BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

Volume 9, Part 1 May, 1962

GEOLOGY OF THE SOUTHERN WASATCH MOUNTAINS AND VICINITY, UTAH

CONTENTS

Brigham Young University Geology Studies

Volume 9, Part 1 — May 1962

Geology of the Southern Wasatch Mountains and Vicinity, Utah

a symposium

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Prepared for the 1962 meetings of the Rocky Mountain Section of the Geological Society of America held on the Brigham Young University Campus, May 10-12, 1962.

A publication of the
Department of Geology
Brigham Young University
Provo, Utah

Part I partially supported by the Rocky Mountain Section.

Price $2.00

Extra copies of map available at $1.00 each.

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Geology of the Southern Wasatch Mountains and Vicinity, Utah

INTRODUCTION

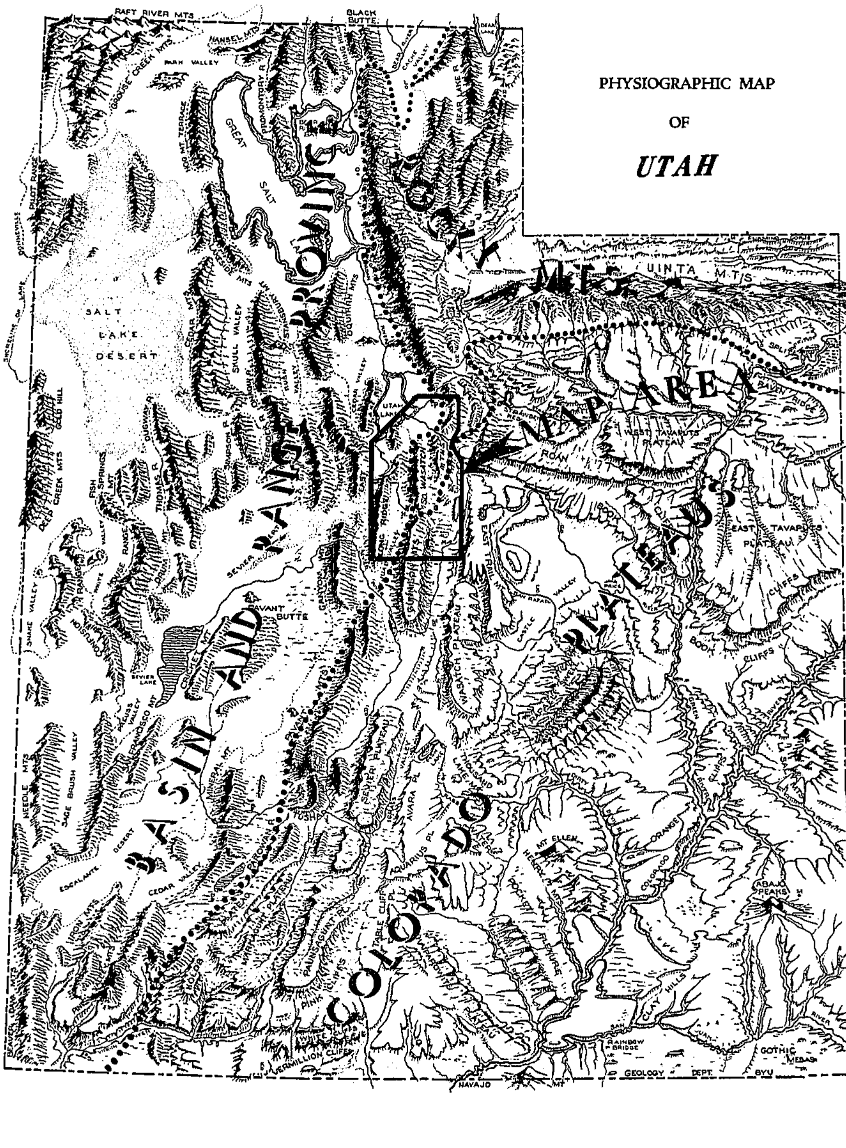
Utah is blessed with geologic features of unusual interest and great variety. The Canyon Lands, the Henry Mountains, the San Rafael Swell, the High Plateaus, the features of Lake Bonneville, the famous mining districts of Tintic, Bingham, and Iron Springs, the magnificent stratigraphic sections exposed in the Book Cliffs and in the Basin Ranges, all have revealed to geologists the tremendous sweep of geologic history and have been made classic through the writings of such pioneer geologists as C. E. Dutton, William M. Davis, C. D. Walcott, and G. K. Gilbert. So complex is Utah's geologic history and so numerous its problems that further detailed work, using improved procedures, continues to increase our understanding of this fascinating area. Each year some aspect is clarified and we wonder why it did not seem more obvious to us before.

In this light we embark on a summary of the current knowledge of the geology of the Southern Wasatch Mountains. The area lies at the junction of three major physiographic divisions: the Middle Rocky Mountains, the Colorado Plateaus, and the Basin and Range Province. It includes sedimentary, igneous, and metamorphic rocks ranging in age from Precambrian to Quaternary, and representing dominantly marine deposits of the Early Paleozoic Cordilleran miogeosyncline, the later Paleozoic Madison and Oquirrh Basins, the Cretaceous Rocky Mountain exogeosyncline, and Cenozoic deposits in freshwater lakes. The area has been involved in major structural deformation in Precambrian time, in folding and thrusting in Late Cretaceous (Laramide) time, and in block faulting in later Cenozoic time. In all, a greater variety of geologic features can scarcely be found in so limited an area.

The area is part of what is sometimes referred to as the "transition zone" in Utah. The transition involves more than the change from Basin and Range landforms to those of the Plateaus, it also involves older transitions from Cretaceous orogenic elements on the west to depositional sites on the east, from Paleozoic cratonic deposition on the east to geosynclinal behavior on the west. Two previous guidebooks have discussed the transition zone in Utah: to the north the Intermountain Association of Petroleum Geologists 10th Annual Field Conference in 1959 considered the Wasatch-Uinta Mountains transition area; to the south the Utah Geological Society 4th Annual Field Conference in 1949 traversed the transition between the Colorado Plateaus and the Great Basin in central Utah.

GEOLOGIC MAP

The geologic map accompanying this report was compiled from a great many sources, most of them published and unpublished theses by graduate students of Ohio State University and Brigham Young University (see "Index to sources of data" printed on the map). The original mapping was done on a variety of base maps, some prepared by plane table, some from air photos, and some on U.S.



INDEX MAP.—Shows Southern Wasatch map area in relation to physiographic provinces.

Geological Survey topographic quadrangles. In transferring the mapping from these diverse bases to the common base used innumerable minor adjustments were made in order to fit the original mapping to the new base as well as possible. Air photos aided in making the transfer for it was sometimes necessary to transfer data from the original map to the photos and thence to the final map in case the original map was too distorted to use directly.

In addition, in cases where adjacent mappers disagreed, the compiler has attempted to resolve their differences as best he could in order to eliminate map boundary faults. Many problems, yet to be solved, became apparent during the compilation and it is hoped that the present map may serve as a means of pointing out these problems in their regional setting for the benefit of future students of this complex and interesting area.

ACKNOWLEDGMENTS

Although many famous pioneer geologists such as William M. Davis and G. K. Gilbert had made reconnaissance observations pertaining to the Southern Wasatch Mountains, the first modern areal mapping in the area was done by Armand J. Eardley in the early 1930's. All later workers are indebted to the perspicacity of his observations.

Impetus for further work in the area came from Professor Edmund M. Spieker who extended his earlier interest in the Mesozoic problems of central Utah by directing Ohio State University graduate students in areas surrounding that of his initial work with the U.S. Geological Survey. Under him, S. L. Schoff's work in the Cedar Hills in 1937 was followed by that of many others of whom the following did work in the area of the present report: Dorothy Taylor, H. D. Zeller, R. E. Hunt, S. J. Muessig, R. E. Metter, A. C. Fograscher, J. E. Cooper, M. A. Khin, R. E. Mase, J. D. Hayes, and G. E. Thomas. Professor George E. Moore, Jr., of Ohio State University acted as graduate thesis advisor for some of these students.

For the past 25 years Professor Harold J. Bissell has been involved in problems relating to Utah Valley and the adjoining ranges. He has inspired a number of students to work in the West Mountain-Long Ridge-Southern Wasatch area and has served as adviser to most of the following Brigham Young University graduate students who have worked in this area: W. O. Abbott, R. S. Brown, R. S. Clark, L. C. Demars, J. H. Elison, D. R. Foutz, P. W. Gaines, R. W. Gates, T. A. Gwynn, H. D. Harris, R. A. Hodgson, K. D. Johnson, J. W. Madsen, D. F. Mecham, C. H. Peacock, H. N. Petersen, D. J. Peterson, D. O. Peterson, R. P. Peterson, J. R. Price, R. R. Rawson, J. A. Rhodes, S. F. Schindler, G. K. Sirrine, C. V. Smith, J. W. Swanson, and B. O. White.

Arthur A. Baker of the U.S. Geological Survey has mapped in the Wasatch Range from Spanish Fork Canyon northward and his work and advice have served as a guide to many of the above listed workers. In addition to the many people whose field work has made the present compilation possible, I wish to acknowledge the efforts of the authors of the papers in the present volume. I also wish to thank Professors Clyde T. Hardy and J. Keith Rigby for help in preparing the road log, and Mr. Colbeth Killip for drafting the geologic map.

The Editor

Pennsylvanian-Permian Oquirrh Basin of Utah

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Thirty years ago the name Oquirrh Formation was given formal definition and a type locality designated in the Oquirrh Mountains of Utah. Since that date a number of references to occurrence and age of this formation in Utah and Idaho have appeared. It is the purpose of this paper to clarify ideas related to sedimentary history and paleotectonic setting of the depositional basin; less emphasis will be placed upon nomenclature and age relationships. To date a clear definition of limits of the Oquirrh Basin has not been made, nor a synthesis of concepts relating to its sedimentation and contemporaneous tectonism advanced. It now seems reasonably clear that during Pennsylvanian and Early Permian time the depocenter or basin in which a tremendous pile of clastic and related sediment accumulated had an area of approximately 21,000 square miles in the eastern part of the Cordilleran geosyncline and contiguous shelf on the east. About 18,000 square miles of the basin occupied what is now central and north-central Utah, and the remainder was in south-central Idaho. The present discussion relates to the Utah sector of the Oquirrh Basin.

PENNSYLVANIAN AND PERMIAN

Oquirrh Formation

Gilluly (1932, p. 34-38) defined this formation for extensive outcrops in the Oquirrh Mountains, northwest of Provo, Utah, and assigned a Pennsylvanian (Pottsville and post-Pottsville) age to more than 17,000 feet of alternating limestones and sandstones (or quartzites). It has been pointed out (Bissell, 1959b, p. 93-94) that Keyes (1924) and Nolan (1930) applied the name Oquirrh prior to actual definition of the formation; Keyes referred the name to 500 feet of quartzite at the base of his Weberian series, and Nolan used the name for Pennsylvanian rocks of lithic similarity to Oquirrh in the Gold Hill quadrangle of western Utah. Later, Nolan (1935) assigned the rocks he believed to be Oquirrh Formation to the Pennsylvanian and Permian. As early as 1936, and continuing to the present, some of the significant features relating to stratigraphy of the Oquirrh Formation have been pointed out by Bissell (1936a; 1936b; 1939; 1952; 1959a; 1959b; 1960), and with others (Thompson, Verville and Bissell, 1950; Thompson and Bissell, 1954; Bissell and Childs, 1958). The most recent discussion of the Oquirrh is in the type area of the Oquirrh Mountains: Tooker and Roberts (1961) mapped seven discrete units of the formation (two of which are of Permian age) in the northern part of the range, while farther south Welsh and James (1961) proposed that the Oquirrh be advanced to group rank, having four formations and a total of eighteen members. The latter geologists proposed two new formations for the Permian portion of what others consider highest units of the Oquirrh.

Hall Canyon Member

Basal sequence of units (Krumbein and Sloss, 1928, p. 26) of the Oquirrh Formation consist of micritic to bioclastic limestones, and have been named the

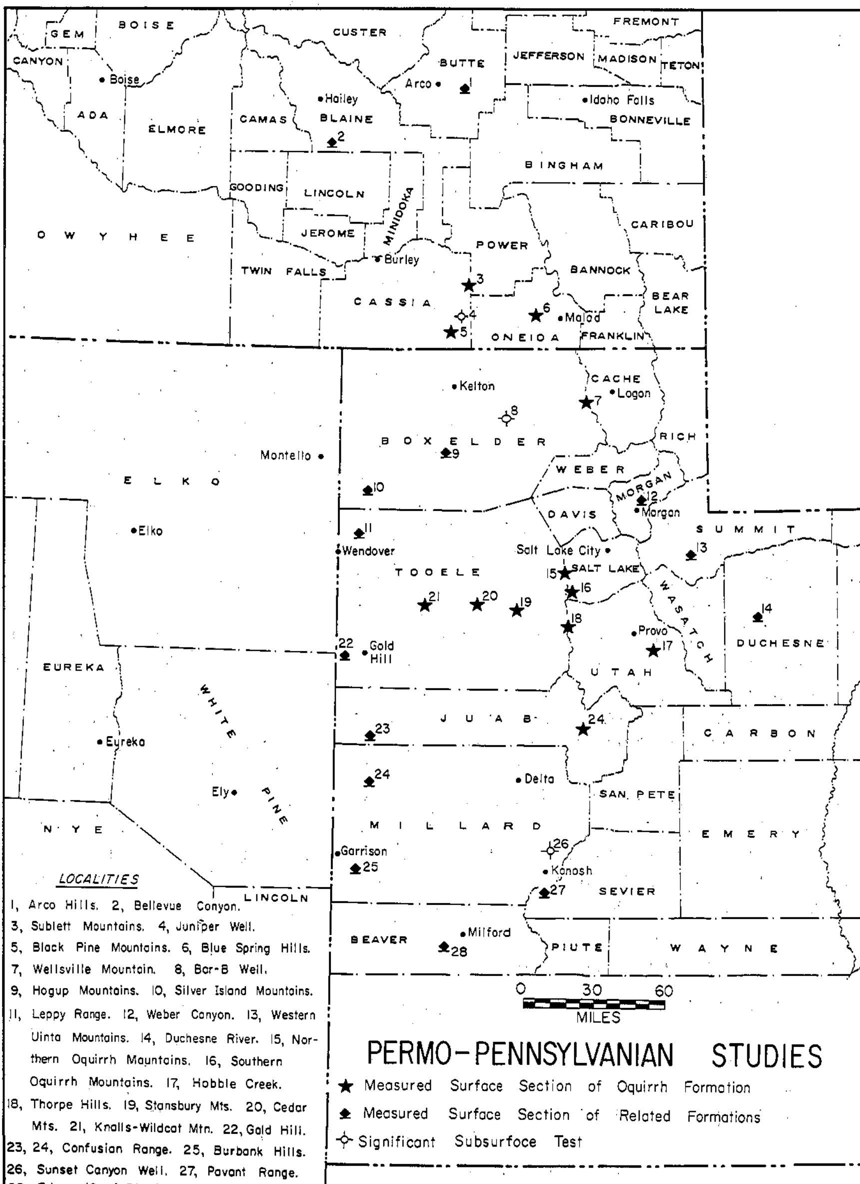


FIG. 1.—Location map of significant stratigraphic sections of Oquirrh and related formations.

Hall Canyon Member (Bissell, 1959a, p. 94-100). This is one of the most distinctive of mappable members of the Oquirrh Formation, and I have recognized it over all the Oquirrh Basin (Fig. 1). It measures 915 feet in thickness at the type locality east of Ophir in the Oquirrh Mountains, but is slightly more than 1,400 feet thick in the walls of Provo Canyon of the south-central Wasatch Mountains. At the latter locality this part of the Oquirrh is referred to the Bridal Veil Falls Member by Baker and Crittenden (1969) who indicate its thickness at about 1,200 feet. Other significant measurements of the Hall Canyon Member include: 850 feet in the Jericho Pass area in the southern part of the Tintic Mountains, 1.300 feet at Lake Mountain west of Utah Valley; 650 feet in the Stansbury Mountains; 450 feet in the Cedar Mountains; 400 feet at Wildcat Mountain farther west; and 350 feet at Wellsville Mountain east of Deweyville, northern Utah. I have recognized the member also in the Blue Spring Hills of south-central Idaho, where it is 700 feet thick. A few tens of miles to the west in the Black Pine Mountains it totals about 500 feet, and to the north in the Sublett Mountains,it aggregates at least 700 feet. Strata of essentially comparable age to the Hall Canyon are present on the Weber Shelf, included in the Morgan Formation and measuring at least 500 feet. Age of the Hall Canyon Member and equivalent rocks are Morrowan, as proved by ubiquitous occurrence of the following fusulinids: *Millerella* spp., *Nankinella* spp., and *Staffella* spp.; possibly, basal strata of the member may locally be of post-Chesteran, pre-Morrowan Early Pennsylvanian age because of presence of *Paramillerella* (*Eostaffella*) spp., *Paraplectogyra* spp., and *Plectogyra* spp. They are equivalent to what provisionally has been termed "Springeran" in the Cordilleran area. It is suggested that until the name "Springeran" is officially accepted or rejected in the Cordilleran area, caution is to be exercised in applying it to basal beds of the Oquirrh. Assigning basal beds of the Oquirrh to the Mississippian as suggested by Tooker and Roberts (1961, p. 21-26) is in direct opposition to data provided by Foraminferal faunas. Coral faunas (which Tooker and Roberts based age determinations for basal beds of their unit 1) have not proved as useful as Foraminiferal faunas in the Oquirrh. The genera which I have cited above (and in particular certain diagnostic species) prove an Early Pennsylvanian age for the basal beds of the Oquirrh, and a Morrowan age for remainder of the Hall Canyon Member. By contrast, limestones in uppermost units of the underlying Manning Canyon Formation contain the Late Chesteran age forms: *Atetsuella* spp., *Endothyra* spp., and *Plectogyra* spp. (see Bissell, 1961, p. 7-8).

Meadow Canyon Member

Type locality of this member of Oquirrh Formation is in the Oquirrh Mountains, in and adjacent to a small canyon of that name west of Lewiston Peak (Bissell, 1959a, p. 100-108). These distinctive fusulinids prove it to be of Derryan age: *Profusulinella* spp., *Eoschubertella* spp., *Fusulinella* spp., and *Pseudostaffella* spp. The member has distinctive lithology in all sections I have measured, and consists of interbedded sandy calcarenites, orthoquartzites, calcareous sandstones, calcareous orthoquartzites, calcarenaceous orthoquartzites, arenaceous limestones, and crystalline to bioclastic limestones. Some beds display pronounced cross-stratification. The member is 945 feet thick at the type locality, thins to 810 feet a few miles to the south in the Thorpe Hills, thickens to 1,300 feet in the Stansbury Mountains,then progressively thins westward to 950 feet in the Cedar Mountains, and is represented by a few scores of feet of sandy limestone in the Wildcat Mountain area (presumably, post-depositional erosion has removed a considerable thickness here). At Lake Mountain, southeast of the Oquirrh Mountains, Meadow Canyon Member is about 1,100 feet thick, is essentially the same in Provo Canyon, and maintains this thickness southward as far as the Southern Wasatch Mountains, and also to the south end of the Tintic Mountains near Jericho Pass, west of Nephi. It is not present in the Wasatch Mountains near Salt Lake City, but equivalent strata (in part at least) are represented there in the Weber formation. In Wellsville Mountain in the Northern Wasatch Mountains, Meadow Canyon Member is 600 feet thick, but aggregates 900 feet in the Blue Spring Hills of southern Idaho west of Malad. Furthermore, I have recognized it in the Black Pine Mountains west of Holbrook (about 900 feet) and in the Sublett Mountains farther north (1,000 feet). It is present east of Rockland, Idaho in the Deep Creek Mountains. Somewhat similar facies, but part of the Wood River formation, is shown in the Bellevue Canyon area; strata of close lithic type is represented in the Lemhi formation of the Arco Hills east of Arco, Idaho. All sections carry distinctive fusulinid faunas, but very few megafossils.

Cedar Fort Member

Some geologists have erronously referred to a particular facies of the Oquirrh formation as the "sandy Oquirrh." Such nomenclature is not only unwieldy but is incorrect. The name Cedar Fort Member of the Oquirrh Formation was proposed for a sequence of dominantly orthoquartzites, with subordinate amounts of sandy limestones, cherty and argillaceous limestones, and some micritic to bioclastic limestones (Bissell, 1959a, p. 108-115). Type locality is in the southeastern part of the Oquirrh Mountains, west of the town of Cedar Fort and on the east limb of the Pole Canyon syncline; measured thickness there totals 1,371 feet. Diagnostic fusulinids indicate a Desmonian age; some of the more useful ones include: *Fusulinella alta* Verville, Thompson and Lokke, *Fusulina novamexicana* Needham, *Wedekindellina euthysepta* (Henbest), *W. excentrica* (Roth and Skinner), and *W. matura* Thompson (all of Early Desmoinesian age); *Fusulina curta* Thompson, *F. leei* Skinner, *F. rockymontana* Roth and Skinner (of Medial Desmonian age); and *Fusulina eximia, F. haworthi* Dunbar and Condra, and *F. megista* Thompson (of Late Desmoinesian age).

This member is 1,131 feet thick in the Thorpe Hills to the south of Oquirrh Mountains, reaches a total of 4,500 feet to the west in the Stansbury Mountains, is approximately 2,800 feet thick in the Cedar Mountains, but seemingly is absent in the Wildcat Mountain area farther west (possibly was not deposited, or at most was very thin). I have measured an excellent section of the Cedar Fort Member in the south-central Wasatch Mountains between Provo Canyon and Hobble Creek Canyon, where it totals approximately 6,200 feet. The member thins rather noticeably southward to about 3,000 feet in the Mount Nebo area, and is only 1,000 feet thick to the west in the south end of the Tintic Mountains. Strata of at least partial equivalency on the Weber Shelf (particularly in Weber Canyon) are represented by about 1,000 feet of fine-grained orthoquartzites and calcareous orthoquartzites in the Weber Formation at the type locality. In the Northern Wasatch Mountains, however, Cedar Fort Member measures approximately 1,100 feet at Wellsville Mountain. The member is also present in certain ranges of southern Idaho; it is 900 to 950 feet thick in the Blue Spring Hills, 500 feet in the Black Pine Mountains, and 500 to 600 feet

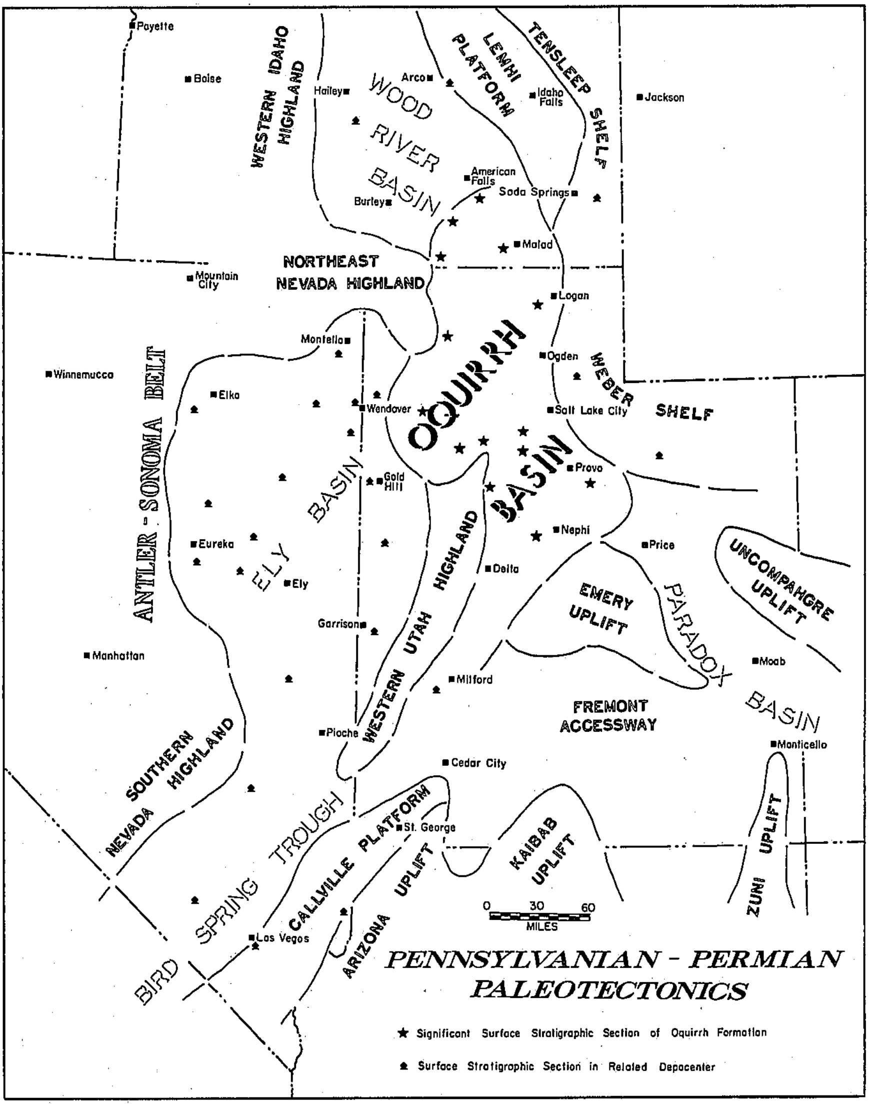


FIG. 2.—Paleotectonic map of Cordilleran area during Pennsylvanian and Early Permian time.

in the Sublett Mountains. Thickness and extent were not determined for the Deep Creek Mountains southeast of American Falls. Strata of similar lithology are represented by approximately 1,800 feet of Desmoinesian-age clastics and carbonates of the Wood River formation near Bellevue, Idaho, and by about 1,300 feet of less sandy carbonates and some orthoquartzites in the Lemhi formation of the Arco area. For the most part, strata of Desmoinesian age are relatively thin to absent in western Utah and eastern Nevada.

Lewiston Peak Member

This member of the Oquirrh Formation was proposed for a distinctive assemblage of Misourian-age cherty limestones and silty-argillaceous limestones with minor sandstone beds in the Oquirrh Mountains (Bissell, 1959a, p. 115-120). Type locality is near Lewiston Peak, and the section measures 1,409 feet. The member is 1,900 to 3,300 feet thick in the Stansbury Mountains, where a considerable thickness of orthoquartzite is present; it is only 500 to 600 feet thick in the Cedar Mountains. It measures slightly more than 800 feet in the southern part of the Tintic Mountains, thickens to more than 1,500 feet in the Southern Wasatch Mountains, and is more than 2,600 feet in thickness in Hobble Creek Canyon of the south-central Wasatch Mountains. Rocks of Missourian age seemingly are absent from the Weber Formation in the central Wasatch Mountains, but the Lewiston Peak Member of the Oquirrh is present in the Northern Wasatch Mountains at Wellsville Mountain, where it measures only 450 feet. However, it thickens northwesterly and in the Blue Spring Hills of southern Idaho is almost 900 feet thick; it is 650 feet thick in the Black Pine Mountains, and evidently is represented by about 400 feet of sandy limestones and calcarenaceous orthoquartzites in the Sublett Mountains. Diagnostic fusulinids provide a Missourian age for the Lewiston Peak member, and include the following: *Triticites nebraskensis* Thompson, *T. springvillensis* Thompson, Verville and Bissell, and *Wedekindellina ultimata* Newell and Keroher (Early Missourian); *Triticites planus* Thompson and Thomas, and *T. provoensis* Thompson, Verville and Bissell (Medial Missourian); and *Kansanella grangerensis* (Thompson, Verville and Bissell), *K. neglectus* (Newell) and *Triticites wyomingensis* Thompson and Thomas (Late Missourian). Locally there are fair to excellent biostromes and patch reefs of the rugose coral *Caninia* sp., such as in the Cedar Mountains of Utah where solitary corals measure from six to ten inches in length and are two to five inches in diameter. This biotope has also been observed in the Oquirrh Mountains, Wasatch Mountains, and southern part of the Tintic Mountains.

Pole Canyon Member

Pole Canyon in the southeastern part of the Oquirrh Mountains has formed in a syncline of Oquirrh formation; the west limb of the fold contains excellent outcrops of interbedded and intercalated orthoquartzites, calcareous orthoquartzites, calcareous sandstones, micritic to bioclastic limestones, and silty limestones to siltstones. To this sequence, aggregating 1,526 feet, Bissell (1959a, p. 121-126) proposed the name Pole Canyon Member. It is recognized throughout the Oquirrh Mountains, and on South Mountain west of Stockton. Thickness of the member in the Stansbury Mountains is 2,000 to 2,600 feet, and in some sections various types of limestones are characteristic. The member thins to less than 1,000 feet in the Cedar Mountains farther west. I measured slightly less than 700 feet for the Pole Canyon Member in the southern part of the Tintic Mountains, and slightly more than 2,000 feet in the Right Fork of Hobble Creek Canyon. Seemingly, it is about 1,000 feet thick in the Mount Nebo area of the Southern Wasatch Mountains. It is not present, either time-wise or lithologically, in the central Wasatch Mountains, because the Weber Formation evidently lacks rocks of Virgilian age. It is present however, in Wellsville Mountain where I measured slightly more than 900 feet of typical strata of this member. I have also recognized it in the Blue Spring Hills of southern Idaho (thickness, 550 feet), in the Black Pine Mountains farther west (thickness, 300 feet), and in the Sublett Mountains to the north (thickness, 300 to 400 feet). Strata of strikingly similar lithology are in the Wood River formation near Bellevue, Idaho; a thickness of almost 2,000 feet of Virgilian-age orthoquartzites and sandy limestones contains fusulinids conspecific with those of Oquirrh Basin. Of further interest is a carbonate and sandy limestone sequence of Virgilian age rocks in the Lemhi formation of the platform near Arco, Idaho, where it measures slightly less than 800 feet.

Fusulinids of Virgilian age, which characterize the Pole Canyon Member of the Oquirrh Formation and correlative strata in adjacent basins (particularly Wood River Basin and Lemhi Platform of Idaho), include the following: *Triticites mediocris* Dunbar and Henbest, *T. gallowayi* Needham, *T. plummeri* Dunbar and Condra, *T. secalicus* (Say), and *Waeringella bailkeyi* Thompson, Verville and Bissell (Early Virgilian); *Triticites kelleyensis* Needham, *T. milleri* Thompson, and *T. moorei* Dunbar and Condra (Medial Virgilian); *Triticites beedei* Dunbar and Condra, *T. cullomensis* Dunbar and Condra, and *T. hobblensis* Thompson, Verville and Bissell (Late Virgilian). Many of these species have proven unusually valuable in my studies of the Oquirrh and related basins; megafossils are scarce to rare in the Pole Canyon Member, but fusulinids are present and locally abundant.

Wolfcampian-Age Oquirrh

Nolan (1935, p. 33-39) considered the Oquirrh Formation to be present in the Gold Hill district of western Utah, and assigned a Pennsylvanian and Permian age to it. However, strata originally considered by Nolan to be Oquirrh are better called Pennsylvanian Ely Limestone, Permian Ferguson Mountain and Pequop Formations (Bissell, 1960, p. 1427; Hodgkinson, 1961, p. 167-196).

Wolfcampian age of upper units of the Oquirrh Formation in the Wasatch Mountains was first pointed out by Bissell (1936a); this was challenged by Baker and Williams (1940, p. 627), but was accepted later by Baker (1947), whose stratigraphic chart of the Oquirrh Formation of the Wasatch Mountains near Provo indicates from 8,000 to 11,000 feet of Wolfcampian-age strata. My measured section (obtained recently) was taken in the Right Fork of Hobble Creek in the area of Lawrence Canyon to Days Canyon, and totals almost 6,200 feet of Early, Medial, and Late Wolfcampian age calcarenites, siltstones, calcarenaceous orthoquartzites, sandy limestones, and calcareous orthoquartzites.

In the course of studying and mapping Oquirrh Formation in the southern part of the Oquirrh Mountains, definitive Permian age rocks were not found, and it is my interpretation that Permian rocks have been removed by post-depositional erosion (Bissell, 1959a, p. 126-127). Recently however, Wolfcampian-age Oquirrh has been recognized and mapped in the central and northern parts of the range by Welsh and James (1961, p. 1-7) and Tooker and Roberts (1961, p. 17-32). The first two authors proposed that the Oquirrh Formation be raised to group rank, including (in ascending order) the Maple Formation, White Pine Formation, Butterfield Formation, and Bingham Mine Formation, all restricted to the Pennsylvanian. To what others consider Wolfcampian-age Oquirrh, these geologists also proposed the new names Curry Formation (below), measuring 2,800 feet, and Clinker Formation, measuring 2,000 feet. Furthermore, they (p. 3) indicated that the Clinker and Curry Formations have been recognized "throughout the Oquirrh Range, at South Mountain, and in the Hobble Creek area east of Springville in the Wasatch Mountains." I cannot wholly subscribe to this statement; until demonstrable utility of these two names by geologic mapping and detailed stratigraphic work are forthcoming, their proposals must be examined with caution. A similar word of caution must be expressed concerning raising rank of the Oquirrh to group, and particularly to restricting it to the Pennsylvanian. Welsh and James proposed a host of new member names to their four new formations in the Oquirrh, including such as "Mostest Limestone," "Maybe Limestone," "Commercial Limestone," Sub Jordan Limestone," "Billiard Ball Limestone," "Step Limestone," and others of similar local usage. Their new name Maple Formation for lower Oquirrh is invalid, because either name now extant (Hall Canyon Member, or Bridal Veil Falls Member) is utilitarian. Their new name White Pine Formation is preoccupied (White Pine Shale, Upper Mississippian age, Eureka district, Hague, 1883, p. 266-268). I have already in the present paper pointed up the utility of five mappable members, all paleontologically dated throughout the entire Oquirrh Basin, for the Pennsylvanian portion of the Oquirrh formation; therefore, in my estimation the names Butterfield and Bingham Mine Formation as used by Welsh and James have local value only, and presumably for purposes of economic convenience in the Bingham Mining district.

In addition to the superb section of Wolfcampian-age Oquirrh in the Hobble Creek Canyon area, I recognized similar lithologies and fusulinid paleontology in the following areas: Stansbury Mountains, 3,000 feet plus; Cedar Mountains, 750 feet; southern part of Tintic Mountains, 2,600 feet; West Mountain near Payson, 5,600 feet; Wellsville Mountain, 2,700 feet; Blue Spring Hills of Idaho, 1,100 feet; Sublett Mountains, about 2,000 feet. Tooker and Roberts (1961, p. 17-32) assigned at least 4,500 feet of orthoquartzites, limestones, sandstone and dolomites of the Oquirrh Formation to the Permian in the northern part of the Oquirrh Mountains. They allocated seven members or units to the Oquirrh Formation; top of their number five, plus numbers six and seven, are of Permian age and the remainder below are "Late Mississippian" through Pennsylvanian age.

Megafossils are scarce to negligible in upper members of the Oquirrh; fusulinids by contrast are abundant and diagnostic. The following have been recognized in my various collectcions taken throughout the Oquirrh Basin: *Dunbarinella extenta* Thompson, *D. hughesensis* Thompson, *Oketaella waldripensis* Thompson, *Schwagerina andresensis* Thompson, *Pseudofusulinella utahensis* Thompson and Bissell, *Triticites cellamagnus* Thompson and Bissell, and *T. creekensis* Thompson (Early Wolfcampian); *Dunbarinella wetherensis* Thompson, *Pseudoschwagerina fusulinoides* Needham, *Pseudofusulina robleda* Thompson, *Schwagerina elkoensis* Thompson and Hansen, *S. wellensis* Thompson and Hansen, *S. franklinensis* Dunbar and Skinner, and *Triticites meeki* (Möller), (Medial Wolfcampian); *Oketaella fryei* Thompson, *Paraschwagerina kansasensis* (Beede and Kniker), *Pseudofusulina moranensis* Thompson, *Pseudoschwagerina uddeni* (Beede and Knider), *Schwagerina aculeata* Thompson and Hazzard, *S. linearis* Dunbar and Skinner, and *S. youngquisti* Thompson and Hansen (Late Wolfcampian).

PERMIAN SYSTEM

Kirkman Limestone

The name Kirkman Limestone was proposed by Baker and Williams (1940) for a distinctive assemblage of fine- to medium-grained, medium-gray limestone and in part of black, finely laminated, fetid limestone with contorted bedding which crops out in the Right Fork of Hobble Creek Canyon; they indicate a maximum thickness of 1,600 feet for the formation at the type locality. Since that time I have recognized Kirkman Limestone in the following localities: North Strawberry Valley (375 feet); Mount Nebo area (300 feet); southern part of Tintic Mountains (1,150 feet); West Mountain west of Payson (1,000 feet); South Mountain west of Stockton approximately 400 feet); Cedar Mountains (approximately 280 feet); east side of Wellsville Mountain, north side of Deep Canyon west of Mendon (about 160 feet). In re-studying the type Kirkman I measured its thickness to be slightly less than 1,500 feet and found it to contain diagnostic fusulinids of Medial to Late Wolfcampian age as follows: *Pseudoschwagerina uddeni* (Beede and Kniker), *Schwagerina linearis* Dunbar and Skinner, and *Schwagerina youngquisti* Thompson and Hansen. Thus, I cannot agree with Dunbar, Baker and others (1960, Column 29, Correlation Chart) that age of the Kirkman Limestone at Hobble Creek is Early Leonard. In fact, at all localities at which I studied the Kirkman, diagnostic fusulinids prove a Medial to Late Wolfcampian age.

Recently Morris and Lovering (1961, p. 114-118) of the U.S. Geological Survey discussed the Oquirrh Formation in the Tintic Mountains, assigning it to the Pennsylvanian and Permian systems. Time lag between writing and printing of Geological Survey publications being as long as it is, they were unable to cite work done previously in the Thorpe Hills (Bissell, 1959a) in which Oquirrh Formation was discussed. They erred in their interpretation of hydrothermal dolomite in upper beds of the Oquirrh in the southern part of the Tintic Mountains. They interpreted the stratigraphy there to be Diamond Creek (?) Sandstone resting disconformably upon Oquirrh Formation. My measured section of the same surface section was obtained near Sandstone Gulch; it is my interpretation that Diamond Creek Formation there rests upon Kirkman Formation, and this in turn is conformably upon Wolfcampian-age Oquirrh Formation. Thus they did not recognize the Kirkman. The Kirkman Formation undergoes facies changes southward through the southern Wasatch Mountains and has interbedded dolomite and limestone in the Mount Nebo area. To the west it becomes dominantly dolomitic, but nevertheless is present in the southern part of the Tintic Mountains. I obtained excellent fusulinid suites from the Kirkman and underlying Oquirrh; Wolfcampian-age species are abundant. Instead of interpreting the dolomite in this and other areas of outcrop where it is present in Oquirrh, Kirkman and Diamond Creek as of hydrothermal origin, I consider it largely of depositional origin, having formed in a transgressive-regressive marine sea in the epineritic to littoral environment in proximity to landmasses. Identical conditions typify part of the Oquirrh Formation, part of the Kirkman Formation, and part of the Diamond Creek Sandstone in the Cedar Mountains; nearness to the Western Utah Highland and in shallow marine waters accounts for this dolomite. I believe similar conditions obtained accounting for most if not all the dolomite in upper Oquirrh in the Tintic Mountains.

In the present paper, sedimentary environment and paleotectonics of the post-Oquirrh, Permian strata have not been elaborated upon. Isopach maps were constructed for the Oquirrh Formation only, and the discussion was related to them. Sediments of the Kirkman Formation accumulated in a basin which seemingly represents closing episodes of this particular setting. I interpret conditions of sedimentation for the Kirkman to have been littoral to neritic, but surrounded by remnants of the former highlands. During the succeeding epochs when the Diamond Creek Sandstone was being laid down as eolian and beach sands, and as transgressive-regressive littoral and neritic sands and dolomites, not even a counterpart of the Oquirrh Basin remained. Subsequently when sediments of the Park City Group accumulated, marine conditions again characterized the Eastern Great Basin region.

Diamond Creek Sandstone

Baker and Williams (1940) proposed the new name Diamond Creek Sandstone for a distinctive suite of fine- to coarse-grained, gray to buff and red, friable sandstones that measure about 1,000 feet at Little Diamond Creek Canyon, it type locality. I measured about 850 feet at the type locality and approximately the same thickness in Right Fork of Hobble Creek Canyon, and 400 feet in the Mount Nebo area. It thickens to almost 600 feet at Sandstone Gulch in the southern part of the Tintic Mountains, specifically in SE 1/4 Sec. 18, T. 13 S., R. 2 W., Juab County. The formation contains considerable intercalated and interbedded calcareous and sandy dolomite and dolomitic sandstone, reflecting in its sedimentary environment proximity to the Western Utah Highland. The formation thins to about 200 feet of sandstone and dolomitic sandstone at West Mountain west of Payson, is as much as 1,000 feet thick at South Mountain west of Stockton, and is about 450 feet thick in the Cedar Mountains where dolomites are also interbedded and intercalated. The formation is 165 feet thick in North Strawberry Valley.

Park City Formation

The name Park City Formation has been applied in the Wasatch Mountains, but has been elevated to group rank in the Confusion Range of western Utah (Hose and Repenning, 1959, p. 2178). Of formation rank in the Wasatch sector, it includes (in ascending order), Grandeur Member, Meade Peak Member, and Franson Member. In western Utah and some parts of eastern Nevada it contains Kaibab Limestone below, overlain by Plympton Formation and Gerster Limestone. Space does not permit discussion relating to problems of nomenclature and thickness here, but it should be noted that Park City Formation contains thick- to massively-bedded cherty limestones and some dolomites, with phosphatic and siliceous shale in the middle. Aggregate thickness of the three members at Hobble Creek Canyon is slightly in excess of 1,600 feet (vis. 1,890 feet as reported by Baker, 1947). It is about 650 feet thick in the Mount Nebo area, thickens to almost 1,150 feet farther west in the southern part of the Tintic Mountains (south of Sandstone Gulch), and is represented by a few hundred feet of limestones and shales in the central Oquirrh Mountains. It is more than 950 feet thick in the Cedar Mountains; in that area about 430 feet of Plympton Dolomite is overlain in succession by Grandeur Member, Meade Peak Member, and Franson Member. Park City Formation is 1,495 feet thick in North Strawberry Valley.

PALEOTECTONICS AND SEDIMENTARY ENVIRONMENTS IN THE OQUIRRH BASIN

Gilluly (1932, p. 38) had this to say concerning conditions of deposition of the Oquirrh Formation: "The area must have been subjected to widely fluctuating currents, with tremendous amounts of detritus, almost wholly of sand, supplied by the strong currents and with great quantities of lime available for deposition during more quiet times. The numerous fossils of the limestone layers and the grain and bedding of the sandstones show that at no time were the waters very deep, yet no continental deposits have been recognized in the formation, and it seems likely that the rate of deposition never exceeded that of depression in the district." Bissell (1936b, p. 242-243) made this note: "It appears that in the region of the southern Wasatch Mountains the Oquirrh . . . was deposited in relatively shallow water not far from land and upon an unevenly and constantly sinking sea bottom." Additional details of history of sedimentation as related to paleotectonics of the Oquirrh Basin were added in subsequent papers (Bissell, 1950; 1952, p. 626, 627; 1953, p. 27-29).

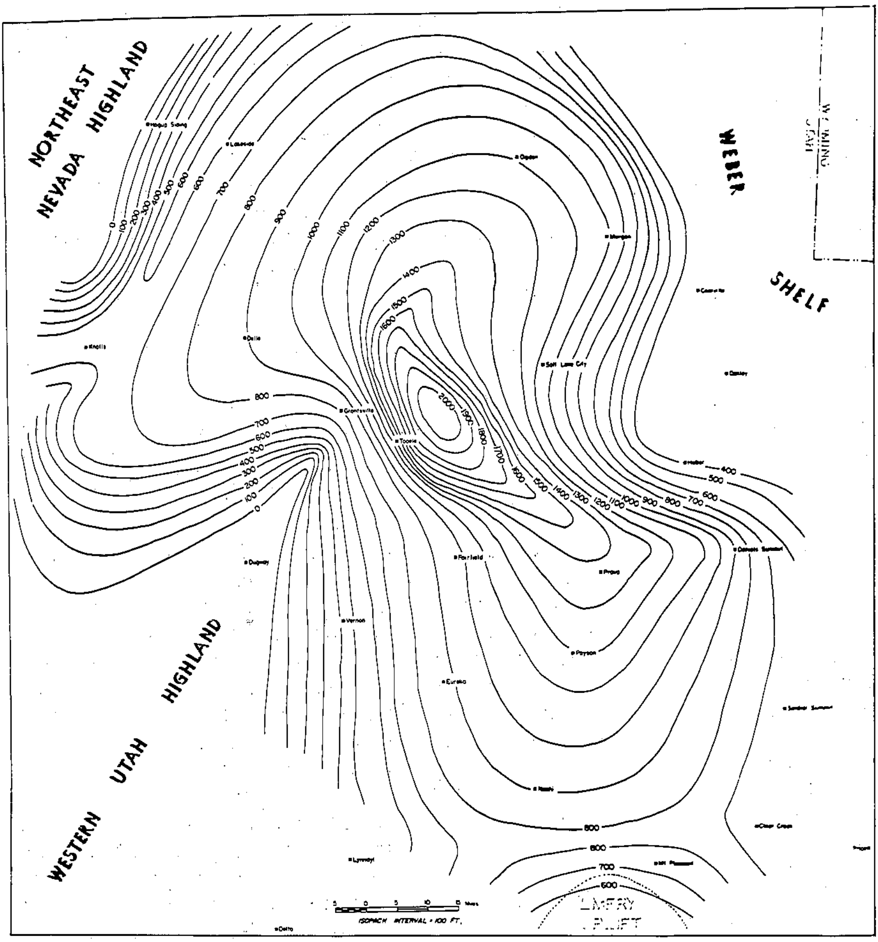
During the past one-quarter of a century the writer has had opportunity to measure and study scores of stratigraphic sections of Oquirrh Formation and to study the sediments and associated fusulinid faunas. Similar studies have been made of contiguous depocenters which were forming contemporaneously in the eastern part of the Cordilleran geosyncline and shelf to the east. The ancient geosyncline is thus considered to have consisted of numerous basins, troughs, platforms, accessways, thresholds, and other repositories and related source areas; source areas existed as orogenic to epeirogenic highlands and other positive areas (see Fig. 2). The present report summarizes the information, and Figure 2 depicts some of the features which are inferred to have typified the ancient geosyncline. Figures 3, 4, 5 and 6 are isopach maps relating to the Oquirrh Basin in the Utah sector of this geosyncline.

Late Mississippian Sedimentation

Throughout the area formerly covered by the Oquirrh Basin, strata of the Hall Canyon Member of the Oquirrh Formation rest in conformable to blended disconformable relations upon Manning Canyon Formation. This latter formation is of Chesteran age (Sadlick, 1960, p. 83, indicates it to be Late Chester, or Elvira, age), and consists dominantly of dark gray, brown, and black shales with interbedded dark colored siltstones and limestones. Moyle (1959, p. 59-92) presented a thorough analysis of the Manning Canyon Formation in terms of sedimentary environment. He (p. 84-85) stated: "Sediments were possibly deposited on an unstable shelf directly adjacent to the deeper zones of the geosyncline. Calcareous content suggests a tidal flat environment for the brown and brown-gray shales . . . Abundance of organic material suggests deposition farther from shore or under slightly reducing conditions for the black shales. . . . The environment of the limestones appears to have been shallow marine to open marine. The fossil fauna suggests epineritic clear water to shallow infraneritic clear water." Moyle further pointed out the cyclic nature of sedimentation, inasmuch as some sediments display characteristics and faunal and floral elements which suggest transgressive-regressive cyclothemic conditions.

Lower Pennsylvanian Sedimentation

With an environmental setting of oscillating marine and non-marine conditions as a foundation, we can proceed to analysis and interpretation of



OQUIRRH BASIN - LOWER PENNSYLVANIAN

FIG. 3.—Isopach map of Oquirrh Basin and adjacent areas for Lower Pennsylvanian "Springeran" and Morrowan rocks including the Hall Canyon Member of the Oquirrh Formation.

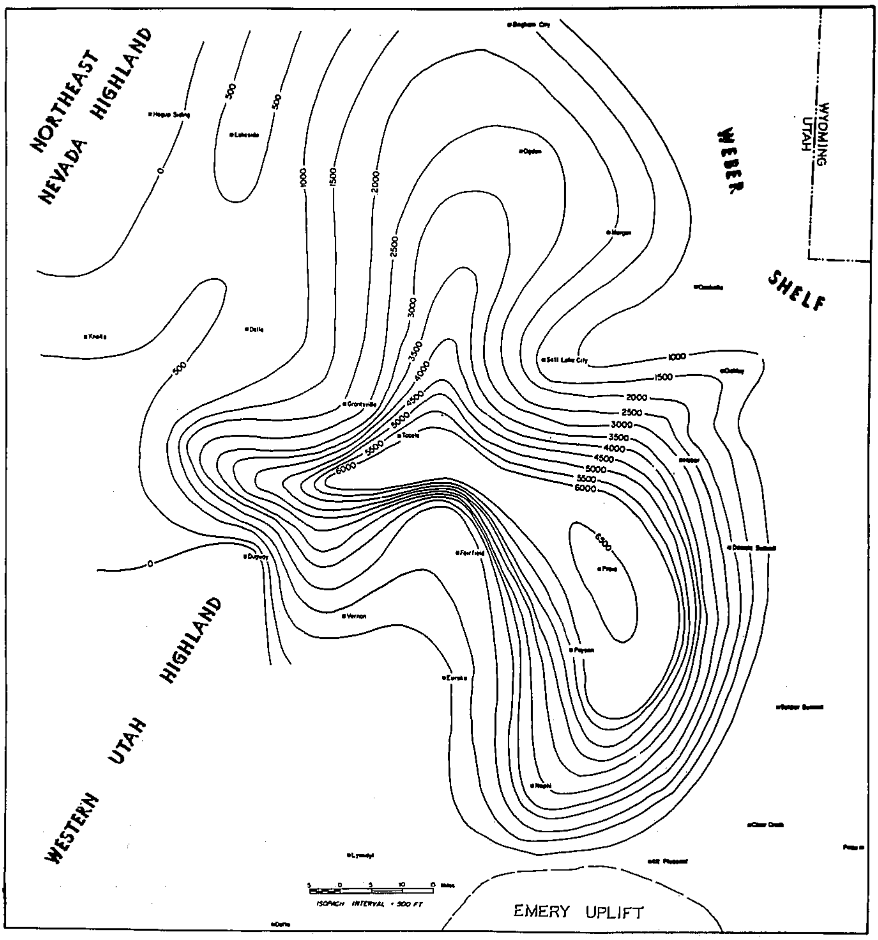
sedimentary conditions under which the Oquirrh Formation accumulated. The Oquirrh Basin in Early Pennsylvanian time was sinking with acceleration marine waters spread throughout its extent, epeirogenic upwarping of certain contiguous landmasses occurred, and areally extensive blankets of lime muds, fossiliferous-fragmental or skeletal-lime-muds, and sands were laid down. The Oquirrh Basin soon assumed the pattern of a broadly-flaring figure-8 (see Fig. 3), with thickest accumulation of micritic, arenaceous, bioclastic, and other limestones and interbedded shaly limestones and orthoquartzites occurring in a northwesterly-trending trough. Weber Shelf was a broad and stable to only slightly unstable region situated between the subsiding miogeosyncline and the craton farther east. Some sediments of the Hall Canyon Member must have accumulated upon an unstable shelf; they possibly interfingered with shelf sediments of the Morgan Formation to the east and northeast. For the most part Hall Canyon sediments formed in the epineritic environment, although possibly an infraneritic environment obtained locally and at times. Littoral environment conditions characterized certain areas next to positive elements, and delta-plain conditions, replete with bar-finger sands, were the rule at times and places adjacent to epeirogenically and orogenically raised landmasses. Western Utah Highland, for example, was rising and crowding against the west-central part of the basin, and from it floods of detrital material poured into the negative basin. Emery Uplift to the south may have been incipient only, and likely existed as a shallow submarine bank rather than as a pronounced positive block. Northeast Nevada Highland in northwestern Utah and adjacent area was in the throes of the later pulses of the Antler Orogeny, and exhibited severe positive mobility. The Western Utah Highland and NortheastNevada Highland displayed most pronounced activity, and controlled the sedimentary pattern of the seas nearest them. Important physical and faunal breaks occurred, and in many places the record of Early Pennsylvanian sedimenation is lacking, for example, places in Stansbury Mountains (Wright, 1961, p. 147-166). Hiatuses and vacuities (Wheeler, 1958, p. 1057-1058) locally are the rule.

Any connection between Oquirrh Basin and Paradox Basin of southeastern Utah was not a pronounced sag, but existed as a broad threshold which has been termed the Strawberry Accessway (Bissell, 1960, p. 1426). Blankets of quartz sand and silt, along with lime muds and some bioclastic limestones, algal limestones, and locally patch reefs formed upon this threshold. Detritus swept across this platform-like area was derived from the Weber Shelf and craton on the north, and Emery Uplift on the west, and Uncompahgre Uplift on the east. It is tempting to generalize that the southeast-northwest trend of the most negative mobile portion of the Oquirrh Basin (that is, area of present site of Oquirrh Mountains and south-central Wasatch Mountains) was controlled by a lineament or lineaments inherited from earlier epochs of diastrophism. Kelley (1955, p. 58-51) discusses and illustrates some of these lineaments of southeastern Utah and contiguous regions; noteworthy among them is the Uncompahgre Lineament extending from Colorado northwesterly as far as the north end of the present Oquirrh Mountains. If this bedrock, structurally-controlled rectilinear belt of weakness and contiguous belt of strength extended from the western side of the Uncompahgre Uplift to the boundary between Weber Shelf and east side of Oquirrh Basin, then is the possibility strong that not only is the Paradox Basin taphrogenic in origin, but the Oquirrh Basin behaved similarly at times under such diastrophic control. Principal difference is that the junction of this northwesterly-projected Uncompahgre Lineament with the east-west trending Uinta flank lineament (Tooele Arch) may have forced the Oquirrh Basin to subside, not as a half-graben, but as an asymmetric sag or trough. The northerly and northeasterly trending Western Utah Highland at this time gave greater asymmetry to the west side of the Oquirrh Basin than to the east side. One could, of course, argue by analogy that the southwestern side of the Oquirrh Basin sank with greater acceleration than the northeastern side, and therefore behaved as a half-graben with the "fault" along the southwestern side. Rather severe orogenic activity in the eastern projection of the Northeastern Nevada Highland in Early Pennsylvanian time forced the Oquirrh Basin to be deflected in trend, thereby aligning this basin north-south in northern Utah. If Kelley's suggestion is tenable that the Uncompahgre and/or Zuni lineament(s) extended into and in essence controlled mobility of the Oquirrh Basin, then one should also consider the possibility that a "hinge" or fulcrum area could also have been a controlling feature. That is, most active subsidence of the Paradox Basin was along its eastern to northeastern side adjacent to the actively rising Uncompahgre landmass; by contrast, most active sinking at this time of the Oquirrh Basin was along its western side near the Western Utah Highland. Perhaps the fulcrum was situated in the threshold area between the two basins, and a scissors-effect to pivot-effect resulted.

Oquirrh Basin was "blocked-out" early in Pennsylvanian time, and maintained this fundamental alignment of northwesterly trend in the sector of the Oquirrh-southcentral Wasatch Mountains, with a northerly trend north of the Oquirrh Mountains. The basin projected into south-central Idaho as far north as the present site of the Deep Creek Mountains southeast of American Falls, and as far south possibly as the Star Range near Milford, Utah. In this latter area it evidently was narrowly restricted and thus was merely a threshold or accessway to the northern part of the Bird Spring Trough; upon this threshold the carbonates and sands of the Callville (totaling approximately 1,100 feet in thickness) and later the sands of the Talisman (also about 1,100 feet thick) were deposited as blankets. Thus, the southern or tail-like projection of the Oquirrh Basin terminated in the Milford area or directly to the north; carbonates and clastics of the Bird Spring Formation formed a trough south of the threshold upon which the Callville and Talisman accumulated. Admittedly, this is an arbitrary separation of Bird Spring Trough on the south from Oquirrh Basin to the north by a relatively small threshold between.

I have shown (Fig. 3) the Oquirrh Basin to extend to the northwest in Utah, being bordered there by the Northeast Nevada Highland; the Gold Hill Accessway (Bissell, 1960, p. 1426) connected Oquirrh Basin with the Ely Basin of eastern Nevada and western Utah. Steele (1960, p. 97-100) indicates the Oquirrh Basin to have extended to the Utah-Nevada border area in northwestern Utah during Morrowan-Middle Desmoinesian time. In following this concept, and applying the name Oquirrh that far west in Utah, Schaeffer (1960, p. 88-94) states: "The general stratigraphic term 'lower portion of the Oquirrh Formation,' is used by the writer to denote the more clastic facies of the Ely Formation." Schaeffer had reference to the Silver Island Mountains, northeast of Wendover, Utah. I cannot concur with either of these geologists in extending the name Oquirrh Formation that far into northwestern Utah; Figures 2 and 3 of the present report depict the interpretation based on my field work.

Patterns of sedimentation during "Springeran" and Morrowan time in the Oquirrh Basin consist therefore, of carbonate muds, clean sands, minor shales, some orthoquartzite, numerous bioclastic limestones, and clean micritic limestones. Clear and relatively quiet marine waters provided optimum conditions for widespread development at times and places of algal, bryalgal, and coralgal limestones. At the same time but in other parts of the basin delta sands and muds were being formed in the repository, having been transported to the depocenter from nearby highlands; also as a contemporary phase of sedimentation was the formation of relative abundance of siliceous sediment, primarily in form of chert bands, "lunch-meat" layers, blebs, gobs and irregular masses, and as cement for the quartz sands with resultant orthoquartzites. This aspect of silica



OQUIRRH BASIN - MIDDLE PENNSYLVANIAN

FIG. 4.—Isopach map of Oquirrh Basin and adjacent areas for Middle Pennsylvanian Derryan and Desmoinsian rocks, including the Meadow Canyon and Cedar Fort Members of the Oquirrh Formation.

sedimentation has been discussed elsewhere (Bissell, 1959b, p. 160-165). Encrinal and related "hash-bed" limestones formed locally and to notable thickness; biostromes of productid, spiriferid and compositid brachiopods are areally extensive. Many limestones contain the Foraminifera *Millerella* spp., *Nankinella* spp, and *Staffella* spp. Alternating with these fossiliferous limestones are argillaceous limestones, orthoquartzites, cherty limestones, and locally shales. This repetitive or interbedded to intercalated arrangement of the sequence in the Hall Canyon Member of Oquirrh Formation testifies to cyclic-type of sedimentation within the Oquirrh Basin, at times at least. Fluctuation and variation in intensity of ocean currents, waves, tides in the neritic and littoral zones would account for this sequence. However, it is to be noted at the outset that variation in degree of tectonism in adjacent positive areas also accounted for times of copious supplies of detrital sediment and also for times of lime mud formation.

Middle Pennsylvanian Sedimentation

Sedimentation in Oquirrh Basin in Derryan time accounted for a considerable thickness of lithoclastic and bioclastic sediment interbedded and intercalated with detrital quartz sand and silt. At the time of formation of Meadow Canyon Member of the Oquirrh Formation, and related units, great quantities of materials were swept into the subsiding basin and washed and sorted to a degree by various currents and waves. High energy conditions obtained at times and places; cross-stratified calcarenites are present at numerous localities indicating that certain currents were powerful enough to sort and stratify enormous quantities of detritals. In approximately mid-Derryan time there formed widespread biostromes and reefs of algae and particularly of the "hair" coral *Chaetetes milleporaceous.* This species also formed extensive reefs later in Derryan time; the conditions which were at optima permitted this coral to form throughout much of the Oquirrh and related basins (Bissell, 1960, p. 1432) in the Cordilleran miogeoosyncline and upon the Weber and other shelves and in the Paradox and other basins to the southeast. Numerous beds in the Meadow Canyon Member contain an abundance of the fusulinids *Profusulinella* spp., *Eoschubertella* spp., *Fusulinella* spp., and *Pseudostaffella* spp., while others contain such algae as *Osagia* spp., and *Komia* spp.

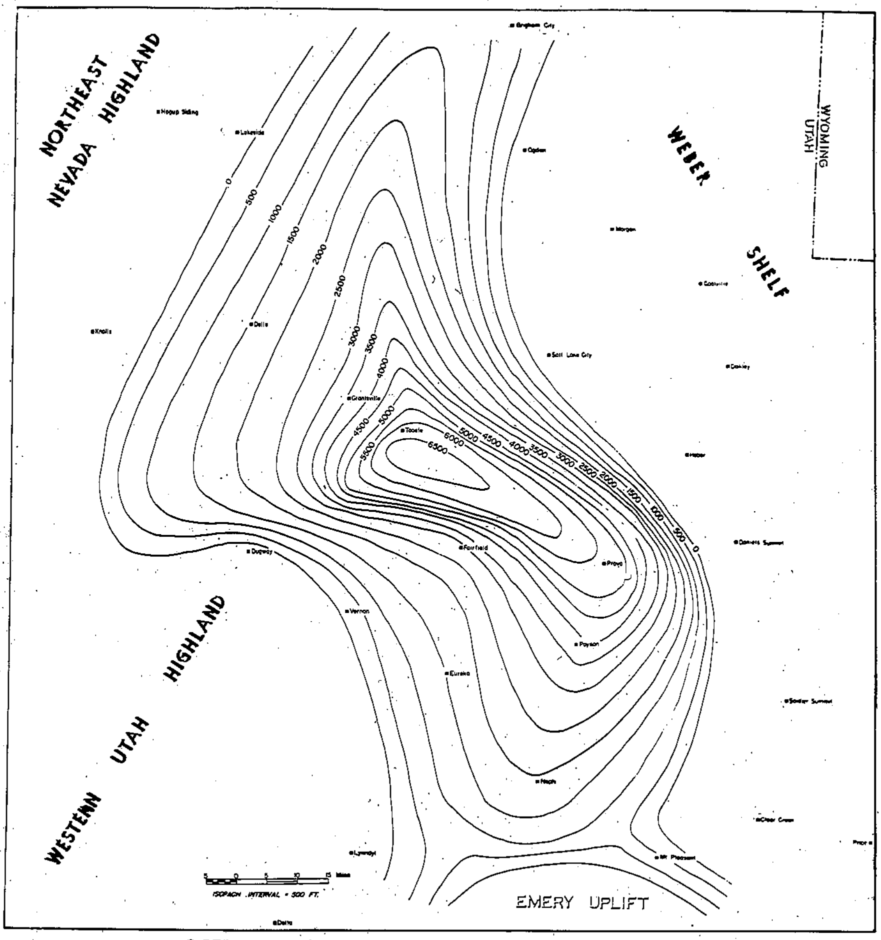
Configuration of the Oquirrh Basin was not so simple as during Morrowan time; rather, the northwesterly trend in the southeastern part shifted slightly to a more north-south alignment and the central part bifurcated to a westerly-trending segment and a northerly-trending but open-flaring portion. This outline continued into Desmoinesian time (see Fig. 4). The Weber Shelf assumed a more pronounced east-west trending arch, the Western Utah Highland was more broadly flaring and may have actually had a dual nature, the Northeast Nevada Highland continued to dominate northwestern Utah, and the Emery Uplift of central Utah assumed a more positive nature. In fact, the Emery Uplift likely accounted for much detrital materials in the southern part of the Oquirrh Basin. The Western Utah Highland, particularly in and near its northern extremity, accounted for considerable amounts of detritals to the more negative part of the basin. A broad bank or platform extended across part of northwestern Utah adjacent to the Northeast Nevada Highland. Analysis of direction and intensity of paleocurrents in Oquirrh Basin during Derryan time has not been attempted; this would comprise an excellent field of research in sedimentation.

Figure 4 shows isopachs of Middle Pennsylvanian in and adjacent to Oquirrh Basin; Desmoinesian and Derryan time is covered, and the Cedar Fort Member is included with the Meadow Canyon Member. However, Cedar Fort is thicker of the two. Area of thickest sedimentation, and thus the region of greatest negative mobility, lay in an arcuate pattern in what is now the south-central and southern Wasatch Mountains and to the northwest and west around the north end of the Western Utah Highland. A tongue-like trough or embayment extended to the north as far as south-central Idaho. Tremendous quantities of fine- to medium-grained quartz sand were dumped into the depocenter; some of this may have had a substantial period of washing, cleaning and sorting on shelves and platforms (adjacent to the craton on the east, adjacent to highlands on south, west and northwest) before being swept into the Oquirrh Basin, particularly in its central part. Furthermore, much of this in all likelihood represents second-, third-, and even fourth-cycle quartz sand and silt, having been reworked from older Paleozoic rocks and also from Precambrian terrains. In all this thickness of more than 6,000 feet there is no evidence of turbidite formation. Yet sand and silt grains of quartz were widely distributed and admixed at places and at certain times with calcarenitic material. Also, there were times when bioclastic and other types of limestones accumulated to notable thickness over wide areas. Seemingly, moderate to high energy conditions prevailed in and upon the epineritic and infraneritic zones; perhaps some of these currents transported detrital sediment considerable distances. Studies of paleocurrent directions have not been made for the Cedar Fort Member.

Desmoinesian time in the Eastern Great Basin area was one of interplay of tectonism in and adjacent to the Oquirrh Basin; Western Utah Highland and Emery Uplift were epeirogenically active in a positive direction, and the Weber Shelf was unstable. Northeast Nevada Highland possibly was not as active orogenically as it was during Derryan and Morrowan time, but nevertheless exerted a certain amount of diastrophic influence on sedimentary patterns adjacent to it on the south and east. Acting as a source area, it shed considerable amounts of detrital materials into the basin; probably much of this sediment was swept eastward upon the submarine delta plain, only to be diverted southward to aid in filling Oquirrh Basin in a longitudinal fashion. Western Utah Highland controlled sedimentary trends to a remarkable degree in the west-central, central, and southwestern part of the basin. Material transported from the northern part of the Emery Uplift moved into the Oquirrh Basin, accounting for at least part of the thick pile of sediment in the area now embraced by the south-central Wasatch Mountains. No more than a threshold or "sill" separated the Oquirrh from the Paradox Basin, but evidently a pronounced sag did not typify the southeastern part of Oquirrh Basin; that is, this basin did not have a bottle-neck shaped prong extending southeasterly to connect with the Paradox. It did however, extend in a southerly to southwesterly direction as a bottle-neck prong to the Milford area; from that region south there existed a sand depocenter that acted as a transitory zone between the Oquirrh Basin and Bird Spring Trough to the south (see Fig. 2). All in all, Oquirrh Basin during Desmoinesian time was unusually mobile in a negative way, and contiguous landmasses likewise were undergoing positive uplift. A facet of this over-all study that in my estimation is worthy of further research is one relating to heavy minerals from Middle Pennsylvanian Oquirrh sediments; information thus gained might indicate if the Northern Utah Highland (composed of Precambrian crystalline rocks) was a source for certain sediment types.

Upper Pennsylvanian Sedimentation

Shift from predominantly arenite sedimentation to deposition of sandy and siliceous limestones, with interbedded calcareous orthoquartzites and some normal orthoquartzites occurred by Missourian time. Deposition of the Lewiston Peak Member of Oquirrh Formation in the Oquirrh Basin was under strictly marine conditions; the epineritic realm predominated, although some materials such as siliceous and cherty, fine-textured dark gray limestones probably formed in deeper, or at least quieter, waters. Periodically high-energy conditions prevailed upon the banks, platforms, and other shallow portions of the neritic zone and



OQUIRRH BASIN - UPPER PENNSYLVANIAN

FIG. 5.—Isopach map of Oquirrh Basin and adjacent areas for Upper Pennsylvanian Missourian and Virgilian rocks including the Lewiston Peak and Pole Canyon members of the Oquirrh Formation.

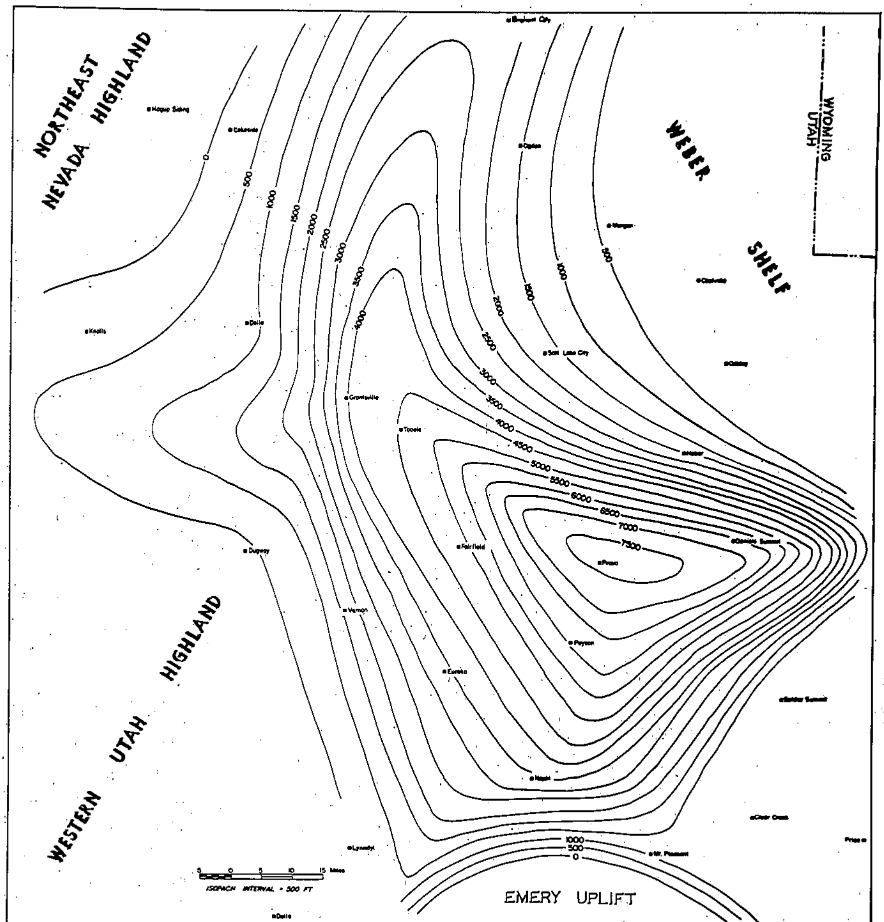
coral biostromes and varieties of reefs formed. *Caninia* spp. and *Syringopora* spp. were locally abundant and important biotopes. This is particularly true of the Cedar Mountains area and the southern part of the Tintic Mountains. This part of the Oquirrh Basin lay in a trend ofactive currents and waves directly east of the Western Utah Highland.

Emery Uplift to the south continued to provide much detrital material; Western Utah Highland likewise was a most important source region. The Northeastern Nevada Highland and Weber Shelf consisted of broad and gradually sloping regions, across which streams and sheetfloods moved in order to transport sediment to the depocenter. Not only these conditions, but other environmental circumstances, set the stage for limestone and sandstone sedimentation. Source of silica in certain limestones and all orthoquartzites in the Lewiston Peak Member (as well as for the Cedar Fort and other members) is not known with surety. The probability is high that some of it entered the Oquirrh Basin from adjacent landmasses as a silicic acid, being carried in colloidal suspension and solution in the streams which drained the uplands. Probably the largest percentage of the silica which admixed with fine-textured limestones, and which provided the cementing material *contemporaneously* with quartz sand accumulation (thereby accounting for orthoquartzites) entered the geosyncline from the volcanic eugeosyncline area farther west (Bissell, 1959b, p. 178-182).

Conditions of sedimentation during Virgilian time, during deposition of the Pole Canyon Member of the Oquirrh, and equivalent units, continued with only slight modification in the Oquirrh Basin. Figure 5 illustrates total Upper Pennsylvanian time, including Lewiston Peak and Pole Canyon Members. There was continued dumping of quartz sand and silt into Oquirrh Basin from at least four directions; formation of bioclastic and other limestone types also occurred. It may be that the general finer texture of orthoquartzites and calcarenaceous orthoquartzites as well as of the sandy limestones in strata of Virgilian age reflects greater distance of transit from the highlands to the Oquirrh depocenter. Epineritic to infraneritic environmental conditions prevailed; well washed and sorted arenaceous materials were moved about in these zones. Streams moving from the craton and from the highlands may have had lower gradients, at times at least, and thereby transported fine- to medium-grained clastics. Reefs and biostromes are not numerous in sediments of Virgilian age, thus indicating conditions were not at optima for their formation.

Tectonism during Upper Pennsylvanian time in and contiguous to the Oquirrh Basin apparently was less vigorous than during Desmoinesian time; Figure 5 indicates that the Weber Shelf was broad and gently shelving. Western Utah Highland was still epeirogenically active, and the Northeast Nevada Highland similarly was positive. Emery Uplift dominated the southern part of the region. Configuration of the Oquirrh Basin now displayed a southeast-northwest trend from the southern Wasatch Mountains to the Oquirrh Mountains sector; a slight embayment protruded to the west, but not to the degree as in Middle Pennsylvanian time. An elongated, trough-like extension northward into south-central Idaho contrasted with the broad tongue-shaped embayment that persisted in earlier times. A narrow, bottle-neck shaped protrusion extended south along a threshold bordered on the west by the Western Utah Highland and on the east by Emery Uplift. Probably this gradually restricted protrusion did not extend as far south as the Milford area; that region may have been subaerial or at most a shallow platform, separating the Oquirrh Basin from the Bird Spring Trough farther south. Taken as a whole, the Oquirrh Basin in Upper Pennsylvanian time is seen to have become a much narrower and arcuate basin; its central portion was almost trough-like. An aggregate of 6,500 feet of sediment accumulated in this trough or axial part of the basin during Missourian and Virgilian time. Negative mobility still persisted in the central part.

Throughout the Pennsylvanian period, the dominantly negative part of Oquirrh Basin (now site of Oquirrh and south-central Wasatch Mountains) sank at least three miles. Probably at no time did water depth exceed a few tens of fathoms, unless spasmodically there were certain portions of the ancient depo-



OQUIRRH BASIN - LOWER PERMIAN

FIG. 6.—Isopach map of Oquirrh Basin and adjacent areas for Lower Permian Wolfcampian rocks.

center which subsided sufficiently to permit water depths of a few hundreds of feet to be characteristic.

Lower Permian Sedimentation

Environmental conditions which obtained during Late Pennsylvanian time in the Oquirrh Basin persisted with only slight modification into Wolfcampian time. The fundamental pattern of clastic sedimentation, punctuated periodically and perhaps locally only by accumulation of bioclastic and sandy limestones, continued through most if not all this basin. Various source areas provided vast qualtities of detrital and chemical constituents and these were organized in the depocenter by waves, currents, and organisms as fast as the streams, mudflows, sheetfloods, and other transporting media could supply them. High energy requirements of corals, algae, fusulinids and other life forms were met by the waves and currents; sorting, washing, and stratification were at times at optima. No evidence of unusual "dumping in" of unsorted materials is found; rather, long periods of cleaning up evidently were characteristic, thereby permitting areally-extensive sedimentation of orthoquartzites, bioclastic limestones, siltstones, and calcarenaceous orthoquartzites. These conditions persisted for a long span of time, and considerable thicknesses of these sediments are present. Tectonic pattern of the Weber Shelf substantially changed, particularly in its southern region, and it bordered a vast east-trending embayment of the Oquirrh Basin (see Fig. 6). Western Utah Highland persisted with little change over Medial Pennsylvanian time, and the Northeast Nevada Highland similarly was a positive area, and perhaps was epeirogenically active. Oquirrh Basin was a more broadly flaring region to the north, and also opened up to the west across the Gold Hill Accessway to the Ferguson Basin and Deep Creek Trough of Nevada. Gradually the Western Utah Highland was worn low, and marine waters encroached westward to merge with those of western Utah and eastern Nevada. Emery Uplift persisted, and exerted considerable influence on sedimentary patterns. Shift of pronounced subsidence to the present site of south-central Wasatch Mountains occurred, and Oquirrh Basin assumed an east-west trend for part of its limits, and a north to slightly northeast trend of the Oquirrh Mountains. Bifurcation of the basin around the northern end of the Western Utah Highland was not so much a matter of tremendous variation from basin to upland (which typified Middle Pennsylvanian time), as it was accelerated subsidence of the westerly tongue of the Oquirrh Basin.

In Medial to Late Wolfcampian time conditions of sedimentation changed significantly, in part due to widespread shallowing of the seas which may in turn have been brought about by less negativeness of Oquirrh Basin. Sediments of the Kirkman Formation accumulated in part in littoral and in part in epineritic areas, but nonetheless within the rapidly shrinking Oquirrh Basin counterpart. Shortly thereafter, eolian conditions persisted over at least part of the region formerly occupied by the eastern one-half of the Oquirrh Basin, and arenites of the Diamond Creek Sandstone and uppermost Weber Sandstone accumulated under conditions of aridity to semi-aridity.

STRUCTURAL IMPLICATIONS

Construction of the isopach maps (Figs. 3-6 inclusive) is predicated upon the idea that minor rather than major structural adjustments have occurred in central Utah subsequent to final phases of the Oquirrh Basin. I believe that Laramide deformation did not obliterate the data which justify this construction of isopach maps. These are not palinspastic maps. If it is considered as a working hypothesis that the Oquirrh Basin *per se* came into existence as a negative and mobile portion of the eastern part of the Cordilleran miogeosyncline and contiguous shelf during Early Pennsylvanian time, and was a long-lived negative area but was bordered by epeirogenically and orogenically active landmasses, the problem then is amenable to easier solution. Perhaps certain lineaments controlled or at least modified the outline and extent of the Oquirrh Basin; at least they have exerted significant influence on the northwesterly trend of the most negative part. Possibly a lineament controlled or substantially influenced the hinge-line area between the Weber Shelf and the Oquirrh Basin; if so, this would explain the approximate position of a later lineament, the Charleston thrust fault. Because today we find a thick pile of basin rocks juxtaposed against and over shelf strata, the temptation is strong to interpret it only as due to large-scale overthrusting in which the upper plate was translated scores of miles to the east during Laramide diastrophism. In fact, some would insist on a decollement type of mechanism to accomplish this eastward shove. The problem of space behind the upper plate presents an enigma that is more real than can be easily swept under a rug ofTertiary volcanics, lacustrine sediments, and Quaternary alluvium. It is true that certain overthrusts have been mapped, but I caution those who apply the "tar brush" in connecting all these faults throughout the eastern Great Basin region, attempting to make it one grand overthrust sheet, with total disregard for stratigraphic evidence. More convincing is the evidence for isolated upper plates and local diastrophism.

If we analyze the entire stratigraphic record of Paleozoic rocks in the area embraced by the central, south-central, and southern Wasatch Mountains and contiguous area of mountain ranges to the west which are in the eastern Great Basin, we discover no profound change in thickness and lithology (as well as fauna) from west to east except locally. If an unusually large upper plate traveled 50, 40, or even 30 miles toward the east from the basin to shelf, we should find drastically greater changes than are actually present. Along the Deer Creek-Charleston-Strawberry Valley thrust we do find tremendous differences where local juxtaposition of facies has occurred. This has been interpreted as horizontal translation of some scores of miles of the upper plate to accomplish this variance. If, however, we approach the problem after critically analyzing the relations of basin to shelf sedimentation (such as I have done for the Oquirrh Basin), perhaps necessity of decollement or even smaller-scale overthrusting is substantially modified. As an alternate explanation for this overriding of basin rocks upon shelf rocks, I suggest that during the pulses attending Laramide orogeny in Late Cretaceous time a geanticlinal welt (akin to or extension of the Sevier Arch) uplifted a part of the former geosynclinal pile, permitting eastward movement of sedimentary rocks toward the foreland. It may have been an ecoulement, lubricated and hydrostatically driven and then perpetuated as a gravitative slide. Movement along the Charleston-Strawberry Valley thrust may have amounted to no more than twelve miles, and no more than six miles in the Mount Nebo segment. Buttressing effect to the south may have limited this eastward movement to six miles or less, but the shelf area to the north permitted twice as much gravitative sliding. The block pivoted and rotated slightly, but evidently it did not move forward in bulldozer fashion. If this thesis merits consideration, it should also point up the concept that one should look for over-riding blocks (or gravitative slides) of significance east of the Sevier Arch and its northern counterpart. If such gravitative sliding occurred, the space problem is at least partially solved and the mechanism of ecoulement properly related to observed field data. These inferences harmonize with conclusions of Costain and Christiansen (1961, p. 115-116) for gravitative sliding in Gilson Mountain area from Sevier Arch.

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