Environmental Analysis of the Swan Peak Formation in the Bear River Range, North-Central Utah and Southeastern Idaho

Philip L. VanDorston
Utah State University

ENVIRONMENTAL ANALYSIS OF THE SWAN PEAK FORMATION IN THE BEAR RIVER RANGE, NORTH-CENTRAL UTAH AND SOUTHEASTERN IDAHO

by

Philip L. VanDorston

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

of

MASTER OF SCIENCE

in

Geology

UTAH STATE UNIVERSITY
Logan, Utah

1969

ACKNOWLEDGMENTS

My sincerest appreciation is extended to Dr. Robert Q. Oaks, Jr., for allowing me to develop the study along the directions I preferred, and for imposing few restrictions on the methodology, approach, and ensuing interpretations. The assistance of Dr. J. Stewart Williams in identification of many of the fossils collected throughout the study was gratefully received. My appreciation is also extended to Dr. Raymond L. Kerns for assistance in obtaining the thin sections used in this study.

Most of the photographs were processed and enlarged by my father, who, I am sure, enjoyed the task equally as much as I welcomed his considerate and professional service.

To my wife, Joan, I extend my deepest and sincerest appreciation for her understanding and perserverance during the hours of discussion, compilation, and revision of the manuscript.

The financial support offered by Amerada Petroleum Corp., Gulf Oil Co., Marathon Oil Co., and Sinclair Oil Corp., is greatly appreciated. Without their assistance the extent and depth of the study would have been considerably less.

Last but not least, my thanks go to Mrs. Paul Harris for her help in preparing the final manuscript.

Philip L. VanDorston

Philip L. VanDorston

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF PLATES

LIST OF PLATES (Continued)

LIST OF PLATES (Continued)

ABSTRACT

Environmental Analysis of the Swan Peak Formation

in the Bear River Range, North-Central

Utah and Southeastern Idaho

by

Philip L. VanDorston, Master of Science

Utah State University, 1969

Major Professor: Dr. Robert Q. Oaks, Jr.
Department: Geology

The Swan Peak Formation in the Bear River Range of northern Utah and southern Idaho varies in thickness from 0 feet to over 400 feet. It consists of three units: (1) A lower unit of interbedded quartzites, shales, and limestones; (2) A middle unit of interbedded quartzites and shales; (3) An upper unit of nearly homogeneous quartzites. The different sedimentary structures, ichnofossils, body fossils, and mineral compositions of each unit represent different environments of deposition. The lower unit probably was deposited in a shallow-shelf environment, and its sediments grade upward into probable shoreface-, tidal-flat-, and lagoonal deposits of the middle unit. The upper unit is believed to be a shallow-marine sand deposited by south-flowing currents.

The lower and middle units of the Swan Peak Formation consist of a progradational suite of nearshore lithologies formed during the regression of the sea that terminated the early Paleozoic Sauk Sequence. The formation lies disconformably beneath the Ordovician Fish Haven Dolomite, and rests conformably on the underlying Ordovician Garden City Formation.

The upper and middle units thin eastward and south-eastward to a feather edge, whereas the lower unit is thickest along an east-west trending belt and thins northward and southward. The lower unit could be time-equivalent to the upper and middle units in the north.

Possible estuarine deposits containing detrital hydroxyapatite suggest a local fluvial source in the southeast. The immediate source for much of the sand in the middle and upper units lay northward in Idaho.

"Fucoidal markings" within the middle unit appear to be feeding burrows filled with reworked sediment that was consumed or searched for the organic content by littoral to sublittoral benthonic predators or scavengers, probably orthoconic cephalopods.

(136 pages)

INTRODUCTION

Location

The prominent light-colored orthoquartzite cliffs of the upper part of the Swan Peak Formation in the Bear River Range offer a sharp contrast to the thick sequence of dark gray carbonates and shales that otherwise comprise the range. The formation offers a study of environments quite different from the ones in which most of the thousands of feet of limestones and dolostones were deposited in this same area between Cambrian and Permian time.

Throughout the southern portion of the Bear River Range, the Swan Peak Formation crops out in two nearly parallel bands trending approximately north-south (Figure 1). One continuous exposure lies along the west side of the range, whereas the second occurs near the crest of the range, west of Bear Lake and east of Logan Peak Syncline.

The area of study was restricted to the central part of the Bear River Range, and covers about 600 square miles (Figure 1). The northern limit of investigation lies within Franklin Basin, 4 miles north of the Utah-Idaho State Line, and the southern boundary is 3.5 miles south of Avon, Utah, in the James Peak Quadrangle. The west and east boundaries are formed by the respective limits of the Bear River Range.

The area is mountainous, heavily forested, and covered by thick winter snows. Outcrops above 7,000 feet are accessible only between June and

November, and field work in lower areas is hampered by early snows and late springs. Most of the exposures can be easily reached in the dry summer months. A vehicle with good clearance and a three-hour hike will permit access to all good outcrops.

The size of the area allowed adequate detail for environmental interpretation of units within the formation. A smaller geographic area would have allowed more detailed study of micro-environments; however, such an investigation is not presently appropriate, for previous work on the Swan Peak Formation in northern and central Utah and Nevada has been regional in approach only. The next logical step was to narrow study of the formation to a more limited area, but one that was not so restricted that it would have little relation to the regional picture.

Purpose

The purposes of the investigation were: (1) to analyze and subdivide the Swan Peak Formation, by determining the stratigraphic relations between units and characterizing the internal sedimentary structures of each unit; and (2) to interpret depositional environments and paleogeographic settings of each unit. Environments of deposition were interpreted from the composition, grain size, sedimentary structures, lateral and vertical sequences, shape, geometry, trace fossils, body fossils, facies changes of each unit, and the relation of each unit to the other.

Detailed studies of sedimentary rocks are necessary to understand ancient environments of deposition. By such studies the source area, paleogeography, and paleoclimate during deposition can be better understood.

Perhaps the most important potential of this type of study is its application to petroleum exploration. Many oil fields in the intermountain West produce from porous, permeable, sheet-like sand bodies similar to the Swan Peak Formation. These generally form in marginal areas between stable land masses and subsiding basins. Such sands can be restricted in extent, or can be spread over thousands of square miles. They make excellent reservoir rocks because of their position adjacent to marine source beds. Therefore, a more thorough understanding of sand bodies and their origins is needed. How, why, when, and where they form, how they can be recognized, and how their trends can be predicted are important to petroleum exploration. The study of sedimentary rocks in vertical and lateral sequences in exposures permits recognition of the same sequences in oil-well cores, and aids in predicting trends of the sand bodies and of the barriers to oil migration within them.

FIELD- AND LABORATORY METHODS

During this study 17 sections between 0.5 and 9.5 miles apart were measured, and many of the intervening outcrops were visited (Figure 1). Sections were measured where an exposure was very well developed, and also in intervening areas wherever more control was needed. The entire formation is exposed in only a few sections. A thorough search was made at each section to find the internal structures and bedding features that lay scattered throughout each unit.

Each section was measured in vertical profile with a steel tape 10 feet long. A Brunton compass was used to traverse covered intervals. The study of bedding features and internal structures necessitated traversing the outcrop laterally on both sides of the measured section.

During measurement, details were recorded in appropriate columns of a special data sheet, which permitted a quick, visual comparison between measured sections. Sedimentary features such as lithology, grain size, color, sorting, porosity, bedding thickness, nature of bedding surfaces, sharpness of contacts, cross-laminations, body fossils, trace fossils, ripple marks, and mud cracks, were used to infer sources, processes of deposition, and energy states, from which the environment of deposition in turn was interpreted.

In total, about 40 days were involved in field work. Due to repeated visits, an average of about 2 days were spent on most measured sections.

At the beginning of this study, 24 samples were collected from the three major units in several different sections. Thin sections prepared from these samples revealed sufficient variation in porosity, grain size, angularity, orientation, and mineral and organic content, to warrant expanded usage of this procedure in a more detailed study.

Differential thermal analyses and X-ray diffraction analyses were run on shale samples from the lower and middle units to determine predominant clay minerals and total composition. X-ray diffraction analyses also were run on heavy minerals in the upper and middle units, and X-ray fluorescence analyses were made of purple quartzites of the middle unit to determine origin of the color.

PREVIOUS WORK

The present investigation is the first detailed study of the Swan Peak Formation in a restricted area. The formation, as a whole or in part, has been mentioned or described in many publications, but only as a segment of the entire sequence of rocks in regional reviews or at one location (Hintze, 1951, 1954, 1959, 1963a, 1963b; Ketner, 1968; Richardson, 1913, 1941; Ross, 1953, 1964; Webb, 1956, 1958; Williams, 1948).

In the literature covering such subjects as regressions and transgressions, facies changes, and historical geology in general, the Swan Peak Formation is discussed only incidentally (Churkin, 1962; Clark and Stearn, 1960; Dapples, 1955; Kay, 1960; Ketner, 1966; Moore, 1958).

The formation was named the "Swan Peak Quartzite" by Richardson (1913, p. 407) from the outcrop at the crest of Swan Peak in the northwest corner of the Randolph Quadrangle, west of Bear Lake. Mansfield (1927, p. 57) and Richardson (1941, p. 16) also noted the quartzite in their investigation of the surrounding area. Williams (1948, p. 1136), however, was the first to subdivide the formation informally into three lithologic units.

There is some uncertainty about the exact correlation of the Swan Peak Formation in northeastern Utah with the Swan Peak in the Ibex Basin of central Utah (Hintze, 1951, p. 21; Webb, 1956, p. 21). Webb (1958, p. 2356) questioned whether quartzites included in the Swan Peak Formation in northern

Utah all belong to the Swan Peak Formation, or whether the upper parts are possibly equivalent to the younger Eureka Quartzite found farther west. Webb suggested that the higher beds at Promontory Point could be sand of Swan Peak age reworked and redeposited during Eureka time. Webb also suggested that the entire Swan Peak Formation in northern Utah could be part of the transgressive Eureka Quartzite. One of the major objectives of the present investigation was to determine whether the Swan Peak in the area of study is entirely regressive, entirely transgressive, or, in part, both.

Fauna previously collected from the Swan Peak are described by Ross (1951, 1968), Hintze (1952), and Cooper (1956). Identifications of specimens collected during the present study have been based mainly on the descriptions and photographs in these references.

Among the most striking features of the Swan Peak Formation are the abundant "fucoidal markings" on bedding surfaces and within the quartzites. Such markings have been discussed in the literature since their initial discovery in 1838 in Ohio (Coulter, 1955, p. 282-284). Most of the earliest investigators regarded the markings as impressions of seaweed, and so the term "fucoid" was adopted from the generic name of a seaweed. Hypotheses of an inorganic origin or tracks of organisms were also proposed by several early authors. Eventually the term "fucoid" was adopted for most unidentifiable markings regardless of the proposed origin. Coulter (1955, p. 282-284) exhaustively reviewed the subject and its history.

Hantzschel (1962, p. 177-222) discussed trace fossils (ichnofossils) in great detail. The "fucoidal markings" found in the Swan Peak Formation most closely resemble those he pictured and described as Phycodes. The name Phycodes identifies a type of structure only, and, like other ichnofossil names, implies no relationship to organisms or processes that possibly produced the impressions.

However, Phycodes, as pictured and described, appears to be an internal feeding-and-protection tunnel or burrow, whereas the markings in the Swan Peak Formation are probably bedding-surface trails or burrows. Because the shapes of the latter rarely radiate from a point, as do the illustrated Phycodes, the less specific, yet descriptive, name "feeding burrow" will be used in place of the less desirable former term "fucoidal marking."

The feeding burrows in the Swan Peak Formation occur with features characteristic of the Cruziana Facies of Seilacher (1964), representative of littoral to sublittoral environments characterized by well-sorted sandstones and sandstone-shale sequences, in which oscillation-ripple marks and other shallow-water features are common. Various organisms typically found in these environments, such as gastropods, arthropods, and cephalopods, probably formed at least some of the tracks, trails, and burrows of this trace-fossil assemblage.

Seilacher (1964, p. 309) regarded the Phycodes structures as organic (biogenic) in origin, and noted that they are restricted to the Cruziana Facies. Such structures are reported from Lower Cambrain strata in Pakistan and from Ordovician strata in Asia, Europe, and North America. The Kinnikinic

Quartzite of Idaho contains "fucoidal markings" (Ross, 1947, p. 1103; Hobbs and others, 1968, p. J8), similar to the feeding burrows in the Swan Peak Formation, as do several other Ordovician sandstones in the western United States. All such structures perhaps eventually will be regarded as Phycodes.

GEOLOGIC SETTING

During Swan Peak time, shallow-water, miogeosynclinal sand, mud, and carbonate were deposited throughout what is now Utah and eastern Nevada. The sand was swept into the Cordilleran trough from cratonic sources in the north, east, and south. Farther west, siliceous muds and volcanics were deposited in a deeper-water, eugeosynclinal environment.

The greatest thicknesses of miogeosynclinal sediment accumulated along a northeast-southwest trending belt through western and northern Utah, southeastern Idaho, and eastern Nevada. This area of thick sedimentation was divided into two parts by an east-west topographic high that extended from the present position of Cortez, Utah, in the west, through Gold Hill and Salt Lake City, to the west end of the present Uinta Mountains in the east. Hintze (1959, p. 46, Figures 1 and 3) named this transverse positive element the Tooele Arch.

This arch divided the major trough into two distinct basins: the Northern Utah Basin in the north, and the Ibex Basin in the south. During Early Middle Ordovician time, the northern basin received large quantities of sand, while the southern basin received chiefly muds and carbonates. Muddy carbonates were deposited across the arch itself. Most of the coarse detrital material in the north occurs in the upper part of the formation. Because of uplift along the Tooele Arch this coarse detrital material apparently was not deposited across the arch or was removed subsequently from the topographic high.

Coarse detrital deposits of Late Middle Ordovician age are found in both the Northern Utah Basin and the Ibex Basin. Possibly, the Tooele Arch was no longer prominent enough to prevent the influx of sand from the north from spilling over that structure into the Ibex Basin. It appears more probable, however, that the arch was developed sufficiently to separate the region into two distinct basins during most of Swan Peak time, but failed to halt the sand when the latter finally reached the north side of the arch.

Because sedimentary structures indicate an apparent southerly drift of sand from Idaho to southern Utah and Nevada during Late Middle Ordovician time, a principally northern source of the quartz sands seems most likely. However, exposed areas of mature Cambrian sandstones in the Uinta Mountains and areas farther east may have been adequately extensive to supply, in part, the sand of the Swan Peak Formation (Laporte, 1968, p. 102-111; Baker and others, 1949, p. 1195-1270).

Ketner (1966, p. 59) believed that Ordovician quartzites of the Cordilleran miogeosyncline were derived from sedimentary terrains composed, at least in part, of quartz sands. He discarded an igneous or metamorphic source because of the high degree of compositional and textural maturity of these sands. Ketner (1968, p. 174) suggested that the Peace River-Athabaska Arch in northern British Columbia and Alberta supplied most of the sands by erosion from Cambrian sandstones exposed on the flanks of the Canadian Shield. He inferred a southward migration of sand from the Peace River area on the basis of the decrease in grain size of Ordovician quartzites southward from Canada to California, and from changes in the geometric shape of the Cordilleran sands from narrow but thick in the north to widespread but thin in the south.

The Swan Peak Formation occurs at the top of the Sauk Sequence of Sloss (1963, p. 95). The Sauk Sequence consists of a nearly continuous succession of rock units of Late Precambrian to Middle Ordovician age that overlie an interregional unconformity at the base of the Late Precambrian rocks, and in turn underlie an interregional unconformity at the base of the succeeding Tippecanoe Sequence.

Figure 2 indicates a proposed correlation of Ordovician rocks in the central Rocky Mountains. Wheeler (1960, p. 52) suggested that the various Middle Ordovician sands, such as the Swan Peak, St. Peter, Eureka, and Kinnikinic, were deposited as a result of one of the periodic but intermittent uplifts of the craton. Certainly, various independent source areas must have accounted for different sand bodies found in the Cordilleran trough throughout Early Paleozoic time.

CLASSIFICATION AND DEFINITION OF DEPOSITIONAL ENVIRONMENTS

Stratification, Classification and Energy Relationships

The term environment constitutes the sum total of conditions that prevail while a sediment is being deposited. Facies is the sum of the lithologic and paleontologic characteristics of a sedimentary deposit at a given place. The characteristics of the deposit depend on conditions that controlled the formation of the deposit.

Few sedimentary structures or energy conditions are restricted to any single environment, so that an individual structure is seldom diagnostic by itself. Hence, it is usually necessary to use a combination of many different features of a rock unit to determine the sedimentary environment.

The vertical sequence of differing lithologies may record a superposition of several successive lateral environments (Figure 3). Proceeding from bottom to top of a progradational coastal sequence, the stratification reflects, in order, the various lateral environments. From offshore to backshore, the environments recognized in the lower two members of the Swan Peak Formation are as follows: shelf, shoreface, tidal flat, and lagoon. This sequence consists of environments that are seldom all represented together in any one outcrop due to nonoccurrence or to failure of exposure. However, probably all existed simultaneously at some position along the coastline.

The classifications proposed by Twenhofel (1939, p. 51) and by Shepard (1963, p. 168-170) have generally been adopted by geologists to differentiate depositional environments of the shoreline. The classification used in this study incorporates the concepts of Twenhofel and Shepard, modified for the purposes of this study (Figure 3).

This writer has not found described in the available English literature a modern coast directly analogous to that in which the Swan Peak Formation was deposited. This report therefore contains few references to modern coastal studies or a detailed review of described coastal sedimentary structures, although such a review was made.

Because direct analogies of sedimentary structures with those in modern environments were seldom possible, energy relationships were exploited in the interpretation of sedimentary structures. These energy conditions, along with other lines of evidence discussed later, constitute the primary lines of reasoning rather than a direct comparison of similarities with modern offshore sediments, whose structures are poorly known.

Offshore Environment

Shelf

The offshore environment includes the entire area of the sea that is continuously submerged, that is, the area seaward of lowest low tide. This area in present seas is subdivided into oceanic basins, continental slope, continental shelf, and shoreface. The shoreface extends seaward from the low-tide level to a decrease in slope between -30 and -60 feet on most modern coasts. This slope break apparently coincides with lower energy conditions seaward (effective wave base). The shelf extends seaward today from this slope break to an average depth of 600 feet, where steeper slopes extend downward to true oceanic depths.

Such depth zonations cannot be inferred readily from ancient sediments; however, the position of effective wave base often can be inferred in a vertical sequence, so that a distinction is possible between shoreface and shelfal environments. Additionally, deep-water deposits apparently are diagnostic, and can be distinguished from shelfal sediments. Most of the shelfal environment of marginal seas of the past lay within the range of wave and current action, particularly during storms (Figure 3). This is particularly true of the shoreward portions where the sediments may attain only temporary deposition.

Streams deposit the major portions of their load directly into the sea along its margin. Much of the finer, suspended sediment comes to rest on the bottom close to shore, a short distance below effective wave base. This deposition may be permanent or temporary. If the bottom is at or above base level, the fines may be swept far out to sea. However, if the shelf is broad and shallow, and if sediment is abundant, the effect of waves and currents can be checked by the sheer volume of sediment above wave base that must be moved. In this case, coarse-grained sediments can spread widely across a shelfal environment.

In general, the coarser sediment is adjacent to the shore and grades into finer deposits seaward, but exceptions to this generalization are many. Adjacent to low-energy shores without streams the shoreface is apt to receive fine sediment. However, longshore drift or currents may be sufficiently strong to introduce coarse sediment from a distant source. Wave erosion of the bottom can accomplish the same effect if coarse sediment is available.

On many existing tidal-flat shorelines, muds and calcareous sediment are being deposited as far up as the waters reach. Adjacent to highlands undergoing active erosion the shoreface commonly receives much coarse material derived from the land mass. At greater depths, the sediments tend to be more uniform in character, and to consist largely of calcareous and clastic muds. Shelfs with strong waves and currents will have muds and sands interbedded to considerable depths.

Shoreface

The shoreface on present coasts is the zone that extends seaward from the low-tide line to a decrease in slope near -30 to -60 feet. The zone is permanently covered by water and is the area where the deposition of sands, gravels, and muds oscillates with sediment supply and energy of waves and currents. The shoreface generally has a slope considerably steeper than the foreshore or tidal flat that lies adjacent to it shoreward.

Foreshore Environment

Foreshore

The foreshore environment consists of coastal zones that lie landward of the low-tide line and seaward of the high-tide line. These zones include the foreshore and tidal flat. Shepard (1963, p. 169) defined the foreshore as the sloping part of the shore between high tide and low tide. Characteristics of this zone result from a dynamic equilibrium between the swash of water up the beach face and the backwash of water down the slope. The laminae dip seaward at differing angles depending on the size, shape, and sorting of beach sediment and the spectrum of wave energy available. Longshore currents and littoral drift, which cause migration of the beach material, are also important factors along a shoreline.

Ancient beach deposits seldom attain a thickness greater than fifty feet. Many Cretaceous beach sands studied by the author in the intermountain region average only ten to twenty feet thick.

Tidal flat

A tidal flat is a segment of the foreshore environment that can lie adjacent to the foreshore or entirely replace it (Figure 3). The presence of the tidal flat is determined by the morphology of the coastal profile. As used here, a tidal flat is a broad, flat, sandy or muddy area that is covered and uncovered during the rise and fall of the tide. Much of the time it is covered by a shallow, standing body of water replenished and recirculated in adequate amounts to deter stagnation. This marginal area differs from a lagoon by unrestricted and recurrent flushing by the tides. At high tide, when the tidal flat is covered, the energy of the waves decreases shoreward. This is due, in part, to the breaking of the waves offshore where the bottom shallows. By the time the waves reach the inner part of the tidal flat, they have lost most of their energy.

The tidal flat lies in a position that allows the deposition of muds as well as agitation of sand by storms, exceptional high tides, and currents. The deposits can range from sand to mud to interlaminations of the two. A large part of the muddy sediment is undoubtedly derived from the suspended matter carried into the sea by streams. The main period of deposition occurs at the turn of the tide, when water movement is slow, and fine sediment settles out.

The distinctive suite of sedimentary structures that develop in tidal flats are due to rapid changes in water depths and energy conditions. Shallow-water waves generate oscillation ripples with short wavelengths and long crests. These can be altered to flat-topped ripples by a reduction in water depth and/or the wash of the retreating tide (Masters, 1965, p. 53).

Burrowing organisms are abundant in tidal flats, and locally, bedding can be destroyed by their action. However, reworking and restratification of the sediment by waves often proceeds so rapidly that these burrowing animals do not modify or destroy many of the newly deposited laminae.

Backshore Environment

Barrier

The backshore environment consists of coastal zones that lie landward of the normal high-tide line. These zones include barriers, lagoon, and dune areas. The writer uses the term barrier for that segment of the shore just above normal wave action and high tide, yet commonly inundated by exceptionally high water due to storms and spring tide. This is not to be confused with a tidal flat or a foreshore, both of which are exposed during low tide and covered at high tide, and either of which can lie seaward of a barrier (Figure 3). Except at inlets, a barrier separates a lagoon from influx of marine water caused by tides and the wind. This allows periods of quiescence long enough to permit stagnation and reducing conditions, or deposition of evaporites, to develop in the backshore lagoon. However, a barrier does not protect against periodic washovers caused by storms.

The barrier would probably be best interpreted or inferred by the relationships of the vertical sequence of rock units. In some cases it is possible that the barrier would develop no significant characteristics to warrant its identification. The inference of its presence by the stratigraphic succession may be all that can be said about such a feature. A topographic high only a few feet above high-tide level could form a very effective barrier, yet could be impossible to detect in the resulting sediment.

Lagoon

A lagoon lies shoreward and adjacent to a barrier. The water is not circulated or flushed with oxygenated marine water except near inlets or during storms. Stagnation and reducing conditions are common. A lagoonal environment may consist of several sub-environments, among which are tidal-channel, tidal-delta, swamp, and bay. Waves, reversing currents, and unidirectional currents all can be present.

Sediments are usually dark colored and pyritiferous, but can also include evaporites. The different rock types and minerals present are diagnostic, to different degrees, of the energy states and redox potentials that affected the sediment.

Dune

Among the various environments of the shore profile backshore, dune deposits are the least likely to be preserved in the geologic column. Any major rise or fall of sea level would immediately subject the backshore units, respectively, to submarine or subaerial erosion. Therefore, in most areas the backshore dunes are the most likely to be absent from the section. Where found, the units should show some characteristics of dune structure. In Paleozoic rocks these would be primarily wedge-shaped cross-strata, trough-shaped scours filled with coarse- to fine-grained sand, and lack of fossils, trails, burrows, parallel laminae, and oscillation ripple mark.

DESCRIPTIVE STRATIGRAPHY

Definition of Units

Lower quartzite, shale, and limestone unit

The Swan Peak Formation is readily subdivided into three distinct and widespread units. The lower unit, informally designated here as the interbedded orthoquartzite, shale, and limestone unit, conformably overlies the Garden City Formation. The base of the lower unit is placed at the first shale or sand bed above the Garden City Formation. This contact is well displayed where exposures are good, because of the striking morphologic break between steep slopes of the resistant limestones of the Garden City Formation and the gentler, covered slopes of the lower unit of the Swan Peak. The lower unit passes vertically, by gradation, into quartzites and shales of the middle unit. The thickness of the lower unit ranges from 0 to 160 feet (Figures 4, 5, and 6). The top of the unit is defined at the top of the highest limestone bed. The vertical position of this arbitrary division between the lower unit and the middle unit is variable from section to section. However, the two units are morphologically distinct and apparently were deposited in different, but probably adjacent, environments. They therefore merit division into two separate, major units.

Middle quartzite and shale unit

The middle unit, informally designated here as the interbedded orthoquartzite and shale unit, displays the most numerous and varied depositional features found within the Swan Peak Formation. The thickness of the middle unit ranges from 0 feet to 196 feet (Figures 4, 5, and 7). Both the upper and lower limits are arbitrary and gradational, through short intervals, with the units above and below. The unit is defined as interbedded quartzites and shales characterized by abundant feeding burrows, mostly parallel laminae, and, locally, a distinct purple color. Because of the shales present, the lower portion of the middle unit and its basal contact are often covered.

Usually, the distinctive feeding burrows are restricted to the middle unit and do not occur in either the lower unit or the upper unit. This criterion was used for selecting the upper boundary in faulted sections or in poorly exposed outcrops.

Upper quartzite unit

The upper unit, informally designated here as the quartzite unit, is defined as a distinctive, light-colored sequence of orthoquartzite and sandstone at the top of the Swan Peak Formation. It is void of feeding burrows and body fossils, and contains minor thin shale partings near the base or none at all. Strata of this unit are characterized by parallel bedding, planar cross strata, and abundant, short vertical burrows. The upper unit lies conformably above interbedded quartzite and shale of the middle unit, and disconformably underlies the Fish Haven Dolomite along a sharp, planar contact.

The thickness of the upper unit ranges from 0 to 290 feet (Figures 4, 5 and 8).

The boundary between the upper and middle units is drawn where light-colored quartzite with vertical burrows overlies cream to purple quartzite that displays parallel laminae and horizontal feeding burrows. The upper unit forms distinctive, steep cliffs.

Description of Units

Lower quartzite, shale, and limestone unit

The best exposures of the lower unit occur in canyons along the west side of the Bear River Range. Failure of exposure of the lower unit elsewhere is due partly to dip and to structural position relative to the axis of the Logan Peak Syncline, and partly to original depositional characteristics of the lower unit.

The lower unit is not present in all of the sections measured or outcrops studied. The unit is clearly present and ranges from 30 feet to 79 feet in thickness in sections 2, 4, 6, and 16 (Figure 1). The lower part of the formation is covered and the presence of the unit could not be established with certainty in sections 1, 3, 5, 8, 9, 10, 13, and 15 (Figure 6). The lower unit is absent and the middle unit rests directly upon the Garden City Formation in sections 7, 11, 12, 14, and 17. All three of the units are absent in section 0. The omissions appear to result from lack of deposition; evidence of erosional removal of the lower unit was not apparent at any of the localities where it is missing.

Individual strata of the lower unit range in thickness from less than one inch to slightly greater than five feet. Wavy, smooth parallel bedding surfaces predominate, and the beds are commonly lenticular (Plate 1). Comparison of sections less than one mile apart reveals lack of continuity of even the thicker beds. Good exposures are rare and discontinuous, and thus individual beds cannot be traced for sufficient distances in most places to disclose their lateral changes in detail.

Calcareous strata are black to gray on fresh surfaces; however, white patches of calcium carbonate form on bedding surfaces due to weathering. Quartzite strata are black to brown on fresh surfaces. The shale is dark gray and weathers into very small fragments less than one inch in diameter.

Limestones in the lower unit contain Orthambonites swanensis (Ulrich and Cooper) and O. michaelis Clark. Analysis of thin sections of one such limestone bed revealed an estimated 60 percent organic fragments, chiefly spicules, ostracods, fragments of brachiopods, and unidentifiable shell material, which form a distinct framework. It was not possible to do extensive paleontological study of the shale layers because of their splintery character.

Wherever exposed the lower unit is noticeably void of feeding burrows. Small trails attributed to gastropods are present locally.

Middle quartzite and shale unit

The middle unit thickens northwestward in the area of study, as does the upper unit (Figures 7 and 8). The middle unit is present in all sections except section 0.

The color of the quartzite on fresh surfaces is quite variable; white, tan, gray, and purple predominate. The variable color appears to be a reliable criterion for recognizing this unit. Thin sections revealed that the color results from fine matrix material, for the grains are virtually all colorless quartz (Plate 2). Light-colored samples have a transparent silica cement, and purple-colored samples have a purple matrix. Detailed analysis of coloring agents was attempted by X-ray diffraction, but the rather small amounts were insufficient for successful identification. However, X-ray fluorescence analyses revealed that iron was responsible for the purple color.

The unit is composed of quartzite beds, three inches to fifteen feet thick, interbedded with black to green shales a fraction of an inch to two or three feet thick. The upper third of the unit consists mainly of quartzite beds averaging 10 feet thick, which are separated locally by green shale partings ranging from one inch to two feet thick. The lower part of the middle unit contains progressively more shale and less quartzite. Bedding of both quartzite and shale becomes thinner toward the base of the unit (Plates 3 and 4).

Quartzites of the middle unit are well sorted and fine- to medium-grained. Average roundness and sphericity of the sand grains are 0.5 and 0.7, respectively (Krumbein and Sloss, 1963, p. 111). The grains are tightly packed, pore spaces are filled with silica cement, and porosity in most samples is less than 1 percent.

Shales of the middle unit are black, blue, gray and green on fresh surfaces. Shale beds low in the unit are chiefly black, but a change to lighter colored blues, grays, and greens, respectively, occurs higher in the section. The shales are quite fissile, and weather into small pieces. Some shales are better lithified than others. Many of the fossils obtained from this unit came from the well lithified shales.

Differential thermal analysis and X-ray diffraction analysis of the shales in this unit reveal that quartz and illite comprise most of the clay-sized particles. The percentage of illite decreases vertically in shales of the middle unit. This is the case in modern coastal sediments for illite occurs predominantly offshore in deeper water (Grim, 1953, p. 349-356).

Black to yellow, sulfurous, bioturbated quartzite containing feeding burrows locally lie at the top of the interbedded quartzites and shales of the middle unit (Plate 5). The total thickness of these yellow beds ranges from only a trace in most of the northern sections to between 10 and 20 feet in most of the southern sections. Shaly partings less than an inch thick are present, but comprise a very small part of the beds. Usually no more than three or four such shaly layers are present in the sulfurous quartzites. No body fossils have been found in these beds, but feeding burrows are common throughout.

In section 4, quartzites of the middle unit with steep planar laminae and fish scales also have traces of the sulfurous yellow beds. Generally, however, the series of sulfurous beds lie above such phosphatic, cross-bedded strata. The sulfurous beds generally lie near the top of the middle unit and near the base of the upper unit. The presence of feeding burrows and the absence of sedimentary structures characteristic of the upper unit place the sulfurous beds, in most cases, in the upper part of the middle unit.

The sedimentary structures of the middle unit are numerous, and appear to represent laterally and sequentially variable energy conditions. Throughout the lower two-thirds of the unit the beds are thin and display parallel to wavy laminations. Surfaces of quartzite beds commonly show oscillation and interference ripple mark (Plates 6 and 7). In the southern part of the area the majority of the ripple marks have crests that strike E-W (Plate 8); however, a less prominent second group have crests that strike NE-SW (Plate 9). Ripples of the predominant set are much flatter, and have an index ($\frac{\lambda}{A}$) of about 14. In section 10, ripple crests trend N-S and NW-SE. Still farther north, in section 15, the ripple crests assume a predominantly NW-SE strike.

Quartzite beds higher in the unit display parallel laminae and planar cross strata. With a few exceptions nearly all cross laminae dip west to south between 20° and 30°. The laminae locally are truncated at the top; however, most are tangential at both the top and the bottom. In a few exposures rare cosets consist of laminae, in sets about 6 inches thick, that dip in opposite directions (Plate 10).

White flakes, apparently scales of primitive fish or fragments of ostracoderm plates, are abundant in certain quartzite beds in the middle unit. They appear as white layers in a blue background, and offer a sharp contrast to the surrounding, lighter quartzite. Minor sedimentary structures are strikingly outlined by these white, contrasting laminae (Plate 11).

The scales are generally in sets of either parallel or cross laminae less than one foot thick (Plate 12). The scales also occur scattered throughout the quartzites in the upper part of the middle unit, and probably contribute to the dirty gray color of many of the beds. Laminae of hydroxyapatite ($10CaO \cdot 3P_2O_5 \cdot H_2O$) less than one inch thick occur in strata associated with the scales; that is, the scales are present within and/or a few feet above or below the laminae containing the mineral. Hydroxyapatite is the mineral form of the protein Collagen which is present in bones, teeth, and some brachiopods (Degens, 1965, p. 220).

Most outcrops do not allow a study of bedding surfaces because the units are exposed only in profile. However, where bedding surfaces are well exposed high in the middle unit, mud cracks (Plate 13), flat-topped ripple marks and raindrop imprints (Plates 14 and 15) are common features.

Feeding burrows are scattered throughout the middle unit and appear on the underside of nearly every bedding surface of exposed quartzite (Plate 16). Features resembling feeding burrows occur in homogeneous quartzite beds, but normally the removal of an underlying shale layer is necessary for their positive recognition. The structures in places also occur within shale layers.

Quartzites of the middle unit are poorly cemented locally and exhibit circular to elongate sandstone pockets several inches in diameter. These pockets are commonly quite fossiliferous, and are the source of many of the brachiopods collected.

Fauna collected from sandstone pockets in various quartzite beds in the middle unit include:

1. Orthambonites swanensis (Ulrich and Cooper)
2. Anomalorthis sp.
3. Hesperorthis sp.
4. Lopospira? sp.

Fauna from shale strata of the middle unit include:

1. Eleutherocentrus petersoni Clark
2. Tetranota sp. Ulrich and Scofield
3. Protocycloceras debilis Clark
4. Linguella sp.
5. Lingulepis sp.
6. Didymograptus bifidus (Hall)
7. D. artus Elles and Wood
8. Macluritella sp.
9. ostracods

P. debilis Clark, O. swanensis (Ulrich and Cooper), Macluritella sp., and E. petersoni Clark are present in many of the quartzite beds in the middle unit. In addition, Hyolithes sp. and Illaenus sp. were found in section 6 in purple quartzites just above the thick shale sequence of the middle unit.

The shales of the lower part of the middle unit contain excellent graptolite assemblages. Clark (1935, p. 244) described the following fauna, collected near Mt. Pisgah, probably from the middle unit:

1. Didymograptus nitidus (Hall)

2. D. bifidus (Hall)

3. Orthis michaelis Clark

4. Linguella pogonipensis (Walcott)

5. L. bellesculpta Clark

6. P. debilis Clark

7. E. petersoni Clark

8. Tuzoia subtile Clark

D. nitidus (Hall) was not found in shales of the lower part of the middle unit in this study, whereas D. artus Elles and Wood is the most common species present. Berry (1962, p. 298) stated that D. artus and D. bifidus commonly occur together in North America, and this appears to be true for shales of the lower part of the middle unit. D. artus was either absent from the area studied by Clark or not collected.

The purple quartzite that lies high in the middle unit in Green Canyon (section 6) has layers of gastropods, vrom which the following were collected:

1. Macluritella sp.

2. Barnesella sp.

3. Eunema sp.

These fossils occur above the quartzite face exposed in Red Rock quarry in Green Canyon, and the fossils are easily collected from the talus material.

Drepensator sp., a primitive brittle starfish, and Goniotelus? sp. were found in section 7 in a quartzite of the middle unit a few feet above the

Garden City Formation. Both are unique in their rarity and apparent absence elsewhere in the Swan Peak Formation.

A complete cast of the trilobite E. petersoni Clark was found in section 13 in talus of the purple quartzite of the middle unit. This is apparently the first complete imprint of the organism, which was originally described from incomplete specimens. This trilobite is a little over an inch long and has 10 thoracic segments. A single specimen of the gastropod Hormotoma sp. also was found in the same talus.

Upper quartzite unit

Thickness of the upper unit varies from 0 to 290 feet. The unit is thickest in the north and west, and thins southeastward (Figure 8). Section 8, near the Utah-Idaho border, was the thickest section measured. The unit is absent in sections 0, 1, and 7 in the south. The omission of the upper unit from these sections appears to be a depositional feature: evidence of erosion was not apparent at any of the localities where the upper unit is absent. However, since the contact between the upper unit and the overlying Fish Haven Dolomite is an unconformity, the possibility that a considerable amount of the upper unit was removed prior to the deposition of the Fish Haven Dolomite cannot be discarded.

In the northern part of the study area the upper unit contains two distinct lithologies. One is primarily a well-sorted, white, porous sandstone or quartzite; the other is a well-cemented tan quartzite. The sequence of tan beds underlies the white strata in most places, but locally thin beds of white, porous quartzite occur within the tan strata. Total thickness of the tan beds in each section is less than that of the white beds.

Throughout the unit planar horizontal bedding surfaces range from a few feet to greater than ten feet apart. Beds of white quartzite are thicker than beds of tan quartzite, which usually lie low in the upper unit. Beds of the upper unit commonly weather along diagonal joints. Locally these joints follow steeply dipping cross laminae, but it is not clear whether or not all such joints follow primary sedimentary structures.

Average grain size of the sand increases vertically through the upper unit, from .20mm at the bottom to .60mm at the top. Roundness and sphericity of the grains for the entire unit average 0.3 and 0.9, respectively. Numerous cross laminae present were rather steep, and not continuous laterally for great distances (Plate 17). Most cross laminae in sets greater than one or two feet thick dip south to southwest, whereas cross laminae in some smaller sets and cosets dip north to west.

In most cases, cross laminae are indistinct. Planar types predominate, and such structures are either better developed or more readily weathered differentially in the lower part of the unit, where they are more commonly seen. Near the base of the upper white sand in most areas are cosets of planar cross strata two feet to ten feet thick that are composed of individual sets each a foot or more thick (Plate 18). The planar cross strata dip west to southwest at an average of 25^{o}. They are truncated to tangential on top and tangential at the base.

Directly beneath the Fish Haven Dolomite in section 2 (Plates 19 and 20) and near the base of the upper unit in sections 3 and 10 is a distinctive sequence of beds, 10 feet thick, that display planar cross laminae, rich in hydroxyapatite, that dip 5^{o} to 20^{o} west to northwest. These were the only measured sections where such cross laminae of concentrated heavy minerals occur (Figure 5). Farther north and west such heavy minerals are dispersed throughout the quartzite or along parallel laminae, but in about the same position stratigraphically near the base of the upper unit.

The upper unit displays distinctive vertical and diagonal burrows. Most of the vertical burrows (Plate 21) are two to four inches long, but tubes eight inches long are common where the burrows are well displayed due to differential weathering. The burrows are two to five mm in diameter. Locally they weather in relief along exposed bedding surfaces to give the top of the bed an organ-pipe appearance. The vertical burrows are best displayed in the tan strata below the more massive white beds (Plate 22). In many places where advanced weathering has not accentuated the burrows, white, noncalcareous spots a few millimeters in diameter mottle bedding surfaces.

Diagonal burrows are usually less than three or four centimeters in length and about two to four millimeters in diameter. They appear to connect the vertical burrows, although it is difficult to establish this relation with certainty because preservation is poor. The white quartzite beds locally display a maze of vertical and diagonal burrows that resemble a mass of heavy cobwebs (Plates 23 and 24). These burrows are different from the vertical burrows in tan quartzite beds, described above, which chiefly occur low in the unit. The upper unit is very porous locally, where burrowing is heaviest, so that porosity in the upper unit apparently is related to the amount of burrowing. The more burrows present, the greater the porosity and the easier the sand weathers. At all locations where the upper unit is present, each outcrop displays local areas where primary sedimentary structures were destroyed by burrowing, as well as places in the unit where undisturbed primary structures prevail. No body fossils were found in the upper unit.

Interpretation of Units

Lower quartzite, shale, and limestone unit

The fossil content, lithology, and gradational stratigraphic relationships with the overlying middle unit and the underlying Garden City Formation, indicate that the lower unit originated in an offshore-marine, shelfal environment. Sandstone, shale, and limestone are unsystematically distributed both vertically and laterally through the unit. Several factors could have caused the alternating accumulation of limes, muds, and fine clastics in some areas and the absence of these in others. Possible variables are rate of sedimentation, wave and current energy, availability of clastics, differential subsidence or compaction, distance from source areas, transportation and deposition mechanisms, pH, Eh, and organic activity.

Figure 6, a map showing thickness of the lower unit, indicates that deposition of this unit was concentrated in an E-W trending belt located at present just north of Logan, Utah. Differential subsidence along this belt possibly created intermittently deeper or quieter water, and thereby enhanced carbonate deposition. During periods of carbonate accumulation, clastic influx was rather low, and organic productivity was correspondingly quite high.

Finer material comprising the shales of this unit may have been derived from local, turbid streams, especially if the coastal sand was a clean, second-cycle sediment derived chiefly by longshore drifting from a source far outside the area studied. The thin sandstones probably represent short periods of increased wave energy, perhaps during storms.

Because the lower unit is thickest along an axis trending E-W in the center of the study area, and the middle and upper units are thickest northwestward from this axis (Figures 6, 7, and 8), the lower unit could be time equivalent to parts of the middle and upper units in the north.

Middle quartzite and shale unit

The quartzites and shales of the lower part of the middle unit probably were deposited in the shoreface or very shallow shelf. The lower part of this unit represents a transition from the low-energy conditions of the lower unit to higher-energy conditions of the upper part of the middle unit. The shales of the middle unit probably represent fines deposited in the shoreface or tidal flat by waves and by tidal action. This fine, clastic material may have been introduced from coastal tributaries, or simply removed from the nearshore sands by the customary sorting action of breaking waves.

Some of the interfingering of the sands and muds may be due to cycles of slight rise and fall of sea level. The retreating or advancing shoreline would change the position of the offshore and foreshore environments and affect the type of deposition also. However, in Virginia, a thin layer of sand four to six inches thick covered the surface of the bottom to -60 feet just after a storm; after three months of quiet weather, mud covered this sand to depths as shallow as -30 feet, yet the shoreline and sea level were essentially stable (Oaks, oral communication). Both conditions could have affected the type of sedimentation in the middle unit.

The wavy, parallel bedding surfaces predominant throughout the unit, and oscillation ripples with an average wavelength of six inches indicate some current movement or oscillation of the bottom sediments before burial by overlying sand or mud.

The lower part of the littoral zone during Swan Peak time was probably similar to areas of shallow shelf to shoreface today, which display numerous depressions that trap and hold large amounts of fines. Therefore, variations in total thicknesses of the quartzite of the middle unit from section to section could be due to irregular bottom topography, differential subsidence, local clastic influx, or shoreline configuration. Local, transient conditions favorable to deposition of limestone would affect the total thickness assigned to the middle unit, but variations caused in this manner are believed minor on the basis of regularity in trends in Figures 6, 7, and 8.

The thinness of quartzite beds low in the unit would indicate that periods of higher energy and deposition of coarser material were short-lived. Ripple marks are rarer in the lower part of the unit than in the upper part, which may indicate that once the sediment was transported and deposited by temporarily higher-energy conditions, it was left undisturbed except by burrowing organisms.

The majority of the ripple marks present in the middle unit in the southern part of the area trend between NE-SW and E-W. A second set, somewhat smaller and superimposed on the first, strikes nearly perpendicular to this direction, or about NW-SE. Assuming the oscillation ripples trend nearly parallel to the coastline, as they chiefly do today, the shoreline probably had a NE-SW to E-W strike. The NW-SE trend of the ripple marks in this unit farther north suggests that the strike of the shoreline there was more nearly NW-SE. In southern Idaho a single set of ripples again strike WNW-ESE. Thus the shoreline in the area of study may have been somewhat irregular and locally embayed, rather than straight. The shoreline configuration inferred from sedimentary structures agrees with the configuration suggested by the map showing thickness of the unit (Figure 7).

Further inferences on bottom conditions at the time of deposition are derived from the color and fossil content of the shales. The blackness of the shales in the lower part of the middle unit results from a high organic content. The rich fauna of trilobites, cephalopods, articulate brachiopods, gastropods, ostracods, and delicate graptolites indicate a relatively quiet, reducing bottom environment. The organisms may have been washed into the area, or else accumulated in such numbers because of a low rate of mud deposition or of a high productivity rate due to a large nutrient supply.

Near the middle of the unit, pockets of fossiliferous sandstones were found locally in horizontal zones in the quartzite strata. The unworn, articulated brachiopods and trilobites in these pockets indicate rapid burial. These fossiliferous pockets are interpreted to be small, local depressions where shells of benthonic creatures accumulated after gentle transport by low-energy currents or wave action near the base of the foreshore environment.

The middle unit in section 7 is unlike those near Logan, Utah, and farther north. Here, sandstones and shales rest directly on the Garden City Formation. The section is faulted, and the upper contact of this unit was covered. Paleontologically, the middle unit in section 7 is similar to the middle unit elsewhere. E. petersoni Clark and O. swanensis (Ulrich and Cooper) are present. However, O. michaelis Clark is also abundant in the sandstones, whereas, in Logan Canyon and farther north, this species appears limited to the lower part of the lower unit, a few feet above the Garden City Formation. This occurrence suggests that there is no hiatus of any significant length between deposition of the Garden City Formation and of the middle unit at this location, and that noncalcareous sands and shales were being deposited at this location at the same time the calcareous strata of the lower unit were being deposited farther offshore. No feeding burrows were found in section 7, although trail-like impressions were present on some bedding surfaces. In this one respect the section in unlike the middle unit elsewhere.

In the upper part of the middle unit in most sections, delicate fossils are absent in the shales, the shales are thinner and less common, both shales and sandstones are bioturbated, feeding burrows are more abundant, and thick accumulations of fish plates and scales are common. Mud cracks, raindrop imprints, and oscillation- and flat-topped ripples are attributed to shallow water and probable tidal-flat conditions.

The fish scales and/or ostracoderm fragments are characteristically absent in the more offshore sediments of the lower unit and the lower part of the middle unit. This material either was destroyed selectively within the offshore environment or else was concentrated along a belt adjacent to the coastline by waves and marine currents. The blue color of the beds containing the scales or plates is attributed to the mineral hydroxyapatite ($10CaO \cdot 3P_2O_5 \cdot H_2O$) a phosphate mineral evidently formed by diagenic alteration of the ostracoderm material after burial.

The purple color characteristic of the quartzite and shale beds in this unit results from iron in the matrix, based on X-ray fluorescence analysis. The iron probably resulted from a ground-water table that was relatively stable and continuous throughout most of the period of lithification. A similar red staining has been observed from cores and pits in Galveston Island where the water table has remained constant over a long period of time.

Where present, sulfurous beds occur at either the top of the middle unit or at the base of the upper unit. The presence of sulfur suggests reducing conditions contemporaneous with deposition. These conditions are common in coastal lagoons. Differential thermal analysis and X-ray diffraction studies of the shaly partings in the sulfurous beds revealed the presence of gypsum. This evaporite mineral in the unfossiliferous, sulfurous sands probably represents local, oxidized lagoonal environments or evaporating ponds near high-tide level that were conducive to short periods of evaporation. Where the sulfurous and gypsiferous sands and shale partings are exposed, they lie stratigraphically just above or at the position occupied by tidal-flat deposits in other sections. Since the shaly partings in which gypsum was identified were in the zone of weathering, the gypsum may be due to the hydration of original anhydrite. Either mineral suggests an increase in salinity of the sea water.

It is evident that the nearshore environments were quite varied: in some locations restricted, stagnant lagoons may have formed, elsewhere lagoonal depressions apparently were absent; in some places a rather wide zone was periodically inundated by the tides, elsewhere this zone could have been quite narrow, and in other areas small restricted evaporation basins occurred.

Deposition of the upper unit as an offshore sand could have reduced nearshore wave- and current energies, and thereby enhanced lagoon formation and stagnation along the coast. All lagoonal deposits occur south or south-east (landward) of the offshore-marine sand. The marine sand eventually covered these local, reducing environments and precluded their development on a large scale.

Upper quartzite unit

In sections 2, 3, and 10, planar cross laminae with hydroxyapatite nodules 3mm to 10mm in diameter occur within parallel beds in the lower part of the upper unit. The cross laminae dip north to northwest, perpendicular to the E-W to NE-SW strike of the shoreline inferred from the map showing thickness of the upper unit (Figure 8). This orientation suggests origin in a fluvial, estuarine, inlet, or rip-current environment. The very regular parallel and planar bedding probably excludes fluvial deposition. The planar surfaces and planar cross laminae could have formed during still water and ebb tide, respectively. These may reflect spring tides, or possibly even daily tidal surges alternating with primarily quiet water.

The abundant detrital hydroxyapatite, which evidently was carried from the southeast, was not found in such quantity elsewhere in the unit. This suggests that at least some detrital sediment probably was derived locally from lands to the south or southeast, as well as from the north as suggested by strata higher in the upper unit. Within a few miles of section 2 the dark hydroxyapatite grains either have been completely dispersed and lost within the clean sands, or have been destroyed altogether. The lower strata of the upper unit in general show less dark grains progressively northward. Sections 4, 5, 8, 9, 12, 13, 14, 15, and 17 displayed no dark minerals at all.

The upper unit thickens north and west of sections 2 and 3, and is characterized by vertical and diagonal burrows in cross-laminated medium- to coarse-grained sands with parallel bedding. The vertical burrows indicate that organisms had to build protective structures strong enough to prevent collapse within a coarse substrate. This better-sorted sediment is distinctly coarser than sediment of the middle unit. From the distribution of burrows and the lack of scours and ripples in the sand, it appears that the sand beds were deposited quickly, followed by quieter periods of burrowing activity with little or no further current- or wave activity. Possibly, the burrowers simply moved upward as nearly continuous and rather rapid deposition proceeded. These features suggest that higher wave- and current energies prevailed during deposition of the upper unit, and provided conditions unfavorable to the life and/or preservation of the type of fauna found in the middle unit.

Interpretation of the nearly homogeneous quartzites of the upper unit is inferred rather than direct. None of the internal structures are diagnostic or indicative of a definite environment. The vertical and diagonal burrows, coarse grain size, south-dipping cross laminae, stratigraphic position, geographical occurrence, and wedge-shaped geometry that thins southeastward, indicate a probable offshore-marine sand body that prograded southward and westward. The lack of foreshore, berm, or tidal-flat features, especially ripples, scours, mud cracks, raindrop imprints, wedge-shaped dune structures or any other backshore indicators, coupled with the abundant and presumably marine burrows and predominant south-dipping cross laminae and parallel bedding, narrows the probable environment to rather high energy and marine. The high sphericity, good sorting, and cleaness of the sand indicate a multiple-cycle sediment derived from older, rather mature sandstones or quartzites.

The unit apparently is a marine sand overlying finer-grained tidal-flat sediments represented by the middle unit. Because southward thinning of the upper unit (Figure 8) is partly compensated by southward thickening of the middle and lower units, the present distribution of each unit may represent closely the maximum distribution of each unit during deposition. Thus, the upper unit possibly never extended very far south of the present position of Logan Canyon. Such a southward depositional limit possibly resulted from a positive area present in the south or southeast. Absence of the lower unit in section 7, and the absence of the formation altogether in section 0, indicate an emergent condition in these areas during deposition, or, possibly, post-depositional removal by erosion prior to the Fish Haven transgression.

The positive area could have been a local feature of small extent; however, it also could have been the northward extension of the east-west trending Tooele Arch, which considerably influenced deposition of the Swan Peak Formation farther south. This positive area caused the Swan Peak shoreline, which probably trended approximately north-south in the north, to curve to a nearly east-west trend in the south, near the present position of Logan Canyon. Deposition of the offshore sands also corresponded to the trend of the shoreline, for the upper unit is absent south of sections 4 and 5, where lagoons with thick, sulfurous, gypsiferous sediments of the middle unit formed.

Time lines, therefore, did not necessarily follow lithologic boundaries. While the marine sand accumulated near the Idaho border, marine shale, tidal-flat sands and shales, and sulfurous shaly sands formed farther south, and offshore, shelfal limestones of the Garden City Formation probably accumulated farther west. Because the upper unit always overlies the middle unit, it is probable that the respective environments were adjacent, and that the upper unit transgressed southward, an inference borne out by the sedimentary structures of the upper unit. The tidal-flat- and shoreface sediments of the middle unit probably were deposited shoreward of the offshore sand of the upper unit.

It is also possible that the tidal flats of the middle unit were well developed for a long period of time in this area before the influx of marine conditions allowed deposition of the upper unit over most of the area. The three units of the formation would not be time equivalent in this case.

The vertical sequence of lithologies and sedimentary structures of the lower and middle units indicate that progressively shallower marine conditions were developing. This succession appears to terminate at the top of the middle unit, where raindrop impressions, possible mud cracks, and flat-topped interference ripple marks indicate a very shallow-water environment periodically exposed subaerially. The contact between the top of the middle unit and the overlying upper unit is sharp, but not erosional. This upper unit is not aeolian dune, or other terrestrial sediment that one would expect if the emergent trend had continued. It is, instead, a burrowed marine sand void of intertidal features. This unit suggests that subsidence and/or rise in sea level produced slightly deeper-water conditions and thereby allowed deposition of the shallow-marine sands above the tidal-flat- and shoreface deposits.

Whether or not this upper unit marks the return of the sea and should be called transgressive is uncertain. If the contact between the upper unit and the Fish Haven Dolomite were conformable, the upper unit could represent the initial stage of the Fish Haven transgression. However, the contact displays breccia locally, so that the upper unit could have been exposed for a short period after deposition. Until further work definitively resolves this problem, the break between regressive and transgressive cycles is placed tentatively at the contact between the Swan Peak Formation and the Fish Haven Dolomite. The thickness of the upper unit suggests that the deeper-water conditions may have lasted locally for a considerable length of time. However, an overall regressive situation must have prevailed at this time to account for the very thick accumulations of the upper unit farther west.

ORIGIN AND SIGNIFICANCE OF "FUCOIDAL MARKINGS"

A study of the Swan Peak Formation would be incomplete without an attempt to determine the origin of the "fucoidal markings" found throughout the middle unit of the formation. Outcrops in Green Canyon, Dry Canyon (Plate 16), Logan Canyon, and in other, less accessible locations along the west and east sides of the Logan Peak Syncline, illustrate the great number and diversity of these structures.

In almost all instances the structures are best developed on the underside of quartzite beds, although they commonly occur throughout most quartzite beds. In only a few outcrops were there traces on the bedding surface. The enhancement of preservation is interpreted to result from the removal of the underlying shale strata and subsequent exposure of the base of the overlying bed. The "fucoidal markings" are feeding burrows as discussed on page 8.

The feeding burrows are present in the middle quartzite and shale unit, and disappear, or at least were not detected, in the more homogeneous upper unit. In all cases where a bed is interpreted as being littoral to sublittoral from independent evidence, the burrows are abundant, whereas deeper-marine deposits are characteristically void of them. Numerous horizontal trails are present in the lower unit, but they have little resemblance to the horizontal or nearly horizontal burrows.

The feeding burrows are 5 to 30 cm long and rather linear. They are seldom more than 2 cm deep and 1 to 2 cm in cross section. The superposition of several burrows often make them appear to be 3 or 4 cm deep, but there is no evidence that any single burrow is that deep. Locally they exhibit faint, regular, transverse fluting. In places, the structures are radially distributed and some appear to branch from a central point. Some structures indeed may branch laterally from a central tube, but most clearly intersect at a large angle, and so were formed at different times. The structures go over and under each other at intersections, and indicate avoidance of pre-existing burrows.

Some vertical burrows are found locally in the middle unit, but do not appear to be related to the horizontal feeding burrows. Modern tidal-flat and shoreface environments, represented by the middle unit, are highly burrowed by many different organisms. Therefore, different types of burrows, unrelated, should be expected in the middle unit also.

Several homogeneous beds of quartzite within the middle unit have no apparent feeding burrows in them. These beds probably resulted from rapid accumulations of sediment that precluded extensive reworking by benthonic organisms.

The pattern of occurrence of the burrows is summarized as follows:

1. Present in low-energy to medium-energy environments with sandy and shaly sediments.
2. Most numerous in medium-energy, shallow-water environments, presumably shoreface and possibly tidal flat.

3. Absent in thick beds of shale.

4. Absent in calcareous muds and sands.

5. Absent in thick sand interpreted as deposited rapidly.

6. Associated with abundant body fossils, especially orthoconic cephalopods, trilobites, and gastropods.

7. Absent in most unfossiliferous beds.

In many strata there is a sharp contact between parallel-laminated, parallel-bedded sand above, and bioturbated sand beneath. The boundary between the bioturbated and parallel-laminated sand is not linear, but irregular, and many depressions a centimeter deep occur in the lower reworked sand.

Thin sections of quartzite with abundant burrows, and of the overlying unburrowed quartzite, reveal several obvious differences between composition and textures of the two (Plate 2). The overlying, undisturbed sand has a high organic content consisting mostly of specules and unidentified debris. This material constitutes 5 to 10 percent of the sediment, and varies only slightly throughout the samples studied. The primary porosity of the undisturbed sand, represented by the present silica cement, is less than 5 percent. However, the burrowed sand is almost void of organic material. Fragmentary pieces of broken spicules and unidentified debris constitute 1 percent or less, by volume, of the sand. The porosity, however, is greatly increased, to more than 15 percent.

The increased porosity and decreased organic content of the bioturbated sediment, together with the overlying, undisturbed, organic-rich, compact sand, indicate that reworking of the disturbed sediment has occurred, probably before the overlying laminae were deposited. Such evidence also suggests that the disturbed sediment was searched for organic material that was removed selectively before the sediment was redeposited in a burrow-shaped pattern.

These characteristics suggest that the feeding burrows consist of reworked, perhaps partially digested, sediment that was sieved for food by epifauna that burrowed less than 2 cm below the surface. After the sediment was reworked, the surface apparently remained quite irregular, as shown by numerous depressions found in the boundary between the reworked material and the overlying, undisturbed sediment deposited later.

Organisms responsible for the feeding burrows probably were quite mobile and/or very abundant, to produce the huge number of burrows. Scavengers and/or carnivores, probably benthonic epifauna, apparently formed the burrows. The burrows are too large for snails, whose trails are seen elsewhere, and are not the right shape to be formed by trilobites. Echinoderms such as holothurians, or worm-like creatures that leave little fossil evidence besides burrows, or cephalopods apparently were responsible for the burrows.

About a dozen straight-shelled cephalopods, Protocycloceras debilis Clark, were found on the lower surfaces otherwise covered with abundant feeding burrows. The siphuncles and chambers of the organisms are clearly visible (Plates 25 and 26). Probable casts of extended tentacles were found on two specimens (Plate 25). These casts closely resemble the feeding burrows in shape, size, and general appearance. The ventral side of the fossils was always downward, which suggests that the organisms lived on or just above the bottom when they died, rather than some distance above the bottom. In the latter case they should have sunk to the bottom with a less well-developed orientation, unless the siphuncle and cameral deposits made the ventral side quite heavy. The occurrence of resting tracks (Plate 27) clearly indicates a benthonic life habit, at least in part, for the orthoconic cephalopods.

Flower (1955) described tentacular impressions of orthoconic cephalopods in Ordovician sandstones in Ohio. His study indicated that most orthoconic cephalopods were benthonic organisms at least part of the time.

The feeding burrows are probably a combination of shallow burrows and trails made by the tentacles of the organisms. The tentacles may have been used to propel the animal as well as to scoop sediment into the oral cavity. Undoubtedly, not all the sand was sifted or reworked, or the organisms were somewhat inefficient, for some organic material remains in the sediment.

The question of why so few cephalopods were found in view of the vast vertical and lateral extent of the feeding burrows can be partly explained by the difficulty of recognition of the conchs within the maze of burrows. Also, the total amount of burrows one organism can form in its lifetime is very large. A few active feeders in a relatively large area would leave a considerable amount of reworked sediment and burrows.

However, part of the answer may lie in the processes of preservation during subsequent diagenesis of both sediments and fossils. Because the burrows consist of quartz sand, and because the original cephalopod conchs consisted of calcite or aragonite, the latter were less resistant to postdepositional solution and destruction. The conchs also would be subject to breakage by waves and currents on the bottom, and by other predators.

The burrows actually aided preservation to some extent. As the sediment is worked over or cleaned up, it appears to be packed back into the burrow or trail formed. New sediment is deposited over the filled burrows and protects it. The best-preserved examples are the structures on the underside of quartzite beds that overlie a shale bed, because the shale sloughs off due to differential weathering, and leaves the burrows as structures in relief above.

If the organism was buried in sand and preserved, it would not be available for detection later because the quartzite probably would weather massively. However, if the organism died while above or on a mud bottom which was quickly covered by sand, then preservation would be enhanced. This appears to be the process involved for most of the cephalopods found. Nearly all of the cephalopod conchs and burrows occur on the underside of sand beds directly above shale partings. Such conditions are rather special, and the number of cephalopods actually buried in this manner could be small compared with the total number of cephalopods originally present in the sediment, and perhaps still preserved, though inaccessible, within quartzite beds.

The occurrence of the burrows and of resting tracks of orthoconic cephalopods in only the middle unit suggests that Protocycloceras debile Clark was restricted to shoreface environments, and probably to tidal flats also.

GEOLOGIC HISTORY AND PALEOGEOGRAPHY

Swan Peak time in northern Utah and southeastern Idaho, as reflected by the Swan Peak Formation, was a time of westward progradation of a sandy, tidal-flat shoreline in the south, and probable local subsidence in the north, where deposition of a marine sand occurred. The marginal shelf of the miogeosyncline in the west originally extended into this area during deposition of the Garden City Formation and of the fossiliferous, calcareous lower unit of the Swan Peak Formation. The eastern limit of this shelf is not precisely known, but the existence of the Garden City Formation and the lower unit in the easternmost outcrops indicates that rather deep water extended across the entire area of study and probably into Wyoming in early Swan Peak time. Southward the Garden City Formation extends across the Tooele Arch, but individual units of the Swan Peak Formation may not.

During deposition of the Swan Peak Formation, a positive area formed in the present vicinity of Avon and Blacksmith Fork Canyon, Utah, while differential subsidence apparently occurred in the north. The shoreline advanced westward as sands of the middle and upper units prograded westward and southward, respectively. Shoreface- and foreshore deposits of the middle unit covered shelfal deposits of the lower unit, and were in turn covered by marine sand from the north. A northern source for the upper unit also is supported by regional studies of Ordovician sandstones in the Rocky Mountains by Ketner (1968).

Local accumulations of detrital hydroxyapatite and sedimentary structures in sections 2, 3, and 10 represent clastic material probably introduced by a local tributary in the south or southeast, where a positive area also is inferred from paleogeographic considerations based on maps showing thickness of each unit.

Characteristics of shallow water and intertidal conditions in the middle unit suggest a broad, low-lying coastal area with numerous local lagoons. Ripple-mark orientations and cross-laminae in the middle unit indicate an irregular coastline that extended roughly northeast-southwest throughout the area, but displayed local irregularities or even embayments. Southward the coast probably curved north-south whereas in the north the coast trended east-west.

The clean, well-sorted, and well-rounded grains of the upper quartzite indicate a mature sedimentary source terrain, which is expected if the sands were derived from Cambrian and Precambrian quartzites farther north. An attempt to find Cambrian quartzites in northern Utah that are not covered by younger Cambrian or early Ordovician shales and carbonates revealed that there probably were insufficient sandy source rocks widely exposed nearby to supply all of the Swan Peak sand deposited.

A regional study of the paleogeography of Ordovician time is beyond the scope of this study. However, the Ordovician Kinnikinic Quartzite in central Idaho resembles the middle and upper units of the Swan Peak Formation and similarly appears to thicken northward. The fact that the Northern Utah

Basin received abundant clastic sediment before the Ibex Basin in the south also indicates that the source of sand was in the north.

Fossil evidence and deposition of carbonates indicates that the Swan Peak sea was warm and shallow. Unfortunately, the absence of terrigenous plants or animals in Ordovician time prevents any inferences of the terrestrial climatic conditions during Swan Peak time, or of the length of exposure that occurred prior to the Fish Haven transgression. Numerous coral species of the overlying Fish Haven Dolomite suggest that a long period of warm marine conditions prevailed after and possibly during Swan Peak time.

Deposition of the Swan Peak Formation was terminated by the Fish Haven transgression. Whether this was due to eustatic control or to tectonic adjustments of the adjacent land mass is not known. Either subsidence, rising sea level, or both, caused the ocean to transgress rapidly eastward onto the continental platform. The rapidness of transgression is reflected by the sharp contact between the overlying Fish Haven Dolomite and the Swan Peak Formation. Some exposures reveal a zone a few inches thick along the contact in which a mixture of arenaceous and calcareous sediment occur, but in most outcrops the boundary between quartzite and non-arenaceous dolomite is sharp (Plate 28). Nowhere is evidence found indicative of a slowly advancing sea.

The environment or coastal platform today that most closely resembles the one of Middle Ordovician time is the immense tidal area of Hudson Bay in central Canada. The center of Hudson Bay is about 200 meters deep and the distance between high-tide- and low-tidelines is eight miles in places. If this area were placed under the same climatic conditions experienced by the Swan Peak in Ordovician time, the sedimentary structures, lithologies, variations in environments, and vertical sequence possibly would be quite similar.

CONCLUSIONS

The Swan Peak Formation consists of a three-fold succession: (1) A basal unit of interbedded orthoquartzite, shale, and limestone; (2) A middle unit of interbedded orthoquartzite and shale; and (3) An upper unit of orthoquartzite only. Sedimentary and paleontologic evidence indicates that this vertical succession of differing lithologies represents a continuum of environments from offshore, shallow shelf through shoreface, tidal flat, and lagoon, to shallow-marine sand.

The lower unit conformably overlies the Garden City Formation; the contact is gradational through a short distance vertically. A shelfal environment removed from high-energy conditions is indicated by the occurrence in the lower unit of delicate fossils, calcareous black shales, high illite content, and variations in thickness, together with stratigraphic position.

Shoreface-, tidal-flat-, and lagoonal environments are suggested by the presence in the middle unit of burrows, predators, flat-topped ripples, raindrop imprints, mud cracks, parallel laminae, sulfur, lack of carbonates, and stratigraphic position. Probably all three environments existed simultaneously in three bands along a low-lying coastal area. The middle unit prograded seaward (westward) over the lower unit and locally over the Garden City Formation.

The upper quartzite unit is unfossiliferous, non-calcareous, and nonargillaceous. It thins southward and eastward and has sedimentary structures that indicate a northern source. The coarser grain size and greater porosity than quartzites of the two lower units, and its lack of body fossils but high numbers of vertical protection burrows, all indicate a different source and a different, yet marine, origin of the upper unit compared to the middle and lower units. The three units may be in part time-equivalent to each other. The upper unit apparently accumulated in an area of differential subsidence.

The numerous "fucoidal markings" in the middle unit probably are shallow feeding burrows of benthonic orthoconic cephalopods. Typical "fucoidal markings" extend from anterior openings of the cephalopod conchs. Organic content in reworked sediment is low compared to that in undisturbed sediment, an indication that the bioturbated sediment was searched for the organic material. This reworking of the sediment also may account for the smaller grain size compared with that in the undisturbed sand. Sand bodies indicating high energy and rapid deposition and transportation of sand are void of this ichnofossil, as are the calcareous strata that formed in lower-energy and presumably deeper-water environments. The cephalopod Protocycloceras debilis Clark that is found among the markings probably made the feeding burrows.

From the standpoint of petroleum exploration, the upper quartzite is interesting for at least three reasons: (1) The strata in the lower units are primarily shallow-marine sediments and are richly fossiliferous; (2) Lateral changes exist between the three units; similar changes in other formations have formed effective stratigraphic traps; and (3) The upper quartzite unit covers a large geographical area and is both thick and porous in places. Two types of potential stratigraphic traps are present: (1) Offshore, shallow-marine sands of the upper unit that grade seaward (westward) into marine shales and pinch out landward; and (2) Coastal sands of the middle unit that exhibit depositional pinchout southward near a positive area in the south or southeast.

Unfortunately the upper unit is not highly permeable because of rather complete diagenetic cementation by silica. This fact, coupled with the faulting of the formation locally in the more southern and northern exposures, limits the chances that any permanent entrapment of petroleum has occurred in the Swan Peak Formation in the immediate area. Also, the unit lacks any oil staining.

However, the present study of vertical successions, faunal differences, sedimentary features, variability of thickness and porosity, and source areas, of a coastal deposit, reveals that deposits of nearshore environments can be recognized and interpreted. It is also important to understand that other coastal deposits will reflect the interaction of numerous divergent environmental factors, so that the resulting deposits will differ from place to place, even along the same coastline.

Recognition of suites of related features in cores or in outcrops will enable a better interpretation of the environment encountered, especially in terms of energy conditions in vertical sequence. This will determine the direction to proceed, laterally, to find better reservoir sands and/or stratigraphic traps.

REFERENCES CITED

Baker, A. A.; Huddle, J. W.; and Kinney, D. M., 1949, Paleozoic geology of north and west sides of Uinta Basin, Utah: Am. Assoc. Petroleum Geologists, v. 33, no. 7, p. 1161-97.

Berry, W. B., 1962, Didymograptus bifidus (J. Hall)--Its lectotype, description, and occurrence: Jour. Paleontology, v. 5, p. 294-299.

Churkin, Michael, Jr., 1962, Facies across Paleozoic miogeosynclinal margin of central Idaho: Am. Assoc. Petroleum Geologists, v. 46, p. 569-591.

Clark, T. H., 1935, A new Ordovician graptolite locality in Utah: Jour. Paleontology, v. 9, 239 p.

________, and Stearn, C. W., 1960, The Geological Evolution of North America: The Ronald Press Co., New York, 434 p.

Cooper, G. A., 1956, Chazyan and related brachiopods: Smithsonian Miscellaneous Collections, v. 127, pts. I and II.

Coulter, H. W., 1955, Fucoidal markings in the Swan Peak Formation southeast Idaho: Jour. Sed. Petrology, v. 25, p. 282.

Dapples, E. C., 1955, General lithofacies relationship of St. Peter Sandstone and Simpson Group: Am. Assoc. Petroleum Geologists, v. 39, p. 444-467.

Degens, E. T., 1965, Geochemistry of Sediments: A Brief Survey: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 342 p.

Flower, R. H., 1955, Trails and tentacular impressions of orthoconic cephalopods: Jour. Paleontology, v. 29, p. 857-867.

Grim, R. E., 1953, Clay Mineralogy: McGraw-Hill Book Co., Inc., New York, 384 p.

Hantzschel, W., 1962, Trace fossils and problematica: in Treatise on Invertebrate Paleontology, Moore, R. C. (Ed.). University of Kansas Press, v. W, p. 177-222.

Hintze, L. F., 1951, Lower Ordovician detailed stratigraphic sections for western Utah: Utah Geol. and Min. Survey, Bull. 39, 99 p.

________. 1952, Lower Ordovician trilobites from western Utah and eastern Nevada: Utah Geol. and Min. Survey, Bull. 48, 249 p.

________. 1954, Mid-Ordovician erosion in Utah: Geol. Soc. America, Bull., v. 65, p. 1343.

________. 1959, Ordovician regional relationships in north-central Utah and adjacent areas: in Guidebook to the geology of the Wasatch and Uinta Mountains transition area: Intermountain Assoc. Petroleum Geologists, 10th Ann. Field Conference, p. 46-53.

________. 1963a, Ordovician systems of Utah: in Oil and Gas Possibilities of Utah: Utah Geol. and Min. Survey, Bull. 54, p. 51-62.

________. 1963b, Summary of Ordovician stratigraphy of Utah: in Surface structure and stratigraphy of Utah: Utah Geol. and Min. Survey, Bull. 54A, p. 51-62.

Hobbs, S. W.; Hays, W. H.; and Ross, R. J., 1968, The Kinnikinic Quartzite of central Idaho-redefinition and subdivision: U. S. Geol. Survey, Bull. 1254-J, 22 p.

Kay, Marshall, 1960, Paleozoic continental margin in central Nevada, western U.S.: Internat. Geol. Cong., 21st., Copenhagen, 1960 Rpt., section 7, p. 28-33.

Ketner, K. B., 1966, Comparison of eugeosynclinal and miogeosynclinal quartzites of the Cordilleran geosyncline: U. S. Geol. Survey, Prof. Paper 550-C, p. 54-60.

________. 1968, Origin of Ordovician quartzite in the Cordilleran miogeosyncline: U. S. Geol. Survey, Prof. Paper 600-B, p. 169-177.

Krumbein, W. C.; and Sloss, L. L., 1963, Stratigraphy and Sedimentation, (2nd ed.): W. H. Freeman and Co., San Francisco, 660 p.

Laporte, L. F., 1968, Ancient Environments: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 116 p.

Mansfield, G. R., 1927, Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey, Prof. Paper 152, 57 p.

Masters, C. D., 1965, Sedimentology of the Mesaverde Group and of the upper part of the Mancos Formation, northwestern Colorado: PhD Dissertation, Yale Univ. (unpublished), 112 p.

Moore, R. C., 1958, Introduction to Historical Geology: McGraw-Hill Book Co., Inc., New York, 656 p.

Richardson, G. B., 1913, Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., v. 36, p. 406.

________. 1941, Geology and mineral resources of the Randolph Quadrangle, Utah-Wyoming: U. S. Geol. Survey, Bull. 923, p. 89.

Ross, C. P., 1947, Geology of the Borah Peak Quadrangle, Idaho: Geol. Soc. America Bull., v. 58, p. 1085-1160.

Ross, R. J., Jr., 1951, Stratigraphy of the Garden City Formation in northeastern Utah and its trilobite faunas: Peabody Mus. of Nat. Hist., Yale Univ., Bull. 6, 169 p.

________. 1953, The Ordovician system in northeastern Utah and southeastern Idaho: in Guidebook to the geology of northern Utah and southeastern Idaho: Intermountain Assoc. Petroleum Geologists, 4th Ann. Field Conference, p. 22-26.

________. 1964, Relations of Middle Ordovician time and rock units in basin ranges, western U. S.: Am. Assoc. Petroleum Geologists, Bull., v. 48, no. 9, p. 1526.

________. 1968, Brachiopods from the upper part of the Garden City Formation (Ordovician) north-central Utah: U. S. Geol. Survey, Prof. Paper 593-H, p. 1-13.

Seilacher, A., 1964, Biogenic sedimentary structures: in Approaches to Paleoecology, Imbrie, John and Newell, Norman (Eds.). John Wiley and Sons, Inc., New York, p. 296-316.

Shepard, F. P., 1963, Submarine Geology, (2nd ed.): Harper and Row, New York, 577 p.

Sloss, L. L., 1963, Sequences in the cratonic interior of North America: Geol. Soc. America, Bull., v. 74, p. 93-114.

Twenhofel, W. H., 1939, Principles of Sedimentation: McGraw-Hill Book Co., Inc., New York, 610 p.

Webb, G. W. , 1956, Middle Ordovician detailed stratigraphic sections for western Utah and eastern Nevada: Utah Geol. and Min. Survey, Bull. 57, 77 p.

________. 1958, Middle Ordovician stratigraphy in eastern Nevada and western Utah: Am. Assoc. Petroleum Geologists, v. 42, no. 10, p. 2335-2377.

Wheeler, H. E. , 1960, Early Paleozoic tecto-stratigraphic patterns in the U. S.: Internat. Geol. Cong. , 21st. , Copenhagen 1960 Rpt. , p. 55.

Williams, J. S. , 1948, Geology of the Paleozoic rocks, Logan Quadrangle, Utah: Geol. Soc. America, Bull. , v. 59, p. 1121-1164.

APPENDIXES

Appendix A

Figures

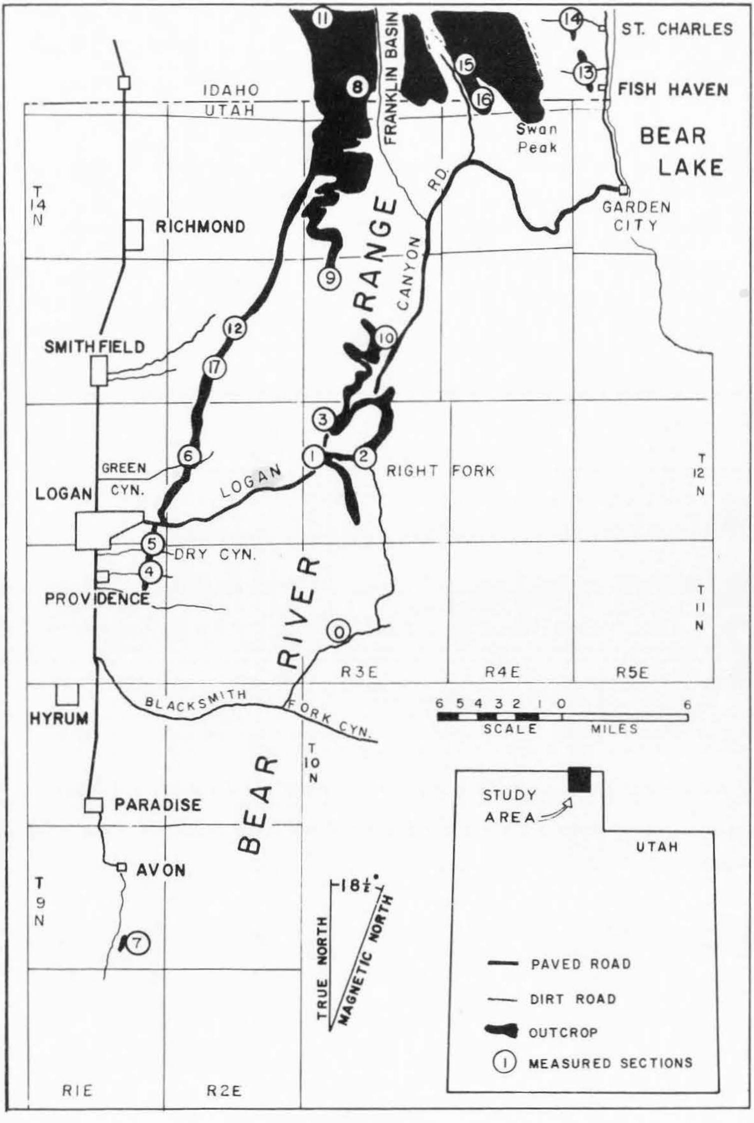


FIGURE 1. INDEX MAP SHOWING LOCALITIES MENTIONED IN TEXT.

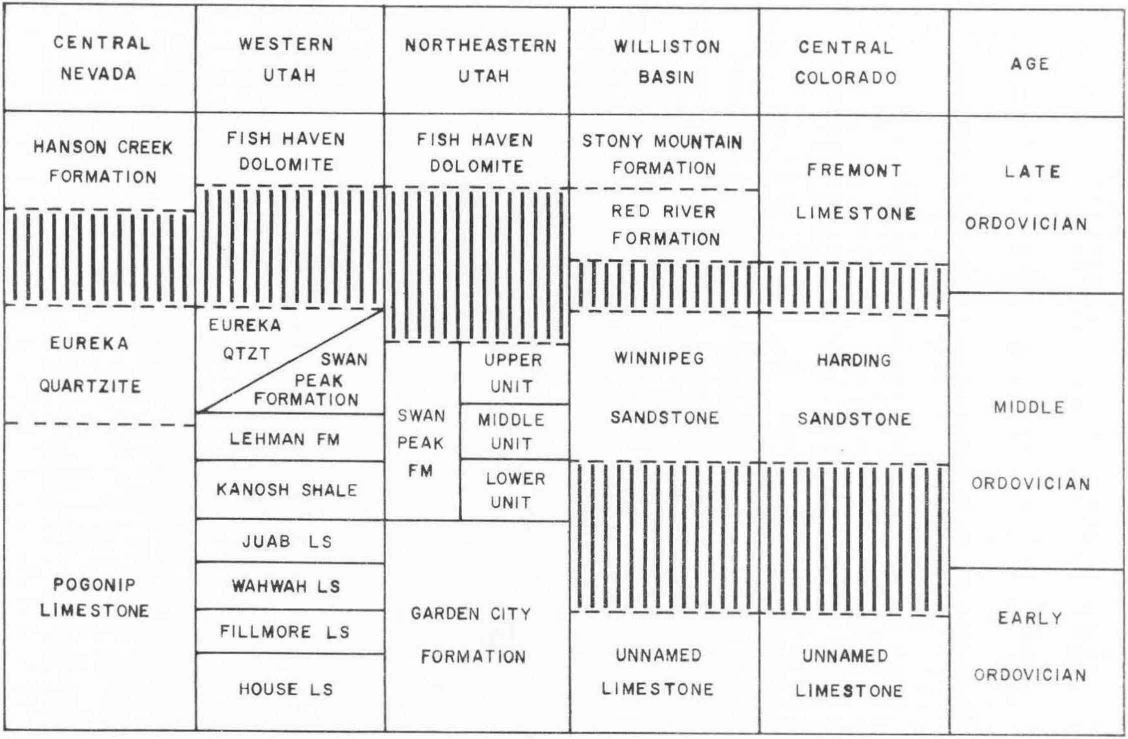


FIGURE 2. CORRELATION OF ORDOVICIAN ROCKS IN THE CENTRAL ROCKIES (MODIFIED FROM ROSS, 1953).

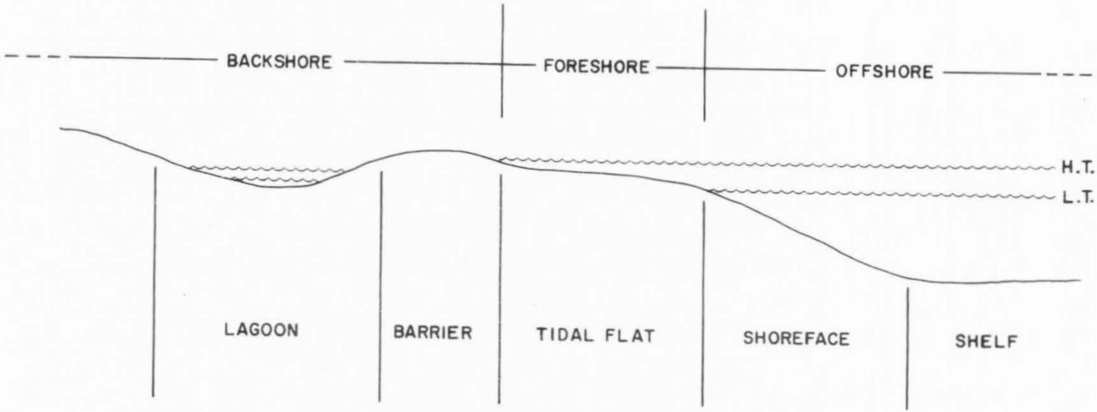


FIGURE 3. INTERPRETATION OF NEARSHORE ENVIRONMENTS REPRESENTED BY FACIES OF THE SWAN PEAK FORMATION, NORTH-CENTRAL UTAH AND SOUTHEASTERN IDAHO.

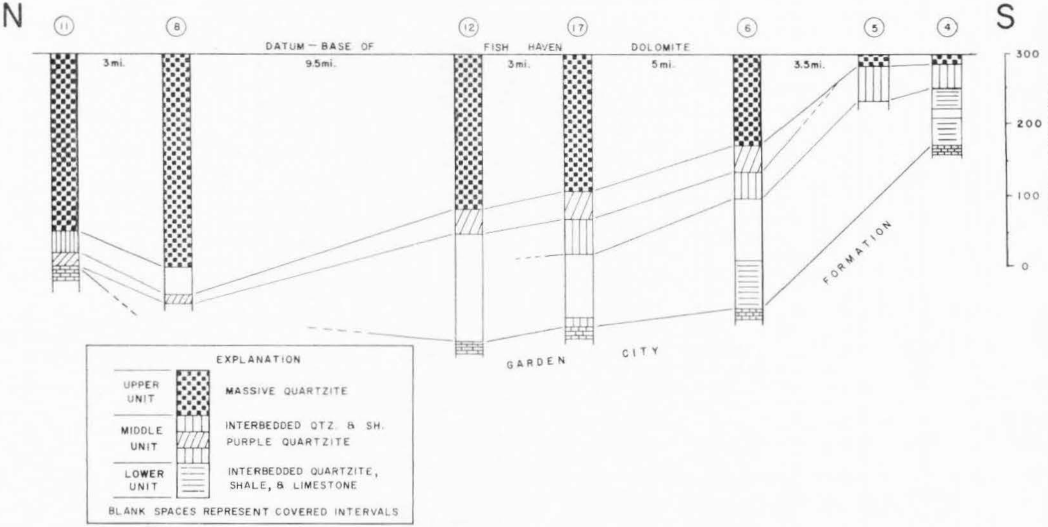


FIGURE 4. PHYSICAL CORRELATION OF DISTINCTIVE LITHOLOGIC UNITS IN SECTIONS OF SWAN PEAK FORMATION MEASURED FROM NORTH TO SOUTH ALONG WESTERN MARGIN OF BEAR RIVER RANGE. NOTE THAT UPPER UNIT THINS SOUTHWARD, WHEREAS LOWER UNIT THINS NORTHWARD. LOCATIONS OF NUMBERED SECTIONS ARE SHOWN IN FIGURE 1.

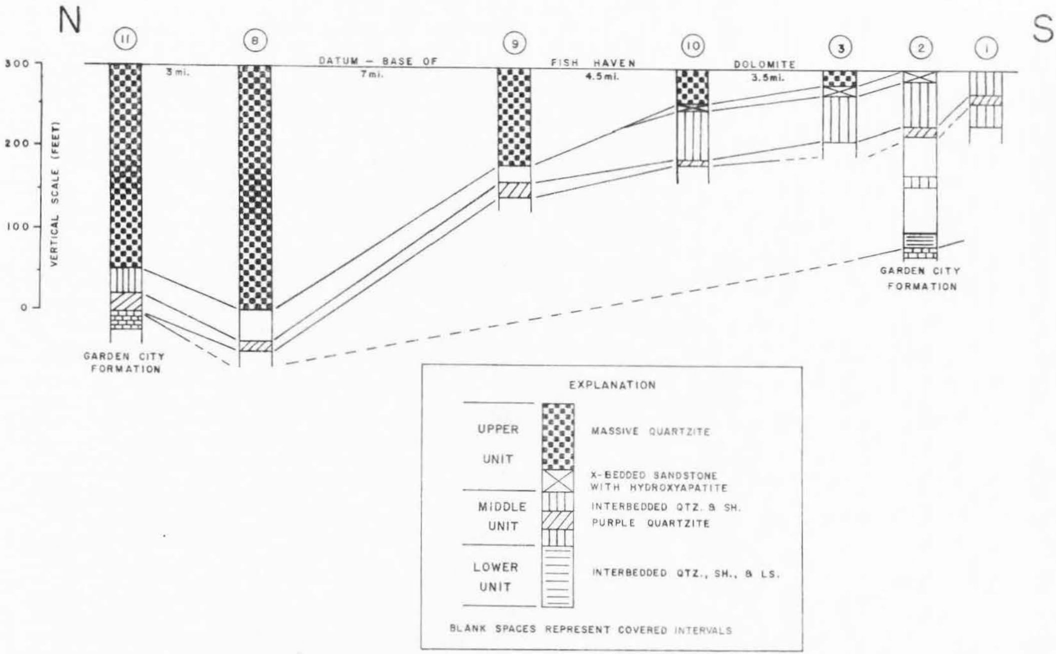


FIGURE 5. PHYSICAL CORRELATION OF DISTINCTIVE LITHOLOGIC UNITS IN SECTIONS OF SWAN PEAK FORMATION MEASURED FROM NORTH TO SOUTH ALONG AXIS OF BEAR RIVER RANGE. NOTE THAT UPPER UNIT THINS SOUTHWARD, WHEREAS LOWER (AND MIDDLE) UNITS THIN NORTHWARD. LOCATIONS OF NUMBERED SECTIONS ARE SHOWN IN FIGURE 1.

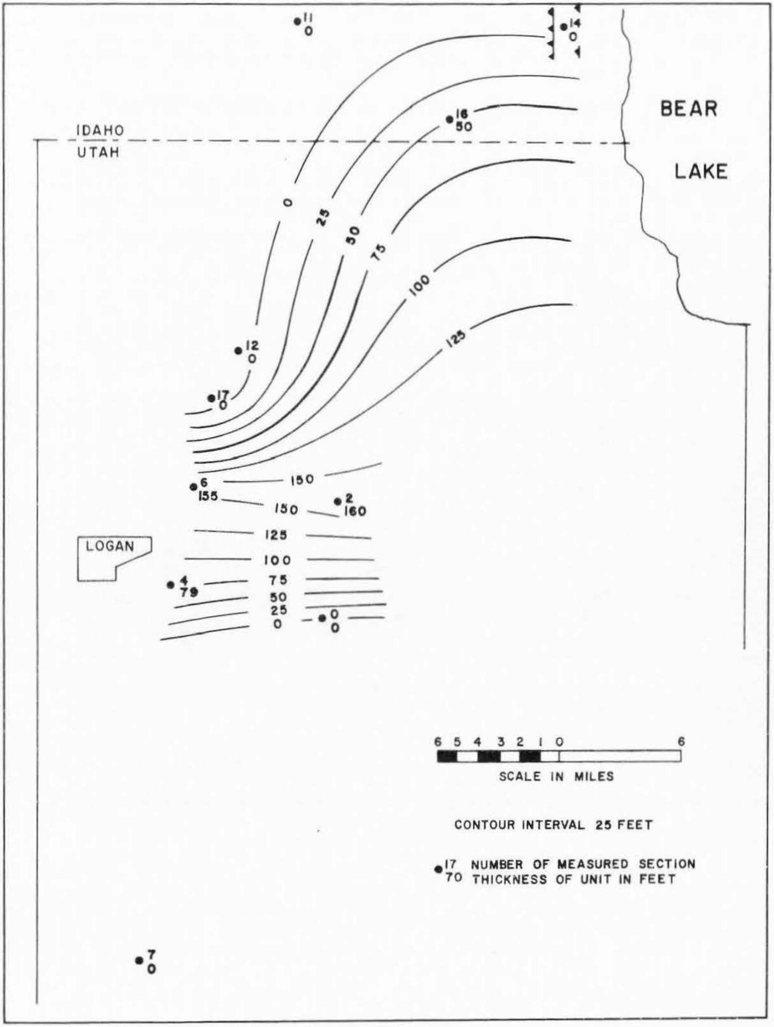


FIGURE 6. MAP SHOWING THICKNESS OF LOWER UNIT OF SWAN PEAK FORMATION. LOCATIONS OF MEASURED SECTIONS ARE SHOWN IN FIGURE 1.

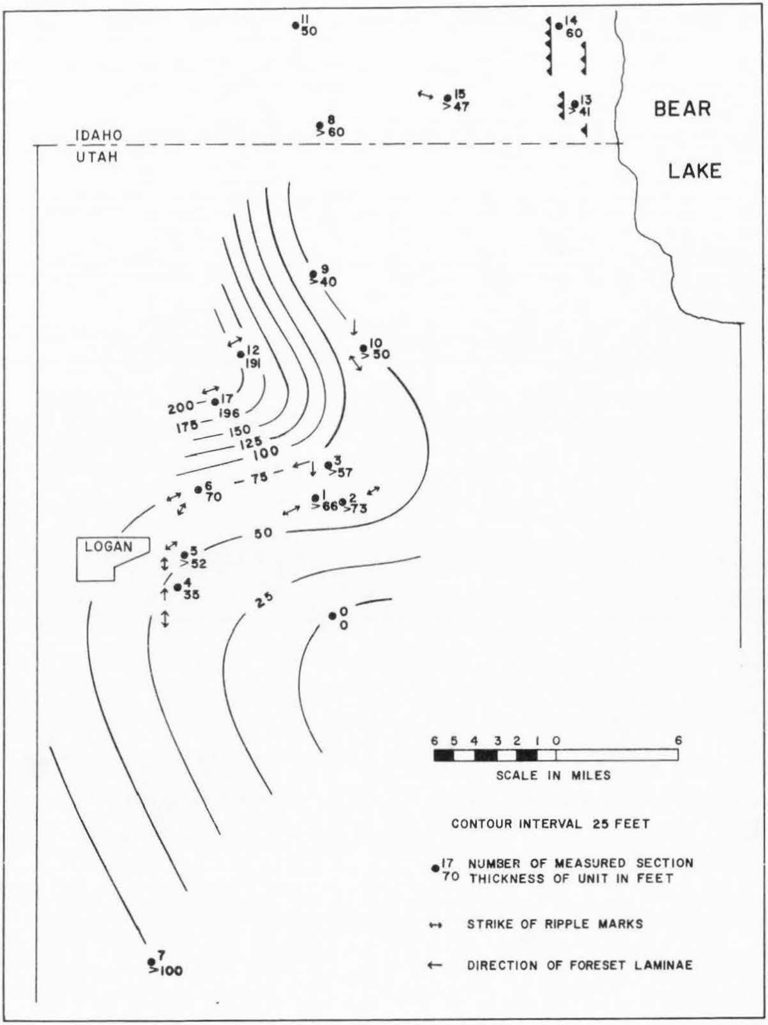


FIGURE 7. MAP SHOWING THICKNESS OF MIDDLE UNIT OF SWAN PEAK FORMATION. LOCATIONS OF MEASURED SECTIONS ARE SHOWN IN FIGURE 1.

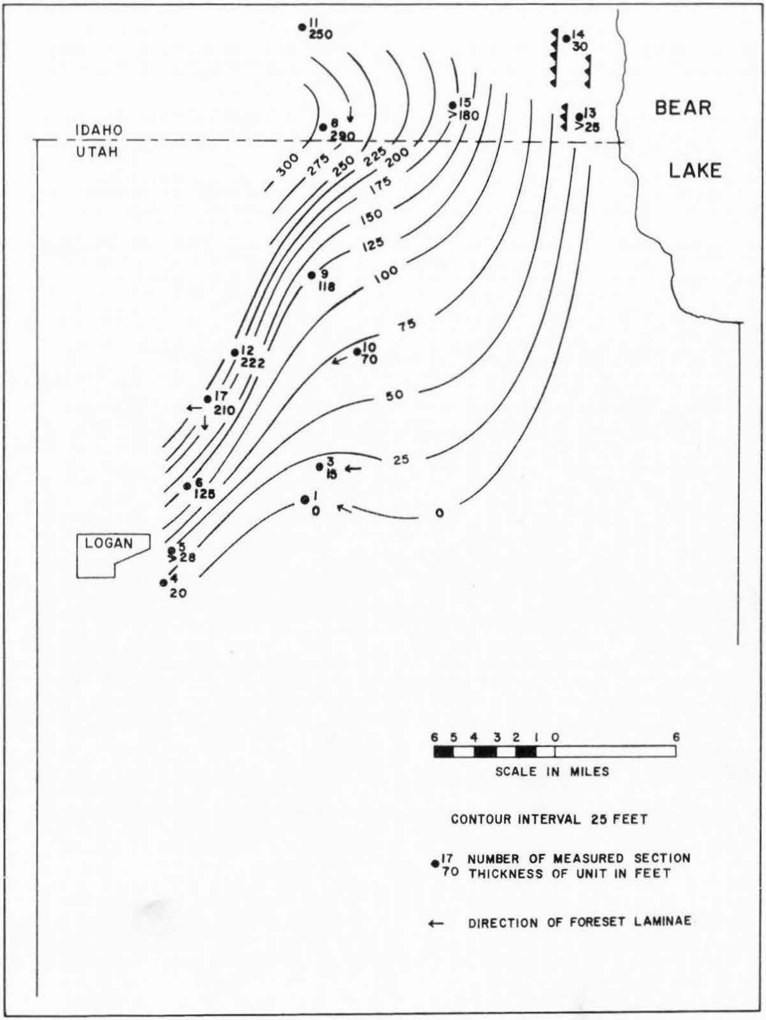


FIGURE 8. MAP SHOWING THICKNESS OF UPPER UNIT OF SWAN PEAK FORMATION. LOCATIONS OF MEASURED SECTIONS ARE SHOWN IN FIGURE 1.

Appendix B

Plates

Plate 1

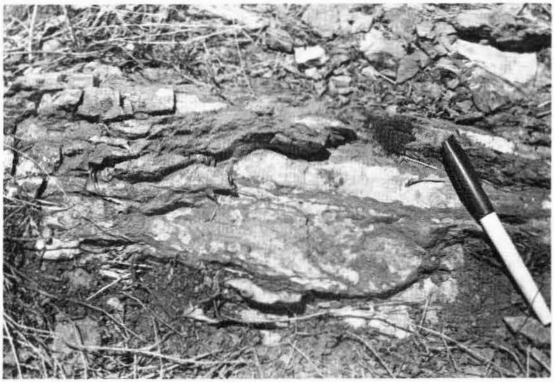
Lower unit, near contact with Garden City Formation, section 4, north side of canyon, view north. Characteristic lenticular, wavy bedding of limestone and quartzite interlayered with calcareous shale. Pen is 5 inches long.

ENVIRONMENT: Offshore shelf.

Plate 2

Middle unit, near middle, section 1, north side of road (Plate 3). Photomicrograph of thin section illustrates differences in grain size, organic content, and porosity between undisturbed sediment (right) and bioturbated sediment of the feeding burrows (left). Bioturbated sediment exhibits decreased organic content and average grain size, and increased interstitial porosity. Dark material in the left half of the photograph is iron-rich cement that gives the quartzite its distinctive purple color.

INTERPRETATION: Disturbed sediment (left) has been reworked by organisms that extracted the organic nutrients and reduced the grain size by digestive, abrasive, or selective processes. The sand redeposited by the organisms was not as compact as that which accumulated by natural processes of sedimentation.



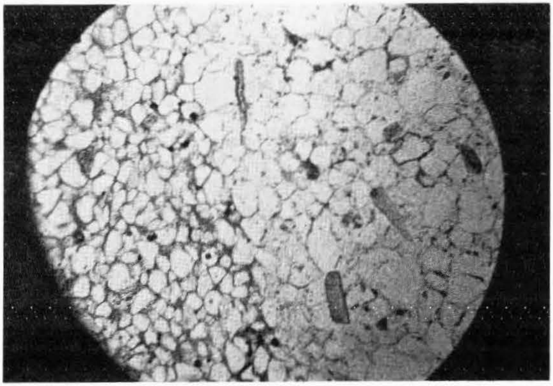


Plate 3

Middle unit, section 1, north side of Logan Canyon near Right Fork, view northeast. Black shales near the figure contain a varied fauna including several graptolites. Nearly all of the fossils found in the Swan Peak Formation elsewhere were collected at this location also. The upper unit is missing here, so that the Fish Haven Dolomite rests unconformably on the middle unit just above the top of the picture. The lower unit is covered here. Photograph courtesy R. Q. Oaks, Jr.

ENVIRONMENT: Shoreface-shelf transition at base.

Plate 4

Middle unit, lower part, section 6, Red Rock Quarry, north side of Green Canyon, view east. Interbedded, noncalcareous quartzite and shale. Bedding surfaces of quartzite display both parallel laminae and ripple marks. Hammer is 13 inches long.

ENVIRONMENT: Shoreface.

Plate 5

Middle and upper units, section 4, north side of canyon, view north, beds vertical. Fish Haven Dolomite forms dark strata in upper most right. Prominent, light beds in right comprise upper unit. Dark strata, in center, are sulfurous, gypsiferous quartzite with feeding burrows but no body fossils, at top of middle unit. Light beds in left form lower part of middle unit, which extends to shale slopes in left of picture. Upper unit is 20 feet thick.

ENVIRONMENT: Lower part of middle unit: shoreface to tidal flat. Upper part of middle unit: lagoon. Upper unit: shallow marine.

Plate 6

Middle unit, near middle, section 6, Red Rock Quarry, north side of Green Canyon, view west. Oscillation ripple marks on quartzite bedding surfaces strike NE-SW.

ENVIRONMENT: Shoreface.

Plate 7

Middle unit, near middle, section 6, Red Rock Quarry, north side of Green Canyon, stripped upper surface of quartzite bed. Flat-topped ripple marks trend normal to the pen. A trilobite pygidium an inch from the black tip of the marker lies near the crest of the middle ripple. A second, smaller set of interference ripples is superimposed on the first and normal to it, producing small depressions resembling fish "nests." The numerous semi-linear markings are trails left by gastropods such as the gastropod Macluritella sp. (shown near the center in the lower part of the picture).

ENVIRONMENT: Shoreface.

Plate 8

Middle unit, near middle, section 5, south side of Dry Canyon, view southwest, beds vertical. Oscillation ripple marks on upper surface of quartzite bed strike E-W.

ENVIRONMENT: Shoreface to tidal flat.

Plate 9

Middle unit, near middle, section 5, south side of Dry Canyon, a few yards from beds in Plate 8, view southwest, beds overturned. Interference ripple marks on upper surface of quartzite bed.

ENVIRONMENT: Shoreface to tidal flat.

Plate 10

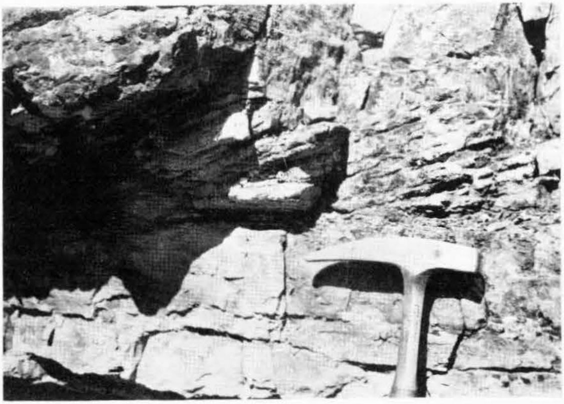
Middle unit, near contact with upper unit, section 3, north side of Logan Canyon near Wood Camp, view north. Cross laminae in quartzite bed at top dip 25^o south, whereas those in quartzite bed beneath dip 10^o north, in the opposite direction.

ENVIRONMENT: Shallow-water, influenced by tidal action.

Plate 11

Middle unit, near middle, section 5, south side of Dry Canyon, view west, beds overturned. Cross laminae dip north; they are tangential at the bottom and truncated at the top. White laminae consist of phosphate material.

ENVIRONMENT: Tidal flat.



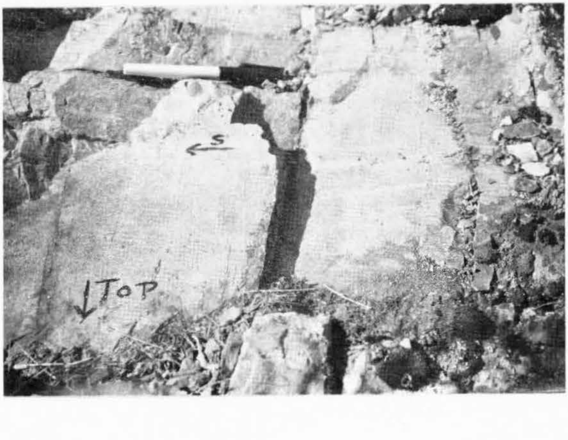

S
TOP

Plate 12

Middle unit, near middle, section 6, north side of Red Rock Quarry, view east. Subparallel white laminae of fish scales in light colored band of hydroxyapatite. Hydroxyapatite ($10CaO.\ 3P_2O_5 \cdot H_2O$) is the mineral form of the protein Collagen that could have formed under diagenetic conditions from the fish scale material or possibly was introduced as clastic sediment from tributaries nearby.

ENVIRONMENT: Tidal flat.

Plate 13

Middle unit, near top, section 2, near Right Fork in Logan Canyon. Sample from the underside of a quartzite bed. The ring-like features appear to be remnants of sand-filled mud cracks in the underlying dessicated shale. The shale has since been removed from part of outcrop, leaving the polygonal to circular sand ridges on the underside of the overlying quartzite bed. The specimen is from the same set of beds that display raindrop imprints at other section.

ENVIRONMENT: Tidal flat.

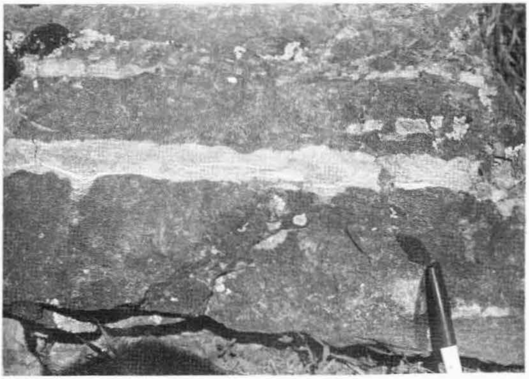


Plate 14

Middle unit, a few feet from location described in Plate 13. Probable raindrop imprints on upper surfaces of quartzite bed. These imprints are found in nearly every outcrop, and always occur on the purple quartzites near the top of the middle unit. In the vertical sequence of lithologies this series of strata lies stratigraphically near the same horizon occupied by mud-cracked beds at other locations.

ENVIRONMENT: Very shallow shoreface or tidal flat, with periodic subaerial exposure.

Plate 15

Detail of bed in Plate 14. Several circular cavities are juxtaposed to form elliptical or irregular, elongate shapes. However, most impressions remain singular.

INTERPRETATION: A hard but brief rainfall.

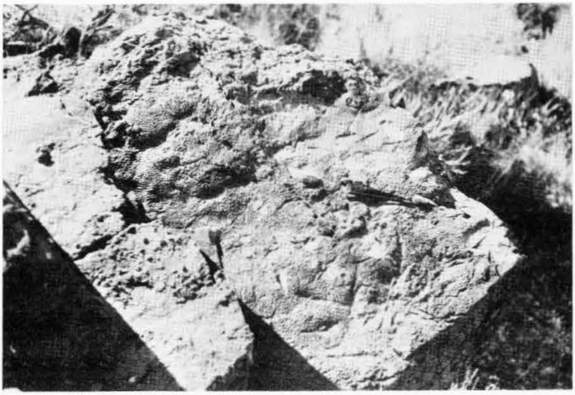


Plate 16

Middle unit, near middle, section 4, north side of canyon, view southeast. Typical "fucoidal markings" (feeding burrows). Such burrows occur on the lower side of nearly every bed in this unit.

INTERPRETATION: Cephalopod feeding burrows.

Plate 17

Upper unit, near contact with middle unit, section 17, view east. Cross-laminae in each bed dip 20° south, and are truncated at the top, tangential at the bottom. Similar cosets, dipping predominantly south to southwest, occur locally in the upper unit in most sections. With the exception of burrows, these planar cosets constitute the only sedimentary structures found in the upper unit.

ENVIRONMENT: Shallow marine; sand transported southward or southwestward by longshore marine currents.

Plate 18

Upper unit, near middle, section 8, west side of road, view west. South-dipping cross-laminae with tangential relationships at top and at bottom indicate deposition of sand from north to south with no erosion between cycles of sedimentation.

ENVIRONMENT: Shallow marine.

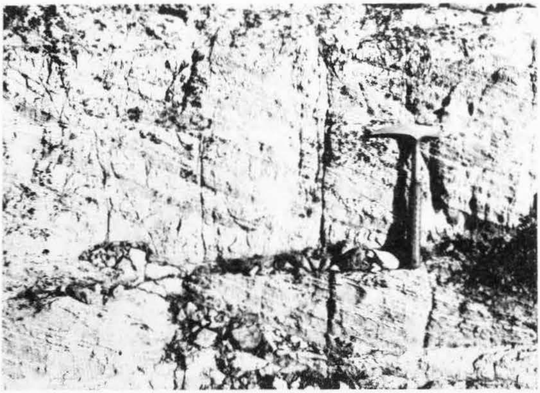


Plate 19

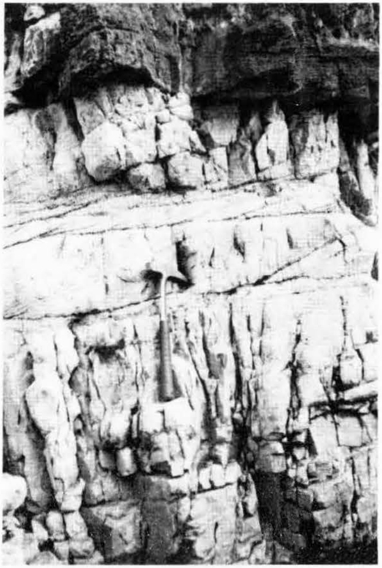
Upper unit, at contact with overlying Fish Haven Dolomite, section 2, top of steep slope north of road in Right Fork, view north. Planar cross-laminae in unfossiliferous quartzite. Dark, hydroxyapatite laminae accentuate the stratification. Laminae dip northwest to west between 5^{o} and 20^{o}. The northward direction of transport was perpendicular to the shoreline. Note disconformity at top of sandstone.

ENVIRONMENT: Estuary to stream.

Plate 20

Details of cross stratification a few feet from the location in Plate 19. Most laminae are truncated on top, tangential on bottom.

INTERPRETATION: Varying current conditions prevailed. Clastic material appears to have arrived in cycles, with periods of relative quiescence or erosion intervening. This would be expected in an estuarine environment.



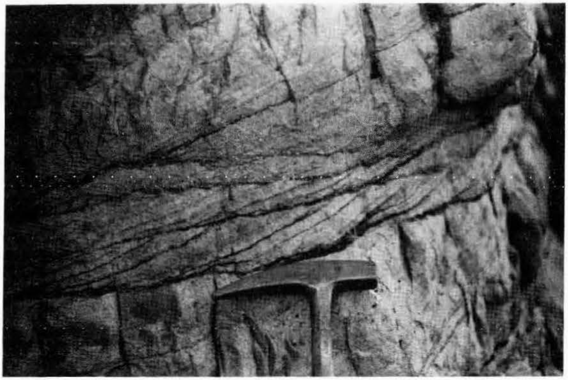


Plate 21

Upper unit, near middle, 0.2 mile north of section 9 at Tony Grove Lake. Vertical burrows at the top of a tan quartzite bed. The tan beds displaying these vertical burrows are less porous than white strata higher in the unit which appear to be burrowed differently and more extensively, as shown in Plate 24.

ENVIRONMENT: Shallow marine.

Plate 22

Upper unit, same location described in Plate 21, view southwest. Tan quartzite beds that display the vertical burrows illustrated in Plate 21.

Plate 23

Upper unit, near contact with middle unit, east of section 3, north of road in Logan Canyon, view north. Segment of white quartzite bed ten feet thick that exhibits pores about the size of peas throughout.

ENVIRONMENT: Shallow marine.

Plate 24

Upper unit, near middle, 0.1 mile north of section 9 at Tony Grove Lake, view west. Extensively burrowed white quartzite. Top of bed near top of photograph. This bed lies higher in the unit than those in Plate 22. Burrows are both vertical and diagonal, and may interconnect.

INTERPRETATION: Differences in porosity of the upper unit appear to be related to the amount of burrowing. No body fossils were found.

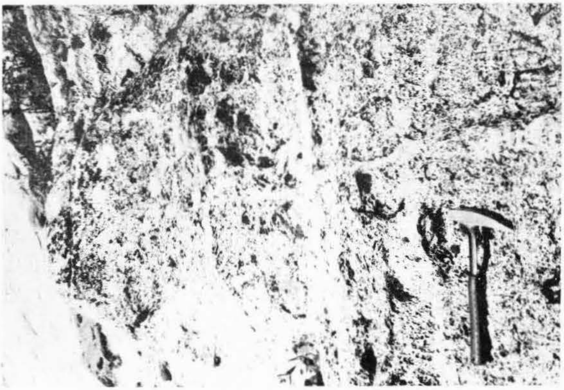


Plate 25

Protocycloceras debilis Clark, the orthoconic cephalopod found in strata containing abundant "fucoidal markings." Probable casts of tentacles extend from the anterior of the conch and resemble the surrounding feeding burrows. Specimens were collected from section 6. Scale in inches.

Plate 26

The largest orthoconic cephalopod conch, collected from section 17, measures 7 inches long and 1.3 inches wide. All cephalopod conchs were found in quartzites of the middle unit. Photograph courtesy R. Q. Oaks, Jr.

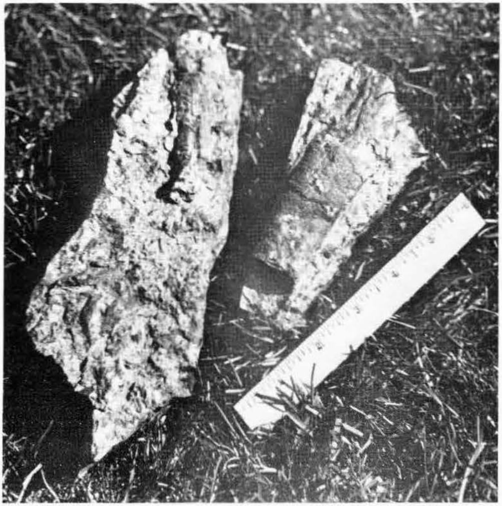


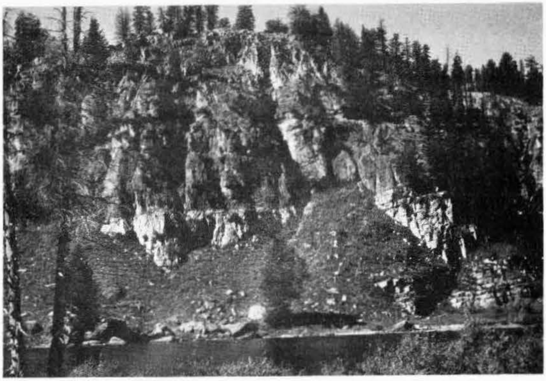
Plate 27

Middle unit, near middle, section 2, near top of steep slope north of Right Fork in Logan Canyon. Shallow indentations about 0.5 inch deep on the upper surface of a quartzite bed.

INTERPRETATION: The indentations are probably resting tracks of orthoconic cephalopods similar to the tracks described by Flower (1955). The two nearest the pen are probably from orthoconic cephalopod conchs, whereas the two to the right perhaps were made by the tentacles while the organism was resting on the bottom

Plate 28

Upper unit, west of Tony Grove Lake, section 9, view west. Sharp, planar nature of the disconformity between the Swan Peak Formation (white) and overlying Fish Haven Dolomite (dark). Photograph courtesy R. Q. Oaks, Jr.



Appendix C

Measured Sections

SECTION 1

Roadcut, Logan Canyon, north side of U. S. 89, 200 feet west of bridge and Right Fork of Logan River, C NE 1/4 Sec. 18, T12N, R3E, Lat. 41°40'42" N., Long. 111°30'51" W. See Plate 3.

	Description	Thickness (feet)
	Fish Haven Dolomite	
	Sharp, planar contact--disconformity	
Middle Unit		
22.	Quartzite, light tan to white, fine- to medium-grained, thin parallel white laminae; burrows	3.5
21.	Quartzite, tan, and shale, gray, interbedded, quartzite beds 1 inch to 2 inches thick, shale beds less than 1 inch thick; fish scales and burrows throughout	3.0
20.	Quartzite, bluish-gray, fine- to medium-grained; burrows throughout	4.5
19.	Shale, greenish tan, 3 inches of dark gray quartzite at top	2.0
18.	Quartzite and shale, both tan, interbedded, beds about 1 inch thick; burrows	1.0
17.	Quartzite, dark gray at top, grades to tan at bottom, fine- to medium-grained; abundant fish scales at top, oscillation ripple marks strike NE-SW and E-W	4.5
16.	Quartzite, reddish tan, fine- to medium-grained, minor shale lenses near top; faint burrows on underside of bottom bed	2.0
15.	Quartzite, reddish tan, and shale, reddish gray, interbedded, quartzite beds 1 inch to 2 inches thick, shale beds less than 1 inch thick; burrows	1.5
14.	Quartzite, reddish tan, fine- to medium-grained; parallel laminae disturbed near top and bottom by burrows	3.0
13.	Quartzite and shale, both orange, interbedded, quartzite beds 3 inches thick, shale beds 1 inch to 4 inches thick, fine- to medium-grained; burrows	1.5

12. Quartzite, orange, fine- to medium-grained; burrows . . . 1.5

11. Quartzite, tan, and shale, bluish green, interbedded; parallel laminae, burrows 1.0

10. Quartzite, gray at top to tan at bottom, fine- to medium-grained; burrows 6.0

9. Quartzite, reddish brown, shale, bluish green, interbedded; burrows 1.5

8. Quartzite, tan at top to purple at bottom, interbedded shale, 1 inch to 2 inches thick, every 6 inches to 18 inches; some small pockets of sandstone in lower 2 feet; burrows 11.0

7. Quartzite, purple, fine- to medium-grained 1.0

6. Quartzite, purple, shale, reddish green, interbedded, quartzite fine- to medium-grained; burrows 2.5

5. Quartzite, purple, fine- to medium-grained; yellow-orange sandstone pockets 3 inches thick, 6 inches to 12 inches long; Orthambonites swanensis, Anomalorthis sp., Lophospira? sp., Eleutherocentras petersoni, Hesperorthis sp. 2.0

4. Shale and quartzite, black to red, interbedded, beds less than 1 inch thick 2.0

3. Quartzite, purple, some parallel light banding less than 1 inch thick throughout; burrows at bottom 2.5

2. Shale and quartzite, purple, interbedded 3.0

1. Quartzite, reddish brown, shale, red, blue-green and black, interbedded, strata 1 inch to 2 inches thick; burrows, Tetranota sp., Didymograptus bifidus, D. artus, E. petersoni, Protocycloceras debilis, Macluritella sp., Linguella sp. Lingulepis sp., and ostracods 5.0

Covered

Total thickness 65.5

SECTION 2

Top of hill above north side of Right Fork Road, one fourth of a mile east of U. S. 89, C NW 1/4 Sec. 17, T12N, R3E, Lat. 41°40'43" N., Long. 111° 30'48" W.

		Thickness (feet)
	Fish Haven Dolomite	
	Sharp, planar contact--disconformity	
Upper Unit		
6.	Sandstone, white, coarse-grained, poorly cemented, top 2 feet weathers sandy; trough to planar cross laminae of hydroxyapatite dip 20° NW to W. dark mineral grains 2 to 5mm in diameter	10
	Subtotal	10
Middle Unit		
5.	Quartzite, brown, fine- to medium-grained, thin laminae of shale; ostracoderm scales and dark minerals throughout, raindrop imprints, mud cracks, and resting tracks on bedding surfaces near top; burrows	46
4.	Quartzite, gray, some pink wavy laminae in places; thin shaly partings appear quite clayey	18
3.	Quartzite, purple, fine-grained, numerous shaly partings; burrows	9
	Subtotal	73
Lower Unit		
2.	Covered	130
1.	Quartzite, brown, and shale, green to black, interbedded, calcareous, quartzite weathers vuggy; Orthambonites swanensis	30
	Subtotal	160
	Gradational contact	
	Garden City Formation	
	Total	243

SECTION 3

Cliff north of U. S. 89 one half of a mile east of Wood Camp in Logan Canyon, SW 1/4 SW 1/4 Sec. 5, T12N, R3E, Lat. 41°40'51" N., Long. 111° 30'48" W.

		Thickness (feet)
	Fish Haven Dolomite	
	Sharp, planar contact--disconformity	
Upper Unit		
9.	Quartzite, tan, fine-grained, poorly cemented	1
8.	Quartzite, tan, fine-grained, well-cemented, slightly calcareous, parallel reddish-brown stains on surface, weathers blocky	2
7.	Sandstone, light gray, weathers tan, very fine-grained, poorly cemented	7
6.	Quartzite, light gray, weathers tan; coarse-grained dark mineral fragments scattered throughout; burrows on underside of bottom strata only	5
	Subtotal	15
Middle Unit		
5.	Quartzite, gray, yellow; sulfur on surface	10
4.	Quartzite, light gray; set 6 inches to 2 feet contains forset laminae that dip 25° S, weathers blocky	2
3.	Quartzite, light gray, fine- to medium-grained, dark minerals in planar and cross-laminae; burrows	9
2.	Quartzite, gray, fine- to medium-grained, parallel laminae	10
1.	Quartzite, gray, fine- to medium-grained, fish scales throughout, faint foresetting; burrows	26
	Subtotal	57
	Covered	
	Total	72

SECTION 4

Vertical beds, north side of canyon one mile east of Providence, Utah, C NW 1/4 Sec. 12, T11N, R1E, Lat. 41°40'16" N., Long. 111°40'46" W. See Plate 5.

		Thickness (feet)
	Fish Haven Dolomite	
	Contact poorly exposed, but appears sharp	
Upper Unit		
10.	Quartzite, white to brown, some red, fine- to medium-grained; burrows at bottom of lower strata only	20
	Subtotal	20
Middle Unit		
9.	Quartzite, gray, medium- to corase-grained, fish scales, ripple mark strike N-S; coated with black and yellow sulfurous deposits in places; burrows	25
8.	Quartzite, gray, fine- to medium-grained; fish scales, brachiopod and ostracods in places; burrows	10
	Subtotal	35
Lower Unit		
7.	Shale and quartzite, blue-gray, interbedded, calcareous	20
6.	Shale and limestone, blue-gray, interbedded, beds are 1 inch to 2 inches thick	5
5.	Shale, blue-gray, badly weathered	2
4.	Covered	15
3.	Quartzite and limestone, shaly, black and brown, fine- to medium-grained, calcareous, mostly covered	30
2.	Shale, blue-gray, badly weathered	2
1.	Quartzite, black, fine- to medium-grained	5
	Subtotal	79
	Gradational contact	
	Garden City Formation	
	Total	134

SECTION 5

South side of Dry Canyon, two miles east of Logan, Utah. NE 1/4 NW 1/4 Sec. 1, T11N, R1E, Lat. 41°40'22" N., Long. 111°40'46" W.

		Thickness (feet)
	Covered	
Upper Unit		
5.	Quartzite, gray to reddish-brown, fine-grained, black and yellow color on surface in places; burrows on bottom strata only	28
	Subtotal	28
Middle Unit		
4.	Quartzite, gray, fine- to medium-grained	17
3.	Quartzite, gray, fine- to medium-grained; fish scales in cross laminae, shaly partings; burrows	10
2.	Quartzite, gray, fine- to medium-grained, oscillation ripple mark strike E-W; burrows	5
1.	Quartzite, brown to gray, red coating on surface near middle; parallel laminae, interference ripple mark strike WSW-ENE, and NNW-SSE; burrows	20
	Subtotal	52
	Covered	
	Total	80

SECTION 6

North and west sides of Red Rock Quarry in Green Canyon, five miles northeast of Logan, Utah, NE 1/4 NW 1/4 Sec. 20, T12N, R2E, Lat. 41°40'39" N., Long. 111°40'30" W.

		Thickness (feet)
	Fish Haven Dolomite	
	Sharp, planar contact--disconformity	
Upper Unit		
8.	Quartzite, white to tan, fine-grained; parallel bedding, some cross laminae, very fine-grained dark minerals scattered throughout	30
7.	Quartzite, gray to white and tan, fine-grained; parallel bedding and diagonal joints; iron sulphide pockets locally	95
	Subtotal	125
Middle Unit		
6.	Quartzite, purple, fine- to medium-grained; wavy parallel laminae, fish scales in white laminae, oscillation and interference ripple mark strike N-S to WSW-ENE; Hyolithes, Protocycloceras debilis, Macluritella sp., Linguella sp., Eleutherocentrus petersoni, Barnesella sp., Eunema sp. ostracods; burrows	35
5.	Quartzite, brown to gray, shale, greenish-blue, more purple in top 10 feet, shale beds thin and less abundant near top 15 feet; burrows	35
	Subtotal	70
Lower Unit		
4.	Covered	85
3.	Shale and limestone, gray to black interbedded, beds less than 3 inches thick; limestone contains Orthambonites swanensis	40

		Thickness (feet)
Lower Unit (Continued)		
2.	Quartzite, brown, shaly, fine-grained, calcareous	10
1.	Quartzite, limestone, and shale, brown to black, interbedded, beds less than 4 inches thick	20
	Subtotal	155
	Gradational contact	
	Garden City Formation (contains Orthambonites michaelis)	
	Total	350

SECTION 7

Hill 200 feet east of Utah Highway 162, 3.5 miles south of Avon, Utah, N1/2 SE 1/4 Sec. 27, T9N, R1E, Lat. 41°29'00" N., Long. 111°49'00" W.

Exposure is in a fault block, top contact covered	Thickness (feet)
Middle Unit	
Quartzite, gray, weathers tan on surface, fine- to medium-grained; Orthambonites michaelis, Drepenastor sp., Eleutherocentrus petersoni	100
Sharp contact	
Garden City Formation	
Total exposed thickness	100

SECTION 8

Cliff west side of Franklin Basin, one half of a mile west of dirt road, one half of a mile south of the Utah-Idaho state line, Lat. 42°00'00" N., Long. 111°36'25" W.

		Thickness (feet)
	Fish Haven Dolomite	
	Sharp, planar contact with breccia 2 feet thick in places	
Upper Unit		
5.	Sandstone, white, medium-grained, very porous, vertical and diagonal burrows, bioturbated sediment	140
4.	Sandstone, white, porous, weathers vuggy	10
3.	Quartzite, tan and white, fine- to medium-grained, parallel-bedded, parallel laminae, foreset laminae near lower part of unit dip 25° S to SW; dark knobs of iron oxide weather in relief	140
	Subtotal	290
Middle Unit		
2.	Covered	45
1.	Quartzite, purple, fine- to medium-grained, parallel laminae, ripple mark; burrows	15
	Subtotal	60
	Covered	
	Total	350

SECTION 9

Cliff, northwest side of Tony Grove Lake, Lat. 41°50'22" N., Long. 111°30'52" W. See Plate 28.

	Fish Haven Dolomite	Thickness (feet)
	Sharp, planar contact--disconformity	
Upper Unit		
6.	Quartzite, white, medium-grained, porous; vertical and diagonal burrows, parallel-bedded, possible cross laminae, lower 5 feet less porous, calcareous in places, bioturbated	38
5.	Quartzite, light tan, medium-grained, not porous, faint parallel laminae, parallel-bedded, iron brown knobs weather in relief, not calcareous	45
4.	Quartzite, white, medium-grained	5
3.	Quartzite, tan, fine- to medium-grained, not porous, vertical burrows, some reddish beds 2 feet thick within tan quartzite; sulfurous in places	30
	Subtotal	118
Middle Unit		
2.	Covered	20
1.	Quartzite, purple, fine- to medium-grained; burrows . . .	20
	Subtotal	40
	Covered	
	Total	158

SECTION 10

Cliff, 1000 feet northwest of U. S. 89 in Logan Canyon, one half of a mile south of Rick's Spring, Lat. 41°50'04" N., Long. 111°30'36" W.

	Fish Haven Dolomite	Thickness (feet)
	Sharp, planar contact--disconformity	
Upper Unit		
7.	Quartzite, white, medium-grained; vertical burrows in places, parallel-bedded	45
6.	Quartzite, white, fine-grained; foreset laminae dip 25° S, some hydroxyapatite	10
5.	Quartzite, white, fine-grained; some small foreset laminae less than 6 inches thick dip S	15
	Subtotal	70
Middle Unit		
4.	Quartzite, white, fine-grained; parallel laminae, fish scales; burrows	15
3.	Quartzite, gray, fine- to medium-grained; parallel-bedded, wavy laminae; oscillation ripple mark strike N20°E, interference ripple mark	15
2.	Quartzite, pink, fine-grained; oscillation ripple mark, wavelength 2.5 inches strike N25°E, interference ripple mark; foreset laminae 2 inches thick dip south, laminae tangential at top and bottom; burrows, Eleutherocentrus petersoni, Orthambonites swanensis, Macluritella sp.	10
1.	Quartzite, purple, fine-grained; parallel-bedded, wavy laminae; burrows	10
	Subtotal	50
	Covered	
	Total	120

SECTION 11

Two hundred feet southwest of Boy Scout Camp Wilderness in Franklin Basin, Franklin Co., Idaho, 2.5 miles north of the Idaho-Utah state line, Lat. 42^{o} 00'14" N., Long. $111^{o}30'50''$ W.

		Thickness (feet)
	Covered	
Upper Unit		
3.	Quartzite, white, medium-grained; vertical and diagonal burrows, very porous in places, possible cross laminae .	250
	Subtotal	250
Middle Unit		
2.	Quartzite, white, weathers tan, fine- to medium-grained, dark mineral grains scattered throughout, parallel-bedded, possible cross laminae; _Macluritella_ sp.	30
1.	Quartzites, tan and purple, fine- to medium-grained; parallel laminae, fish scales, interference ripple mark; burrows	20
	Subtotal	50
	Gradational contact through short vertical distance, no shale	
	Garden City Formation (sandy)	
	Total	300

SECTION 12

Cliff above east end of Rocky Canyon, 7.5 miles northeast of Smithfield, Utah, Lat. 41°50'16" N., Long. 111°40'11" W.

		Thickness (feet)
	Fish Haven Dolomite	
	Sharp, planar contact--disconformity	
Upper Unit		
7.	Quartzite, white, medium-grained; iron knobs weather in relief, parallel-bedded, possible planar cross laminae, oscillation ripple mark, 3 inch wavelength, strike E-W . . .	100
6.	Quartzite, tan to white, medium-grained; parallel-bedded, vertical and diagonal burrows	87
5.	Quartzite, white, fine- to medium-grained; parallel-bedded, porous in places, possible cross laminae, top 8 feet sulfurous	23
4.	Quartzite, white, weathers tan, medium-grained; parallel-bedded, possible cross-laminae, vertical burrows extend 1 foot into the purple quartzite below	12
	Subtotal	222
Middle Unit		
3.	Quartzite, purple, fine-grained; parallel laminae, oscillation ripple mark, 2.8 inches wavelength, strike N15°E, beds thinner in bottom half; Protocycloceras debilis, Eleutherocentrus petersoni, ostracods, burrows	34
2.	Covered	142
1.	Quartzite, tan, fine-grained; parallel laminae, lower 10 feet slightly calcareous	15
	Subtotal	191
	Gradational contact	
	Garden City Formation	
	Total	413

SECTION 13

Canyon, 1.3 miles west of Utah Highway 30, 2 miles northwest of Fish Haven, Idaho, Lat. $42^{o}00'22''$ N., Long. $111^{o}20'27''$ W.

	Formation exposed in thrust sheet		Thickness (feet)
	Covered		
Upper Unit			
3.	Quartzite, white, weathers tan in lower 15 feet, fine-grained; vertical burrows		25
		Subtotal	25
Middle Unit			
2.	Shale, green, mostly covered		1
1.	Quartzite, reddish brown, purple, gray towards top, fine- to medium-grained; parallel bedding, wavy laminae, laminae of hydroxyapatite 3 inches thick, fish scales; burrows, Orthambonites swanensis, complete intact Eleutherocentrus petersoni found in talus, Hesperorthis sp.		40
		Subtotal	41
	Covered		
		Total	66

SECTION 14

North side of St. Charles Canyon, 1.5 miles west of St. Charles, Idaho, C NW 1/4 Sec. 15, T15S, R43E, Lat. 42°00'45" N., Long. 111°20'31" W.

	Formation exposed in thrust sheet, beds everturned	Thickness (feet)
	Fish Haven Dolomite	
	Sharp, planar contact--disconformity	
Upper Unit		
4.	Quartzite, white, medium-grained; parallel-bedded, some vertical burrows	15
3.	Quartzite, white, weathers tan, fine- to medium-grained; some vertical burrows	15
	Subtotal	30
Middle Unit		
2.	Quartzite, dark gray, weathers dark brown to purple, fine-grained; parallel-bedded, slightly calcareous at bottom; burrows	40
1.	Sandstone, dark brown, fine-grained; parallel-bedded, wavy laminae, slightly calcareous; burrows, *Eleutherocentrus petersoni*	20
	Subtotal	60
	Covered	
	Garden City Formation	
	Total	90

SECTION 15

Cliff and slope a few feet east of Beaver Creek, Idaho, 3 miles northeast of Beaver Mountain, one half of a mile north of the Idaho-Utah state line, Lat. 42°00'02" N., Long. 111°30'04" W.

		Thickness (feet)
	Covered	
Upper Unit		
3.	Quartzite, tan, some red, fine- to medium-grained; parallel bedding, liesegang banding, vertical burrows, dark knobs of iron oxide weather in relief near top of exposure	180
	Subtotal	180
Middle Unit		
2.	Quartzite, white, fine- to medium-grained; parallel-bedded, dark fish scales throughout	17
1.	Quartzite, purple, fine- to medium-grained; parallel-bedded, wavy laminae, shaly partings 2 inches thick at bottom, quartzite beds 1 foot to 2 feet thick, interference ripple mark at top, oscillation ripple mark, 3 inch wavelength, strike N40°W, possible raindrop imprints; burrows, Eleutherocentrus petersoni, Orthambonites swanensis, Protocycloceras debilis, ostracods	30
	Subtotal	47
	Covered	
	Total	227

SECTION 16

Slope east of Beaver Creek, 50 feet from road, one half a mile south of section 15, Lat. $42^{o}00'00''$ N., Long. $111^{o}30'06''$ W.

	Thickness (feet)
Only part of the lower unit is exposed, top and bottom contacts covered	
Lower Unit	
Quartzite, limestone, and shale, black, interbedded; parallel-bedded, beds 5 inches thick, wavy laminae, quartzite calcareous, shale beds thinner at top, quartzite beds thicker at top	50
Covered	
Total exposed thickness	50

SECTION 17

Cliff on north side of Dry Canyon, 5.5 miles east of Smithfield, Utah, Lat. 41°50'03" N., Long., 111°40'23" W.

		Thickness (feet)
	Fish Haven Dolomite	
	Sharp, planar contact--disconformity	
Upper Unit		
7.	Quartzite, white, medium-grained; porous, vertical burrows, iron oxide knobs weather in relief, parallel-bedded, parallel laminae, some sulfurous beds 3 feet thick	65
6.	Quartzite, red to tan, fine- to medium-grained; vertical burrows, parallel-bedded, parallel laminae	90
5.	Quartzite, white, coarse-grained, parallel-bedded, parallel laminae, in lower 20 feet is a bed of cosets, 10 feet thick with foresets 1 foot thick dipping 20° S, separated by planar surfaces, laminae truncated on top, tangential on bottom	55
	Subtotal	210
Middle Unit		
4.	Quartzite, white and purple, fine- to medium-grained, vertical burrows top 2 feet, wavy laminae, fish scales, interference ripple mark strike E-W and NW-SE, cross laminae dip 20° S; raindrop imprints, abundant cephalopods; burrows	40
3.	Quartzite, brown, fine- to medium-grained, slightly calcareous, beds 2 to 6 inches thick	50
2.	Covered	96
1.	Quartzite, and shale, brown, interbedded	10
	Subtotal	196
	Sharp but conformable contact	
	Garden City Formation	
	Total	406

VITA

Philip L. Van Dorston

Candidate for the Degree of

Master of Science

Thesis: Environmental Analysis of the Swan Peak Formation in the Bear River Range, North-Central Utah and Southeastern Idaho

Major Field: Geology

Biographical Information:

Personal Data: Born at Goshen, Indiana, December 1, 1942, son of Karl and Lila VanDorston; married Joan Diann Boyer February 18, 1963; one child--Baron.

Education: Attended elementary school in Goshen, Indiana; graduated from Goshen High School in 1961; received the Bachelor of Science degree from Utah State University, with a major in geology in 1968; did graduate work in sedimentary environments, 1968-69; completed requirements for the Master of Science degree at Utah State University in 1969.

Prior Professional Experience: Summer 1968, geologist, Texaco, Inc. ; Summer 1967, geologist, Union Oil of California; 1962-66, personnel specialist, United States Air Force.

Present Position: Exploration geologist, Gulf Oil Co. , Casper, Wyoming.