present unless the granitic source was quartz poor, thus reducing the possibility of quartz grain-to-grain contact; unless feldspar is much more resistant to abrasion and weathering than is commonly believed; or unless the basal arkose has been greatly diluted by polycyclic quartz sands. A few rounded quartz grains, which are probably polycyclic, are present in the basal arkose, but dilution appears to be negligible. Still another alternative is the possibility that polycrystalline quartz of the granitic type (unsutured boundaries are most common) is highly susceptible to disaggregation. That boundary type is a major factor in the survival of polycrystalline quartz grains is indicated by an examination of 75 grains of this type in the lower quartzite (basal Bliss member). Of this number, 84 percent showed interlocking of the constituent grains in varying degrees. Most of the interlocked contacts were not of the sutured type, but determination of boundary type was complicated in some cases by postdepositional suturing. Thin sections of all Bliss members were inspected for sutured, stretched polycrystalline quartz grains, which would indicate a metamorphic source. The number observed was negligible, which suggests a granitic rather than metamorphic origin for most quartz grains in the Bliss.

The mean percentage of polycrystalline quartz grains in the Bliss Formation varied but little (Table 1) except for the middle calcareous sandstone and thin-bedded glauconite members (Fig. 15). In the former, polycrystalline quartz averaged five percent, as compared with an average of 1.9 percent for all Bliss members, while the latter averaged 0.4 percent. This relationship persisted when percentages of polycrystalline grains of approximately +2ϕ size in the various members were compared. The distinction, however, was less noticable in the thin-bedded glauconite.

Blatt and Christie (1963) suggested that the relative abundance of polycrystalline quartz might be a useful correlation tool. As previously noted, the concentration of polycrystalline quartz grains in the middle calcareous sandstone is significantly greater than that of the other Bliss members, and local correlation on this basis is possible. Due to the scarcity of polycrystalline quartz grains, however, several samples are required in order to establish a definite correlation. It is also possible that the thin-bedded glauconite member could be correlated locally on this basis, but the abundance of glauconite is more distinctive than is the percentage of polycrystalline quartz.

Nonundulatory Quartz

Blatt and Christie (1963) noted from a study of 51 thin

Table 1.--Size and Percentage Data on Polycrystalline Quartz and Total Quartz in Undisintegrated Samples of the Bliss and Cable Canyon Formations

Sample Source	Number of Samples	Mean Percentage of Polycrystalline Quartz	Mean Polycrystalline Grain Size	Percentage of Polycrystalline Quartz (+2ϕ Size)	Mean Size Total Quartz	Standard Deviation
Cable Canyon (Montoya)	2	0.5	+1.50ϕ	0.5	+1.47ϕ	---
Middle calcareous sandstone	5	5.0	+1.20ϕ	2.5	+0.81ϕ	0.22ϕ
Middle quartzite	15	1.3	+1.40ϕ	0.9	+1.24ϕ	0.44ϕ
Thin-bedded glauconite	5	0.4	+2.00ϕ	0.2	+1.98ϕ	0.22ϕ
Lower hematitic sandstone	4	1.7	+2.20ϕ	1.0	+1.40ϕ	0.28ϕ
Lower quartzite	15	2.0	+0.80ϕ	0.4	+1.51ϕ	0.44ϕ
Bliss Average	44	1.9	+1.56ϕ	---	+1.37ϕ	---

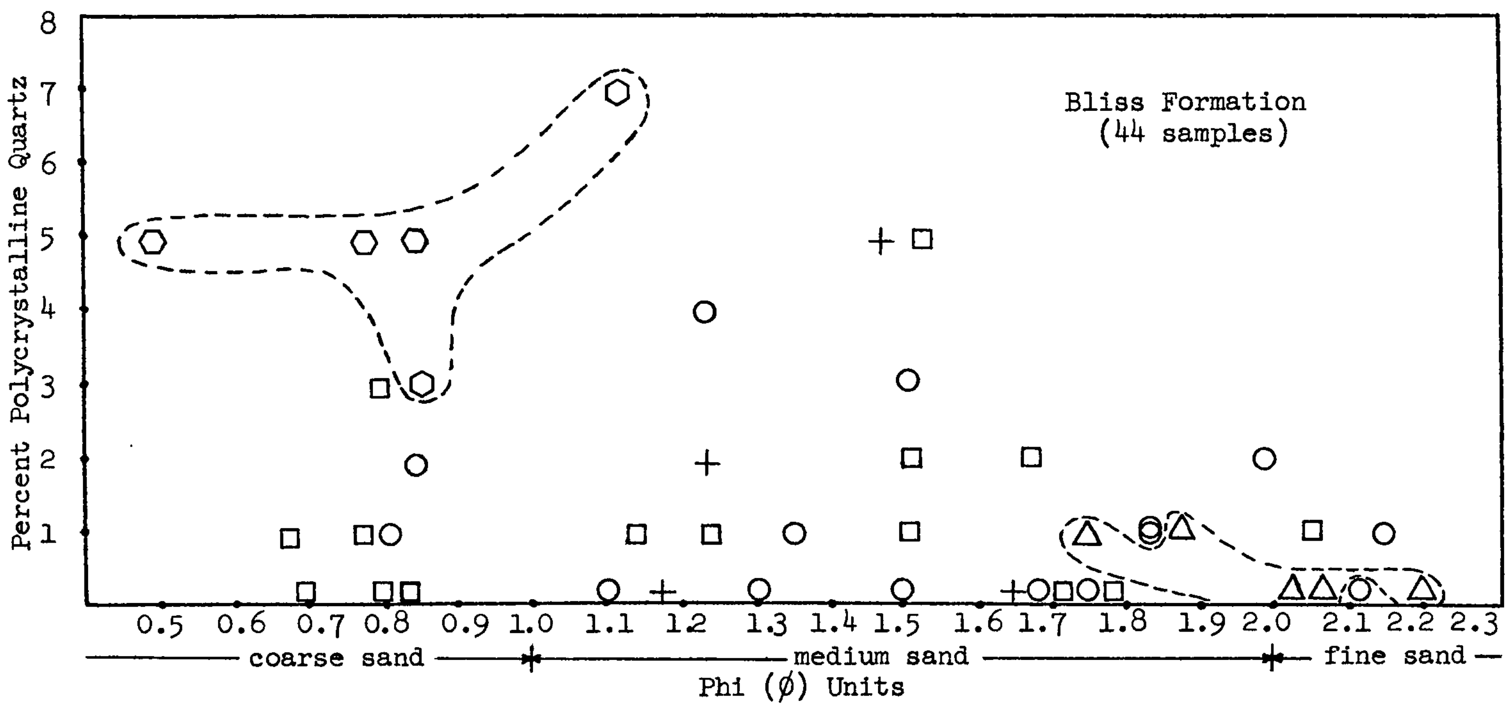


Figure 15.--Relationship between Quartz Grain Size and Abundance of Polycrystalline Quartz Grains

Symbols: ⬡, middle calcareous sandstone; □, middle quartzite; △, thin-bedded glauconite; +, lower hematitic sandstone; ○, lower quartzite.

sections that plutonic igneous rocks tend to contain either small (0 to 10 percent) or large amounts (70 to 100 percent) of nonundulatory quartz grains. They suggested that this bimodality is related to the age of the rock, as younger rocks have a relatively high percentage of nonundulatory quartz grains, presumably due to the greater probability that older rocks would have been subjected to postemplacement deformation. The three undisintegrated granite samples collected in the Silver City area have an average of 28.7 percent nonundulatory quartz grains (Table 2) and a standard deviation of 13.0 percent, which is somewhat higher than the mean percentage reported by Blatt and Christie (13.4 percent).

With occasional exceptions, the abundance of nonundulatory quartz tends to increase as grain size decreases. Blatt (1963, p. 67) gave two possible explanations for this relationship: "...grains of different sizes, derived from the same uniformly bent larger grain, will have different degrees of undulatory extinction as indicated by the extreme orientation of the c-axis in the grains." Also, "... many grains which in reality have two or three degrees of undulatory extinction appeared to have less than one degree on the flat stage. It also appears quite likely that this effect is more prominent in smaller sized grains, as the scale over which the variation in extinction position is occurring becomes relatively large compared to the size of the quartz grains." In regard to the latter statement, it

Table 2.--Average Percentages of Nonundulatory Quartz Grains in Undisintegrated Samples of Cable Canyon, Bliss and Precambrian Rocks

Sample Source	Number of Samples	Mean Size Total Quartz	Percentage of Nonundulatory Quartz	Standard Deviation (Percent)
Cable Canyon (Montoya)	2	+1.47ø	42.0	---
Middle calcareous sandstone	5	+0.81ø	30.0	10.8
Middle quartzite	15	+1.24ø	27.4	7.9
Thin-bedded glauconite	5	+1.98ø	38.8	15.2
Lower hematitic sandstone	4	+1.40ø	23.3	8.3
Lower quartzite	15	+1.51ø	31.0	8.5
Bliss Average	44	+1.37ø	30.1	5.2
Granite	3	+0.03ø	28.7	13.0
Schist	7	+1.77ø	66.3	7.8
Metaquartzite	5	+1.18ø	66.0	20.1
Meta-arkose	1	+2.20ø	60.0	---

should be noted that Figure 16 shows a reversal of the normal trend in the silt-size range. The t-test indicates an 85 percent probability that the difference between the means of the +3ϕ to +4ϕ grains and the silt-sized grains is real. This tendency was present in three of the five samples, neutral in one, and in one sample the normal trend was continued. The reason for this result is not clear.

Conolly (1965, p. 130), working in an area in which volcanic rocks made important contributions of nonundulatory quartz to the local sedimentary rocks, found that "the percentages of nonundulatory quartz present in a sandstone become very useful when some knowledge of the mineralogy of the source rocks is already known, and will be particularly useful in verticle profile studies to trace the effects of known basement rocks from the base of a sequence." Blatt and Christie (1963) also suggested that relative proportions of nonundulatory quartz grains might be used as a basis for correlating some rocks. However, mean percentages of nonundulatory quartz grains in the Bliss Formation were rather uniform throughout, and this parameter appears to have no utility as an intraformational correlation tool in the Silver City area.

With the exception of volcanic quartz grains, which are mainly nonundulatory and characteristically are inclusion-free, partially resorbed, and idiomorphic, Blatt and Christie (1963) conclude that extinction type is not a reliable provenance indicator. Conolly

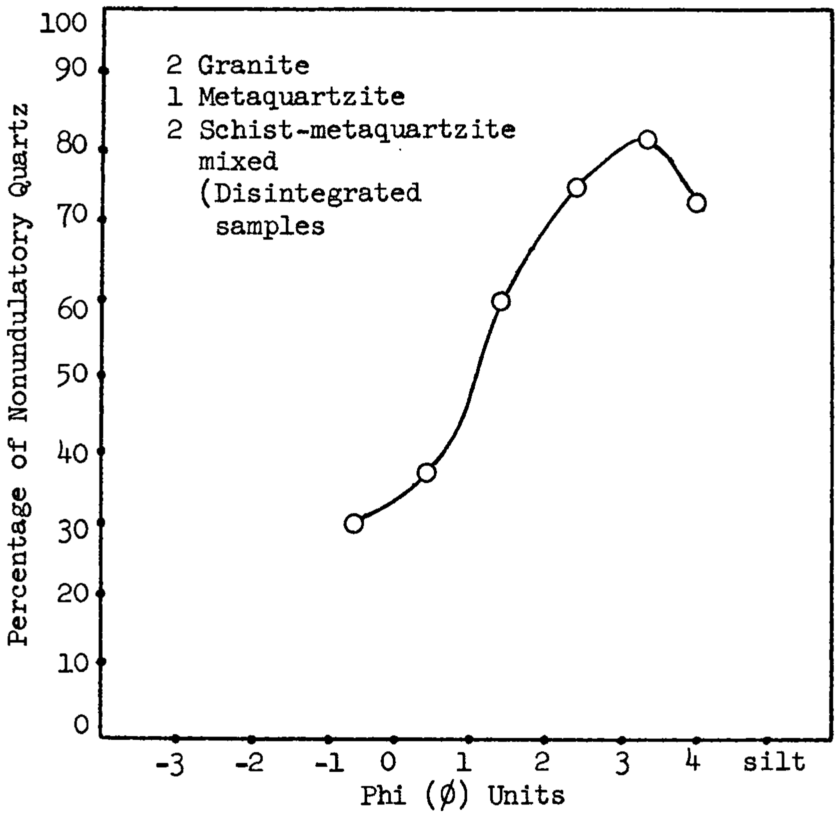


Figure 16.--Relationship between Size and Abundance of Nonundulatory Quartz Grains

(1965) feels that, after due consideration of postdepositional history (including faulting), the percentage of nonundulatory quartz in sandstones should be helpful in determining the mineralogy of the source rocks. In his investigation, however, volcanic rocks were a significant source of the quartz grains in some sedimentary units.

The conclusion (Blatt and Christie, 1963) that relatively large amounts of nonundulatory quartz are indicative of advanced mineralogic maturity appears to be substantiated by the work of Greensmith (1964), who examined 44 samples of British Carboniferous orthoquartzites. As indicated by the maturity of the heavy mineral suite, a polycyclic sedimentary history for these sandstones is considered probable. His average for nonundulatory quartz grains was 75 percent, which is much greater than the average of 43.1 percent obtained by Blatt and Christie (1963) from 20 samples. Since the amount of quartz in a sedimentary rock is usually a reliable indicator of mineralogic maturity, and monocrystalline, nonundulatory quartz grains are the most stable type of detrital quartz, Blatt (1963) suggested that the percentage of these grains present in a sedimentary rock may be used to refine the estimate of mineralogic maturity. In the present study, the lower quartzite and middle quartzite members of the Bliss Formation, both mineralogically mature orthoquartzites (except sample 5, which is an arkose), contained an average of 29.3 percent nonundulatory quartz (30 samples) as compared with a mean of 39.0 percent (five samples) for the local granite in a comparable size range (+1ø to +2ø). The observed difference in percentages may be due to the small number of granite samples examined, since individual averages varied from 17.5 percent to 100 percent. The average for the Bliss in a similar size range was 30.7 percent. Still greater percentages (average 67.0 percent; 16 samples) of nonundulatory quartz were present in the metamorphic rocks in an equivalent size range. Unless a source unlike the local basement rocks can be established for the quartz grains in the Bliss, the use of abundance of nonundulatory, monocrystalline quartz as an additional refinement of the estimate of mineralogic maturity has no application in the Silver City area.

In contrast to the high mean percentage (64.1) of nonundulatory quartz grains in the total quartz of the metamorphic rocks in the Silver City area, a value of 11.9 percent was obtained by Blatt (1963) from 23 gneisses and six metaquartzites, which were collected at widely separated localities. It is probable that recrystallization after plastic deformation of the quartz grains eliminated most of the undulatory extinction in the quartz of metamorphic rocks near Silver City.

The possibility that the comparatively low percentage of nonundulatory quartz in the Bliss might be due to postdepositional deformation was considered. Lowry (1956) concluded from his observation of quartz overgrowths which were strained as much as the original quartz grain, that undulatory extinction (in some Virginia sandstones) was produced after deposition. However, since quartz overgrowths develop in optical continuity with the original grain (Ernst and Blatt, 1964) it appears that undulatory extinction in the overgrowths could have been inherited from the host grain, and may not indicate postdepositional deformation. Conolly (1965) showed that the percentage of nonundulatory quartz in sedimentary rocks tended to decrease as the angle of dip increased, and was abnormally low within 20 to 100 feet of faults. Faults with a wide range of displacement are present in the Silver City area and sample suites B and C were located within 100 feet of faults (undetermined displacement was in excess of "a few feet"). It was found, however, that percentages of nonundulatory quartz (35.6 and 27.7) did not differ significantly from the average of 30.1 percent for the Bliss Formation. (The remaining A, D, and E sample suites were collected in relatively undisturbed areas). The results of this study suggest that deformation must be moderately intense before its effect on the type of extinction in quartz grains is noticeable. Although bubble trains occasionally transect adjacent quartz grains, demonstrating some postdepositional stress, glauconite grains in the Bliss are not deformed to any significant degree, which indicates that the stress was mild.

In attempting to determine the significance of the low percentage of nonundulatory quartz in the Bliss Formation, the effect of polycyclic sedimentation on quartz grains of this type was investigated. A group of 200 rounded to well-rounded quartz grains were selected at random from 12 randomly chosen Bliss samples and were examined for extinction type. (It should be noted that suturing and replacement of quartz by hematite, carbonate, and glauconite made the roundness classification of some grains difficult). Since these grains are more likely to be products of polycyclic sedimentation than the remainder, this group should have a higher percentage of nonundulatory quartz grains. Surprisingly, only 16 percent of the rounded quartz grains were nonundulatory as compared with 30.1 percent for the total quartz. Since the percentage of undulatory quartz grains tends to increase as grain size increases, it was considered possible that the relatively large size of the well-rounded quartz grains was responsible for the result. To test this possibility, 500 rounded to well-rounded quartz grains (100 in each Bliss member) were inspected for extinction type. These grains were chosen so that none were larger than the mean size of the quartz grains in sample in which they occurred. This resulted in an average of 19 percent nonundulatory quartz. By *t*-test, there is a 98 percent probability that the difference between the mean percentage of nonundulatory quartz among rounded quartz grains and that of total quartz is real. As a final experiment, an additional 500 rounded to well-rounded quartz grains were examined. These grains were restricted to fine sand size (+2ø to +3ø) which corresponds to the average size of nonundulatory quartz grains in the Bliss (+2.31ø). In this case, the percentage of rounded, nonundulatory quartz (26.4) did not differ significantly from the average for total quartz (30.1 percent), which strongly indicates that the undulatory, rounded (and presumably polycyclic) quartz grains were not preferentially eliminated (owing to relative instability) to any significant degree, by prolonged or repeated cycles of sedimentation. Conversely, quartz grains in the sandy Cable Canyon dolomite (two samples), approximately 600 feet higher stratigraphically than the Bliss Formation, appear to reflect the effects of repeated sedimentary cycles on the amount of nonundulatory quartz present, if the quartz grains were derived from the Bliss. Average roundness, 3.36 as compared with 2.62 for the Bliss, indicates that quartz grains in the Cable Canyon Formation have undergone a greater number of sedimentary cycles than the Bliss, and the mean percentage of nonundulatory quartz present in this unit is somewhat higher (42.0 percent) than that of the lower quartzite and middle quartzite (29.3 percent).

Since postdepositional deformation does not seem to have affected appreciably the percentages of nonundulatory quartz in the Bliss, the high concentration of this type of quartz grain in the metamorphic rocks near Silver City appears to eliminate them as a source of most Bliss quartz grains. Percentages of nonundulatory quartz in the local granite are such that it (or similar rocks) may reasonably be regarded as a significant ultimate source of Bliss quartz grains.

Form

It appears that use of grain shape as a provenance indicator is unreliable (Blatt, 1963). However, since width/length data were available from the investigation of other parameters, width/length ratios were calculated.

Sorby (1877) described the form of granitic quartz grains as being irregular, but generally equidimensional.

Bokman (1952) concluded from measurements of some 3000 quartz grains from the Stanley and Jackfork formations (Pennsylvanian) that a mean width/length ratio of 0.70 (which approaches equidimensional form) was indicative of an igneous source for the Stanley; and that a ratio of 0.64 denoted a metamorphic provenance for the Jackfork. Subsequent statistical studies of these data by Blatt (1963) failed to verify this conclusion; also, heavy mineral studies by Bokman in 1953 suggested that his earlier conclusion was probably incorrect.

Width/length ratios of quartz grains in samples of undisintegrated granite in the Silver City area averaged 0.48, which was less than that of the adjacent metamorphic rocks as follows: schist, 0.64;

metaquartzite, 0.65; meta-arkose, 0.73. Width/length ratios one foot above the Bliss-basement contact at the five major sample localities averaged 0.66, which is identical with that of the total Bliss, 0.66. It appears that succeeding cycles of sedimentation did not effect appreciable reduction of this ratio, possibly due to the influx of quartz grains with a shorter sedimentary history.

The results of this investigation support Blatt's (1963) view that width/length ratios of quartz grains are not reliably characteristic of either igneous or metamorphic source rocks.

Roundness

The relationship between roundness and extinction type has been discussed in the section on nonundulatory quartz grains.

As indicated in Table 3, the normal trend of increasing roundness in younger strata, due to recycling of the grains (probably from lower Bliss units to upper ones) is interrupted by an increase in angularity in the thin-bedded glauconite. Since this unit has the smallest mean quartz grain size of any of the members (+1.98ϕ as compared with the next smallest +1.51ϕ), this factor is believed to be responsible for the anomaly.

At the point where the quartz grains become predominantly subrounded (middle quartzite), the roundness sorting abruptly changes from moderate to poor (Fig. 17). The bimodality of roundness sorting (Fig. 18) suggests that this variation is due to an influx of recycled

Table 3.--Roundness Data for the Bliss and Cable Canyon Formations

Sample Source	Number of Samples	Mean Roundness	Roundness Sorting	Mean Size Quartz
Cable Canyon (Montoya)	2	3.36	1.20	+1.47ϕ
Middle calcareous sandstone	5	3.07	1.19	+0.81ϕ
Middle quartzite	15	3.08	1.14	+1.24ϕ
Thin-bedded glauconite	5	2.15	0.84	+1.98ϕ
Lower hematitic sandstone	4	2.55	0.90	+1.40ϕ
Lower quartzite	15	2.24	0.88	+1.51ϕ

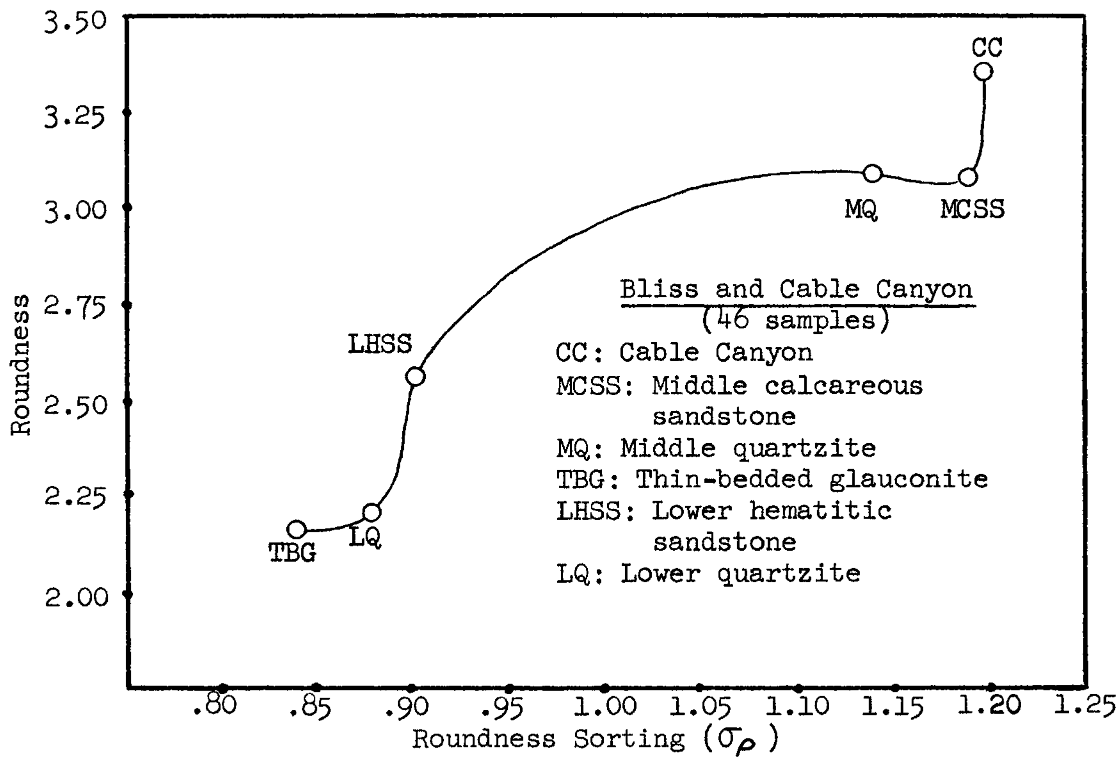


Figure 17.--Comparison of Roundness with Roundness Sorting

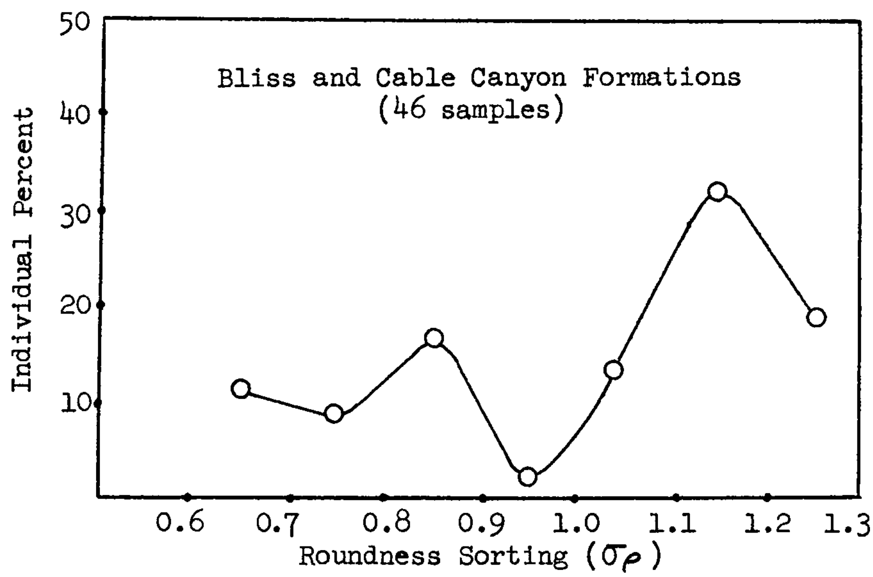


Figure 18.--Distribution of Roundness Sorting

quartz grains.

Graphic plots of size versus roundness were generally indeterminate.

Inclusions

At the beginning of this investigation it was considered possible that diagnostic inclusions or suites of inclusions would be found in the quartz of the local basement rocks which could be traced into the overlying Bliss Formation, thus indicating the distribution and abundance of quartz grains derived from each variety of source rock (igneous or metamorphic). With only minor exceptions this anticipation did not materialize. Occasional quartz grains with sillimanite inclusions were observed in the Bliss. Very rare idiomorphic (prismatic) quartz grains were considered to be vein or vug quartz, and a few grains with peripheral concentrations of acicular and irregular inclusions were regarded as metamorphic.

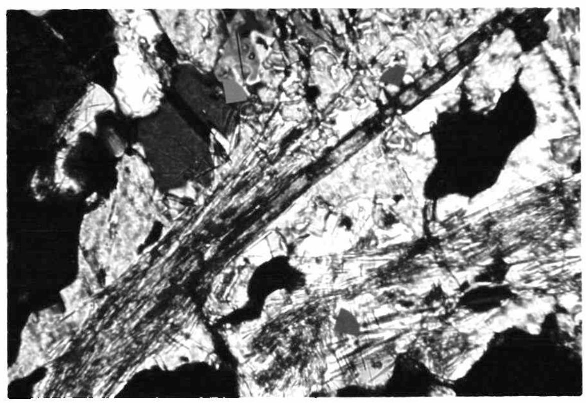
The small size of many of the inclusions made identification uncertain and a detailed statistical study was not attempted. However, 25 quartz grains were chosen at random in each thin section of undisintegrated basement rock and sedimentary rock (62 total) and the percentages of grains which were barren or contained inclusions of specified types were determined.

Acicular and irregular inclusions predominate in the granite samples collected in the Silver City area. Inclusions identified were muscovite, altered biotite (chlorite ?), undifferentiated feldspar, zircon, apatite, tourmaline, rutile, quartz and hematite. As hematite seldom occurs as an original constituent of igneous rocks (Kerr, 1959), and since this granite is badly weathered, the hematite is probably an alteration product of magnetite.

Inclusions in the single sample of meta-arkose, mainly irregular and acicular in form, were not abundant. Those present were muscovite, biotite, undifferentiated feldspar, zircon, magnetite, and rutile.

Acicular inclusions, usually sillimanite, (Fig. 19) are the most common form in the metaquartzite samples. Interstitial growth of muscovite, subsequently altered to a considerable extent to sillimanite, resulted in peripheral penetration of adjacent quartz grains by these acicular crystals. This often imparts a distinctive appearance to the grain (Fig. 20), and a few such grains observed in the overlying Bliss Formation were identified as metamorphic on this basis. Other inclusions were biotite, chlorite, tourmaline, undifferentiated feldspar, magnetite, hematite, and limonite. The latter two are probably alteration products of magnetite.

In contrast to the results obtained by Keller and Littlefield (1950), who found most acicular inclusions to be of plutonic igneous origin, the quartzose schists near Silver City were abundantly endowed with inclusions of this type (mainly sillimanite). Additional



1 mm

Figure 19.--Sillimanite in Muscovite

Sample 30 (-3∅) (disintegrated schist-metaquartzite). Crossed nicols. Note characteristic transverse fractures in large crystal and acicular, felted habit in smaller crystals (red arrows). The dark gray grain (orange arrow) is quartz. Black areas are altered biotite at extinction. Muscovite is white or light gray.

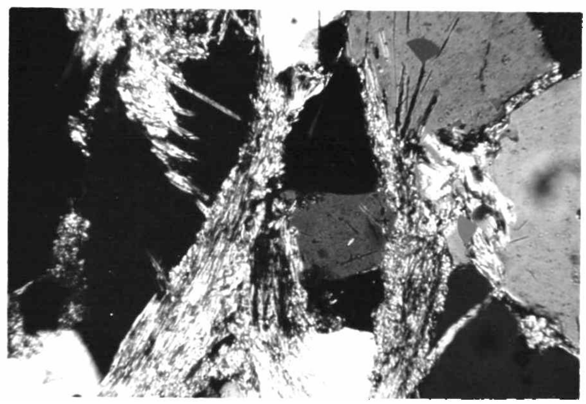


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Figure 20.--Peripheral Penetration of Quartz Grains by Sillimanite and Muscovite

Sample 31 (metaquartzite). Crossed nicols. Sillimanite is indicated by red arrow; muscovite by orange arrow.

inclusions were magnetite, chlorite, and zircon.

No inclusions of a composition different from those in the plutonic igneous and metamorphic rocks of the Silver City area were observed in the Bliss and Montoya sedimentary rocks, which suggests that most of the quartz grains in these units were derived from local primary source rocks or from similar rocks in the surrounding area. However, the variety of inclusions is so large that outside sources cannot be ruled out on this basis. Also, sillimanite inclusions, though abundant in the metamorphic basement rocks of the Silver City area, are present only in traces in the overlying Bliss Formation. This could signify either that local basement rocks are not important as sources, or that most of the basement rock in the Silver City area is granitic and not metamorphic.

Bubble Trains

It is generally agreed that bubble trains are a result of the isolation of areas of liquid along fracture planes by secondary deposition of quartz. Thus, it appears that the abundance of bubble trains is dependent primarily upon the stresses to which the quartz grains have been subjected.

Bowen (1955) noted that the percentage of quartz grains with bubble trains decreased as grain size decreased. This relationship was partially substantiated by this investigation (Fig. 21). Bowen concluded that this was indicative of preferential fracture during

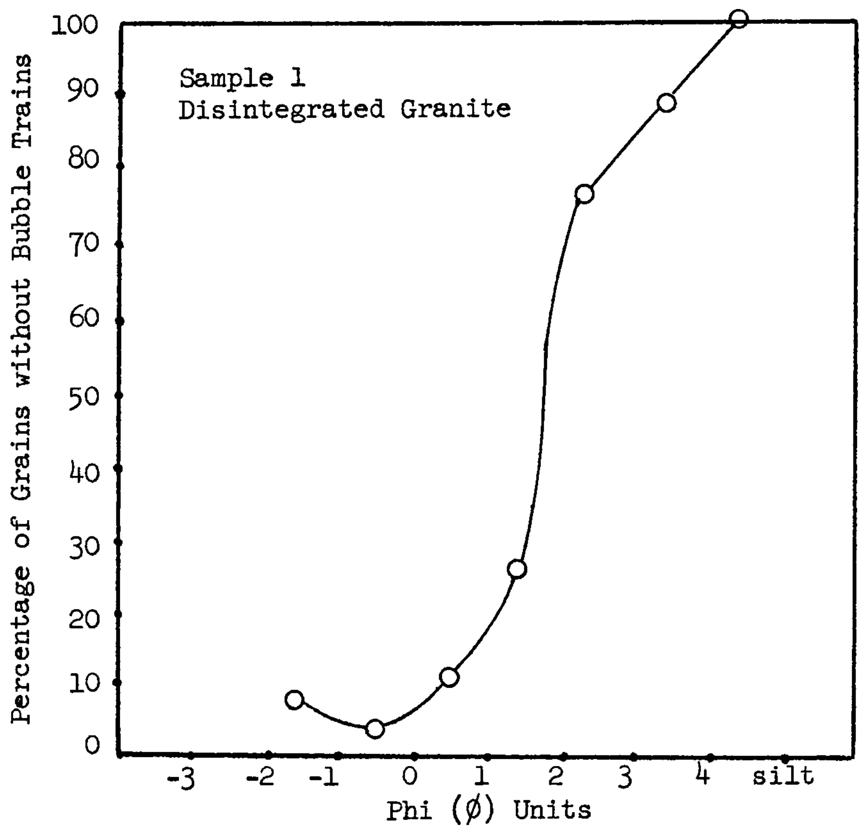

Figure 21.--Relationship between Bubble Train Abundance and Quartz Grain Size

transport along the planes of bubble inclusions with consequent reduction of their number per grain as size decreased. The probability that a grain in a source rock will be intersected by a fracture is also reduced for smaller grains. In the present study the abundance of bubble trains was first computed on a "per square millimeter" basis (thin section area) in an attempt to make a valid comparison between quartz grains of different size, but the data obtained were misleading. It was found that quartz grains with 300 or more (700 maximum) bubble trains per square millimeter usually fell within the 0.01 to 0.04 square millimeter size range, whereas the maximum number of bubble trains observed in a single quartz grain (approximately six square millimeters in area) was 300, which became 50 bubble trains per square millimeter after conversion. This discrepancy is due mainly to the fact that bubble trains in large grains usually have greater linear extent than those in the very small grains, thus reducing the number per unit area. Also, the wide range of values (0 to 700 bubble trains per square millimeter) presented a problem in grouping for statistical study. Since the majority of grains had less than 100 bubble trains per square millimeter, all values above 90 were combined. The resulting mean values were somewhat low, and standard deviations were meaningless; therefore this approach was abandoned in favor of a more useful parameter--"percentage of quartz grains without bubble trains". For percentage comparisons in the following discussion, grain size is limited approximately to +2ø.

Rock type apparently also influences the quantity of bubble trains present. In the highly micaceous schists of the Silver City area, an average of 92.6 percent (Table 4) of the quartz grains had no bubble trains. The incompetent nature of these rocks and small quartz grain size apparently permits response to stress by intercrystalline slippage of the platy minerals rather than by brittle fracture of the quartz grains. However, the meta-arkose and, to a lesser degree, the metaquartzite also have large percentages (83 and 71.8 percent respectively) of quartz grains without bubble trains. These are competent rocks. The extent to which metamorphism after brittle fracture of quartz grains was effective in reducing the abundance of bubble trains in these recrystallized rocks is difficult to determine, but the grouping of the metamorphic rocks in Figure 22 suggests that it was an important factor in the Silver City area. The granite contained the lowest percentage (42.0) of quartz grains without bubble trains. This may have been a result of late-stage movement in the consolidated or semiconsolidated intrusive.

The thin-bedded glauconite member of the Bliss Formation and the Cable Canyon Formation both have percentages (80.6 and 84.5 respectively) of quartz grains without bubble trains considerably in excess of the average for the remainder of the sedimentary samples (44.7 percent). Since the Cable Canyon Formation is approximately

Table 4.--Bubble Train Data from Undisintegrated Samples of Cable Canyon, Bliss and Precambrian Rocks

Sample Source	Number of Samples	Mean Size Total Quartz	Percentage of Grains Without Bubble Trains (Total Quartz)	Percentage of Grains Without Bubble Trains (+2∅ Size)
Cable Canyon (Montoya)	2	+1.47∅	81	84.5
Middle calcareous sandstone	5	+0.81∅	42	48.0
Middle quartzite	15	+1.24∅	39	41.8
Thin-bedded glauconite	5	+1.98∅	87	80.6
Lower hematitic sandstone	4	+1.40∅	52	46.2
Lower quartzite	15	+1.51∅	44	46.2
Bliss Average	44	+1.37∅	53	49.0
Granite	3	+0.03∅	21	42.0
Meta-arkose	1	+2.20∅	94	83.0
Schist	7	+1.77∅	96	92.6
Metaquartzite	5	+1.18∅	65	71.8

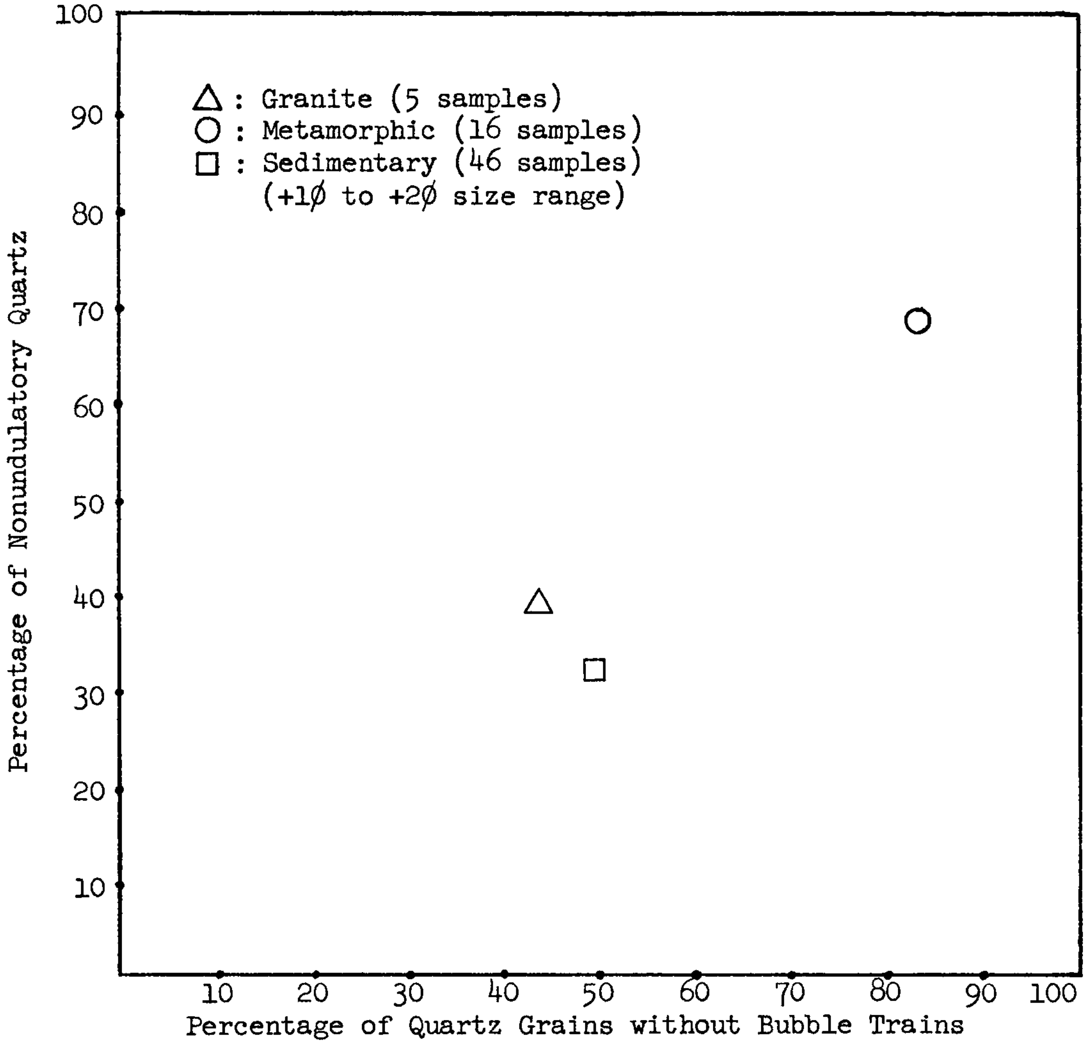

Figure 22.--Comparison of Quartz Grains without Bubble Trains with Percentage of Nonundulatory Quartz

600 feet stratigraphically higher than the Bliss and roundness data indicate that it has undergone more sedimentary cycles than the latter, it is postulated that most quartz grains with bubble trains (in the size range considered) were eliminated during recycling, by preferential fracture along planes of bubble inclusions prior to the latest deposition. The reason for the anomalous percentage of quartz grains without bubble trains in the thin-bedded glauconite is not clear, unless it is due to a variation in source areas.

Since bubble trains reflect postemplacement and, to some extent, postdepositional tectonic history, it appears that this parameter has very limited application to provenance determination. However, the abundance of quartz grains without bubble trains in the granite (42.0 percent) is very similar to that of the Bliss (44.7 percent, excluding the anomalous thin-bedded glauconite member) and the t-test shows that this similarity is not due to chance. Consequently, this congruity of averages is regarded as evidence that many or most of the quartz grains in the Bliss were derived from rocks similar to the local granite.

Heavy Minerals

This investigation did not include heavy mineral separations. Data were derived from thin sections only.

Detrital heavy minerals are uncommon in the orthoquartzites of the Bliss Formation near Silver City. Those observed, with the rare exception epidote, were exclusively zircon. Epidote, typical of metamorphic rocks (Pettijohn, 1957), is quantitatively negligible in the area investigated. Zircon occurs commonly in acid igneous rocks and less commonly in metamorphic rocks. Although the dominance of zircon in the heavy mineral suite probably denotes elimination of less stable species by recycling and does not exclude a metamorphic source, it does indicate a granitic origin for at least some of the quartz grains in the Bliss.

CONCLUSIONS

Nine conclusions, concerning the ultimate provenance and various parameters of quartz grains in the Bliss Formation, have resulted from this investigation. In view of the small number of samples collected, particularly disintegrated samples, some of these conclusions are suggestive rather than statistically definitive.

1. The abundance and distribution of bubble trains, polycrystalline, monocrystalline, nonundulatory and undulatory quartz grains in a sample are dependent to a larger extent upon grain size.

2. Polycrystalline quartz grains derived from source rocks of the Bliss Formation were apparently very susceptible to disaggregation, as indicated by their rarity near the basal contact with underlying Precambrian rocks. Boundaries of most surviving polycrystalline quartz grains (84 percent in the lower quartzite) are interlocking to some degree, but very few are stretched.

3. After due consideration of grain size and tectonic history (faulting has not significantly affected percentages of nonundulatory quartz in the sampled area), and with the following evidence in support, a granitic rather than metamorphic origin for most quartz grains in the Bliss Formation is indicated by the percentage of monocrystalline, nonundulatory quartz present in the Bliss: (a) Granite pebbles are present in the basal arkose. (b) Granite is the most logical source of the feldspar present in the basal arkose.

The single alternative local source--meta-arkose--was observed at only one locality in the area (Turner Peak), and the quartz grains in this metamorphic rock are much smaller (mean +2.20∅) than those in the arkose (+0.85∅). (c) Only a negligible number of the polycrystalline quartz grains present in the Bliss are stretched and sutured. (d) The percentage of quartz grains without bubble trains (44.7 percent) is very near that of the local granite (42.0 percent) and is much less than the average of the metamorphic rocks (84.3 percent in the same size range). (e) With rare exceptions, inclusions identified in the quartz grains of the Bliss did not differ from those in the granitic quartz of the area. Sillimanite inclusions, characteristic of the local schists, were extremely rare in the overlying Bliss. (f) The heavy mineral suite in the orthoquartzites of the Bliss is composed largely of zircon, which indicates a polycyclic sedimentary history, but also denotes a probable acid igneous origin for at least some of the quartz grains.

4. Since percentages of monocrystalline nonundulatory quartz in the mature orthoquartzites of the Bliss are similar to that of the local granite and are considerably less than that of the metamorphic rocks, the use of this parameter to refine the estimate of mineralogic maturity appears to have no application in the Bliss Formation of the Silver City area, unless a source unlike the local basement rocks can be established.

5. Data suggest that faulting of less than moderate intensity does not produce significant undulatory extinction in nearby quartz grains (100 feet or less).

6. Percentages of polycrystalline quartz present in some members of the Bliss Formation may be used as a correlation tool in the Silver City area but stratigraphic units of this area can not be separated on the basis of extinction type.

7. Width/length ratios of quartz grains cannot be relied upon to determine source.

8. Percentages of nonundulatory grains among rounded and well-rounded (presumably polycyclic) quartz grains in the Bliss shows that preferential destruction of relatively less stable undulatory grains by recycling was insignificant.

9. Quartz grains in the Bliss Formation having peripheral concentrations of acicular and/or irregular inclusions were probably derived from a local or similar metamorphic source.

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APPENDICES

APPENDIX 1

Sample Locations

Explanation: Samples were numbered consecutively as collected. Several samples were collected at each detailed locality (A, B, C, D, and E). It should also be noted that a few of the samples collected were not included in this study (some were subsequently found to be contaminated or otherwise unsuitable for use). All sample localities are in Grant County, New Mexico.

Appendix 1-A.--Detailed Sample Suites

Locality	Section	Township South	Range West
A	NE-1/4 23	17	15
B	NW-1/4 23	17	15
C	SW-1/4 24	17	15
D	SE-1/4 31	17	14
E	NE-1/4 29	18	13

Appendix 1-B.--Random Samples

Locality	Section	Township South	Range West
1	NW-1/4 23	17	15
2	SW-1/4 23	17	15
3	SE-1/4 23	17	15
29	NE-1/4 25	17	15
30	NE-1/4 25	17	15
44	NW-1/4 25	17	15
45	SE-1/4 14	17	15
46	SE-1/4 14	17	15
71	NW-1/4 24	17	15
75	NW-1/4 23	17	15
77	SW-1/4 24	17	15
78	SW-1/4 24	17	15
79	SW-1/4 24	17	15
80	SE-1/4 24	17	15
81	NE-1/4 25	17	15

APPENDIX 2

Descriptions of Sedimentary Rock Samples

Explanation: The following samples were collected in suites at localities A, B, C, D, and E excepting samples 45 and 46, which are from the Cable Canyon Formation, and are listed consecutively regardless of locality. Data (except color and most structure) were derived from thin sections. The Folk (1961) roundness scale is used in the following numerical descriptions of texture. All thin section grain sizes were converted to sieve sizes using Friedman's (1962) graphs. Distance from sample to the base of the unit is approximate when the sample was collected at the top. The percentages listed under "Cement and/or Matrix" indicate the proportion of the total sample which is composed of cement and/or matrix material. Cement and matrix material are generally consolidated, but clay minerals, which are usually insignificant, may be lost in minor amounts through the use of water in the process of grinding the thin sections.

Sample 5, Locality A

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	One foot above base

Rock Type: Arkose

Color: Pinkish gray

Structure: Massive bedding; vertical jointing

Cement and/or Matrix: Negligible

Texture: Medium-grained (+0.85Ø); poorly sorted (1.00Ø) subangular (2.06); moderate roundness sorting (0.85); mode, +1.25Ø; width/length, 0.62

Inclusions: Feldspar, rutile, magnetite, hematite (secondary), sillimanite

Grain boundaries: Commonly sutured

Alterations: Feldspar altered to sericite, illite, kaolinite

Fossils: None

Sample 6, Locality A

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	Five feet above base

Rock Type: Orthoquartzite

Color: Brownish gray

Structure: Massive, vertical jointing

Cement and/or Matrix: Minor kaolinite, illite, hematite, limonite

Texture: Medium-grained (+1.15ϕ); poorly sorted (1.00); subangular (2.00); moderate roundness sorting (0.85); mode, +1.25ϕ; width/length, 0.66

Inclusions: Zircon, apatite, muscovite, hematite (secondary), feldspar, rutile

Grain boundaries: Irregular to moderately sutured

Alteration: Feldspar altered to kaolinite

Fossils: None

Sample 7, Locality A

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	11 feet above base

Rock Type: Orthoquartzite

Color: Brownish gray

Structure: Microstylolitic; prominant worm tubes

Cement and/or Matrix: Hematite (10 percent); minor kaolinite and illite (3 percent)

Texture: Fine-grained (+1.75∅); moderately sorted (0.81∅); angular (1.63); good roundness sorting (0.70); mode, +1.80∅; width/length, 0.67

Inclusions: Rutile, manganese, feldspar, tourmaline, zircon, hematite (secondary), chlorite

Grain boundaries: Incipient to moderate suturing

Alterations: Hematite and limonite replace quartz

Fossils: None

Sample 8, Locality A

Rock Unit	Stratigraphic Position of Sample
Lower hematite sandstone	One foot above base

Rock Type: Sandy, glauconitic hematite

Color: Reddish brown

Structure: Thin-bedded

Cement and/or Matrix: (Hematite)

Texture: (Quartz grains only) fine-grained (+1.70ϕ); moderately sorted (0.88ϕ); angular (1.90); good roundness sorting (0.62); mode, +1.30ϕ; width/length, 0.66

Inclusions: Sillimanite, magnetite, hematite (secondary), feldspar, zircon, rutile, tourmaline

Grain boundaries: Most quartz grains "float" in hematite

Alterations: Feldspar altered to illite; collophane replaced by quartz; quartz replaced by hematite; feldspar replaced by hematite

Fossils: Phosphatic brachiopod shell fragments common

Sample 11, Locality A

Rock Unit	Stratigraphic Position of Sample
Thin-bedded glauconite	20 feet above base

Rock Type: Glauconitic sandstone

Color: Light greenish gray

Structure: Thin-bedded; bedding defined by change in grain size and cement

Cement and/or Matrix: Calcite (15 percent); quartz (2 percent)

Texture: Fine grained (+2.05ϕ); moderately well sorted (0.55ϕ); angular (1.86); good roundness sorting (0.62); mode, +2.25ϕ; width/length, 0.69

Inclusions: Muscovite, hematite (secondary), rutile, zircon, chlorite, sillimanite

Grain boundaries: Quartz-to-quartz boundaries usually irregular of slightly sutured; in calcite-cemented areas, quartz borders commonly embayed due to replacement by calcite

Alterations: Quartz replaced by calcite, hematite, and glauconite; calcite replaced by hematite; glauconite replaced by calcite and hematite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 12, Locality A

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	One foot above base

Rock Type: Glauconitic sandstone

Color: Purplish gray

Structure: Cross-bedded

Cement and/or Matrix: Hematite (7 percent)

Texture: Fine-grained (+1.27ϕ); moderately well sorted (0.59ϕ); angular (1.86); good roundness sorting (0.62); mode, +1.43ϕ; width/length, 0.63

Inclusions: Tourmaline, muscovite, zircon, rutile, hematite (secondary), apatite, sillimanite

Grain boundaries: Irregular, minor suturing

Alterations: Quartz replaced by hematite and glauconite; glauconite replaced by hematite and altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 13, Locality A

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	10 feet above base

Rock Type: Orthoquartzite

Color: Reddish gray

Structure: Cross-bedded; solution along bedding planes

Cement and/or Matrix: Quartz (5 percent); calcite and hematite (5 percent)

Texture: Fine-grained (+1.77Ø); moderately well sorted (0.60Ø); subangular (2.53); very poor roundness sorting (1.21); mode, +1.30Ø; width/length, 0.63

Inclusions: Rutile, chlorite, zircon, feldspar, muscovite, hematite (secondary)

Grain boundaries: Commonly irregular

Alterations: Quartz and calcite replaced by hematite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 14, Locality A

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	Top (20 feet above base)

Rock Type: Orthoquartzite

Color: Brownish gray

Structure: Massive

Cement and/or Matrix: Quartz (3 percent); trace of calcite

Texture: Medium-grained (+.70ϕ); moderately well sorted (0.60ϕ); subrounded (3.10); poor roundness sorting (1.15); mode, +0.50ϕ; width/length, 0.63

Inclusions: Hematite (secondary), tourmaline, zircon, muscovite, feldspar, rutile

Grain boundaries: Mild suturing is common

Alterations: Limonite altered to goethite; quartz and collophane replaced by hematite

Fossils: Rare collophane brachiopod shell fragments

Sample 15, Locality A

Rock Unit	Stratigraphic Position of Sample
Middle calcareous sandstone	10 feet above base

Rock Type: Sandy, dolomitic limestone

Color: Brownish gray

Structure: Microstylolitic; minor fractures

Cement and/or Matrix: (limestone)

Structure: Medium thin-bedded

Texture: (Quartz grains only) medium-grained (+0.78ϕ); well sorted (0.76ϕ); subangular (2.86); poor roundness sorting (1.21); mode, +0.95ϕ; width/length, 0.62

Inclusions: Rutile, hematite (secondary), muscovite, feldspar, quartz

Grain boundaries: (most quartz grains float in calcite)

Alterations: Quartz replaced by calcite, dolomite and hematite; calcite replaced by dolomite and hematite; dolomite replaced by hematite; calcite partially recrystallized

Fossils: Few phosphatic brachipod shell fragments and fossil ghosts

Sample 16, Locality B

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	One foot above base

Rock Type: Orthoquartzite

Color: Reddish gray

Structure: Massive to medium-bedded; minor shear zone

Cement and/or Matrix: Quartz (1 percent); hematite (2 percent); minor illite

Texture: Medium-grained (+1.15ø); moderately sorted (0.86ø); angular (1.96); good roundness sorting (0.72); mode, +1.10 and -2.20ø; width/length, 0.58

Inclusions: Hematite (secondary), rutile, feldspar, zircon, sillimanite, muscovite

Grain boundaries: Planar to strongly sutured

Alterations: Feldspar altered to illite; quartz and feldspar replaced by hematite

Fossils: None

Sample 17, Locality B

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	Five feet above base

Rock Type: Orthoquartzite

Color: Reddish gray

Structure: Massive

Cement and/or Matrix: Minor quartz; illite and kaolinite (5 percent)

Texture: Medium-grained (+1.30ϕ); poorly sorted (1.50ϕ); subangular (2.06); good roundness sorting (0.62); mode, +1.20ϕ; width/length, 0.68

Inclusions: Feldspar, zircon, rutile, muscovite, epidote, hematite (secondary), chlorite

Grain boundaries: Planar to strongly sutured

Alterations: Quartz and feldspar replaced by hematite; feldspar altered to illite and kaolinite

Fossils: None

Sample 18, Locality B

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	Top (11 feet above base)

Rock Type: Orthoquartzite

Color: Reddish gray

Structure: Massive

Cement and/or Matrix: Negligible

Texture: Medium-grained (+1.50Ø); moderately sorted (0.97Ø); subangular (2.26); poor roundness sorting (1.05); mode, +1.25Ø; width/length, 0.63

Inclusions: Rutile, chlorite, feldspar, zircon, sillimanite

Grain boundaries: Irregular; few planar and sutured boundaries

Alterations: Quartz and glauconite replaced by hematite; hematite altered to limonite

Fossils: None

Sample 19, Locality B

Rock Unit	Stratigraphic Position of Sample
Lower hematitic sandstone	One foot above base

Rock Type: Hematitic, glauconitic sandstone

Color: Reddish brown

Structure: Cross-bedded

Cement and/or Matrix: Hematite (35 percent)

Texture: Medium-grained (+1.24ϕ); poorly sorted (1.10ϕ); subangular (2.33); poor roundness sorting (1.11); mode, +1.26ϕ; width/length, 0.65

Inclusions: Feldspar, rutile, zircon

Grain boundaries: Most grains appear to "float" in hematite

Alterations: Quartz and glauconite replaced by hematite; hematite altered to limonite; collophane replaced by hematite

Rossils: Phosphatic brachiopod shell fragments common

Sample 20, Locality B

Rock Unit	Stratigraphic Position of Sample
Thin-bedded glauconite	20 feet above base

Rock Type: Dolomitic, glauconitic sandstone

Color: Reddish, gray-green

Structure: Thin-bedding defined by change in grain size and cement

Cement and/or Matrix: Quartz (2 percent); dolomite (10 percent); minor hematite and trace of calcite

Texture: Fine-grained (+1.85ϕ); moderately sorted (0.78ϕ); subangular (2.03); moderate roundness sorting (0.85); mode, +1.65ϕ; width/length, 0.70

Inclusions: Chlorite, sillimanite, rutile, tourmaline, zircon

Grain boundaries: Mainly irregular; few planar

Alterations: Quartz replaced by dolomite, glauconite, hematite; collophane replaced by hematite and glauconite; dolomite replaced by hematite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 21, Locality B

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	One foot above base

Rock Type: Orthoquartzite

Color: Reddish gray-green

Structure: Bedding defined by changes in cement; "hairline" fractures

Cement and/or Matrix: Quartz (4 percent); dolomite (12 percent); calcite (3 percent); minor hematite

Texture: Fine-grained (+1.53ϕ); moderately well sorted (0.61ϕ); subangular (2.50); poor roundness sorting (1.19); mode, +1.26; width/length, 0.66

Inclusions: Tourmaline, chlorite, hematite (secondary), quartz, feldspar

Grain boundaries: Planar to irregular

Alterations: Quartz replaced by hematite, dolomite, calcite, glauconite; feldspar replaced by glauconite; glauconite replaced by hematite and altered to limonite

Fossils: Phosphatic brachiopod shell fragments common

Sample 23, Locality B

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	10 feet above base

Rock Type: Orthoquartzite

Color: Reddish gray

Structure: Cross-bedded

Cement and/or Matrix: Quartz (15 percent); dolomite (2 percent); calcite (2 percent); minor hematite

Texture: Medium-grained (+1.15ϕ); moderately well sorted (0.62ϕ); subrounded (3.23); poor roundness sorting (1.17); mode, +0.35ϕ; width/length, 0.66

Inclusions: Muscovite, tourmaline, zircon, quartz, rutile, hematite (secondary), chlorite

Grain boundaries: Irregular

Alterations: Quartz, dolomite, and calcite replaced by hematite; quartz replaced by dolomite and calcite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 24, Locality B

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	Top (20 feet above base

Rock Type: Orthoquartzite

Color: Light reddish gray

Structure: Massive

Cement and/or Matrix: Quartz (12 percent); minor calcite and dolomite

Texture: Medium-grained (+0.68Ø); moderately well sorted (0.69Ø); subangular (2.90); poor roundness sorting (1.26); mode, +0.35Ø; and -3.70Ø; width/length, 0.64

Inclusions: Tourmaline, rutile, quartz, muscovite, zircon, hematite (secondary)

Grain boundaries: Mainly irregular or moderately sutured

Alterations: Calcite and dolomite replaced by hematite

Fossils: Rare phosphatic brochiopod shell fragments

Sample 32, Locality C

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	One foot above base

Rock Type: Orthoquartzite

Color: Reddish gray

Structure: Massive; rare cross-bedding

Cement and/or Matrix: Quartz (3 percent)

Texture: Medium-grained (+0.80ϕ); moderately sorted (0.92ϕ); angular (1.73); good roundness sorting (0.73); mode, +1.20ϕ; width/length, 0.62

Inclusions: Tourmaline, feldspar, muscovite, sillimanite, rutile, zircon, hematite (secondary)

Grain boundaries: Irregular; minor suturing

Alterations: Quartz and feldspar replaced by hematite; feldspar altered to sericite and kaolinite

Fossils: None

Sample 33, Locality C

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	Five feet above base

Rock Type: Orthoquartzite

Color: Mottled, reddish gray-green

Structure: Massive; rare cross-bedding

Cement and/or Matrix: Hematite (5 percent); minor quartz

Texture: Fine-grained (+1.70ϕ); moderately sorted (0.95ϕ); angular (1.73); good roundness sorting (0.73); mode, +1.30ϕ; width/length, 0.71

Inclusions: Zircon, rutile, hematite (secondary), chlorite, feldspar, quartz, tourmaline

Grain boundaries: Predominantly irregular; occasional moderate suturing

Alterations: Quartz, feldspar and illite replaced by hematite; feldspar altered to illite

Fossils: None

Sample 34, Locality C

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	Top (11 feet above base)

Rock Type: Orthoquartzite

Color: Reddish green

Structure: Massive; rare cross-bedding

Cement and/or Matrix: Illite and kaolinite (11 percent), minor hematite

Texture: Medium-grained (+1.36ϕ); moderately sorted (0.92ϕ); subangular (2.00); moderate roundness sorting (0.82); mode, +1.23ϕ; width/length, 0.70

Inclusions: Rutile, zircon, quartz, feldspar, apatite

Grain boundaries: Irregular; occasional suturing

Alterations: Quartz, glauconite, illite, and kaolinite replaced by hematite; illite altered to kaolinite

Fossils: None

Sample 35, Locality C

Rock Unit	Stratigraphic Position of Sample
Lower hematitic sandstone	One foot above base

Rock Type: Sandy hematite

Color: Reddish brown

Structure: Thin-bedded

Cement and/or Matrix: (Hematite)

Texture: (Quartz grains only) medium-grained (+1.48ø); moderately sorted (0.81ø); subangular, (2.43); moderate roundness sorting (0.81); mode, +1.33ø; width/length, 0.68

Inclusions: Hematite (secondary), zircon, chlorite, rutile, apatite, feldspar, muscovite

Grain boundaries: Most quartz grains "float" in hematite

Alterations: Quartz and glauconite replaced by hematite; quartz and feldspar replaced by glauconite; collophane replaced by quartz

Fossils: Phosphatic brachiopod shell fragments common

Sample 36, Locality C

Rock Unit	Stratigraphic Position of Sample
Thin-bedded glauconite	20 feet above base

Rock Type: Sandy, glauconitic, intraclastic dolomite

Color: Greenish gray

Structure: Microstylolites; minor fractures

Cement and/or Matrix: Rare quartz cement between dolomite grains

Texture: Fine-grained (+1.75ϕ); moderately well sorted (0.69ϕ); subangular (2.13); moderate roundness sorting (0.92); mode, +1.35ϕ; width/length, 0.70

Inclusions: Apatite, chlorite, sillimanite

Grain boundaries: Irregular to slightly sutured

Alterations: Quartz, dolomite, glauconite and collophane replaced by hematite; quartz and collophane replaced by dolomite

Fossils: Phosphatic brachiopod shell fragments common

Sample 37, Locality C

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	One foot above base

Rock Type: Orthoquartzite

Color: Reddish gray-green

Structure: Cross-bedded

Cement and/or Matrix: Quartz (8 percent); minor dolomite

Texture: Fine-grained (+1.28∅); moderately well sorted (0.56∅); subangular (2.23); poor roundness sorting (1.03); mode, +1.40∅; width/length, 0.70

Inclusions: Rutile; quartz, chlorite; hematite (secondary), zircon

Grain boundaries: Irregular

Alterations: Quartz and glauconite replaced by hematite; quartz replaced by glauconite and dolomite; glauconite and hematite altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 38, Locality C

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	10 feet above base

Rock Type: Orthoquartzite

Color: Gray to reddish gray

Structure: Cross-bedded; solution pits along cross-bedding planes; microstylotites

Cement and/or Matrix: Quartz (10 percent); dolomite (3 percent); trace calcite

Texture: Medium-grained (+1.25ϕ); well sorted (0.44ϕ); subangular (2.73); very poor roundness sorting (1.24); mode, +1.25ϕ; width/length, 0.58

Inclusions: Tourmaline, biotite; hematite (secondary), zircon

Grain boundaries: Irregular

Alterations: Quartz and dolomite replaced by hematite; quartz replaced by dolomite; hematite altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 39, Locality A

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	Top (20 feet above base)

Rock Type: Orthoquartzite

Color: Reddish gray

Structure: Massive; minor cross-bedding

Cement and/or Matrix: Quartz (12 percent); dolomite (2 percent); trace of calcite

Texture: Medium-grained (+0.87ϕ); well sorted (0.46ϕ); subrounded (3.60); poor roundness sorting (1.19); mode, +1.26ϕ; width/length, 0.65

Inclusions: Feldspar, tourmaline, hematite (secondary), zircon, rutile, chlorite

Grain boundaries: Irregular

Alterations: Quartz and dolomite replaced by hematite; quartz replaced by dolomite; hematite altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 40, Locality C

Rock Unit	Stratigraphic Position of Sample
Middle calcareous sandstone	12 feet above base

Rock Type: Sandy dolomite

Color: Reddish gray

Structure: Massive; obscure cross-bedding

Cement and/or Matrix: (Dolomite)

Texture: (Quartz grains only) medium-grained (+1.13ϕ); moderately sorted (0.85ϕ); subangular (2.70); poor roundness sorting (1.17); mode, +1.10ϕ; width/length, 0.62

Inclusions: Sillimanite, hematite (secondary), rutile, chlorite

Grain boundaries: Most grains "float" in dolomite

Alterations: Dolomite and quartz replaced by hematite; quartz replaced by dolomite; hematite altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 45

Rock Unit	Stratigraphic Position of Sample
Cable Canyon	Two feet above base sandy member

Rock Type: Sandy dolomite

Color: Gray

Structure: Massive

Cement and/or Matrix: (Dolomite)

Texture: (Quartz grains only) medium-grained (+1.28ϕ); moderately well sorted (0.66ϕ); subrounded (3.66); poor roundness sorting (1.22); mode, +1.20ϕ; width/length, 0.63

Inclusions: Rutile, tourmaline, quartz, chlorite, muscovite

Grain boundaries: Most quartz grains "float" in dolomite

Alterations: Quartz replaced by dolomite

Fossils: Rare dolomitized shell fragments

Sample 46

Rock Unit	Stratigraphic Position of Sample
Cable Canyon	10 feet above base of sandy member

Rock Type: Sandy dolomite

Color: Gray

Structure: Massive

Cement and/or Matrix: (Dolomite)

Texture: (Quartz grains only) fine-grained (+1.67ø); moderately well sorted (0.64ø); subrounded (3.06); poor roundness sorting (1.19); mode, +1.30ø; width/length, 0.71

Inclusions: Quartz, muscovite, rutile

Grain boundaries: Most quartz grains "float" in dolomite

Alterations: Quartz replaced by dolomite

Fossils: Rare dolomitized shell fragments

Sample 48, Locality B

Rock Unit	Stratigraphic Position of Sample
Middle calcareous sandstone	11 feet above base

Rock Type: Sandy dolomite

Color: Brownish gray

Structure: Cross-bedded

Cement and/or Matrix: Minor hematite

Texture: (Quartz grains only) medium-grained (+0.85ϕ); well sorted (0.42ϕ); subrounded (3.20); poor roundness sorting (1.19); mode, +0.88ϕ; width/length, 0.61

Inclusions: Zircon, feldspar, quartz, muscovite, chlorite, apatite

Grain boundaries: Most "float" in dolomite

Alterations: Dolomite and quartz replaced by hematite; quartz and collophane replaced by dolomite; hematite altered to limonite

Fossils: Phosphatic brachiopod shell fragments common

Sample 52, Locality E

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	One foot above base

Rock Type: Orthoquartzite

Color: Pinkish gray

Structure: Massive

Cement and/or Matrix: Trace of dolomite; illite; kaolinite; cholorite (?)

Texture: Fine-grained (+1.85ϕ); poorly sorted (1.04ϕ); subangular (2.53); very poor roundness sorting (1.21); mode, +2.20ϕ; width/length, 0.71

Inclusions: Tourmaline, rutile, feldspar, zircon, apatite, quartz

Grain boundaries: Irregular

Alterations: Quartz, feldspar replaced by glauconite; glauconite replaced by hematite; glauconite, hematite, and quartz replaced by dolomite

Fossils: None

Sample 53, Locality E

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	Five feet above base

Rock Type: Orthoquartzite

Color: Pinkish gray

Structure: Massive

Cement and/or Matrix: Trace of calcite

Texture: Fine-grained (+2.00ϕ); moderately sorted (0.72ϕ); subangular (2.03); moderate roundness sorting (0.84); mode, +1.90ϕ; width/length, 0.72

Inclusions: Rutile, muscovite, tourmaline, feldspar

Grain boundaries: Irregular

Alterations: Quartz and feldspar replaced by chlorite; quartz also replaced by calcite and hematite; feldspar altered to illite and replaced by hematite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 54, Locality E

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	One foot from top

Rock Type: Orthoquartzite

Color: Pinkish gray

Structure: Massive

Cement and/or Matrix: Hematite (3 percent); trace of limonite

Texture: Medium-grained (+1.25ϕ); moderately sorted (0.97ϕ); subrounded (3.26); poor roundness sorting (1.15); mode, +1.20ϕ; width/length, 0.72

Inclusions: Hematite (secondary), tourmaline, rutile, biotite, muscovite, quartz, limonite

Alterations: Feldspar replaced by hematite; hematite altered to limonite; quartz replaced by hematite

Grain boundaries: Irregular to moderately sutured

Fossils: None

Sample 55, Locality E

Rock Unit	Stratigraphic Position of Sample
Thin-bedded glauconite	20 feet above base

Rock Type: Glauconite sandstone

Color: Greenish gray

Structure: Thin-bedded; bedding planes defined by grain size change

Cement and/or Matrix: Calcite (4 percent); trace of hematite and quartz

Texture: Fine-grained (+2.20ϕ); moderately well sorted (0.57ϕ); subangular (2.06); good roundness sorting (0.74); mode, +2.25ϕ; width/length, 0.71

Inclusions: Rutile, hematite (secondary), zircon, muscovite, chlorite

Grain boundaries: Irregular

Alterations: Quartz, glauconite, and calcite replaced by hematite; quartz replaced by glauconite and calcite; hematite altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 56, Locality E

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	One foot above base

Rock Type: Orthoquartzite

Color: Dark greenish gray

Structure: Thin-bedded; some micro-cross-bedding, defined by hematite and limonite

Cement and/or Matrix: Hematite (8 percent)

Texture: Fine-grained (+2.05ø); moderately well sorted (0.54ø); subangular (2.66); poor roundness sorting (1.17); mode, +1.85ø; width/length, 0.71

Inclusions: Chlorite, rutile, quartz, tourmaline, zircon, sillimanite

Grain boundaries: Irregular

Alterations: Quartz replaced by hematite, limonite, and glauconite; glauconite replaced by hematite; hematite altered to limonite; feldspar altered to illite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 57, Locality E

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	10 feet above base

Rock Type: Orthoquartzite

Color: Light gray

Structure: Massive

Color and/or Matrix: Quartz (8 percent); minor hematite

Texture: Medium-grained (+0.78ϕ); moderately sorted (0.75ϕ); subrounded (3.56); poor roundness sorting (1.18); mode, +0.48ϕ; width/length, 0.66

Inclusions: Sericite, rutile, quartz, zircon, chlorite, apatite

Grain boundaries: Irregular; incipient to moderate suturing

Alterations: Quartz replaced by hematite which altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 58, Locality E

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	Top (20 feet above base)

Rock Type: Orthoquartzite

Color: Light gray

Structure: Thin-bedded; bedding defined by slight grain size change and concentration of hematite and limonite

Cement and/or Matrix: Quartz (2 percent); dolomite (7 percent); illite (3 percent)

Texture: Medium-grained (0.81ϕ); moderately well sorted (0.61ϕ); subrounded (3.50); very poor roundness sorting (1.28); mode, +0.65ϕ; width/length, 0.62

Inclusions: Sillimanite (?), rutile, quartz, zircon, muscovite, apatite, biotite

Grain boundaries: Irregular; minor suturing

Alterations: Quartz replaced by dolomite, hematite, and illite; dolomite and illite replaced by hematite; hematite altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 59, Locality E

Rock Unit	Stratigraphic Position of Sample
Middle calcareous sandstone	10 feet above base

Rock Type: Orthoquartzite

Color: Light gray

Structure: Medium-bedded

Cement and/or Matrix: Calcite (2 percent); quartz (5 percent)

Texture: Coarse-grained (+0.51ϕ); moderately well sorted (0.59ϕ); subrounded (3.20); very poor roundness sorting (1.21); mode, +0.35ϕ; width/length, 0.61

Inclusions: Quartz, chlorite, zircon, biotite, muscovite, rutile

Grain boundaries: Irregular to moderately sutured

Alterations: Quartz and calcite replaced by hematite; quartz replaced by calcite; hematite altered to limonite; feldspar altered to kaolinite

Fossils: None

Sample 62, Locality D

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	One foot above base

Rock Type: Orthoquartzite

Color: Pinkish gray

Structure: Massive; fractured

Cement and/or Matrix: Illite (8 percent)

Texture: Fine-grained (+1.85ϕ); moderately sorted (0.86ϕ); subrounded (3.03); poor roundness sorting (1.07); mode, +1.80ϕ; width/length, 0.63

Inclusions: Rutile, apatite, zircon, muscovite, hematite (secondary)

Grain boundaries: Irregular to moderately sutured

Alterations: Quartz, illite, and feldspar replaced by hematite

Fossils: None

Sample 63, Locality D

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	Five feet above base

Rock Type: Orthoquartzite

Color: Reddish gray

Structure: Massive, fractured

Cement and/or Matrix: Illite, partially replaced by hematite (15 percent)

Texture: Fine-grained (+2.10ϕ); moderately well sorted (0.69ϕ); subangular (2.23); moderate roundness sorting (0.83); mode, +2.20ϕ; width/length, 0.70

Inclusions: Rutile, zircon, hematite (secondary), quartz, muscovite

Grain boundaries: Irregular

Alterations: Quartz and feldspar replaced by hematite

Fossils: None

Sample 64, Locality D

Rock Unit	Stratigraphic Position of Sample
Lower quartzite	Top (11 feet above base)

Rock Type: Orthoquartzite

Color: Reddish gray

Structure: Massive; worm borings

Cement and/or Matrix: Illite and kaolinite partially replaced by hematite (5 percent)

Texture: Fine-grained (+2.15ϕ); moderately sorted (0.72ϕ); subrounded (3.16); poor roundness sorting (1.10); mode, +1.25ϕ; width/length, 0.61

Inclusions: Rutile, sillimanite (?), hematite (secondary), zircon feldspar, biotite

Grain boundaries: Irregular

Alterations: Quartz and illite replaced by hematite; illite altered to kaolinite

Fossils: None

Sample 65, Locality D

Rock Unit	Stratigraphic Position of Sample
Lower hematitic sandstone	One foot above base

Rock Type: Sandy hematite

Color: Dark red

Structure: Thin-bedded

Cement and/or Matrix: (Hematite)

Texture: (Quartz grains only) medium-grained (+1.18ϕ); moderately sorted (0.92ϕ); subrounded (3.53); poor roundness sorting (1.08); mode, +1.25ϕ; width/length, 0.60

Inclusions: Apatite, rutile, zircon, chlorite, tourmaline, feldspar, hematite (secondary)

Grain boundaries: Most quartz grains "float" in hematite

Alterations: Quartz and feldspar replaced by hematite; collophane replaced by quartz

Fossils: Rare phosphatic brachiopod shell fragments

Sample 66, Locality D

Rock Unit	Stratigraphic Position of Sample
Thin-bedded glauconite	20 feet above base

Rock Type: Glauconitic sandstone

Color: Pinkish gray-green

Structure: Scattered, small solution channels; thin-bedded

Cement and/or Matrix: Quartz (2 percent); hematite (2 percent); calcite (1 percent)

Texture: Fine-grained (+2.05ϕ); moderately well sorted (0.55ϕ); subangular (2.56); poor roundness sorting (1.07); mode, +1.95ϕ; width/length, 0.72

Inclusions: Tourmaline, rutile, apatite, hematite (secondary)

Grain boundaries: Irregular, minor suturing

Alterations: Quartz replaced by calcite, glauconite, and hematite; glauconite replaced by calcite and hematite; hematite altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 67, Locality D

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	One foot above base

Rock Type: Orthoquartzite

Color: Brownish gray

Structure: Irregular bedding; fractured

Cement and/or Matrix: Quartz (2 percent); dolomite (5 percent); hematite (7 percent)

Texture: Fine-grained (+1.51ø); moderately well sorted (0.54ø); subrounded (3.80); poor roundness sorting (1.12); mode, +0.95ø; width/length, 0.64

Inclusions: Apatite, muscovite, quartz, rutile, chlorite

Grain boundaries: Irregular

Alterations: Quartz and glauconite replaced by dolomite; quartz, glauconite and dolomite replaced by hematite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 68, Locality D

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	10 feet above base

Rock Type: Orthoquartzite

Color: Brownish gray

Structure: Microstylolites; irregular bedding; fractures

Cement and/or Matrix: Quartz (10 percent); minor calcite, and illite

Texture: Fine-grained (+1.69ø); moderately well sorted (0.57ø); subrounded (3.66); poor roundness sorting (1.17); mode, +1.30ø; width/length, 0.71

Inclusions: Rutile, chlorite, tourmaline, quartz, hematite (secondary)

Grain boundaries: Irregular

Alterations: Quartz replaced by calcite and hematite; illite replaced by calcite; hematite altered to limonite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 69, Locality D

Rock Unit	Stratigraphic Position of Sample
Middle quartzite	Top (20 feet above base)

Rock Type: Orthoquartzite

Color: Brownish gray

Structure: Irregular bedding; microstylolites

Cement and/or Matrix: Dolomite (10 percent); trace illite

Texture: Medium-grained (+0.82ϕ); moderately sorted (0.81ϕ); subrounded (3.26); poor roundness sorting (1.18); mode, +0.65ϕ; width/length, 0.63

Inclusions: Quartz, rutile, tourmaline, zircon, chlorite

Grain boundaries: Irregular to strongly sutured

Alterations: Quartz replaced by dolomite and hematite; dolomite replaced by hematite

Fossils: Rare phosphatic brachiopod shell fragments

Sample 70, Locality D

Rock Unit	Stratigraphic Position of Sample
Middle calcareous sandstone	10 feet above base

Rock Type: Dolomitic sandstone

Color: Brownish gray

Structure: Irregular bedding; small scale cross-bedding

Cement and/or Matrix: Dolomite (12 percent)

Texture: Medium-grained (+0.81ϕ); moderately sorted (0.76ϕ); subrounded (3.43); poor roundness sorting (1.15); mode, +1.10ϕ; width/length, 0.64

Inclusions: Rutile, chlorite, apatite, tourmaline, feldspar, zircon, hematite (secondary)

Grain boundaries: Irregular to moderately sutured

Alterations: Quartz replaced by dolomite and hematite; dolomite replaced by hematite

Fossils: Rare phosphatic brachiopod shell fragments

APPENDIX 3

Descriptions of Basement Samples

Explanation: Samples without a locality designation were collected at random as described in Appendix 1. Textural data apply to quartz only. Data on all parameters, except color, were derived from thin sections. All thin section grain sizes were converted to sieve sizes using Friedman's (1962) graphs.

Sample 3-C

Rock Type: Metaquartzite

Color: Pinkish gray

Texture of quartz:

Mean size: Coarse-grained (+0.25ϕ)

Standard deviation: 0.78ϕ

Mode: +0.25ϕ

Mean width/length: 0.48

Inclusions: Muscovite, sillimanite, biotite, magnetite, hematite (secondary), zircon

Grain boundaries: Commonly planar; occasionally sutured

Alterations: Muscovite altered to illite and sillimanite

Sample 4, Locality A

Rock Type: Microcline granite

Color: Pink

Texture of quartz:

Mean size: Very coarse-grained (-0.40ϕ)

Standard deviation: 1.41ϕ

Mode: +0.25ϕ

Mean width/length: 0.43

Inclusions: Muscovite, feldspar, magnetite, zircon, hematite (secondary)

Grain boundaries: Planar to irregular

Alterations: Feldspar altered to illite, kaolinite; muscovite to illite, kaolinite and chlorite

Sample 27

Rock Type: Quartz-sillimanite-muscovite-biotite schist

Color: Brownish gray

Texture of quartz:

Mean size: Medium-grained (+1.20ϕ)

Standard deviation: 0.60ϕ

Mode: +1.20ϕ

Mean width/length: 0.48

Inclusions: Muscovite, biotite, sillimanite

Grain boundaries: Commonly planar

Alterations: Muscovite altered to sillimanite and chlorite

Sample 28

Rock Type: Quartz-muscovite-biotite-sillimanite schist

Color: Greenish gray

Texture of quartz:

Mean size: Medium-grained (+1.80ϕ)

Standard deviation: 0.62ϕ

Mode: +1.65ϕ

Mean width/length: 0.69

Inclusions: Sillimanite, muscovite, biotite

Grain boundaries: Usually planar; rarely sutured

Alterations: Muscovite altered to kaolin

Sample 31, Locality C

Rock Type: Metaquartzite

Color: Gray

Texture of quartz:

Mean size: Medium-grained (+1.30ϕ)

Standard deviation: 0.67ϕ

Mode: +1.25ϕ

Mean width/length: 0.63

Inclusions: Sillimanite, muscovite

Grain boundaries: Commonly slightly sutured

Alterations: Muscovite altered to sillimanite, illite, kaolinite; biotite to chlorite

Sample 42

Rock Type: Quartz-sillimanite-muscovite-biotite schist

Color: Brownish gray

Texture of quartz:

Mean size: Medium-grained (+1.85ϕ)

Standard deviation: 0.87ϕ

Mode: +1.70ϕ

Mean width/length: 0.69

Inclusions: Sillimanite, muscovite

Grain boundaries: Irregular

Alterations: Muscovite altered to sillimanite, illite, kaolinite; biotite to chlorite

Sample 43

Rock Type: Quartz-sillimanite-muscovite-chlorite schist

Color: Gray

Texture of quartz:

Mean size: Medium-grained (+1.75ø)

Standard deviation: 0.87ø

Mode: +1.69ø

Mean width/length: 0.66

Inclusions: Sillimanite, muscovite, biotite, magnetite, chlorite

Grain boundaries: Planar to irregular

Alterations: Muscovite altered to sillimanite, illite; biotite to chlorite

Sample 44

Rock Type: Metaquartzite

Color: Brownish gray

Texture of quartz:

Mean size: Fine-grained (+2.25ϕ)

Standard deviation: 0.55ϕ

Mode: +2.35ϕ

Mean width/length: 0.88

Inclusions: Sillimanite, muscovite, biotite, chlorite, magnetite, zircon

Grain boundaries: Irregular

Alterations: Muscovite altered to sillimanite and illite; biotite to chlorite; magnetite to hematite

Sample 47, Locality B

Rock Type: Microcline granite

Color: Pink

Texture of quartz:

Mean size: Coarse-grained (+0.20ø)

Standard deviation: 1.14ø

Mode: +0.40ø

Mean width/length: 0.53

Inclusions: Quartz, feldspar, muscovite, rutile, magnetite

Grain boundaries: Planar to irregular

Alterations: Muscovite altered to illite and kaolinite; feldspar to illite, kaolinite, hematite

Sample 51-B, Locality E

Rock Type: Microcline granite

Color: Pink

Texture of quartz:

Mean size: Coarse-grained (+0.30ϕ)

Standard deviation: 1.33ϕ

Mode: +0.10ϕ

Mean width/length: 0.48

Inclusions: Rutile, tourmaline, apatite, feldspar

Grain boundaries: Planar to irregular

Alterations: Feldspar altered to sericite, illite, kaolinite, chlorite; micas to chlorite; feldspar and micas replaced by hematite

Sample 61, Locality D

Rock Type: Meta-arkose

Color: Pink

Texture of quartz:

Mean size: Fine-grained (+2.20ø)

Standard deviation: 0.67ø

Mode: +2.25ø

Mean width/length: 0.73

Inclusions: Muscovite, magnetite, tourmaline, zircon, chlorite, apatite, oriented rutile

Grain boundaries: Planar to irregular

Alterations: Feldspar altered to sericite, illite, kaolinite; biotite to chlorite; biotite replaced by hematite

Sample 71

Rock Type: Quartz-sillimanite-muscovite-biotite schist

Color: Gray

Texture of quartz:

Mean size: Medium-grained (+1.90ϕ)

Standard deviation: 0.67ϕ

Mode: +1.50ϕ

Mean width/length: 0.73

Inclusions: Muscovite, biotite, sillimanite, chlorite, hematite (probably altered magnetite)

Grain boundaries: Irregular to planar

Alterations: Muscovite altered to illite; biotite to chlorite; magnetite to hematite

Sample 75

Rock Type: Vein quartz

General description: Highly polygonized with "sutured" polygon boundaries; numerous fractures, some healed, some partially filled with muscovite. Feather joints along some fractures indicate slight movement.

Inclusions: Muscovite

Sample 78

Rock Type: Metaquartzite

Color: Gray

Texture of quartz:

Mean size: Coarse-grained (+0.35Ø)

Standard deviation: 0.65Ø

Mode: +0.30Ø

Mean width/length: 0.56

Inclusions: Sillimanite, tourmaline, zircon, muscovite, hematite (probably altered magnetite or late replacement of quartz), chlorite

Grain boundaries: Moderately sutured

Alterations: Muscovite altered to sillimanite, illite and kaolinite; biolite to chlorite; hematite to limonite; magnetite to hematite; biotite replaced by hematite

Sample 79

Rock Type: Metaquartzite

Color: Light greenish gray

Texture of quartz

Mean size: Medium-grained (+1.75ø)

Standard deviation: 0.78ø

Mode: +0.97ø

Mean width/length: 0.71

Inclusions: Sillimanite, muscovite, biotite, zircon, apatite

Grain boundaries: Planar to irregular

Alterations: Muscovite altered to sillimanite; biotite to kaolinite

Sample 80

Rock Type: Quartz-sillimanite-muscovite-biotite schist

Color: Greenish gray

Texture of quartz:

Mean size: Medium-grained (+1.70ϕ)

Standard deviation: 0.85ϕ

Mode: +1.45ϕ

Mean width/length: 0.50

Inclusions: Sillimanite, muscovite, biotite, hematite (probably altered magnetite)

Grain boundaries: Planar to irregular

Alterations: Muscovite and biotite altered to sillimanite; biotite to chlorite; hematite to limonite; possibly magnetite to hematite; biotite replaced by hematite

Sample 81

Rock Type: Quartz-sillimanite-muscovite-biotite schist

Color: Brownish gray

Texture of quartz:

Mean size: Fine-grained (+2.25∅)

Standard deviation: 0.55∅

Mode: +2.25∅

Mean width/length: 0.73

Inclusions: Sillimanite, muscovite, biotite, magnetite, zircon

Grain boundaries: Irregular to planar

Alterations: Muscovite and biotite altered to sillimanite

APPENDIX 4

Size Distribution Data

Explanation: These data are derived from disintegrated sieved samples of Precambrian basement rocks.

Appendix 4.--Size Distribution (Disintegrated Basement Samples)

	Total Sample	Total Quartz	Monocryst-alline Quartz	Polycryst-alline Quartz	Undulatory Quartz	Nonundulatory Quartz
Sample 1 (Granite)						
Mode ϕ	-1.73	-1.87	+0.30 1st -1.60 2nd	-1.80	-1.60 1st -0.70 2nd	+1.85
M_Z ϕ	-0.85	-0.34	+0.10	-0.98	-0.42	+1.83
σ_I ϕ	1.94	1.63	1.70	1.11	1.34	1.06
SK_I	+0.11	+0.28	+0.09	+0.69	+0.07	+0.04
K_G	0.97	0.82	0.87	1.38	0.89	0.91
Sample 2-B (Granite)						
Mode ϕ	-1.47	-1.20	-0.78	-2.20 1st -0.82 2nd	-0.62	-0.95 1st -2.83 2nd
M_Z ϕ	-0.71	-0.70	+0.50	-1.83	-0.02	+1.40
σ_I ϕ	1.94	1.75	1.48	1.16	1.50	1.65
SK_I	+0.06	+0.27	+0.32	+0.44	+0.19	-0.15
K_G	1.16	0.92	1.04	0.87	0.96	0.55

Appendix 4.--Continued

	Total Sample	Total Quartz	Monocryst-alline Quartz	Polycryst-alline Quartz	Undulatory Quartz	Nonundulatory Quartz
			Sample 29 (Mixed Schist and Metaquartzite)			
Mode ϕ	+0.30	+1.10 1st -3.10 2nd	+1.22	+0.16 1st -2.04 2nd	+0.11 1st +3.73 2nd	+1.30
M_z ϕ	+0.43	+1.43	+1.62	+0.08	+1.05	+1.83
σ_I ϕ	1.72	1.39	1.23	1.40	1.52	1.16
SK_I	0.00	+0.02	+0.08	-0.17	+0.72	+0.12
K_G	1.01	0.68	0.89	1.62	0.97	0.92
			Sample 30 (Mixed Schist and Metaquartzite)			
Mode ϕ	+0.17	+0.75	+0.80	-0.85	+0.10	+0.90
M_z ϕ	-0.70	+0.60	+0.93	-0.83	+0.30	+1.10
σ_I ϕ	1.73	1.13	1.21	1.10	0.94	0.85
SK_I	-0.12	-0.04	+0.13	+0.01	+0.38	+0.20
K_G	1.10	1.14	1.14	1.19	1.26	1.07

Appendix 4.--Continued

	Total Sample	Total Quartz	Monocryst-alline Quartz	Polycryst-alline Quartz	Undulatory Quartz	Nonundulatory Quartz
Sample 3-A (Metaquartzite)						
Mode ϕ	-0.98 1st	-0.79 1st	+0.11 1st	-3.90 1st	-0.97	+0.70
	-3.94 2nd	-3.90 2nd	+2.75 2nd	-1.91 2nd		
M_z ϕ	-1.48	-1.56	+0.38	-2.47	-0.13	+0.60
σ_I ϕ	1.92	1.91	1.16	1.59	0.62	0.97
SK_I	-0.10	-0.14	+1.04	+0.17	-0.03	-0.21
K_G	0.82	0.73	1.20	0.84	1.21	0.66

APPENDIX 5

Width/Length Ratios

Explanation: These data are a result of an examination of 5964 quartz grains in thin sections of undisintegrated samples of the Bliss Formation, Cable Canyon Formation, and Precambrian basement rocks.

Appendix 5.--Average Width/Length Ratios of Potential Source Rocks and Sedimentary Rocks in the Silver City Area (Undisintegrated Samples)

Sample Source	Number of Samples	Mean Width/Length Ratio
Cable Canyon (Montoya)	2	0.67
Middle calcareous sandstone	5	0.62
Middle quartzite	15	0.65
Thin-bedded glauconite	5	0.70
Lower hematitic sandstone	4	0.65
Lower quartzite	15	0.66
Average Bliss	44	0.66
Granite	3	0.48
Meta-arkose	1	0.73
Metaquartzite	5	0.65
Schist	7	0.64

APPENDIX 6

Inclusion Data

Explanation: These data were derived from thin sections of undisintegrated samples of the Bliss Formation, Cable Canyon Formation, and Precambrian basement rocks. Secondary minerals are not included.

Appendix 6-A.--Percentage of Quartz Grains Which Are Barren, or Contain Inclusions of a Specified Type. Samples Are Undisintegrated Basement Rocks

	Schist	Meta-quartzite	Meta-arkose	Granite
Total Quartz Grains	175	125	25	75
Inclusion Type				
Unidentified Irregular	---	---	---	6.7
None	1.2	1.0	72.0	42.7
Rutile	---	---	8.0	9.2
Tourmaline	0.6	---	---	2.7
Muscovite	20.1	38.0	---	2.7
Biotite	4.5	15.0	---	---
Chlorite	2.3	3.2	---	1.3
Sillimanite	81.0	62.0	---	---
Feldspar	---	0.8	8.0	31.0
Apatite	---	---	---	2.7
Quartz	1.7	---	12.0	2.7
Magnetite	28.0	9.6	---	---
Zircon	1.7	1.6	---	1.3

Appendix 6-B.--Percentage of Quartz Grains Which Are Barren, or Contain Inclusions of a Specified Type. Samples Are Undisintegrated; from the Bliss and Cable Canyon Formations

	Lower quartzite	Lower hematitic sandstone	Thin-bedded glauconite	Middle quartzite	Middle calcareous sandstone	Cable Canyon (Montoya)
Total Quartz Grains	375	100	125	375	125	50
Inclusion Type						
Unidentified Irregular	22.0	8	20.1	12.0	4.8	2.0
None	22.4	72	64.0	70.0	69.0	82.0
Rutile	12.5	6	4.0	7.0	11.2	8.0
Tourmaline	2.4	4	4.8	4.3	4.0	6.0
Muscovite	2.6	4	2.4	1.9	1.6	---
Biotite	0.5	--	---	---	---	---
Chlorite	---	--	1.6	2.4	7.2	---
Sillimanite	0.2	2	0.8	0.8	---	---
Feldspar	3.7	1	0.8	1.1	---	---
Apatite	2.6	2	---	---	1.6	---
Quartz	0.4	--	---	0.8	2.4	---
Magnetite	---	--	---	0.3	---	2.0
Zircon	0.4	--	0.8	---	0.8	---