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CONTENTS

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Orthoquartzites of the Oquirrh Formations*

RICHARD B. WELLS

Humble Oil and Refining Company, Casper, Wyoming

ABSTRACT.—The Oquirrh Formation of Pennsylvanian and Wolfcampian Permian age in the Oquirrh Basin of northwest central Utah consists mainly of calcareous and siliceous clastic sedimentary rocks. A thickness of 15,540 feet of Oquirrh Formation was measured at South Mountain west of Stockton in Tooele County, Utah, consisting principally of orthoquartzite, calcareous and calcarenaceous orthoquartzite, and siliceous quartz sandstone, with minor cherty limestone and calcarenite. Approximately 7,250 feet of Wolfcampian age Oquirrh rocks is exposed in Hobble Creek Canyon east of Springville, Utah and is of similar lithology. The Wolfcampian interval of the Weber Formation exposed in Weber Canyon consists of 714 feet, of which, approximately 80 percent is orthoquartzite, none of which is calcareous.

Orthoquartzites of the Oquirrh Formation constitute a unique suite of sedimentary rocks, deposited in shallow water in a large marine basin which was subject to irregular instability and deep subsidence. Clastic sediments in the Oquirrh Formation were eroded from local positive areas peripheral to the Oquirrh Basin, and contributed to the basin through various accessways. These sediments are fairly well sorted and generally subrounded to subangular, equant, anhedral grains. Much of the quartz was derived from pre-existing sedimentary rocks.

A study of orthoquartzites from approximately thirty other formations in the United States failed to reveal any other examples of calcarenaceous orthoquartzite such as found in the Oquirrh Formation, but did reveal certain characteristic aspects of orthoquartzite petrography. Orthoquartzites in general are non-porous, light colored rocks consisting of 95% or more anhedral quartz grains, in which silica cementation has taken place through pressure solution or by addition of new silica, or both.

CONTENTS

TEXT

ILLUSTRATIONS

text - figures

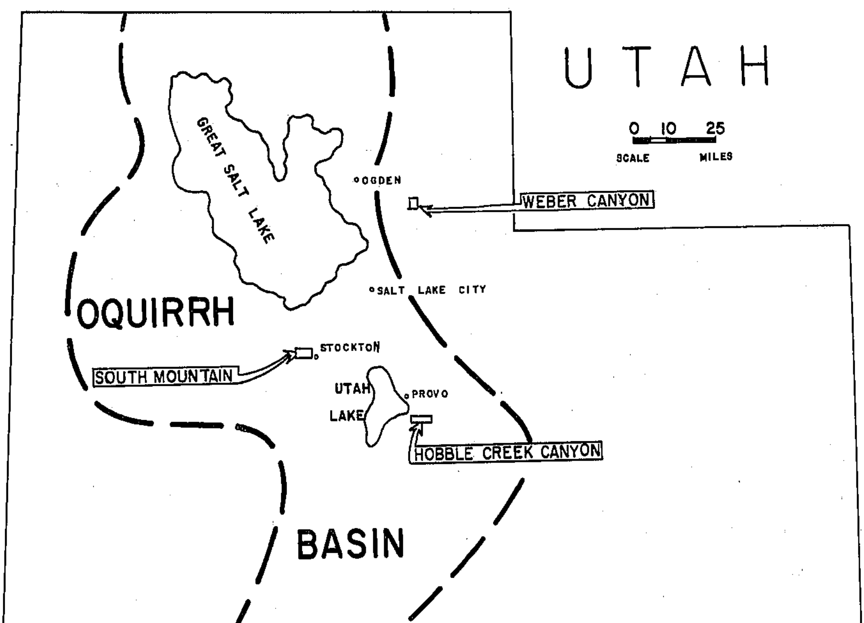
*A thesis submitted to the Faculty of the Department of Geology, Brigham Young University in partial fulfillment of the requirements for the degree of Master of Science.

CONTENTS (CONT.)

INTRODUCTION

This report is concerned with the petrology and petrography of some clastic sedimentary rocks of the Oquirrh and Weber Formations of Pennsylvanian and Permian ages. Stratigraphic sections were studied and sampled at South Mountain in Tooele County, Utah, Hobble Creek Canyon in Utah County Utah, and Weber Canyon in Morgan County, Utah (Text-fig. 1).

The Oquirrh Formation is an unusually thick miogeosynclinal sequence of calcareous and clastic sedimentary rocks ranging from Morrowan (Early Pennsylvanian) through Wolfcampian (Early Permian) age in central and northern Utah and southern Idaho. The Oquirrh Formation lies conformably on the Manning Canyon Formation of late Mississippian and early Pennsylvanian age, except in the Stansbury Mountains, where the contact is an angular un-



TEXT-FIGURE 1. Index map of the Oquirrh Basin showing location of sections.

conformity (Wright, 1961, p. 166). The Oquirrh Formation is conformably overlain by Wolfcampian age limestones of the Kirkman Formation (Bissell, 1962a, p. 34).

The Weber Formation is essentially the stable shelf equivalent of the Oquirrh Formation in northeastern Utah and northwestern Colorado. It is largely an unfossiliferous series of sandstone and orthoquartzite with a few interbedded limestone units, and ranges in age from Desmoinesian (late Medial Pennsylvanian) to Wolfcampian. It is 2260 feet thick at its type locality near Morgan in Weber Canyon. The Weber thins gradually eastward to about 1000 feet at the Colorado border, and eventually interfingers with the Maroon Formation to the east (Bissell and Childs, 1958, p. 26). The Weber disconformably overlies Pennsylvanian limestones and shales of the Morgan Formation, and is disconformably overlain by the Permian Park City-Phosphoria Formations.

Purpose

This study is primarily an investigation of the orthoquartzites of the Oquirrh Basin, undertaken to clarify and revise classification and nomenclature of these clastic sedimentary rocks, and to aid evaluation of the geologic history of the Oquirrh Basin and contiguous shelf areas. This is part of a continuing study of this unique geologic region by various faculty members and graduate students in the Geology Department of Brigham Young University (Bissell, 1936, 1959a, 1959b, 1960, 1962a, 1962b; Croft, 1956; Hodgkinson, 1961; Moyle, 1958; Rigby, 1958; and Wright, 1961).

Procedure

Methods applied in this investigation include standard megascopic petrologic examination, description, measurement, and sampling of the strata involved, observation of stratigraphic relationships such as lateral variations, directions of thickening or thinning, nature of contacts, and lithologic variations, petrographic analysis of 66 thin sections, including samples of each rock type from each locality, insoluble residue study of the calcareous samples, and comparison of the orthoquartzites of the Oquirrh and Weber Formations with sandstones and quartzites from other formations. Because of the objectives of the study, greater effort was devoted to investigation of the orthoquartzites than to the other rocks in the section, both in the field and in the laboratory.

Field work was begun in February, 1962, and continued through June 1962. Thickness of the South Mountain section was obtained by means of steel tape and Brunton compass. Laboratory and petrographic work was done in the Geology Department of Brigham Young University. Location of the Pennsylvanian-Permian boundary in all the sections is based on faunal studies by Bissell and others.

Acknowledgments

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Humble Oil and Refining Company. Ideas presented in this report are not to be construed as official opinions of the Humble Oil and Refining Company.

Previous Investigation

The first published reference to what is now known as the Oquirrh Formation was by J. E. Spurr in his 1895 report on the geology of the Mercur Mining District, in the southwestern part of the Oquirrh Range. The name "Oquirrh" was first used by Keyes (1924, p. 37) for 500 feet of "quartzite" at the base of his "Weberian" series. Nolan (1930) applied the name "Oquirrh" to Pennsylvanian rocks lithologically similar to the Oquirrh Formation of present usage in the Gold Hill Mining District in far western Tooele County. Gilluly (1932) gave formal definition to the Oquirrh Formation, and established a type locality in the Oquirrh Mountains, immediately west of Salt Lake Valley and east of Tooele Valley and Rush Valley. The first successful attempt at subdivision and faunal zonation within the Oquirrh Formation was the fusulinid work of Bissell (1936). In later reports Bissell (1959a, 1959b, 1960, 1962a, 1962b) has discussed the distribution, sedimentation, tectonics, and biostratigraphy of the Oquirrh and other Upper Paleozoic formations in western Utah, eastern Nevada, and southern Idaho. Another important fusulinid study was done by Thompson, Verville, and Bissell in 1950.

Baker (1947) published a description of the stratigraphy of the southern Wasatch Mountains, including two stratigraphic sections of the Oquirrh Formation. In that report, he confirmed the presence of Wolfcampian strata within the formation.

Wright (1961) discussed stratigraphy and tectonic setting of the Oquirrh Formation in the Stansbury Mountains, which lie to the west of Tooele Valley and Rush Valley.

Welsh and James (1961 p. 1-16) proposed the advancement of the Oquirrh Formation to group rank, restriction of the name to Pennsylvanian strata, and subdivided it into four formations with eighteen members. These changes have not been generally adopted, and are not herein recommended because of their apparent local utility. Tooker and Roberts, in the same guidebook, (1961 p. 17-26) mapped seven units of the Oquirrh Formation, five Pennsylvanian and two Permian, in the northern Oquirrh Mountains.

Terminology

In any dynamic science such as geology certain terms have been given various meanings by different authors. The following is a list of terms as used in this paper, which, in general, follows nomenclature advocated by Dunbar and Rodgers (1958, p. 165-167).

Terms

Sandstone.—Any clastic sedimentary rock composed predominantly of sand size grains (mean diameter between 2.0 and 1/16 mm) of quartz and silicate minerals.

Siltstone.—As above, except that the majority of grains are in the silt size range (1/16 to 1/256 mm). If the rock is sufficiently well cemented with silica that it breaks with an intragranular fracture, the term "silicasiltite" may be applied. In field examination of silica cemented rocks grain size is often obscured by cement, the more general terms quartzite, orthoquartzite, or metaquartzite are applicable.

Quartzite.—A rock composed principally of sand and/or silt size quartz grains cemented by silica. Because of the equal tenacity of the grains and the cement, the rock fractures with a general intragranular fracture. Traditionally, the term quartzite has indicated a metamorphic rock, although such a rock can result from strictly non-metamorphic processes.

Orthoquartzite.—A sedimentary quartzite in which the silica cement is diagenetic or authigenic and not a product of metamorphism. Cementation has occurred at a pressure and temperature below that of metamorphism, either by filling voids or replacement of primary cement by secondary silica. These rocks also display characteristic intragranular fracture and, at least megascopically, closely resemble metaquartzites.

An alternate meaning for the term orthoquartzite has been proposed (Krynine, 1948, p. 149-152). Krynine would apply the terms quartzite or orthoquartzite to any sandstone in which the clastic fraction is quartz and chert and the cement is at least 50% silica, regardless of the amount of cement or the degree of compaction. This usage has been accepted by certain authors. (Siever, 1960, p. 182; Folk, 1961, personal communication) and rejected by others (Dunbar and Rodgers, 1958, p. 165; Gilbert, in Williams, Turner, and Gilbert, 1954; American Geological Institute, 1957). As a result, ambiguity in use of this term is common in geologic literature.

Metaquartzite.—A quartzite of unquestioned metamorphic origin, as evidenced by presence of characteristic metamorphic minerals, micaceous minerals arranged in foliation planes, or an overlying sequence of metamorphic rocks in normal contact. Metaquartzites can seldom be distinguished from orthoquartzites in hand samples, and thus arises utility of the term quartzite, which may be applied to both varieties.

Prefixes

The term "quartz" may be used as a prefix to indicate at least 90% of the detrital fraction of a clastic sedimentary rock is composed of quartz, including chert, chalcedony, and quartzite or sandstone fragments.

Qualifying adjectives such as "siliceous," "calcareous," "dolomitic," etc., indicate mineral cement or matrix present in subordinate amounts. Thus, a "calcarenaceous orthoquartzite" is a consolidated aggregate of quartz grains, cemented by silica, containing detrital calcite sand or silt.

"Calcareous" is mainly a field term applied to those rocks which readily react with dilute hydrochloric acid, whereas the term "calcarenaceous" is applied to those rocks in which calcite is in detrital grains.

Because the calcarenaceous orthoquartzites in the Oquirrh Formation are often obviously clastic, and usually develop a dense, non-calcareous, siliceous weathering rind, and yet will readily effervesce when dilute acid is applied to a fresh exposure, they have been called by a wide variety of names. For example, the Wolfcampian part of the Oquirrh Formation, which is made up largely of this rock type, has been referred to as limestone, sandy limestone, sandstone, quartzite, orthoquartzite, and calcareous orthoquartzite. Such variability in petrologic nomenclature is at best misleading, and as a result construction of meaningful clastic ratio maps, sandstone isoliths and isopachs, and lithofacies maps is impossible.

OQUIRRH BASIN STUDY

South Mountain Section

The entire exposure of Oquirrh Formation at South Mountain (T. 4 S., R. 5 and 6 W.), west of Stockton in Tooele County, Utah, was measured, described, and sampled. South Mountain contains a broad, northwest plunging anticline with overturned strata on the nose of the fold. Approximately 15,540 feet of Oquirrh strata is exposed here, ranging from Morrowan through Wolfcampian ages, based on fusulinid studies by Welsh and James (1961, p. 7) and Bissell (1962, personal communication). The Wolfcampian portion of the Oquirrh Formation is 9,410 feet thick.

The underlying Manning Canyon Shale is not exposed, but the contact with the overlying Wolfcampian Kirkman Formation is at the base of the west slope of the western summit of South Mountain. The measured section is shown graphically in text-figure 2, and the relative proportion of rock types present is given in table 1.

The following rock types were observed in the Oquirrh Formation at South Mountain:

Calcarenite.—Units 1, 2, 7, and 8 are gray to dark gray, clastic limestones composed mainly of detrital calcite grains and skeletal material in a matrix of micrite or fine calcitic mud (Pl. 1, fig. 1). This calcarenite ranges from 73% to 98% carbonate, and the insoluble residue contains silt, clay, silica, and various skeletal fragments.

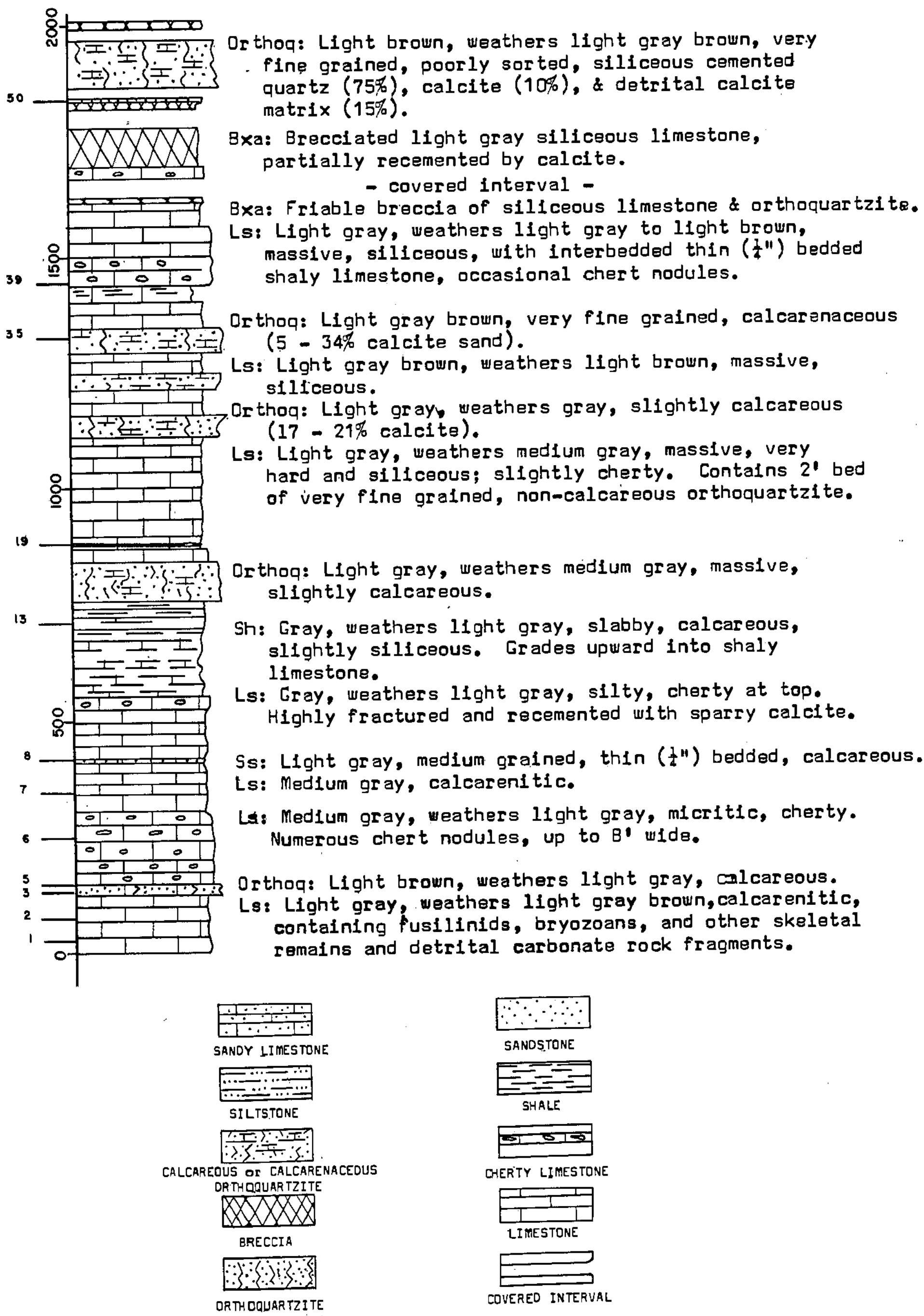
Cherty limestone.—Units 6, 39, and 78 are medium gray, light gray weathering, aphanic to slightly silty, siliceous limestones which contain nodules and stringers of massive, concretionary, and bedded gray to brown chert in discontinuous and irregular distribution. The largest chert nodule was observed in unit six, and measured slightly more than eight feet across. Dissolved samples of these cherty limestones indicated 7% to 88% carbonate, and yielded a residue of angular fragments of dense, vitreous, dark gray to black chert.

Shale.—Units 13 and 79 are gray, calcareous, platy shales which weather a light brown color and commonly split into quarter-inch laminae. Also present are some gray, highly argillaceous, platy limestones which are gradational with the shale.

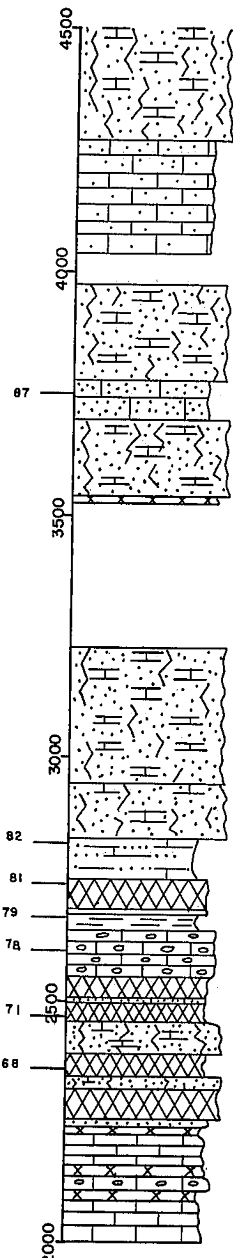
Quartz sandstone.—Units 91 and 130 are light gray to light brown, friable, non-calcareous rocks composed of very fine grained quartz sand and silt, partially cemented with silica or calcite. A typical sample of this sandstone consists of 97% quartz, 1% clay, and 1% cement, with traces of microcline, detrital chalcedony, and heavy minerals. The sand ranges from very fine to silt size, and grains are well sorted, sub-rounded to well rounded, anhedral and equant. Grain boundaries are rough and quartz grains are occasionally intergrown (Pl. 1, fig. 2).

Siliceous quartz sandstone.—As above, but with an increase in silica cement, resulting in increased tenacity, but still with a tendency to break around rather

TEXT-FIGURE 2. Columnar section of the Oquirrh Formation exposed at South Mountain (T. 4 S., R. 5 W.) Tooele County, Utah. Numbers in lefthand margin indicate location of samples mentioned in text.



(TEXT-FIG. 2, CONT.)



Orthoq: Light gray, weathers light brown, very fine grained to silty, slightly calcareous.

Ls: Light gray, sandy/silty, partially covered. Insoluble residue contains sand, silt, light gray clay, and quartzite rock fragments.

Ss: Light brown, weathers light gray, very fine grained to silt size grains, matrix of granular calcite silt, (37% calcite), trace of silica cement. Grades upward into calcareous orthoquartzite as silica cement increases.

Bxa: Zone of brecciated orthoquartzite at top of covered interval.

- covered interval -

Orthoq: Light brown, weathers very light brown, hard, dense, highly jointed, 12% calcite. Quartz grains form an interlocking mosaic in which the original grain shape is obscured pressure solution and silica cementation.

Slst: Light gray, calcite cemented quartz silt, 10% calcite.

Sh: Light gray, calcareous, grades into shaly limestone.

Ls: Light gray, weathers very light gray, micritic, cherty, ledge former; contains fossil corals.

Bxa: Light brown brecciated orthoquartzite, calcite cemented.

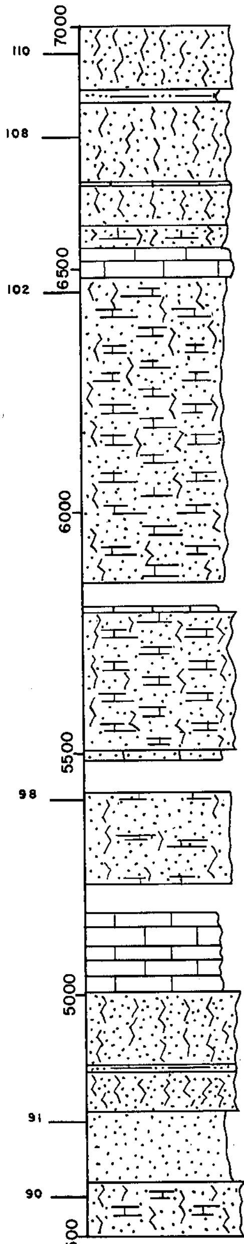
Orthoq: Light gray to light brown, very fine grained to silt size grains, 5 to 10% calcite silt matrix.

Bxa: Light brown, siliceous, ledge former.

Ss: Light brown, very fine grained to silty, poorly sorted, slightly siliceous.

Bxa: Light brown, light gray weathering, friable, calcite cemented breccia of siliceous limestone & orthoquartzite.

(TEXT-FIG. 2, CONT.)



Orthoq: Light brown, silty, alternating layers of sub-angular very fine grained quartz sand and well rounded medium grained quartz sand; non-calcareous.

Ls: Light gray, weathers very light gray with mottled light brown stain, thin bedded, micritic to slightly sandy texture. Fossil "worm trails" near top.

Orthoq: Light gray, weathers very light brown, very fine grained, massive, calcarenaceous (10% calcite), trace of detrital microcline. Weathers into ½" slabs.

Orthoq: as above

Ss: Light gray brown, weathers light brown, fine to very fine grained, slightly siliceous, calcareous.

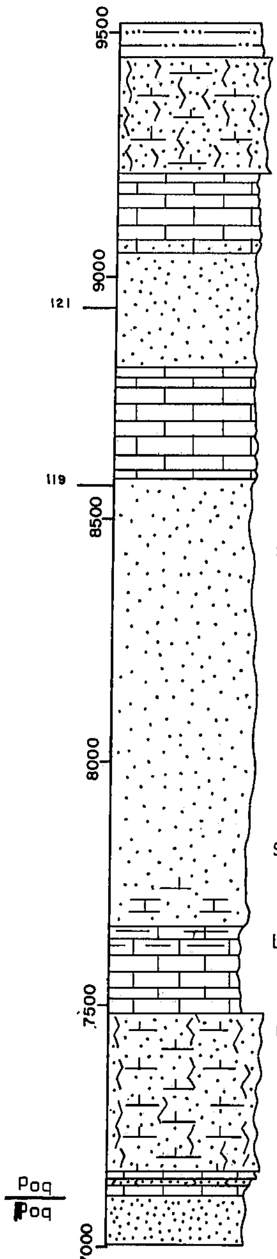
Ls: Very dark gray, weathers medium gray, hard, dense, siliceous.

Orthoq: Light gray brown, weathers very light brown, fine grained, massive, non-calcareous, well cemented. Trace of porosity as isolated silt size voids.

Ss: Very light brown, very fine grained, massive, highly weathered, non-calcareous, slightly porous. Grains are 99% well sorted, anhedral, equant, interlocking quartz; trace of microcline, chalcedony, clay.

Orthoq: Light gray, weathers light brown, very fine grained, slightly calcareous.

(TEXT-FIG. 2, CONT.)



Slst: Light gray, weathers light brown, calcite cemented quartz siltstone.

Orthoq: Light gray, weathers light brown, silt size silica cemented quartz grains, calcareous matrix. Dense & non-porous; breaks with smooth intra-granular fracture.

Ls: Light gray, weathers light brown, massive to slightly silty. Contains fossil "worm trails".

Ss: Light brown, weathers light gray, very fine grained & silty, well bedded, partially cemented by silica; Trace of porosity. Original shape of sand grains is obscured by secondary quartz overgrowths.

Ls: Medium gray, weathers light gray, slightly silty, dense, massive, non-porous.

Ss: Light gray, weathers pinkish gray, fine to very fine grained with trace of siliceous cement. Grains are quartz 95%, chalcedony 3%, detrital calcite 2%; 5% clay matrix, up to 5% porosity, trace of hematite. Quartz intergrowths are common. This type may be the weathered/leached equivalent of the calcareous/calcarenaceous orthoquartzite.

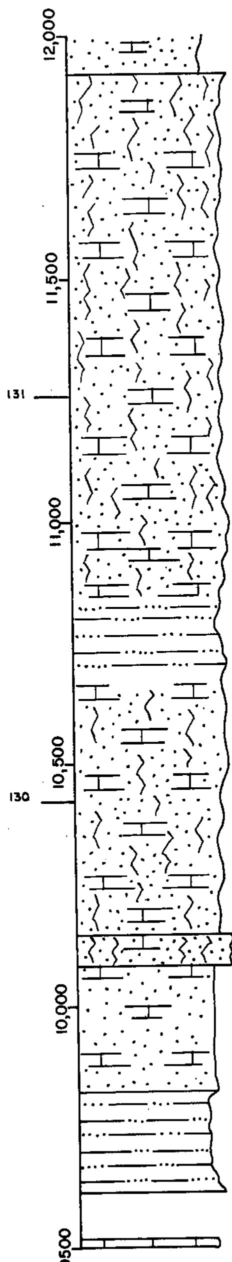
Ss: Light gray, very fine grained, silty, calcite cemented. Weathers to friable, light brown, non-calcareous sandstone.

Ls: Very dark gray to black, weathers light gray, silty & argillaceous, thin undulatory bedding, becomes fissile at top.

Orthoq: Dark to medium gray, weathers light brown, very fine to silt size quartz sand, 15% calcite silt. Gradational change to overlying silty, siliceous limestone.

Ls: Light gray, weathers light brown, slightly silty siliceous calcilutite.

(TEXT-FIG. 2, CONT.)



Orthoq: Light gray brown, weathers light brown; predominantly very fine grained with occasional beds of fine grained sand and silt, with matrix of detrital calcite silt (13% calcite). Cement is mainly silica, with some calcite. Sand fraction is 97% quartz, with minor microcline and calcite sand. Grain boundaries are irregular/ragged due to pressure solution and re-precipitation of silica, and etching of calcite-quartz grain contacts.

Slst: Medium gray, weathers medium brown, very massive, calcite cemented quartz silt. Grades upward into calcareous orthoquartzite as silica cement increases.

Ss: Medium gray, weathers medium brown, very coarse grained, angular quartz sand, slightly calcareous, partially cemented by silica.

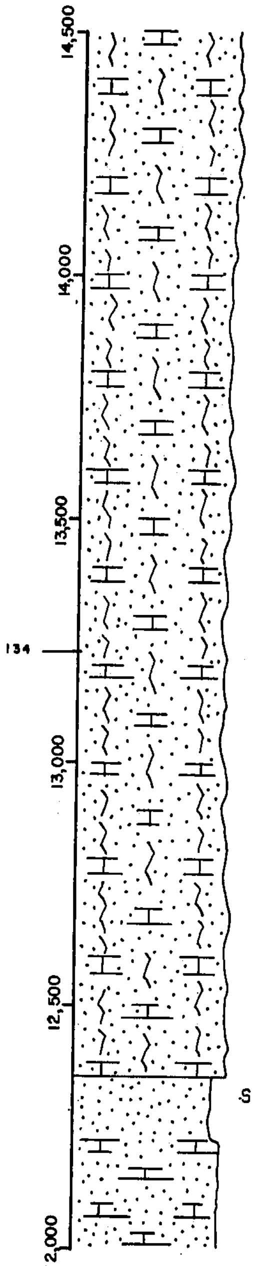
Orthoq: Medium gray, weathers red-brown, silt size quartz grains, calcite matrix, silica cement.

Ss: Yellow brown, weathers gray brown, very fine grained, calcite cemented; trace of porosity.

Slst: Medium gray, weathers medium brown, calcite cemented silt size quartz grains, 5 to 10% clay matrix, 30% calcite.

- covered interval - Tertiary basalt flow -

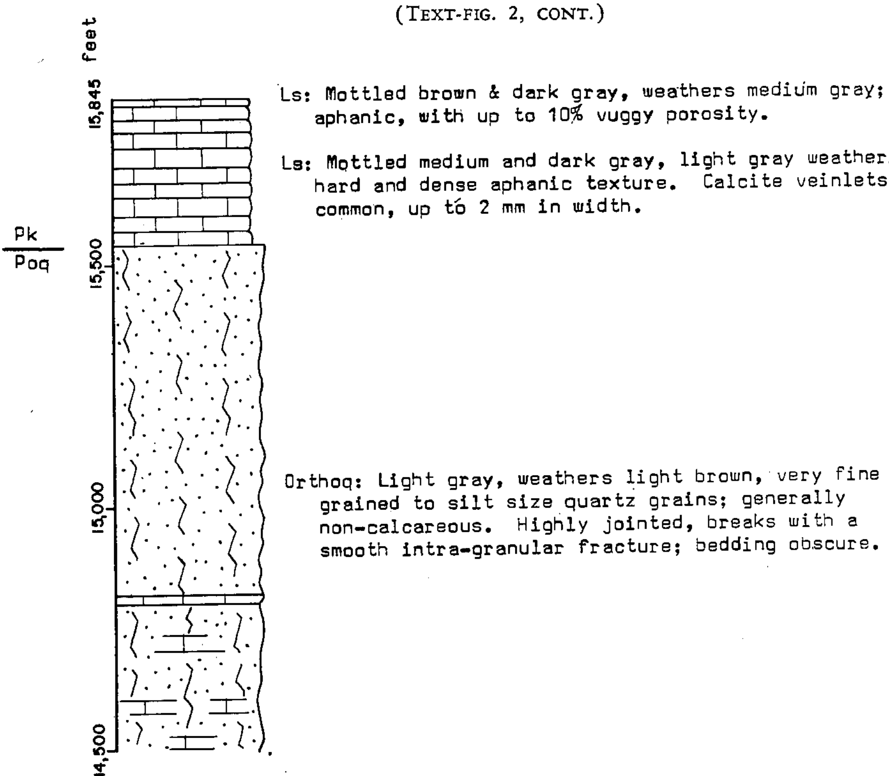
(TEXT-FIG. 2, CONT.)



Orthoq: Light gray to very light brown, weathers light brown, very fine grained quartz sand and silt. Matrix is detrital calcite silt, silica cement. Calcite content ranges from 0 to 7%. Sand grains are quartz (98 to 100%) calcite (0 to 2%), chalcedony and microcline (trace). Weathered portion is non-calcareous, smooth, dense, due to redeposition of silica.

Ss: Dark to light gray, weathers light gray, fine & medium grained quartz sand, calcite & silica cement. Porosity ranges from a trace to 15%. Bedding is generally obscure, with occasional discontinuous, slightly contorted micro-laminae.

(TEXT-FIG. 2, CONT.)



than across grains. These rocks of units 119 and 121 are gradational between friable quartz sandstones and orthoquartzite. Weathered surfaces are generally smoother than fresh rock. This rock is similar to quartz sandstone, except with a larger number of intergrown quartz grains and a decrease in porosity to five percent or less. Original grain shape is increasingly obscured by secondary quartz (Pl. 1, fig. 3).

Calcareous quartz sandstone.—As above, except that a significant amount of calcite is present either as matrix or cement. In unit 98, for example, calcite is present as fine granular silt rather than as a chemical precipitate, and fills interstices between quartz grains. A small amount of silica cement is also present. In the thin sections bedding is commonly visible with layers of fine and very fine grained, well sorted, well rounded, equant, anhedral quartz sand. Grain boundaries are highly etched where quartz is in contact with calcite; quartz intergrowths are rare. Calcite content of 20% is average, and insoluble residues include frosted grains of very fine quartz sand and silt, both as isolated grains and as fragments of porous, friable sandstone and siltstone. Minute veinlets of sparry calcite are also common, as in unit 82 (Pl. 1, fig. 4).

Calcareous quartz siltstone.—As above, except that most quartz grains are of silt size. The quartz grains are well sorted, equant, and angular to sub-angular in shape in unit 87. The rock contains up to five per cent second cycle quartz and quartzite or sandstone rock fragments. Carbonate content ranges from 10% to 37%, and the residue consists of light gray, vitreous, silty orthoquartzite, siltstone and gray clay (Pl. 1, fig. 5).

Orthoquartzite.—Units 90, 108, 110, and 134 are light gray to light brown, non-calcareous, silica cemented sandstone which breaks with a smooth, subconchoidal fracture. Sand grains, which are not easily seen in the hand sample, are fine to very fine grained quartz (95% to 100%), chert, chalcedony, orthoclase, or microcline. These rocks are typically homogeneous, tenacious, and nonporous. Grains are well sorted, well bedded, and tightly intergrown, and grain boundaries are generally smooth, curved, and deeply embayed. Carbonate content in the samples analyzed was three percent or less (Pl. 2, figs. 2, 3, 4; Pl. 3, fig. 2).

Calcareous orthoquartzite.—As above, with 3% to 30% interstitial calcite matrix. Silica cement still predominates and the rock still displays intragranular fracture in units 3, 5, 105, 131. Minor amounts of detrital microcline, orthoclase, chalcedony, and sandstone rock fragments are present. In many cases silica cementation and quartz intergrowths have developed around detrital calcite grains, giving ragged edges to the quartz. Insoluble residues include clear and frosted grains of quartz sand and silt, and fragments of porous quartz sandstone and siltstone (Pl. 1, fig. 6; Pl. 3, fig. 1).

Calcarenaceous orthoquartzite.—Units 35, 50, and 102 are orthoquartzites which contain detrital calcite sand grains. The cement is silica, and fracture is intragranular. Maximum calcite content observed in this type was 25% in unit 50. The term "calcarenaceous orthoquartzite" (Pettijohn, 1949, p. 305) is mainly a laboratory term, since in the field these rocks often cannot be distinguished from calcareous orthoquartzite, with which they are gradational. In addition to quartz and calcite sand, a certain amount of calcite silt is present. The sand is very fine grained, sub-rounded to well rounded, and the quartz grains are interlocking with crenulated contacts. Insoluble residues consist of light gray to white, hard, dense, vitreous quartzite fragments and very fine quartz and grains (Pl. 2, figs. 5, 6; Pl. 3, fig. 3).

Quartzite breccia.—Units 68, 71, and 81 are composed of a variety of cataclastite which has resulted from local faulting. This rock is a light brown, often friable breccia of very fine grained orthoquartzite fragments, generally less than one centimeter in diameter, scattered in a matrix of coarse, angular, quartz sand and silt. In rare cases, post brecciation recementation by silica has occurred. Calcite content ranges from zero to ten percent in fresh samples, and weathered samples are generally leached of calcite. Insoluble residues consist of angular fragments of quartzite and quartz siltstone, clay, and silt.

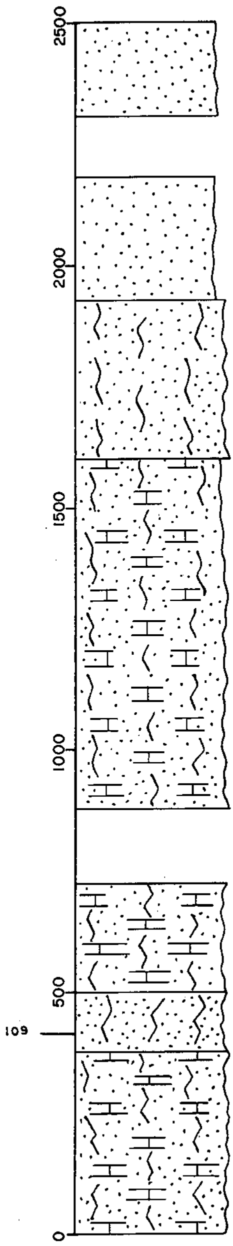
Amount of Exposure

Exposures are fair to good at South Mountain; rocks concealed by soils, landslide debris, and Tertiary lava flows represent six per cent of the section. Minor variations in cementation as well as geomorphic vicissitudes can be responsible for the non-exposure of any interval in a stratigraphic section.

Hobble Creek Canyon Section

Wolfcampian strata of the Oquirrh Formation in Hobble Creek Canyon in Secs. 23, 24, T. 7 S., R. 4 E., and Sec. 18, T. 7 S., R. 5 E., Utah County, Utah, were examined and sampled at regular intervals. Wolfcampian beds

TEXT-FIGURE 3. Columnar section of the Wolfcampian interval, Oquirrh Formation, as exposed in Hobble Creek Canyon (Secs. 23, 24, T. 7 S., R. 4 E., and Sec. 18, T. 7 S., R. 5 E.)



Ss: White to light gray, weathers pale yellow gray; fine to very fine grained pure quartz sandstone, fairly porous, massive.

Orthoq: Light gray, weathers light brownish gray, very fine grained, hard, dense, non-calcareous.

Orthoq: Light gray, very fine grained quartz sand & silt; hard, dense, massive, calcareous, blocky joint pattern.

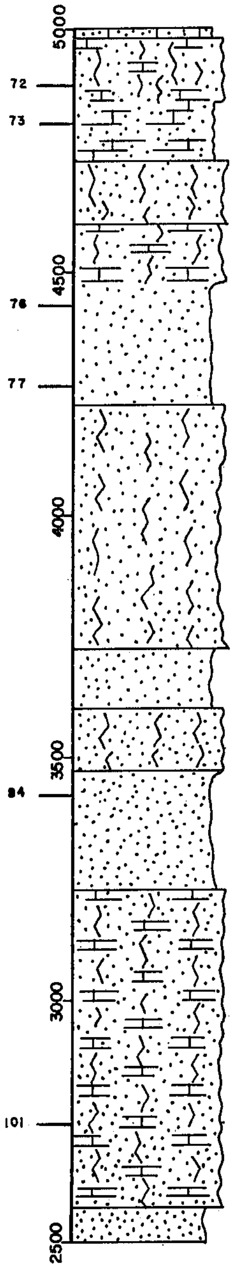
- covered interval -

Orthoq: Light gray, weathers very light gray, very fine grained, dense, calcareous.

Orthoq: Light gray, weathers light brown gray; very fine grained quartz, chalcedony; even bedded, non-calcareous.

Orthoq: Light gray, weathers very light gray; very fine grained, calcareous, non-porous; breaks with smooth intra-granular fracture.

(TEXT-FIG. 3, CONT.)



Ss: Light gray, weathers light brown, very fine grained & silty, very calcareous, bordering on sandy/silty limestone; fossil "worm trails".

Orthoq: White to very light gray, weathers brown, fine grained, non-calcareous, grades upward into calcareous sandy siltstone.

Orthoq: Light gray, weathers very dark brown, very fine grained, hard, dense, calcareous.

Ss: Light gray, weathers light brown, fine to medium grained, non-calcareous; fair to good porosity. Grains are sub-rounded, well sorted, equant, anhedral, partially cemented by silica. Few quartz intergrowths are present.

Orthoq: Light to very light gray, weathers light brown, fine to very fine grained, non-porous, non-calcareous; sharp intra-granular fracture.

Ss: Light gray to white, weathers dark brown, fine grained pure quartz sand, trace of porosity.

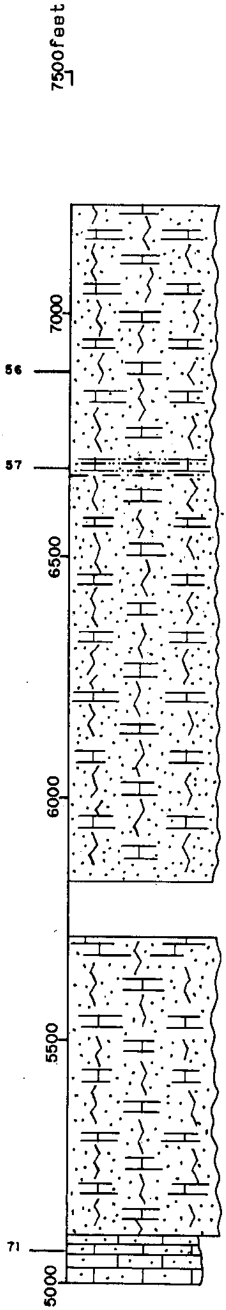
Orthoq: Light gray, weathers light brown, fine grained, hard, dense, non-calcareous.

Ss: Light gray brown, weathers light to dark brown, fine grained, non-calcareous, fairly porous.

Orthoq: Light gray, very fine grained, calcarenaceous, hard, dense, breaks with smooth fracture.

Orthoq: Light gray, weathers light brownish gray, predominantly medium grained (75%), with some fine grained quartz sand (10%), detrital calcite silt (15%), calcite sand (trace); Grains are well rounded, equant, anhedral, with ragged or etched boundaries.

(TEXT-FIG. 3, CONT.)



Orthoq: Light gray, weathers light brown, calcareous, (10 to 23% calcite), very fine grained, non-porous. Grains are quartz, (95 to 97%), calcite (2%), & microcline (trace); matrix is detrital calcite silt (up to 20%), cement is predominantly silica. Grains are poorly sorted, sub-rounded, anhedral, equant, with occasional coarse, rounded & frosted quartz grains distributed at random.

Orthoq: Gray to light gray, brown weathering, fine to very fine grained, hard, dense, calcareous. Develops good porosity in weathered zone.

Ls: Light gray, weathers light brown, contains up to 13% very fine grained sand & silt; residue contains silicified bryozoan & crinoid fragments, gray clay.

here include nearly 7,250 feet of orthoquartzite, calcareous siltstone, and sandy limestone (Baker, 1947, Bissell, 1936, 1962a). These sequences bear striking resemblance to equivalent beds at South Mountain. Best exposures are on the north side of the south fork of Hobble Creek Canyon.

The Hobble Creek Canyon section (Text-fig. 3) was measured by Bissell in 1935 and 1961 and sampled by the writer in 1962. Estimate of thickness is based on information provided by Bissell, on a published section by Baker (1947), and on personal observation in the field. An estimate of relative proportions of rock types present in this section is given in table 1.

Lithology

Orthoquartzite.—Very fine grained, subrounded, interlocking grains of quartz (95% or more), chalcedony, and microcline, cemented by quartz and chalcedony. These rocks of unit 109 are characteristically ridge formers, hard and tenacious, and split with a smooth, subconchoidal fracture. Although this type is apparently non-calcareous in field examination, acid solution reveals up to four percent carbonate present.

Calcareous and calcarenaceous orthoquartzite.—These rocks, in units 56, 72, and 101, consist of very fine grained, silica cemented, quartz sandstone and siltstone, and contain up to 25% of fine calcite silt as a matrix. The rock breaks with a general intragranular fracture, but the broken surface is not as smooth as in the non-calcareous orthoquartzites. In thin section more than half the quartz grains appear intergrown, and grain boundaries are generally ragged and etched. A few random grains of well rounded, coarse quartz and calcite sand are present, and clay content is less than one percent (Pl. 3, figs. 5,6).

Quartz sandstone.—Units 76, 77, and 84 are composed of predominantly fine to medium grained, light gray to light brown, fairly to poorly sorted, friable, quartz sandstone with up to 30% porosity. This type is not common in the section and may represent weathered calcareous orthoquartzite. Carbonate content is two percent or less.

Calcareous siltstone.—Light gray, brown weathering, nonporous siltstone comprises units 57 and 73. Both the weathered and unweathered portions are highly calcareous with up to 34% carbonate. Petrographically, this rock type resembles calcareous orthoquartzite, of which it is a gradational phase. Cement is mainly calcite, with minor amounts of silica and up to three percent clay.

Sandy limestone.—Light gray, sandy to silty, light brown weathering limestone which includes all gradations from sandy, micritic limestone, to bioclastic calcarenite forms unit 71. Occasional traces of authigenic opal, and silicified bryozoan fragments, crinoid columnals, and miscellaneous skeletal material, and siliceous casts of skeletal material are contained.

Amount of Exposure

Exposures of Wolfcamp age strata in Hobble Creek Canyon are generally good, with approximately three per cent of the section covered.

Weber Canyon Section

The Wolfcampian interval of the Weber Formation, on the north-east margin of the Oquirrh Basin, was measured and sampled in Weber Canyon (T. 4 N., R. 3 E.), Morgan County, Utah. This area was part of the Weber

Shelf during much of Pennsylvanian and Permian time, and shows stratigraphic variation from the central to the marginal part of the basin (Text-figs. 1, 5). Thickness of Wolfcampian strata here is 714 feet. The Weber Canyon section is shown graphically in text-figure 4, and relative proportions of rock types present in the section are summarized as table 1.

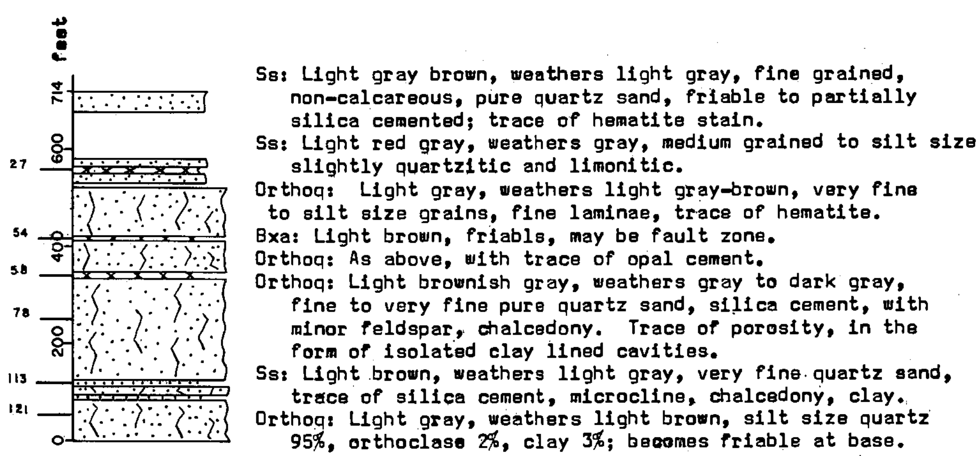
Principal lithologic changes noted in going from basin to shelf areas are absence of calcite in the matrix and cement of clastic rocks, and lack of limestone in the section.

Lithology

Orthoquartzite.—This is the most common rock type in the Weber section, and typically consists of fine to very fine, and silt size, subangular to subrounded, anhedral quartz grains and silica cement in units 58, 78, and 121. Grains have secondary quartz overgrowths and form an interlocking meshwork in which interstices have been filled with precipitated quartz. Porosity varies from a trace to one percent as widely scattered, clay-lined cavities, one quarter millimeter or less in diameter. Grain boundaries are generally smooth and curved to slightly crenulated and embayed, and extinction is normal to moderately undulatory. Traces of detrital orthoclase, microcline, and chalcedony are present. These rocks have a sharp, intragranular fracture and would be difficult or impossible to separate from metaquartzite in a comparison of hand samples (Pl. 3, fig. 4).

Siliceous quartz sandstone.—Unit 113 is composed of rocks similar to the above, but with less complete silica cementation, and a more rough, uneven, intergranular fracture.

Sandstone breccia.—Light gray to light brown breccias made of fragments up to 3 inches long of medium grained sandstone and orthoquartzite, in a matrix of friable, coarse, angular quartz sand compose units 27 and 54. These are the result of local faulting of rocks which, judging from the common association of orthoquartzites with cataclastites, apparently have a low limit of plastic deformation.



TEXT-FIGURE 4. Columnar section of the Wolfcampian interval, Weber Formation, as exposed in Weber Canyon (T. 4 N., R. 3 E.), Morgan County, Utah.

Amount of Exposure

Exposures at this locality are good, due to vertical strata and steep canyon walls. Covered intervals comprise 16% of the section and occur mainly in zones of faulting and fault breccia.

TABLE 1

Estimate of relative proportions of rock types in Wolfcampian strata in three sections in central Utah.

	Cumulative Percentage
HOBBLE CREEK CANYON SECTION:	
Orthoquartzite	14
Calcareous orthoquartzite	35
Calcarenaceous orthoquartzite	30
Quartz sandstone	17
Calcareous siltstone and silty limestone	2
Limestone - all other varieties	2
	100
SOUTH MOUNTAIN SECTION:	
Orthoquartzite	10
Calcareous orthoquartzite	24
Calcarenaceous orthoquartzite	20
Quartz sandstone	17
Calcareous siltstone and silty limestone	5
Calcarenite	5
Limestone - all other varieties	14
Breccia	4
Shale	1
	100
WEBER CANYON SECTION:	
Orthoquartzite	80
Quartz sandstone	15
Sandstone breccia	5
	100

Lateral Variations Within the Oquirrh Formation

There are rapid facies changes in the Oquirrh Formation, particularly in the Wolfcampian segment, for individual strata usually die out or merge with adjacent strata within short distances, and seldom persist as much as one-half mile. Abrupt local changes in the character and degree of cementation were noted, particularly near the top of South Mountain. Bedding varies from apparently massive to thin and platy, with quarter-inch laminae, or to other types of stratification, within a few yards laterally. Such changes are believed to be due to subtle differences in cementation, or amount and composition of matrix material. The matrix here is largely a fine carbonate silt of detrital origin.

The overall aspect of the section is generally unchanged from one canyon, or exposure, to the next at South Mountain, but individual lithologic units do not persist. No definite pattern of lateral zonation could be seen in the Oquirrh strata, and directions of facies change appear random.

Attempts at lithologic correlation have not been very successful within the Oquirrh Formation (Wright, 1961, p. 150). Correlation is possible by paleontological studies, and fusulinids have been used successfully by Bissell (1936, 1959b, 1962a, 1962b), Wright (1961), and others to delineate time-rock units.

The lensing character of Oquirrh strata is believed to be a depositional feature, and is not the result of post-diagenetic erosion or strike-slip faulting. Sediment may have been eroded by currents and waves prior to lithification, and redeposited unevenly because of intermittent and irregular subsidence within the basin.

Quartz Types

Quartz grains in the Oquirrh Formation were studied in an attempt to determine a history of the sediment. Common occurrence of detrital chalcedony grains, general deficiency of heavy minerals, presence of quartzite and sandstone rock fragments, scarcity of inclusions in the quartz grains, and lack of euhedral crystal faces on quartz grains all indicate that these quartz sands are at least second cycle sediments derived from pre-existing sedimentary rocks.

Quartz grains in the Oquirrh Formation in the Stansbury Range west of South Mountain, are described by Wright (1961, p. 164) as consisting of two distinct types. These are, (1) angular to sub-angular, silt size to fine grained quartz with normal extinction, and (2) sub-rounded to rounded, medium to coarse grained quartz with undulatory extinction. Both of these types were noted during the present study, in varying amounts, along with several other types. The grains, are mainly silt size to fine grained sand, with rough, embayed, or crenulated borders, moderate undulatory extinction, and whose original grain shape is commonly hidden by secondary quartz.

Criteria suggested by Krynine (1946, p. 40) were applied in the identification of quartz types. The most common type is of sedimentary origin or was derived from sedimentary rocks, identified mainly on the presence of rounded, abraded secondary quartz overgrowths, carbonate inclusions, and dust inclusions which outline the shape of original quartz grains. Plutonic igneous quartz, vein quartz, and pressure type metamorphic quartz are also present. Approximate composition of the quartz sand in the Oquirrh Formation orthoquartzites is as follows:

Sedimentary	50%
Plutonic Igneous	35%
Vein Quartz	10%
Pressure Type Metamorphic	5%

Weathering Characteristics

Surface alteration of calcareous and calcarenaceous orthoquartzites in the temperate, semi-arid climate of the eastern Great Basin commonly produces a concentric series of zones or rinds which are readily seen on broken rock surfaces. The outer zone is generally a brown or dark brown, porous, friable quartz sandstone from which calcite has been leached, and clay and iron oxide content increased to about five percent. In some cases, particularly those rocks with a lower original calcite content such as unit 134 at South Mountain, the outer surface of this zone will be casehardened, with a thin veneer of smooth, dense silica. Contact of the weathered and unweathered zones is fairly sharp and represents the maximum depth of effective water penetration. Weathered zones range from one-eighth inch to several inches thick, but are usually less than two inches deep. Nature of the weathered surface is a function of lithology, climate, drainage, and length of time that the rock has been exposed.

Zonation is strongest in samples from Hobble Creek Canyon, which is likely due to increased precipitation and heavier vegetation at this locality, but which may also reflect subtle lithologic differences.

Porosity of weathered zones may be as much as twenty percent or more, sufficient to permit migration of fluids, were this zone encountered in the subsurface.

Cementation

Cement most commonly found in sandstone is silica and carbonate. Sufficient cementation of pure quartz sandstones by silica under normal sedimentary conditions produces an orthoquartzite. Cementation occurs by addition of silica to the environment, by pressure solution of the quartz grains, or by a combination of these processes.

Addition of silica to a sand under conditions of low pressure gives rise to euhedral overgrowths on the quartz grains, usually in optical continuity with the original grain. Euhedral faces are likely to develop if the sand is porous and loosely packed, and if the grains do not interpenetrate each other. Silica may originate as a product of mineral alteration, such as alteration of montmorillonite to illite in interbedded clays (Towe, 1962, p. 26), or by replacement of quartz or chert by carbonate, or from connate water or ground water.

Pressure solution phenomena develop because increased pressure on a solid reduces the melting point of that solid for any given set of chemical conditions. Quartz dissolves at the points of highest pressure, especially in zones of high pH, and is precipitated at points of lower pressure and low pH. Presence of interstitial clays and water is important. The clay contributes potassium ions, which are replaced by calcium and magnesium ions through base exchange, and K_2CO_3 forms, which raises the pH in clay-rich zones. The water aids in silica solution, and acts as a vehicle for migration of the dissolved silica (Thomson, 1959, p. 106). Compaction thus proceeds, and grains become tightly packed and usually interpenetrating.

Cementation of the orthoquartzites in the Oquirrh Formation at South Mountain and at Hobble Creek Canyon is apparently the result of combined pressure solution and addition of new silica. The majority of orthoquartzite thin sections examined shows quartz grains welded together both by interpenetration and by deposition of secondary silica in pore spaces as rims or overgrowth on original quartz grains. Grain contacts are, in the absence of carbonate, sinuous, curved, and sutured. In calcareous and calcarenaceous orthoquartzites the effect of calcite has been development of rough, etched grain borders. However, intergrown quartz grains still predominate.

The Weber Formation thin sections also show both pressure solution and secondary overgrowths, although euhedral overgrowths are rare. Grain boundaries are embayed and crenulated to the extent that original grain shapes are obscured.

Implications are that there was a plethora of silica in the Oquirrh Basin during deposition of the Oquirrh Formation or shortly thereafter, and that strong tectonic forces were active in the area. Furthermore, the abundance of silica makes it unlikely that zones of good porosity would be encountered in Wolfcampian strata of the formation in the subsurface.

TECTONIC SETTING

Excellent summaries of the tectonic history of central Utah during late Paleozoic time are given in reports by Bissell (1952, 1962a) and Wright (1961). It is felt that a brief resumé of the ideas of these and other authors is appropriate to a discussion of orthoquartzite of the Oquirrh Formation so that these rocks may be considered in their proper geological context.

Regional Sketch

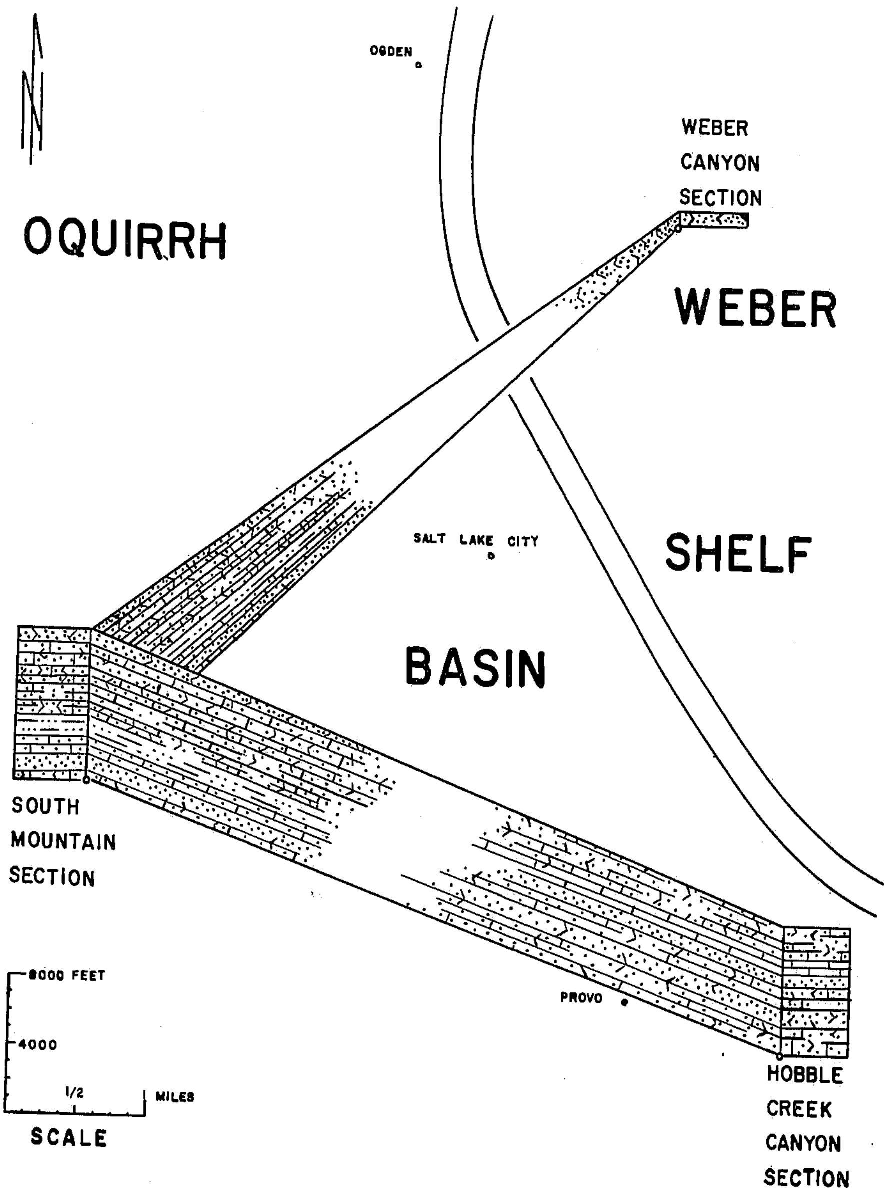
The area occupied by the Oquirrh Basin was part of the Cordilleran Geosyncline during Early Paleozoic time. From the Devonian until the end of the Paleozoic, the older orthogeosyncline was divided by a geanticline which arose in western and central Nevada and which effectively separated the western eugeosyncline from the eastern miogeosyncline (Nolan, 1943; Bissell, 1952, p. 625). The approximate western limit of the late Paleozoic miogeosyncline is termed the Manhattan Line, and bisects the state of Nevada in a nearly north-south direction along the Antler-Sonoma orogenic belt (Bissell, 1960, p. 1425). The eastern limit, a line of flexure called the Wasatch Line (Kay, 1951, p. 14), follows approximately the eastern edge of the Great Basin geomorphic province. The Wasatch Line separated the miogeosyncline from the stable shelf and cratonic areas to the east. This hinge line is a narrow zone of rapid change in sedimentary thickness and lithology, and it is across this line that the Oquirrh and Weber formations interfinger (Text-fig. 5). It is immediately west of the Wasatch Line, in the eastern part of the miogeosyncline, that the thickest known section of Pennsylvanian and Permian rocks found anywhere in the United States, with the possible exception of the Ouachita Mountain region of Oklahoma and Arkansas, accumulated (Nolan, 1943; Bissell, 1962b). End of the miogeosyncline came toward the close of the Permian period. No Late Permian rocks are known in the area, and Triassic strata were deposited unconformably on the Permian rocks.

Depositional Environment

The overall depositional pattern in the Oquirrh Basin was one of clastic sedimentation, including both quartz and calcite sand and silt, with intermittent shorter periods of limestone deposition. Lithologic variability, abrupt changes in thickness of individual units, and abundance of clastic materials indicate that Pennsylvanian and Early Permian was a time of general instability. Subsidence was continuous but uneven, with considerable local adjustment. It is possible that littoral and lagoonal sediments were deposited at various places within the basin, but, if so, much of the sequence was destroyed by erosion. That erosion occurred at various times is suggested by numerous small unconformities and diastemic breaks observed at South Mountain and in Hobble Creek Canyon.

Environments ranged from infraneritic to epineritic and epineritic biostromal, with water depth variable but probably never more than a few hundred feet (Bissell, 1952, p. 585). Sediments are in general fairly well sorted and rounded, which, coupled with a deficiency in clay size material, indicates long periods of washing and, indirectly, transportation over long distances. Current ripple marks and small scale cross bedding are commonly apparent on weathered surfaces, but silica cementation tends to obscure these and other primary structures. Areas of thickest accumulation of sediment varied from epoch to epoch, as shown on isopach maps published by Bissell (1962a).

Precipitation of silica cement in an environment where carbonate sediments are forming requires rather precise geochemical conditions. According to Krauskopf (1959, p. 10) silica does not precipitate above a pH of 8.8. Calcite



TEXT-FIGURE 5.—Fence diagram showing relationships of the Wolfcampian strata of the Oquirrh and Weber Formations in a portion of Central Utah.

does not precipitate appreciably below a pH of 8.0 (Krumbein and Garrels, 1952, p. 26). The oxidation potential (E_h) may be either positive or negative, and is apparently not a controlling factor.

Paleogeography

Borderland areas adjacent to the Oquirrh Basin during the Pennsylvanian and Early Permian include the Weber Shelf to the northeast, the Northeast Nevada Highland to the northwest, the Western Utah Highland to the west and southwest, the Callville-Hermosa Platform to the south, and the Emery Uplift to the southeast. These positive areas were breached at various places by inlets or accessways which permitted contact with open ocean waters, and through which considerable amounts of sediment may have been transported to the basin.

During Medial and Late Wolfcampian time there was a pronounced decrease in size of the Oquirrh Basin, probably due to an interruption of the relatively rapid rate of subsidence experienced earlier. Eolian sediments of the Diamond Creek and upper Weber Formation covered the Weber Shelf, and the littoral and epineritic Kirkman Limestone was deposited over the Oquirrh sediments (Bissell, 1962a, p. 46).

Paleontologic Evidence

Limestone units of the Oquirrh Formation contain a varied fauna, principally fusulinids, crinoids, bryozoans, brachiopods, corals, and various forms of algae. Of these, the most widely distributed, both arealy and stratigraphically are the fusulinids.

Fusulinids are predominantly benthonic calcareous foraminifera which apparently were tolerant of a wide range of environmental conditions. Rock types in which they generally are found include a wide variety of limestones, sandy limestones, and calcareous shale and siltstone (Slade, 1961, p. 90; Weller, 1957, p. 353). Normally fusulinids thrived in fairly quiet marine waters at depths considered to range from one to thirty fathoms (Dunbar, 1957, p. 753; Tasch, 1957, p. 396). Variation in fusulinid lithotopes, and their common occurrence in layers which are barren of other organisms indicates that they were tolerant of greater ecological extremes.

Occasional local abundance of corals, crinoids, algae, brachiopods, and bryozoans indicates that at times the water was shallow enough to permit penetration of sunlight, sufficiently agitated to provide sufficient oxygen and nutrients, and also clear enough to permit these forms to flourish. A picture of shifting environments, oscillating between littoral, epineritic, and infraneritic conditions, with generally moderate to strong bottom currents and abundant clastic sediment supply, with continuous subsidence is compatible with paleontological evidence.

Rate of Sedimentation

The unusual thickness of the Oquirrh Formation has prompted the writer to investigate the rate of sedimentation for the unit, and to compare this with calculated rates of other Late Paleozoic accumulations. A thickness of 16,000 feet of Pennsylvanian age sediments was used in the calculations, which includes 15,000 feet of Oquirrh Formation and 1,000 feet of Pennsylvanian age Manning Canyon Formation. The Pennsylvanian period, according to Kulp (1959, p. 1634) lasted 55 million years. The calculated average rate of Oquirrh sedimentation is 290 feet per million years, or 3435 years per foot of sedimentary rock (Table 2).

This rate is somewhat greater than the maximum miogeosynclinal rate given by Kay (1951), but less than the maximum rate cited for intracratonal geosynclines. Apparently the Oquirrh Basin was more active than most miogeosynclinal basins, and more similar to intracratonal basins in its tectonic behavior.

TABLE 2

Calculated rates of deposition of sedimentary rocks in geosynclines.

	Feet per million years:	Years per foot:	Reference:
Maximum for Late Paleozoic	692	1445	Pettijohn, 1957, p. 688
Maximum for miogeosynclines	202	4950	Kay, 1951, p. 96
Average maximum for North American intracratonic geosynclines	317	3155	Kay, 1951, p. 95
Oquirrh Basin	290	3435	This report

COMPARISON WITH QUARTZITES FROM OTHER FORMATIONS

As far as could be determined by the writer, the variety of calcarenaceous orthoquartzite predominating in the Oquirrh Formation has not been found elsewhere. A comprehensive review of the standard texts on sedimentary petrology (Dunbar and Rodgers, 1958; Pettijohn, 1949 and 1957; Krumbein and Sloss, 1951; Williams, Turner, and Gilbert, 1954; Carozzi, 1960; Barth, 1960) and of the periodical literature failed to produce any reference to other rocks of similar lithology.

To provide a basis for comparison of the orthoquartzites in the Oquirrh Formation, and also to see whether a random sampling of other quartzites would turn up rocks of similar lithology, quartzites from a number of other formations were investigated. Approximately 35 formations from different areas and several systems were considered, and from these about two dozen thin sections were prepared. Study of these rocks failed to reveal any other examples of calcarenaceous orthoquartzite. Similarities in texture, nature of the quartz grains, and in the type of cement were noted, but the combination of fine and very fine quartz sand, carbonate silt, and silica cement was not found.

Observations on Quartzites in General

As a result of the study of the thin sections from the Oquirrh, Weber, and other formations, some additional observations were made which seem to indicate characteristic aspects of quartzite lithology. Certain petrographic properties observed in most or all of the quartzites examined are listed below.

Petrographic Characteristics

Nature of the Cement.—Cementation in orthoquartzite is mainly a combination of pressure solution of detrital quartz grains and addition of new silica, but occasionally examples may be found where these processes have occurred separately.

High Quartz Content.—The detrital fraction of more than 95% of the thin sections analyzed contained at least 95% quartz, including detrital chert grains and quartzose rock fragments. More than 91% contained 99% quartz.

Light Color.—More than 75% of the samples examined were, megascopically, light shades of gray, brown, pink, etc., and none of the thin sections were measurably colored.

Lack of Porosity.—There is a complete lack of effective porosity in orthoquartzites. More than 90% of the samples studied had less than 1% isolated pore spaces, and none had as much as 5%.

Idiomorphism.—Detrital quartz in the orthoquartzites examined consisted of essentially all anhedral grains. Occasionally grains of subhedral vein quartz are found, and in some cases crystal faces may develop on secondary quartz which formed in veins or cavities in an orthoquartzite after diagenesis.

Dissimilarities

Some properties of the examined orthoquartzites are consistently variable, such as grain size, sorting, roundness of grains, nature of grain boundaries, inter-grain relationships, and inclusions present in the quartz grains.

Orthoquartzite versus Metaquartzite

Differentiation of orthoquartzite from metaquartzite has traditionally depended upon a study of field relationships of the rocks involved, or the identification of characteristic metamorphic minerals which might be present in any given sample. Although no new infallible rules for separating orthoquartzite from metaquartzite can be established from this study, certain indicative criteria are suggested. These include the following:

Orthoquartzite Criteria

Foliation.—Non-foliated; bedding and cross bedding may or may not be present.

Grain shape.—Detrital grain outlines may be visible enclosed in secondary silica; may have any degree of rounding.

Grain packing.—Grains may be tightly packed and intergrown, or, loosely packed with a fair amount of minus cement porosity.

Extinction.—Most quartz grains show moderate strain shadows, some have normal extinction.

Deformation.—Fractures commonly seen in thin section, cutting across grains and cement.

Faunal evidence.—May contain unaltered plant or animal fossils.

Metaquartzite Criteria

Foliation.—Will show a parallel or sub-parallel orientation of new minerals, such as micas, provided the materials are available for development of these minerals.

Grain shape.—Original grain shape obscured by recrystallization; absence of dust rims.

Grain packing.—Grains are tightly packed, intergrown and interlocking, with crenulated or sutured grain contacts.

Extinction.—Highly undulatory with strong strain shadows.

Deformation.—May be evidence of shearing in crushed, strung out, and recrystallized grains.

Faunal evidence.—Preservation of fossils unlikely.

Since processes of metamorphism are gradational with those of diagenesis, no sharp line can be drawn between orthoquartzite and metaquartzite. Some of the criteria listed above under metaquartzite may develop to some degree during diagenesis and be found in orthoquartzite.

SUMMARY STATEMENT

Calcarenaceous orthoquartzite in the Oquirrh Formation is a lithology unique, or at least uncommon in American stratigraphy. Reasons for development of this anomalous lithology are obscure, but certain clues may be gained from a study of the sediments, their sources, and their environments of deposition. Calcareous sediment in the calcarenaceous orthoquartzite is probably derived from within the basin. The quartz sand is probably a mixture of materials derived from the various highlands adjacent to the Oquirrh Basin and contributed from outside the basin. Much of this is second cycle sediment. A possible source of the chemically precipitated silica is the volcanic area in the Cordilleran eugeosyncline to the west. Conditions which prevailed within the basin permitted chemical precipitation of both calcite and silica. These conditions persisted throughout most of Pennsylvanian and Wolfcampian time, while sufficient subsidence was taking place so that nearly five miles of sediment accumulated (Bissell, 1962b, p. 1106).

CONCLUSIONS

1. The Oquirrh Formation constitutes an unusual suite of sedimentary rocks which reflect conditions of tectonics and sediment supply which are perhaps unique in geologic history. The Oquirrh Formation is unique in its great thickness, in the lack of shale or claystone, and in the abundance of calcarenaceous orthoquartzite.

3. Shallow water marine conditions prevailed in the Oquirrh Basin during Pennsylvanian and Early Permian times in conjunction with tectonic conditions of irregular instability and deep subsidence.

3. Sediment of the Oquirrh Formation was derived from various adjacent land masses, from local positive areas within the Oquirrh Basin, and perhaps also contributed from beyond the basin through peripheral accessways. This material was subjected to effective sorting and cleaning by wave and current action.

4. Orthoquartzite and calcarenaceous orthoquartzite of the Oquirrh Formation are rock types which do not fit neatly into the present system of sed-

imentary rock nomenclature; therefore caution should be exercised when describing these rocks or when studying published descriptions of Oquirrh strata.

5. Classification of lithoclastic sedimentary rocks is in need of revision and standardization, and those who are active in the revision should be aware of rock types such as are herein described.

6. The term orthoquartzite is a useful one which describes an important group of sedimentary rocks. It should be applied discreetly, however, with due regard to its original meaning and traditional usage.

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EXPLANATION OF PLATE 1

PHOTOMICROGRAPHS OF TYPICAL OQUIRRH FORMATION ROCKS FROM SOUTH MOUNTAIN.

FIG. 1. Calcarenite. Consists of skeletal material and detrital carbonate grains in micrite. Unit 1, plain light, 24x.

FIG. 2. Quartz sandstone. Predominantly very fine quartz sand with a small amount of silica cement. A microcline grain is in lower center. Unit 91, crossed nicols, 24x.

FIG. 3. Siliceous quartz sandstone. The original grain shape is obscured by contiguous quartz cement. Unit 121, crossed nicols, 24x.

FIG. 4. Calcareous quartz sandstone. Matrix material is calcite silt; both calcite and quartz cement are present. A calcite vein occurs near center. Unit 82, crossed nicols, 24x.

FIG. 5. Calcareous quartz siltstone. Clastic material is mainly quartz silt, with some calcite, in a mixture of micrite, clay, and authigenic silica. Unit 87, crossed nicols, 24x.

FIG. 6. Calcareous orthoquartzite. Edges of some quartz grains have been etched by calcite, giving them a ragged appearance. Unit 131, crossed nicols, 24x.

EXPLANATION OF PLATE 2

PHOTOMICROGRAPHS OF TYPICAL OQUIRRH FORMATION ORTHOQUARTZITES FROM SOUTH MOUNTAIN

FIGS. 1, 2, 3. Orthoquartzite. 1, Shows silica cementation and isolated, clay filled pore spaces. Unit 108, plain light, 24x; 2, same as 1, crossed nicols, Note optical continuity of quartz cement with original quartz grains. 24x; 3, an enlargement of 2, showing detail of grain-cement relationships. Original grain shapes can sometimes be seen as a line of dust or clay inclusions within the secondary silica. Crossed nicols, 24x.

FIG. 4. Orthoquartzite. Cement is mainly quartz, with chalcedony. Cementation has obscured original grain shape and produced the interlocking texture typical of quartzites in general. Unit 110, crossed nicols, 24x.

FIGS. 5, 6. Calcarenaceous orthoquartzite; 5. A mixture of quartz sand, calcite sand and silt, bonded by silica cement. Unit 50, crossed nicols, 24x; 6. Same as 5, plain light. Medium-gray material is calcite sand. 24x.

EXPLANATION OF PLATE 3

PHOTOMICROGRAPHS OF ORTHOQUARTZITES FROM THE OQUIRRH FORMATION AT SOUTH MOUNTAIN AND HOBBLE CREEK CANYON, AND FROM THE WEBER FORMATION IN WEBER CANYON.

FIG. 1. Calcareous orthoquartzite from South Mountain. Note optical continuity of some intergrown quartz grains and abundance of carbonate silt. Acid solution indicates a carbonate content of 29%. Unit 3, crossed nicols. 24x.

FIG. 2. Orthoquartzite from South Mountain. Secondary quartz has overgrown large grain to the right of center, delineated by enclosed dust rim. Unit 134, crossed nicols, 24x.

FIG. 3. Calcarenaceous orthoquartzite from South Mountain. Calcite sand grains appear as medium-gray, granular grains in upper right and lower left, with silica cement. Unit 35, crossed nicols, 24x.

FIG. 4. Orthoquartzite, Weber Canyon section, unit 78. Abundance of silica cement, high degree of sorting, and complete absence of carbonate are typical. Crossed nicols, 24x.

FIGS. 5, 6. Calcarenaceous orthoquartzite from Hobble Creek Canyon section, unit 101. Large, well rounded grains in upper center are carbonate, plain light, 32x; 6. Same as 5, crossed nicols. Both sand and silt size carbonate material are present. 32x.

PLATE 1 – RICHARD B. WELLS

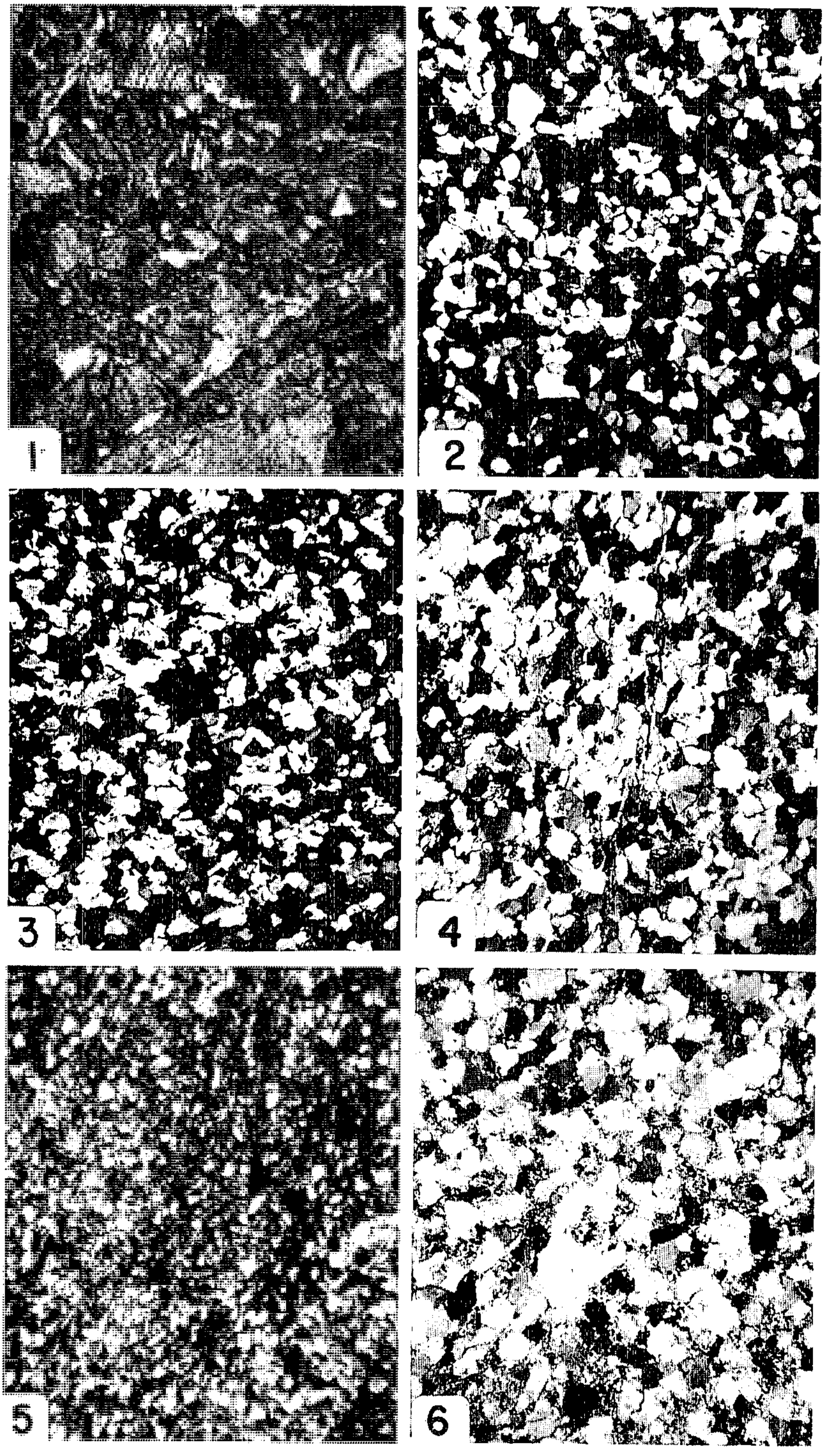

PLATE 2 — RICHARD B. WELLS

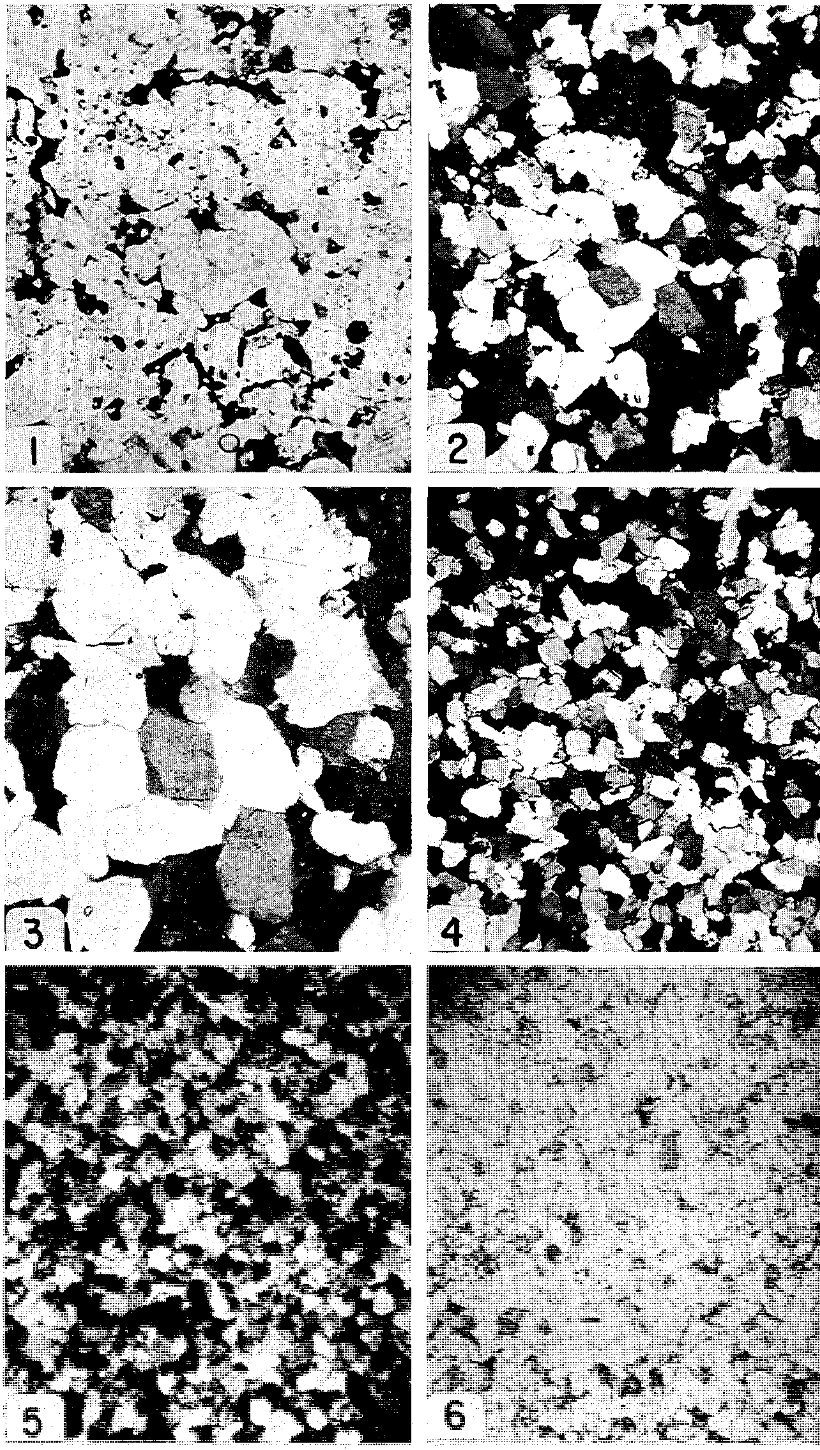

PLATE 3 — RICHARD B. WELLS