5-1972

Stratigraphy and Environmental Analysis of the Swan Peak Formation and Eureka Quartzite, Northern Utah

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STRATIGRAPHY AND ENVIRONMENTAL ANALYSIS OF THE SWAN PEAK FORMATION AND EUREKA QUARTZITE, NORTHERN UTAH

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

Approved:

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Committee Member

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UTAH STATE UNIVERSITY
Logan, Utah

1972

ACKNOWLEDGMENT

The author wishes to express his appreciation to Dr. Robert Q. Oaks for his technical assistance and inspiration throughout the study. Special thanks are due to Dr. J. Stewart Williams for identification of many Ordovician fossils, and to Dr. Donald R. Olsen and Dr. Williams for careful reading of the manuscript and suggestions for its improvement.

Appreciation is extended to Walter Holmes, Calvin James, Robert Oaks, and Warren Schulingkamp for their assistance and companionship in the field.

To Dr. Leo Laporte of Brown University and Dr. Donald Rhoads of Yale University, I extend my sincerest thanks for help and guidance in examining both ancient and modern depositional environments during a National Science Foundation Advanced Seminar in Paleoecology.

Financial support provided by Gulf Oil Corporation and the Society of the Sigma Xi is greatly appreciated. The completeness and depth of the study would have been considerably less without their generous support.

Special thanks is extended to Lyle A. Hale and Mountain Fuel Supply for their generous support during the final preparation of the thesis.

To my wife Dianne, I extend my deepest appreciation for her patience, understanding, and timely help in the preparation of this manuscript.

George Gregory Francis

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ABSTRACT

Stratigraphy and Environmental Analysis of

The Swan Peak Formation and Eureka

Quartzite, Northern Utah

by

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Utah State University, 1972

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The Swan Peak Formation in north-central Utah thickens westward, from zero feet near Logan to 687 feet in the Promontory Range. The unit is subdivided into three distinct members: 1) A lower member of interbedded shales, limestones, and quartzites; 2) A middle member of interbedded shales and brown quartzites; and 3) An upper member of white quartzites. The Swan Peak thins southward toward the east-west-trending Tooele Arch in the area of study; this thinning probably reflects both lesser deposition and greater subsequent erosion there than elsewhere. The lower member in northern Utah probably was deposited in shallow-shelf and/or transitional shoreface-shelf environments. The middle member represents shoreface to intertidal environments. Western miogeosynclinal equivalents of the lower and middle members are more carbonate-rich, the results of their more basinward position and thus greater distance from terrigenous sediment sources. The upper

member was deposited in a shallow-shelf to intertidal environment by strong, predominantly south-flowing currents.

The Eureka Quartzite in northwestern Utah thickens northward from 288 feet near the Tooele Arch to 542 feet in the Silver Island Mountains near the Nevada state line. It consists of unfossiliferous, white to medium light gray quartzite. The Eureka represents a shallow-shelf to intertidal environment swept by strong, predominantly south-flowing currents.

Correlation of the upper member of the Swan Peak Formation in north-central Utah and southeastern Idaho with the Eureka Quartzite in northwestern Utah appears well established, on the basis of: 1) A previously unrecognized low-angle regional unconformity at the base of the upper member; 2) Similar thicknesses of the easternmost Eureka and the westernmost upper member, first recognized by Webb (1956. Middle Ordovician detailed stratigraphic sections for western Utah and eastern Nevada. Utah Geol. and Mineral. Survey, Bull. 57, 77 p.); 3) Similar south-flowing paleocurrents for both; 4) Distinctive and identical trace fossils in both; 5) Identical lighologic characteristics; and 6) Similar stratigraphic position below the Fish Haven Dolomite, and above similar time-correlative faunal suites of Ross (1951. Stratigraphy of the Garden City Formation in northeastern Utah, and its trilobite faunas. Peabody Mus. Nat. Hist., Yale Univ., Bull. 6, 161 p) and of Hintze (1952. Lower Ordovician trilobites from western Utah and eastern Nevada. Utah Geol. and Mineral. Survey, Bull. 48. 249 p.).

Fossil assemblages in the lower and middle members of the Swan Peak Formation are chiefly mixed and transported assemblages, although residual fossil communities persist locally. Diversity and density of trace fossils show that numerous unpreserved soft-bodied organisms contributed significantly to the community structure of the Swan Peak Formation and Eureka Quartzite in northern Utah.

(136 pages)

INTRODUCTION

General Statement

This report summarizes a detailed geologic investigation of environmental conditions during deposition of Middle Ordovician clastic sediments in northern Utah (Figure 1). These sediments constitute the Swan Peak Formation and the Eureka Quartzite. In north-central Utah the Swan Peak is overlain by the Fish Haven Dolomite and underlain by the Garden City Formation. In northwestern Utah the Fish Haven overlies the Eureka Quartzite, and the Crystal Peak Dolomite underlies and separates the Eureka from underlying units generally correlated with or even called the Swan Peak Formation.

The area of study was selected because extensive outcrops permitted detailed environmental and stratigraphic analysis. The area has an additional advantage in that both the miogeosyncline and the craton of Middle Ordovician time are included in the area of study. A greater emphasis in the study was placed on the border between the miogeosyncline and craton, because of the more continuous and closely spaced exposures in the Logan area, in contrast to the less continuous and more widely separated exposures in mountain ranges westward in the Great Salt Lake Desert.

Purpose of Investigation

The purpose of the study was to establish: 1) Environments of deposition of the Eureka Quartzite and members of the Swan Peak Formation;

2) Body-fossil and trace-fossil assemblages of these units; and 3) Stratigraphic relations of each lithic unit to the others in northern Utah. Stratigraphic sections measured along lines both perpendicular and parallel to depositional strike established the vertical and lateral ranges of sedimentary structures and fossils within each unit. These features then formed the basis for interpretations of depth of water, current activity, clastic sources, and transgressive and progradational-regressive sequences.

Important also is the practical application of such a study to petroleum exploration. Many oil fields produce from porous, permeable, sheet-like sands similar to those of the Swan Peak Formation and Eureka Quartzite. Knowledge of such sedimentary rocks, especially vertical variations and lateral relationships, should minimize the many variables associated with locating and producing petroleum from these and similar sand bodies.

Location and Accessibility

The region studied covers northwest and north-central Utah, an area that extends from the Utah-Nevada state line in the west to the Bear River Range in the east, and from U. S. Highway 40 in the south to the northern end of the Great Salt Lake in the north (Figure 1), except for the sourthern Lakeside and northern Stansbury Mountain ranges. The area of study consists of approximately 5,800 square miles. The study was regional enough to provide a framework that would not obscure the environmental and stratigraphic relationships, but small enough to allow adequate detail for interpretation of the Ordovician units studied.

In the area of investigation individual thrust plates contain rather straight forward and continuous lithic sequences ranging from Precambrian to Permian in age. The thrust plates are broken by normal faulting and partly obscured by subsequent alluvial, colluvial, and lacustrine cover.

The area varies from high forested mountains in the Bear River Range to nearly barren mountain ridges in the Great Salt Lake Desert. Snow in early fall and late spring limits accessibility to sections in the southern Bear River Range and Wellsville Mountain area of the Wasatch Range to the summer months. Most other locations of the study are accessible even during winter if proper precautions are taken and fair weather prevails. Most exposures can be reached with a vehicle of good clearance and a two-hour climb.

Field and Laboratory Methods

During the latter part of the summer of 1969 and throughout the summer and fall of 1970, a total of 67 days were spent in the field measuring sections and collecting specimens for laboratory analysis. Middle Ordovician exposures outside the area of study were also visited. These included the Northern Bear River Range of Utah and Idaho, and the Fish Creek Range, Malad Range, and Soda Springs Hills of Idaho. These visits aided the author in obtaining a regional overview of Middle Ordovician strata, and helped verify the interpretations of lateral and vertical sequences observed in the area of study.

Sections were measured with a steel tape 10 feet long. A Brunton compass and Jacob's staff were used to traverse covered intervals. Individual bed-by-bed thicknesses were obtained for nine entire sections of the 15 sections measured. It was hoped that vertical variations in bedding thicknesses would provide an additional means of correlation of one section with another. The method permitted ready distinction among the different units, but failed to provide marker horizons for detailed correlation within these units.

Both body fossils and trace fossils were collected from the Swan Peak Formation and Eureka Quartzite. Analyses of the major body fossils were made to determine environmental factors and kinds of fossil assemblages present at the time of deposition. Body fossils at each section were examined for density, orientation, dispersion, size frequency, relative abundance, associations, articulation, degree of fragmentation, and morphologic characteristics. A detailed statistical comparison of individual assemblages in various sections was not attempted due to poor exposures of the fossiliferous units, and the inability to use the same sampling method for all sections measured. Ross (1951, 1967, 1968), Hintze (1952), and Cooper (1956) have collected and described in detail fauna from the Swan Peak Formation and its equivalents. Identifications of specimens collected during the present study have been based on descriptions and illustrations in these references.

The mineralogies of approximately 34 samples were determined by X-ray diffraction and X-ray fluorescence, with the intent of using unusual mineralogic suites as an additional basis for correlation among sections. Hydroxylapatite was the only unusual mineral found that could be used as a stratigraphic marker, but this material is readily identified in the field without geochemical analysis. Petrographic differentiation of quartz arenites from quartz siltites was impractical for the present study, so that these end-members, were combined and described simply as quartzites.

Rock-slabbing, X-ray radiography, and thin-sectioning were done on the trace fossils. These methods provided the basis for the classification of behavioral types, mode of formation, preservation, and environmental significance of the different trace fossils.

Although the study concentrated on the environmental aspects of deposition, a review of all the different possible depositional environments and related sedimentary facies will not be undertaken. The interested reader is referred to more complete works (King, 1961; McKee, 1957a; Potter and Pettijohn, 1963; Potter, 1967; Selley, 1970; Shelton, 1967; Shepart, 1963; Visher, 1963). Campbell's (1967) terminology for bedding and laminations, and McKee and Weir's (1953) classification of cross-stratification were used in the study. The two-dimensional aspect of most exposures and the requirement of a three-dimensional view made the use of Allen's (1963a) classification of cross-stratification difficult and often impractical for the present study.

PREVIOUS WORK

Because they are widespread, the Swan Peak Formation and Eureka Quartzite have been mentioned or described in many publications. Richardson (1913, p. 407) named the "Swan Peak Quartzite" from an outcrop at the crest of Swan Peak in the northwest corner of the Randolph Quadrangle, Utah (Sec. 11, T 14 N, R 4 E). Mansfield (1927, p. 57) noted the northward extension of this quartzite unit into the Montpelier Quadrangle in southeastern Idaho. The lower member is commonly covered, so that Owen (1931) and Williams (1948, p. 1136) were the first to note the tripartite lithic division of the Swan Peak Formation in common use today. VanDorston (1969, 1970) more recently refined Williams' general subdivisions and gave criteria for selection of formational and member boundaries in the northern Bear River Range.

Hague (1883, p. 253) named the Eureka Quartzite from exposures at Eureka, Nevada, but Kirk (1933, p. 30) later redesignated the type section at Lone Mountain, 18 miles north of Eureka, because the section at Eureka was incomplete. At the type section both the overlying Hanson Creek Dolomite (equivalent to the Fish Haven Dolomite) and the underlying Pogonip Group are exposed. A similar stratigraphic sequence was found by Langenheim and others (1956) as far west as the Independence Quadrangle, California. Subsequent work in central and southern Nevada and in southern Utah (Ibex Basin) is summarized by Hintze (1951, 1952, 1954, 1959, 1960, 1963a, 1963b); by

Ross (1951, 1953, 1964a, 1964b, 1967, 1968); and by Webb (1956, 1958). Little will be said about these studies of the paleontologic and stratigraphic relations outside the area of study, except where they relate directly to the present study of northern Utah.

In the Ibex Basin of southwest Utah, Hintze (1951, 1952) subdivided the Pogonip Group (equivalent chiefly to the Garden City Formation, but including the younger Kanosh Shale) into time-correlative faunal zones. In the Northern Utah Basin Ross (1951) also subdivided the Garden City Formation and the lower member of the Swan Peak Formation into similar time-correlative faunal zones. Excellent agreement between these two basins appears to indicate the time-correlative nature of the Kanosh and Lehman with the lower and middle members of the Swan Peak. However, no definite faunal correlation of the unfossiliferous upper member of the Swan Peak with the unfossiliferous Eureka Quartzite could be established for north-central Utah. Ross (1964a) indicated that both are post-middle Whiterock and pre-middle Barnveld, i.e., possibly Marmor, Porterfield, and/or Wilderness.

Thus, when the present study began, some uncertainty existed concerning correlation of Middle Ordovician quartzite units, both north and south of the Tooele Arch and within northern Utah itself. Hintze (1951, p. 21) and Webb (1956, p. 21) have questioned the exact correlation of the Swan Peak Formation in northern Utah with the Swan Peak in the Ibex Basin of southwestern Utah. Webb (1958, p. 2356) proposed three hypothetical relationships for the Swan Peak Formation and Eureka Quartzite in northern Utah: 1) The Swan Peak Formation has no western equivalent; or 2) The upper part (either the upper and middle members or perhaps only the upper members of Williams, (1948), is equivalent to the Eureka Quartzite; or 3) The entire Swan Peak Formation is equivalent to the Eureka Quartzite. Webb (1956, p. 43) believed the white quartzite at the top of the Swan Peak in the Promontory Range could be Eureka, but gave little evidence other than lithology for his tentative correlation. The two other hypothetical correlations he considered he apparently liked less.

In the Silver Island Range of western Utah, Schaeffer (1961) recognized, in descending order, the Eureka Quartzite, Crystal Peak Dolomite, Swan Peak Formation, Lehman Formation, and Kanosh Shale (Figure 3). In the Newfoundland Range in the central Great Salt Lake Desert, Paddock (1956, p. 29) recognized both the Eureka and Swan Peak, separated by 147 feet of Crystal Peak Dolomite. He subdivided the Swan Peak into an "upper" and "lower" member (Figure 3). East of the Newfoundland Range, in the Lakeside Range (Doelling, 1964, Figure 15) and in the Promontory Range (Olson, 1956, p. 50), the Crystal Peak Dolomite is absent, and both authors explicitly assumed that Eureka also is absent. Olson (1956, pp. 89-90) believed that Webb was incorrect in postulating that the upper part of the Swan Peak in the Promontory Range might be equivalent to the Eureka Quartzite, but he presented no substantiating evidence.

Farther east, at Wellsville Mountain and the Bear River Range, the Swan Peak Formation again contains the only major Ordovician quartzite. The Crystal Peak Dolomite is missing here also. This eastern area occupies the transitional position between the miogeosyncline to the west and craton to the east (Eardley, 1963, p. 19).

Correlation of Middle Ordovician strata has, in the past, been based on the classical dual approaches of physical stratigraphy and guide fossils. The present study concentrated on the environmental aspects of deposition determined from sedimentary structures, and the paleoecology of faunal and trace-fossil assemblages. Such environmental data, combined with physical stratigraphy, then proved useful in firmly establishing the stratigraphic relations previously suspected by Webb and suggested by Ross.

GEOLOGIC SETTING

Pre-Ordovician Strata

Late Precambrian erosion of the continental margins preceded the Late Precambrian-Early Cambrian transgressive sequence. During much of the Cambrian, repeated transgressive and the progradational-regressive sequences were deposited in northern Utah. The Cambrian system averages 7000 to 8000 feet thick, and is divided into 8 to 14 formations in Utah and Nevada. Unit-for-unit lithic correlation is fairly good through wide areas, but different nomenclatural schemes have resulted in confusion, especially for the lower Cambrian. The basal transgressive quartzites grade upward into chiefly shales; by Middle and Late Cambrian mostly carbonates were being deposited. During Late Cambrian time the sea withdrew from northern Utah, and much if not all the area was exposed and eroded.

Ordovician System

During Early Ordovican time the sea transgressed eastward, and the Garden City Formation of Utah and its equivalent, the Manitou Formation of central Colorado, were deposited. At this time most of western Utah and eastern Nevada lay in the Cordilleran miogeosynclinal belt and received chiefly carbonates. Within the miogeosynclinal belt, a northern and a southern depositional basin formed as early as late Cambrian time, and these basins were separated by the east-west-trending Tooele Arch. Hintze (1963a, p. 58) named these, respectively, the Northern Utah Basin and the Ibex Basin. The positive Tooele Arch influenced deposition of sediments from Cambrian through at least Late Ordovician time (Hintze, 1959, p. 53). The position and trend of the Tooele Arch is defined by the absence and/or thinning of Ordovician units in the Stansbury and Lakeside Ranges, and in the Tintic and Gold Hill mining districts. Ordovician strata are also absent in the Uinta Mountains, and most authors, including Ross (1964a, p. 1550) consider the Tooele Arch a westward extension of the ancient Uinta Arch.

The shoreline migrated westward in Middle Ordovician time to a position near Logan, Utah. Sand, mud, and carbonate then were deposited in roughly arcuate bands in successively offshore regions in the Utah-Nevada area. These bands trended north-south in the east and east-west in the west. Farther west siliceous muds and volcanics were deposited in the deeper water of the eugeosyncline (Ketner, 1966, p. 54).

The Swan Peak Formation and the Eureka Quartzite occur at the top of the Sauk Sequence of Sloss (1963, p. 95). The Sauk Sequence consists of rock units of Late Precambrian to Middle Ordovician age that are bound by supposedly time-correlative interregional unconformities representing widespread withdrawal of the sea.

The Lander Formation in Wyoming and the Harding Formation in central Colorado are believed to be eastern time-equivalents of the Swan Peak Formation of Utah (Allison, 1966). These two formations are thin compared to their more western, miogeosynclinal equivalents. A very shallow-shelfal cratonic environment of deposition has been proposed for the Lander and Harding. The Harding Formation has received notice because of fragmental parts of the earliest known vertebrates, which occur in the upper part of that formation in Colorado.

DESCRIPTIVE STRATIGRAPHY AND ENVIRONMENTAL ANALYSIS

General Statement

The Swan Peak Formation in northeastern Utah thickens both north and west (Figure 2), and can be subdivided into three distinct members based on lithology, paleontology, and sedimentary structures. Williams (1948, p. 1136) and Ross (1951, p. 6) discussed these subdivisions, but more recently Van-Dorston (1970, p. 1143) defined detailed criteria for selecting member boundaries. In the Silver Island and Newfoundland Ranges the transition to thick carbonate sequences complicate VanDorston's criteria for subdivision of members (Figure 3). Subdivision of the stratigraphic sequence in the Silver Island Range was based on Schaeffer (1961), and the criteria of Paddock (1956) were used for formational boundaries in the Newfoundland Range. Generally, the Eureka Quartzite and its equivalents lie between carbonate units, and upper and lower formational contacts are easily defined and located.

Lower Member of Swan Peak Formation

In north-central Utah the lower member of the Swan Peak Formation varies in thickness from zero to 160 feet (Figure 4). The basal contact of the Swan Peak Formation generally is gradational through a short distance. Criteria include: 1) The first shale or quartzite above the Garden City Formation; 2) A generally sharp transition from dark colored calcilutites and calcisiltites of the Garden City, to lighter colored biocalcarenites and biocalcirudites of the overlying Swan Peak Formation; 3) The topographic break between the resistant upper member of the Garden City Formation and the less-resistant lower member of the Swan Peak; and 4) The transition from the cherty and dolomitic carbonates of the upper member of the Garden City, to the limestones of the lower member of the Swan Peak Formation. The criteria are listed in order of decreasing reliability. In most cases where several criteria are present, they are coincident.

Below the Swan Peak Formation, abundant dolomite beds alternate with aphanitic limestones (calcisiltites and calcilutites) at the top of the black-chert-bearing upper member of the Garden City Formation. Ross (1951, p. 8) found that some dolomitic beds changed laterally to limestone without any apparent physical demarcation. In the present study it was also noted that zones of dolomitization cut across bedding at some localities, and therefore, dolomitic beds are unreliable as a consistent stratigraphic marker below the lower member Swan Peak Formation.

Beds of the lower member range in thickness from less than one inch to greater than four feet, and average 0.4 foot thick. The thicker-bedded units are predominantly limestone, but some shale units appear to approach the same upper limit. Bed thicknesses exhibit a general upward increase through the lower unit, with the possible exception of the quartzite beds, which appear to be thicker and more abundant toward the base. However, bed thicknesses are obscure because of commonly poor and incomplete exposures of the lower member. Sedimentary structures of the lower member are characterized by wavy and parallel laminae with a noticeable lack of scours and much bioturbation of the sediment. Beds display a lenticular nature, and lateral tracing of even the thickest limestone and quartzite beds reveals a lack of continuity through more than 80 feet.

Ostracods, fragmental brachipods, and disarticulated echinoderms are common constituents of limestones in the lower member. The quartzites and sandstones vary from light brown to pale red, and are fine grained and well sorted. Locally, thin sandstone beds are cemented with calcite. Shales vary from medium gray (N5) to dark gray (N3), and contrast sharply with the lighter-colored shales of the middle member of the Swan Peak Formation.

In the northeastern part of the study area three lithologic subunits occur in a vertical sequence in the lower member. These are: 1) A lower subunit of interbedded shale (45 per cent), quartzite (35 per cent), and limestone (20 per cent) with the quartzite commonly concentrated near the base; 2) A middle subunit of interbedded shale (50 per cent) and limestone (40 per cent) with only minor quartzite (10 per cent); and 3) An upper subunit of interbedded shale (80 per cent) and quartzite (20 per cent). The percentage values given for each lithology are approximate averages based on several sections. These three subunits were recognized at north Mantua (Section 10), south Wellsville (Section 8) and particularly at East Mantua (Section 11), where the lower member is well exposed. A summary of the vertical ranges of lithologic subunits, sedimentary structures, body fossils, and trace fossils is given in Tables 1 to 4.

Alterations of fossiliferous sand, limestone, and shale indicate a transitional environment between the carbonates of the open shelf and the sands, silts, and clays of the shoreface. Hence the lower member of the Swan Peak Formation probably was deposited in a shelfal-marine environment. Based on modern studies and isopach data, water depths perhaps varied from 50 to 60 feet along the shoreward margin to possibly as much as 150 to 250 feet seaward. The width of this shaly zone probably varied in response to the local paleogeography, currents, and sediment sources. Shale deposition was presumably slow, and once deposited, the sediments were seldom reworked except locally by benthic fauna. The temperature, salinity, dissolved gases, and nutrient content probably varied considerably over the shelfal area, and affected faunal and floral distributions more than sediment distribution. The presence of carbonates suggests warm water temperatures.

Middle Member of Swan Peak Formation

In north-central Utah the middle member varies in thickness from zero to 86 feet (Figure 5). The contact between the lower and middle members is gradational through an interval of less than 20 feet. Criteria used to select the member boundaries include: 1) The top of the transition zone from the thick-bedded shale sequence (upper subunit of lower member) into burrowed (Plate 1), interbedded quartzite and shale; 2) The top of the highest limestone bed (included in the lower member); 3) The transition from dark gray shales into light greenish gray shales; 4) The first appearance of *Annelidichnus*; and 5) A more resistant and steeper topographic slope in the middle member than in the lower member. As with the lower member, the criteria are listed in order of decreasing reliability; in most cases where several criteria are present they are coincident.

In the Newfoundland Range, Paddock (1956, p. 27) recognized only an "upper" and a lower member of the Swan Peak Formation. The middle member in north-central Utah is apparently equivalent to Paddock's "upper" member (Figure 3). Paddock defined the base of his "upper" member (shown as Swan Peak and Lehman in Figure 3) at the first quartzite bed above the argillites of the lower member (shown as Kanosh in Figure 3). Limestone beds occur in Paddock's "upper" member, so that not all criteria used in north-central Utah are applicable. The relative position of the Newfoundland Range well within the Ordovician miogeosyncline perhaps explains the limestone interbeds of Paddock's "upper" member. However, correlation between his "upper" member and the middle quartzite and shale member in north-eastern Utah appears to be established on the basis of stratigraphic position and paleontologic evidence (Ross, 1964a, Figure 3).

Quartzites in the middle member are usually brown to tan and are highly bioturbated. Shales are generally lighter in color than shales of the lower member, and range from dark gray to light greenish gray near the base of the middle member to light gray and light green in the middle and top.

Quartzite beds in the middle member range in thickness from one inch to two feet. Lateral tracing of individual beds along depositional strike reveals lack of continunity of even the thicker beds through more than 30 feet. Beds at the top of the middle member were traced laterally and examined for trunction by the upper member. However, jointing, faulting, and covered intervals obscured any indication of low-angle discordance. A general upward gradation from parallel laminae through wavy parallel laminae to oscillation wave ripples was noted in the middle member of the Swan Peak Formation. Near the top of the middle member, mud cracks, interference ripple marks, small flat-topped ripple marks (Kinneyia, c.f. Hantzschel 1962, p.W235 or Runzelmarken, c.f. Teichert, 1970, p. 1056), simple cross-laminae and hydroxylapatite occur, although all are very rare. VanDorston (1970, p. 1146) reported these shallow-water sedimentary structures and a purple quartzite subunit as common in the northern Bear River Range. The diminished occurrence southward of shallow-water sedimentary structures and the absence of the purple quartzite unit at the top of the middle member suggest that erosion may have played a far more significant role prior to deposition of the upper member than previous studies have indicated.

In north-central Utah abundant horizontal feeding burrows ("fucoids") characterize the middle member. Similar fucoids were recognized by Paddock (1956, p. 58) and by the author in this member in the Newfoundland Range. Two lithic subunits commonly occur in vertical sequence in the middle member: 1) A lower subunit of interbedded quartzite (75 per cent) and light green and brown shale (25 per cent); and 2) An upper subunit of interbedded shale (50 per cent) and brown quartzite (50 per cent), with rare white quartzite (Table 1). The ratios of quartzite to shale represent an average for several measured sections, and vary from one section to another. The lower and upper subunits of the middle member have been recognized at East Mantua, North

Mantua, and South Dry Lake (sections 11, 10, and 9, respectively). These two subunits of the middle member are often covered by talus of the upper member; erosion and nondeposition probably played a significant role in their occurrence, distribution and preservation. The horizontal feeding burrows ("fucoids") are found in both subunits of the middle member, but seen more abundant and better developed in the lower subunit. A summary of the vertical ranges of the lithologic subunits, sedimentary structures, and fossils is given in Tables 1 to 4.

The middle member probably represents a distinct environment adjacent to that of the lower member of the Swan Peak Formation. The interbedded quartzites and shales of the entire middle member probably represent a shoreface to intertidal environment. Vertical successions of sedimentary structures, fossils, and thicker beds of quartzite indicate progressively higher-energy conditions upward.

VanDorston (1970, p. 1149) believed the upper part of the middle member represents tidal-flat deposits. He based this interpretation on the presence of mud cracks, presumed raindrop imprints, oscillation ripples, small flat-topped ripples, and fossil evidence. Van Straaten (1961, p. 214) stated that mud cracks, tracks of invertebrate animals, and certain types of ripples are indicative of environments periodically exposed and covered by water, but do not necessarily prove a tidal-flat environment. Such sedimentary structures are common on the floors of shallow lagoons which have become exposed, in coastal playa sediments, in slat-marsh environments, and on river banks, as well as on tidal flats. Channels and scours are very rare or absent in the middle member of the Swan Peak Formation. Tidal channels are so frequently associated with modern tidal-flats that such a relationship should be true for ancient deposits, yet distinct channels and evidence of current reversals ("flaser" structures) are not found in the middle member of the Swan Peak. The diminished occurrence southward of shallow-water sedimentary structures found near the top of the middle member by VanDorston (1970) near the Idaho state line indicates that such shallow-water strata may have been successively truncated southward toward the Tooele Arch, presumably prior to deposition of the upper member.

Both erosion and sedimentation probably played important roles in the distribution and occurrence of the fauna and flora. The salinity probably varied from normal marine seaward to slightly brackish shoreward. The width of the shoreface zone was probably greater than two miles, and water depth, if based on modern environments, presumably was less than about 60 feet. Temperature was probably warm, but probably fluctuated as a result of storms and seasonal variations.

Upper Member of Swan Peak Formation

The upper member of the Swan Peak Formation forms steep, distinctive cliffs in north-central Utah. The upper member consists of a clean, white quartzite that thickens to the north and west (Figure 2) and ranges in thickness from zero to 476 feet (Figures 6 and 7). The basal contact of the upper member is defined at: 1) The top of the highest shale bed; 2) The transition from brown and dark tan quartzites to white and/or medium light gray quartzites that weather white or light tan; and 3) The top of the highest bed with horizontal feeding burrows ("fucoids") and the base of the lowest bed with vertical burrows. Generally this is a sharp, well-defined contact with no evidence of reworking. However, thin beds of white quartzite occur locally in the upper subunit of the middle member.

The upper contact of the Swan Peak Formation is a sharp, planar surface between the white quartzites of the upper member and the dark dolomite of the Fish Haven. The basal Fish Haven Dolomite locally contains fragments of white quartzite in the lower foot that appear to be reworded from the upper member. No angular discordance was observed between the Fish Haven and the upper member of the Swan Peak in the area of study. However, Coulter (1956, p. 25-26) described an angular discordance between the two formations near Bloomington Lake, Idaho.

Wavy parallel laminae, oscillation ripples, and simple bottom-tangent cross-stratification are common in the upper member. Cross-strata are usually indistinct, but where displayed, dip predominantly southward. Scour surfaces one to two feet deep were observed only locally near the top of the Promontory and Cottonwood Canyon section (Sections 6 and 7, respectively). Bedding thickness ranges from less than 0.5 foot to greater than 10 feet, with an average thickness of 2 feet. Lateral tracing of even the thicker beds in the upper member revealed a lateral continuity of less than 25 feet. In the basal part of the upper member sedimentary structures are often outlined by hydroxylapatite, a mineral form of collophane. Hydroxylapatite was found at the base of most exposures in the eastern part of the study area, except at

South Mantua (Section 12), where nondeposition and/or erosion may have occurred. Hydroxylapatite decreases in abundance westward, and is absent at Strongknob Mountain and points westward. However, the absence at such locations may be related to erosion of the stratigraphic interval prior to further deposition of the upper member rather than to nondeposition. The quartzite of the upper member of the Swan Peak is white, vitreous, and almost entirely silica cemented. Grain size is fine, and sorting appears good to excellent for most outcrops studied. VanDorston (1970, p. 1143) found that grain size increased upward in the upper member of the Swan Peak Formation in the northern Bear River Range. In the southern Bear River Range no vertical differences in grain size were noted, although upper strata probably are absent here due to postdepositional erosion.

The structureless appearance of most exposures of the upper member probably results from a combination of bioturbation, pervasive silica cementation, and jointing. Wholly internal horizontal feeding burrows are absent, and vertical protection burrows like Skolithos are abundant and often weather into relief on bedding surfaces. Conodonts and fish remains (hydroxylapatite) were the only fossils found in the upper member of the Swan Peak in the area of study.

The environmental interpretation of the upper member will be discussed with the Eureka Quartzite because both units had similar depositional histories.

Eureka Quartzite

In northwestern Utah the Eureka varies in thickness from 288 to 542 feet in the area studied (Figure 8). In the Silver Island and Newfoundland Mountains the Eureka Quartzite forms vertical cliffs that lie between two dark carbonate units. Contacts with the underlying Crystal Peak Dolomite and overlying Fish Haven Dolomite are sharp and planar. The base of the Eureka Quartzite is defined at the top of the highest dolomitic limestone of the Crystal Peak Dolomite, and the base of the first quartzite. A sandy dolomite one foot thick at the base of the overlying Fish Haven Dolomite is common throughout the area studied, and probably represent reworked Eureka sands.

Wavy parallel laminae and cross-laminae are common in the Eureka Quartzite. Cross-strata are large scale (greater than 5 cm) and solitary in their occurence. The lower boundaries are usually planar and nonerosional. Cross-strata are usually indistinct, but at some localities (Flirtation Ridge, Section 3) the upper two-thirds has well-preserved cross-laminae that dip predominantly south. Bedding thickness ranges from less than 0.2 foot to greater than 8.0 feet, with an average thickness of 1.2 feet. Individual beds could be traced laterally for no more than 40 feet where well developed in the upper part of the Eureka Quartzite. As with the upper member of the Swan Peak Formation, bioturbation, jointing, and covered intervals often made lateral tracing of beds difficult.

Three lithologic subunits appear to be present locally in western exposure of the Eureka Quartzite. These are: 1) A lower unbioturbated thinly bedded quartzite, with shale partings; 2) A middle bioturbated quartzite subunit, usually much more than half of the total thickness of the Eureka; and

3) An upper unbioturbated thinly bedded quartzite. The upper and lower sub-units are often absent or else obscured by faulting, jointing and covered intervals.

Biogenic structures in the lower part of the Eureka Formation were described by Paddock (1956, p. 32) as "weathered pits and pockets." These same trace fossils were observed by the author, and probably correspond to different preservational types of the trace fossil Laevicyclus (Hantzschel, 1962, p. W201). Trace fossils of the Eureka Quartzite are summarized in Table 4.

Two hypotheses for the environment of deposition of the Eureka Quartzite and the upper member of the Swan Peak Formation appear plausible in light of this evidence: 1) A nearshore to intertidal environment during repeated progradations (regressions) following transgressions; 2) A slowly subsiding shallow-shelf environment swept by strong currents.

At first glance the nearshore to intertidal hypothesis is appealing. In many ancient deposits well-sorted, coarse clastics are deposited nearshore and grade seaward into siltstone, mudstone, and limestone. Recent studies in the Gulf of Mexico indicate that post-glacial rise of sea level has resulted in re-working of older regressive fluvial and barrier-lagoonal sands and muds, re-distributing them in a similar seaward-fining sequence. However, exceptions to this ideal pattern of seaward decrease in grain size are known from recent studies of turbidity currents along continental margins. Shepard (1963, p. 259) believed that an outward decrease in grain size and sorting of sediments is rare in its occurrence and distribution at present, and probably requires a protracted period of stillstand to develop. James D. Howard has also noted that individual progradational beach sands seldom exceed 50 feet in thickness, except near former inlets, whereas C. V. Campbell has noted that transgressive beach sediments are rarely more than ten feet thick, and commonly are thinner or even absent (Oaks, oral communication). Thompson (1937, p. 726-747), McKee (1957b, p. 1706-1718), Potter (1967, p. 351-354), and Van De Graff (1969, p. 35) also report examples of ancient barrier beaches less than 50 feet thick, Vertical stacking of successive regressive and transgressive beach sands with no associated shales over the entire miogeosynclinal shelf from Owens Valley, California, to Logan, Utah, would hardly be a reasonable explanation for these thick Middle Ordovician sands, although locally such conditions may have occurred, especially during deposition of the lower and upper subunits of the Eureka Quartzite.

Tidal flats and deltaic environments also are implausible for the environment of deposition of the Eureka Quartzite and upper member of the Swan Peak Formation. Tidal and distributary channels are absent, and shales so often associated with both of these environments are absent (Van Straaten, 1961; Klein, 1970).

The rather constant characeristics of sedimentary structures, trace fossils, bedding thicknesses, grain sizes, and regional depositional characteristics support a broad, shallow-shelf environment for the deposition of both the Eureka Quartzite and upper member of the Swan Peak Formation. Slow basinal subsidence during deposition probably explains the great thicknesses of these units.

In addition, any model of Middle Ordovician sand deposition must account for the evidence of strong ocean currents. Two shelfal current systems are plausible for these Middle Ordovician sheet sands: 1) Large permanent unidirectional current systems related to density differences and/or maintained by prevailing trade winds, and 2) Tidal currents. In middle latitudes, principal oceanic currents move approximately parallel to continental margins. Paleomagnetic reconstructions (Irving, 1964, p. 123) place the Ordovician equator in Colorado, with a north east-south west orientation; deposition of Middle Ordovician sands would occur within a belt of now southward-moving trade winds.

Sediment transportation by tidal currents is not often deemed important because of the supposed oscillatory nature of such currents (King, 1961, p. 33). However, Bowsher (1967, p. 320) concluded that broad shallow-shelf areas are strongly affected by tidal currents, and Caston and Stride (1970), Terwindt (1971), and McCave (1971) documented the importance of tidal currents in forming and maintaining sand waves up to 40 meters high in the North Sea. Ebb and flood currents usually do not have the same maximum velocities (Off, 1963, p. 326). Ebb currents are generally localized, but faster, whereas flood currents generally affect very broad areas, but are slower. However, Kelin (1970) has shown, for intertidal bars, that flood-current velocities over steep slopes ($<$8 degrees) can exceed those of ebb currents. Winnowing of fine clastic sediments by tidal currents can act through large areas, and with little loss of tidal velocities from the surface to the bottom (Shepard, 1963, p. 96; Klein, 1970, Figure 3).

Merifield and Lamar (1966) have suggested that late Precambrian tidal-current velocities may have been 4 to 14 times greater than those of today. Ordovician tidal-current velocities presumably would have been less than those of the late Precambrian, but still significantly greater than at present. Merifield and Lamar's hypothesis is based on paleontological evidence of Wells (1963) and Scrutton (1964); and the astronomical evidence of MacDonald (1964) and Munk and MacDonald (1960, p. 203). Stewart (1970, p. 68) believed high-velocity tidal currents were responsible for well-sorted Upper Precambrian and Lower Cambrian sheet sands in California and Nevada.

PALEONTOLOGY AND PALEOECOLOGY

General Statement

Past studies of Middle Ordovician strata have utilized the fossil taxa as time-stratigraphic tools. More recently the value of fossils as a paleoecological means of studying ancient environments has begun to be appreciated. Autecology and synecology are the two primary methods of studying paleoenvironments. Autecology is the study of populations of single species, or a few closely related species, and the manner in which they affect and are affected by the environment. By contrast, biotic and abiotic factors such as trophic levels, density and diversity of taxa, species interrelationships, and lateral and vertical changes in assemblages are the concern of synecology. Primarily a synecological analysis of the fossil assemblages was used in the present study.

Paleontology

The Swan Peak Formation is generally fossiliferous in the lower and middle members (Tables 2 and 3). No macrofossils other than trace fossils (Table 4) were found in the upper member of the Swan Peak and its equivalents. Conodonts were collected near the base of the upper member in the Logan Quadrangle, and Ross (1964b, p. 47) collected conodonts that had a "high Middle Ordovician aspect" from the lower part of the Eureka in the southwest end of the Spotted Range, Nevada.

The descriptive taxonomy and the time-stratigraphic relationships of the major Ordovician fossil taxa have been described elsewhere (Ross, 1951, 1964a, 1969; Cooper, 1956; Hintze, 1952). No attempt will be made to discuss these descriptive aspects in detail except where pertinent to the environment of deposition or paleoecological synthesis. The detailed faunal and flora list is presented in Table 5, and is the result of collecting in the lower and middle members, primarily in the Wellsville and Bear River Ranges of north-central Utah.

Fossil Assemblages

Fagerstrom (1964, p. 1198) defined a fossil assemblage as ". . . any group of fossils from a suitably restricted stratigraphic interval and geographic locality." Fagerstrom (1964, p. 1199) modified Johnson's (1960) three types of fossil assemblages into four end members: 1) Fossil community; 2) Residual fossil community; 3) Transported assemblage and 4) Mixed assemblage. These end members represent idealized abstractions, and their recognition in strata depends upon many variables, including the following (Johnson 1960, p. 1039):

1) Variety and kinds of fossils
2) Functional morphology (autecology of each kind; not studied)
3) Density, dispersion, and orientation of fossils
4) Size-frequency distribution of fossils
5) Dissociation, fragmentation, and abrasion of hard parts
6) Chemical and mineralogical composition of hard parts (not studied)

7) Texture and structure of enclosing sediments

With these variables, Johnson (1964, p. 109) defined a community as an "assemblage of organisms inhabiting a specified space." In addition to Johnson's definition, the present study recognizes that organisms in a marine invertebrate community may or may not be mutually interdependent.

Approximately 500 samples from 10 measured sections were analyzed. Fossiliferous pockets with unimodal, size-sorted assemblages are common in both middle and lower members. Predepositional dissociation and fragmentation of skeletal parts appears common. Coquinas of Orthambonites Sp. are common in the upper half of the lower member, and trilobite pygidia are usually the only remains found of Eleutherocentrus petersoni. Although molting probably caused dissociation, sorting and concentration of pygidia presumably resulted from waver or currents. The relative fossil percentages of the lower and middle members of the Swan Peak Formation are: Brachiopoda 21 per cent, Gastropoda 17 per cent, Trilobita and miscellanea 11 per cent each, Cephalopoda, and Graptolithina 8 per cent each, Bryozoa, Calyptomatida, Echinodermata, and Agnatha (hydroxylapatite) 4 per cent each.

Nonpreservation and selective transport probably have significantly altered the original fossil assemblage. Taphonomic studies indicate that from 40 to 70 per cent of recent marine communities are soft-bodied and have little potential for preservation (Lawrence, 1968, p. 1317). The chemical and mineralogical composition and thickness and structural reinforcements of skeletal material would also affect the relative durability and preservation of hard parts. Losses through transport are more readily identified by statistical methods, but such an approach was beyond the scope of the present study.

In addition to the criteria of Johnson and Fagerstrom, assemblage analysis utilizing trophic levels and faunal-substrate relationships has recently been used for benthic studies (Johnson 1964; Purdy, 1964; Walker and Laporte, 1970). Lindermann (1942) categorized organisms into trophic levels based on how they obtain energy or nourishment for maintaining and sustaining life functions. A photosynthetic organism would occupy the lowest tropic level, a herbivore the second, and a carnivore the third level or higher. In free-living forms, both the biomass and the number of individuals decreases at each higher trophic level. Individuals in the higher trophic levels tend to be larger and generally reproduce and grow at slower rates than organisms in lower trophic levels. Analysis of trophic level and substrate relationships (Table 3) indicates that essentially every available ecological niche was occupied by one or more organisms during deposition of the lower and middle members, and that diversity and density generally decrease in successively higher trophic levels.

Numerical analysis of the species composition of each trophic level was not attempted because of incomplete taxonomic identification, lack of definite information on trophic level for a significant number of species with no known living close relatives, and bias caused by nonpreservation. Results of ostracod identifications are incomplete, and data relating to their functional morphology are poorly known, so that placement in a trophic level would be tenuous and inconclusive. Trophic levels are also significantly modifed by species that utilize different trophic levels with changes in biological, chemical, and physical factors of the ecosystem. Multiple trophic-level utilization has been observed by the author in the snail Nassarius on an intertidal sand flat in Massachusetts, so that assignment to a trophic level was difficult if not impossible for that species. Such multi-level utilization is probably much more common and widespread in many phyla than previous studies have indicated.

Nonpreservation of soft-bodied organisms also makes statistical evaluation of species composition difficult or impractical for fossils. The high density and diversity of biogenic structures indicate that numerous soft-bodied organisms contributed significantly to the fossil community in the lower, middle and upper members of the Swan Peak Formation. Such nonpreservable organisms, particularly Polychaeta, are important and numerically significant members of modern communities (Brett, 1963; Cerame-Vivas and Gray, 1966; Fagerstrom, 1964; Rhoads 1967; Rhoads and Waage, 1969; Rhoads and Young, 1970; Sanders, 1962; Thorson, 1966).

A general analysis of Johnson's and Fagerstrom's criteria for the recognition of assemblage types indicates that organisms in the lower and middle members in the Swan Peak Formation represent chiefly mixed and/or transported assemblages. However, trophic-level and taxa-substrate relationships indicate that residual (winnowed) fossil communities are still evident locally.

Trace Fossils of the Swan Peak Formation And Eureka Quartzite

General statement

Trace fossils (also called ichnofossils and lebensspuren) are sedimentary structures resulting from biological activity. Trace fossils have several distinct advantages and uses for paleoecological analyses: 1) A long time range of many; 2) A narrow facies range of many; 3) Non-transportable; 4) Commonly preserved in clastic sediments where other fossils are absent or not preserved; and 5) Commonly enhanced by diagenesis. Behavioral types and bathimetric zonation are also two important aspects that make trace fossils ideal for a paleoecological study of the Swan Peak Formation and the Eureka Quartzite.

Deep vertical protection burrows occur in high-energy conditions (generally shallow), and usually indicate a suspension feeder. Horizontal traces that are branching, winding, or have intricate grazing patterns generally occur in sediments, deposited in quiet water (often, but not always, deep), and indicate a deposit-feeding organism. These and other characteristics led Seilacher (1953, 1964) to subdivide trace fossils into five behavioral groups, as follows: 1) Domichnia, or protection burrows; 2) Fodinichnia, or internal feeding-and- protection burrows; 3) Pascichnia, or of nonselective feeders (often wholly internal); 4) Repichnia, or surface locomotion trails; 5) Cubichnia, or surface resting tracks. Such divisions often combine trace fossils made by taxonically diverse groups into the same category.

Bathimetirc zones are the second feature that make certain types of trace fossils important in reconstructing paleoenvironments. Seilacher (1967a, p. 414) believed certain types of trace fossils are ". . . directly or indirectly related to depth. . ." no matter what primary factors cause the difference in distribution and occurrence. His four depth associations, named for characteristic forms are listed in order of generally decreasing depth: 1) Nereites; 2) Zoophycos; 3) Cruziana; and 4) Skolithos. A summary of the bathimetric, behavioral and preservational types of trace fossile is found in Table 4.

Trace-fossil descriptions

Annelidichnus (Plate 1) is proposed informally here, for a cylindrical, horizontal, branching feeding burrow that is preserved as positive hyporeliefs on the bottom surface of sand beds. Individual burrows rarely can be differentiated because of the complex intertwining and high density of the burrows. The average length is 14.0 cm, width, 1.0 cm, and branching is at angles less than 90 degrees. Individual burrows go over and under one another, sytematically avoiding double coverage. Branching is common, but hard to distinguish because of the high density and intertwining of the burrows. In some specimens of Annelidichnus, the burrows displayed a retrusive nature (spreiten concave-up in vertical section) that probably resulted from periodic increase in sedimentation and the subsequent upward movement of the organism. Examination of numerous specimens reveals a systematic transverse V-shaped pattern on at least part of the wall surface of the trace fossil. Rarely is the V-shaped pattern preserved, and slight post-depositional compaction of the clay and sand commonly have obliterated this transverse marking. Annelidichnus is the most abundant trace fossil (approximately 80 per cent) in the middle member.

Two subtypes of Annelidichnus were distinguished in the middle member of the Swan Peak Formation. Annelidichnus in the upper middle member is commonly associated with hydroxylapatite, a calcium phosphate mineral. Thin sectioning, X-ray radiography, and rock slabbing show that hydroxylapatite in subtype A was distributed evenly throughout the burrow, whereas in subtype B, the plate-like mineral fragments are aligned into imbricated, uniformly oriented particles lining the burrow. The difference in these two subtypes may reflect environmental changes that could have affected the digestive processes, or it could also result from two different organisms that produced similar biogenic structures. Annelidichnus is believed to represent the back-filled burrows of marine annelids on the basis of the burrow morphology, V-shaped transverse ridges that suggest segmentation, density, and vertical and horizontal distribution.

Annelidichnus is restricted to the middle member of the Swan Peak Formation, and has been described in past studies simply as a "fucoidal marking." Fucoidal markings have been discussed in the literature since early in the nineteenth century (Locke, 1838). Most of the early investigators attributed the markings to impressions of seaweed, and adopted the term "fucoid" from the generic name Fucus, a modern seaweed. Subgeneric differentiation was usually based on the angle of branching, and little attention was paid to any other morphologic features of the individual trace fossils.

Coulter (1955, p. 283) listed the following hypotheses proposed for the origin of fucoidal markings in the middle member of the Swan Peak Formation:

1) Fossilized remains of various organisms

2) Impressions of various organisms

3) Back-filled burrows or borings of small annelids, mollusks or crustaceans

4) Burrows or borings of small annelids, mollusks or crustaceans which have been filled by later collapsing of overlying material

5) In-filled tracks or trails of small organisms

6) In-filled mud cracks

Coulter believed all of the above hypotheses were inadequate, and suggested Raymond's (1922) description of the preservation of a presumed Precambrian jellyfish as an explanation for fucoid of the middle member. Raymond proposed that sand grains adhered to a partially dehydrated, stranded jellyfish. The tissue supposedly cemented the grains of sand together, and the mass of sand grains prevented excessive shrinkage of the organism. A similar hypothesis with a different organism was proposed by Coulter. Although such examples in the modern environment have been described, the density, the vertical repetition, the retrusive nature of the gallery complex, and narrow environmental range of this trace fossil make such a hypothesis highly improbable.

VanDorston (1970, p. 1153) ascribed the origin of the fucoidal markings found in the middle member of the Swan Peak Formation to the tentacular impressions of orthoconic cephalopods. Such an explanation is inadequate for several reasons. First, VanDorston (1970, p. 1152) stated that the fucoidal markings are ". . . almost devoid of organic material. . ." and that porosity is ". . . increased to more than 15 per cent within the burrow."

Based on the morphology, analogy with the closest related living taxon, and paleontologic studies, cephalopods do not possess the means for selectively sifting out organic matter dispersed throughout the sediments, nor the ability to increase the porosity of sediments. Secondly, Flower (1955) has described tentacular impressions of orthoconic cephalopods in Ordovician sandstones of Ohio. Such impressions were not profuse nor widely occurring, and, unlike the Swan Peak fucoids, were uniformly aligned and did not branch. Flower believed that these impressions were resting tracks, and that the tentacles were used as a mechanism of attachment for cephalopods in strong currents. Third, X-ray radiography and rock slabbing revealed a retrusive nature of the burrow complex. Such features suggest movement of the organism upward in response, perhaps, to sedimentation. VanDorston's and Coulter's explanations for fucoids of the lower and middle members have exploited exotic local occurrences in the geologic record. Unconventional explanations are known for some trace fossils, but these make up relatively insignificant and restricted geological occurrences.

Asterophycus (Plate 2) is a flattened,chiefly horizontal, star-shaped trace fossil with a round vertical stock at the center (See Figure 111, in Hantzschel, 1962 pW, 186). The central stock is round to oval in cross-section, and ranges from 0.5 to 1.0 cm in diameter for specimens collected in the Swan Peak Formation. The bulbous galleries exhibit concentrie lamellae, and are radially placed around the central vertical tube. Asterophycus is preserved as negative epireliefs (depressions in the tops of beds), and is relatively rare. It is restricted (approximately 10 per cent) to sand beds in the middle member.

Differentiation between Asterosoma and Asterophycus has, in the past, been based on size, but the two probably reflect differences in sediment type and texture, or in maturity of the original organism. Hantzschel (1962, p. W184) has interpreted Asterophycus as a questionable feeding trail; Specimens observed in the present study indicates it is probably the burrow of a non-selective deposit feeder living entirely within the sediment.

Chondrites (Buthotrephis) (Plate 3) has a complex tunnel structure, and probably was made by a non-selective deposit feeder that occurred only in the environment of the lower member. Chondrites galleries are subcircular to ellipsoidal in cross-section, and preserved as full reliefs. The galleries are usually observed on bedding planes as branching horizontal traces, but oblique galleries are equally as abundant, although observed less often. The density of Chrondrites is usually high for shale and sandy shale intervals in the lower member, where it is the most abundant trace fossil (approximately 70 per cent). Two variations of branching were observed for Chondrites. In subtype A, a dendritic pattern was observed in both shale and sand beds, and the individual galleries were internally structureless. Subtype B was restricted to shale units, and exhibited branching at right angles. Subtype B also has spherical or ellipsoidal excrement pills within the galleries. Individual galleries in both varieties had a fairly uniform diameter of 0.3 to 0.5 cm for each specimen. Chrondrites quite possibly was made by marine worms. The two subtypes may represent activities of different organisms or differences in sediment texture, water content or organic content of the sediment, and/or hydrodynamic forces.

Cruziana (Figure 119-5 in Hantzschel, 1962) consists of two parallel ridges separated by a central furrow. On the ridges, two sets of parallel, oblique microridges form a V-shaped pattern that extends inward and backward on both sides of the central groove. The maximum trackway observed in the middle member was 6.0 cm long, 2.0 cm wide, and was excavated to a depth of 0.4 cm. Cruziana is rare (approximately 2 per cent) and preserved as positive hyporeliefs and negative epireliefs on sand beds of the middle member of the Swan Peak Formation. The lower member of the Swan Peak was often covered, and the occurrence or absence of forms as rare as Cruziana often could not be verified. Crimes (1970, p. 55) agreed with earlier workers that Cruziana represents the locomotion trail of a trilobite along the sediment surface; he also has found Cruziana continuous with both anterior and posterior ends of Rusophycus, a preserved trilobite resting track. Crimes attributed the V-shaped pattern to the movement of the walking legs inward and backward during locomotion.

Gorida (Figure 121-2, in Hantzschel, 1962) represents a trail of an unknown organism. It is less than 15 cm long and 0.5 cm wide, with a uniform width throughout its length. It is unbranched and bent, but not truly meandering. Gorida is preserved as both negative and positive epireliefs. Only two specimens were observed, and these were collected from the lower subunit of the lower member of the Swan Peak at Blacksmith Fork (Section 15).

Laevicyclus, when seen on a bedding surface, consists of a series of concentric, circular or elliptical furrows (Plate 4). A vertical section reveals a spherical or subrectangular shape (Plates 5 and 6) with a pelleted or pseudo-pelleted wall (Plate 6). A complete gradation from weathered pits or pockets to the concentric circular furrows was observed. When viewed on a bedding surface and when the pelleted outline of the original trace fossil is preserved, a median ridge appears to divide the excavation into two different halves. The central "canal" that has been incompletely described (Hantzschel 1962, p. W198) was observed, and does not represent a canal or tube, but a shallow, sediment-filled depression made by the original organism. The subcircular plus bilateral symmetry suggests a possible arthropod origin. It is common in quartzites of the Eureka and upper member of the Swan Peak (approximately 20 per cent).

Pin-hole-pits (Plate 7) constitute a nondescript trace fossil. These weather as circular to elliptical negative epireliefs 0.1 to 1 cm in diameter on both bedding surfaces, and vertical surfaces. Rock slabbing and X-ray radiography revealed no vertical or horizontal burrow structure associated with the trace fossil. The pin-hole-pits were found in great abundance (approximately 50 per cent) in the Eureka Quartzite and upper member of the Swan Peak Formation.

Planolites (Figure 129-7 in Hantzschel, 1962) is a randomly oriented, branching feeding burrow that is preserved as full reliefs. The diameter of individual burrows ranges from 0.1 to 0.4 cm. Planolites is relatively rare in rocks of Middle Ordovician age in northern Utah, but where it does occur, its density is usually extremely high. Planolites is restricted to sandy limestone beds, and was found only in the middle two-thirds of the Swan Peak Formation in the Newfoundland Range.

Rusophycus (Figure 131-5, in Hantzschel, 1962) is a bilobate, coffee-bean shaped impression that is tapered at one end and gaped at the other. Rarely, parallel, oblique microridges are preserved; these form a V-shaped pattern that converges toward the tapered end, and terminated at a median groove. Rusophycus traces vary in length from 0.7 to 3.0 cm, and have a maximum width of 1.6 cm for specimens found in the Swan Peak Formation. Negative epireliefs and positive hyporeliefs are common preservational types of Rusophycus. This trace fossil is relatively rare (approximately 6-10 per cent) in sand units of the middle and lower members, and absent in other lithologies. Hantzschel (1962, p. W213) and Crimes (1970, p. 53) have interpreted Rusophycus as a resting track of a trilobite. However, a trilobite for the Rusophycus tracks found in the Swan Peak Formation is lacking. The tapering posterior and expanding anterior ends of the resting track indicate that the trilobite had a relatively small pygidium; the broad pygidia of Eleutherocentrus, Illaenus and Ptyocephalus preclude their likelihood as the maker of Rusophycus.

Scolicia trails (Plates 8 to 11) are usually greater than 3.0 cm long, oval in cross-section, and preserved as positive epireliefs and hyporeliefs on sand beds. Transverse furrows (Plate 9) are uniformly spaced throughout the length of the trails, and probably represent traces of the waves of muscular contraction on the sole of the gastropod foot. Both monotaxic and ditaxic forms (bilobate in Section - Plates 9 and 10) are present, although rare (approximately 2 per cent), and found only in quartzites of the Eureka and upper middle members of the Swan Peak. Gastropod trace fossils have a confusing variety of preservational forms, which has resulted in many forms being described. Paleobullia, Subphyllochorda, Aulichnites, Olivellites, and Curolithus are only a few of the recognized gastropod trace fossils. The diversity of Gastropoda traces probably is more related to the system of muscular foot contractions, position, size, and weight of the shell, grain size and moisture content of the sediment, position of the track within or at the top of a bed, type of overlying sediment, etc., rather than to specify generic differences.

Skolithos (Plate 12) is a vertical protection tube that is straight and unbranched. It is less than 0.5 cm in diameter and varies in length. Skolithos is preserved as positive epireliefs and as full reliefs on vertical exposures. Tubes of Skolithos are common (approximately 20 per cent) and are found in most exposures of Eureka and the upper member of the Swan Peak in northern Utah and southeastern Idaho. The density of this trace fossil is often the cause for the structureless appearance of the upper member. Ross (1964b, p. 32) also reported Skolithos in the Eureka Quartzite of the Quartz Spring area, California, and in other areas.

Teichichnus (Plates 13 to 15) is a protection-and-feeding burrow formed by two vertical stacking of gently curved (concave downward) galleries. Individual galleries are usually less than 0.5 cm in diameter, and are 12 cm in length. Teichichnus is preserved as full reliefs, and is in the basal upper member of the Swan Peak Formation. It also occurs in the Eureka Quartzite where it is relatively rare (approximately 10 per cent). Two vertically restricted subtypes of Teichichnus were found to be important environmental indicators. Near the base of the upper member, subtype A, an aligned protrusive variety is present. Upward, a randomly orientated or unaligned protrusive variety subtype B, occurs. Paleocurrent directions, thickness of cross-stratified units, and steepness of cross-strata indicate that each aligned Teichichnus is orientated with its long axis perpendicular to the predominant current direction, and formed under higher-energy conditions than the unaligned Teichichnus variety. A transverse vertical cross-section of Teichichnus may be confused with the spreiten structures of a Diplocraterion (Corophium-type) burrow. Teichichnus may also be confused with Rhizocorallium or Dictyodora if only a longitudinal transverse section is seen. Without X-ray radiography or slabbing of the specimen, a longitudinal vertical cross-section is necessary for positive identification. Chisholm (1970, p. 33) reported Teichichnus transitional to Rhizocorallium in the Kinniny Limestone at St. Monance on the Fife Coast of England. Such transitional forms were not observed in the upper member of the Swan Peak Formation or the Eureka Quartzite.

Tomaculum (Plate 16) consists of clusters of elliptical fecal pellets found in the lower member of the Swan Peak Formation. The individual clusters are usually found in shale and shaly sand. The clusters are 0.2 cm in diameter and appear to be randomly scattered. No strands or trails of clusters such as those illustrated in Hantzschel (1962, Figure 133-1) were observed. Tomaculum is common (approximately 20 per cent) and found as positive epireliefs.

STRATIGRAPHIC RELATIONSHIPS OF EUREKA QUARTZITE AND SWAN PEAK FORMATION

Correlation of the upper member of the Swan Peak Formation of north-central Utah and southeastern Idaho, with the Eureka Quartzite in northwestern Utah appears to be established by the following evidence: 1) Similar stratigraphic position beneath the Fish Haven Dolomite and above the same faunal zone (Hintze 1951, 1952; Ross, 1951, 1964a); 2) Similar lithologies (Webb, 1956, 1958); 3) Similar south-flowing paleocurrents (Ketner 1968 and the present study); 4) Identical trace-fossil assemblages (present study); and 5) The probable presence of a low-angle, regional unconformity at the base of the upper member (present study).

Ross (1964a, 1968) and Cooper (1956) have shown that both the Eureka Quartzite and the upper member of the Swan Peak rest on strata of the same faunal zone (trilobite zone M). Also, both quartzite units underlie the Fish Haven Dolomite. This supports the environmental and stratigraphic evidence for correlation of the Eureka Quartzite and the upper member of the Swan Peak Formation.

In the Silver Island and Newfoundland Ranges the progradational lower and middle members of the Swan Peak and the presumed "transgressive" Eureka (Webb, 1958; Ross, 1964a) are separated by the Crystal Peak Dolomite. Farther east where the Crystal Peak is absent, the sharp basal contact of the white quartzite over regionally truncated quartzites previously was unrecognized. It is apparent that the Crystal Peak Dolomite pinches out east of the Newfoundland Range, and that the Eureka Quartzite is equivalent to the quartzite at Strongknob Mountain and to the upper member of the swan peak of Williams (1948) in north-central Utah.

Similar paleocurrent directions are another reason for correlation of the upper member of the Swan Peak Formation in north-central Utah with the Eureka Quartzite. A predominantly northern source of the sands is strongly suggested by predominantly south-flowing paleocurrents in both the Eureka Quartzite and upper member of the Swan Peak Formation. Post-Cambrian to pre-Devonian erosion in the Uinta and central Wasatch Mountains cut deeply into Cambrian and Precambrian sands, but Ketner (1968, p. B180) dismissed this and also the craton (cf. Kay, 1951; Lockman-Balk, 1970) as an adequate source for the enormous volume of Middle Ordovician sands.

Ketner (1966, 1968) proposed possible sources for Ordovician quartzites and graywackes of the Cordilleran geosyncline. He postulated that eugeosynclinal quartzites were derived from a western borderland of Precambrian and Cambrian strata, and that the Cordilleran miogeosynclinal sands were derived from Cambrian sands exposed along the Peace River-Athabaska Arch in northern Alberta (Ketner, 1968, p. 1969). Ketner presented five arguments for this northern source:

1) An apparently adequate volume of available sand there and the presumed absence of adequate sources elsewhere, based on volumetric calculations.

2) The progressively younger age of the basal Middle Ordovician quartzite beds from north to south, suggested by the work of Ross (1953).

3) Decreased thickness and increased width of Middle Ordovician sand deposits southward.

4) A decrease in median grain size from north to south.

5) Improved sorting southward.

Locally, however, the Uinta and central Wasatch Mountain areas (Tooele Arch) may have contributed clastics to the upper member of the Swan Peak Formation. At the Right Fork of Logan River, ten feet of high-angle, north-dipping planar cross-strata suggest a southerly source for some of the Ordovician sand. The very minor differences in textural maturity, grain size, and sorting between the upper member of the Swan Peak and the Eureka Quartzite (Schulingkamp, 1972, Tables 1 and 2) probably can be attributed to local source areas.

Trace-fossil assemblages are yet another reason for correlation of the upper member of the Swan Peak with the Eureka Quartzite (Table 4). Paddock (1956, p. 32) mentioned "weathered pockets and pits" in the Eureka Quartzite and fucoids in the Swan Peak Formation. Doelling (1964, p. 115) described "quartzites pocketed with pits" at Strongknob Mountain, and reported that, when a boulder is broken, the pits were filled with unconsolidated sand. Samples containing these "pockets and pits" and other trace fossils were collected from the Eureka Quartzite in the Newfoundland Range and the quartzite exposure at Strongknob Mountain. Slabbing, X-ray radiography, and thin-sectioning of the rocks confirmed the biogenic origin of these sedimentary structures. The pockets correspond very closely to Laevicyclus (Plates 4 to 7). This common and distinctive trace fossil also occurs in the upper member of the Swan Peak in the Promontory Range of Utah and in the Fish Creek Range and Soda Springs Hills in Idaho. The absence of these trace fossils in the upper member in the Wellsville and Bear River Ranges may reflect slightly different environmental or post-depositional factors. Isopachous maps (Figures 4 to 8) show that this fossil occurs in areas of thicker accumulations, which presumably occupied a more basinward position in the miogeosyncline.

Many sedimentary and biogenic structures occur in highly jointed exposures or on freshly broken surfaces, which make recognition and identification of trace fossils difficult, if not impossible. Skolithos is very common in exposures of the upper member of the Swan Peak Formation in north-central Utah and southeastern Idaho. These commonly weather in relief on bedding surfaces, and locally obscure the primary sedimentary structures. The trace-fossil Skolithos was also reported by Ross (1964b, p. 32) from the Eureka Quartzite in the Quartz Spring area, California, and in other areas.

It is significant that all four trace fossils found in the upper member also occur in the Eureka Quartzite, and vice versa, and that only Scolicia occurs also in the middle member. Trace fossils of the upper member and of the Eureka Quartzite are therefore distinct from those of the lower and middle members of the Swan Peak Formation (Table 4).

The probable presence of a low-angle regional unconformity between the upper and middle members also suggests correlation of the upper member of the Swan Peak with the Eureka Quartzite. Although no angular discordence is discernible between these two members in a single outcrop, the probable presence of an unconformity is shown in the Bear River Range by: 1) The southward disappearance, beneath the upper member, of shallow-water sedimentary structures and a distinctive, widespread purple quartzite-and-shale sequence at the top of the middle member; 2) The sharp contact, without transition, between shale plus quartzite of the middle member and quartzite of the upper member; 3) A similarly abrupt change in clay content, from more than five per cent in the middle member to less than one per cent in the upper member, at this contact (Schulingkamp, 1972); 4) The sharp (nontransitional) change from horizontal feeding and locomotion types of trace fossils in the middle member to vertical protection types of trace fossils in the upper member; and 5) The different regional extents of the upper and middle members (Figures 5, 6, and Schulingkamp, 1972).

Truncation of the middle member prior to deposition of the upper member suggests elevation of the Tooele Arch, causing the sea to withdraw westward to the present position of the Crystal Peak Dolomite, and resulting in removal of the middle and lower members across the Tooele Arch (Ross, 1964a, Figures 7 and 9). A similar low-angle regional unconformity between the Fish Haven and members of the Swan Peak has long been recognized (Hintze, 1959, Figure 3), yet angular discordance is not evident at the base of the Fish Haven in a single outcrop either.

GEOLOGIC HISTORY, PALEOGEOGRAPHY, PALEOCLIMATOLOGY

In early Ordovician time a rise in sea level or the tectonic subsidence of the continental margin drowned the river valleys and probably trapped much of the coarse terrigenous clastic sediment in estauries. During this time the Lower Ordovician Garden City Formation and its stratigraphic equivalents were deposited as far east as central Colorado (Manitou Formation).

Intraformational conglomerates associated with channels and scours dominate the lower two-thirds (lower member) of the Garden City Formation, together with rhombohedral, symmetric, and asymmetric ripple marks, stromatolites, and algal-mat structures. Such features generally are attributed to intertidal or high subtidal environments (Walker and Laporte, 1970). Conglomerates of the lower member grade upward into thick-bedded limestone containing black chert nodules, (upper member). Progressively greater faunal densities and diversities upward in the Garden City Formation also suggest a somewhat deeper-water origin for the upper cherty member.

Deposition of the Garden City Formation in north-central Utah was followed by a relative fall of sea level and the westward retreat of the shoreline. This fall of sea level exposed to erosion large areas of Precambrian and Cambrian quartzite (Uintas, Canadian Shield), which led to a westward progradation of the middle and lower members of the Swan Peak Formation onto the broad miogeosynclinal shelf. The Crystal Peak Dolomite was probably deposited following this regression. Because of possible uplift of the Tooele Arch at this time, and other possible positive areas in Idaho and westward, the position of the strand line in northern Utah at the time of maximum withdrawal of the sea is uncertain. In Blacksmith Fork Canyon and the East Fork of the little Bear River the middle member is missing yet the lower member remains in part, so that erosion must have taken place in the Logan area prior to deposition of the Fish Haven Dolomite, presumably also prior to the upper member.

A rise in sea level and the essentially simultaneous deposition of the Eureka Quartzite and the upper member of the Swan Peak Formation was the next event in the deposition of Middle Ordovician strata. A widespread, shallow, subsiding shelf probably existed in northern Utah, Idaho, Wyoming, and Colorado during this time. The Lander Formation in Wyoming, and the Harding Formation of central Colorado probably represent deposits of cratonic marine embayments equivalent to the Eureka Quartzite and upper member of the Swan Peak Formation (Allison, 1966).

Deposition of the upper member of the Swan Peak Formation, the Eureka Quartzite, and their eastern cratonic equivalents probably was followed by a westward retreat of the strand-line into western Nevada or California. The exact amount of time represented by the post-Eureka, pre-Fish Haven hiatus is uncertain, largely due to the absence of datable body fossils in the Eureka and upper member of the Swan Peak. However, faunal zones indicate a late Ordovician age (Budge, 1964) for the transgressive Fish Haven Dolomite;

whether the Eureka and upper member of the Swan Peak are entirely of Middle Ordovician age, or partly Middle and partly Late Ordovician is uncertain at present.

During much of Ordovician time, a broad shallow sea occupied eastern Nevada, northern Utah, and western Wyoming. Paleomagnetic reconstructions place northern Utah within 20^{o} of the paleoequator (Irving, 1964; Nairn, 1961, p. 78; Opdyke, 1962, p. 57; Schwarzbach, 1963, p. 212-214). Receptaculites and biostromes of Eofletcheria substantiate the tropical to subtropical environment of northern Utah during Middle Ordovician time.

Receptaculites has been found in the Pogonip Group and the Ely Springs Dolomite by Ross (1964a) and in the lower member of the Swan Peak Formation by the author. Byrnes (1968) believed the distribution and occurrence of Receptaculites indicates a warm shallow sea, within approximately 20^{o} of the equator. Byrnes analyzed the adaptive morphology, structural morphology, and consistency of environmental parameters, and concluded that Receptaculites is a dasycladacean alga.

Eofletcheria biostromes in the Crystal Peak Dolomite form the second faunal evidence for paleolatitude reconstructions. Comparison of the Eofletcheria biostromes with the distributions and occurrences of modern and ancient coral biostromes suggests a warm shallow sea. Modern coral biostromes develop best where the mean annual water temperature lies within the range of 23^{o} to 25^{o} C. Such biostromes do not develop to any significant extent in regions where water temperatures fall below 18^{o} C, nor where waters have high turbidity or low transmissibility of light.

CONCLUSIONS

The conclusions of this study of the Swan Peak Formation and Eureka Quartzite of northern Utah can be summarized as follows:

1) Correlation of the upper member of the Swan Peak Formation with the Eureka Quartzite is considered established. Equivalence of these two quartzite units is based on: A) A probably unconformity at the base of the upper member, shown by its sharp basal contact and its southward trucation of shallow-water sedimentary structures and a purple quartzite subunit in the underlying middle member; B) Similar thicknesses of the easternmost Eureka and the westernmost upper member (Figures 3, 7, and 8); C) Similar south-flowing paleocurrents (and presumably a northern source) for both; D) Distinctive, unique, and identical trace-fossil assemblages; E) Similar stratigraphic position below the Fish Haven Dolomite and above a similar faunal zone; and F) Identical lithologic characteristics.

2) The lower member in north-central Utah was deposited in shallow-shelf and transitional shoreface-shelf environments during westward progradation. The middle member of the Swan Peak Formation represents more shoreward shoreface to intertidal environments. Erosion following deposition of the lower and middle member removed shallow-water sediment progressively southward, so that little indication of intertidal conditions occurs south of Logan,

Utah. Both the upper member of the Swan Peak Formation and the Eureka Quartzite were deposited in a shallow-shelf to inter-tidal environment swept by strong, predominantly south-flowing currents.

3) Analyses of the fossil assemblages in the lower and middle members of the Swan Peak Formation in north-central Utah indicate the presence of primarily both mixed and transported fossil assemblages. However, synecologic data suggest that locally a residual (winnowed) fossil community may be present.

4) Trace fossils change upward from wholly internal horizontal feeding and locomation burrows in the lower and middle members to vertical protection burrows in the upper member.

5) The Eureka Quartzite and Swan Peak Formation are surrounded by organic-rich marine source rocks. These two units have a wide geographic distribution; they pinch out southward against the Tooele Arch and eastward toward the craton. The middle member grades westward into fine-grained marine sediments, and becomes separated from the upper member by the Crystal Peak Dolomite. However, the likelihood of petroleum production from these sands is poor. No oil staining was observed, and due to extensive diagenetic silica cementation the quartzites are porous only locally.

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APPENDIXES

Appendix A

Figures

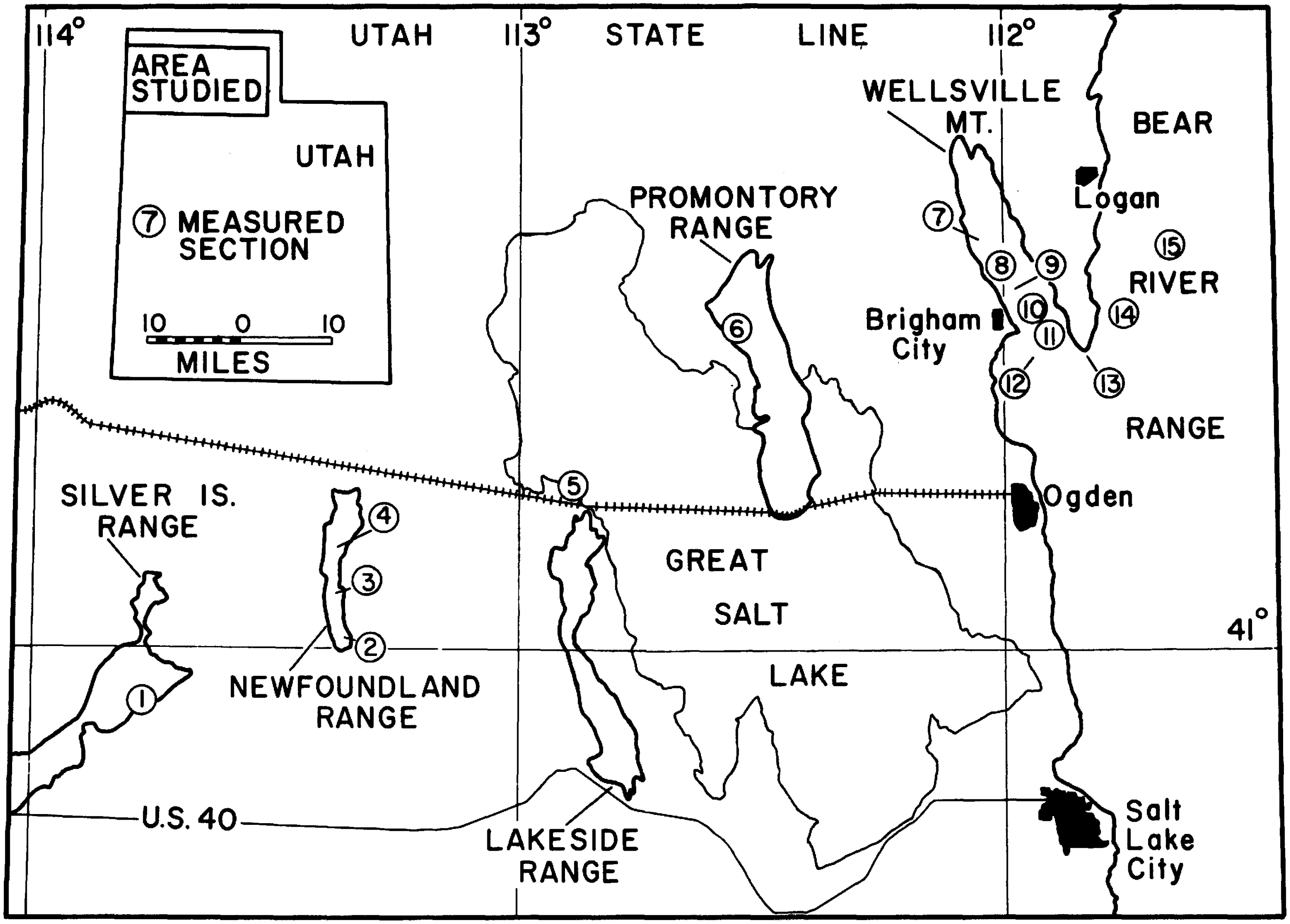

FIGURE I. INDEX MAP SHOWING LOCATIONS OF MEASURED SECTIONS.

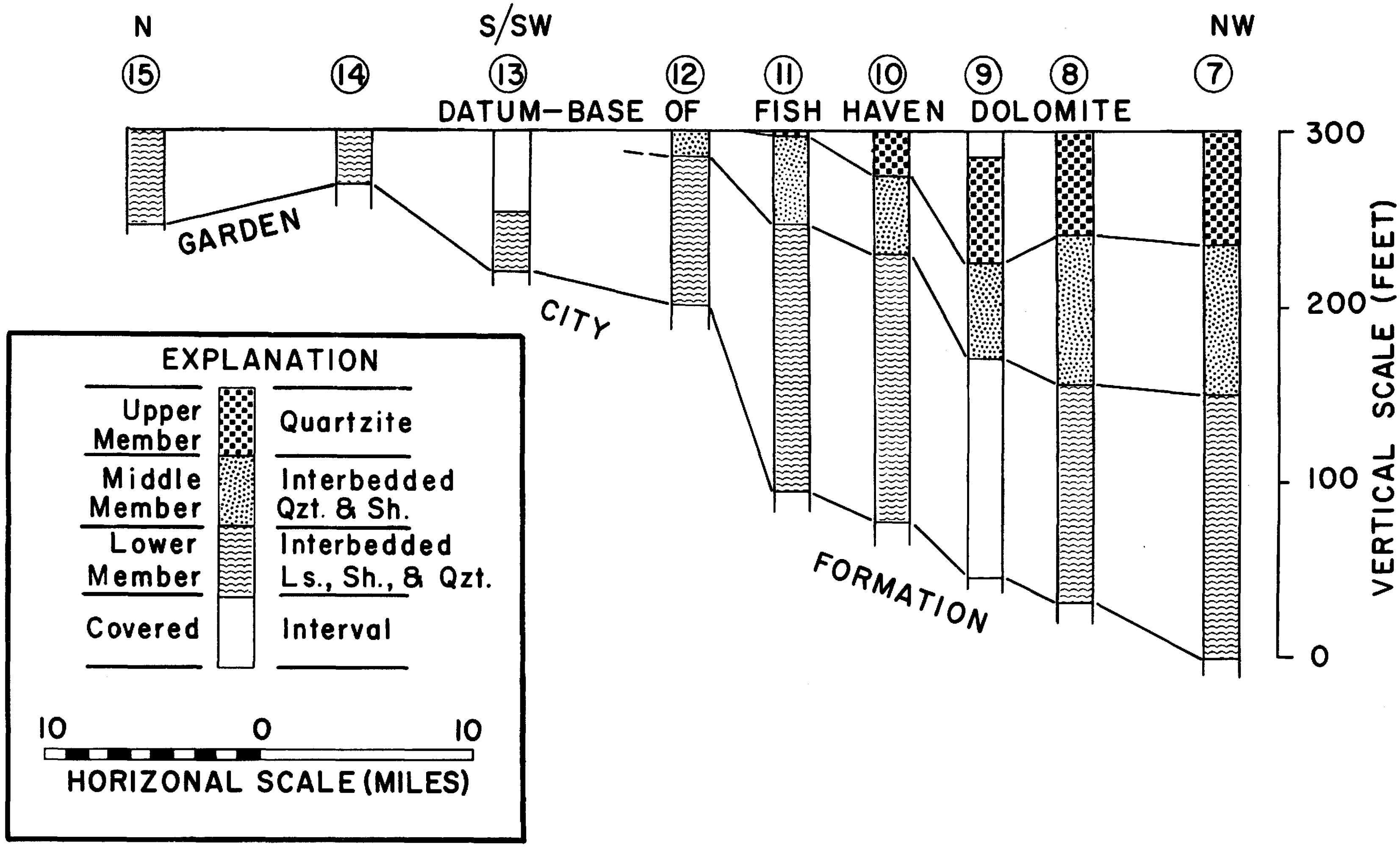

FIGURE 2. PHYSICAL CORRELATION OF DISTINCTIVE LITHOLOGIC UNITS, SWAN PEAK FORMATION, WELLSVILLE MOUNTAIN & BEAR RIVER RANGE, UTAH.

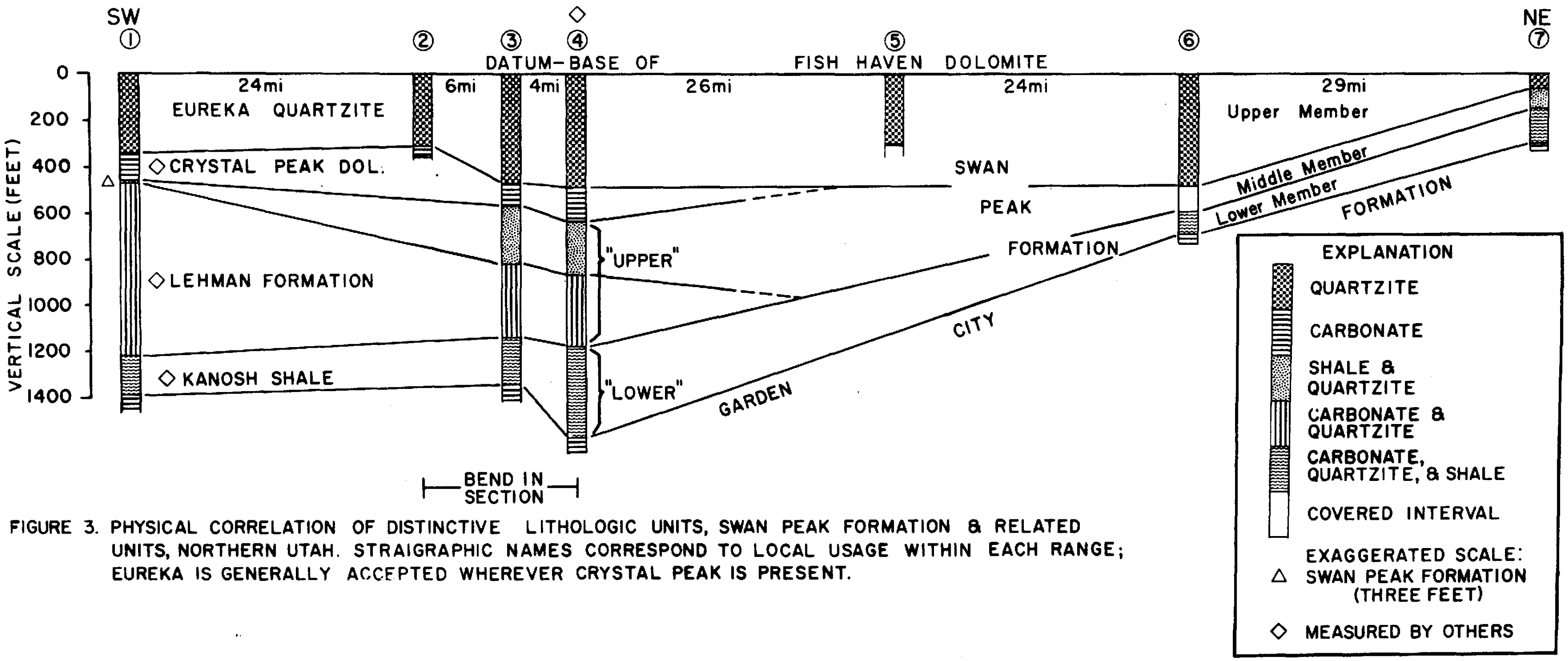

FIGURE 3. PHYSICAL CORRELATION OF DISTINCTIVE LITHOLOGIC UNITS, SWAN PEAK FORMATION & RELATED UNITS, NORTHERN UTAH. STRAIGRAPHIC NAMES CORRESPOND TO LOCAL USAGE WITHIN EACH RANGE; EUREKA IS GENERALLY ACCEPTED WHEREVER CRYSTAL PEAK IS PRESENT.

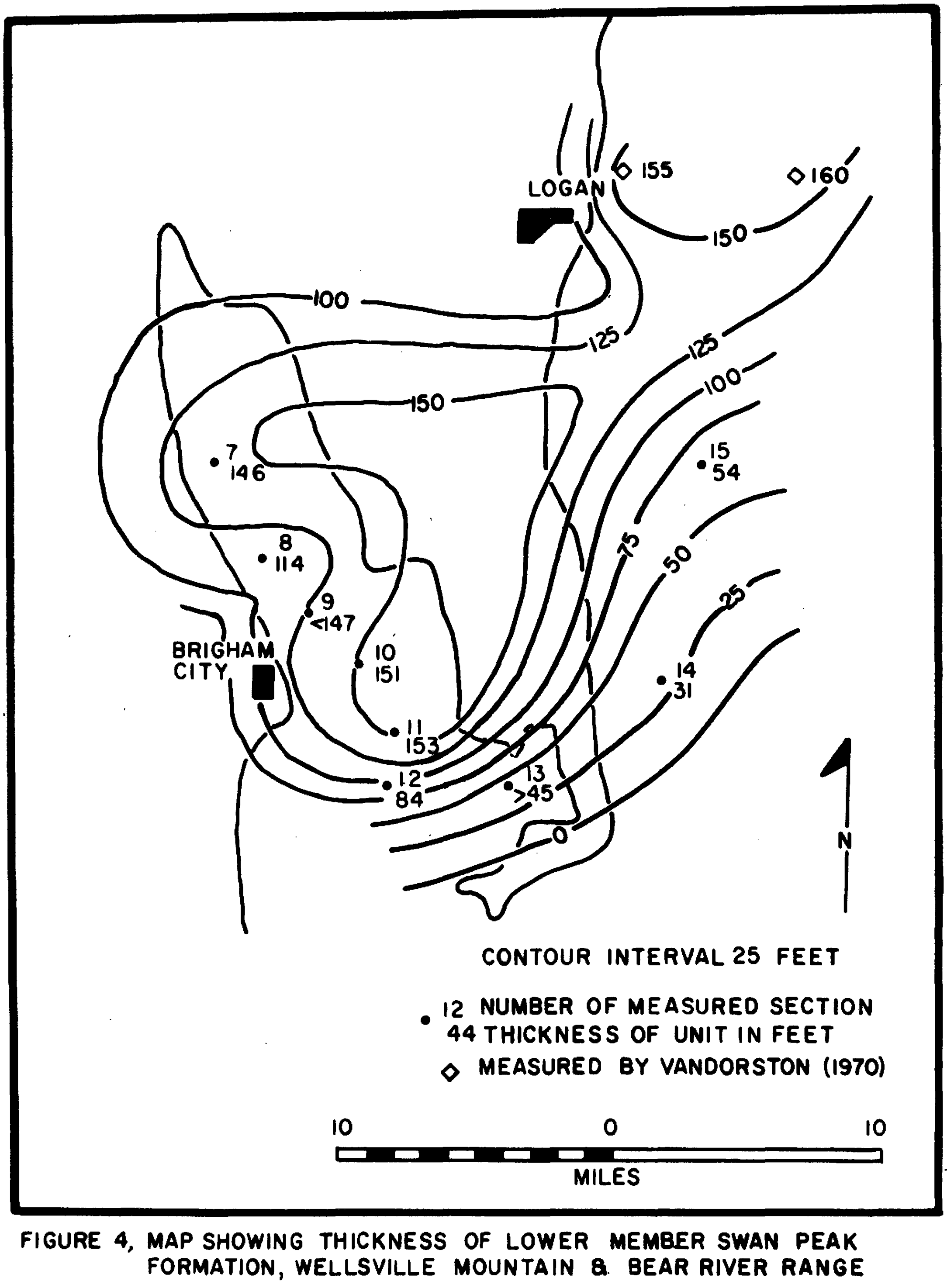

FIGURE 4, MAP SHOWING THICKNESS OF LOWER MEMBER SWAN PEAK FORMATION, WELLSVILLE MOUNTAIN & BEAR RIVER RANGE

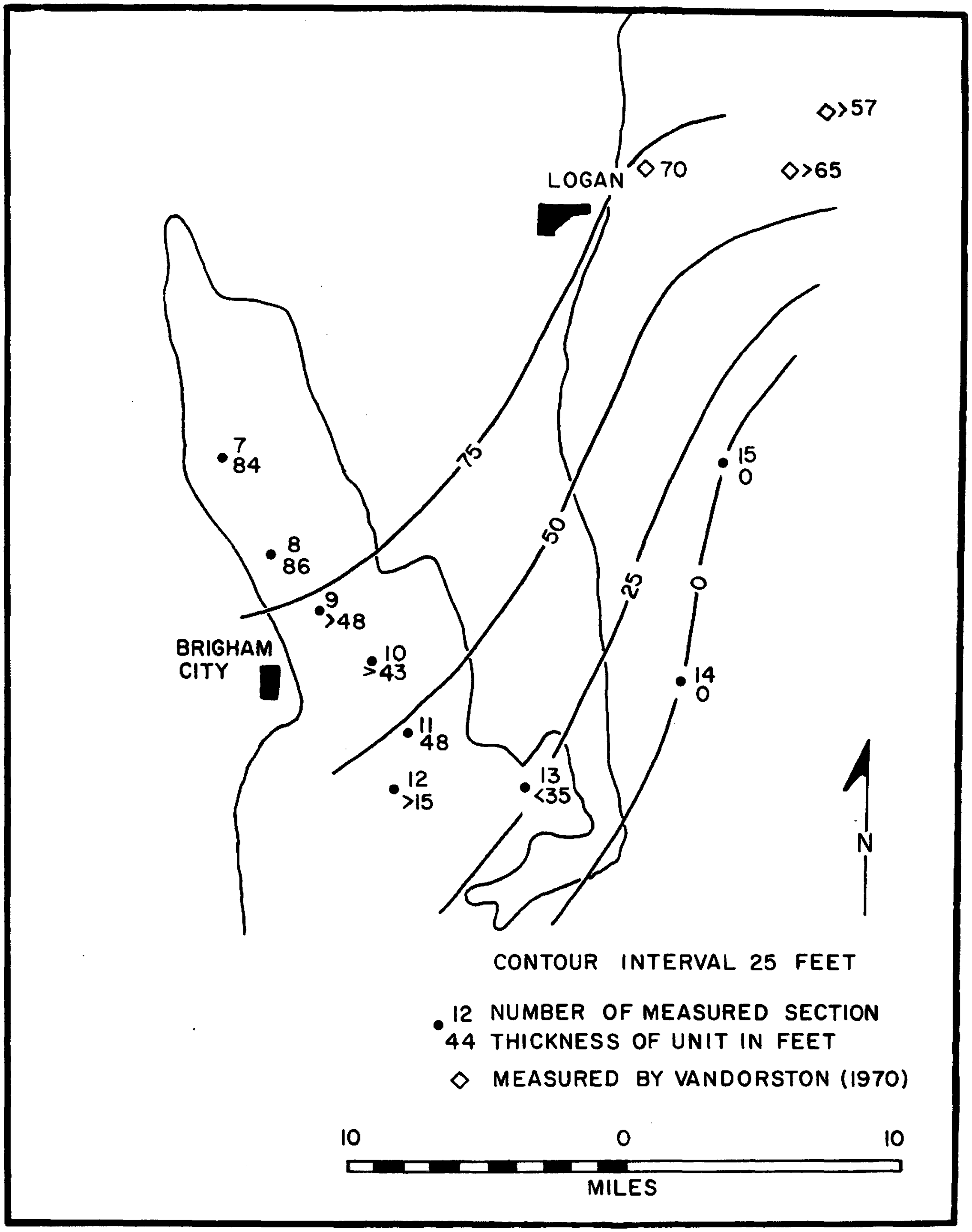

FIGURE 5. MAP SHOWING THICKNESS OF MIDDLE MEMBER SWAN PEAK FORMATION, WELLSVILLE MOUNTAIN & BEAR RIVER RANGE

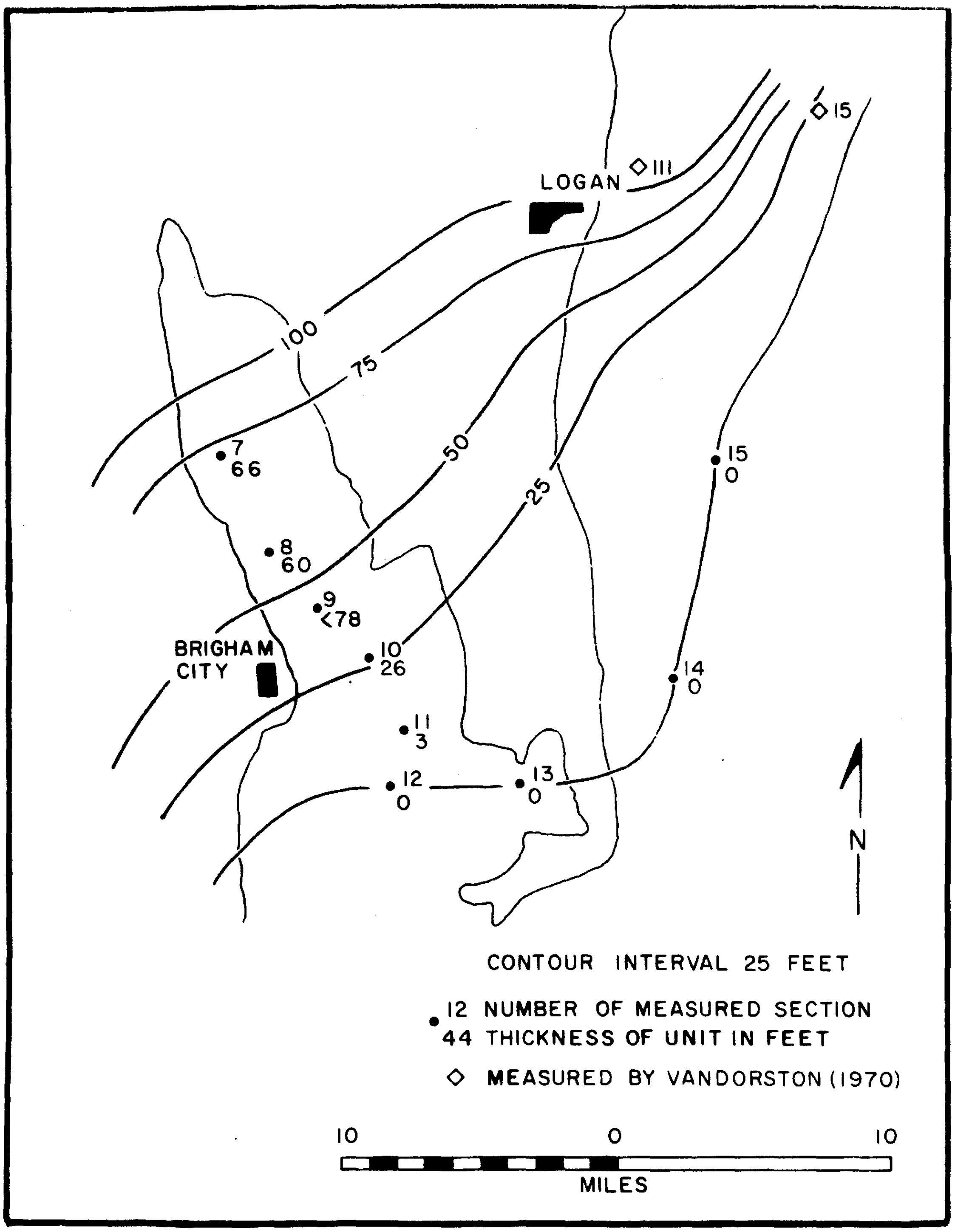

FIGURE 6. MAP SHOWING THICKNESS OF UPPER MEMBER SWAN PEAK FORMATION, WELLSVILLE MOUNTAIN & BEAR RIVER RANGE.

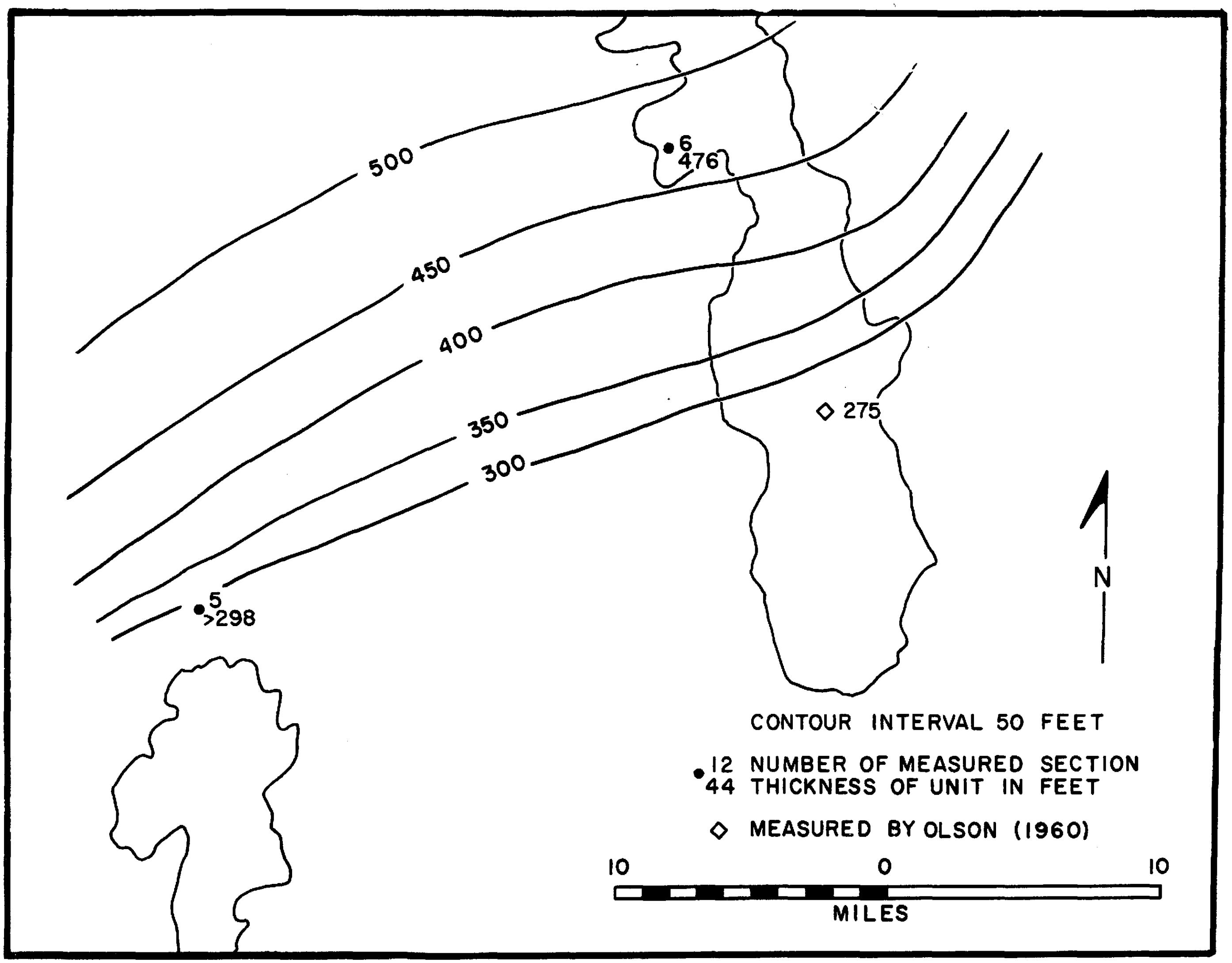

FIGURE 7. MAP SHOWING THICKNESS OF UPPER MEMBER SWAN PEAK FORMATION, LAKESIDE & PROMONTORY MOUNTAIN RANGES.

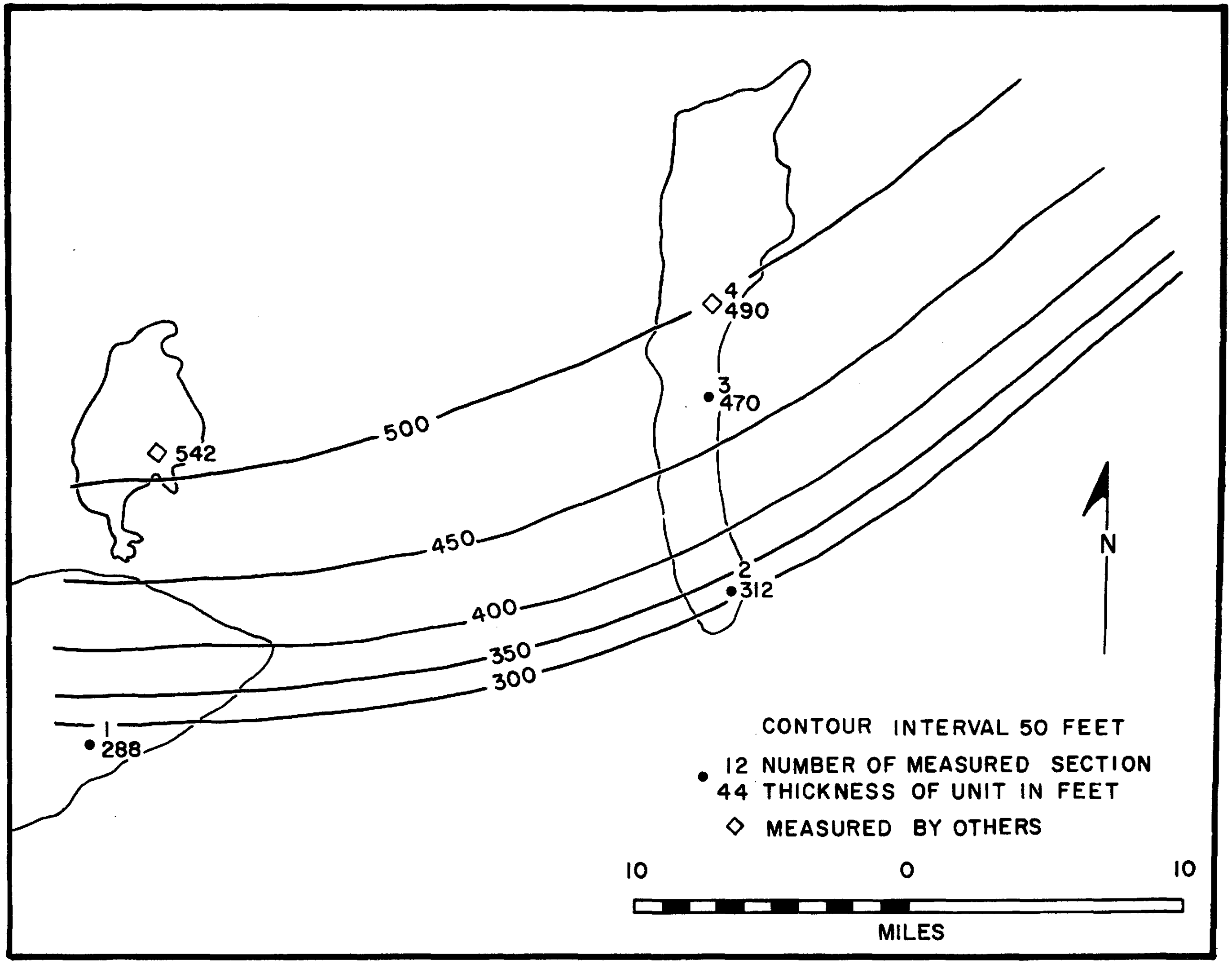

FIGURE 8. MAP SHOWING THICKNESS OF EUREKA QUARTZITE, SILVER ISLAND & NEWFOUNDLAND MOUNTAIN RANGES.

Appendix B

Tables

Table 1. Vertical ranges of the characteristic lithologies and sedimentary structures, Swan Peak Formation, north-central Utah.

	LOWER MEMBER	MIDDLE MEMBER	UPPER MEMBER
LITHOLOGY	Sh., Qzt., Ls. (45/35/20%)		
	Sh., Ls., Qzt. (50/40/10%)		
	Shale & Quartzite (80/20%)		
		Quartzite & Shale (75/25%)	
			Shale & Brown Qzt. (rare white) (50/50%)
			White Quartzite (100%)
SEDIMENTARY STRUCTURES	Horizonal Burrows		
			Vertical Burrows
	Parallel Laminae		
		Wavy Parallel Laminae	
		Oscillation Ripples	
		Small Scale Flat Top Ripples	
			Simple Cross-stratification
			Planar Cross-stratification

Table 2. Vertical ranges of the characteristic fauna and flora, Swan Peak Formation, north-central Utah.

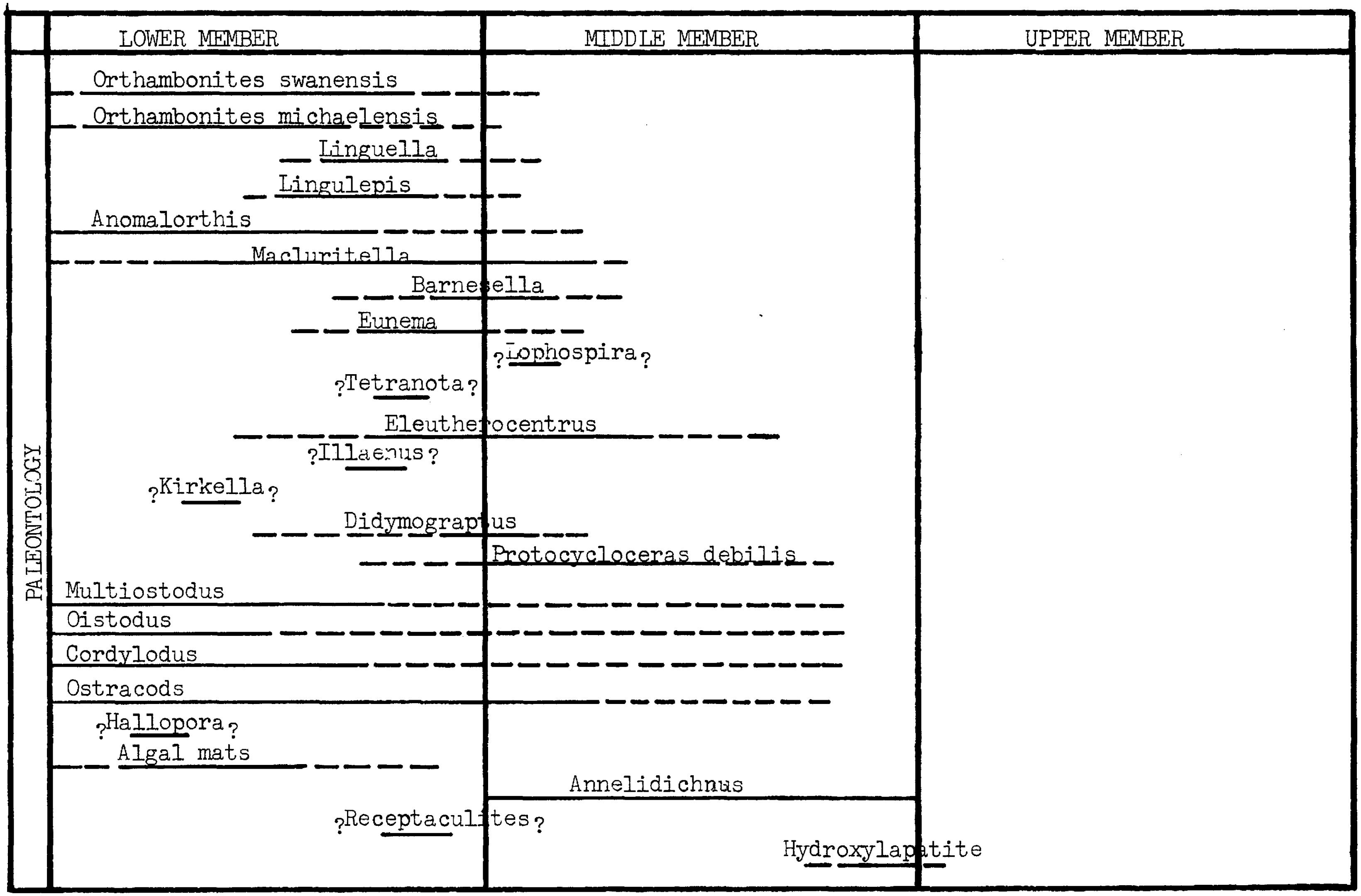

Table 3. Paleoecologic and lithologic characteristics of fossil taxa, Swan Peak Formation, north-central Utah

MAJOR TAXA	FEEDING TYPE: Primary Producers	FEEDING TYPE: Herbivores	FEEDING TYPE: Suspension Feeder	FEEDING TYPE: Non-selective Deposit Feeder	FEEDING TYPE: Selective Dep. Feeder/scav.	FEEDING TYPE: Pred./omnivore	RELATION TO ENVIRONMENT: Planktonic	RELATION TO ENVIRONMENT: Nektobenthonic	Epifaunal: Attached	Epifaunal: Sessile	Epifaunal: Mobile	Infaunal: Sessile	Infaunal: Mobile	SAL.TOL: Wide	SAL.TOL: Narrow (Normal)	ASSEMBLAGE: Upper Member	ASSEMBLAGE: Middle Member	ASSEMBLAGE: Lower Member	TYPE OF SUBSTRATE FOUND IN: Quartzite	TYPE OF SUBSTRATE FOUND IN: Shale	TYPE OF SUBSTRATE FOUND IN: Limestone
GASTROPODA																					
Barnesella		X									X				X		X			X	X
Eunema		X									X				X		X		X	X	
Lophospira		X									X				X		X			X	X
Macluritella		X									X				X		X			X	X
Tetranota		X									X				X		X	X	X	X	X
BRACHIOPODA																					
Anomalorthis			X						X						X		X	X			X
Hesperorthis			X						X						X		X			X	X
Linguella			X							(?)		X		X			X	X	X	X	X
Lingulepis			X							(?)		X		X			X	X	X	X	X
Orthambonites			X						X						X		X	X	X		X
TRILOBITAS																					
Eleutherocentrus					X						X				X		X		X	X	X
Illaenus					X			(?)			X				X		X		X	X	
CALYPTOPTOMATIDA																					
Hyolithes					(?)						(?)				X		X		X	X	
CEPHALOPODA																					
Proteoyoloceras					(?)	X		X							X		X	X	X	X	X
OSTRACODA			X		X						X				X		X	X	X	X	X
GYMNOLAEMATA																					
(?) Hallopora			X						X						X			X			X
STELLEROIDEA																					
Salteraster						X					X			X	X	(?)	X		X		
GRAPTOLITHINA																					
Didymograptus			X				X								X		X			X	
MISCELLANEA																					
Receptaculites	X									X					X			X			X
algal mats	X									X				X				X			X
vertical burrows			X									X		X		X			X		
horizontal burrows				X	X								X		X	(?)	X	X	X	X	X
Agnatha					X			X							X	X	X		X		

Table 4. Summary of the trace fossils and their characteristics in the Swan Peak Formation and Eureka Quartzite.

TRACE FOSSILS	BEHAVIORAL TYPES					FORMATION OR MEMBER				PRESERVATIONAL TYPES							SUBSTRATE			FACIES (Seilacher, 1964)			
										SEMI-RELIEFS				FULL RELIEFS									
										Epi-reliefs		Hypo-reliefs			Filling								
	Repichnia	Pascichnia	Fodinichnia	Domichnia	Cubichnia	Eureka	Upper member	Middle member	Lower member	Positive	Negative	Positive	Negative	Original Cavity	Sedimen-tation	Backfilled	Quartzite	Shale	Limestone	Skolithos	Cruziana	Zoophycos	Nereites
Annelidichnus			X					X				X				X	X	X			X		
Asterophycus			X					X		X			X			X	X				X		
Chondrites			X						X							X	X	X	X		X	X	
Cruziana	X							X	(?)		X	X					X	(?)	(?)		X		
Gorida	X									X	X						X				X		
Laevicyclus				X		X	X				X			X	X	X	X			X			
Pin-hole pits						X																	
Planolites			X						X						(?)	X	(?)		X			X	
Rusophycus					X			X			X	X					X				X		
Scolicia	X	X				X	X	X		X		X					X			X	X		
Skolithos				X		X	X			X	X				X		X			X			
Teichichnus			X	(?)		X	X								X	X	X			X			
Tomaculum	X							X	X	X							X	X			X	X	

Table 5. List of fossils collected from the lower and middle members, Swan Peak Formation, north-central Utah.

Phylum Arthropoda
- Class Trilobita
  - *Eleutherocentrus petersoni*
  - *Kirkella* sp.
  - *Illaenus* sp.
- Class Ostracoda
  - unidentified genus

Phylum Brachipoda
- Class Inarticulata
  - *Linguella* sp.
  - *Lingulepis* sp.
- Class Articulata sp.
  - *Anomalorthis* sp.
  - *Hesperorthis* sp.
  - *Orthambonites michaelis*
  - *Orthambonites swanensis*

Phylum Bryozoa
- Class Gymnolaemata
  - (?)*Hallopora* sp.

Phylum Chordata
- Class Graptolithina
  - *Didymograptus artes*
  - *Didymograptus bifidus*
- Class Agnatha
  - unidentified genus (Hydroxylapatite plates)

Phylum Echinodermata
- Class Stelleroidea
  - *Salteraster* sp.

Phylum Mollusca
- Class Calyptomatida
  - *Hyolithes* sp.
- Class Cephalopoda
  - *Protocycloceras debillis*
  - unidentified genus
- Class Castropoda
  - *Barnesella* sp.
  - *Eunema* sp.
  - *Lophospira* sp.
  - *Macluritella* sp.
  - *Tetranota* sp.

Table 5. Continued

Miscellanea
Cordylodus sp.
Multiostodus sp.
Oistodus sp.
Trace fossils (See text and Table 4)
Flora
Receptaculites (two species)
Algal mats

Appendix C

Plates

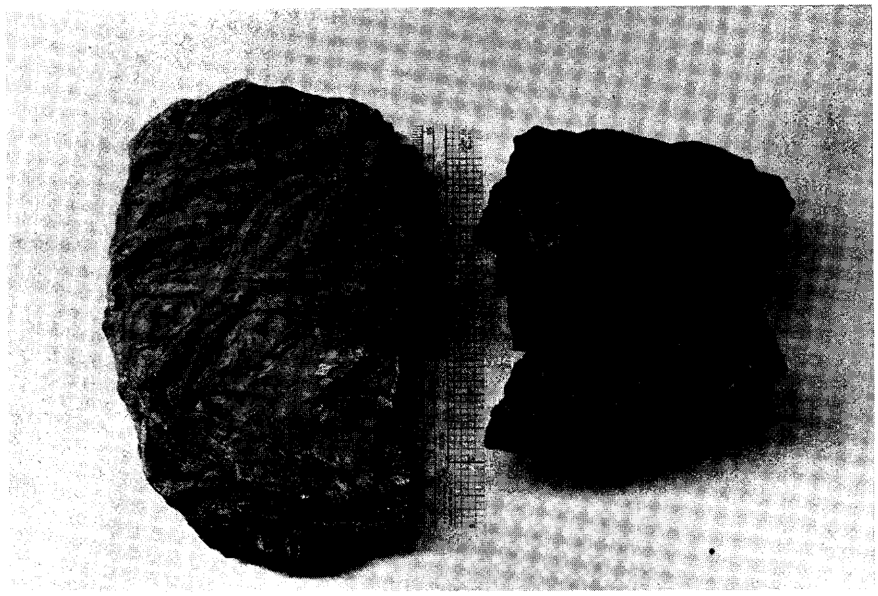

PLATE 1 Annelidichnus, characteristic trace fossil common in the middle member of the Swan Peak Formation.

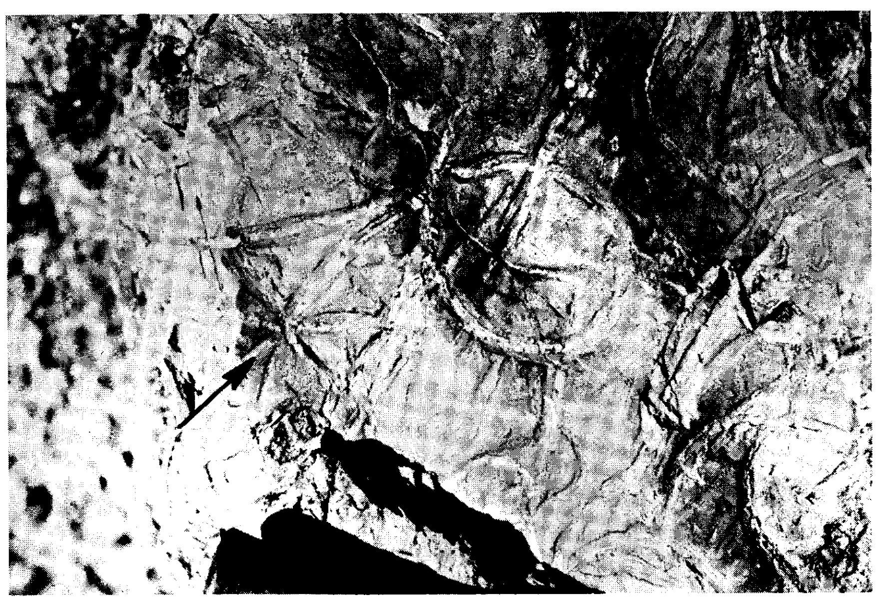

PLATE 2 Asterophycus; note intersection of radiating bulbous galleries at a central vertical shaft. Upper middle member, Swan Peak Formation, Wellsville Mountain.

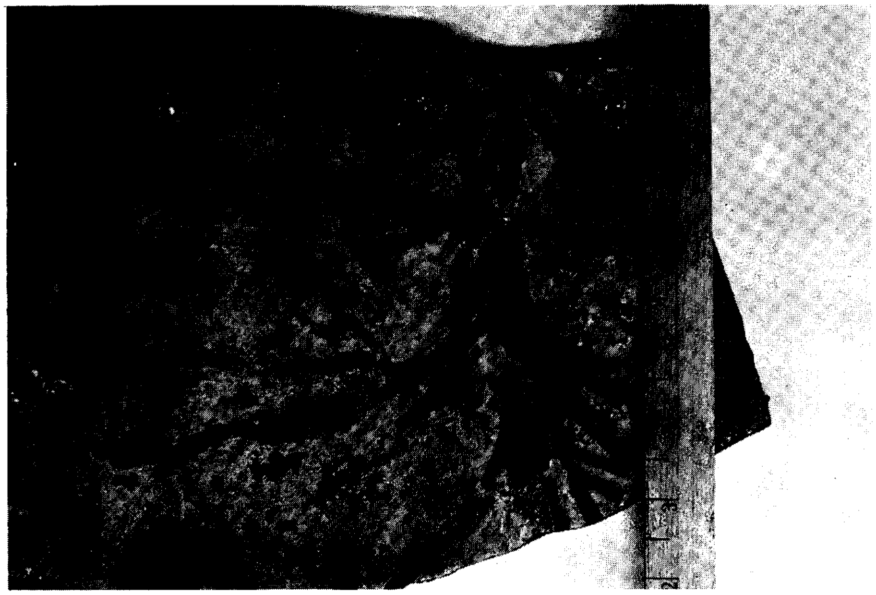

PLATE 3 Chondrites, a feeding burrow common in the lower member, Swan Peak Formation.

PLATE 4 Laevicyclus; preservational types vary from a simple one-ring variety to a complex ring-in-ring variety with a central stock.

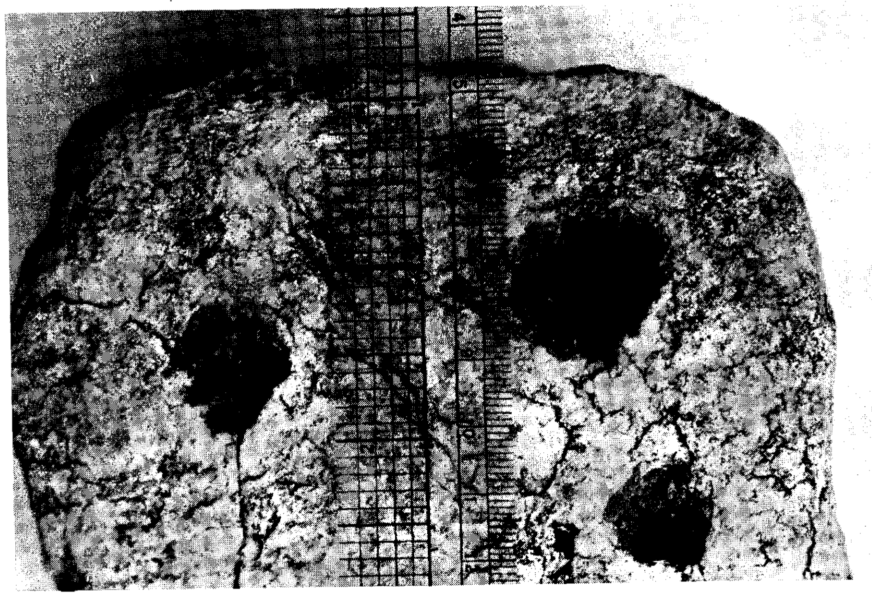

PLATE 5 The weathered "burrow" of Laevicyclus, from the upper member, Swan Peak Formation, Soda Springs Hills, Idaho (Schulingkamp 1972, Section F)

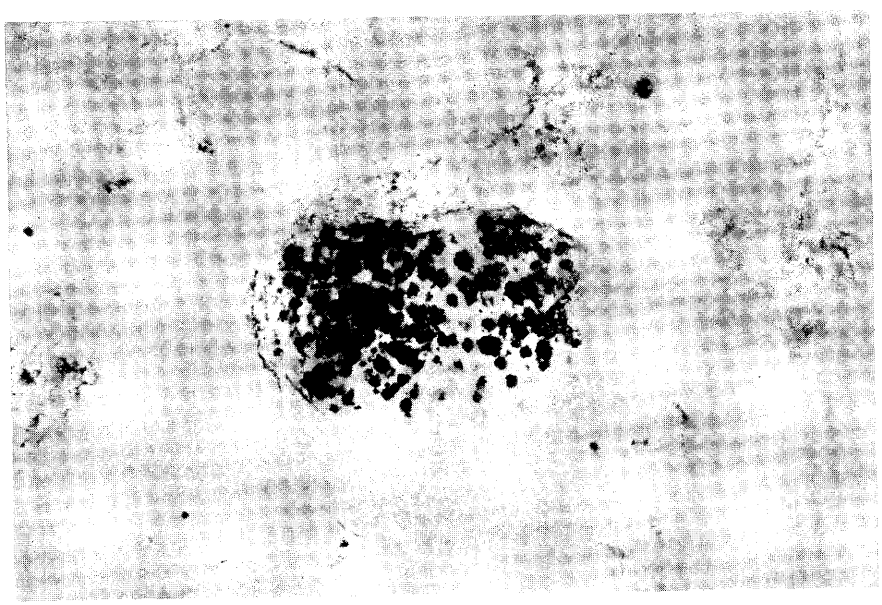

PLATE 6 Pseudopelleted wall of Laevicyclus, Eureka Quartzite Newfoundland Range (Section 3). (Trace fossil is approximately 2.5 cm across)

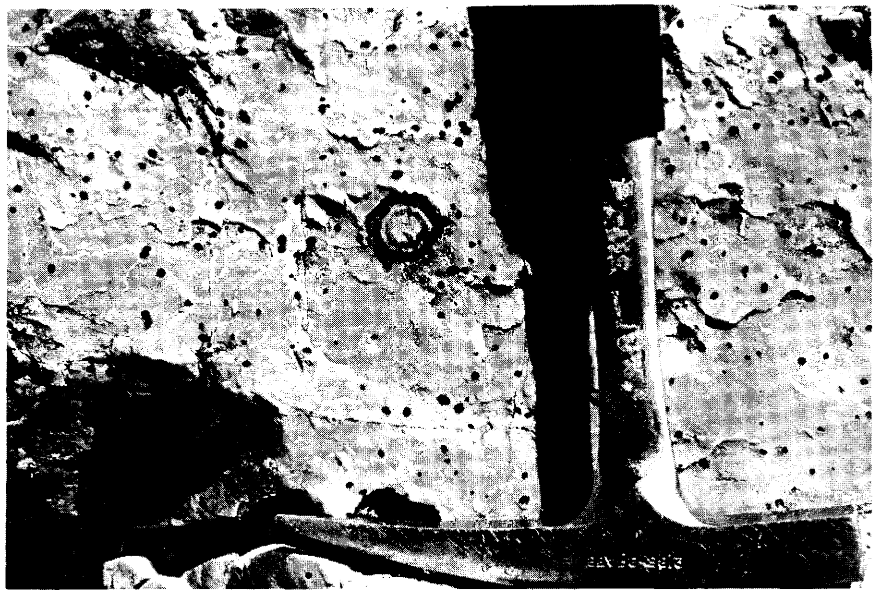

PLATE 7 Laevicyclus and pin-hole-pits, Eureka Quartzite, Newfoundland Range, (Section 3).

PLATE 8 Scolicia, a gastropod pascichnia, middle member, Swan Peak Formation, Hilyard's Canyon, Utah (Schulingkamp, 1972, Section L).

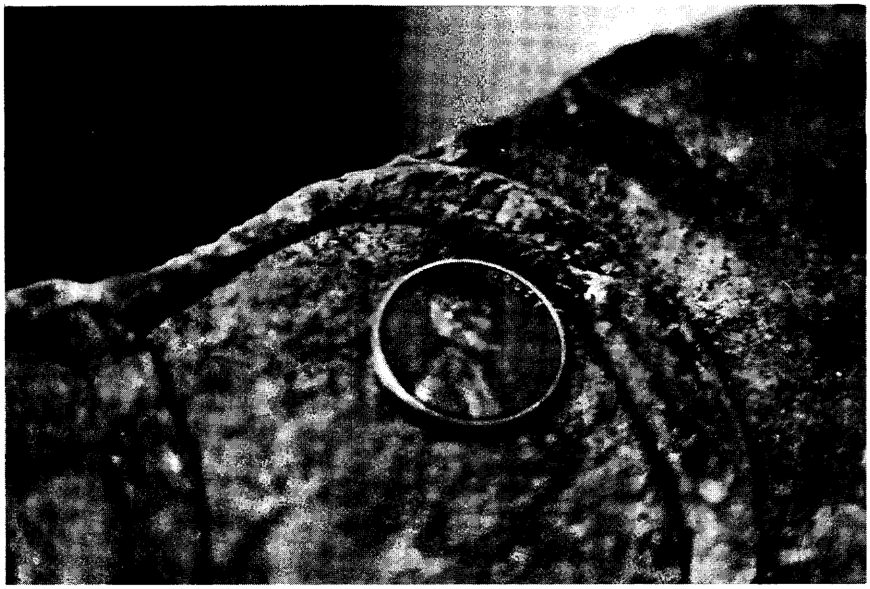

PLATE 9 Close-up of diataxic trail of Scolicia shown in Plate 8.

PLATE 10 Another preservational type of Scolicia, middle member, Swan Peak Formation, Hilyard's Canyon, Utah.

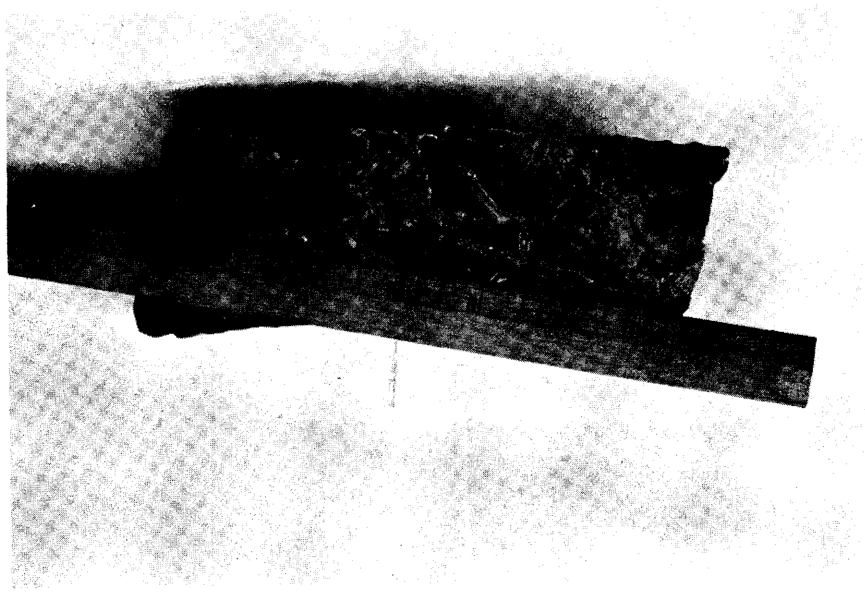

PLATE 11 Scolicia from the Eureka Quartzite Newfoundland Range, (Section 3).

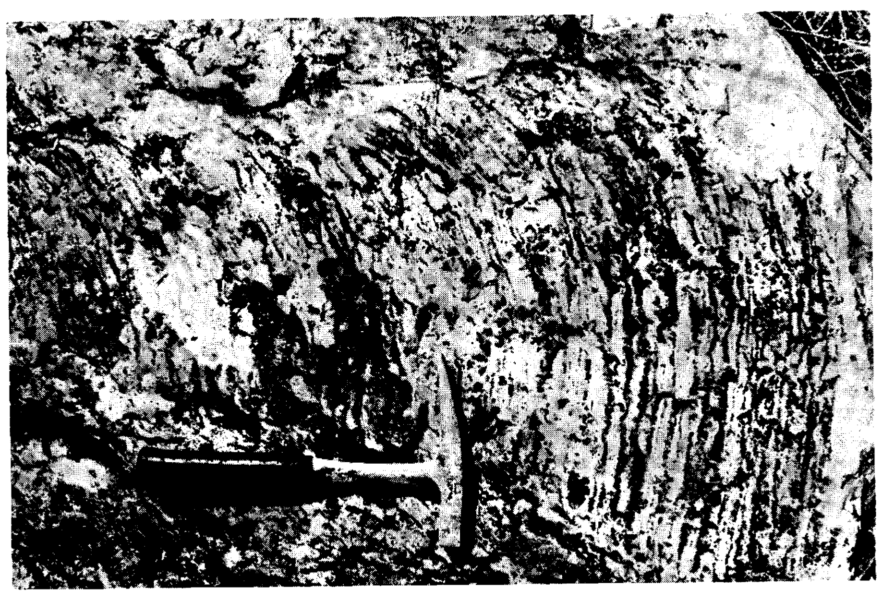

PLATE 12 Skolithos, a characteristic trace fossil common in the upper member of the Swan Peak Formation.

PLATE 13 Teichichnus, both longitudinal and transverse vertical sections, lower part of upper member, Swan Peak Formation (near Section 11).

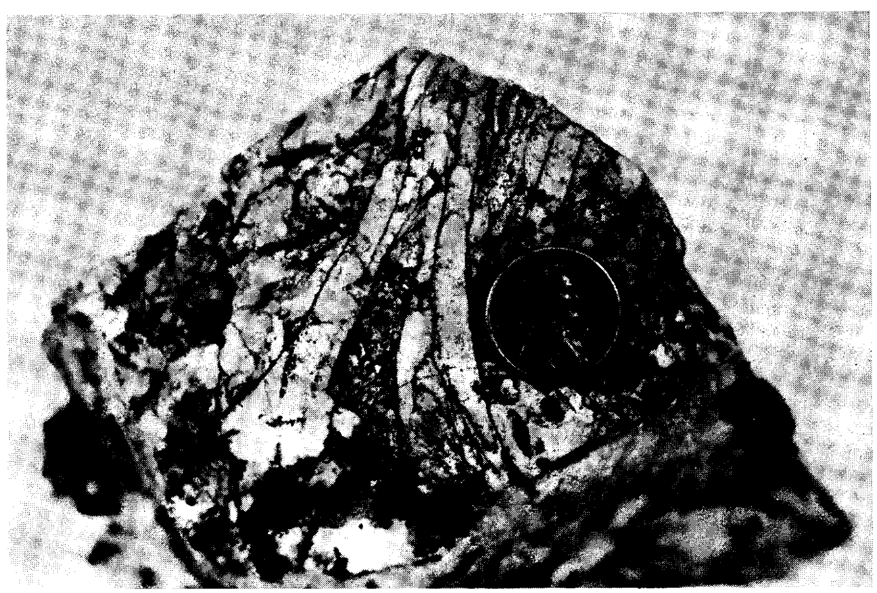

PLATE 14 Teichichnus, vertical transverse section.

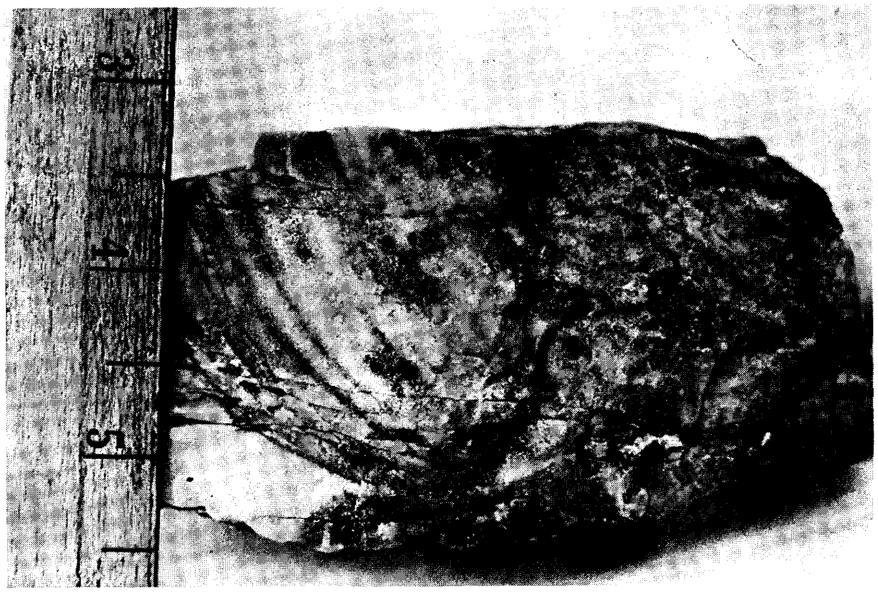

PLATE 15 Teichichnus, longitudinal section exhibiting vertically stacked galleries.

PLATE 16 Tomaculum, clusters of fecal material found in the lower member, Swan Peak Formation.

Appendix D

Stratigraphic Sections

SECTION 1

Location: Steep east-facing slope just north of fault, south side of Jenkins Canyon, Silver Island Range, Tooele County, Utah. SE, NW, Sec. 9, T2N, R17W.

Fish Haven Dolomite

Sharp, planar contact

Eureka Quartzite		Thickness in feet
18.	Quartzite, grayish blue (5PB5/2) to medium dark gray (N4), weathers light brown (5YR6/4) to grayish orange (10YR7/4), fine to medium grained, parallel and wavy parallel laminated, common horizontal burrow 0.3 foot long and 0.03 foot in diameter, Skolothos rare but more common near base of unit, average bed thickness 1.19 ft.	10.8
17.	Covered interval, quartzite talus	7.8
16.	Quartzite, medium bluish gray (5B5/1) to light gray (N7), weathers pinkish gray (5YR8/1) to very light gray (N8), fine grained, parallel laminated in upper part, structureless and burrow mottled in lower part, average bed thickness 2.12 ft.	19.1
15.	Quartzite, grayish orange pink (5YR7/2) to very light gray (N8), weathers grayish orange (10YR7/4), fine grained, parallel laminated in upper foot but structureless otherwise, average bed thickness 1.94 ft.	9.7
14.	Quartzite, light gray (N7), weathers very light gray (N8), fine grained, low-angle south-dipping simple cross-laminae less than 0.02 foot thick, average bed thickness 0.6 ft.	4.0
13.	Quartzite, light gray (N7) to medium gray (N5), weathers pinkish gray (5YR8/1) to grayish orange pink (5YR8/4), very fine grained, structureless, average bed thickness 2.12 ft.	17.0
12.	Quartzite, medium light gray (N6) to light bluish gray (5B7/1), weathers moderate reddish borwn (10R4/6), fine grained, upper 2.0 ft. simple cross-laminae with common low-angle south-dipping laminae, lower 6.1 feet structureless, average bed thickness 2.10 ft.	8.1

		Thickness in feet
11.	Quartzite, medium light gray (N6) to light bluish gray (5B7/1), weathers light gray (N7), very fine grained, structureless, but weathered surfaces display slight mottling, average bed thickness 2.10 ft.	28.5
10.	Covered interval, quartzite talus	74.0
9.	Quartzite, medium light gray (N6), weathers light gray (N7) to moderate brown (5YR4/4), medium grained, slightly calcareous, parallel and wavy parallel laminae 0.01 to 0.03 foot thick present in upper half of unit, common Skolithos in lower half of unit	2.7
8.	Covered interval, quartzite talus	14.5
7.	Quartzite, dark gray (N3) to pale yellowish brown (10YR6/2) to light gray (N7), weathers dark reddish brown (10R3/4) to pale yellowish brown (10YR6/2), fine grained to medium grained, simple south-dipping cross-laminae in upper parts of beds, structureless to burrow mottled in lower parts of beds, average bed thickness 0.91 ft.	6..4
6.	Covered interval, quartzite talus	11.2
5.	Dolomite, medium light gray (N6), weathers medium gray (N5), finely crystalline, highly contorted to convoluted laminae	0.4
4.	Quartzite, medium bluish gray (5B5/1) to light gray (N7), weathers light gray (N7), fine grained, slightly calcareous, structureless, average bed thickness 2.76 ft.	22.1
3.	Covered interval, quartzite talus	15.1
2.	Quartzite, dark bluish gray (5B3/1), weathers moderate reddish brown (10R4/6), very fine grained, upper 0.4 foot and lower 0.2 foot of unit parallel and wavy parallel laminated, abundant Skolithos in middle of unit, average bed thickness 1.75 ft.	3.5
1.	Covered interval, quartzite talus	33.5
	Total	288.4

Crystal Peak Dolomite

SECTION 2

Location: East-facing slope above low escarpment formed by Crystal Peak Dolomite, southernmost exposure of Eureka Quartzite, eastern side of Newfoundland Range, Box Elder County, Utah. Sec. 6 (unsurveyed), T3N, R13W, Lat. 41°01'00"N, Long. 113°21'00"W.

Fish Haven Dolomite

Sharp, planar contact

Eureka Quartzite		Thickness in feet
16.	Covered interval, quartzite talus	3.6
17.	Quartzite, medium dark gray (N4) to dark gray (N3), weathers moderate brown (5YR4/4) to light gray (N7), fine to medium grained, very slightly calcareous in part, common Skolithos and rare Laevicyclus, average bed thickness 1.03 ft.	14.1
16.	Covered interval, quartzite talus	3.6
15.	Quartzite, light bluish gray (5B/1) to medium bluish gray (5B7/1), weathers light gray (N7) to grayish orange pink (5YR7/2), fine grained, predominantly south-dipping simple cross-laminae with less common north-dipping laminae, rare poorly preserved u-shaped burrows near top of unit, average bed thickness 1.09 ft.	15.3
14.	Quartzite, light bluish gray (5B7/1) to medium bluish gray (5B5/1), weathers very light gray (N8), iron-oxide stains, fine-grained, structureless, rare Laevicyclus, average bed thickness 1.88 ft.	30.1
13.	Quartzite, light bluish gray (5B7/1) to medium bluish gray (5B5/1), weathers light brown (5YR5/6) to grayish orange pink (5YR7/2), common iron-oxide stains, fine grained, common to abundant Skolithos and Laevicyclus in upper parts of beds, parallel laminae and south-dipping simple cross-laminae 0.01 ft thick common near base of beds, average bed thickness 3.66 ft.	51.3

		Thickness in feet
12.	Quartzite, light bluish gray (5B7/1) to grayish blue (5PB5/2), weathers white (N9) to moderate yellowish brown (10YR5/4), common iron-oxide stains, fine grained common south-dipping simple cross-laminae 0.02 ft. thick, common Skolithos and abundant Laevicyclus, average bed thickness 4.23 ft.	59.3
11.	Quartzite, medium bluish gray (5B5/1) to light gray (5B7/1), weathers light gray (N7), common iron-oxide stains, fine grained common north-dipping simple cross-laminae 0.02 ft. thick, structureless elsewhere, average bed thickness 1.88 ft.	17.0
	Offset lower part of section to approximately same stratigraphic horizon 100 yards north on adjacent ridge.	
10.	Quartzite, pale blue (5PB7/2) to grayish blue (5PB5/2), weathers light bluish gray (5B7/1), common iron-oxide stains, medium grained, upper half of unit structureless with rare Laevicyclus and pin-hole pits, lower half with common parallel laminae 0.02 ft. thick, individual bedding surfaces poorly displayed on vertical joint face	26.8
9.	Covered interval, quartzite talus	20.8
8.	Quartzite, grayish blue (5PB5/2) to pale blue (5PB7/2), weathers grayish orange (10YR7/4), common iron-oxide stains, medium grained, common south-dipping simple cross-laminae 0.02 ft. thick, rare Laevicyclus and common Skolithos in upper parts of beds, average bed thickness 2.25 ft.	9.0
7.	Covered interval, quartzite talus	12.8
6.	Quartzite, grayish blue (5PB5/2) to pale blue (5PB7/2), iron-oxide stains, medium grained, structureless	2.6
5.	Covered interval, quartzite talus	2.6
4.	Quartzite, white (N9) to bluish white (5B9/1) to pale blue (5PB7/2), weathers very pale orange (10YR8/2), medium grained, upper part of unit structureless and bioturbated, common southwest-dipping simple and planar cross-laminae in lower part of unit, average bed thickness 2.70 ft.	12.0
3.	Covered interval, quartzite talus	7.1

		Thickness in feet
2.	Quartzite, grayish blue (5PB5/2) to pale blue (5PB7/2), fine grained, iron-oxide stains, structureless, average bed thickness 1.63 ft.	4.9
1.	Covered interval, quartzite talus	19.2
	Total	312.1

Crystal Peak Dolomite

SECTION 3

Location: top of section near crest on east side of Flirtation Ridge, in steep east-facing slope, Newfoundland Range, Box Elder County, Utah. NW, NW, Sec. 6, T4N, R13W.

Fish Haven Dolomite

Sharp, planar contact

Eureka Quartzite		Thickness in feet
16.	Quartzite, light gray (N7), weathers pale brown (5YR5/2), very fine to fine grained, common south-dipping low-angle simple cross-laminae, rare Laevicyclus, average bed thickness 1.30 ft.	5.2
15.	Quartzite, light gray (N7), weathers light brown (5YR6/4) to moderate brown (5YR3/4), fine to medium grained, wavy parallel laminated in upper part of unit and structureless in lower part, rare Laevicyclus, average bed thickness 0.81 ft.	13.8
14.	Quartzite, light gray (N7) to medium light gary (N6), weathers moderate brown (5YR3/4) to dark yellowish brown (10YR4/2), fine to medium grained, common south-dipping simple cross-laminae in upper two-thirds, structureless otherwise, common Laevicyclus and pin-hole pits (Plate 7), average bed thickness 2.40 ft.	47.9
13.	Quartzite, light gray (N7) to medium light gray (N6), weathers dark yellowish brown (10YR4/2), fine to medium grained, abundant south-dipping simple cross-laminae and rare sets of oscillation ripples, rare Laevicyclus and pin-hole pits, average bed thickness 3.35 ft.	47.0
12.	Quartzite, medium light gray (N6), weathers moderate yellowish brown (10 YR 5/4), fine to medium grained, structureless with abundant Laevicyclus and pin-hole pits, average bed thickness 2.57 ft.	20.4
11.	Quartzite, medium light gray (N6), weathers light brown (5YR6/4 to 5YR5/6), fine to medium grained, common high and low-angle south-dipping simple cross-laminae with rare sets of oscillation ripple marks, abundant Laevicyclus and pin-hole pits, average bed thickness 1.52 ft.	85.2

		Thickness in feet
10.	Quartzite, medium light gray (N6), weathers light brown (5YR6/4 to 5YR5/6), fine to medium grained, common to abundant low-angle southeast-dipping simple cross-laminae in upper half of unit, structureless to parallel laminae in lower part, rare to common Laevicyclus and pin-hole pits throughout unit, average bed thickness 1.35 ft.	35.3
9.	Quartzite, medium light gray (N6), weathers light brown (5YR6/4 to 5YR5/6), fine to medium grained, rare to common parallel laminae and south-dipping simple cross-laminae, rare Laevicyclus and pin-hole pits, average bed thickness 1.76 ft.	27.7
8.	Quartzite, medium light gray (N6), weathers light brown (5YR6/4 to 5YR5/6), fine to medium grained, structureless, average bed thickness 1.39 ft.	19.4
7.	Quartzite, medium light gray (N6), weathers light brown (5YR6/4 to 5YR5/6), fine to medium grained, parallel laminated, rare Laevicyclus, average bed thickness 0.75 ft.	9.0
6.	Covered interval, quartzite talus	7.0
5.	Quartzite, medium light gray (N6), weathers light brown (5YR6/4 to 5YR5/6), medium grained, slightly calcareous, structureless, average bed thickness 2.24 ft.	15.7
4.	Quartzite, medium light gray (N6), weathers light brown (5YR6/4 to grayish orange pink (5YR7/2), fine grained wavy parallel laminae, very rare Laevicyclus, average bed thickness 1.94 ft.	49.5
3.	Quartzite, medium light gray (N6) to light gray (N7), weathers light brown (5YR5/6) to grayish orange (10YR7/4), fine grained, predominantly wavy parallel laminae with rare low-angle southwest-dipping simple cross-laminae near middle of unit, average bed thickness 1.43 ft.	23.8
2.	Quartzite, medium light gray (N6), weathers moderate brown (5YR4/4) to light brown (5YR6/4), fine to medium grained, low-angle south-dipping cross-laminae and common wavy parallel laminae, average bed thickness 0.80 ft.	14.7

		Thickness in feet
1.	Quartzite, medium light gray (N6), weathers light brown (5YR5/6), very fine to fine grained, parallel laminae with rare sets of oscillation wave ripples, average bed thickness 0.35 ft.	48.5
	Total	470.1

Sharp, planar contact

Crystal Peak Dolomite	Total	97.0

Swan Peak Formation

13.	Quartzite, medium light gray (N6) to light brownish gray (5YR6/1), weathers very light gray (N8) to grayish orange (10YR7/4), fine grained, wavy parallel laminae, common thin (0.02 ft) shale partings, average bed thickness 0.64 ft.	31.4
12.	Dolostone, dark gray (N4), weathers light brownish gray (5YR6/1), finely crystalline, predominantly structureless with hint of algal laminae, average bed thickness 0.25 ft. ...	23.4
11.	Quartzite, medium light gray (N6) to light brownish gray (5YR6/1), weathers very light gray (N8) to grayish orange (10YR7/4), fine grained, wavy parallel laminae, very thin (0.02 ft.) shale partings common, average bed thickness 0.45 ft.	6.4
10.	Dolostone, medium dark gray (N4), weathers light brownish gray (5YR6/1), finely crystalline, structureless, average bed thickness 0.28 ft.	13.0
9.	Quartzite, medium light gray (N6) to light brownish gray (5YR6/1), weathers very light gray (N8) to grayish orange (10YR6/4), fine grained, wavy parallel laminae with rare low-angle south-dipping cross-laminae near base of unit, rare Annelidichnus, average bed thickness 0.56 ft.	18.0
8.	Quartzite and calcilutite, interbedded; Quartzite, dark gray (N3), coarse grained, structureless and bioturbated, average bed thickness 0.74 ft.; Calcilutite, medium dark gray (N4), weathers medium light gray (N6), local iron-oxide stains, wavy parallel laminae, unidentifiable arcuate fossils possibly bivalves or brachipods, average bed thickness 0.60 ft.	53.0

		Thickness in feet
7.	Calcarenite and shale, interbedded; Calcarentite, medium dark gray (N4), weathers medium light gray (N6), common algal laminae, average bed thickness 0.30 ft.; Shale, pale yellowish brown (10YR6/2), hard, thinly laminated, average bed thickness 0.02 ft.	5.2
6.	Quartzite, very light gray (N8), weathers light gray (N7), coarse grained, hint of wavy parallel laminae and rare low-angle south-dipping simple cross-laminae, average bed thickness 0.75 ft.	13.6
5.	Dolostone and calcisiltite; interbedded; Dolostone, medium dark gray (N4), weathers light gray (N7), finely crystalline, structureless, average bed thickness 0.25 ft; Calcisilitite, medium light gray (N6), weathers pale red (5R6/2), wavy parallel laminae with many beds displaying boudinage-like structure, average bed thickness 0.35 ft.	14.4
4.	Calcarenite, medium gray (N5), weathers light olive gray (5Y6/1) to medium light gray (N6), quartzose, individual laminae pinch and swell laterally, rare to common algal laminae, rare interlaminated shale, average bed thickness 0.50 ft.	29.4
3.	Dolostone, medium gray (N5), weathers light gray (N7) to light olive gray (5Y6/'), medium crystalline, wavy parallel laminae, common unidentifiable recrystallized fossil hash, average bed thickness 0.20 ft.	3.0
2.	Calcarenite, dark gray (N3) to medium gray (N5), weathers very pale orange (10YR8/2) to grayish orange pink (5YR7/2), sandy, wavy parallel laminae with rare to common algal laminae, rare to common fossil hash of ostracods and unidentifiable material, average bed thickness 0.50 ft.	39.0
1.	Sandstone, medium light gray (N6) to medium dark gray (N4), weathers grayish orange pink (5YR7/2) to medium gray (N5), coarse grained, calcareous, predominantely structureless with hint of wavy parallel laminae, rare to common <u>Annelidichnus</u>, average bed thickness 0.35 ft.	6.0
	Total	255.8

		Thickness in feet
Lehman Formation		
2.	Calcilutite, calcisiltite and shale, interbedded; Limestone, medium dark gray (N4) to grayish black (N2), weathers dusky blue (5PB3/2) to dark gray (N3), argillaceous, thinly and uniformly bedded, common oscillation ripple marks, average bed thickness 0.32 ft.; Shale, grayish red purple (5RP4/2), very thinly bedded (0.02 ft.); interbeds of pale reddish brown (10R5/4), fine-grained sandstone that increase in abundance upward in unit, rare to common <u>Annelidichnus</u> in sandstone beds	107.2
1.	Calcilutite and shale, interbedded; Calcilutite, dusky blue 5(PB3/2) to dark gray (N3), weathers medium dark gray (N4) to dark greenish gray (5GY4/1), argillaceious, thinly and uniformly bedded, rare to common oscillation ripples, average bed thickness 0.41 ft.; Shale, grayish red purple (5RP4/2), thinly laminated (0.03 ft.) throughout unit, rare to common <u>Eleutherocentrus</u> sp. and unidentifiable fossils throughout unit	217.6
	Total	324.8
Kanosh Shale		
5.	Calcilutite, calcarenite and argillite, interbedded; Limestone light gray (N7), weathers medium light gray (N6), silty and argillaceous, parallel laminae, rare oscillation ripples, rare Orthambonites sp. and unidentifiable fossils, average bed thickness 0.70 ft.; Argillite, olive black (5Y2/1) to olive gray (5Y4/1) to yellowish brown (!)YR4/2), hard, average bed thickness 0.11 ft.	114.0
4.	Argillite, olive black (5Y2/1), hard, sandy in upper part, average bed thickness 0.40 ft., rare interbedded light brown (5Yr6/4), fine-grained sandstone and medium light gray (N6) calcarenite	42.5
3.	Calcilutite, medium light gray (N6) weathers light gray (N7), parallel laminae, sandy and silty, average bed thickness 2.20 ft.	10.0

		Thickness in feet
2.	Argillite, dark yellowish brown (10YR4/2), weathers grayish orange (10YR7/4) to dark yellowish brown (10 YR4/2), silty and calcareous, average bed thickness 0.50 ft.	7.5
1.	Argillite, olive black (5Y2/1) to olive gray (5Y4/1), hard, silty, average bed thickness 0.20 ft.	11.0
	Total	205.0

Sharp, planar contact

Garden City Formation

SECTION 4

(Eureka Quartzite thur Kanosh Shale measured by Paddock, 1956)

Fish Haven Dolomite

		Thickness in feet
Eureka Quartzite		
3.	Quartzite, dark gray, fine grained, thick bedded, some weathered exposure are sandy and friable	20
2.	Quartzite, grayish-white, fine grained, massively bedded, highly jointed, weathers brownish-gray to white, iron-oxide staining with dark brown weathering spots, small pits and pocks with dark brownish stain occur 50 feet from the base to 150 feet, unit becomes dark gray toward the top	455
1.	Covered interval, quartzite talus	15
	Total	490
Crystal Peak Dolomite	Total	147.0
Swan Peak Formation (upper member of Swan Peak of Paddock)		
10.	Quartzite, gray white, fine grained, weathers brown-gray thick bedded and calcareous	38
9.	Dolomite, black, fine crystalline, weathers brown-gray, thin bedded, platy toward top with silty laminae standing out as irregular brown streaks, two feet below top is tons of gastropod hash 3" to 6" thick	25
8.	Quartzite, dark gray, fine grained, weaters brown, cross bedded with dolomitic intercalations	5
7.	Dolomite, black, fine crystalline, fucoidal, thin bedded, weathers brown-gray	20
6.	Quartzite, dark gray, very fine grained to fine grained weathers brown, cross bedded, thick bedded and calcareous	50

		Thickness in feet
5.	Limestone, black, fine crystalline to dense, thin bedded and platy	5
4.	Dolomite, black, fine crystalline, thick bedded	5
3.	Limestone, black, fine crystalline to dense, thin bedded and platy	48
2.	Sandstone, medium gray, fine grained, semi-quartzitic, weathers pink to brown-gray, very calcareous, thin bedded	5
1.	Calcarenite, medium gray to black, dolomitic at base, fine crystalline, weathers brown-gray, massive bedded to platy in local spots, forms blacky cliff and slope, 20 feet from base are orthid? brachiopod and gastropod steinkerns. Coarse crystalline and darker gray toward top	32
	Total	233

Lehman Formation (upper member of Swan Peak of Paddock subdivision based on Sections 2 and 3)

11.	Quartzite, white, fine grained, massive bedded	6
10.	Dolomite, light gray, fine crystalline, weathers brown-gray	5
9.	Quartzite, white, fine grained, calcareous, weathers gray-white	6
8.	Calcarenite, medium gray, fine to coarse crystalline, weathers brownish-gray, thin bedded, slope former, becomes sandy toward top. Contains Rhaphistoma? sp., gastropod steinkerns, and organic debris 15 feet from the top. Silt content gives tan brown-gray weathering appearance	55
7.	Quartzite, very dark gray, fine grained, calcareous, weathers brown-gray, slightly friable on weathered exposure	4

		Thickness in feet
6.	Calcarenite, medium gray, fine to coarse crystalline, weathers brownish-gray, thin bedded, slope former, becomes sandy toward top. Contains Rhaphistoma? sp., gastropod steinkerns, and organic debris 15 feet from the top	14
5.	Sandstone, dark gray, fine grained, semi-quartitic to sandy, weathers brownish-gray, friable	70
4.	Covered, float indicates calcarenite as below and medium grained, dark gray quartz sandstone	45
3.	Calcarenite, medium gray, fine to coarse crystalline, weathers brownish-gray, thin bedded, slope former, becomes sandy toward top. Contains Rhaphistoma? sp., gastropod steinkerns, and organic debris 15 feet from the top	35
2.	Quartzite, medium gray, fine grained, cross-bedded, weathers tan-gray, calcareous, ledgemaker	35
1.	Quartzite, dark gray, weathers brownish-gray, semi-quartzitic in spots, medium grained, sub-angular grains, calcareous, with a few argillitic inter-calcations about two feet thick, five feet from base; base covered, thin bedded to platy, top one foot very dark gray to black	35
	Total	310

Kanosh Shale (lower member of Swan Peak of Paddock)

8.	Siltstone argillitic, dark to medium gray, weathers reddish-brown to brownish-black, platy and slightly calcareous, contains orthid brachiopods, graptolites, ostrocods, and trilobite pygidia, fauna occur in middle and basal portions, with some zones rendered shaly. (zone "M")	100
7.	Argillite, intercalated with brown-gray limestone beds irregular bedded, brachiopods found throughout basal member from this horizon up	220
6.	Argillite, black and dense, weathers to carbonaceous black-red hue with greasy appearance, slightly calcareous, massive bedded	15

		Thickness in feet
5.	Limestone conglomerate, gray-brown	1
4.	Argillite, black and dense, weathers to carbonaceous black-red hue with greasy appearance, slightly calcareous, massive bedded	15
3.	Limestone, light gray, fine crystalline, weathers light gray, slightly silty, thick bedded	10
2.	Argillite, tan, weathers brownish-tan, calcareous, massive bed	10
1.	Argillite, gray-green, very slightly calcareous, hard and thin bedded, some silty streaks, weathers brown-red to brown-gray	12
	Total	398

Garden City Formation

SECTION 5

Location: Strongknob Mountain Section, approximately 2 miles northwest of the town of Lakeside, Box Elder County, Utah. Sec. 16 T6N, R9W. Lat, 41° 14'20" N, Long. 112°52'30" W.

Fish Haven Dolomite

	Sharp planar contact	Thickness in feet
Eureka Quartzite		
8.	Quartzite, white (N9) to very light gray (N8), weathers very pale orange (10YR8/2) to pinkish gray (5YR8/1), medium grained, common parallel laminae and high-angle south-dipping cross-laminae, predominantly unburrowed.	60.0
7.	Quartzite, white (N9) to very light gray (N8), weathers very pale orange (10YR8/2) to pinkish gray (5YR8/1), abundant *Laevicyclus* and pin-hole pits	25.0
6.	Quartzite, white (N9) to very light gray (N8), weathers very pale orange (10YR8/2) to pinkish gray (5YR8/1), medium grained, common parallel laminae and high-angle south-dipping cross-laminae predominantly unburrowed.	70.0
5.	Quartzite, white (N9) to very light gray (N8), weathers very pale orange (10YR8/2) to pinkish gray (5YR8/1) abundant *Laevicyclus* and pin-hole pits.	60.0
4.	Quartzite, white (N9) to very light gray (N8), weathers very pale orange (10YR8/2) to pinkish gray (5YR8/1), medium grained, common parallel laminae and high-angle south-dipping cross-laminae, predominantly unburrowed	2.0
3.	Quartzite, white (N9) to very light gray (N8), weathers very pale orange (10YR8/2) to pinkish gray (5YR8/1), abundant *Laevicyclus* and pin-hole pits	9.0
2.	Quartzite, white (N9) to very light gray (N8), weathers very pale orange (10YR8/2) to pinkish gray (5YR8/1), medium grained, common parallel laminae and high-angle south-dipping cross-laminae, predominantly unburrowed	10.0

1.	Quartzite, white (N9) to very light gray (N8), weathers very plae orange (10YR8/2) to pinkish gray (5YR8/1), abundant <u>Laevicyclus</u> and pin-hole pits	60.0
	Total	298.0

Covered, base not exposed

SECTION 6

Location: West Promontory Range, measured approximately 1.5 miles east of the road to the Old Fort Station, Box Elder County, Utah, NW, NW, Sec. 29, T9N, R6W.

Fish Haven Dolomite

Swan Peak Formation

Sharp planar contact

Upper Member		Thickness in feet
22.	Quartzite, white (N9), weathers pinkish gray (5YR8/1), fine to medium grained, structureless and heavily jointed, average bed thickness 2.45 ft.	22.1
21.	Quartzite, white (N9), weathers pinkish gray (5YR8/1), find to medium grained, Skolithos weathered in relief on top bedding surfaces but structureless otherwise, fault breccia present, average bed thickness 5.67 ft.	22.7
20.	Quartzite, very light gray (N8), weathers very light gray (N8), fine grained, scour surface, 1.0 to deep and 2.5 feet wide present at top of unit	3.9
19.	Quartzite, very light gray (N8), fine grained, common low-angle (5°) simple south-dipping cross-laminae present	3.9
18.	Quartzite, very light gray (N8) to mottle grayish orange pink (10R8/2), weathers very light gray (N8) to grayish orange (10YR7/4) fine grained, structureless with hint of low-angle (3°) simple south-dipping cross-laminae, average bed thickness 2.91 ft.	38.1
17.	Quartzite, mottled grayish orange pink (10R8/2) to pale red (10R6/2), weathers grayish orange (10YR7/4), fine grained, rare low angle (12°) simple north-dipping cross-laminae present with abundant burrow mottled structures, average bed thickness 2.05 ft.	8.20
16.	Quartzite, mottled grayish orange pink (10R8/2) to pale red (10R6/2) weathers grayish orange (10YR7/4), fine grained, structureless average bed thickness 2.10 ft.	33.7
15.	Quartzite, white (N9), weathers grayish orange (10YR7/4), medium grained, common-low angle (10°) cosets of simple north and south-dipping cross-laminae present	2.1

		Thickness in feet
14.	Quartzite, white (N9), weathers grayish orange (10YR7/4), medium grained, Skolithos weathered in relief on top bedding surfaces but structureless otherwise with 0.1 ft. diameter grayish red (10R4/2) rare to common concretions, average bed thickness, 3.19 ft	47.9
13.	Quartzite, moderate orange pink (10R7/4) to grayish orange pink (5YR7/2), weathers grayish brown (5YR3/2 to light brown (5YR6/4), fine grained, structureless, average bed thickness 2.75 ft.	49.5
12.	Quartzite, grayish orange pink (5YR7/2), weathers light brown (5YR6/4) to moderate orange pink (5YR8/4), find grained, parallel laminated, average bed thickness 2.16 ft.	13.0
11.	Quartzite, very light gray (N8) to very pale orange (10YR8/2), weathers light brown (5YR5/6) to very pale orange (10YR8/2), fine to medium grained, structureless with common to rare Laevicyclus near top of unit, average bed thickness 3.44 ft.	24.1
10.	Quartzite, pinkish gray (5YR8/1) to grayish orange pink (10R8/2) to pale red (5R6/2), weathers grayish red (5R4/2) to light brown (5YR5/6), fine grained, structureless with common Skolithos weathered in relief on bedding surfaces, average bed thickness 2.97 ft.	77.3
9.	Quartzite, grayish orange (10YR7/4), weathers light brown (5YR6/4) to grayish orange (10YR7/4), fine to medium grained, structureless with local scour channels present, bed thickness 2.97 ft.	17.9
8.	Quartzite, grayish red (5R4/2), weathers light brown (5YR5/6), fine to medium grained, structureless with some liesagang-like bands, rare Skolithos on bedding surfaces, average bed thickness 2.18 ft.	21.9
7.	Quartzite, light gray (N7) to light brown (5YR6/4), weathers grayish pink (5R8/2) to grayish orange pink (10R8/2) to pale red (10R6/2), very fine to fine grained, structureless, average bed thickness 2.91 ft.	90.3
6.	Quartzite, very pale orange (10YR8/2), weathers very pale orange (10YR8/2) to dark yellowish orange (10YR6/6) fine grained, predominately structureless with hint of parallel laminae, scours 0.3 ft. deep and 1.0 ft. wide present in upper part of unit	5.2
	Subtotal	475.7

Middle Member		Thickness in feet
5.	Covered interval, Lake Bonneville terraces and talus of the upper quartzite member of the Swan Peak Formation obscure interval. Rock float of the characteristic middle member with Annelidichnus is present near base of covered interval	110.2
	Subtotal	110.2

Lower Member

4.	Calcarenite and shale, interbedded; calcarenite, medium dark gray (N4), weathers grayish orange (10YR7/4) to medium gray (N5), wavy parallel laminated, common Orthambonites swanensis shell hash near base of unit, shale, medium light gray (N6), hard and slightly calcereous, rare Receptaculites sp., average bed thickness 0.64 ft.	9.0
3.	Covered interval	51.0
2.	Sandstone, light gray (N7), weathers pale brown (5YR5/2), calcareous, hint of parallel laminae, common Chondrites and rare Planolites, average bed thickness 1.08 ft.	8.7
1.	Covered interval	31.6
	Subtotal	100.3
	Total	686.1

Garden City Formation

SECTION 7

Location: North Wellsville Section, Cottonwood Canyon, Box Elder County, Utah, SW, NW, Sec. 2, T10N, R2W.

Fish Haven Dolomite

Sharp planar contact

Swan Peak Formation

Upper Member		Thickness in feet
11.	Quartzite, very light gray (N8), weathers very pale orange (10YR8/2) fine grained, structureless, average bed thickness 1.24 ft.	10.0
10.	Quartzite, white (N9), weathers pinkish gray (5YR8/1), fine grained, structureless with common Skolithos weathered in relief on bedding surfaces, average bed thickness 1.07 ft.	18.3
9.	Quartzite, pale orange (10YR8/2) to pinkish gray (5YR8/1), weathers very pale orange (10YR8/2), fine grained, structureless with common grayish brown (5YR3/2) elongate (2.0 cm long and 0.5 cm thick) concretions, beds weather to a rouned blocky appearance, average bed thickness 1.49 ft.	16.4
8.	Quartzite, very pale orange (10YR8/2), weathers grayish orange (10YR7/4) to very pale orange (10YR8/2), fine grained abundant Skolithos, average bed thickness 1.60 ft.	8.0
7.	Quartzite, mottled grayish orange (10YR7/4) to grayish orange (10YR7/4), weathers dark yellowish orange (10YR6/6) to light brown (5YR6/4) to pale red (10R6/2), fine grained, structureless	4.9
6.	Quartzite, grayish orange (10YR7/4), weathers light brown (5YR6/4) to dark yellowish orange (10YR6/6), fine grained, burrow mottled, trace of hydroxylapatite near base of unit, average bed thickness 0.9 ft.	8.3
	Subtotal	65.9

Middle Member	Thickness in feet
5. Quartzite and shale, interbedded; Quartzite, light brown (5YR6/2) to grayish orange (10YR7/4), weathers very pale orange (10YR8/2) to dark yellowish orange (10YR6/6), very fine to fine grained, predominantly structureless with hint of parallel laminae outlined by hydroxylapatite, average bed thickness 0.64 ft; Shale, greenish gray (5GY6/1) to grayish orange pink (5YR7/2), hard, average bed thickness 0.10 ft., abundant _Annelidichnus_ throughout unit	15.6
4. Quartzite and shale, interbedded; Quartzite, grayish orange (10R3/4) to light brown (5YR5/6), weathers dark reddish brown (10R3/4) to pale yellowish brown (10YR6/2), fine grained, structureless, average bed thickness 0.38 ft; Shale, light olive gray (5Y6/1), shale units weathers to a chippy thinly laminated character, average bed thickness 0.04 ft., abundant _Annelidichnus_ throughout unit	17.3
3. Quartzite and shale, interbedded; Quartzite, grayish orange pink (5YR7/2) to grayish orange (10YR7/4), weathers moderate reddish orange (10YR6/6) to grayish orange (10YR7/4), fine grained, parallel and wavy parallel laminated, average bed thickness 0.30 ft.; Shale, grayish brown (5YR3/2) to light greenish gray (5GY6/1), average bed thickness 0.15 ft. common _Annelidichnus_ throughout unit but more poorly developed than in above unit	27.5
2. Covered interval, contact between middle and lower members picked on the basis of slope change, the highest occurrence of _Orthambonites michaelis_, _Linguella_ sp. and color change in shales	23.7
Subtotal	84.1

Lower Member	
1. Covered interval; Quartzite, shale and limestone interbedded; Quartzite float, light brown (5YR5/6), weathers dark reddish brown (10R3/4), fine grained; Shale float, brownish gray (5YR4/1) to dark gray (N3), fossil; Calcarenite float, medium gray (N5), fossiliferous	146.4
Subtotal	146.4
Total	296.3

Garden City Formation

SECTION 8

Location: South Wellsville Section, measured approximately 300 feet above Baker Mine, Box Elder County, Utah, NW, NW, Sec. 30 TION, R1W.

Fish Haven Dolomite

Sharp, planar contact

Swan Peak Formation

Upper Member		Thickness in feet
5.	Quartzite, grayish orange pink (10R8/2) white (N9), weathers very light gray (N8) to very pale orange (10YR8/2), fine to medium grained, rare to common hydroxylapatite near base of unit, predominantly structureless with abundant Skolithos weathered in relief on bedding surfaces, 12 feet above base of unit high-angle south-dipping cross-laminae common, average bed thickness 0.95 ft.	60.0
	Subtotal	60.0

Middle Member

4.	Quartzite and shale, interbedded; Quartzite, light brown (5YR6/4) to light brown (5YR5/6), weathers moderate brown (5YR3/4) to dark reddish brown (10R3/4), fine grained, common hydroxylapatite common wavy parallel laminae, average bed thickness 0.45 ft.; Shale, moderate reddish brown (10R4/6) to olive gray (5Y4/1), average bed thickness 0.12 ft., abundant Annelidichnus throughout unit	20.0
3.	Quartzite and shale, interbedded; Quartzite light brown (5YR6/4) to light brown (5YT5/6), weathers moderate brown (5YR3/4) to dark reddish brown (10R3/4), fine grained, common parallel and wavy parallel laminae, rare to common oscillation ripples near base of unit (wave length 0.25 cm and amplitude 0.03 ft.), average bed thickness 0.50 ft.; Shale, light brown (5YR5/6) with some grayish green (10GY5/2), average bed thickness 0.10 ft., abundant Annelidichnus throughout unit	24.5

		Thickness in feet
2.	Predominantly covered interval; Quartzite and shale interbedded; Quartzite light brown (5YR5/6), weathers moderate brown (5YR3/4) to dark reddish brown (10R3/4), fine grained; Shale light brown (5YR5/6) to medium dark gray (N4), fissile, abundnant <u>Annelidichnus</u> throughout unit	41.5
	Subtotal	86.0

<u>Lower Member</u>

1.	Covered interval, float of Quartzite, shale and calcarenite; Quartzite light brown (5YR6/4), weathers moderate brown (5YT4/4), fine grained; Shale, moderate brown (5YT3/4), sandy; Calcarenite, medium light gray (N6), weathers medium gray (N5), common <u>Chondrites</u> and rare <u>Tomaculum</u>. Basal contact selected at highest occurrences of calcilutite and reverse slope break	114.4
	Subtotal	114.4
	Total	260.4

Sharp, planar contact

Garden City Formation

SECTION 9

Location: South Dry Lake Section, west side of hill, approximately 3,000 feet due west of Sardine Summit, (intersection of U.S. Highways 89 and 91 with Cache County, Box Elder County Line), NW NW Sec. 4, T9N, R1W.

Fish Haven Dolomite

Sharp, planar contact

Swan Peak Formation

		Thickness in feet
Upper Member		
9.	Covered interval, measurement commenced from the highest occurrence of Fish Haven Dolomite float up to well exposed middle member. Highest occurrence of upper member float approximates upper and middle member contact	78.4
	Subtotal	78.4
Middle Member		
8.	Quartzite and siltstone, interbedded; Quartzite, light brown (5YR5/6) to moderate reddish orange (10R6/6), fine grained, hint of parallel laminae near top of unit, abundant *Annelidichnus*; Siltstone, dark yellowish orange (10YR6/6), parallel laminated; Some light brown (5YR6/4) to pale brown (5YR5/2) shale partings between individual quartzite and siltstone beds	0.7
7.	Covered interval	3.0
6.	Quartzite and shale, interbedded; Quartzite, moderate orange pink (10R7/4) to moderate reddish orange (10R6/6), fine grained, weathers light brown (5YR6/4), fine grained, wavy parallel laminated in upper part and burrow mottle in lower part of beds, average bed thickness 0.54 ft.; Shale, moderate red (5R5/4) to light brown (5YR5/6), average bed thickness 0.03 ft.	8.7

		Thickness in feet
5.	Quartzite and shale, interbedded; Quartzite, light brown (5YR6/4), weathers pale reddish brown (10R5/4) to moderate reddish brown (10R4/6), fine grained, wavy parallel laminated in upper part with rare small-scale oscillation-ripple marks preserved on bedding surfaces, average bed thickness 0.46 ft.; Shale moderate brown (5YR4/4), average bed thickness 0.07 ft., abundant <u>Annelidichnus</u> in lower part of unit	5.1
4.	Quartzite and shale, interbedded; Quartzite, pale red (10R6/2) to moderate orange pink (10R7/4), weathers grayish orange pink (10R8/2), fine grained, parallel laminated, average bed thickness 0.61 ft.; Shale, moderate brown (5YR4/4), average bed thckness 0.03 ft., abundant <u>Annelidichnus</u> throughout unit	14.7
3.	Covered interval, offset section	9.7
2.	Quartzite and shale, interbedded; Quartzite, moderate orange pink (10R7/4) to pale red (5R6/2), weathers grayish red (5R4/2) to pale reddish brown (10R5/4), fine grained, parallel laminated average bed thickness 0.32 ft.; Shale light brown (5YR6/4) to moderate brown (5YR3/4), average bed thickness 0.15 ft, abundant <u>Annelidichnus</u> throughout unit.	6.6
	Subtotal	47.9

<u>Lower Member</u>

1.	Covered interval, approximate middle and lower member contact based on slope break and highest occurrence of calcarenite. Lower member and Garden City contact based on highest occurrence of calilutite and reverse slope break	147.8
	Subtotal	147.8
	Total	274.1

Garden City Formation (not exposed)

SECTION 10

Location: North Mantua Section, measured on Gold Hill, approximately 4,000 feet east of highway 89-91, north of the town of Mantua, Box Elder County, Utah SW, SE, Sec 10, T9N, R1W.

Fish Haven Dolomite (not exposed)

Swan Peak Formation

Upper Member		Thickness in feet
16.	Quartzite, pinkish gray (5YR8/1), weathers very light gray (N7), medium grained, common south-dipping high-angle cross-laminae	3.7
15.	Quartzite, mottled very pale orange (10YR8/2) to white (N9) weathers very light gray (N8) to light brown (5YT6/4), fine grained, structureless with rare Teichichnus and Skolithos, average bed thickness 0.80 ft.	4.7
14.	Quartzite, grayish orange pink (10R8/2), weathers grayish pink (5R8/2), medium grained, common north-dipping high-angle, cross-laminae	2.0
13.	Quartzite, grayish orange pink (10R8/2) to pale yellowish orange (10YR8/6), weathers light gray (N8) to grayish orange (10YR7/4) fine grained, wavy parallel laminae with low-angle north and south-dipping cross-laminae in upper part of individual beds, structureless in lower part of beds, rare Teichichnus and abundant Skolithos, average bed thickness 0.62 ft.	13.7
12.	Quartzite, pinkish gray (5YR8/1) to light brownish gray (5YR6/1) weathers light brownish gray (5YR6/1) to light gray (N7), medium grained, abundant hydroxylapatite fragments, hint of low-angle south-dipping cross-laminae, bioturbated in lower part of beds, average bed thickness 0.52 ft	2.1
	Subtotal	26.2

Middle Member	Thickness in feet
11. Quartzite and shale, interbedded; Quartzite, yellowish gray (5YR8/1) to dark yellowish orange (10YR6/6), weathers dark yellowish orange (10YR6/6) to light brown (5YR6/4), fine grained, common hydroxyliapatite fragments, parallel laminated to structureless, average bed thickness 0.67 ft; Shale, light brown (5YR6/4) to light brown (5YR5/6), average bed thickness 0.03 ft. common Annelidichnus throughout unit	10.2
10. Quartzite and shale, interbedded; Quartzite, pale pink (5RP8/2) to grayish orange (10YR7/4), weathers light brown (5YR6/4) to dark yellowish orange (10YR6/6), fine grained, structureless, average bed thickness 0.57 ft; Shale, pale reddish brown (10R5/4) to light brown (10YR6/2), average bed thickness 0.70 ft., common Annelidichnus throughout unit	9.7
9. Covered interval	5.8
8. Quartzite and shale, interbedded; Quartzite, light gray (N7) to light brown (5YR6/4), weathers pale yellowish brown (10YR6/4) to brownish gray (5YR4/1) to pale red (10R6/2), hint of parallel laminae near top of beds, bioturbated near base of beds, average bed thickness 0.49 ft.; Shale, pale reddish brown (10R5/4) to grayish brown (5YT3/2), average bed thickness 0.25 ft., abundant poorly developed Annelidichnus throughout unit	17.4
Subtotal	43.1

Lower Member	
7. Covered interval, (probably corresponds approximately to upper subunit of the lower member)	64.9
6. Calcisiltite and shale, interbedded; Calcisiltite, medium dark gray (N7) to medium gray (N5), irregularly bedded, average bed thickness 0.45 ft; Shale, medium dark gray (N4) with some thinly laminated olive gray (5Y4/1), sandy, with rare lenticular thinly laminated light brown (5YR6/4) sandstone, average bed thickness 0.50 ft.	9.1
5. Covered interval	21.9

		Thickness in feet
4.	Calcarenite, grayish black (N2) to medium gray (N5), sandy and shaly, irregularly bedded, common and unabraded _Orthambonites swanensis_, rare thinly laminated medium gray fossil shale and grayish orange pink (5YR7/2) quartzite, average calcarenite bed thickness 0.45 ft.	
3.	Covered interval	22.3
2.	Quartzite and shale, interbedded; Quartzite, yellowish gray (5Y7/2) to pale red (5R6/2), weathers medium gray (N5) to grayish orange pink (5YR7/2), shaly, very fine to fine grained, parallel laminated, abundant _Chondrites_, average bed thickness 0.45 ft.; Shale grayish brown (5YR3/2) to medium dark gray (N4), sandy and silty, average bed thickness 0.60 ft.	7.2
1.	Covered interval	18.1
	Subtotal	151.5
	Total	220.7

Garden City Formation

SECTION 11

Location: East Mantua Section, 3 miles east of the community of Mantua, on the road to Clay Valley, part of stratigraphic section exposed in road cut, Box Elder County, Utah, NW, SW, Sec 25 T9N, R1W.

Fish Haven Dolomite

Sharp, planar contact

Swan Peak Formation

Upper Member		Thickness in feet
15.	Quartzite, very light gray (N8) to white (N9), weathers pinkish gray (5YR8/1), fine grained, structureless with rare to common *Skolithos*	3.0
	Subtotal	3.0
Middle Member		
14.	Covered Interval, scattered float of upper member, Swan Peak and Fish Haven Dolomite fault breccia	5.0
13.	Quartzite and shale, interbedded; Quartzite, light gray (N7) to grayish orange (10YR7/4), weathers light brown (5YR6/4) to grayish orange pink (5YR7/2), fine grained structureless average bed thickness 1.02 ft.; Shale, dark yellowish orange (10YR6/6), fissile, average bed thickness 0.20 ft. common *Annelidichnus* throughout unit	9.5
12.	Quartzite and shale, interbedded, Quartzite; light gray to grayish orange (10YR7/4), weathers dark yellowish orange (10YR6/6) to grayish orange (10YR7/4), fine grained, abundant hydroxylapatite, structureless, average bed thickness 0.85 ft; Shale,dark yellowish orange (10YR6/6), fissile, average bed thickness 0.30 ft. abundant *Annelidichnus* throughout unit	17.0
11.	Quartzite and shale, interbedded; Quarrzite, moderate yellowish brown (10YR5/4) to very pale blue (5B8/2), weathers very pale orange (10YR8/2) to dark yellowish orange (10YR6/6), fine grained, structureless, average bed thickness 1.24 ft.; Shale, grayish yellowish green (56Y7/2) and pale olive (10Y6/2) and grayish orange (10YR7/4), fissile, average bed thickness 0.12 ft.; abundant *Annelidichnus* throughout unit	15.0
	Subtotal	48.0

Lower Member	Thickness in feet
10. Quartzite, and shales, interbedded, Quartzite, grayish orange (10YR7/4), weathers dark yellowish orange (10YR6/6), fine grained, wavy parallel laminated to structureless to burrow mottled average bed thickness 0.69 ft; Shale dark greenish gray (5GY4/1) to medium dark gray (N6), fossil, individual shale units range in thickness from 0.20 to 5.50 ft.	11.2
9. Shale, ark greenish gray (5GY4/1) to medium dark gray (N6) fossil, rare intrabeds of dark yellowish orange (10YR6/6) to moderate yellowish brown quartzite; Near middle of unit a fault offsets quartzite beds 2.50 ft.	14.1
8. Quartzite and shale, interbedded; Quartzite, grayish orange pink (5YR7/2), weathers moderate yellowish brown (10YR5/4), fine grained, parallel and wavy parallel laminated, average bed thickness 0.54 ft.; Shale, dark greenish gray (5GY4/1) to medium dark gray (N4), fissile, individual shale units range in thickness from 0.40 to 4.70 ft.	16.0
7. Shale, medium dark gray (N4) to dark greenish gray (5GY4/1), very fissile, ...	9.4
6. Calcarenite and shale, interbedded; Calcarenite, medium gray (N5) to dark gray (N3), sandy, irregular and lenticular bedded, abundant spicules, ostracods and fragments of brachiopods, very rare <u>Receptaculites</u> and common <u>Eleutherocentrus petersoni</u>, individual calcarenite beds ranges in thickness from 0.15 to 3.40 ft.; Shale, dark gray (N3) to medium dark gray (N4), individual shale unit range in thickness from 0.03 to 4.19 ft.	28.3
5. Calcarenite and shale, interbedded; Calcarenite, medium gray (N5) to dark gray (N3), sandy, irregular and lenticular bedded, common spicules, ostracods and fragments of braciopods, individual calcarenite units more massive than above unit, beds range in thickness from 2.00 to 13.18 ft.; Shale, dark gray (N3) to medium dark gray (N4), individual shale beds range in thickness from 0.20 to 2.30 ft.	44.9
4. Covered interval	3.0
3. Calcarenite, calcisiltite and shale, interbedded; Limestone medium gray (N5), sandy, irregular and lenticular bedded, abundant <u>Chondrites</u>, average bed thickness 0.95 ft.; Shale, dark gray (N3), average unit thickness 0.50 ft.	7.9

		Thickness in feet
2.	Covered interval	8.0
1.	Calcarenite calcisiltite, shale, and quartzite, interbedded; Limestone, medium gray (N5) to medium light gray (N6), sandy irregular and lenticular bedded, mixed fossil fragments, average bed thickness 0.60 ft.; Shale, dark gray (N3) average unit thickness 0.30 ft.; Quartzite, grayish orange (10YR7/4), fine grained, parallel laminated, average bed thickness 0.15 ft.	10.9
	Subtotal	153.5
	Total	203.6

Sharp, planar contact

Garden City Formation

SECTION 12

Location: South Mantua Section, measured in Devils Hole Canyon, Box Elder County, Utah SE, SE, Sec. 3, T8N, R1W,

Fish Haven Dolomite

Swan Peak Formation

Sharp, planar contact

Middle Member		Thickness in feet
2.	Quartzite and shale, interbedded, Quartzite, very light gray (N8) to grayish orange (10YR7/4) to dark yellowish orange (10YR6/6), weathers pale yellowish brown (10YR6/2) to dark yellowish orange (10YR6/6) to grayish orange (10YR6/6), fine grained, predominantly structureless with hint of parallel laminae near top of some beds, average bed thickness 0.97 ft.; Shale grayish red (10R4/2) to dark yellowish orange (10YR 6/6), average bed thickness 0.10 ft., abundant *Annelidichnus* throughout unit	14.6
	Subtotal	14.6

Lower and (?) Middle Member

1.	Covered interval, float of middle and lower members obscure contact between members, Swan Peak-Garden City Formation poorly exposed but contact is well defined	84.5
	Subtotal	84.5
	Total	99.1

Garden City Formation

SECTION 13

Location: South Canyon Section, measured approximately 4.6 miles south of the town of Avon, Cache County, Utah, SW SW Sec. 34, T9N, R1E.

Fish Haven Dolomite

Sharp, planar contact

Swan Peak Formation

		Thickness in feet
Middle Member		
2.	Covered interval	45.0
Lower Member		
1.	Covered interval	35.4
	Total	80.4

Garden City Formation

SECTION 14

Location: Porcupine Dam Section, measured approximately 150 yards north of the intersection of the East Fork road and the Cache National Forest boundary, Cache County Utah, Sec. 15, T9N, R2E, Lat. 41°31'20"N, Long. 111°43'30" W.

Fish Haven Dolomite

Sharp, planar contact

Swan Peak Formation

Lower Member		Thickness in feet
2.	Quartzite and shale, interbedded; Quartzite, grayish orange (10YR7/4) to light brown (5YR6/4), weathers grayish orange pink (5YR7/2), fine grained, parallel laminated; Shale, olive gray (5Y4/1) to medium gray (N4), fissile, abundant *Chonrities* throughout unit; unit poorly exposed	13.0
1.	Covered interval	17.0
	Total	30.0

Garden City Formation

SECTION 15

Location: Blacksmith Fork Section, measured approximately 300 feet south of Utah Highway 101 above the Shenoah campground, Cache County, Utah, NW, NW, Sec. 2, T2E, R10N.

Fish Haven Dolomite

Sharp, planar contact

Swan Peak Formation

Lower Member		Thickness in feet
2.	Limestone and shale, interbedded; Limestone, medium gray (N5), weathers light gray (N7) to medium dark gray (N4), unit varies from a calcarenite to a calcirudite both vertically and laterally, bedding is irregular and/or lenticular; Shale, medium gray (N5), very fissile; minor intrabeds of light brown (5YR6/4) fine grained quartzite; common to abundant Orthambonites swanensis, Orthambonites michaelis, Eleutherocentrus petersoni, Amomalorthis sp., unidentifiable Ostracoda and Chondrites throughout unit	42.9
1.	Quartzite and shale, interbedded, Quartzite, moderate orange pink (10R7/4) to grayish orange (10YR7/4), weathers light brown (5YR6/4) to moderate brown (5YR4/4) to pale reddish brown (10R5/4), medium grained, parallel to wavy parallel laminated, average bed thickness 0.40 ft.; Shale, light brown (5YR6/4) to light olive gray (5Y6/1), average bed thickness 0.19 ft., minor intrabeds of medium dark gray (N5) calcarenite and calcirudite throughout unit	11.5
	Total	54.5

Sharp, planar contact

Garden City Formation