BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

Volume 10 December 1963

CONTENTS

Brigham Young University Geology Studies

Volume 10 — December 1963

Contents

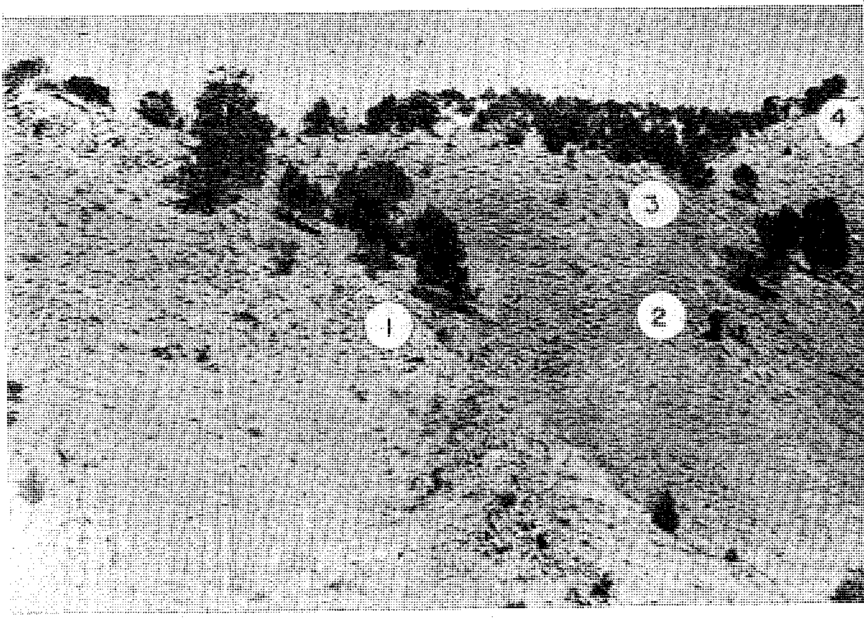
A publication of the
Department of Geology
Brigham Young University
Provo, Utah

Brigham Young University Geology Studies is published annually by the Department. *Geology Studies* consists of graduate students and staff research in the Department and occasional papers from other contributors, and is the successor to *BYU Research Studies, Geology Series,* published in separate numbers from 1954 to 1960.

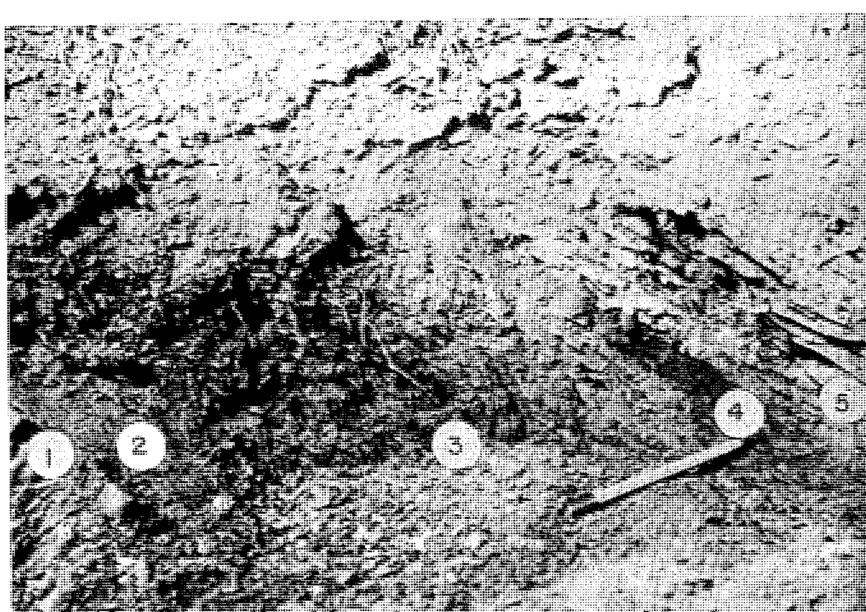
Distributed March 30, 1964

Price $4.00

PLATE 1 – DONALD PRINCE



1



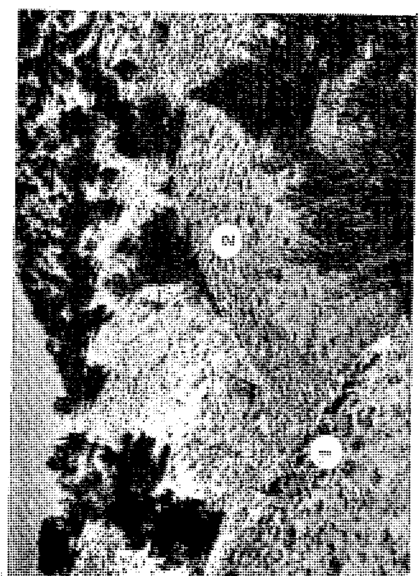
2

PLATE 2 — DONALD PRINCE

2

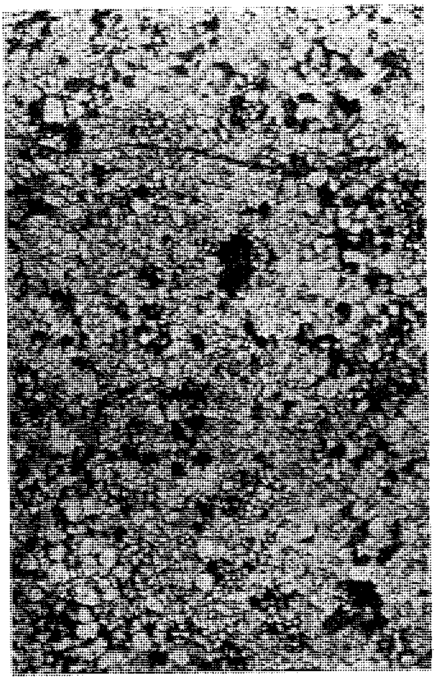
4

1

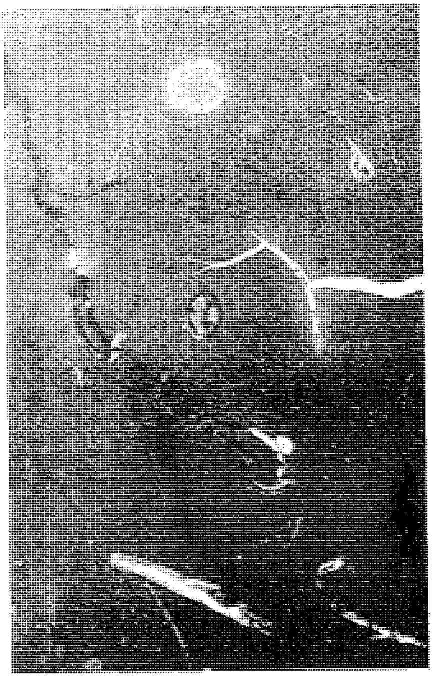


3

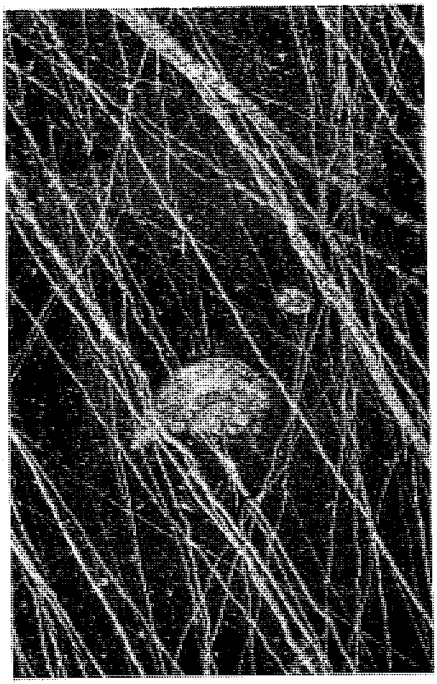
PLATE 3 – DONALD PRINCE



1



2



3

4

Explanation of Plate 1

MANNING CANYON SHALE OUTCROPS IN SOLDIER CANYON

FIG. 1. Spur where detailed section was measured, seen from the east: 1, "medial limestone"; 2, quartzite of lower cyclothem unit 66; 3, quartzite of upper cyclothem, unit 130; 4, limestone of upper partial cycle, unit 189.

FIG. 2. Trenched exposures of lower part of lower cyclothem: 1, quartzite; 2, sandy shale; 3, underclay; 4, coal; 5, roof shale.

Explanation of Plate 2

MANNING CANYON SHALE OUTCROPS IN SOLDIER CANYON

FIG. 1. Unchanneled basal contact of quartzite of upper cyclothem, unit 130, on measured spur. Hammer is fifteen inches long.

FIG. 2. Trenched exposures of lower part of the upper cyclothem, detailed section: 1, basal quartzite; 2, sandy shale; 3, underclay; 4, coal; 5, roof shale; 6, limestone. Hammer is fifteen inches long.

FIG. 3. Characteristic outcrops of cyclothems on the spur west of detailed section (locality 2, Text-fig. 1): 1, lower quartzite; 2, middle quartzite.

FIG. 4. Part of the Jenny section as exposed in a road cut above the prospect (locality 1, Text-fig. 1): 1, lower coal; 2, upper coal.

Explanation of Plate 3

PHOTOMICROGRAPHS.

All x 10, plain light

FIG. 1. Quartzite of lower cyclothem, unit 66.

FIG. 2. Nodular roof shale of lower cyclothem, unit 70, with ostracodes and pelecypods.

FIG. 3. Limestone of upper cyclothem, unit 137, gastropods and ostracodes.

FIG. 4. Marine limestone of limestone-shale sequence, top of "medial limestone", unit 22, pelecypods and crinoids.

Mississippian coal cyclothems in the Manning Canyon Shale of central Utah*

DONALD PRINCE

Phillips Petroleum Company, Bartlesville, Oklahoma

ABSTRACT.—Late Mississippian coal cyclothems occur within the Manning Canyon Shale in Soldier Canyon, five miles southeast of Stockton, Tooele County, Utah. The cyclothems are Chesteran and Springeran age and exhibit typical lithology—quartzites, underclays, coal, roof shales, and limestones.

A stratigraphic section of the middle third of the formation was measured in detail by shallow trenching, and totaled 285 feet. Within this interval exist a lower marine limestone-shale sequence, a lower coal cyclothem, an upper coal cyclothem and an upper partial cycle. The cyclothems are highly asymmetrical with marine strata dominating. Seas, during deposition of the cyclothems, were generally transgressive with alternating short regressive stages. The two cyclothems exhibit characters which compare favorably with mid-continent cyclothems and probably reflect similar environments.

The lower cyclothem is 63 feet thick, 60 feet of which is marine, and is a simplified sequence consisting of a resistant basal quartzite, thin sandy shale and underclay, coal and roof shale. The coal is lenticular, highly weathered lignite, varying from one to two inches thick.

The upper cyclothem is more complete but thinner, 26 feet thick, of which 15 feet is marine; it contains seven of the possible ten members found in the standard idealized mid-continent cyclothem. The same five units of the lower cyclothem are present with an overlying black, fossiliferous limestone and upper shale sequence. The coal is lenticular, brown, banded lignite, varying up to five inches. Gypsum is associated with the coal and the overlying 13 inches of roof shale.

The upper partial cycle consists of a four-foot resistant quartzite and overlying black shales. A thin sandy shale is present immediately above the quartzite, but clay and coal are not present. Abrupt subsidence probably eliminated the environments necessary for the development of underclay and coal.

Cyclothems reflect instability with prolonged marine transgressive and alternating brief regressive nonmarine cycles.

CONTENTS

TEXT

ILLUSTRATIONS

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

CONTENTS (CONT.)

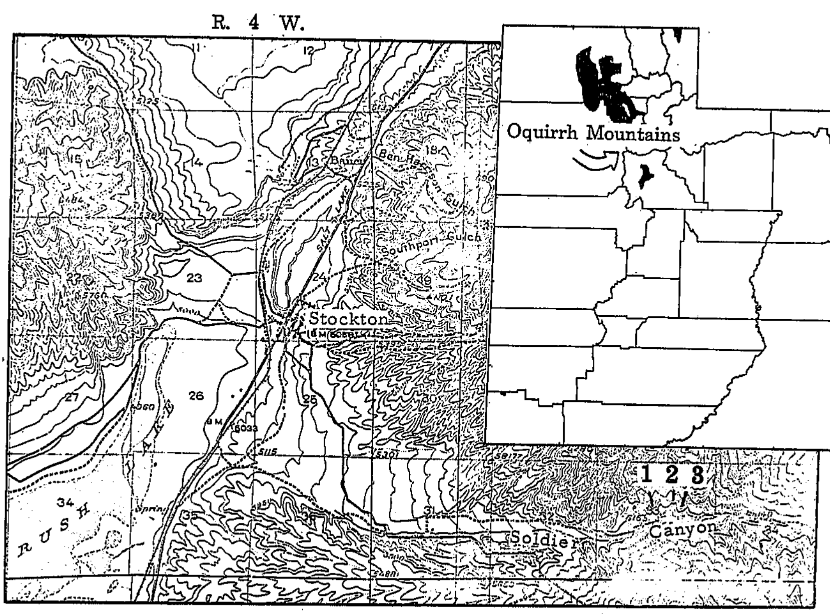
INTRODUCTION

The Manning Canyon Shale in Soldier Canyon contains a wide variety of sediments, part of which are deposited in typical mid-continent-type coal cyclothems. Cyclothem, as used here, denotes cyclical sedimentation typical of coal measures containing sandstone or quartzite, underclay, coal, roof shale, and limestone. No previous coal cyclothems have been reported in central Utah. Two coal beds are present and with their associated sediments compose two cyclothems. A partial third cycle is also present in Soldier Canyon. The presence of these cycles and their similarities with mid-continent types suggests certain paleoenvironments.

The purpose is to describe the cyclothems in detail, discussing their physical character, thickness, fossils, and to reconstruct the sedimentary environments. Since the formation is well exposed at only one location, long distance correlation is difficult if not impossible. The study, therefore, was mainly limited to one detailed section with generalized correlations in adjacent areas.

Location and Setting

Soldier Canyon is in the west central Oquirrh Mountains of central Utah, approximately five miles southeast of Stockton, Tooele County, Utah (Text-fig. 1) and is readily accessible by graded road. Soldier Canyon has been cut perpendicular to the axis of the north plunging nose of the Ophir anticline; Soldier Creek



TEXT-FIGURE 1.—Index and locality map: 1, Jenny section; 2, middle spur; 3, detailed measured section.

drains westward into Rush Valley. The canyon is underlain by Manning Canyon Shale except near the mouth where the formation is exposed on the north wall. The measured section is on the north side of the canyon, three spurs east of the Jenny (Marjorie) prospect and mine dump, one-half mile above the canyon mouth, in the SE¼, NE¼, Sec. 33, T. 4S., R.4W., Salt Lake Base and Meridian (Text-fig. 1). An additional partial section was measured due north of the Jenny mine dump in a road cut. (Pl. 1, fig.1; Pl. 2, fig. 4).

Previous Work

The Manning Canyon Shale crops out widely throughout central Utah. Gilluly (1932, p.31) named the formation from exposures in Manning Canyon, southeast of Soldier Canyon. He stated, "The section measured in Soldier Canyon is believed to represent the formation better than any of the others".

Sadlick (1955) measured a section in Soldier Canyon and stated that the Mississippian-Pennsylvanian boundary could not be precisely located.

Moyle (1958) measured a complete section, 1559 feet, in Soldier Canyon, in addition to studying nine other Manning Canyon sections in central Utah. His work is the most extensive and complete to date. The present study is on the same Soldier Canyon section, investigating in greater detail 285 feet of the middle part of the formation.

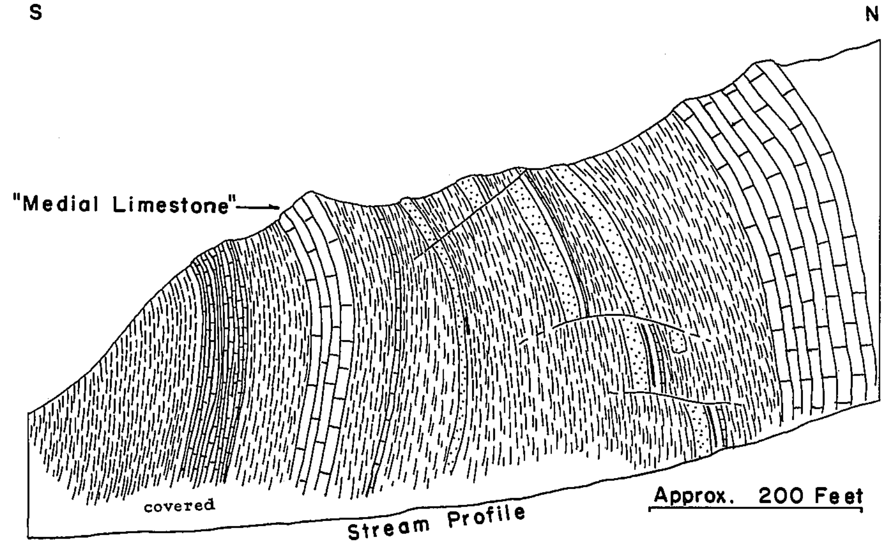
Others who have studied or measured the formation elsewhere include: Nolan (1935) in the Gold Hill district, Utah; Bissell and Hansen (1935) discussed the Mississippian-Pennsylvanian boundary within the formation, and Robertson (1940) discussed the selenium content of the shales. Baker (1947) measured the unit in the Provo Canyon region, and Bullock (1951) in the Pelican Hills and Lake Mountain. Hebertson (1950) was concerned with the origin and composition of the formation, and Calderwood (1951) measured a section in the Cedar Valley Hills. McFarland (1955) measured a complete section in West Canyon of the Oquirrh Mountains, and Croft (1956) studied the formation in the Onaqui Mountains. Pitcher (1959) reported an incomplete section in the Traverse Mountains, and Young (1955) mapped an incomplete section in the Lakeside Mountains. Ornelas (1953) and Hyatt (1956) studied the clays of the formation. Rigby (personal communication) and students discovered one coal bed in Soldier Canyon in 1960, and Tidwell (1962) discussed the flora of the Lake Mountain area.

Field Work

Field work commenced in October 1962 and continued through the Spring of 1963 and consisted of measuring and sampling, in detail, a stratigraphic section with a six-foot steel tape and Brunton compass. Shallow trenching was necessary through approximately two-thirds of the section to insure accurate samples and measurements. Much of the shale shown in text-figure 2 required trenching.

Laboratory Work

Thin sections of quartzites, limestones, nodular siltstones, and shales were prepared and examined. Shales required the use of epoxy resin as a bonding cement. Differential thermal analyses were made on underclays, coals, and shales for determination of mineral content and correlation. Insoluble residues were prepared with HCl, washed, dried and weighed to determine insoluble fractions. and then studied. Fossils were prepared and identified using standard techniques.



TEXT-FIGURE 2.—Cross-section of measured spur.

Acknowledgments

The writer expresses sincere thanks to Dr. J. Keith Rigby, committee chairman, for his direction, assistance with illustrations, and review of the manuscript. Thanks are also extended Dr. Harold J. Bissell, who served as a thesis committee member, and Olivia Villalobos, who typed the manuscript.

STRATIGRAPHY

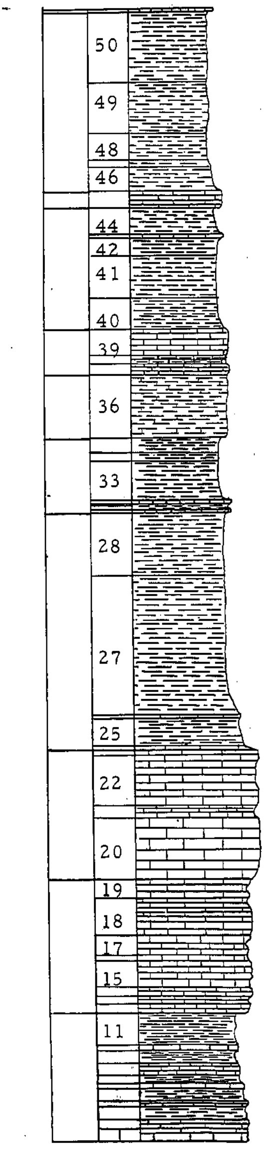
The Manning Canyon Shale is considered latest Mississippian, Chesteran and Springeran. The boundary between the series in Soldier Canyon is not sharp, but is often placed at the top of a persistent marine limestone known as the "medial limestone." The top of this limestone is 484 feet above the base of the formation as measured by Moyle (1958), and it marks the final open normal marine environment of deposition in the formation. The cyclothems studied are stratigraphically above the "medial limestone" unit.

In Soldier Canyon the total Manning Canyon Shale measures 1559 feet (Moyle, 1958, p.8); part of the middle third of the formation is the object of this study.

A detailed section totaling 285 feet was measured beginning below the base of the "medial limestone" and extending up section to a prominent, dense, unfossiliferous limestone, on the north slopes of Soldier Canyon, (Text-fig. 3). The section consists of four main gross subdivisions, and 189 units. The four subdivisions include a lower marine limestone-shale sequence-100 feet thick, a lower coal cyclothem-63 feet thick, an upper coal cyclothem-26 feet thick, and an upper partial cycle-96 feet thick. (Appendix A, measured section).

Lower marine limestone-shale sequence.—The measured section begins ten feet below the "medial limestone" ledge in a series of alternating shale and lime-

TEXT-FIGURE 3.—Measured stratigraphic section of the middle third of the Manning Canyon Shale, Soldier Canyon, Utah. Vertical scale: one inch equals fifteen feet.



Ls, red-purple, skeletal, hash, one inch bed.

Sh, light gray to green, orange mottling, calcareous, clayey, thin laminae to 1/2" platy beds, weak, few low outcrops, nodular undulating bedding at top, unfossiliferous.

Ls, orange-brown, laminated, shaly.

Sh, medium gray to dark green, non-calcareous at base, becomes lighter gray, calcareous, clayey, and waxy toward top; Limestone in center, brown, shaly with shell fragments.

Ls, brown, thin bedded, fossils at base and top *Composita*, *Spirifer*, bryozoans, and crinoids.

Siltst, brown, calcareous, with some shaly limestone, orange and black laminated, *Spirifer* at top.

Sh, with thin limestone at base; sh, medium gray to black, laminae, non-calcareous, unfossiliferous; limestone is thin, brown, shaly, crystalline.

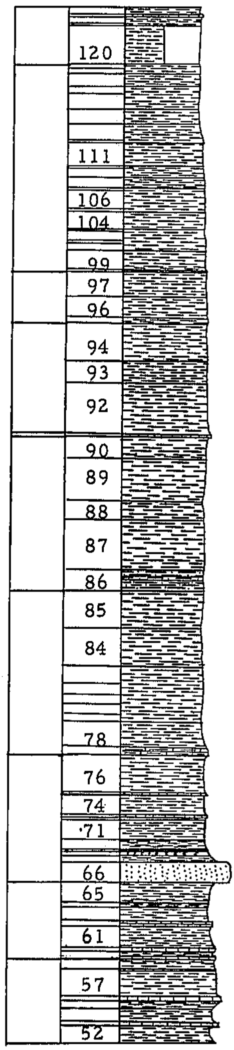
Sh, dark gray to black, paper thin to laminated, 2" calcite bed two feet above base overlain by 12 feet of black non-calcareous shale with spheroidal nodular concretions, somewhat silty, weak slope former, interval unfossiliferous.

Ls, "medial limestone", medium gray, medium to thick bedded, massive ledge, calcite veinlets, contains brachiopods, crinoids, encrusting and fenestellid bryozoans, solitary corals 3' below top, which is capped by brown 3" limestone.

Ls, "medial limestone", medium gray, thin to medium bedded ledge, irregular bedding with shale partings, radiating calcite crystals unit 18, contains brachiopods, pelecypods, crinoids, and solitary corals at top.

Ls, and sh, alternating thin bedded limestone and weak thin laminated shale; ls, light to medium gray, abundantly fossiliferous: brachiopods, *Spirifer*, *Composita*, *Marginifera*, pelecypods, *Pinna*, bryozoans, *Polypora*, *Fenestrellina*, *Archimedes*, crinoids, occasional trilobites and solitary corals.

(TEXT-FIG. 3, CONT.)



Sh, brown, fissle to earthy and gypsiferous, poorly exposed, becomes silty and calcareous toward top.

Sh, and siltstone; Shale varies from dark gray to light gray and from slightly calcareous at the base to non-calcareous toward the top. Pelecypods, Yoldia? are present near base on weathered surfaces. Silt increases toward the top. The siltstones are rather barren of fossils. A thin, brown, shaly limestone is at the base, with pelecypod fragments.

Sh, medium gray to green, non-calcareous, nodular, becomes silty, Yoldia on weathered surfaces, very irregular bedding.

Sh, dark gray to green, slightly calcareous, thin and platy, nodular irregular bedding, possible pelecypod impressions, Yoldia?

Ls, brown, fine grained, abundant pelecypods.

Sh, medium gray to green, non-calcareous, very fissle at base becoming thin platy toward top; Siltstone at base, orange and black mottled, slightly calcareous, nodules are not calcareous, no definite fossils in this interval.

Sh, with ls; Shale is green to black, non-calcareous, very fissle to platy, contains occasional nodules, Yoldia? impressions, limonite replaced, near top. Ls, at base, shaly to silty, brown, with calcite veinlets.

Sh, black, waxy, with nods, plants, pelecypods; and ls, sandy to silty, nautiloid, pelecypods.

Sh, roof, gray, nodular, plants, Yoldia, limonite.

Coal, lignite; and unbedded underclay, brown.

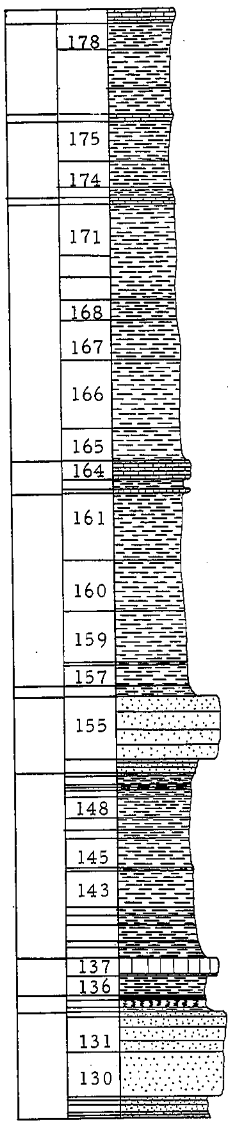
Qtzt, brown, hard, fine grained, crossbedded.

Sh, and interbedded ls, shale is dark green to black, noncalcareous thin and fissle with nodules.

Ls, medium brown, irregular, possible fossils.

Sh and ls, light gray to red, weak slope, thin platy limestones to fissle paper shales, shales, clayey to earthy; zone unfossiliferous.

(TEXT-FIG. 3, CONT.)



Ls, gray, dense, thin bedded, calcite veinlets.

Sh, red-brown, calcareous, clayey, mostly covered; weak slope forming zone, no fossils.

Ls, light brown, silty, thin bedded.

Sh, red-brown, calcareous, earthy at top and base; middle 2' black, irregular, non-calcareous.

Ls, gray, very fine grained, thin bedded.

Sh, red-brown to green, mostly calcareous, somewhat earthy and waxy, paper thin to 1/2 inch beds, weak slope zone, poor exposures, no fossils in this shale interval.

Ls, light brown, fine grained, calcite stringers, thin bedded, unfossiliferous.

Sh, gray to brown at top, basal 5 feet dark gray to black, waxy, fissle, contains nodular concretions; some limonite concretions at base; interval is non-calcareous.

Sh, sandy to silty, brown, thin, platy.

Qtzt, buff, brown and orange mottled weathering, hard, dense, fine grained, well sorted, medium bedded, silica cemented, forms resistant ledge. Few thin beds at base.

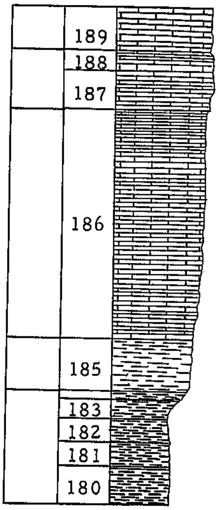
Sh, black to medium gray, mostly non-calcareous, fissle to thin laminae, contains spheroidal nodules throughout, non fossiliferous. Few thin silty and limy beds.

Ls, black, dense, ostracods, gastropods; underlying roof shales, brown and gypsiferous.

Coal, brown, lignite, banded, with black underclay.

Qtzt, buff, hard, fine grained, well sorted, thin bedded at base becomes thick at top, ledge, crossbedded, contains orange limonite mottling, silica cemented.

TEXT-FIGURE 3 (CONT.)



Ls, medium gray, dense to lithographic, laminate to thin bedded, very undulatory.

Ls, medium gray, thin bedded but weathers in massive ledge, dense, undulatory.

Ls, medium gray to tan, weathers light gray to tan, fine grained, thin bedded, beds vary from 1/2" to 4", very platy low outcrops, no fossils.

Sh, tan, calcareous, earthy and clayey, thin laminae; some beds are light green and weather tan.

Sh, red-brown, calcareous, earthy, varies from soft to hard laminae; 3' above base shale is black non-calcareous, 2' chippy unit, no fossils; weak slope zone.

stone. The sequence below the measured interval is mostly platy limestone and shale, thus the measured section begins in marine sediments. The basal ten feet of the section is abundantly fossiliferous containing brachiopods: *Spirifer, Composita, Marginifera;* pelecypods: *Pinna;* crinoids; bryozoans: *Fenestrellina, Polypora, Archimedes;* and occasional trilobites and solitary corals.

The "medial limestone" is a massive, medium to thick bedded, 20-foot resistant ledge, and is a key marker unit for lateral correlations. The lower ten feet is very irregularly bedded, medium gray to blue-gray, light gray weathering limestone with some interbedded shaly partings. Twelve feet above the base of the ledge in unit 18, unusual authigenic calcite crystals occur in a dark gray limestone. These crystals are randomly oriented and radiating; they weather-out in petal-like shapes. The upper ten feet of the "medial limestone" is more massive and thicker bedded.

Fossils occur throughout the limestone but are not as abundant as in the beds below. Brachiopods, pelecypods, crinoids, bryozoans, and solitary corals are represented (Pl. 3, fig. 4). Solitary corals appear in a band three feet below the top, which is capped by a three-inch brown limestone.

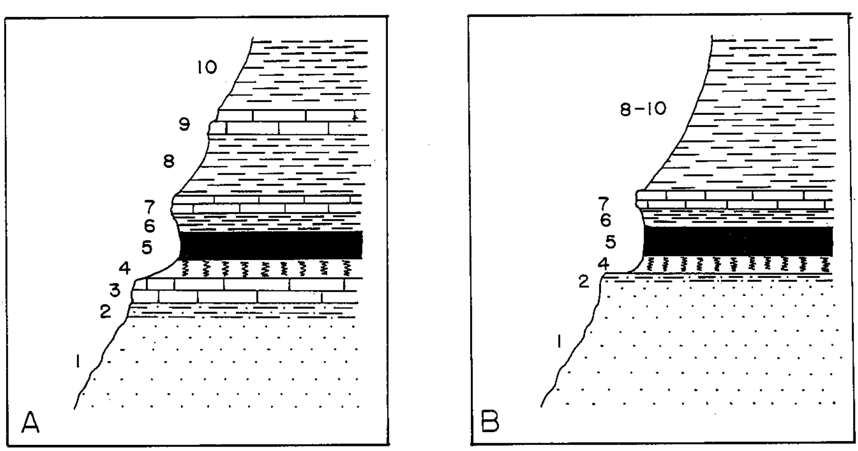
Overlying the "medial limestone" is a slope-forming shale series approximately 68 feet thick. The immediately overlying 14 feet is black fissile shale, which is non-calcareous, unfossiliferous, and highly carbonaceous. Nodular siltstone concretions occur throughout this and most other shale units and are typically very lenticular, dense, black, non-calcareous, and generally unfossiliferous. These nodules are similar to the ironstone concretions of the mid-continent shales. The black shale grades upward into gray, calcareous shale with a few interbedded thin limestones.

Three interbedded limestone units in this shale sequence deserve mention because of their fossil content. Unit 37, 60.5 feet above the base of the section, is a nine-inch, finely crystalline, brown limestone containing abundant *Spirifer* and *Composita,* and broken pelecypod fragments. Unit 39, located eight inches above unit 37, is a two foot, thin bedded limestone with brachiopods, bryozoans, and crinoid debris. Unit 51, 89.3 feet in the measured section, is a one-inch skeletal limestone consisting of brachiopod and pelecypod hash. It is a reddish-purple bed as is the overlying 15 inches of calcareous shale. These three units are the only fossiliferous units in the shale sequence.

Lower coal cyclothem.—The lower cyclothem is 63 feet thick and is partially developed, containing only five members. The standard fully developed cyclothem of the mid-continent contains ten members (Text-fig. 4). Very few cyclothems, however, are fully developed and Weller (1957, p. 330) lists the five members generally present in a simplified sequence as follows: basal sandstone, underclay, coal, limestone, and shale. The lower five standard members are non-marine deposits, while the upper five are considered to be marine; thus the cyclothem is divided into two hemicyclothems. In the Illinois region the two hemicyclothems are about equal whereas to the east in the Appalachian area non-marine strata dominate. In Soldier Canyon the marine sequence predominates in both cyclothems.

The lower cyclothem consists of a basal quartzite, 18 inches thick, a thin two-inch sandy shale, an eight-inch underclay, a one to two-inch weathered coal seam, and two feet of roof shale which grades upward through a few limestone beds into a thick overlying shale sequence.

The basal quartzite is a fine grained, well sorted, light gray to buff, brown-weathering resistant ledge former which is somewhat crossbedded near the base. This unit is a protoquartzite, containing 85 percent sub-angular to sub-rounded quartz grains, ten percent dark minerals mostly limonite, two percent ferromagnesium minerals, and one percent zircon and other heavy minerals (Pl. 3, fig. 1). Feldspar is noticeably absent. Cementing material is principally silica. This quartzite varies in thickness, locally up to four feet thick in outcrops to the west (Pl. 2, fig. 3). Down slope to the east calcirudite, flat-pebble beds are present beneath the quartzite in a thin lens.



TEXT-FIGURE 4.—A. Standard idealized mid-continent cyclothem (after Weller, 1957, p.330). B. Generalized Soldier Canyon upper cyclothem. Basal sandstone 1, sandy shale 2, lower limestone 3, underclay 4, coal 5, roof shale 6, middle limestone 7, middle shale 8, upper limestone 9, upper shale 10. Units 1-5 are considered nonmarine and units 6-10 are marine.

Sandy shale overlying the quartzite is a weak unit which probably is not extensive. It grades upward into a black clay shale which in turn grades into gray to brown earthy underclay. The underclay is about six inches thick, impure, sticky, unbedded, and contains a few poorly preserved root markings.

Coal of the lower cyclothem is a one to two-inch lenticular lignite or sublignite. The seam is highly weathered thus obscuring any structures. The coal appears to thicken to about six inches at the Jenny section one-quarter mile to the west. These four members, the quartzite, sandy shale, underclay and coal are all part of the fresh-water phase. The remaining fifth and possible sixth member would represent the marine cycle.

·Overlying roof shale is a black, thinly laminated to fissile, nodular shale. Nodules are somewhat silty and contain pelecypod and ostracod fragments along with macerated plant remains (Pl. 3, fig. 2). Fossils are replaced by limonite and are poorly preserved. The roof shale is 28 inches thick and is overlain by a thin silty and sandy limestone; unit 75. The sandy limestone contains nautiloids, indicating a marine to brackish- marine environment.

Roof shale grades gradually into an upper shale sequence which is 60 feet thick. A two-inch limestone, unit 91, occurs 35.3 feet above the base of the quartzite, and contains broken brachiopods and pelecypods. Unit 95, 42.2 feet above the base of the cyclothem, is a four inch siltstone bed containing *Yoldia?* fragments on weathered surfaces. The fossils appear to be concentrated on the upper and lower bedding planes.

Upper coal cyclothem.—The upper cyclothem is moderately developed containing seven members. This cyclothem is only 26 feet thick, 15 feet of which is marine. The lower four members are fresh-water deposits, consisting of eight and one-half feet of basal quartzite, two inches of sandy to silty shale, six inches of black shaly underclay, and four to five inches of banded coal (Pl. 2, fig. 2).

The quartzite, the first non-marine deposit, is very similar to unit 66, the basal quartzite of the lower cyclothem. It is a little less clean, with increased orange limonite mottling, and is very hard, forming a resistant medium-bedded ledge (Pl. 2, fig.1). The top six inches is a friable sandstone probably a result of recent weathering of the quartzite.

Friable sandstone grades upward into a dark gray sandy shale which is gradational with the overlying black waxy underclay. The underclay is bedded as shale in part, and is very high in carbonaceous as well as clay content. No fossils or root fragments were observed in this underclay.

Coal occurs as a four-inch banded lignite to sub-bituminous bed. This coal pinches out in the faulted upper cyclothem on the crest of the measured spur. It reappears in the Jenny section as a lenticular seam. Underclay and the overlying roof shale and middle limestone bed are persistent where the coal is missing. Gypsum is associated with the coal and roof shale.

The roof shale is interbedded brown, earthy, and gypsiferous shale and thin shaly limestones totaling 13 inches. Roof shale thickness is variable, where the coal is missing roof shales are very thin.

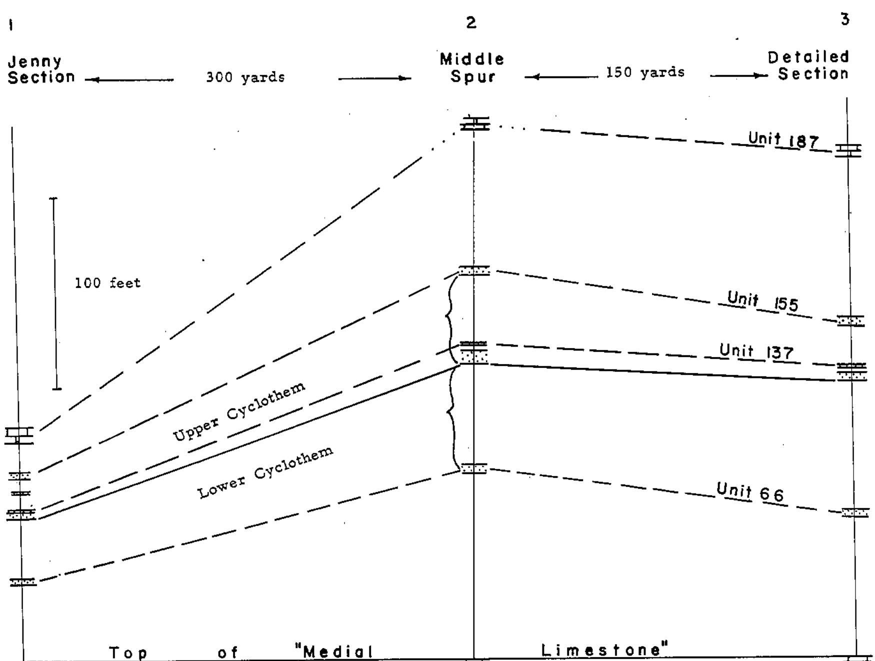
Immediately overlying the roof shale is a twelve-inch limestone bed known as the middle limestone, member seven of Weller (1957). It is black, dense, and is cut by minute vertical calcite and graphitic veinlets. It is a relatively pure limestone (11.3 percent insoluble, Appendix B) but the residue is highly carbonaceous. The unit contains a small fauna of pelecypods, ostracods, and low spired gastropods. Steinkerns of ostracods and gastropods were found in residues as microfossils (Pl. 3, fig. 3). This limestone is a key marker unit in the upper cyclothem and is traceable to the west (Text-fig. 5). It is readily recognized by its consistent thickness, stratigraphic position, and weathering habit.

The remaining member of the upper coal cyclothem is an upper shale sequence. This unit is black, nodular, non-calcareous, and unfossiliferous. It is about 15 feet thick and occupies a gully between the upper two quartzites.

Upper partial cycle.—The final subdivision of the measured section is 96 feet thick and immediately overlies the upper coal cyclothem. A basal quartztie again forms a prominent resistant unit and is similar to the two lower quartzites in composition. It is thick bedded and totals four feet, and is best exposed on the ridge crest.

Ten inches of brown silty to sandy shale overlies the quartzite and may correspond to the sandy shale member of the standard cyclothem. Above this unit is six feet of black, waxy, plastic, shale, high in carbonaceous content, which grades vertically into a brown to gray, silty to calcareous shale. Sixty seven feet of shale is present in this partial cycle. A few thin silty limestones are present but do not contain fossils.

The final 25 feet of the measured section is composed of thin bedded blue-gray limestone which is dense, almost lithographic. Bedding is thicker in the upper seven feet but is undulatory throughout, especially at the top. Lack of fossils and the dense fabric point to a hypersaline bank, as a possible environment of deposition. It is evident that conditions were not present for development of coal or underclays in this cycle. Perhaps subsidence occurred rapidly eliminating possible swamp development.



TEXT-FIGURE 5.—Correlation diagram, Soldier Canyon, Utah.

CONCLUSIONS

Environment of Sedimentation

Basal quartzite.—Three quartzites are present in the Soldier Canyon section and each occupies the basal position of a sedimentary cycle (Text-fig. 5). These beds compare with the basal sandstones, unit one of the standard mid-continent cyclothem which are typically channel, bar, or alluvial deposits (Text-fig. 4).

Soldier Canyon quartzites indicate uplift in the adjacent source regions and slight to moderate regression of the sea; clastic sedimentation exceeded rate of subsidence. They are probably locally extensive deltaic deposits since they show little variation in thickness laterally and are not channeled; no obvious unconformities exist at the base of the quartzites (Pl. 2, fig. 1).

Maturity is indicated by lack of feldspar, though this may be a result of low-feldspar source rock, rounding of the quartz grains, good sorting, and lack of rock fragments. The three quartzites are lithologically very similar and indicate similar conditions of source, transporation, and deposition. All are tightly cemented by silica, indicating an abundance of soluble silica in the streams. Cross-bedding is apparent near the base of the quartzites, reflecting deltaic distributary deposition.

Transgression of the sea, peneplanation of the source area, diminution of stream competency, or sedimentary diversion due to barriers may account for the cessation of clastic sand deposition.

Fossils were not found in the quartzites, although wood fragments and logs have been reported to the south and east in central Utah (Rigby, personal communication).

At the close of sand deposition the region was near base level, topography being uniformly reduced—ideal conditions for development of soils, clays and swamp deposits.

Sandy shale.—Unit two of the standard cyclothem is poorly developed in Soldier Canyon. Thin sandy to silty shales occur above each of the three quartzites and range from two to six inches thick. These units represent the waning phase of coarse clastic deposition, very fine sands grading vertically into fine clastics, silt and clay.

Lower (fresh-water) limestone.—This member is absent in the Soldier Canyon section. Sufficient water depth and calcium carbonate were not present for the development of this unit, number three in the standard sequence.

Underclay.—Underclay, unit four, is one of the most characteristic beds of the mid-continent cyclothems. Soldier Canyon underclays are present above the lower two quartzites but undeveloped above the third or highest quartzite of the measured section.

Underclays exposed in the section are thin, irregular to unbedded, and range from black clayey shales to gray or brown, earthy, sticky clay. Occasional root markings occur, though poorly preserved.

Nearly stable subaerial conditions initiated the development of soil surfaces without accompanying marsh conditions. The area supported vegetation but was adequately drained, and clay soils were produced.

Underclays are generally associated with overlying coal seams, but such clays are present in the measured section without overlying coal beds as in the upper cyclothem. The upper coal pinches out on the ridge but is present to the east above a black underclay. Underclay and associated overlying beds are persistent laterally where coal is missing. These clays probably developed on partially drained surfaces covered with vegetation. Lack of standing water allowed complete plant decay. Underclays, however, are only a step away from swamp development.

Underclay of the lower cyclothem is gray to brown, earthy to very plastic, sticky, clay. The upper cyclothem underclay is rich in organic matter, black, irregular, clayey, waxy shale. The climate was probably warm and moist during underclay development, producing abundant vegetal cover. A few plant fragments are present.

Differential thermal analysis failed to indicate any particular clay mineral. Impurities masked any definitive reaction curves in the specimens analyzed.

Coal.—Coal is member five of the fresh-water hemicyclothem. All of the above discussed members are in the fresh-water phase of a cyclothem.

Soldier Canyon coals are thin, brown to black, banded, lignite to sub-bituminous deposits. They are lenticular, but are locally extensive over one-quarter mile of outcrop.

Coal of the lower cyclothem is one to two inches thick and is highly weathered (Pl. 1, fig. 2). Two spurs to the west this coal may be as much as six inches thick. This seam is sub-lignitic to lignitic.

The upper coal is four to five inches thick, brownish black, banded lignite to sub-bituminous (Pl. 2, fig. 2).

Development of peat in swamps, and subsequent burial and metamorphism to coal require several special conditions. Marsh development indicates reduced topography, such as in the Dismal Swamp of Virginia and North Carolina, and steady slow influx of fresh water. Typical luxuriant Mississippian-Pennsylvanian floras developed, grew, and died in the quiet waters of the coastal swamps. Dead and partially decayed vegetable matter acted a giant sponge to retain and soak up moisture. Biochemical processes of putrefaction and autolysis proceeded in the anaerobic swamp bottoms, thus total plant decay was prevented and peat accumulated.

Rate of peat accumulation depends on climate and vegetation. White (1913, p. 62) states that it generally requires 10 to 20 feet of peat to produce one foot of bituminous coal and roughly in time units, 100 years. Soldier Canyon coals would require approximately five to ten feet of accumulated peat. Vegetation and water-cover depth must necessarily keep pace with each other over a period of time to produce even five feet of peat.

Climate was fairly uniform, generally warm, moist and wet. Seasonal variations were apparently negligible, and rainfall was moderate to heavy but uniform year-round. Flooding would silt-up and choke the swamps in addition to diluting the swamp waters thus aerating, oxygenating, and accelerating plant decay. Topography was likewise uniform and low as evidenced by the lack of clastic deposition. Stable, near shore, uniform environments existed during development of coal swamps.

Lower shale (roof shales.)—Unit six of the standard mid-continent cyclothem is known as the lower or roof shale. It is generally erratic in development and is not present in all cyclothems. Some coals are found directly overlain by limestones (Weller, 1957, p. 330).

Roof shales are developed in the Manning Canyon Shale cyclothems above the two coals of the cyclothems and possibly above the sandy shale unit of the partial cycle at the top of the measured section. They are variable units ranging from black nodular shale to earthy brown gypsiferous zones. They reflect various brackish to marine environments, from the deepened, partially reducing, high organic environment in the lower cyclothem to the shallow, aerated, restricted, oxidizing, environment of the upper cyclothem.

Pelecypods, ostracods, and plant fragments are found in the roof shales. Capping 28 inches of roof shale in the lower cyclothem is a thin limestone containing nautiloids, suggesting nearly normal marine conditions.

Roof shale of the upper cyclothem is 13 inches thick and consists of gypsiferous and calcareous brown earthy shale, and brown shaly limestone. Environment of this unit was probably quite shallow marine to brackish, circulation being restricted at times. This may account for the presence of gypsum in these roof shales. The gypsum may in part be due to a post diagenetic introduction due to solution and weathering.

The upper partial cycle may or may not contain roof shale, if so, it would be represented by a black, plastic, hard shale.

General transgression of the sea with attendant basin subsidence accounts for the lower shale deposits and initiates the marine hemicyclothem, which in both cyclothems is thicker than the fresh-water hemicyclothem.

Middle limestone.—Unit seven of the standard cyclothem section is represented by a single 12 inch bed in Soldier Canyon which occurs above the roof shales of the upper cyclothem. It is a dense, black, carbonaceous nearly pure limestone. Fauna of this limestone consists of small pelecypods, ostracods, and low spired gastropods, observed only in thin sections and residues as microfauna (Pl. 3, fig. 3).

This unit represents a deepening of the basin and a return to more nearly normal marine salinities. Aquatic vegetation may account for the high carbonaceous content and black color of the limestone (Weller, 1957, p. 350). Its absence in the lower cyclothem denotes that the basin was not subsiding fast enough to allow deposition of near normal marine limestone.

Middle shale.—Standard cyclothem unit number eight is the middle shale of the upper or marine hemicyclothem. It is a lower black fissile to chippy shale, and an overlying gray calcareous shale. Delineating this member in the Soldier Canyon section is difficult since gradational effects obscure contacts. Black shales are not well developed in the lower cyclothem. In the upper cyclothem, the middle shale overlying the ostracod-limestone is a black non-calcareous somewhat nodular shale. It is gradational with the upper shale, unit ten, the last member of the marine hemicyclothem.

The middle shale may be present above the sandy shale of the upper partical cycle. If so, it is gradational with a roof shale, where six feet of black shale grade upward into gray to brown calcareous shales.

This member was probably deposited as organic-rich colloidal slimes with subsequent extensive compaction and dehydration. Fossils are rare and as Weller (1957, p. 351) points out, this may be due to prolific growth of seaweed which limited current circulation thus removing oxygen and creating an unfavorable benthonic condition. The seaweed may also account for the high organic content of the shales.

Upper limestone.—Standard unit nine represents culmination of marine to open marine conditions. In the two coal cyclothems this unit is missing or represented by very thin units. Normal marine conditions were not established. The limestone at the top of the measured section may correlate with this standard unit but it is unfossiliferous; the limestone is closer to a precipitated hypersaline deposit.

The "medial limestone" unit at the base of the measured section closely fits the upper limestone category. If it is the upper limestone of a marine hemicyclothem this would make it part of a lower incomplete cycle. Abundant marine fossils occur in the unit and especially in the platy underlying ten feet. The ledge of the "medial limestone" is not as fossiliferous as the thin beds below, but contains brachiopods, pelecypods, crinoids, and near the top a band of solitary corals. The corals probably required relatively warm, clear, silt-free, shallow waters.

Upper shale.—The tenth unit of the standard cyclothem is generally thick, uniform and unfossiliferous.

Change from limestone deposition to fine clastics was fairly sudden in the measured section. The sea retreated and fine clastics, mostly silt, were brought into the basin. Mild uplift had probably begun in the source regions. Fine clastics grade upward into the coarser clastics of the basal quartzite member of the overlying cycle. This unit represents a transition between marine and nonmarine phases.

Influx of turbid silty waters established relatively unfavorable conditions for animal life. Variations of influx might explain the occasional thin pelecypod-bearing siltstones.

Above the "medial limestone" the upper shale is present and totals 60 feet. It contains a few fossiliferous limestone beds indicating momentary return of life to the region. Shales range from black chippy shale to gray and brown calcareous units. Silt, however, increases toward the top indicating the advent of sand deposition, and continued regression of the sea.

In the lower cyclothem the upper 50 feet of shale and siltstone may represent this upper shale member. Concretions are particularly abundant in this interval, and a few beds contain pelecypods on weathered surfaces. The upper cyclothem does not show this unit as well but it is probably present in the uppermost five feet of the cyclothem. In the overlying partial cycle this unit is missing.

APPENDIX A

A section of part of the Manning Canyon Shale exposed on the north wall of Soldier Canyon, one-half mile above the mouth, on the third spur east of the Jenny prospect tunnel. The section is located in the SW¼, NE¼, Sec. 33, T. 4 S., R. 4 W., Tooele County, Utah, five miles southeast of Stockton, Utah.

Only the cyclothem stratigraphy is presented, beginning at the base of the lower cyclothem, unit 66, and extending to the top of unit 159 of the upper partical cycle. The complete section is on file in the Geology Department of Brigham Young University.

Mississippian

Manning Canyon Shale

Unit No.	Description	Thickness in inches	Total feet above base
159	Shale: black, weathers same, waxy, non- calcareous, very thin to paper thin, "ironstone" concretion at 29", orange limonite and calcite in concretion	48	200.8
158	Shale: black, weathers gray, grades into one-half inch vienlet of calcite, possible plant fragments in shale	1	196.8
157	Shale: black, weathers same, waxy, paper thin partings,		

APPENDIX A (CONT.)

	non-calcareous, very fine grained, with brown limonitic nodules at base	18	196.7
156	Shale: light gray to buff, weathers light brown, very silty to sandy, ¼" beds, non-calcareous, silty and sandy at base, nodules at 3"	10	195.2
155	Quartzite: light gray to buff, weathers tan-brown with limonitic spots, medium to thick bedded, one and three foot beds, forms resistant ledge, fine to medium grained, well sorted, non-calcareous, somewhat cross - bedded at base, very hard	48	194.3
154	Quartzite: medium to light gray, weathers tan-brown hard, resistant ledge former, slightly calcareous, silty, thin bedded, marks base of upper partial cycle	12	190.3
153	Siltstone: brown, weathers same, somewhat shaly and nodular	2	189.3
152	Shale: black, dense, non-calcareous, nodular irregular bedded, top 2" is gray clay shale	10	189.2
151	Clay: medium gray to light green, weathers same, very waxy and clayey	1	188.3
150	Shale: medium gray to light green, clayey, and non-calcareous	2	188.2
149	Siltstone: brown, weathers light brown, slightly calcareous, thin 1" beds, hard and compact	6	188.1
148	Shale: nodular, green to brown, weathers brown, slightly calcareous, ¼" to 1" beds	18	187.6
147	Shale: medium gray to dark green, weathers mottled gray-brown, non-calcareous, very thin to ½ inch beds, irregular	12	186.1
146	Shale: light green, weathers brown, calcareous, very thin to ¼" platy beds, somewhat nodular	9	185.1
145	Shale: medium gray to green, weathers gray and brown, slightly calcareous, ¼" to paper thin; 1" at top siltstone medium gray, weathers brown, slightly calcareous, compact	28	184.3
144	Siltstone: medium gray, weathers light gray, nodular bed, lens pinches out within two feet, very fine grained	3	182.0
143	Shale: black, weathers medium gray, non-calcareous, 1" nodules at base and at 15", paper thin to ¼" beds	30	181.8
142	Shale: black, weathers gray, waxy, non-calcareous, ⅛" beds, chippy, hard	6	179.3
141	Shale: black, weathers gray, waxy, clayey, ½" to ¼" beds, contains plant fragments	9	178.6
140	Shale: medium gray to gray, weathers light gray, nodular, irregular 1" to ½" beds. non-calcareous	14	178.0
139	Shale: black, dense, weathers gray to brown, silty, lacks fissility, somewhat nodular, non-calcareous, waxy and clayey, ½" beds	7	176.8
138	Shale: medium to light gray, weathers same with orange mottling, very thin to paper thin bedding; Limestone, brown, shaly at base	8	176.3
137	Limestone: black, weathers brown to gray, dense, weathered surface shows vertical fine black graphitic? seams, resistant ledge, 10½" and 1½" beds, laterally persistent-key marker bed for upper cyclothem, thin-section reveals ostracods, pelecypods, and low spired gastropods; brackish-marine	12	175.6
136	Shale: roof shale, consists of the following: Top 2½" shaly limestone, fine grained; 3" shale, red, earthy; 2" shaly limestone, light brown; 3½" shale,		

APPENDIX A (CONT.)

	medium brown, gypsiferous earthy to paper thin; 2" shale, red to red brown, gypsiferous, paper thin, earthy	13	174.6
135	Coal: brown to dark brown, lignite, banded, associated gypsum, lenticular; some limonite on weathered surface, near vitreous luster	4	173.5
134	Underclay: black to dark gray, irregular bedded to unbedded, waxy and highly carbonaceous	6	173.2
133	Shale: dark gray, silty to sandy, non-calcareous	2	172.7
132	Sandstone: light gray, weathers brown, fine to medium grained, subangular to subrounded grains, noncalcareous, semifriable at top,	6	172.5
131	Quartzite: light gray to buff, weathers brown, fine to medium grained, subangular to subrounded, orange limonite mottled spots thin bedded—6" to 1', vertically jointed and crossbedded in part, resistant ledge	33	172.0
130	Quartzite: light gray to buff, weathers brown, dense, silica cemented, thick bedded, single 41" bed, crossbedded at base, limonite occurs as weathered spots, fine to medium grained and subangular to subrounded	41	169.3
129	Quartzite: same as unit 130 except slightly calcareous	5	165.8
128	Quartzite: light tan, weathers brown, unit consists of 2" of quartzite and 3" of sandstone, weak with very thin partings	5	165.4
127	Quartzite: as unit 125, rippled upper surface	4	165.0
126	Quartzite: as unit 125, but thinner beds ¼ to 1", some sandy shale partings	6	164.7
125	Quartzite: light tan, weathers brown, slightly calcareous, very fine to fine grained, with calcite veinlets, 1-2" beds, marks base of upper cyclothem	2	164.2
124	Shale: light brown, weathers same, silty, although dominantly clay shale	7	164.0
123	Shale: light gray to brown, weathers same, silty	1	163.4
122	Shale: light brown, weathers same, noncalcareous, very thin to paper thin	7	163.3
121	Siltstone: light brown, weathers same, calcite vienlets, irregular ½" to 1" beds	1	162.8
120	Shale: light tan to medium brown, gypsiferous, calcareous, earthy to very thin beds, weathered graphitic soil and limonite present in a lenticular pod	2	162.7
119	Siltstone: light gray to brown, weathers same, calcareous, shaly partings, 1" beds	4	162.5
118	Shale: light gray, weathers same, clayey, contains earthy brown nodules with gypsum, paper shale but in compact beds	12	162.2
117	Calcite: white to yellow-orange, with earthy shale partings	1	161.2
116	Shale: light brown, weathers same, calcareous, very thin to ¼" beds, somewhat earthy	6	161.1
115	Shale: black to dark green, weathers medium gray, hard, thin ⅛" plates, contains nodules near base, lower 4" nodules are laminated brown and gray and calcareous; shale is slightly calcareous	12	160.6
114	Shale: medium gray to brown, weathers light brown, non-calcareous, hard compact ¼" beds but shale parts to near paper thin, contains nodules at very top, nodules are argillaceous to slightly silty, dense, non-calcareous and vary from ¼" to 1" thick and 4" to 6" wide; shale is very irregularly bedded	16	159.6
113	Shale: medium gray and brown mottled, weathers light brown, calcareous, irregularly bedded, may be slightly silty, undulating bedding; varies from paper thin at base to ¼" and ½" beds, 1" irregular nodules	14	158.4

APPENDIX A (CONT.)

112	Siltstone: orange and brown laminated, calcareous, hard 1" ledge, very irregular undulating surface, may be 30% calcareous	1	157.1
111	Shale: light gray to brown, weathers same, non-calcareous, thin-⅜" platy beds, very irregularly bedded, undulating, Pelecypod found 4" above base—one half inch long smooth poorly preserved specimen	21	157.0
110	Siltstone: black, weathers orange-brown, very fine grained, very hard and dense, non-calcareous contains numerous calcite veinlets, irregular bed, pinchs out to west (10 feet) but persistent down slope to east	2	155.2
109	Shale: medium gray to gray and brown laminated calcareous, resistant, compact 4" and 2" beds with shale partings about 1/16 of an inch	6	155.1
108	Shale: medium gray to dark green, weathers light gray to brown, paper thin, low outcrops, non-calcareous to slightly calcareous	10	154.6
107	Siltstone: very fine grained, medium gray, weathers tan, ½" bed, non-calcareous, orange mottled, resistant bed	1	153.8
106	Shale: light brown to green, weathers light gray to brown, weak, slightly calcareous, weathers in thin large sheets 1/16" thick	18	153.7
105	Siltstone. dark gray, weathers medium gray, very fine grained, clayey, dense, hard, with calcite veinlets, orange mottling, resistant 2" ledge	2	152.2
104	Shale: dark green to dark gray, weathers gray, paper thin in compact weak units	14	152.0
103	Siltstone: black to dark gray, weathers tan, very fine grained, hard, cut by calcite and limonite veinlets, resistant ledge	2	150.8
102	Shale: medium gray to greenish brown, weathers tan-gray, orange mottling, slightly calcareous, paper thin	9	150.7
101	Shale: brown and black laminated, calcareous, with orange mottling, irregular thin bedding, ⅛" to ¼", with some paper thin shale	3	149.7
100	Shale: dark green with orange mottling, slightly calcareous	5	149.7
99	Shale: dark gray to black, weathers tan, fissile, brown shaly limestones at 2" and 5", nodular at top, fossiliferous-pelecypods *Yoldia*-like	14	149.3
98	Limestone: medium brown, weathers light brown, shaly, fine crystalline, with calcite veinlets	1	148.1
97	Shale: medium gray, non-calcareous, with nodules and thin limy units, low outcrops	24	148.0
96	Shale: gray to green, weathers brown with orange mottled spots, slightly calcareous, fissile, Pelecypods 10" above base	20	146.0
95	Shale: black, nodular, non-fissile, hard, with calcite veinlets, 1" to 4" bed, contains abundant small pelecypods on upper and lower weathered surface	4	144.3
94	Shale: as unit 96, becomes black and waxy top 1 foot, possible plant or shell fragments	36	143.0
93	Shale: dark gray, weathers gray, calcareous, fissile to nodular at top, ⅜' hard thin plates, 1" to 2" nodules		
92	Shale: dark green to medium gray, slightly calcareous, contains siltstone bed 5" above base with minute calcite vienlets, pelecypod (?) impressions	48	139.1
91	Limestone: brownish-red, weathers tan, very silty, platy irregular bedding, contains abundant small pelecypods	2	135.3

APPENDIX A (CONT.)

90	Shale: medium to dark gray, weathers tan, ⅛" beds, low outcrop, no fossils, slightly calcareous	21	135.1
89	Shale: green to light green-gray, non-calcareous, hard, chippy few nodules	40	133.3
88	Shale: brown to olive green, weathers drab gray, non-calcareous, very thin, few ½" nodules	17	130.0
87	Shale: medium gray to black non-calcareous, thin ⅛" beds, becomes nodular and platy toward top, basal 18" low outcrops	48	128.6
86	Siltstone: gray to black, with orange mottling, slightly calcareous at base to calcareous at top, thin bedded-1", lower 9" is repeated, nodular toward top	16	124.6
85	Shale: medium gray, non-calcareous, platy, with thin black shale partings	38	123.3
84	Shale: gray to green, weathers tan, non-calcareous, contains nodules	36	120.1
83	Shale: black, non-calcareous, earthy, with 1" limestone bed at base, dense, fine grained, cut by calcite veinlets	18	117.1
82	Shale: mostly covered, red-brown, non-calcareous, clayey, with a few thin brown limy units	12	115.6
81	Shale: gray, weathers red-brown, non-calcareous, few compact beds between partings, contains macerated plant fragments and possible broken pelecypods, limonite replaced	9	114.6
80	Shale: medium gray and red, irregular bedding, contains plant fragments, and limonite replaced *Yoldia*-like pelecypods	8	113.8
79	Shale: medium gray, with orange mottling, compact but irregular, contains pelecypods and macerated plants(?)	6	113.2
78	Shale: medium gray weathers light gray, slightly calcareous, platy with nodules, becomes red-brown at top	24	112.7
77	Limestone: black with orange mottling, silty calcite stringers, thin bedded	6	110.7
76	Shale: medium gray, hard, non-calcareous but contains orange mottled calcareous partings, plant fragments, contains silty nodules up to 1" thick	36	110.2
75	Limestone: silty, medium brown, with black-green shale partings, pelecypods and nautiloids present	2	107.2
74	Shale: maroon, fissile, clayey, weathers earthy, gypsiferous(?) partings	18	107.0
73	Limestone: silty, gray to red laminated, slightly fissile but compact 2" bed	2	105.5
72	Shale: light green to reddish-brown, non-calcareous, contains plants and pelecypod fragments	1	105.4
71	Shale: medium to dark gray, hard "sheety", somewhat nodular, contains plant fragments and pelecypods which are replaced by limonite	17	105.3
70	Shale: roof shale, green to dark gray, contains abundant nodules which are silty, non-calcareous, contains plant fragments, and pelecypod valves, nodules contain pelecypods and ostracodes	8	103.8
69	Coal: brown, highly weathered, thin lenticular lignite or sub-lignite, non-banded, varies up to 2" thick	1	103.2
68	Shale and underclay: green, waxy, clayey, shale with orange mottling at base, grades upward into gray, brown, and yellow impure unbedded underclays, macerated plant remains and possible root markings	8	103.1
67	Shale: sandy, mottled green and red, silty to very fine grained, clayey, non-calcareous	1	102.4

APPENDIX A (CONT.)

66 Quartzite: light gray to buff, weathers brown, resistant ledge, hard, fine grained, well sorted, subangular to subrounded grains, silica cemented, weathers with orange limonite spots, crossbedded but not channeled. Base of lower cyclothem	18	102.3

APPENDIX B

Insoluble Residues

Unit No.	Orig. Weight	Final Weight	% Insoluble
23	11.47 gms.	5.92 gms.	51.7%
29	13.70	8.51	50.1
32	21.69	8.11	29.7
36	20.55	17.31	76.1
39	8.38	2.46	29.4
43	10.73	4.94	46.0
47	12.02	8.38	69.7
51	24.52	11.44	32.4
53	14.44	6.24	31.8
56	13.10	6.12	46.7
59	24.62	15.04	21.4
70	24.54	24.15	91.7
72	8.34	1.08	12.9
73	11.56	6.91	46.0
75	12.54	6.35	50.6
77	17.00	11.81	59.4
91	13.01	7.15	54.9
98	11.72	5.55	47.3
121	5.91	3.76	63.7
125	23.73	20.21	85.4
136	4.03	1.25	31.0
137	12.44	4.60	11.3
148	19.25	15.75	81.7
153	13.11	13.80	99.5
162	21.67	5.50	39.5
164	13.85	2.59	18.8
179	19.20	3.55	18.5
189	6.14	0.38	6.2

REFERENCES CITED

Baker, A. A., 1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U.S. Geol. Surv. Oil and Gas Invest. Prelim. Chart 30.

Bissell, H. J., & Hansen, G. H., 1935, The Mississippian-Pennsylvanian contact in the Central Wasatch Mountains, Utah: Utah Acad. Sci., Arts and Letters Proc., v. 12, p. 163.

Bullock, K.C., 1951, Geology of Lake Mountain, Utah: Utah Geol. & Min. Surv. Bull., no. 41, 46 p.

Calderwood, K. W., 1951 *ms.*, Geology of the Cedar Valley Hills area, Utah: unpub. M. S. Thesis, Brigham Young Univ., 116 p.

Croft, M. G., 1956, Geology of the northern Onaqui Mountains, Tooele County, Utah: Brigham Young Univ. Res. Studies, Geol. Ser., v. 3, no. 1, 45 p., 1 pl.

Gilluly, James, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Surv. Prof. Paper 173, 171 p., 32 pls.

Hebertson, K. M., 1950 *ms.*, Origin and composition of the Manning Canyon Formation in central Utah: unpub. M. S. Thesis, Brigham Young Univ., 71 p.

Hyatt, E. P., 1956, Clays of Utah County, Utah: Utah Geol. Min Surv. Bull. 55, 83 p.

McFarland, C. R., 1955, Geology of the West Canyon area, northwestern Utah County, Utah: Brigham Young Univ. Res. Studies, Geol. Ser., v. 2, no. 3, 21 p.

Moyle, R. W., 1958, Paleoecology of the Manning Canyon Shale in central Utah: Brigham Young Univ. Res. Studies, Geol, Ser., v. 5, no. 7, 86 p.

Nolan, T. B., 1935, The Gold Hill Mining District, Utah: U. S. Geol. Surv., Prof. Paper 177, 172 p., 15 pls.

Orneales, R. H., 1953 *ms.,* Clay deposits of Utah County: unpub. M. S. Thesis, Brigham Young Univ., 80 p.

Pitcher, G. G., 1957, The Geology of the Jordan Narrows quadrangle, Utah: Brigham Young Univ. Res. Studies, Geol. Ser., v. 4, no. 4, 46 p.

Robertson, J. A., 1940 *ms.,* A study of the selenium and the possibility of selenium poisoning in Utah: unpub. M. A. Thesis, Brigham Young Univ., 81 p.

Sadlick, Walter, 1955 *ms.,* The Mississippian and Pennsylvanian boundary in northeastern Utah: unpub. M. S. Thesis, Univ. Utah, 77 p.

Tidwell, W. D., 1962, An Early Pennsylvanian flora from the Manning Canyon Shale, Utah: Brigham Young Univ. Geol. Studies, v. 9, part2, pp. 83-101, 5 pls.

Weller, J. M., 1957, Paleoecology of the Pennsylvanian Period in Illinois and Adjacent States: *in* Paleoecology, Geol. Soc. Amer. Memoir 67, pp. 325-365.

White, C. D., & Theissen, R., 1913, The Origin of Coal: U. S. Bur. Mines, Bull. 38., 390 p.

Young, J. C., 1955, Geology of the southern Lakeside Mountains, Utah: Utah Geol. & Min. Surv., Bull. 56., 116 p.

Manuscript received May 13, 1963