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Petrology of the Ordovician Swan Peak Formation, Southeastern Idaho and North-Central Utah

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PETROLOGY OF THE ORDOVICIAN SWAN PEAK FORMATION,

SOUTHEASTERN IDAHO AND NORTH-CENTRAL UTAH

by

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Warren J. Schulingkamp II

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ABSTRACT

Petrology of the Ordovician Swan Peak Formation,

Southeastern Idaho and North-Central Utah

by

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Utah State University, 1972

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The Swan Peak Formation in southeastern Idaho and north-central Utah is a sedimentary unit consisting of orthoquartzite, sandstone, siltite, shale, and limestone. The formation is divisible into three members, and the lower two members each are divisible into two informal lithologic subunits.

The lower member consists of a lower subunit of gray, calcareous sandy siltite composed of subangular to subrounded quartz grains cemented by quartz overgrowths, calcite, or iron oxide, and an upper subunit of black shale with minor interbedded silty quartzose sandstone and biomicrite (limestone).

The middle member consists of a lower subunit of interbedded pale green shale and yellowish brown silty orthoquartzite and an upper subunit of purple orthoquartzite. The brown orthoquartzite consists of well-sorted, well-rounded very fine sand- to silt-sized quartz grains cemented by quartz overgrowths which are in optical continuity with the grains they surround. The purple orthoquartzite consists of well-sorted, well-rounded, very fine to medium sand-sized quartz grains cemented by quartz overgrowths and hematite. Hematite gives the rock its purple color. Hydroxylapatite is locally abundant.

The upper member is an orthoquartzite consisting of very fine to medium sand-sized, well-sorted, well-rounded quartz grains cemented by quartz overgrowths. The gastropod Murchisonia (Hormotoma) sp., the first body fossil found in the upper member, is reported.

Previous work has shown that the upper member of the Swan Peak Formation and the Eureka Quartzite are similar in lithology, stratigraphy, and trace fossils. The Eureka Quartzite in the Newfoundland Range is a very fine to medium sand-sized, well-sorted, well-rounded orthoquartzite cemented predominantly by quartz overgrowths, locally by dolomite. The petrographic similarities of the two units, shown in the present study, strengthens their proposed correlation.

High percentages of well rounded, polycrystalline and undulatory extinction quartz show that source areas for the Eureka Quartzite and Swan Peak Formation probably were immature sandstones or quartzites of Cambrian or Precambrian age, and/or exposed igneous or metamorphic rocks. The source for most of the sand probably was the Northwest Montana Uplift, although local sources along the Uinta Uplift undoubtedly played a minor role in supplying hydroxylapatite to the middle member and fine-grained clastics to the lower member.

(128 pages)

INTRODUCTION

General Statement

From general studies in southeastern Idaho and northern Utah, the lower and middle members of the Swan Peak Formation are known to be of early Middle Ordovician age (Ross, 1951, p. 31-33). These units consist of orthoquartzite, sandstone, siltite, shale, and limestone. The upper member of the Swan Peak Formation, of middle(?) to late(?) Middle Ordovician age, consists of orthoquartzite. Recently, detailed studies of this formation in north-central Utah have identified the environments of deposition of its three members and established their trace-fossil assemblages (VanDorston, 1969, 1970; Francis, 1972). This report contributes information on the petrography, origin, and source areas of the Swan Peak Formation, and gives details of its extent, lithology, and thickness in southeastern Idaho and north-central Utah.

Purpose of Investigation

The objectives of this study were: (1) to determine the rock types of members of the Swan Peak Formation in southeastern Idaho, their thicknesses, and their origins; (2) to describe the petrography of the Swan Peak Formation from microscopic studies of the mineralogy, grain size, quartz extinction types, and heavy minerals; (3) to compare petrographically the upper member of the Swan Peak Formation with the Eureka Quartzite in northwestern Utah, in order to further evaluate the possible correlation of these two units, as suggested by others (see Francis, 1972); and (4) to determine possible source areas for the Swan Peak Formation and Eureka Quartzite.

Location and Accessibility

The area of study is principally in southeastern Idaho, but it also includes adjacent parts of the Bear River Range, Wellsville Mountain, and the Promontory Range in north-central Utah, and the Newfoundland Range in northwestern Utah (Fig. 1). In southeastern Idaho, outcrops of the Swan Peak Formation occur in the Soda Springs Hills, the Fish Creek Range, and the Bear River Range (Figs. 2, 3, and 4).

Thirty-five thin-sections of the Swan Peak Formation and the Eureka Quartzite from five localities (Fig. 1) were studied in detail. These localities were: Soda Springs (Sec. F in Figs. 2 to 4), Midnight Mountain (Sec. J in Figs. 2 to 4), Wellsville Mountain (WM in Fig. 1), and the Promontory Range (PR in Fig. 1) for the Swan Peak Formation, and the Newfoundland Range (NR in Fig. 1) for the Eureka Quartzite. The measured sections for the last three are given in Francis (1972, Sections 7, 6, and 2, respectively).

Access to the measured sections is generally good. U. S. 89 in the south and southeast, U. S. 91 north from Logan, Utah, and U. S. 30N in the north, and Idaho State Highways 34 north from Preston, Idaho, and 36 east from Preston across the Bear River Range, are paved highways. From these, graded and dirt roads lead into the mountains. The latter roads are in mountainous terrain between altitudes of 7000 to 9000 feet, so they are generally closed by snowfall from early Autumn to early Summer.

Field Methods

Known outcrops of the Swan Peak Formation in southeastern Idaho and adjacent north-central Utah were transferred from previously published geologic maps (Armstrong, 1969; Coulter, 1956; Mansfield, 1927, 1929; Oriel, 1968; Oriel and Platt, 1968; Richardson, 1941) to a topographic base, and localities of good exposures were noted. Criteria for selecting localities for measuring stratigraphic sections were: (1) distance from other localities (where possible, four to six miles apart); (2) completeness and exposure of the formation at that locality; and (3) relative accessibility.

Field work was done from July to November, 1970, and from June to August, 1971. Stratigraphic sections of the Swan Peak Formation were measured at 15 localities (Sections A-Q, Figs. 2 to 6). The Swan Peak Formation was observed at several other places, but exposures at these localities were too incomplete to be of stratigraphic use. Section R, in Laketown Canyon, exhibited no definite Swan Peak lithologies in pits dug within a covered interval 15 feet thick between outcrops of Garden City and Fish Haven carbonates, or anywhere else in talus in the area.

Stratigraphic sections were measured with a 10-foot tape where the formation was exposed; covered intervals were measured with a Jacob staff and Abney hand level (Kottlowski, 1965). In covered intervals, pits were dug with a geologic pick at intervals ranging from 10 to 50 feet stratigraphically. Features noted in describing each section included: lithology, fresh and weathered colors, grain size, bedding thickness, sedimentary structures, and fossils. Oriented samples were systematically collected while measuring the section, both for further description in the laboratory and to provide material for making thin-sections. The top of the bed was marked on each sample so that thin-sections could be cut perpendicular to bedding.

Laboratory Methods

Samples from five stratigraphic sections (Fig. 1) measured by the author and/or by G. G. Francis were cut into thin-sections. A total of 105 thin-sections from all three members of the Swan Peak Formation and from the Eureka Quartzite were cut and studied; point counts of 200 grains each were made on 35 of these. The breakdown by members is as follows: two thin-sections were of the lower member, eight were of the middle member, 19 were of the upper member, and five were of the Eureka Quartzite. Thin-sections were stained with sodium cobaltinitrite for potassium feldspar and with sodium thiocyanate for plagioclase (Bailey and Stevens, 1960), and with alizarin red S for calcite (Mueller, 1967, p. 164). X-ray diffractometry was performed on one sample from the lower member and five from the middle member to determine the mineralogy of the clay matrix in these samples. The percentage of carbonate in one sample from the lower member was determined by sealing a weighed sample in a carbonate "bomb" with hydrochloric acid, mixing the two, and measuring the pressure of the carbon dioxide gas given off in the resulting reaction.

Point counts were made using a Zeiss polarizing microscope with an accessory mechanical stage and an integer eyepiece. Characteristics determined with the microscope and recorded were: mineralogy, grain size (largest diameter; see Friedman, 1958), shape, roundness, quartz extinction types (Blatt and Christie, 1963), inclusions, overgrowths on the quartz, and cement and/or matrix, if any. Grain-size data from the point-counting procedure were converted to sieve-size data using the special graph paper of Friedman (1958), which then were used in calculating the graphic mean size, inclusive graphic standard deviation, and inclusive graphic skewness (Folk, 1968) of the samples studied. These data are presented in Tables 1-3, Appendix C.

Rock-Name Terminology

The term "sandstone" refers to a sedimentary rock consisting predominantly of sand-sized grains cemented into a cohesive unit, but which will break around the grains. A "siltite" is a similar sedimentary rock consisting predominantly of silt-sized grains. A "quartzite" is a quartzose rock cemented by silica so that the rock will break through the grains, rather than around them. Although many quartzites are predominantly sand-sized, it is apparent that many other rocks called quartzites consist of quartz of predominantly coarse silt size. The difference between coarse silt and very fine sand is not readily detected in the field, and in many quartzites the size grades are present in subequal amounts. Hence, in this report, the term quartzite will be used to refer to both quartz arenites and quartz siltites. A "quartz arenite" (Folk, 1968, p. 123-124) is a sandstone whose grains consist of at least 95 percent quartz (all types, except chert); matrix, if present, is ignored in naming the rock. A quartz arenite cemented by silica thus is the coarse-grained variety of quartzite described above, and falls within the definition of orthoquartzite of Pettijohn (1957, p. 295-296, Table 48). An "orthoquartzite" is a quartzite in which quartz is greater than 90 percent of the detrital fraction and matrix is less than 15 percent of the entire rock.

A "shale" is a silt- to clay-sized, well-indurated sedimentary rock characterized by fissility. A "biomicrite" (Folk, 1959) is a limestone which has greater than 10 percent allochemical (precipitated within the basin of deposition) constituents, a greater amount of microcrystalline calcite matrix than of sparry calcite cement, less than 25 percent intraclasts (penecontemporaneous pieces of carbonate sediment that have been torn up and redeposited), and a volume ratio of fossils to pellets of greater than 3:1.

Previous Work

Numerous geologic studies, most of which were general in nature, have been made in southeastern Idaho and north-central Utah. The more important works which describe the Swan Peak Formation, or which have geologic maps of parts of this area, are listed below.

The Swan Peak "Quartzite" was named by Richardson (1913, p. 407) from outcrops at the crest of Swan Peak (Plate 1) in the northwest corner of the Randolph Quadrangle, Rich County, Utah. Richardson did not measure a type section. Mansfield (1920, 1927, 1929) studied and mapped geologically several quadrangles in southeastern Idaho, and his work included a small part of the present study area. The emphasis of Mansfield's work was, however, on the commercial phosphate reserves of Permian age in the region. Owen (1931) was the first to study the Swan Peak Formation in the Logan Quadrangle. Richardson (1941) mapped the Randolph Quadrangle which, as mentioned above, includes the type locality. Williams (1948) mapped the Logan Quadrangle, which includes most of the Utah portion of the present study area. He and Owen (1931) were the first to recognize the three distinct lithologic units (members) of the Swan Peak "Formation" used in this report.

Ross (1949, 1951, 1953, 1968) made detailed studies of the stratigraphy and trilobite faunas of the Garden City Formation, which directly underlies the Swan Peak Formation, in "northeastern" (north-central of this report) Utah. His studies also included part of the Swan Peak Formation. Ross defined 13 biostratigraphic faunal zones, A-M, in these formations. Twelve zones (A-L) are in the Garden City Formation, and one (M) is in the lower part of the Swan Peak Formation. From his faunal evidence, Ross concluded that the Swan Peak Formation is early Middle Ordovician in age (1951, p. 31-33). Ross also measured a section of the Swan Peak Formation at its type locality (1951, p. 11).

Coulter (1956) mapped geologically the southeast portion of the Preston 1:125,000 Quadrangle; Oriel and Platt (1968) made a reconnaissance geologic map of the entire quadrangle for the U. S. Geological Survey. The Bancroft Quadrangle (preliminary map) was mapped geologically by Oriel (1968), and the Soda Springs Quadrangle, by Armstrong (1969).

Ketner (1966) compared Ordovician quartzites (including the Swan Peak Formation) of the Cordilleran miogeosyncline to those of the eugeosyncline. Later (1968) he proposed a source for the miogeosynclinal quartzites in the Peace River-Athabasca Arch area of northern Alberta.

Recently, several detailed studies have been made by graduate students of the Department of Geology, Utah State University, on the

Swan Peak Formation of north-central Utah and on its equivalents in central Idaho and northwestern Utah (VanDorston, 1969, 1970; Francis, 1972; this report; James, in progress).

FIELD DESCRIPTION OF STRATIGRAPHY

Introduction

In the Lower Paleozoic section of the Bear River Range, the Swan Peak Formation is a distinctive, light-colored, mostly clastic unit in a predominantly dark-colored carbonate sequence. It conformably overlies the Lower Ordovician Garden City Formation (limestone and dolomite), and disconformably underlies the Upper Ordovician Fish Haven Dolomite, probably along a low-angle, regional unconformity (Hintze, 1959, Fig. 3).

The Swan Peak Formation was informally divided into three lithologic units, or "members" by Williams (1948, p. 1137) and by Owen (1931). Subsequent workers have accepted these members, so that today the threefold subdivision of the Swan Peak Formation is well established. Francis (1972) was the first to describe persistent subunits within each of these members.

Lower Member

The lower member was described by Williams (1948, p. 1137) as a black shale and sandy limestone. VanDorston (1969, p. 21) expanded the description to "...interbedded orthoquartzite, shale, and limestone ...." In Wellsville Mountain, Francis (1972) locally recognized three subunits within the lower member, but only two subunits elsewhere.

Within the present study area, the lower member is readily divided into two distinct subunits. The lower subunit (Plate 2) corresponds only to the lower part of the lower subunit of Francis. It is predominantly a light gray to medium dark gray quartz siltite which weathers pale yellowish brown to dark yellowish brown, locally moderate red. Bedding is thin (1.0 to 2.0 inches, averaging 1.0 inch), wavy parallel, and irregular (terminology of Campbell, 1966, 1967). Grains are predominantly silt-sized, and are cemented by calcite, iron oxide, or by silica. Locally, calcite makes up approximately 40 percent of the rock. Fossils are found sporadically in the lower subunit, and the following is a composite list from all sections included in this study: trilobite Eleutherocentrus petersoni, brachiopods Orthambonites michaelis and O. swanensis, and trace fossils Chondrites and Cruziana.

The contact of the Swan Peak Formation and the Garden City Formation was placed at the base of the first sandstone, siltite, orthoquartzite, or shale bed above the fine-grained dolomitic and cherty limestones of the uppermost Garden City Formation (c. f. Ross, 1951, p. 7). Siltites of the lower subunit usually begin at the contact with the Garden City; locally, however, a shale lens one or two feet thick separates the Garden City Formation and the siltites in the area studied. The lower subunit is very persistent, occurring at every locality where the base was clearly exposed. It was also the only part of the lower member to consistently form an exposed outcrop.

The upper subunit of the lower member corresponds to the upper and middle subunits, and part of the lower subunit, of Francis (1972). It consists of dark shale with minor interbedded quartzose sandstone and limestone. The shale (Plate 3) is medium dark gray to grayish olive to black, fissile, and thin-bedded. Beds range from less than one inch to two inches thick, averaging one inch. The limestones are dark bluish gray to medium dark gray, finely to coarsely crystalline biomicrites. They commonly contain round to irregular lenses of clay-sized material 0.25 inch long. Fossils in the limestones are ostracods and fragments of brachiopods and trilobites. These limestones are distinctive from those of the Garden City Formation in that they contain coarse sand-sized shell material and lack the chert nodules common in the uppermost Garden City beds. The sandstone is dark yellowish orange, weathers moderate to dark yellowish brown, silty, and generally poorly indurated.

The base of the upper subunit of the lower member is the top of the siltite of the lower subunit. The upper subunit grades upward into the lower subunit of the middle member. The upper subunit is present chiefly as covered slopes, except at St. Charles Canyon (Sec. P; Plate 3), where part (29 feet) is well exposed in a roadcut.

In southeastern Idaho, the lower member fills a NNW-trending, presumably tectonic, depression in the Garden City Formation in the vicinity of Paris Peak (Sec. K), where it is over 200 feet thick, and another NNE-trending depression in north-central Utah, between Logan Canyon and the Idaho state line, where it is over 160 feet thick (Fig. 2). It is 84 feet thick at the type locality, Swan Peak (Sec. Q), missing at Laketown Canyon (Sec. R), and 93 feet thick at the northernmost locality, in the Soda Springs Hills. (Sec. E).

Middle Member

Williams (1948) described the middle member as brown quartzite and gray shale. VanDorston (1969, p. 21) placed the contact of the lower and middle members at the top of the uppermost limestone bed, as the two units are gradational. Limestones appear to be much less abundant in the present study area than in areas farther south studied by VanDorston and by Francis. For this reason, and because of a lack of good exposures of the lower and middle members in the present study area, this criterion for separation was not practical. Francis (1972) divided the two members at the appearance of abundant (greater than 50 percent) interbedded quartzite within the stratigraphic sequence. This division was more applicable to the present study area, as the increase in sand beds could be inferred from the talus, a steepening in slope, and/or by digging small pits through the covering regolith. This last method was used in all but two sections where the contact was not exposed.

The middle member in the study area is divisible into two subunits: a lower subunit of interbedded shale and orthoquartzite (Plate 4) and an upper subunit of purple orthoquartzite with minor shale beds and partings (Plate 5). The lower subunit corresponds with the lower subunit of Francis (1972); the upper subunit is absent in his area, presumably due to erosion prior to the deposition of the upper member. The middle and upper subunits of Francis, recognized locally by him in only three sections, do not occur within the area of study. The best and thickest exposure of the lower subunit is near the mouth of the Right Fork of the Logan River (<u>see</u> VanDorston, 1969, Plate 3, and Section 1, p. 107). The best exposure (28 feet) of the lower subunit studied by the present author is at Midnight Mountain (Sec. J), but here the base and lower 63 feet are covered. This subunit is also exposed just south of Boy Scout Camp Wilderness (Sec. M).

The upper half of the lower subunit of the middle member is well exposed only at Midnight Mountain (Sec. J), where it consists of thin, interbedded orthoquartzites and shales. The orthoquartzites are composed of very fine sand- to coarse silt-sized quartz grains. They are moderate to dark yellowish brown, but locally may be purple or white. Beds range from 0.05 foot to 0.80 foot thick, and average 0.35 foot. Sedimentary structures present include parallel and wavy parallel laminae, oscillation (wave) ripples, current ripples indicating southwest migration, and low-angle, bottom-tangent, southwest-dipping cross-laminae.

The shales are pale green. Their light colors contrast with the much darker colors of shales in the lower member, also noted by Francis. Near the bottom of the exposure, shale predominates and quartzite beds are thin. Moving stratigraphically upward, shale intervals decrease in abundance and thickness, whereas quartzite beds correspondingly increase.

Fossils are more abundant in the middle member than elsewhere in the Swan Peak Formation. The following list, which gives all fossils found by the author in the lower subunit of the middle member, is by no means complete, for it does not list those fossils found by others in this unit in other areas. Most of the fossils were found in talus. They are: inarticulate brachiopod *Linguella* sp., articulate brachiopods *Orthambonites michaelis* and *O. swanensis*, trilobite *Eleutherocentrus petersoni*, grastrpod *Macluritella* sp., and the orthoconic cephalopod *Protocycloceras debilis*. Trace fossils are abundant in the quartzite of the lower subunit. They include *Annelidichnus*, *Chondrites*, *Cruziana*, and *Rusophycus* (Francis, 1972).

Annelidichnus (Plate 6), commonly referred to as "fucoids" or "fucoidal markings," is common on the bottom sides of quartzite beds that overlie shale, where the sand/mud interface was extensively burrowed, probably by worms.

Of particular interest is the mineral hydroxylapatite ($Ca_5 (OH) (PO_4)_3$), which occurs as rare plates in the lower subunit of the middle member. These phosphate plates are believed to be the dermal plates of primitive ostracoderms, deposited in shallow water near freshwater or estuarine influx (Romer, 1966, p. 23). They are probably similar to fragments of the earliest known ostracoderms from the apparently correlative Middle Ordovician Harding Sandstone of central Colorado (Walcott, 1892; Kirk, 1930). Thus, Middle Ordovician ostracoderms were probably present near shorelines in Utah and Idaho as well as Colorado and Wyoming. The hypothesis of Allison (1966) that the phosphate replaced shell material of marine invertebrates near the shelf edge and was concentrated by winnowing is inconsistent with the medium- to high-energy, shallow-water origin of the middle member, and the restriction of occurrances of hydroxylapatite chiefly to areas near the eastern pinchout of the middle member.

The upper subunit of the middle member is predominantly a distinctive purple orthoquartzite. It forms the top of the middle member; its base locally is gradational with the lower subunit where interbeds of purple orthoquartzite occur at the top of the quartzite and shale of the lower subunit. Orthoquartzites of the upper subunit consist of fine- to medium-grained quartz sand with minor silt, cemented by hematite and by quartz overgrowths. Minor amounts of shale are present, locally making up as much as 5 percent of the subunit. The subunit locally has current ripples, but these were found in talus, so the direction of transport could not be determined. Beds are 0.1 foot to 1.0 foot thick, averaging 0.5 foot.

Colors range from pale red purple to dusky red purple, weathering very dusky red purple. This subunit is rich in hematite and/or other clay-sized material, which color the rock. Hydroxylapatite is very common to abundant. According to VanDorston (1969, p. 25), X-ray fluorescence shows that the purple color is probably due to the presence of iron. The best, thickest, and most accessible exposure of the upper subunit is at St. Charles Canyon (Sec. P).

Fossils in the upper subunit of the middle member are the same as those in the lower subunit, with the addition of ostracods, probably *Leperditia* sp.

The middle member is 86 feet thick at Swan Peak (Sec. Q), the type locality, and generally thickens westward. However, it is missing in the northern end of both the Fish Creek Range and the Soda Springs Hills (Fig. 3).

Upper Member

The white, cliff-forming orthoquartzite of the upper member of the Swan Peak Formation (Plate 8) contrasts sharply with the usually covered, slope-forming lower and middle members below it and the basal part of the dark gray dolomite of the Fish Haven Dolomite above it. The most conspicuous outcrops of the Swan Peak Formation in the study area are those of the upper member.

The contact of the upper member with the middle member is sharp, and occurs at the base of the first bed of white orthoquartzite overlying the last bed of shale, brown quartzite, or purple quartzite of the middle member. At Midnight Mountain (Sec. J), the upper member overlies shale. At Swan Peak (Sec. Q), and at St. Charles Canyon (Sec. P), the upper member rests on purple quartzite. The contact at other localities is not so well exposed. The loss of middle member in the talus was a good indicator to begin looking for the contact of the middle and upper members. Generally, small outcrops of the upper member in situ can be found within a few feet of the contact, and the contact is invaribly sharp, both in exposures and in pits.

The upper member of the Swan Peak Formation is not so easily divided into lithologic subunits as were the lower and middle members. However, it may be subdivided on the basis of the presence or absence of trace fossils and other evidences of biologic activity. These zones may or may not all be present in a given section.

The basal 20 to 30 feet of the upper member is a yellowish gray to grayish orange orthoquartzite that weathers yellowish gray to medium orange pink. At most sections, it is represented by a covered interval. It may contain reworked material from the middle member, but with the median grain size increased, presumably by winnowing out the fines during reworking. It is devoid of trace fossils, and sedimentary structures are obscure due to poor exposure.

Above this basal part of the upper member is a zone of orthoquartzite, pale yellowish orange to dark grayish orange to light gray, weathering grayish orange and, locally, moderate reddish brown. This zone ranges from 30 to 570 feet thick, and is characterized by vertical protection burrows (Skolithos). Above this is a "churned" zone of white to light gray orthoquartzite which, while often showing signs of intensive bioturbation such as disturbed bedding, contains no recognizable trace-fossil forms. This zone ranges from 50 to 570 feet thick. Continuing stratigraphically upward, there next occurs a zone of white to light gray orthoquartzite which contains numerous small holes, one-fourth to one-half inch in diameter. These have been called "solution pits" or simply "holes" by others (Holmes, 1958; Armstrong, 1969), but have been referred provisionally to the trace fossil Laevicyclus by Francis (1972). This zone ranges from 34 to 120 feet thick. Above this zone, the uppermost part of the upper member is a white to light gray orthoquartzite which is generally less resistant and thinner-bedded than the rest of the member. This zone is generally devoid of trace fossils, ranges from 15 to 89 feet thick, and is best developed in the Fish Creek Range and the Soda Springs Hills (Secs. A, B, C, and E).

Where exposed, the contact of the upper member of the Swan Peak Formation with the overlying Fish Haven Dolomite is invariably sharp and planar. No angular discordance between the two units was noticed by the author anywhere in the study area; however, Coulter (1956, p. 25-26) reported such a relationship at Bloomington Lake (Deep Lake) in the Bear River Range.

As a whole, the upper member is a very clean, white to light gray orthoquartzite. Some beds are soft and friable, but the unit is generally well indurated. The quartz is very fine to medium grained, well sorted, and well rounded, although the roundness is commonly obscured by quartz overgrowths, especially in hand specimen. The rock weathers very light gray to medium light gray and, locally, grayish orange, orange brown, and pinkish gray. Very rare shale partings were noted locally only at Section K (R. Q. Oaks, oral communication).

Common sedimentary structures in the upper member include parallel and wavy parallel laminae; low-angle, bottom-tangent and high-angle, planar cross-laminae dipping to the northeast, east, southeast, south, and southwest; and current ripples indicating southwest migration.

Bedding is usually thin, although the average is thicker than that of the lower and middle members. Beds range from 0.1 to 3.4 feet thick, averaging less than one foot. Several "massive" units are probably composed of several beds, with individual beds not weathered out.

To the author's knowledge, there have been no previous reports of any body fossils found in the upper member of the Swan Peak Formation. Five specimens of the gastropod <u>Murchisonia</u> (<u>Hormotoma</u>) sp. (Plate 9) were found in talus of the upper member at Section C in the Fish Creek Range. The two best-preserved specimens were collected for identification. The specimens are preserved as internal casts, and hence do not exhibit any ornamentation that would make specific identification possible. <u>Hormotoma</u> has been reported from the underlying Garden City Formation (Mansfield, 1927, p. 57; Williams, 1948, p. 1146), from the purple orthoquartzite of the Swan Peak Formation (VanDorston, 1969, p. 31), and from the overlying Fish Haven Dolomite (Mansfield, 1927, p. 58), as well as from Middle Ordovician rocks of western Utah and eastern and central Nevada (Webb, 1956, 1958; Ross, 1970). No other body fossils were found in the upper member of the Swan Peak Formation.

PETROGRAPHY OF THE LOWER MEMBER

Lower Subunit

The lower subunit of the lower member consists predominantly of coarse sandy siltite composed of quartz grains with minor feldspar, cemented by quartz overgrowths, calcite, and/or iron oxide. The porosity of the rock is low.

Sizes of the grains range from 0.02 mm to 0.15 mm, with a graphic mean (Folk, 1968, p. 45) of 0.05 mm (4.31 phi). Size distribution is bimodal with modes at 4.0 and 5.0 phi. The inclusive graphic standard deviation (sorting) (Folk, 1968, p. 46) is 1.151 phi, and the inclusive graphic skewness (Folk, 1968, p. 47) is +0.312. The grains are subangular to subrounded, and equant to bladed (original roundness and shape). The rock is texturally submature (Folk, 1968, p. 102-103).

Sand makes up an estimated 44 percent of the rock, ranges from 0.06 mm to 0.15 mm, and is predominantly very fine sand (Udden-Wentworth scale). Silt makes up an estimated 48 percent of the rock, ranges from 0.02 mm to 0.06 mm, and is predominantly coarse silt. Clay-sized particles and calcite cement make up an estimated 8 percent of the rock. Further size analysis of the clay-sized fraction was not possible. The above estimated percentages are based on observations of all thin-sections of this subunit that were cut for this study, not just the one thin-section which was point-counted.

Cementation is either by interlocking of quartz grains due to overgrowths or by calcite and iron oxide. All three can occur in the same thin-section. Grains of calcite locally are rather large, up to

0.45 mm in diameter.

Quartz is the predominant clastic mineral. Based on observation of all thin-sections of the lower subunit, quartz forms an estimated 90 percent of the rock. The quartz ranges in size from 0.02 mm to 0.15 mm, is subangular to subrounded, and equant to bladed (original roundness and shape). It commonly contains bubbles; rutile inclusions are rare. Overgrowths on the quartz are common but not always present. Undulatory extinction is the most common type.

Feldspars (both plagioclase and potassium feldspar) from about 1 percent of the rock, although they were not encountered during point counting. Feldspar grains have approximately the same size, shape, and roundness as the quartz, and were distinguished by twinning, stains, and by X-ray diffractometry.

The heavy minerals are tourmaline and zircon; tourmaline outnumbers zircon by five to one. Tourmaline is of the green variety, 0.03 mm to 0.05 mm in diameter, rounded to subrounded, and equant to bladed. Zircon is 0.03 mm in diameter, rounded and equant.

Two iron oxides, hematite and limonite, occur as cement, locally forming as much as an estimated 8 percent of the rock. They were identified in thin-section by use of reflected light.

Calcite cement locally forms up to approximately 40 percent of the rock. This percentage was determined by point counting and by comparison of the results from one sample with that from the carbonate "bomb" previously described. In thin-section, calcite occurs as sparry crystals 0.03 mm to 0.45 mm in diameter. The crystals were commonly, but not always, interlocking. Alizarin red S stain was used to determine that the mineral was calcite and not dolomite.

Upper Subunit

Limestones of the upper subunit of the lower member are coarse biomicrites (Folk, 1959). They are comprised of a framework of ostracods and fragments of brachiopods and trilobites in a matrix of microcrystalline calcite (micrite) which has in part recrystallized to microspar (Folk, 1965, p. 37). Also in the matrix are silt-sized quartz grains and iron oxides.

Recognizable shell fragments make up 30 to 35 percent of the limestones. Of these, approximately 70 percent are brachiopod and/or trilobite fragments, and 30 percent are ostracods. These shell fragments range from 0.10 to 1.50 mm in maximum dimension, averaging 0.25 mm. The micrite matrix makes up 60 to 65 percent of the limestones and is about 0.001 mm in size; portions recrystallized to microspar are 0.01 to 0.02 mm, averaging 0.01 mm in size.
Quartz grains average up to 10 percent of the limestones. Grain size ranges from 0.03 mm to 0.13 mm, averaging about 0.06 mm (silt-sand boundary). Grains are subangular to subrounded, and equant (original roundness and shape). The quartz occurs chiefly in lenses and under curved brachiopod shells, protected from currents. Some grains are scattered randomly through the matrix.

Shales of the upper subunit were not examined petrographically; hence statistical parameters were not determined for the shale.

The quartzose sandstone of the upper subunit consists predominantly of quartz grains and clay, with minor heavy minerals and hydroxyl-apatite. One thin-section of this rock was examined petrographically.

Grain size ranges from 0.03 mm to 0.20 mm; grains are equant to bladed, and subangular to subrounded (original shape and roundness).

The graphic mean size is 0.07 mm (3.80 phi), the inclusive graphic standard deviation is 1.379 phi, and the inclusive graphic skewness is +0.550. The rock is texturally immature.

Grain size, shape, and roundness are the same as those given above for the grains. Undulatory extinction is the most common type.

Clay matrix forms up to 10 percent of the rock; further size analysis was not possible.

Hydroxylapatite makes up 2 percent of the rock. Grains are platy, and up to 0.12 mm in length.

Zircon and apatite are rare, making up a combined total of about 1 percent of the rock. Grains are 0.03 mm in size, rounded, and equant.

PETROGRAPHY OF THE MIDDLE MEMBER

Lower Subunit

Orthoquartzite beds of the lower subunit of the middle member consist of very fine sand- or coarse silt-sized quartz grains with minor amounts of feldspar, hydroxylapatite, tourmaline, and zircon. A minor amount of montmorillonite occurs as matrix, and quartz overgrowths and minor iron oxides (hematite and limonite) cement the rock. The large, platy hydroxylapatite grains are aligned parallel to stratification. Porosity of the rock is low.

The grain size ranges from 0.01 mm to 0.63 mm, with an average graphic mean size of 0.11 mm (3.22 phi). Size distribution is bimodal in five of nine samples. The average inclusive graphic standard deviation (sorting) is 0.496 phi, and the average inclusive graphic skewness is +0.134. Texturally, the rock is immature.

Sand-sized grains average 43 percent of the total sediment, and range from 0.06 mm to 0.63 mm. Silt-sized grains average 48 percent and range from 0.01 mm to 0.06 mm. The clay-sized fraction averages 9 percent of the rock; further size analysis was not possible.

Cementation is predominantly by quartz overgrowths, rarely by iron oxide. The quartz overgrowths are in optical continuity with the grains they enclose; thus, it is generally impossible to distinguish the original shapes of the grains, except where they are outlined by very fine-grained "dust."

Quartz is the predominant mineral (approximately 90 percent). It ranges in size from 0.01 mm to 0.15 mm. Grains are subequant in shape, with a tendency toward bladed. They are subrounded to well rounded, but quartz overgrowths obscure both the original shape and roundness. In some thin-sections, in which the original grain shape and roundness could be seen despite the overgrowths, the grains were all well rounded. This is compelling evidence that all of the quartz grains were probably originally well rounded, and that their present subrounded appearance is due to the quartz overgrowths. Undulatory extinction is the most common type. The quartz commonly contains bubbles, and, rarely, inclusions of rutile needles.

Feldspars (both potassium feldspar and plagioclase) are present in minor amounts, averaging about 1 percent. The presence of both feldspars, suspected from optical work, was confirmed by X-ray diffractometry. The feldspars are approximately the same size, shape, and roundness as the quartz.

Hydroxylapatite ($Ca_5 (OH) (PO_4)_3$) grains form about 1 percent of the rock, although more may be present in the clay-sized fraction. The maximum recorded length of a grain was 0.63 mm. The larger grains are usually platy.

Heavy minerals include tourmaline, zircon, and, in two thin-sections, apatite. Tourmaline is the most common. The grains are rounded, equant, and approximately the same size as the quartz. The green variety of tourmaline is the most common, although a few grains of the yellow and brown varieties occur.

The clay-sized fraction includes iron oxides, montmorillonite, and possibly hydroxylapatite and quartz. Iron oxides were identified optically as limonite and hematite. Montmorillonite was identified optically and by X-ray diffractometry.

The green shale of the middle member was not examined in detail. Differential thermal analysis and X-ray diffractometry of this shale by VanDorston (1969, p. 26) showed that it is mostly quartz and illite.

Upper Subunit

The purple orthoquartzite of the middle member consists of very fine- to medium-grained quartz and hydroxylapatite cemented by quartz overgrowths and by hematite. Hematite (iron) gives the rock its purple color, as first suggested by VanDorston (1969, p. 25). Large, platy grains of hydroxylapatite are commonly aligned parallel to stratification. Porosity of the rock is low.

Grain sizes range from 0.02 mm to 0.65 mm. The average graphic mean size is 0.13 mm (2.94 phi); average inclusive graphic standard deviation is 0.460 phi; and average inclusive graphic skewness is +0.271. Grains are well rounded to subrounded, and equant to subequant (original shape and roundness). Texturally, the rock is mature to supermature.

Sand-sized material, from 0.06 mm to 0.65 mm, forms 98 percent of the grains. Silt-sized material, from 0.02 mm to 0.06 mm, forms 2 percent of the grains.

Quartz is the predominant mineral, averaging 92 percent of the rock. It ranges from 0.02 mm to 0.53 mm in size, is well rounded to rounded, and subequant to equant (original roundness and shape). Undulatory extinction is the most common type.

Hydroxylapatite occurs as subrounded to rounded, subequant to platy grains from 0.08 mm to 0.65 mm in length (maximum dimension). It makes up approximately 5 percent of the rock.

Hematite makes up 2 to 3 percent of the rock.

Cementation in the upper subunit is by both quartz overgrowths and by hematite. Pore spaces between the grains are, in most samples of the upper subunit examined in this study, completely filled by one or both of the cementing agents, so that the rock breaks across the grains.

PETROLOGY OF THE LOWER AND MIDDLE MEMBERS

The lower subunit of the lower member, a coarse sandy siltite, is the basal part of a continuous sequence of depostion that includes the entire lower and middle members. Based on lithologic characteristics and on the fossils present, the lower subunit of the lower member probably was deposited in an open-marine environment, probably in shallow water, and under moderate to low-energy conditions during transgression of the sea following the time of deposition of the Garden City Formation. The locally high percentages of calcite may be due to later recrystallization of carbonate mud deposited simultaneously with the quartz, or to later recrystallization and reorganization of shell material, or to subsequent precipitation from pore waters moving upward from underlying carbonates. However, because the present form of calcite is secondary, there is no clear way to discriminate among the above possibilities.

The varied fauna and black shale of the upper subunit of the lower member suggest an increase in water depth and lower energy, probably near or below effective wave base. As the sea advanced during transgression, water depth probably increased, and the shoreline, which ran approximately north-south (Fig. 2), retreated eastward. The biomicrites represent periods of reduced clastic influx, although they do contain up to 10 percent quartz silt. The abundant fossils in these limestones are evidence of the open-marine conditions under which rocks of this subunit formed. Currents may have been moderate, but probably were not persistent (Folk, 1968, p. 156), for the fine-grained carbonate mud, now represented by micrite or microspar, was not winnowed out. The thin, silty sandstones probably represent periods of heavy storms, when sands were swept offshore from nearshore areas.

The interbedded orthoquartzite and shale of the lower subunit of the middle member is gradational with the underlying upper subunit of the lower member. Together, these units represent a decrease in depth and an increase in energy as the shoreline gradually advanced westward, presumably by progradation during a protracted stand of sea level. Orthoquartzite beds are at first thin and few in number, but gradually become thicker and more numerous toward the top of the subunit. The marine environment of deposition is evidenced by the abundant body- and trace fossils (c. f. Francis, 1972).

The upper subunit of the middle member is predominantly sand, with only minor shale, and probably represents a moderate to high energy level and very shallow water. That it was still a marine deposit, though, is evidenced by the marine fossils present. The increase in abundance of the hydroxylapatite as compared to the lower subunit is considered as evidence that the mouths of streams supplying this relatively soft mineral were brought closer to the site of deposition by the shallowing of the sea caused by westward progradation.

Several petrographic parameters, summarized in Table 3, Appendix C, are pertinent to the petrology of the lower and middle members. The increase in percentages of polycrystalline plus undulatory quartz as grain sizes of quartz increase stratigraphically upward would be predicted from Blatt (1967a). Likewise, moving stratigraphically upward, the increase in roundness as mean and maximum grain sizes increase was demonstrated by the abrasion experiments of Kuenen (1960).

The increase in mean and maximum grain sizes and the improved sorting from the lower subunit of the lower member to the upper subunit of the middle member indicate a general increase in the energy level acting on the sediment, probably caused by the shallowing of the sea as the shoreline advanced seaward. These parameters may also be indicative of the length of time an energy level acted upon the sediments.

The relatively high amounts of polycrystalline and undulatory quartz suggest a crystalline and/or immature to submature sandstone source for the quartz grains (Blatt, 1967a, b). Further, the presence of chert, although in small amounts, the scarcity in these orthoquartzites of feldspar and clay minerals that could form diagenetically from feldspar, the fact that only the more resistant heavy minerals are present, and the high degree of rounding of the larger quartz grains, all indicate that the primary source was a sedimentary terrain, probably consisting mainly of second-cycle or polycyclic sandstones. The shales may have resulted either from deep chemical weathering of crystalline rocks or from erosion of fine-grained sedimentary rocks.

The high degree of maturity of quartz in orthoquartzites of the middle member indicates either that high energy was applied to the grains for a long period of time or that a particularly effective high-energy system (such as a beach) acted upon the sediments for perhaps a shorter period of time. A problem exists with either hypothesis when applied to orthoquartzites of the middle member of the Swan Peak Formation, however, because these exhibit a textural inversion wherein moderately well sorted and rounded quartz grains occur together with a persistent, rather high percentage of clay-sized materials. High or very high energy acting upon a sediment should remove such fine-grained material. This possibility indicates: (1) mixing of mature and immature sediments during transport, perhaps in rivers, followed by such rapid deposition that sorting was incomplete despite high energy at the site of deposition; (2) similar mixing, followed by deposition in an environment of moderate energy unable to effectively complete separation of coarse and fine sizes; or (3) post-depositional decomposition of sand- and coarse silt-sized feldspar grains. The latter hypothesis is unlikely, however, because much of the fines is quartz, not clay minerals derivable from feldspar.

PETROGRAPHY OF THE UPPER MEMBER

The upper member of the Swan Peak Formation is a clean, very fine- to medium-grained orthoquartzite tightly cemented by quartz overgrowths. Rare tourmaline and zircon occur as heavy minerals, and minor hydroxylapatite is present in the lowermost part. Only in a few thin-sections does any clay-sized matrix appear. Porosity of the rock is virtually zero.

Grain sizes range from 0.03 mm to 0.55 mm, the average graphic mean size being 0.16 mm (2.66 phi). The inclusive graphic standard deviation averages 0.546 phi, and the inclusive graphic skewness averages +0.303. Grains are subrounded to well rounded, and subequant to equant, where the original roundness and shape are not obscured by overgrowths.

In most thin-sections, the upper member averages greater than 99 percent quartz. The size, shape, and roundness given above for the grains are also those of the quartz. Either the undulatory or the non-undulatory extinction type predominates, depending on the locality and thin-section. Slightly undulatory extinction seems to be the most common type. Rutile needles occur commonly, and there are rare inclusions of tourmaline or zircon in the quartz. Bubbles are very common in the quartz, sometimes occurring in trails.

Heavy minerals make up less than 1 percent of the grains. The most common heavy mineral is the green variety of tourmaline. Zircon occurs rarely. Size, shape, and roundness of these minerals are similar to that of the quartz, but with less variation in size.

Locally, iron oxides form up to 5 percent of the rock, and clay, except for sample WM-45, which has an anomalously large 33 percent clay content, only up to 2 percent. Significantly, no feldspar was found in any of the 17 thin-sections of the upper member that were point counted.

PETROGRAPHY OF THE EUREKA QUARTZITE

The Eureka Quartzite is a clean orthoquartzite consisting of a framework of very fine- to medium-grained quartz cemented by interlocking quartz overgrowths. Feldspar was extremely rare; only one grain was found in five thin-sections that were point counted. Dolomite cement occurs in one thin-section. Porosity is nil.

The grain size ranges from 0.05 mm to 0.52 mm. The average graphic mean size for four of the thin-sections was 0.175 mm (2.61 phi); the average graphic mean size for all five thin-sections was 0.145 mm (2.81 phi). The average inclusive graphic standard deviation for all five thin-sections is 0.489 phi; the average inclusive graphic skewness is +0.071. The grains are subequant to bladed, and subrounded to well rounded. As in the Swan Peak Formation, quartz overgrowhts obscure the original shape and roundness. In the one thin-section which had dolomite cement, the quartz grains were mostly rounded to well rounded, and subequant, which strongly suggests that this was the original shape and roundness of most of the grains throughout the formation. Field observation indicates that overgrowths are the dominant cementing agent for most of the formation.

Quartz forms more than 99 percent of the entire rock, except where it is cemented by dolomite. Thus, the sizes, shapes, and roundnesses given above are also those of the quartz. Undulatory extinction in quartz is the most common type. Bubbles are common, and inclusions of rutile and tourmaline are present but rare.

The heavy minerals, tourmaline and zircon, are rare. Tourmaline forms less than 1 percent of the rock; zircon is even rarer. Yellow, green and brown varieties of tourmaline are all present; the green variety is the most common. Sizes of both of these minerals range from 0.08 mm to 0.10 mm; both are well rounded and subequant.

COMPARISON OF THE UPPER MEMBER AND THE EUREKA QUARTZITE

Nature of the Problem

Two similar Middle Ordovician orthoquartzites of the Cordilleran miogeosyncline occur in Utah: the upper member of the Swan Peak Formation in north-central Utah, and the Eureka Quartzite in western Utah and eastern Nevada. The Swan Peak Formation has been considered to be of early Middle Ordovician age (Ross, 1951, p. 33) and the Eureka Quartzite to be of late Middle to early Late Ordovician age (Webb, 1958, Fig. 6). Ross (1953, p. 24; 1964, Fig. 3) appears to have been the first to suggest that "quartzites" of the Swan Peak Formation may be correlative with those of the Eureka Quartzite. In the Promontory Range of Utah, a section of orthoquartzite was assigned to the Swan Peak Formation by Webb, but he suggested that all or part of the upper quartzite there may actually be Eureka Quartzite (Webb, 1956, p. 68; 1958, p. 2356-2357). Francis (1972) showed that trace-fossil assemblages and sedimentary structures of the two units are identical, further evidence for correlation of the upper member with the Eureka.

To compare petrographically the Eureka Quartzite with the upper member of the Swan Peak Formation, five thin-sections of the Eureka Quartzite from the southern Newfoundland Range (Fig. 1; see Francis, 1972, Section 2) were point counted. Mean size, sorting, and skewness were determined for comparison with similar parameters for the upper member of the Swan Peak Formation.

Similarities

Megascopic similarities of the upper member of the Swan Peak Formation and the Eureka Quartzite were summarized by Francis (1972), who used the following as the basis of his correlation of the two units: (1) similar lithologies of both formations; (2) similar south-flowing paleocurrents in both formations; (3) identical trace-fossil assemblages; (4) similar stratigraphic positions relative to faunal zones and other stratigraphic units; and (5) similar thicknesses of the easternmost Eureka and westernmost upper member.

Similarities petrographically determined in this study include nearly identical mineralogies, heavy mineral assemblages, mean grain sizes and ranges of grain sizes, grain size distributions, standard deviations (sorting), roundnesses, quartz extinction types, and means of cementation (see Table 3). Quartz is the predominant mineral in both formations. The heavy mineral assemblages in both consist entirely of minor tourmaline and zircon, and, in both, tourmaline, particularly the green variety, predominates. The graphic mean for all samples of the upper member of the Swan Peak Formation is 2.66 phi and for four samples of the Eureka Quartzite (p. 35) is 2.61 phi. Grain sizes range from 0.03 mm to 0.55 mm in the upper member of the Swan Peak and from 0.05 mm to 0.52 mm in the Eureka. In both, the grain size distribution may be either unimodal or bimodal, but the unimodal distribution is much more common. Standard deviation in the two units is similar, averaging 0.546 phi in the upper member of the Swan Peak and 0.489 in the Eureka. Grains in both units are subrounded to well rounded where the grains are not obscured by quartz overgrowths. Undulatory extinction in quartz is the most common type in both units.

Quartz overgrowths forming an interlocking framework is the predominant form of cementation in both formations.

Differences

Differences between the upper member of the Swan Peak Formation and the Eureka Quartzite are minor. The main contrast is a slight difference in the skewness. All of the samples of the upper member of the Swan Peak Formation are fine-skewed, ranging from +0.081 to +0.514 and averaging +0.303. The skewness of the Eureka Quartzite ranges from -0.514 to +0.343, averaging +0.071.

Another minor difference is in color. The Eureka Quartzite is commonly medium light gray when fresh and weathers medium light gray to light gray, whereas the upper member of the Swan Peak Formation is commonly white to very light gray and weathers light gray to white.

Conclusions

The upper member of the Swan Peak Formation and the Eureka Quartzite have similar petrographic characteristics, as well as similar lithologic sequences, paleocurrent directions, trace-fossil assemblages, stratigraphic positions, and thicknesses. The correlation of the two formations, long suspected, but first proposed unequivocally by Francis, is here accepted.

PETROLOGY OF THE UPPER MEMBER AND THE EUREKA QUARTZITE

A marine environment of deposition for the upper member of the Swan Peak Formation (VanDorston, 1969, p. 42) and the Eureka Quartzite is almost certain. Both contain similar sedimentary structures (Francis, 1972) that are suggestive of a shallow-marine environment, such as parallel laminae, planar cross-stratification, and both current ripples and truncated wave ripples (Campbell, 1966). Protection-type burrows and other trace fossils of the Skolithos assemblage in both formations are evidence of high-energy conditions, which is also suggested by the virtual absence of silt and clay.

Source areas for the quartz in the upper member of the Swan Peak Formation and the Eureka Quartzite are discussed in the following section.

SOURCE OF ORDOVICIAN QUARTZITES

The similarities of the Middle Ordovician Eureka Quartzite, the upper member of the Swan Peak Formation, and the Kinnikinic Quartzite of central Idaho (C. P. Ross, 1934, 1937; James, in progress, R. Q. Oaks, oral communication) suggest that they are correlative and had a common source. R. J. Ross (1964) suggested a northerly source for the Eurkea Quartzite of southern Nevada. Ketner (1968) suggested that Cambrian sandstones in the Peace River-Athabasca Arch area of northern Alberta were the common source for all Ordovician miogeosynclinal quartzites in the Cordilleran geosyncline. Predominant paleocurrent directions in the Eureka of western Utah and the upper member in north-central Utah are southward (Francis, 1972).

Ketner considered three areas as possible sources for the quartz sand: (1) the Peace River-Athabasca Arch area of northern Alberta; (2) the Northwest Montana Uplift in northwestern Montana and south-eastern British Columbia; and (3) the Uinta Uplift in northeastern Utah. Ketner dismissed the last two areas as possible sources because he believed that they could not contribute a sufficient volume of sand, and he proposed the Athabasca Arch as the main source.

Ketner's evidences for a source in Alberta are: (1) the presence of an adequate source of sand in Alberta and an apparent lack of adequate sources elsewhere; (2) the apparently progressive decrease in age of basal quartzite beds from north to south; (3) the southerly decrease in thickness and increase in width of deposits; (4) an apparently southerly decrease in median grain size (50th percentile);

and (5) an overall southerly trend toward improved sorting.

One of the purposes of this study was to use detailed petrographic data in evaluating possible source areas of the Swan Peak Formation. The possibility of at least two sources for the Swan Peak Formation and the Eureka Quartzite is suggested by the bimodal size distributions that occur in both formations in the absence of clay and fine silt. It is also suggested by the presences of unstable minerals such as hydroxylapatite in eastern exposures of the upper member and the rare occurance of feldspar in the Eureka. The hydroxylapatite must have been derived very locally to be deposited in a narrow, north-south-trending band, within a high-energy environment. VanDorston (1969, p. 41) favored a local source southeast of the Logan Canyon area for the lowermost, hydroxylapatite-bearing part of the upper member. As indicated earlier, hydroxylapatite may be the remains of primitive ostracoderm fish. If so, these fish probably lived in estuaries or streams (Romer, 1966, p. 23), and their remains were carried to the sea after death and deposited. These streams probably also carried other sediments. Feldspar and clay minerals, although rare, are present and probably had a source other than northern Alberta.

Ketner dismissed the Northwest Montana Uplift as a possible source because Cambrian quartz sandstone (Flathead) flanking the east side of that area is too thin, and because rocks of the underlying Belt Series were presumed to have had only minor amounts of sandstone. The amount of Cambrian sandstone originally in the area is debatable because few outcrops of Cambrian rocks are preserved. Those which are preserved are in fault blocks and consist mostly of limestone and shale (Gibson, 1948). However, to the west and southwest, Cambrian sandstones thicken from approximately 150 feet in the St. Regis-Superior area of Montana (Campbell, 1960) to 8500 feet in the Metaline Quadrangle of northeastern Washington (Park and Cannon, 1943). Also, the upper formations of the Belt Series in northwestern Montana contain thousands of geet of quartzite (C. P. Ross, 1963). Ketner's belief that the Belt Series was lacking in quartz sandstone was based on the fact that the lower Belt formations still preserved farther east in Glacier National Park are mostly argillites and carbonates. Rocks of the upper Belt Series in the park (a potential source) have been almost entirely eroded away.

Because rocks of the Belt Series are commonly the only sedimentary strata exposed in much of the Northwest Montana Uplift (except for Quaternary alluvium), the time of erosion is debatable. Erosion could have, and probably has, taken place at various times from the Cambrian to the Recent. However, Sloss (1950, Fig. 6) showed the area in question as one of Precambrian outcrops surrounded by Cambrian and Ordovician deposits prior to deposition of Devonian rocks. Sloss (1950, Fig. 5) also showed this area, as well as all of western Montana, as an area of no Ordovician rocks. Presumably the area was high and subject to erosion throughout Ordovician time. Thus, the Northwest Montana Uplift probably is a potentially adequate source of quartz sand for the Cordilleran miogeosyncline during Ordovician time.

Ketner also dismissed the Uinta Uplift as an inadequate source of sand. However, it may have contributed some sediment to the Ordovician miogeosyncline, particularly in the area of the present study. This could explain the bimodal size distributions of some samples, the abundant clay- and silt-sized particles in the lower and middle members, and the presence of hydroxylapatite in the middle and lowermost upper members. Although the Uinta Uplift apparently could not have contributed the bulk of quartz sand deposited in the Cordilleran miogeosyncline during Ordovician time, it probably did influence local sedimentary patterns there, especially in the area of study. It perhaps was an important contributor during deposition of the lower and middle members.

Ketner presented evidence of a progressive decrease in age of basal Ordovician quartzites in the Cordilleran miogeosyncline from Alberta to California (Ketner, 1968, Fig. 5). However, Ketner's data are based on widely-spaced points, with a large gap between Site 76 in Canada and Site 37 in north-central Utah. Also, no information on the age of the Kinnikinic Quartzite in central Idaho is presented, although such information was presented by Hobbs and others (1968). They established the age of the Kinnikinic Quartzite as Middle Ordovician on the basis of fossils collected from the overlying Saturday Mountain Formation and the underlying Ella Dolomite. The Ella Dolomite is of early Middle Ordovician (Whiterock to Marmor) age (Hobbs and others, 1968, p. J14), and the Saturday Mountain Formation is at least partly of late Middle Ordovician (Trenton) age (Hobbs and others, 1968, p. J11-J12). Thus, as stated by Hobbs and others (1968, p. J11), the Kinnikinic Quartzite, as they redefine it, must have been deposited between the lower part of the Middle Ordovician and the upper part of the Middle Ordovician. This would indicate a Porterfield or Wilderness age for the Kinnikinic Quartzite, considerably younger than the Whiterock age given by Ketner (1968, Fig. 5) for the Swan Peak Formation farther south, in northern Utah, at Site 37.

Ketner suggested mature quartz arenites of Cambrian age in the

Peace River-Athabasca Arch area as the source of Ordovician quartzites. One of the features of most orthoquartzites is their relatively high proportion of quartz with non-undulatory extinction (Blatt and Christie, 1963). In this respect, the Swan Peak Formation differs from most orthoquartzites. The difference is significant for two reasons. Firstly, Blatt (1967a) suggested that the reason the percentages of undulatory extinction and polycrystalline quartz are so low in orthoquartzites is because these quartz types are structurally weaker than quartz with non-undulatory extinction; hence they are selectively removed from the sediment by destruction during transport. This suggests that transport of the many undulatory and polycrystalline grains in the Swan Peak Formation from northern Alberta is unlikely, or, possibly, that these quartz types are more persistent than suggested by Blatt (1967a). A more complete consideration of these possibilities was given earlier in the discussion of petrology of the lower and middle members.

Secondly, Precambrian sedimentary rocks probably were subjected generally to greater diagenesis than Cambrian or Lower Ordovician rocks because, being older and thus at the bottom of the sedimentary pile, they were buried deeper and for a longer period of time. Precambrian quartzites are thus more likely to have been subjected to pre-Middle Ordovician diagenetic and/or metamorphic processes that produced recrystallization to polycrystalline quartz and/or undulatory extinction. Ketner (1968, p. B175) stated that Precambrian rocks in the Peace River-Athabasca Arch area are not significantly eroded, although Cambrian sandstones are nearly completely removed. However, potential source rocks in the Northwest Montana Uplift (Belt Series) and the Uinta Uplift (Uinta Mountain Quartzite and the Red Creek Quartzite) are of Precambrian age. C. P. Ross (1963, p. 39-41) reported that rocks of the Belt Series show effects of low-grade metamorphism, such as recrystallization of sand grains, although original grain outlines could still be seen. Hansen (1965, Fig. 12) reported that quartz of the Uinta Mountain Quartzite of the Flaming Gorge area had relatively straight extinction. However, in the metaquartzite of the Red Creek Quartzite, undulatory extinction and recrystallized grains are common (Hansen, 1965, p. 24).

It is concluded that some of the quartz sand in Ordovician orthoquartzites in the Cordilleran miogeosyncline may have come from the Peace River-Athabasca Arch area, but that area probably was not the major source.

CONCLUSIONS

The Swan Peak Formation in southeastern Idaho and north-central Utah is a sedimentary unit of varied lithologies. It is divisible into three informal members, and the lower two are each divisible into two informal subunits.

The lower member consists of a lower subunit of medium gray, calcareous, coarse quartz siltite and an upper subunit of medium gray to black, fissile shale with minor interbedded silty quartzose sandstone and fossiliferous limestone (biomicrite).

The middle member is gradational with the lower member. The lower subunit is a series of interbedded pale green shales and brown to yellowish brown, silty orthoquartzites. The upper subunit consists of fine- to medium-grained orthoquartzite and minor shale. Hematite gives the upper subunit its purple color. Trace fossils and body fossils are common to abundant in the middle member.

The lower and middle members, with their abundant marine fossils, were deposited in an open-marine environment. The lower siltite subunit was deposited in shallow water under moderate energy conditions during transgression. Water depth perhaps increased nearly to effective wave base during deposition of the upper shale, limestone, and sandstone subunit of the lower member, and then gradually shallowed during progressive deposition of the interbedded shales and orthoquartzites of the lower subunit and then the orthoquartzites of the upper subunit of the middle member.

The upper member is a very fine- to medium-grained, clean, white orthoquartzite cemented by quartz overgrowths. It may be subdivided on the presence or absence of trace fossils. The first body fossils reported from the upper member are of the gastropod *Murchisonia* (*Hormotoma*) sp.

The Eureka Quartzite in western Utah is a very fine- to medium-grained, clean orthoquartzite cemented by quartz overgrowths. It is considered to be correlative with the upper member of the Swan Peak Formation in north-central Utah and southeastern Idaho.

Sources for Ordovician quartzites in the Cordilleran miogeosyncline were probably multiple. Although some of the quartz may have come from northern Alberta, areas in northwestern Montana and southeastern British Columbia appear to be a more likely source. Furthermore, sources in northeastern Utah probably also influenced sedimentary patterns in the miogeosyncline, perhaps to an important degree.

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APPENDIXES

APPENDIX A

FIGURES

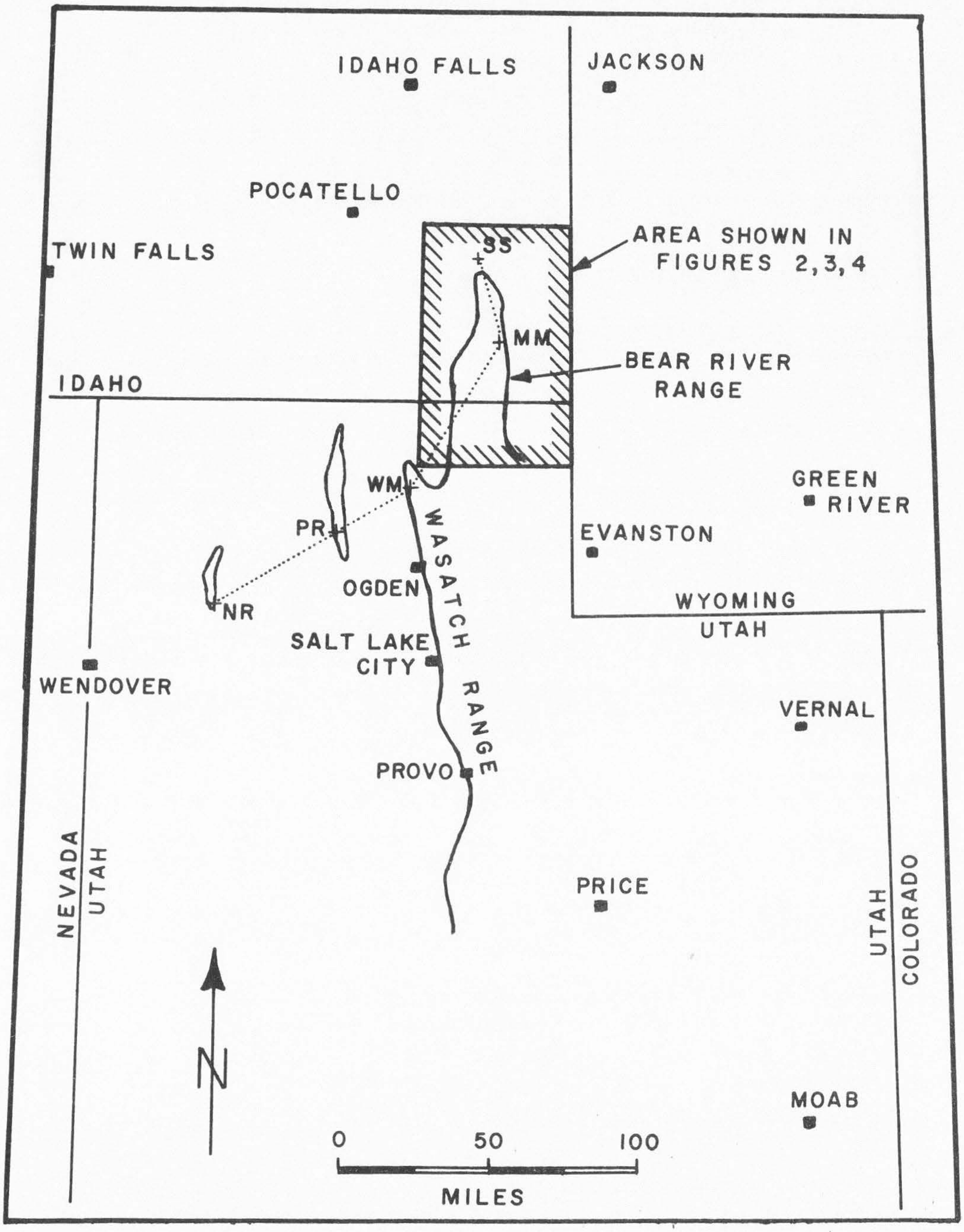


FIGURE I. INDEX MAP SHOWING AREA OF FIGURES 2, 3, & 4, AND LOCATIONS OF SECTIONS SELECTED FOR STUDY OF THIN-SECTIONS. SS = SODA SPRINGS; MM = MIDNIGHT MTN.; WM = WELLSVILLE MTN.; PR = PROMONTORY RANGE; NR = NEWFOUNDLAND RANGE.

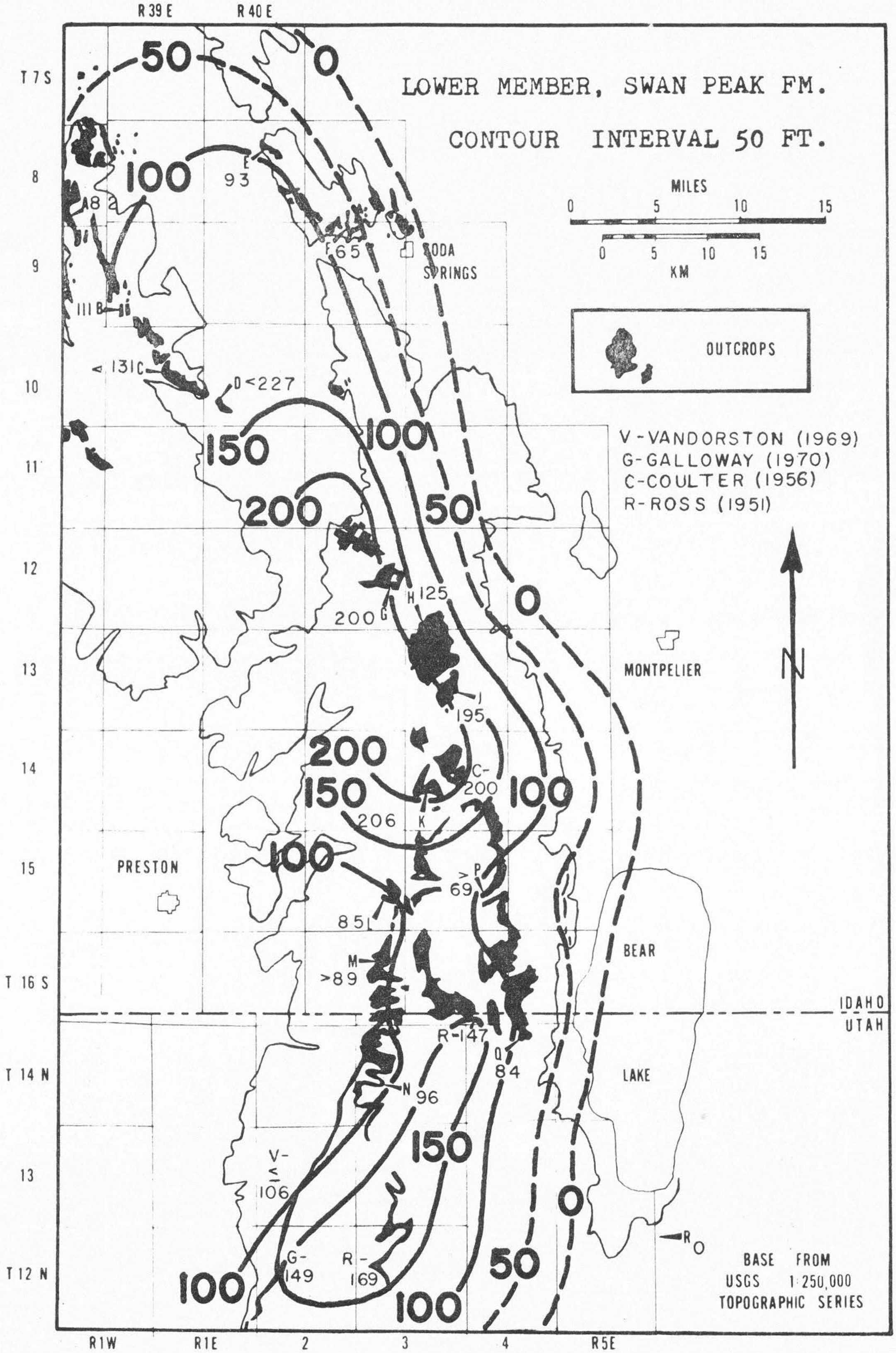


Figure 2. Map showing thickness of lower member, Swan Peak Formation, and locations of measured sections.

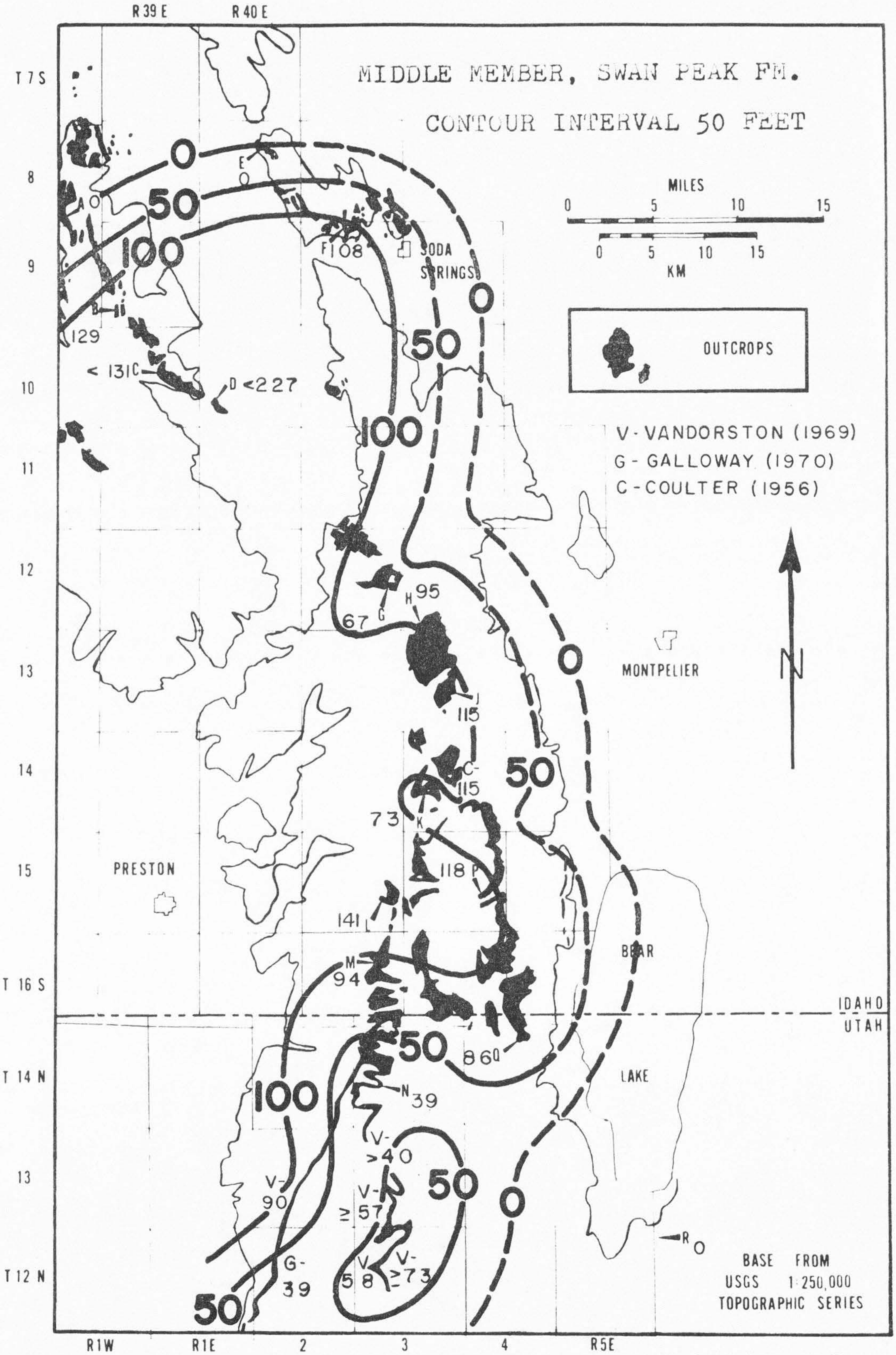


Figure 3. Map showing thickness of middle member, Swan Peak Formation, and locations of measured sections.

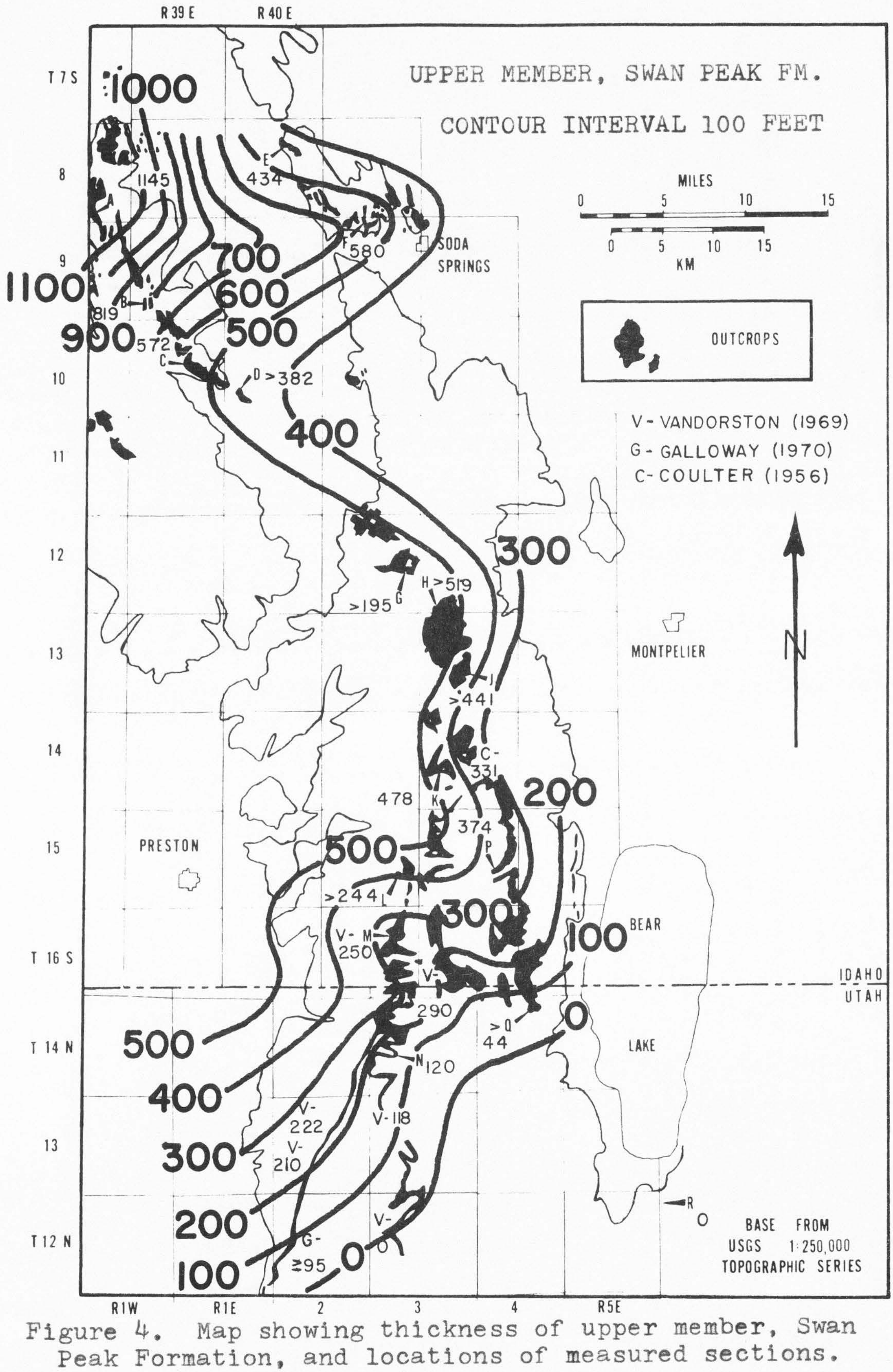


Figure 4. Map showing thickness of upper member, Swan Peak Formation, and locations of measured sections.

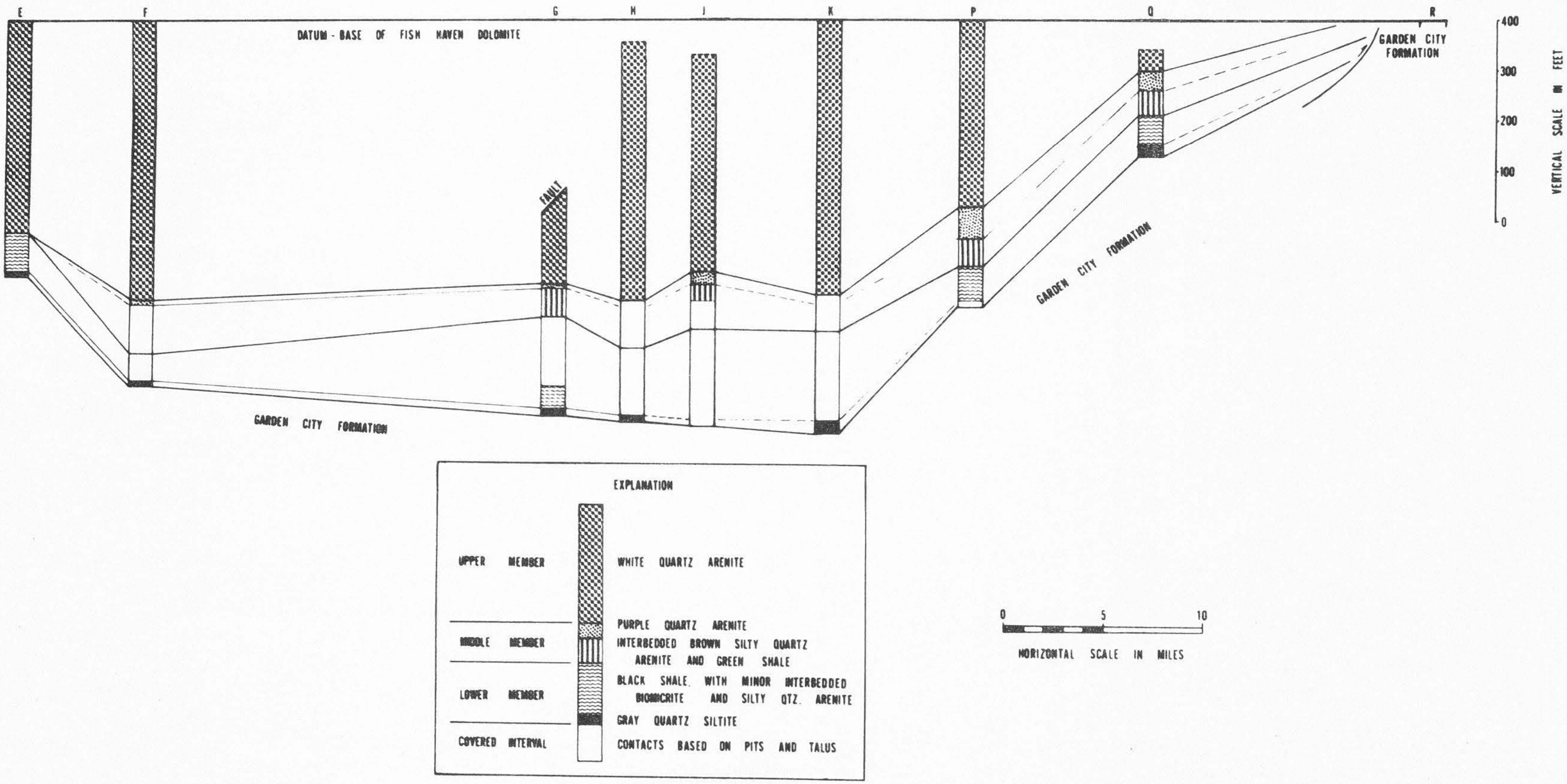


Figure 5. Physical correlation of distinct lithologic subunits in sections of the Swan Peak Formation, Soda Springs Hills and Bear River Range. Locations of sections shown in Figs. 2-4.

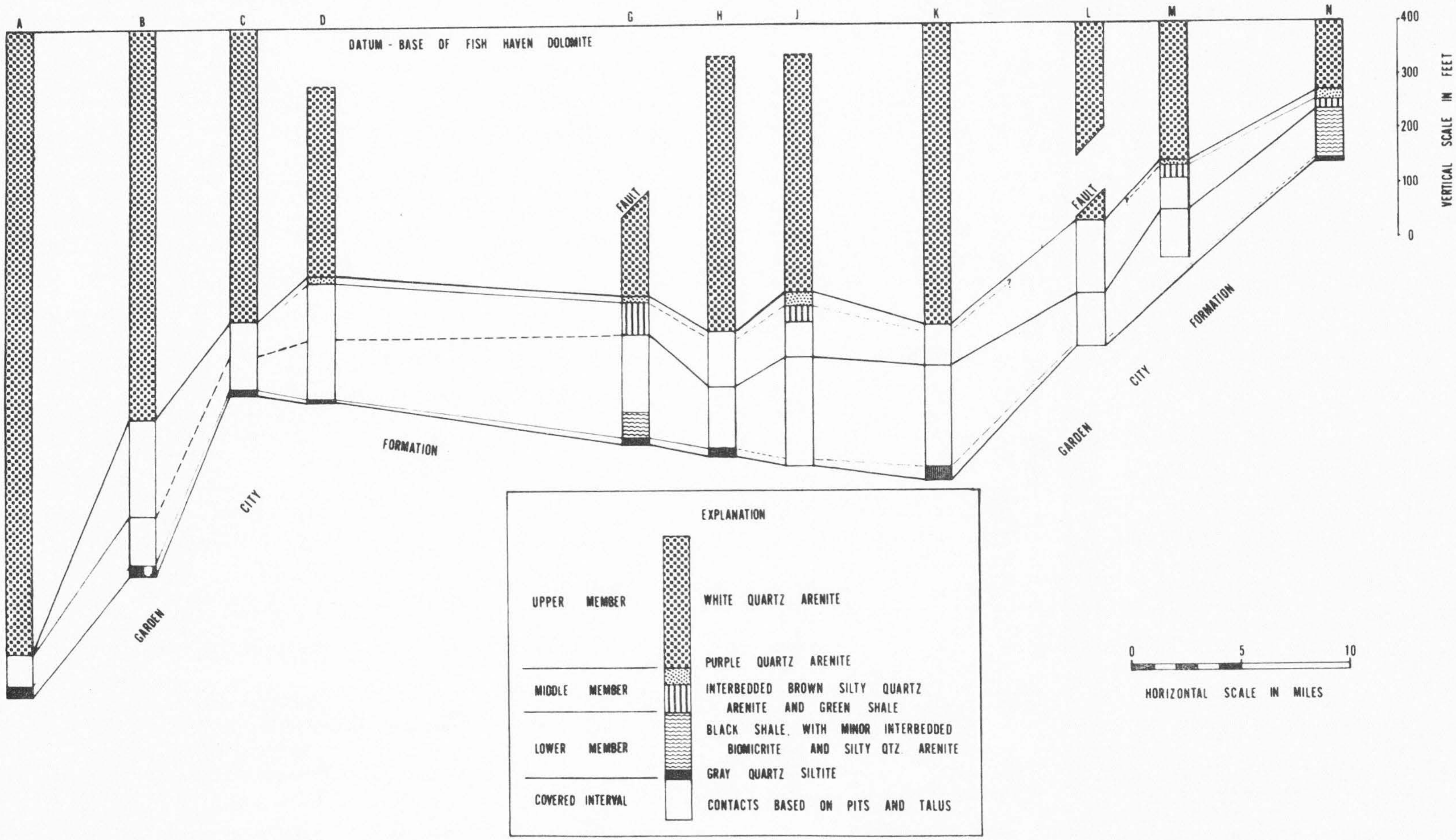


Figure 6. Physical correlation of distinct lithologic subunits in sections of the Swan Peak Formation, Fish Creek and Bear River Ranges. Locations of sections shown in Figs. 2-4.

APPENDIX B

PLATES

Plate 1. Swan Peak; view northwest from Garden City, Utah. This is the type locality of the Swan Peak Formation.

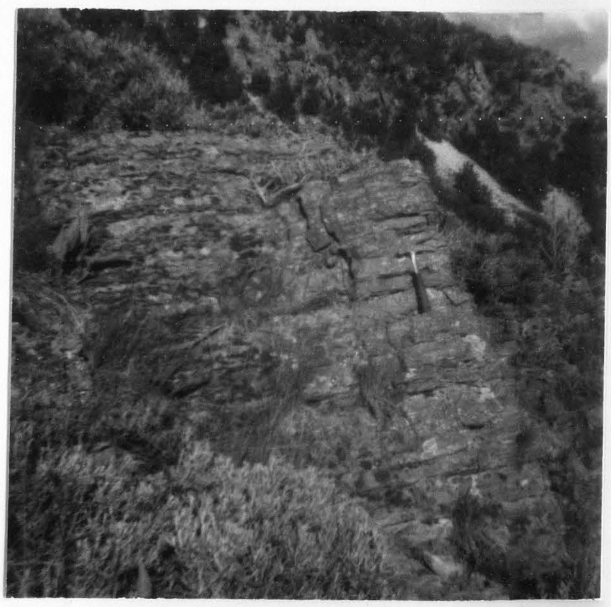


Plate 2. Lower subunit of the lower member, Section A. Hammer 10.5 inches long.

Plate 3. Black shale, upper subunit of the lower member, Section P.

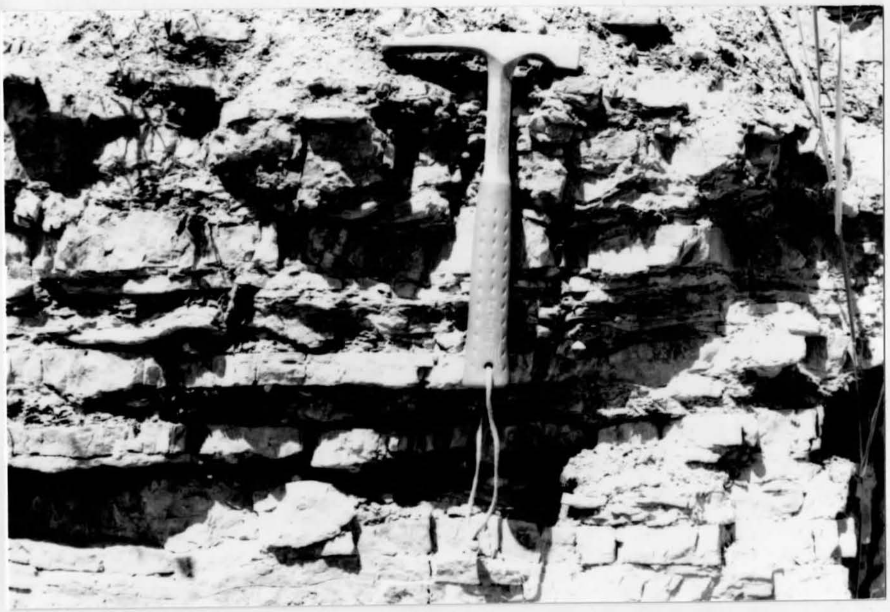


Plate 4. Interbedded orthoquartzite and shale, lower subunit of the middle member, Section P.

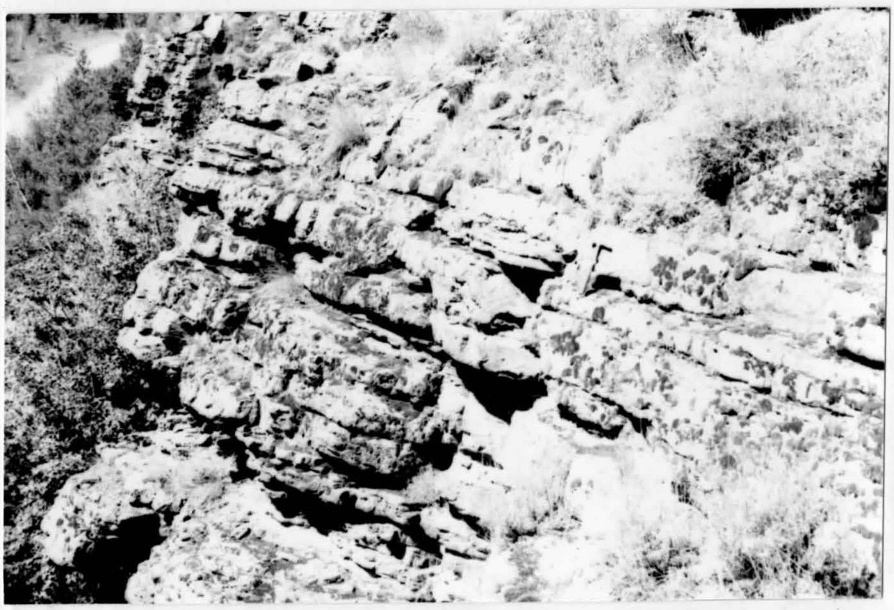


Plate 5. Purple orthoquartzite, upper subunit of the middle member, Section P.

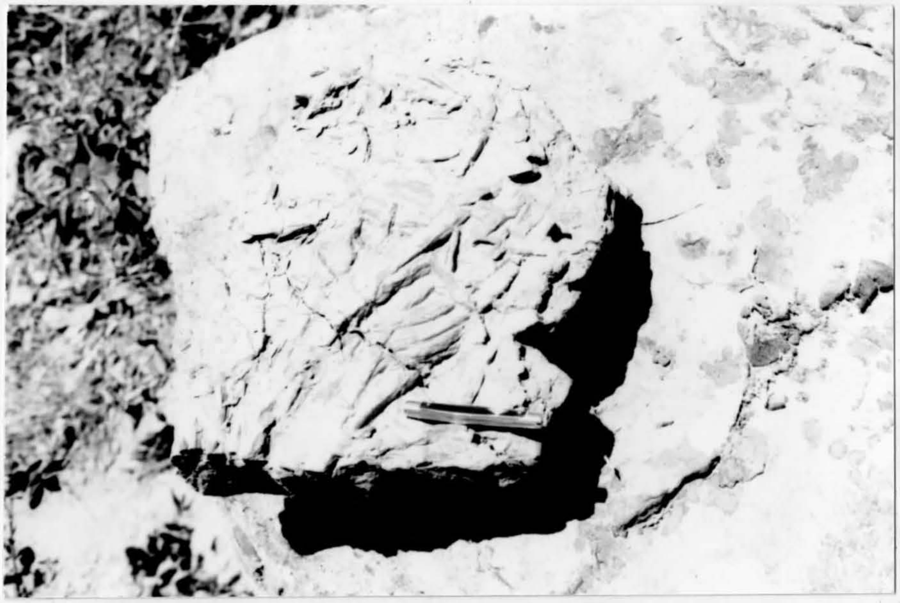


Plate 6. Annelidichnus (one type of "fucoid"), a common trace fossil in the middle member, Section P.

Plate 7. Mold of Protocycloceras debilis, an orthoconic cephalopod, in purple orthoquartzite of the middle member, Section Q.

Plate 8. White orthoquartzite, upper member, north end of Fish Creek Range.

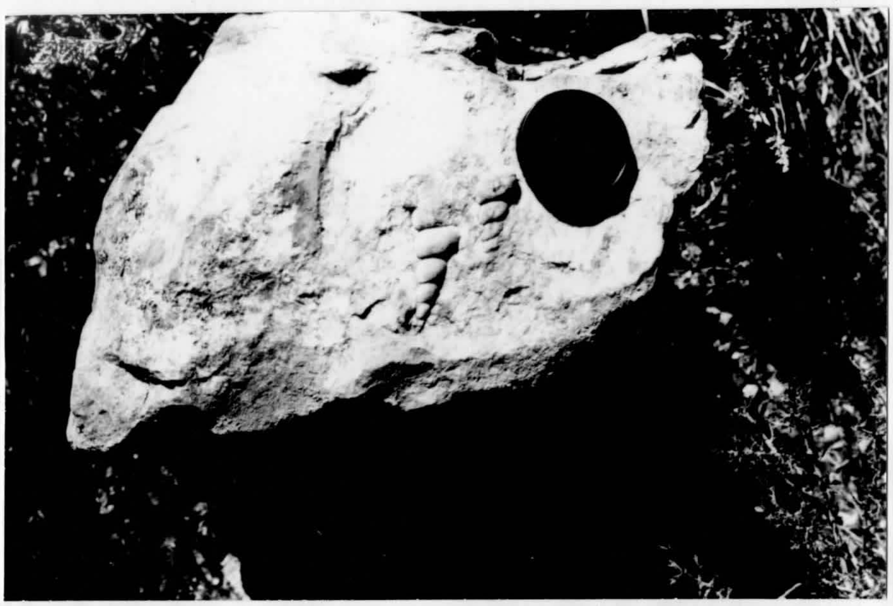


Plate 9. Gastropod Murchisonia (Hormotoma) sp. (probable internal mold), upper member, Section C. These are the first body fossils reported from the upper member. Lens cap indicates scale.

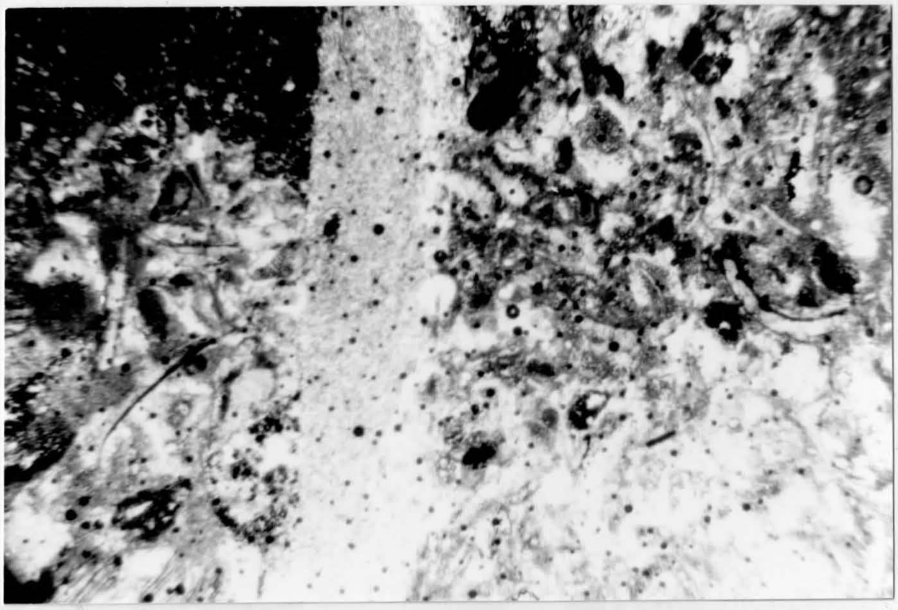


Plate 10. Limestone of the upper subunit of the lower member, Promontory Range (Section 2 of Francis, 1972). Ostracod shell in micrite matrix. Large brachiopod shell in center. Crossed nicols, 20 x.

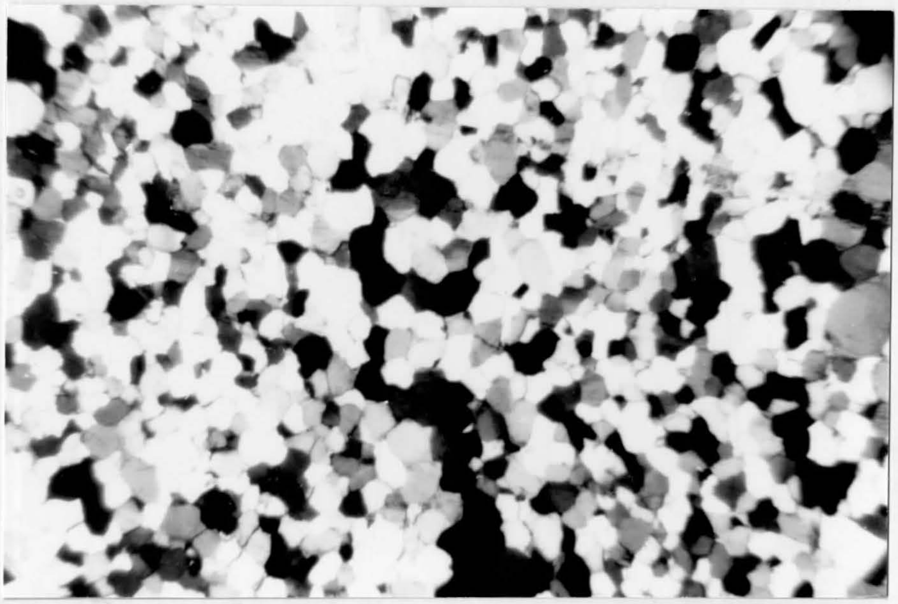


Plate 11. Interlocking quartz grains, brown orthoquartzite of the lower subunit of the middle member, Section J. Crossed nicols, 20 x.

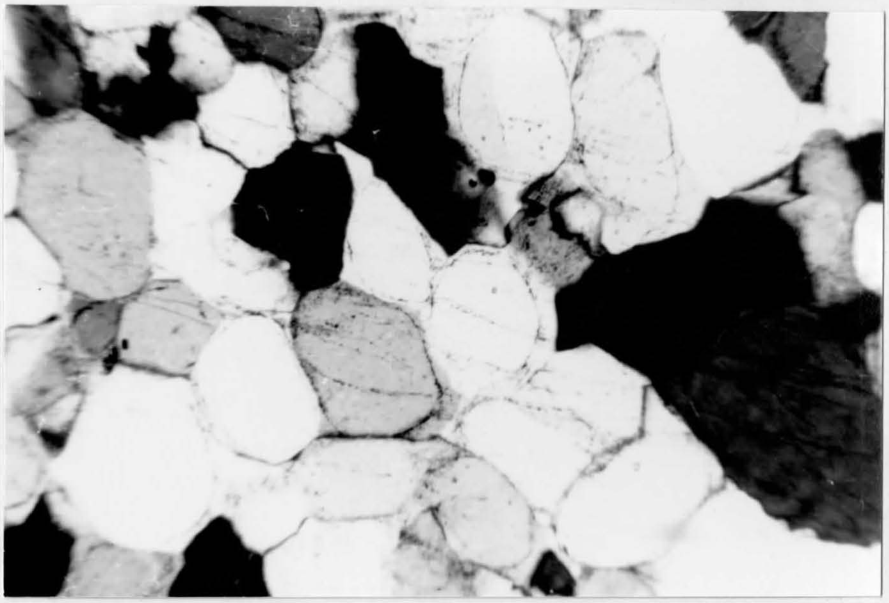


Plate 12. Well-rounded quartz grains with quartz overgrowths; same thin-section as Plate 11. Crossed nicols, 80 x.

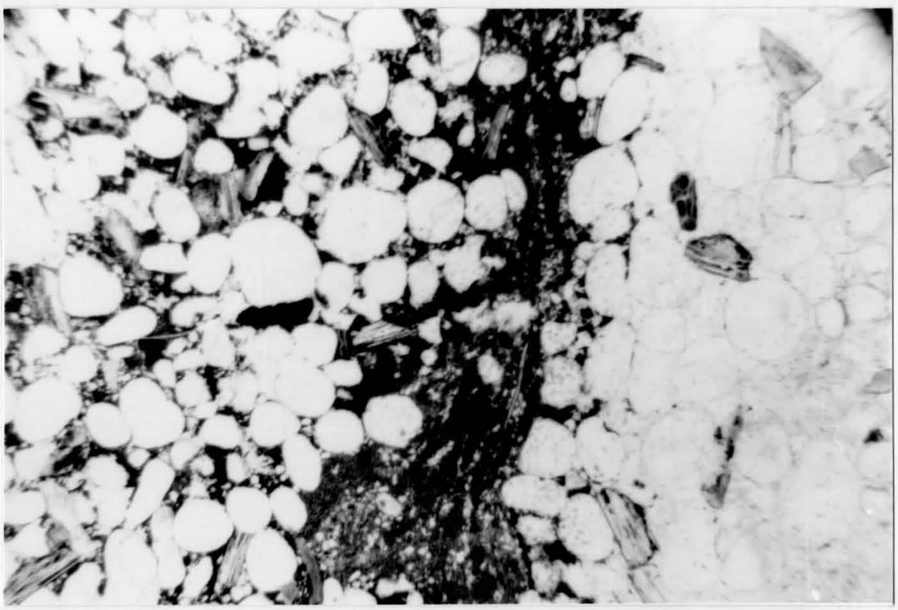


Plate 13. Hydroxylapatite in purple orthoquartzite of upper subunit of the middle member, Section J. Hydroxylapatite grains are platy; note well-rounded quartz grains with overgrowths on right. Uncrossed nicols, 20 x.

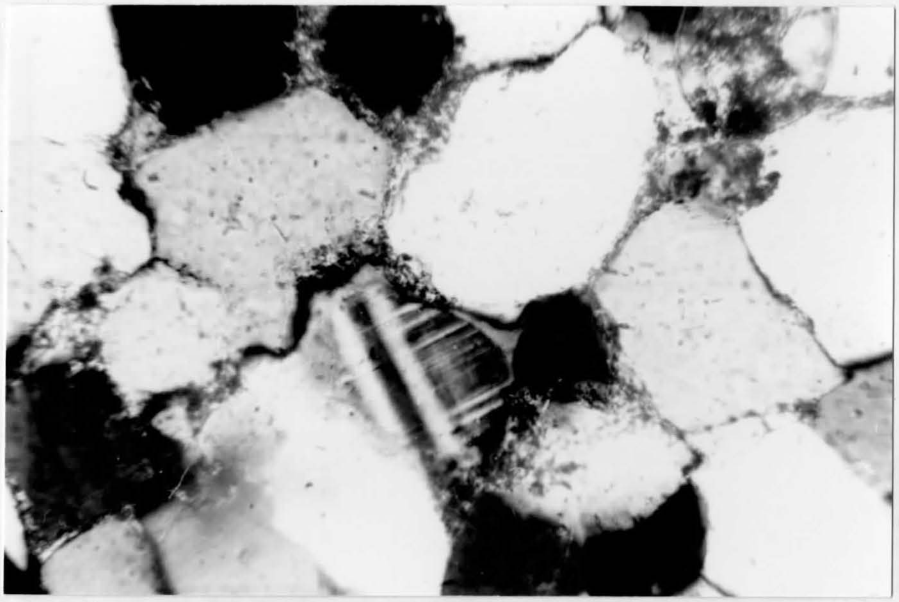


Plate 14. Feldspar grain and quartz with interstitial montmorillonite, lower subunit of the middle member, Section J. Crossed nicols, 80 x.

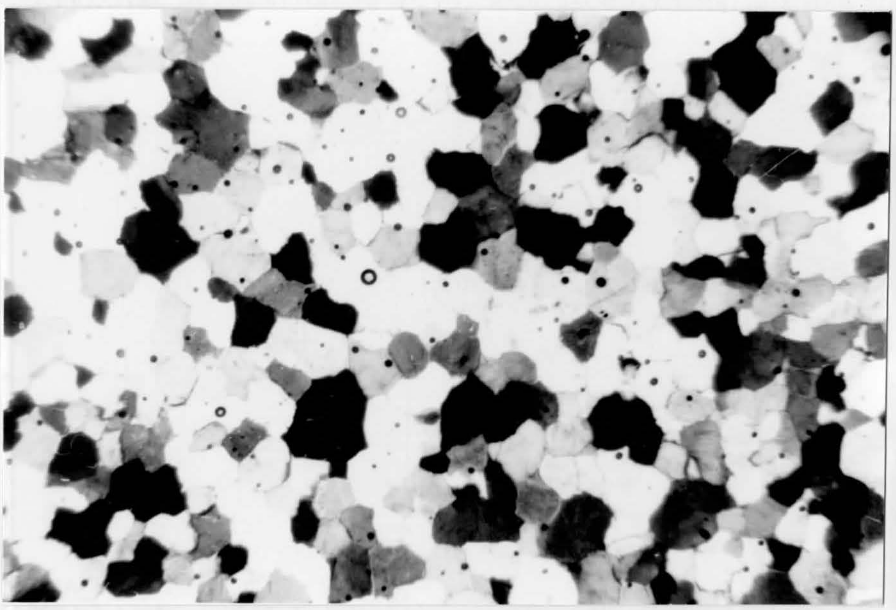


Plate 15. Interlocking overgrowths on rounded quartz grains, orthoquartzite of the upper member, Promontory Range (Section 6 of Francis, 1972). Crossed nicols, 80 x.

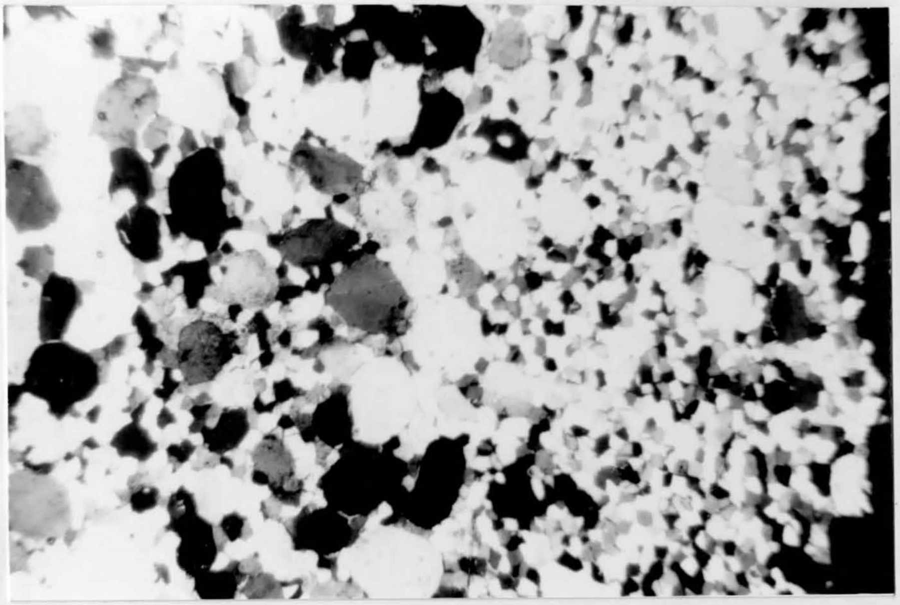


Plate 16. Two distinct grain sizes in Eureka Quartzite, Newfoundland Range (Section 6 of Francis, 1972). Crossed nicols, 80 x.

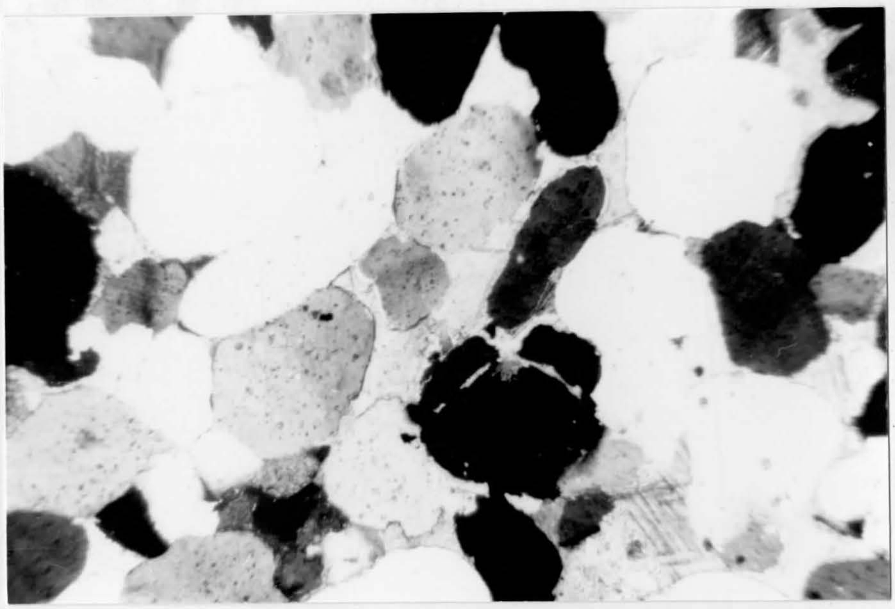


Plate 17. Quartz grains with dolomite cement, Eureka Quartzite, Newfoundland Range (Section 2 of Francis, 1972). Crossed nicols, 80 x.

APPENDIX C

TABLES

Table 1. Statistical parameters of the lower, middle, and upper members, Swan Peak Formation, and the Eureka Quartzite.

Location	Sample number	M_z	σ_I	Sk_I	Member	Subunit
Soda Springs (Section F)	118	2.39	0.520	+0.266		
	115	2.15	0.386	+0.095		
	114	2.15	0.438	+0.170	Upper	
	111	3.09	0.534	+0.057		
	108	3.17	0.595	+0.093		
	Avg.	2.59	0.455	+0.136		
	103	3.45	0.390	+0.362	Middle	Upper
	104	3.10	0.521	+0.109		Lower
	Avg.	3.28	0.456	+0.236		
	102	3.80	1.379	+0.550	Lower	Upper
	101	4.31	1.151	+0.312		Lower
	Avg.	4.06	1.265	+0.431		
Midnight Mountain (Section J)	A	2.43	0.370	+0.332		
	145	2.72	0.562	+0.228		
	22	2.59	0.410	+0.260	Upper	
	17	2.77	0.579	+0.141		
	15	2.80	0.458	+0.222		
	Avg.	2.62	0.476	+0.537		
	9	2.43	0.530	+0.180		Upper
	12	--	--	--	Middle	
	7	3.24	0.384	+0.070		
	4	--	--	--		
	Avg.	2.33	0.457	+0.225		
Wellsville Mountain (Francis, 1972, Section 7)	10	3.07	0.600	+0.202		
	27	2.64	0.496	+0.141	Upper	
	42	2.75	0.634	+0.070		
	45	--	--	--		
	Avg.	2.82	0.577	+0.293		
	72	3.10	0.575	--		
	91	3.43	0.503	+0.222	Middle	Lower
	110	--	--	--		
	Avg.	3.26	0.537	+0.222		

Table 1. Continued

Location	Sample number	M_z	σ_I	Sk_I	Member	Subunit
Promontory	14	2.22	0.352	+0.081		
Range	46	2.79	0.760	+0.267		
(Francis, 1972,	76	2.95	0.821	+0.392	Upper	
Section 6)	96	2.50	0.794	+0.280		
	146	2.91	0.655	+0.207		
	Avg.	2.62	0.676	+0.245		
Newfoundland	102	3.57	0.342	-0.122		
Range	74	2.50	0.444	+0.343		
(Francis, 1972,	45	2.51	0.375	+0.204	Eureka Quartzite	
Section 2)	37	2.55	0.467	+0.160		
	09	2.90	0.817	-0.514		
	Avg.	2.81	0.489	+0.071		

Table 2. Number of grains counted, mineralogies, quartz extinction types, grain roundness types, grain shapes, and cement or matrix minerals in thin-sections of the Swan Peak Formation and Eureka Quartzite.

Thin-section	Grains counted	Mineralogy, %	Quartz extinction types, %			Grain roundness types, %					Grain shapes, %			Cement; Matrix
			P	U	N	A	SA	SR	R	WR	E	SE	Bl	
SS-101	214	Q-54.6 T- 2.5 Z- 0.5 Ca-39.9 Cl- 2.5	10.0	56.7	33.3	10.1	42.1	38.0	8.9	0.9	56.8	0.9	42.3	Qtz. Ogr. Calcite
SS-102	194	Q-86.0 Z- 0.5 A- 0.5 Hy- 2.0 Cl-10.0 He- 1.0	7.5	58.8	32.7	0.0	46.6	41.9	11.5	0.0	59.2	5.2	35.6	Qtz. Ogr. Clay
SS-104	202	Q-97.5 Hy- 2.0 Fe- 1.5	1.6	71.4	27.0	0.5	20.6	32.4	43.0	3.5	62.5	5.0	32.5	Qtz. Ogr.
SS-103	200	Q-97.5 A- 0.5 Hy- 2.0	4.5	78.1	17.4	4.5	66.5	25.5	3.5	0.0	68.0	4.0	28.0	Qtz. Ogr.
SS-108	208	Q-94.3 T- 0.4 He- 2.9 L- 2.4	5.2	60.6	34.2	0.0	10.5	35.0	46.0	8.5	57.5	2.0	40.5	Qtz. Ogr. Iron ox.

Table 2. Continued

Thin-section	Grains counted	Mineralogy, %	Quartz extinction types, %			Grain roundness types, %					Grain shapes, %			Cement; Matrix
			P	U	N	A	SA	SR	R	WR	E	SE	Bl	
SS-111	207	Q-100.0	3.1	60.0	36.9	0.5	23.2	57.8	18.4	0.0	59.4	0.5	40.1	Qtz. Ogr.
SS-114	208	Q-100.0	18.0	41.2	40.8	1.0	16.3	70.2	12.5	0.0	69.2	1.0	29.8	Qtz. Ogr.
SS-115	208	Q-100.0	27.1	36.2	36.7	0.0	25.0	63.5	11.5	0.0	58.6	1.0	40.4	Qtz. Ogr.
SS-118	208	Q-100.0	16.3	49.2	34.5	1.0	14.4	69.2	14.9	0.5	29.8	34.5	35.6	Qtz. Ogr.
MM-4	207	Q- 83.5 Hy- 3.0 Fs- 2.0 Cl- 10.5 Fe- 1.0	12.7	82.0	5.3	0.0	2.3	81.1	16.6	0.0	27.2	44.5	28.3	Qtz. Ogr. Clay
MM-7	208	Q- 97.5 Fs- 1.5 Hy- 1.0	3.6	64.6	31.8	0.0	9.2	85.5	5.3	0.0	26.6	52.7	20.7	Qtz. Ogr.
MM-12	208	Q- 83.6 Ch- 0.5 Fs- 0.5 Cl- 15.4	5.7	39.3	55.0	0.0	20.7	68.4	10.9	0.0	20.5	57.3	22.2	Qtz. Ogr. Clay
MM-9	206	Q- 83.6 Hy- 8.3 He- 5.3	*	*	*	0.0	1.0	21.4	74.0	3.6	27.0	48.0	25.0	Qtz. Ogr. Hematite

Table 2. Continued

Thin-section	Grains counted	Mineralogy, %	Quartz extinction types, %			Grain roundness types, %					Grain shapes, %			Cement; Matrix
			P	U	N	A	SA	SR	R	WR	E	SE	Bl	
MM-15	206	Q-100.0	22.5	58.5	19.0	0.5	2.4	16.0	78.7	2.4	44.2	36.4	19.4	Qtz. Ogr.
MM-17	208	Q-100.0	16.7	70.0	13.3	1.0	3.9	56.7	38.4	0.0	46.7	29.3	24.0	Qtz. Ogr.
MM-22	208	Q-100.0	13.7	54.3	32.0	0.0	9.2	84.1	6.7	0.0	34.1	40.4	25.5	Qtz. Ogr.
MM-145	208	Q-100.0	14.2	69.4	16.4	0.0	4.3	88.5	7.2	0.0	35.1	39.9	25.0	Qtz. Ogr.
MM-A	207	Q-100.0	15.5	56.0	28.5	0.0	2.4	81.2	16.4	0.0	27.9	51.4	20.7	Qtz. Ogr.
WM-110	208	Q- 82.7 Fs- 0.5 Cl- 16.3 Fe- 0.5	0.0	71.6	28.4	0.0	1.7	94.2	4.1	0.0	12.7	71.7	15.6	Clay
WM-91	203	Q- 91.6 Fs- 2.4 A- 2.0 Cl- 3.0 Fe- 1.0	4.7	51.7	43.6	0.0	6.2	77.3	16.5	0.0	7.7	70.1	22.2	Qtz. Ogr. Clay Iron ox.
WM-72	207	Q- 86.5 Hy- 1.0 T- 0.5 Z- 0.5 Cl- 11.5	4.6	73.7	21.7	0.0	2.7	70.9	26.4	0.0	13.7	66.5	19.8	Clay

Table 2. Continued

Thin-section	Grains counted	Mineralogy, %	Quartz extinction types, %			Grain roundness types, %					Grain shapes, %			Cement; Matrix
			P	U	N	A	SA	SR	R	WR	E	SE	Bl	
WM-45	208	Q- 67.3 Cl- 32.7	8.6	65.5	25.9	0.0	5.0	59.7	34.5	0.8	33.8	42.5	23.7	Clay
WM-42	208	Q- 99.0 Fe- 1.0	7.6	63.9	28.5	0.0	0.5	63.1	35.9	0.5	13.6	68.9	17.5	Qtz. Ogr.
WM-27	208	Q-100.0	23.5	38.5	38.0	0.0	1.5	58.2	38.4	1.9	18.8	53.4	27.8	Qtz. Ogr.
WM-10	203	Q-100.0	8.2	43.7	48.1	0.0	4.0	56.1	38.9	1.0	24.1	49.3	26.6	Qtz. Ogr.
PR-146	208	Q- 98.5 Ca- 1.5	4.6	91.8	3.6	0.0	2.4	67.3	30.3	0.0	12.2	70.2	17.6	Qtz. Ogr. Calcite
PR-96	208	Q- 96.5 Ch- 0.5 Cl- 2.0 He- 0.5	1.6	98.4	0.0	0.0	1.0	80.7	18.3	0.0	10.4	63.4	26.2	Qtz. Ogr. Clay
PR-76	207	Q-100.0	5.5	77.0	17.5	0.0	0.5	56.0	43.5	0.0	23.7	57.0	19.3	Qtz. Ogr.
PR-46	208	Q- 99.5 Cl- 0.5	10.2	75.6	14.2	0.0	2.0	64.7	33.3	0.0	17.4	66.7	15.9	Qtz. Ogr.
PR-14	208	Q-100.0	13.4	48.0	38.6	0.0	0.0	41.4	54.3	4.4	25.0	55.3	19.7	Qtz. Ogr.

Table 2. Continued

Thin-section	Grains counted	Mineralogy, %	Quartz extinction types, %			Grain roundness types, %					Grain shapes, %			Cement; Matrix
			P	U	N	A	SA	SR	R	WR	E	SE	Bl	
NR-09	208	Q- 99.0 Fs- 0.5 Ca- 0.5	7.5	69.7	22.8	0.0	3.9	56.0	39.1	1.0	20.6	51.0	28.4	Qtz. Ogr.
NR-37	208	Q- 99.5 T- 0.5	13.7	82.7	3.6	0.0	7.2	85.1	7.2	0.5	18.7	68.8	12.5	Qtz. Ogr.
NR-45	208	Q-100.0	10.7	70.0	19.3	0.0	8.2	85.6	6.2	0.0	19.2	52.0	28.8	Qtz. Ogr.
NR-74	208	Q- 75.5 D- 24.5	9.7	52.0	38.3	0.0	1.3	12.1	48.4	38.2	26.1	51.0	22.9	Dolomite
NR-102	208	Q-100.0	3.1	74.3	22.6	0.0	0.0	82.7	17.3	0.0	14.9	66.3	18.8	Qtz. Ogr.

EXPLANATION OF SYMBOLS

Mineralogy

A-Apatite
Ca-Calcite
Ch-Chert
Cl-Clay
D-Dolomite
Fe-Iron oxides
Fs-Feldspar
He-Hematite
Hy-Hydroxylapatite
L-Limonite
Q-Quartz
T-Tourmaline
Z-Zircon

Quartz extinction types*

U-Undulatory
P-Polycrystalline
N-Non-undulatory
*-Not determined for MM-9

Roundness

A-Angular
SA-Subangular
SR-Subrounded
R-Rounded
WR-Well rounded

Shapes

E-Equant
SE-Subequant
Bl-Bladed or platy

Cement; Matrix

Qtz. Ogr.-Quartz overgrowths
Iron ox.-Iron oxides

Table 3. Averages of pertinent data in Tables 1 and 2.

Quartzite units	Mineralogy			Quartz Grains					Extinction types, %			Number of Samples
	% Qtz.	% Matrix		Orig. shape	Original roundness	Size range (mm)	Mean size (mm)	Sorting (phi)	N	U	P	
		Clays	Fe-oxide									
Eureka Quartzite	99	0.0	0.0	E-Bl	SR-WR	0.05-0.52	0.14	0.489	21	70	9	5
Swan Peak Fm. upper member	99	0.1	0.4	E-SE	SR-WR	0.03-0.55	0.16	0.546	27	61	12	18[a]
middle member upper subunit	92	0[b]	3	E-SE	SR-WR	0.02-0.53	0.13	0.460	17	78	5	2
middle member lower subunit	90	8	1	SE-Bl	R-WR	0.01-0.15	0.11	0.459	30	65	5	7
lower member upper subunit	86	10	1	E-Bl	SA-SR	0.03-0.20	0.07	1.379	33	59	8	1
lower member lower subunit	55[c]	3	0[c]	E-Bl	SA-SR	0.02-0.15	0.05	1.151	33	57	10	1

SAME SYMBOLS AS FIGURE 2

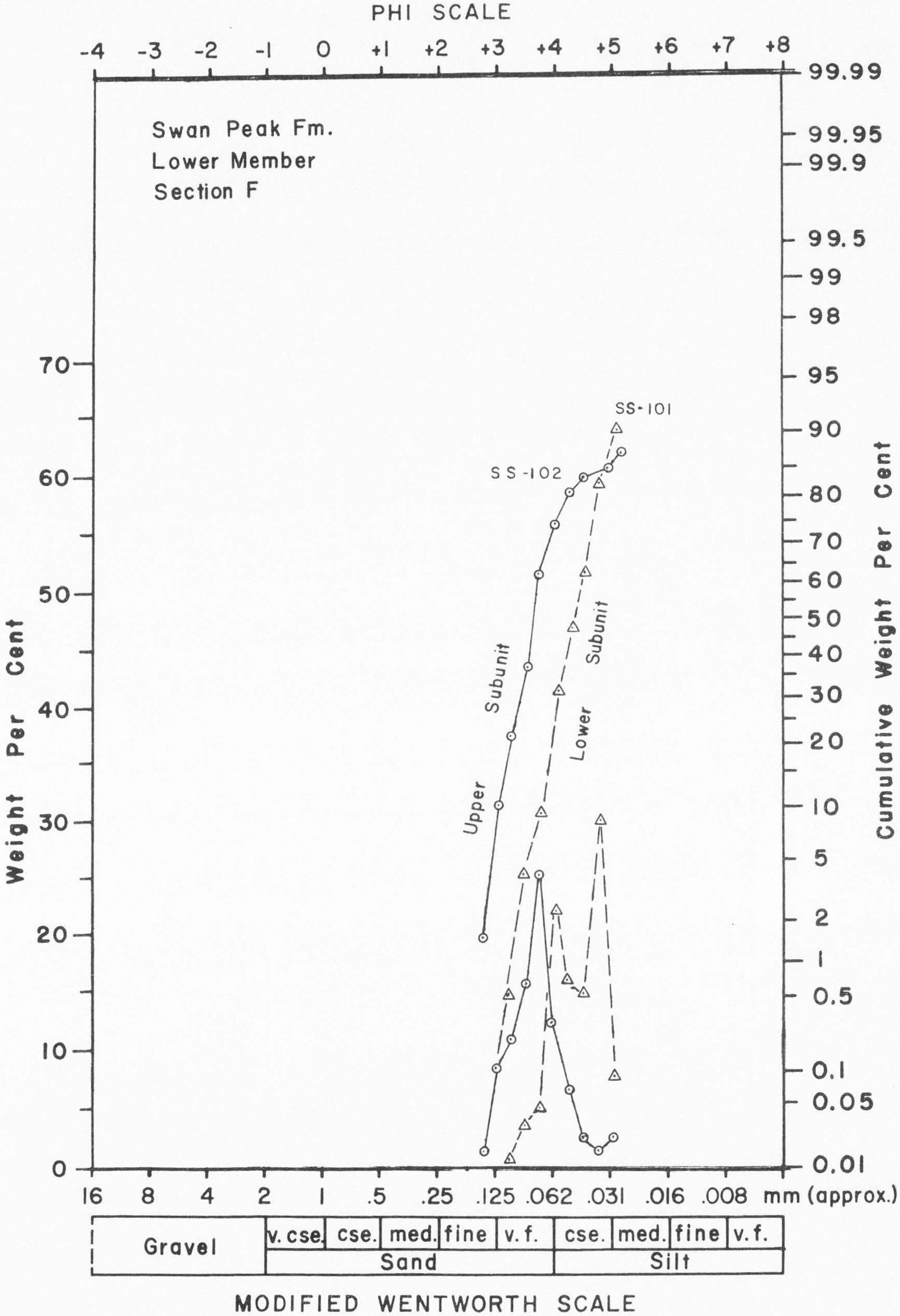
[a] One unusual sample with 33 percent clay (WM-45) was omitted from the averages.

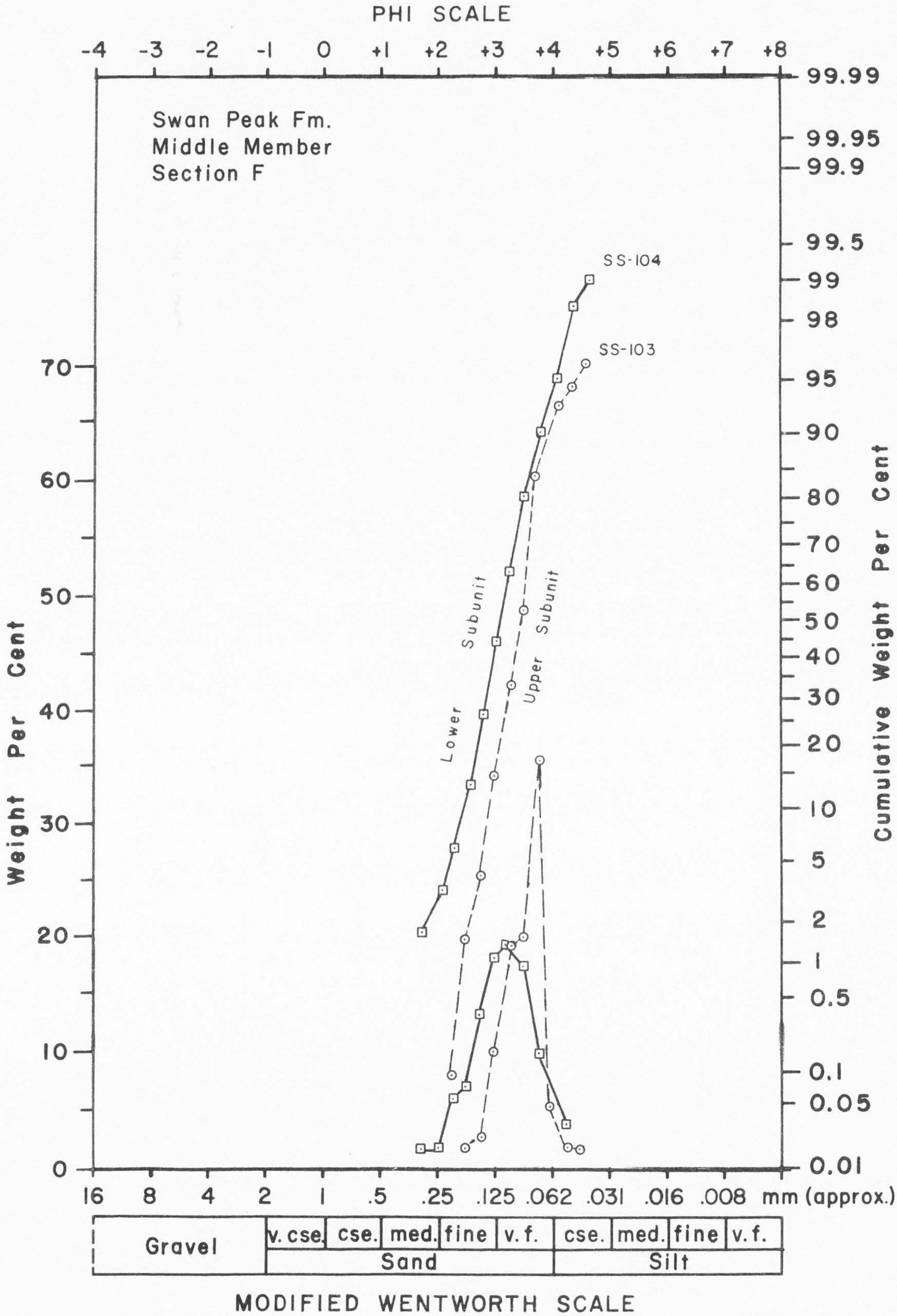
[b] Hand specimens and other thin-sections of this subunit contain up to 5 percent clay (est.).

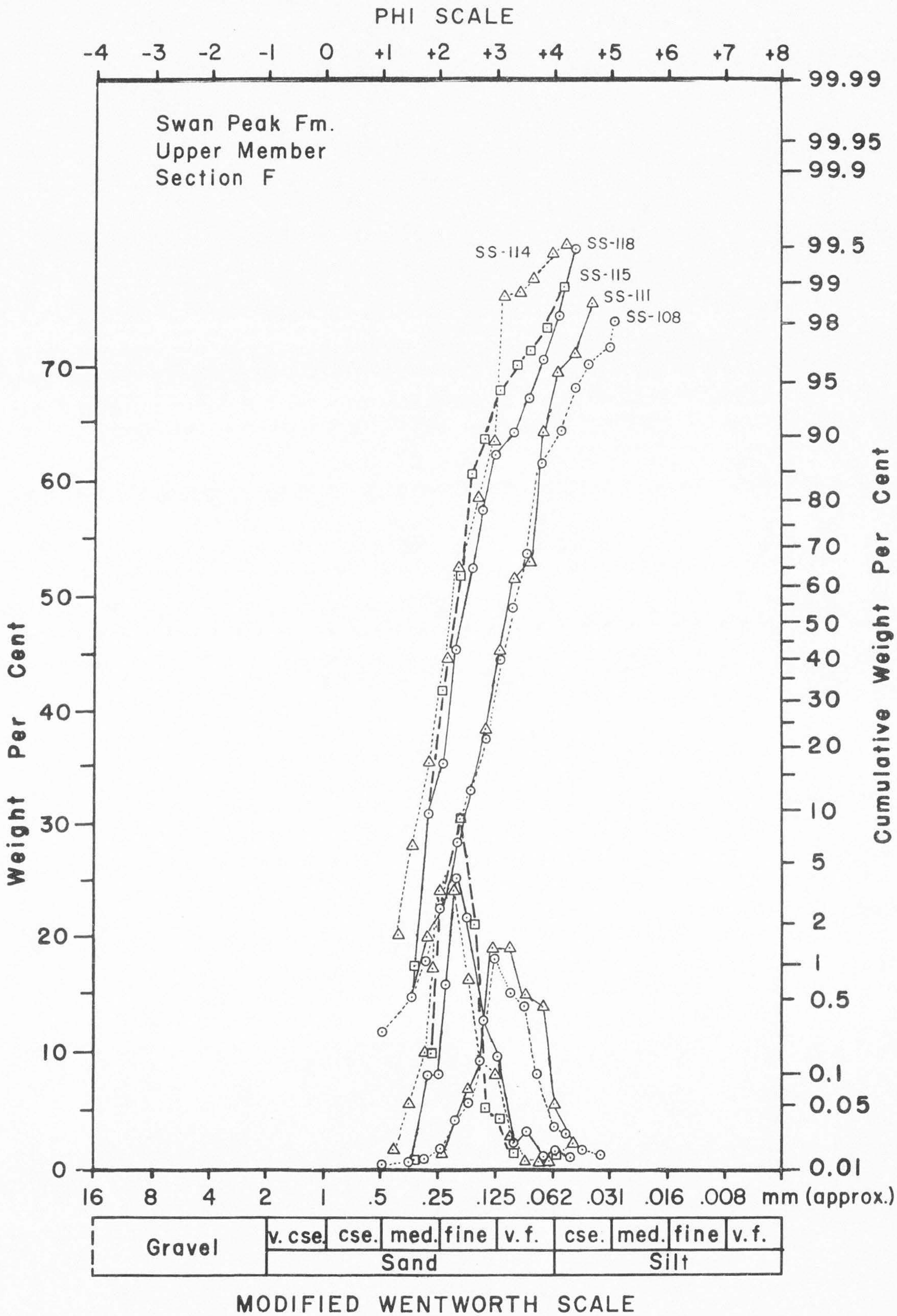
[c] Thin-sections from this subunit at other localities contain much higher percentages of quartz and iron oxides as overgrowths and matrix, respectively; in this sample, calcite was the predominant cement.

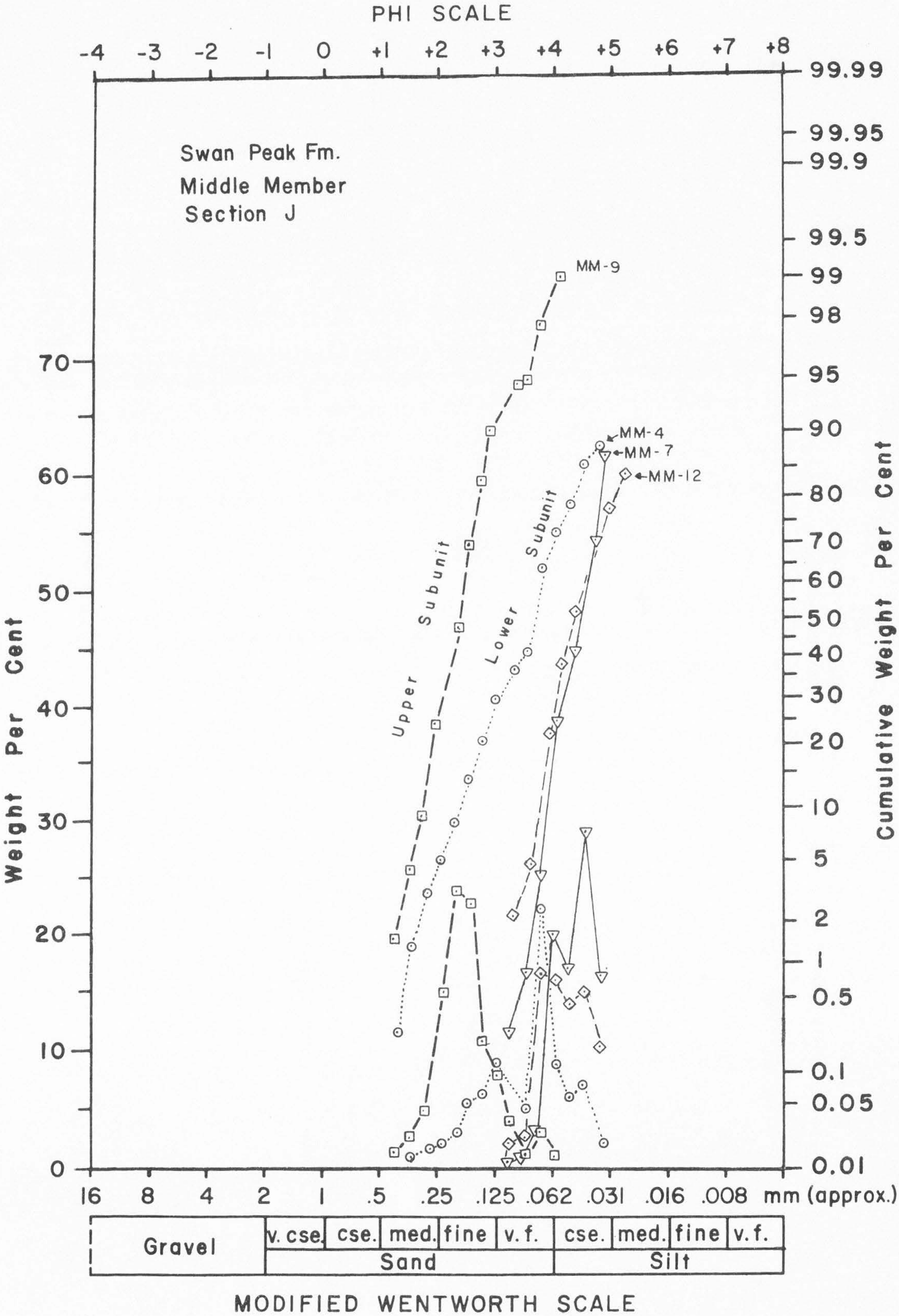
APPENDIX D

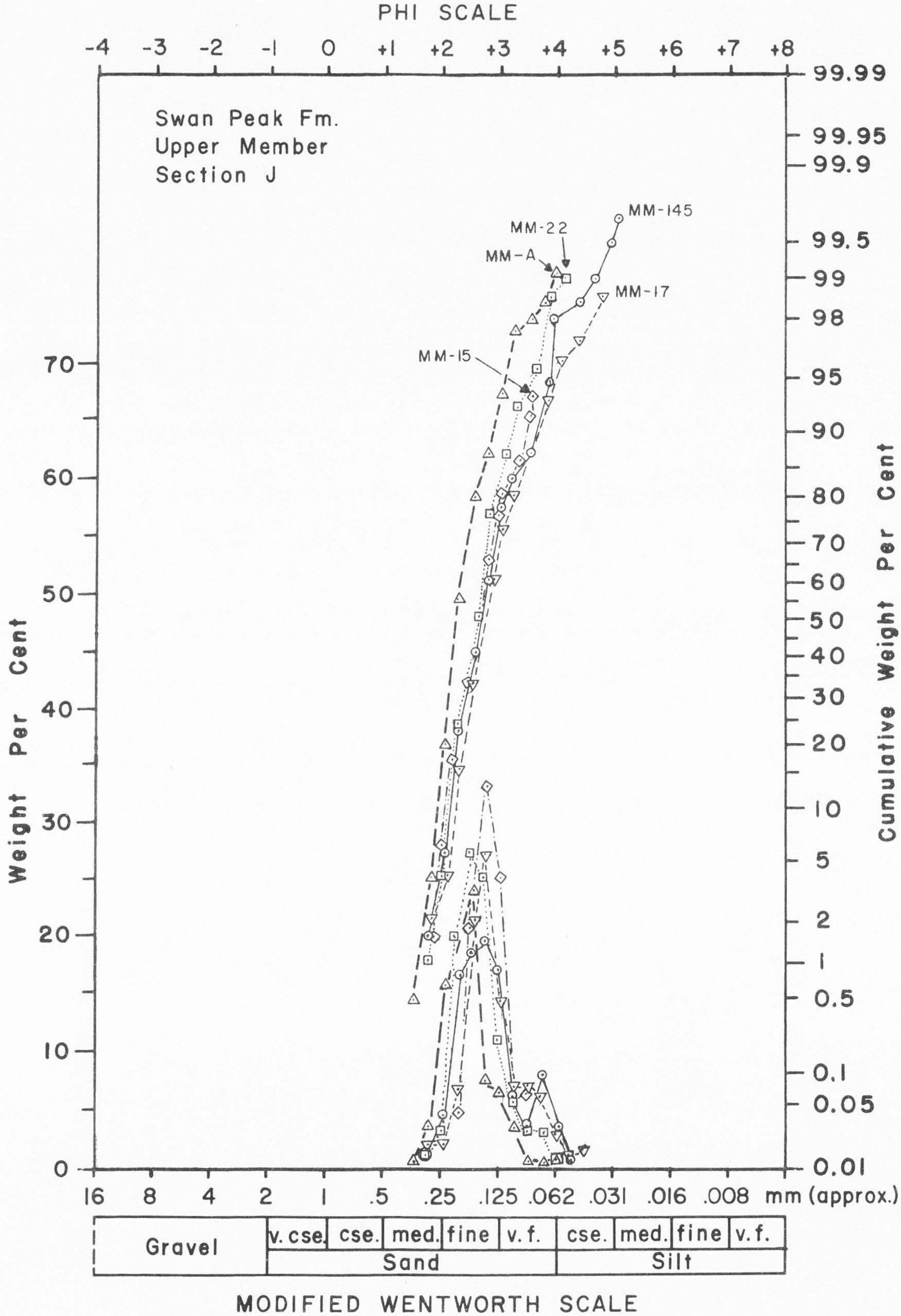
SIZE ANALYSES

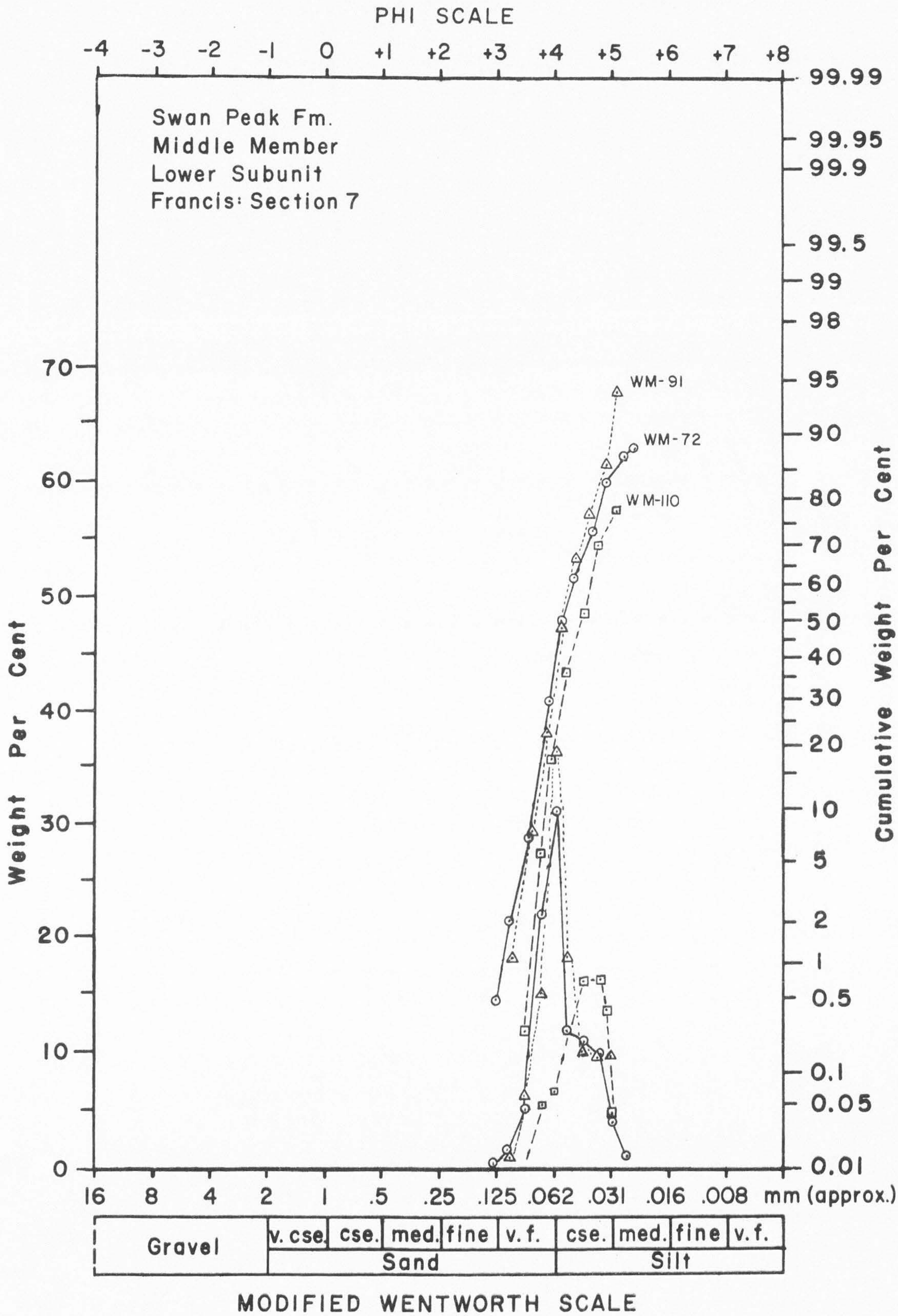

PHI SCALE
-4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8
Swan Peak Fm.
Lower Member
Section F
SS-101
SS-102
Upper Subunit
Lower Subunit
Weight Per Cent
0 10 20 30 40 50 60 70
Cumulative Weight Per Cent
0.01 0.05 0.1 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.9 99.95 99.99
16 8 4 2 1 .5 .25 .125 .062 .031 .016 .008 mm (approx.)
Gravel
v. cse. cse. med. fine v. f.
Sand
cse. med. fine v. f.
Silt
MODIFIED WENTWORTH SCALE

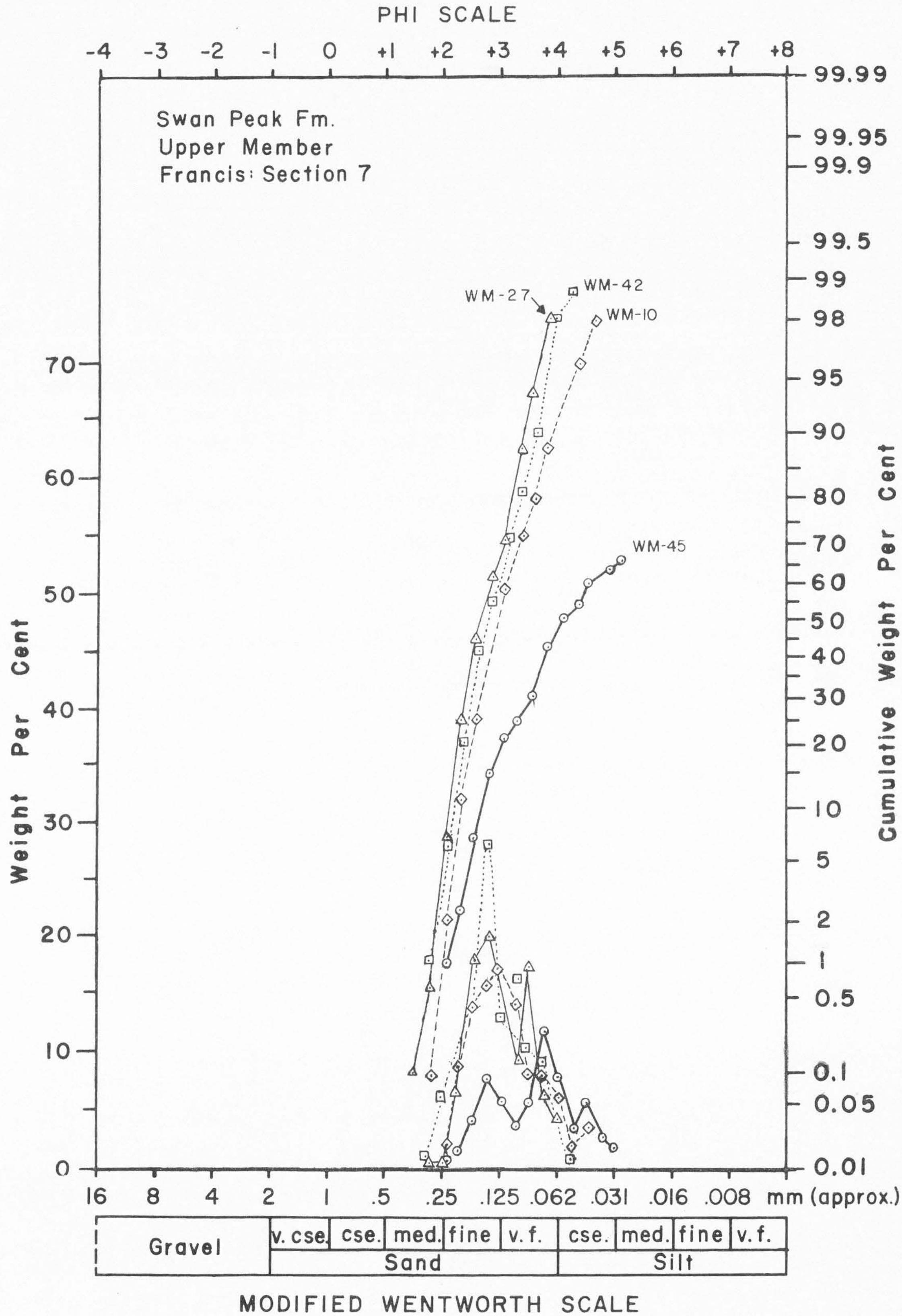

PHI SCALE
-4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8
Swan Peak Fm.
Middle Member
Section F
SS-104
SS-103
Lower Subunit
Upper Subunit
Weight Per Cent
0 10 20 30 40 50 60 70
Cumulative Weight Per Cent
99.99 99.95 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.1 0.05 0.01
16 8 4 2 1 .5 .25 .125 .062 .031 .016 .008 mm (approx.)
Gravel
v. cse. cse. med. fine v. f.
Sand
cse. med. fine v. f.
Silt
MODIFIED WENTWORTH SCALE


PHI SCALE
-4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8
Swan Peak Fm.
Upper Member
Section F
SS-114
SS-118
SS-115
SS-111
SS-108
Weight Per Cent
0 10 20 30 40 50 60 70
Cumulative Weight Per Cent
99.99 99.95 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.1 0.05 0.01
16 8 4 2 1 .5 .25 .125 .062 .031 .016 .008 mm (approx.)
Gravel
v. cse. cse. med. fine v. f.
Sand
cse. med. fine v. f.
Silt
MODIFIED WENTWORTH SCALE

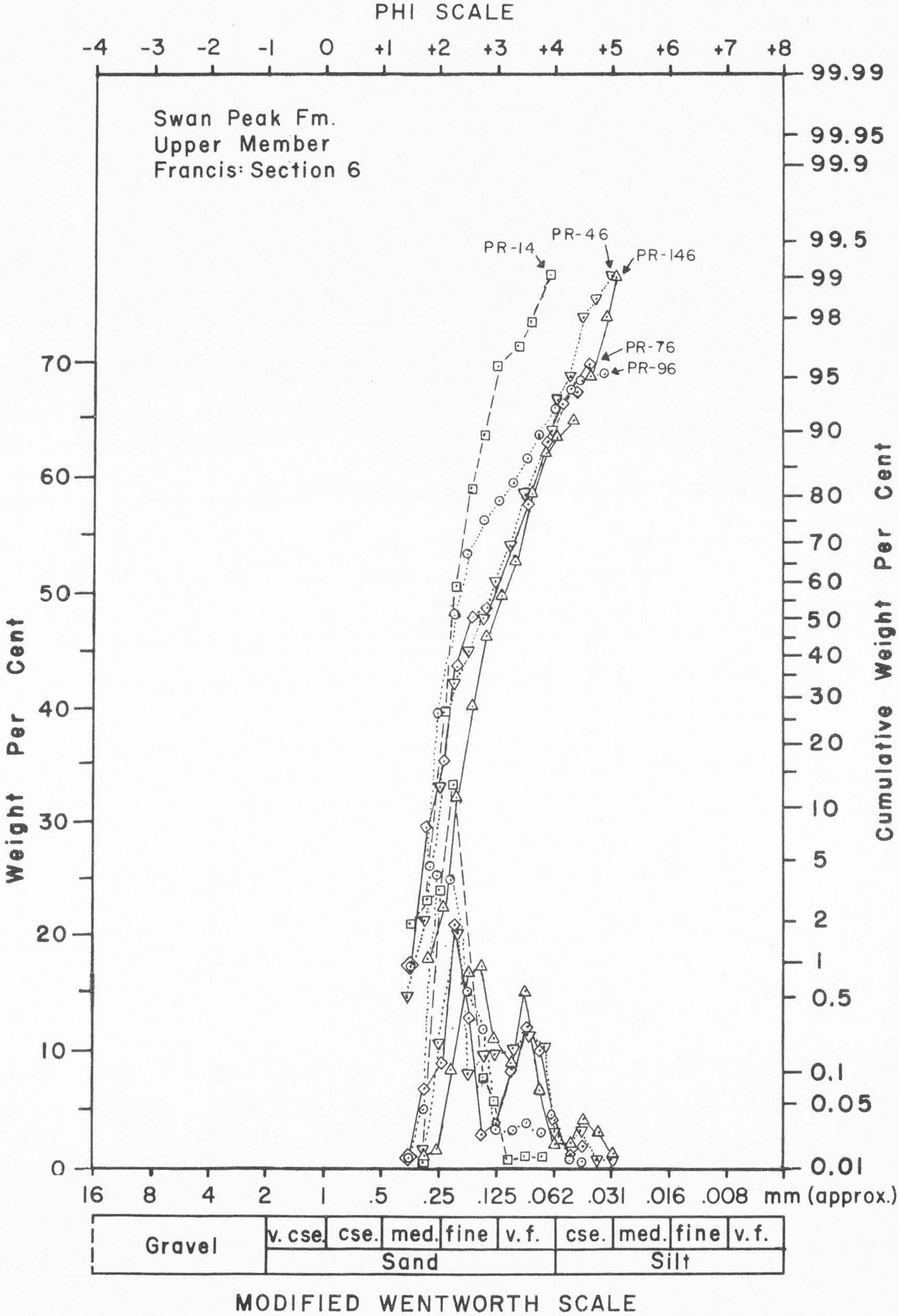

PHI SCALE
-4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8
Swan Peak Fm.
Middle Member
Section J
MM-9
MM-4
MM-7
MM-12
Upper Subunit
Lower Subunit
Weight Per Cent
0 10 20 30 40 50 60 70
Cumulative Weight Per Cent
99.99 99.95 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.1 0.05 0.01
16 8 4 2 1 .5 .25 .125 .062 .031 .016 .008 mm (approx.)
Gravel
v. cse. cse. med. fine v. f.
Sand
cse. med. fine v. f.
Silt
MODIFIED WENTWORTH SCALE

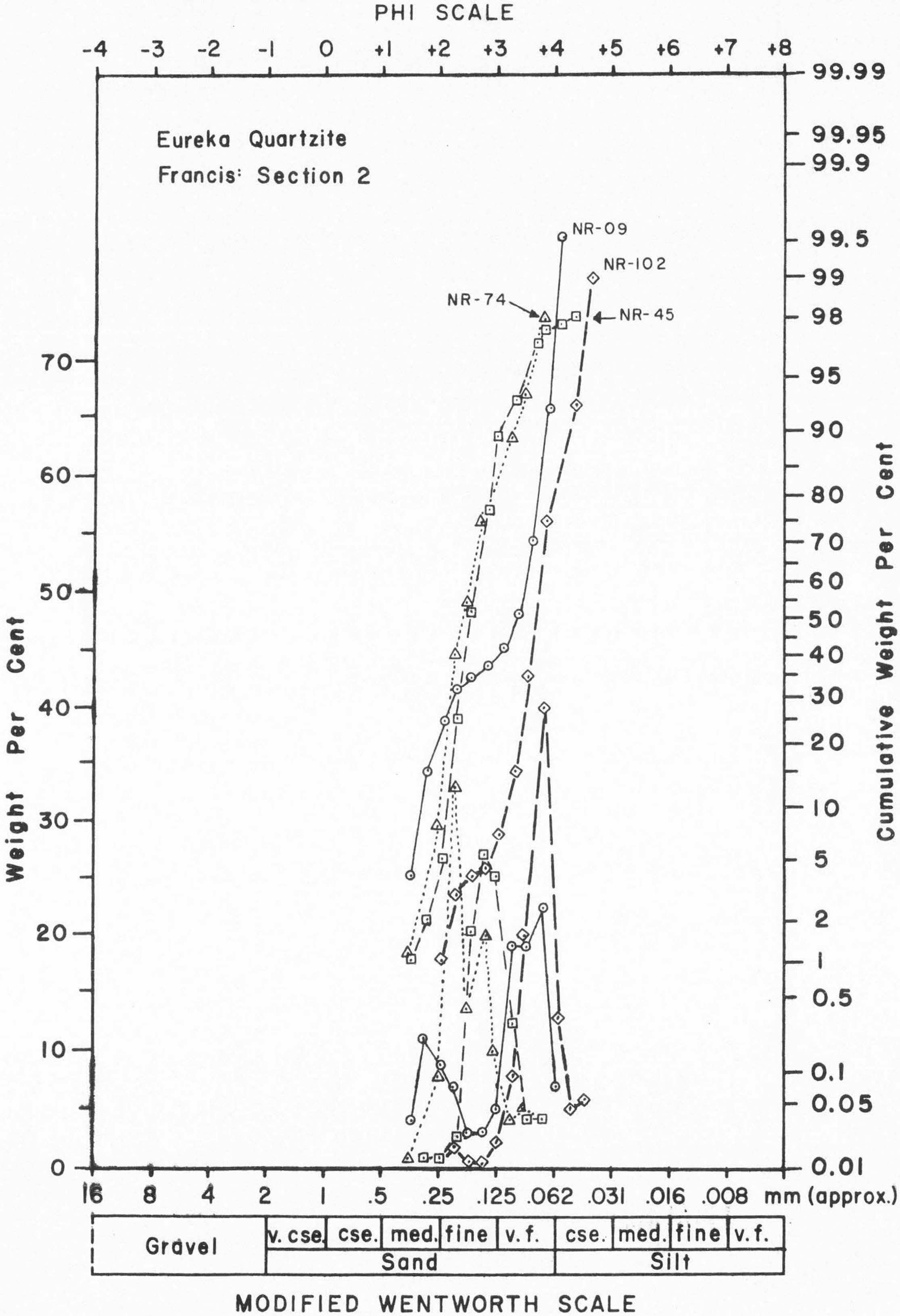

PHI SCALE
-4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8
Swan Peak Fm.
Upper Member
Section J
MM-145
MM-22
MM-A
MM-17
MM-15
99.99
99.95
99.9
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.1
0.05
0.01
Cumulative Weight Per Cent
Weight Per Cent
70
60
50
40
30
20
10
0
16 8 4 2 1 .5 .25 .125 .062 .031 .016 .008 mm (approx.)
Gravel
v. cse. cse. med. fine v. f.
Sand
cse. med. fine v. f.
Silt
MODIFIED WENTWORTH SCALE


PHI SCALE
-4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8
Swan Peak Fm.
Middle Member
Lower Subunit
Francis: Section 7
WM-91
WM-72
WM-110
Weight Per Cent
0 10 20 30 40 50 60 70
Cumulative Weight Per Cent
0.01 0.05 0.1 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.9 99.95 99.99
16 8 4 2 1 .5 .25 .125 .062 .031 .016 .008 mm (approx.)
Gravel
v. cse. cse. med. fine v. f.
Sand
cse. med. fine v. f.
Silt
MODIFIED WENTWORTH SCALE



PHI SCALE
-4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8
Swan Peak Fm.
Upper Member
Francis: Section 7
WM-27
WM-42
WM-10
WM-45
Weight Per Cent
0 10 20 30 40 50 60 70
Cumulative Weight Per Cent
99.99 99.95 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.1 0.05 0.01
16 8 4 2 1 .5 .25 .125 .062 .031 .016 .008 mm (approx.)
Gravel
v. cse. cse. med. fine v. f.
Sand
cse. med. fine v. f.
Silt
MODIFIED WENTWORTH SCALE


PHI SCALE
-4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8
Swan Peak Fm.
Upper Member
Francis: Section 6
PR-14
PR-46
PR-146
PR-76
PR-96
Weight Per Cent
0 10 20 30 40 50 60 70
Cumulative Weight Per Cent
99.99 99.95 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.1 0.05 0.01
16 8 4 2 1 .5 .25 .125 .062 .031 .016 .008 mm (approx.)
Gravel
v. cse. cse. med. fine v. f.
Sand
cse. med. fine v. f.
Silt
MODIFIED WENTWORTH SCALE


PHI SCALE
-4 -3 -2 -1 0 +1 +2 +3 +4 +5 +6 +7 +8
Eureka Quartzite
Francis: Section 2
NR-09
NR-102
NR-74
NR-45
Weight Per Cent
0 10 20 30 40 50 60 70
Cumulative Weight Per Cent
99.99 99.95 99.9 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.1 0.05 0.01
16 8 4 2 1 .5 .25 .125 .062 .031 .016 .008 mm (approx.)
Gravel
v. cse. cse. med. fine v. f.
Sand
cse. med. fine v. f.
Silt
MODIFIED WENTWORTH SCALE

APPENDIX E

MEASURED SECTIONS

SECTION A

Location: Ridge east of U. S. Highway 30N, in NE 1/4, Sec. 3, T. 9 S., R. 38 E., Bannock County, Idaho.

Fish Haven Dolomite

Swan Peak Formation
Upper Member

		Thickness, in feet
23.	Covered interval, to bottom of dip slope. Contact with Fish Haven Dolomite located by digging pits.	89
22.	Orthoquartzite; white; weathers light gray; fine-grained.	6
21.	Covered interval, small outcrops of white orthoquartzite with Laevicyclus.	56
20.	Orthoquartzite; white; weathers light gray; fine-grained; cross-laminae dip east; beds 0.3-1.0 ft. thick, average 0.6 ft.; beds are lenticular; Laevicyclus.	12
19.	Covered interval.	16
18.	Orthoquartzite; white; weathers light gray; fine- to medium-grained; parallel laminae; beds 0.4-0.9 ft. thick, average 0.6 ft.	33
17.	Covered interval.	70
16.	Orthoquartzite; white to light bluish gray; weathers light gray, locally, pale orange; fine-grained; parallel laminae; locally, near base of unit, high-angle, bottom-tangent cross-laminae dip southeast; probable interference ripples near top of unit; beds 0.3-0.9 ft. thick, average 0.7 ft.	77
15.	Mostly covered, small outcrops of orthoquartzite; white to light gray; weathers light gray, locally, pale orange to light brown; fine- to medium-grained; low-angle, bottom-tangent cross-laminae dip north; beds 0.3-1.2 ft. thick, average 0.8 ft.	123
14.	Orthoquartzite; white; weathers light gray; fine-grained.	5
13.	Covered interval.	140
12.	Orthoquartzite; very light gray; weathers light gray to pinkish gray; fine-grained; parallel laminae; scour 0.2 ft. deep, 4 ft. long; beds 0.4-1.1 ft. thick, average 0.8 ft.	95
11.	Covered interval.	25
10.	Orthoquartzite; white; weathers light gray, locally, grayish orange; fine-grained; small burrows abundant, large burrows rare; beds 0.2-0.6 ft. thick, average 0.3 ft.	39
9.	Mostly covered, small outcrops of orthoquartzite; very pale orange to grayish orange; weathers moderate to dark reddish brown; fine-grained; vertical burrows; beds 0.3-1.4 ft. thick, average 0.8 ft.	147

Section A. Continued

		Thickness, in feet
8.	Orthoquartzite; light gray; weathers light gray to white; fine-grained; vertical and curving burrows; beds 0.2-1.3 ft. thick, average 0.5 ft.	16
7.	Covered interval.	41
6.	Orthoquartzite; white; weathers light gray; *Laevicyclus* (?); beds 0.2-1.0 ft. thick, average 0.5 ft.	23
5.	Mostly covered, small outcrops of orthoquartzite; white; weathers light gray; beds 0.5-1.0 ft. thick, average 0.7 ft.	91
4.	Orthoquartzite; grayish orange; weathers moderate orange pink; fine-grained; low-angle, bottom-tangent cross-laminae dipping both to the north and to the southeast.	12
3.	Covered interval, pits have white orthoquartzite only. Contact based on pits.	29
	Total upper member	1145

Middle Member

Not present.

Lower Member
Upper Subunit

2.	Covered interval, pits reveal thick soil with shale beneath; shale is medium dark gray; weathers moderate olive gray.	62

Lower Subunit

1.	Siltite; medium dark gray; weathers medium gray to pale to moderate yellowish brown; very fine-grained; locally cherty; slightly calcareous; beds are both wavy parallel and lenticular, 0.2-0.5 ft. thick, average 0.3 ft.	20
	Total lower member	82

Total Swan Peak Formation 1227

Garden City Formation

SECTION B

Location: Large hill south of Fish Creek Road, on the west side of the Fish Creek Range, in NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 31, T. 9 S., R. 38 E., Bannock County, Idaho.

Fish Haven Dolomite

Swan Peak Formation

Upper member

		Thickness, in feet
13.	Orthoquartzite; white; weathers light gray; fine-grained; dip-slope; partially covered.	46
12.	Orthoquartzite; white; weathers very light gray, locally, pinkish gray; fine-grained; parallel laminae; beds 0.3-1.9 ft. thick, average 0.8 ft.	96
11.	Orthoquartzite; very light gray; weathers very light gray; fine-grained; near base of unit, sets of low-angle, bottom-tangent cross laminae dip to the east, southeast, and south; beds 0.7-2.6 ft. thick, average 1.5 ft.	107
10.	Orthoquartzite; white to very light gray; weathers light gray, locally, pale to moderate yellowish brown; fine-grained; beds 0.4-1.5 ft. thick, average 0.9 ft.	134
9.	Orthoquartzite; very light gray; weathers light gray; fine-grained; parallel laminae; "knobby" burrows weather in relief.	82
8.	Mostly covered, some small outcrops of orthoquartzite; white to very light gray; weathers light gray; fine-grained; beds 0.2-2.1 ft. thick, average 0.9 ft.	261
7.	Orthoquartzite; white; weathers very light gray; fine-grained; beds 0.4-0.9 ft. thick, average 0.8 ft.	22
6.	Partly covered, some small outcrops of orthoquartzite; white; weathers light gray; fine-grained; beds 0.2-1.4 ft. thick, average 0.6 ft.	45
5.	Covered interval.	22
4.	Orthoquartzite; yellowish gray to light gray; weathers yellowish gray; fine-grained; burrow-mottled; planar cross-laminae dip north; beds 0.3-1.1 ft. thick, average 0.7 ft.	4
	Total upper member	819

Middle Member

3.	Covered interval, pits reveal red and moderate yellowish brown sandstone fragments and greenish gray shale, sandstone predominates.	129
	Total middle member	129

Section B. Continued

	Thickness, in feet
Lower Member	
Upper Subunit	
2. Covered interval, pits reveal thick soil and minor yellow sandstone float. Probably shale beneath soil.	98
Lower Subunit	
1. Siltite; light gray to moderate yellowish orange; weathers dark yellowish orange; very fine-grained; slightly calcareous. Includes one foot covered interval at base.	13
Total lower member	111
Total Swan Peak Formation	1059

Garden City Formation

SECTION C

Location: Main ridge of the Fish Creek Range, north of Beaver Basin, in SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 15, and NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 22, T. 10 S., R. 39 E., Caribou County, Idaho.

Fish Haven Dolomite

Swan Peak Formation
Upper Member

		Thickness, in feet
15.	Orthoquartzite; white to very light gray; weathers light gray; fine-grained. Dip slope to contact with Fish Haven Dolomite.	15
14.	Orthoquartzite; white to light gray; weathers light gray; fine-grained; parallel laminae; low-angle, bottom-tangent cross-laminae dip northeast, southeast, northwest, and southwest; high-angle, planar, cross-laminae dip northwest; locally churned.	60
13.	Covered interval.	10
12.	Orthoquartzite; white to light gray; weathers light gray; fine-grained; parallel laminae; low-angle, bottom-tangent, southeast-dipping cross-laminae 25 ft. above base of unit.	100
11.	Covered interval.	63
10.	Orthoquartzite; white to light gray; weathers light gray; fine-grained; churned.	25
9.	Orthoquartzite; white to light gray; weathers moderate orange pink; fine-grained.	10
8.	Orthoquartzite; white to very light gray; weathers light gray; fine-grained; beds locally lenticular, 0.42-1.25 ft. thick, average 0.70 ft.; churned; vertical burrows up to 0.25 ft. long common, locally very abundant.	160
7.	Covered interval.	48
6.	Orthoquartzite; light gray; weathers pinkish gray; fine-grained; parallel laminae; hydroxylapatite.	5
5.	Covered interval.	30
4.	Orthoquartzite; yellowish gray to very pale orange; weathers grayish orange to moderate yellowish brown; parallel and wavy parallel laminae; low-angle, bottom-tangent, southeast-dipping cross-laminae; beds 0.15-0.35 ft. thick, average 0.25 ft.; heavily burrowed zone at base.	20
3.	Covered interval, contact approximate, projected from outcrops 300 feet to the north.	26
	Total upper member	572

Section C. Continued

Thickness, in feet

Middle and Lower Members

2. Covered interval, moderate reddish brown and dusky red purple orthoquartzite containing Orthambonites swanensis, Macluritella sp., Annelidichnus, and hydroxylapatite occurs in float on the surface. 121

Lower Member
Lower Subunit

1. Siltite; medium light gray; weathers pale reddish brown to dark yellowish orange; very fine-grained; slightly calcareous; beds very lenticular, 0.10-0.30 ft. thick, average 0.15 ft. 10

Total lower and middle members 131

Total Swan Peak Formation 703

Garden City Formation

SECTION D

Location: Southwest side of hill northwest of Cove Power Plant, extreme southern end of the Fish Creek Range, in SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 30, T. 10 S., R. 40 E., Caribou County, Idaho.

Top of section not exposed.

Swan Peak Formation

Upper Member

	Thickness, in feet
11. Orthoquartzite; white to light gray; weathers very light gray to light gray, locally, pale yellowish brown; fine-grained; parallel laminae; beds 0.10-2.40 ft. thick, average 0.84 ft.	43
10. Orthoquartzite; white to very light gray; weathers very light gray to light gray; fine- to medium-grained; wavy parallel laminae; southeast-dipping cross-laminae; beds 0.17-2.92 ft. thick, average 0.66 ft.	21
9. Orthoquartzite; white to light gray; weathers light gray to grayish orange, locally, moderate yellowish brown; fine- to medium-grained; beds 0.15-2.15 ft. thick, average 0.99 ft.	110
8. Orthoquartzite; yellowish orange to dark grayish orange; weathers grayish orange to light brown; medium-grained; parallel laminae; poorly indurated; beds 0.33-1.75 ft. thick, average 1.00 ft.	7
7. Orthoquartzite; yellowish orange; weathers very pale orange to grayish orange; fine-grained; vertical burrows; beds 0.33-2.00 ft. thick, average 0.85 ft.	29
6. Orthoquartzite; very light gray to grayish orange, locally dark yellowish orange; weathers light gray to grayish orange, locally, moderate yellowish brown; fine-grained; parallel laminae; locally, vertical burrows; beds 0.15-3.00 ft. thick, average 0.90 ft	63
5. Covered interval.	42
4. Orthoquartzite; white to very light gray; weathers light gray to grayish orange pink, locally, grayish brown; fine- to medium-grained; beds 0.50-3.00 ft. thick, average 1.28 ft.	12
3. Covered interval.	55
Total upper member exposed	382

Middle Member

Upper Subunit

2. Orthoquartzite; grayish red purple; weathers dusky red purple; fine- to medium-grained; current ripples in talus.	12

Section D. Continued

	Thickness, in feet
Middle and Lower Members	
1. Covered interval, near base of unit, talus of siltite; medium light gray; weathers moderate to dark yellowish brown; very fine-grained; wavy parallel laminae; Cruziana(?) (lower subunit of the lower member).	215
Total middle and lower members	227
Total Swan Peak Formation exposed	609

Garden City Formation

SECTION E

Location: Soda Springs Hills, one mile south of Tenmile Pass, in NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 10, T. 10 S., R. 40 E., Caribou County, Idaho.

Fish Haven Dolomite

Swan Peak Formation

Upper Member

		Thickness, in feet
10.	Covered interval, white to very light gray orthoquartzite in talus, no Laevicyclus.	29
9.	Mostly covered, Laevicyclus appears in talus of very light gray to light gray orthoquartzite which weathers light gray; fine-grained.	145
8.	Covered interval, talus of light gray orthoquartzite.	57
7.	Orthoquartzite; light gray; weathers dark yellowish orange; fine-grained; beds 0.6-1.3 ft. thick, average 0.9 ft.; Skolithos zone ends.	22
6.	Covered interval, talus of very light gray orthoquartzite; fine-grained.	117
5.	Mostly covered, some small outcrops of very light gray orthoquartzite; weathers light gray; fine-grained; beds 0.3-0.7 ft. thick, average 0.5 ft.; Skolithos.	5
4.	Mostly covered, some small outcrops of white orthoquartzite.	59
	Total upper member	434

Middle Member

Not present.

Lower Member

Upper Subunit

3.	Covered interval, pits contain dark gray to black shale.	8
2.	Covered interval, pits contain yellowish orange sandstone, probably shale also, rare Orthambonites sp.	66

Lower Subunit

1.	Siltite; light gray to grayish orange; weathers grayish orange to moderate red; very fine-grained; sandy; calcareous; includes one foot covered interval at base.	19
	Total lower member	93
	Total Swan Peak Formation	527

Garden City Formation

SECTION F

Location: Soda Springs Hills, 0.9 mile north of U. S. Highway 30N, in NW ¼, SE ¼, Sec. 4, T. 9 S., R. 41 E., Caribou County, Idaho.

Fish Haven Dolomite

Swan Peak Formation

Upper Member

	Thickness, in feet
7. Mostly covered, small outcrops of orthoquartzite; white; weathers light gray; fine- to medium grained; Sample SS-118 17 ft. below contact with Fish Haven Dolomite.	143
6. Orthoquartzite; white to light gray; weathers very light gray to light gray, locally, moderate to dark yellowish brown; fine- to medium-grained; parallel laminae; very low-angle, bottom-tangent, northeast-dipping cross-laminae in lower third of unit; Laevicyclus; SS-114 65 ft. above base of unit, SS-115 100 ft. above base of unit; partly covered in upper 40 ft.	169
5. Orthoquartzite; light gray to yellowish orange; weathers moderate olive gray to grayish orange; fine-grained; parallel laminae; very low-angle, bottom-tangent, south-dipping cross-laminae near middle of unit; beds 0.2-0.9 ft. thick; burrows rare near top of unit; SS-111 40 ft. from base of unit.	95
4. Mostly covered, small outcrops in place just above the contact are orthoquartzite; white to dark yellowish orange; weathers grayish orange to yellowish gray; fine-grained; SS-108 40 ft. from base of unit.	173
Total upper member	580

Middle Member

3. Covered interval, talus of light olive gray orthoquartzite containing Annelidichnus, hydroxylapatite, SS-103; and pale red purple orthoquartzite, SS-104.	108
Total middle member	108

Lower Member

Upper Subunit

2. Covered interval, talus of dark yellowish orange sandstone, SS-102, and dark bluish gray, coarse-grained, fossiliferous limestone.	55

Section F. C ntinued

	Thickness, in feet
Lower Subunit	
1. Siltite; medium gray; weathers moderate yellowish brown; very fine-grained; calcareous; SS-101.	10
Total lower member	65
Total Swan Peak Formation	753

Garden City Formation

SECTION G

Location: North side of Williams Canyon, in SE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 21, unsurveyed T 12 S., R. 41 E., Franklin County, Idaho.

Fault at bottom of dip slope; end of section.

Swan Peak Formation Upper Member	Thickness, in feet
10. Covered interval, scattered outcrops of grayish orange orthoquartzite; weathers grayish orange to moderate red; fine-grained. Dip slope at end of section.	67
9. Orthoquartzite; pale to dark yellowish orange; weathers grayish orange to dark yellowish orange; fine-grained.	29
8. Covered interval.	28
7. Orthoquartzite; white to very pale orange; weathers pinkish gray; fine-grained.	19
6. Covered interval, small outcrops of orthoquartzite; white to very pale orange; weathers dark grayish orange; fine-grained; vertical burrows common. Contact with middle member located by digging pits.	52
Minimum total upper member present	195
Middle Member Upper Subunit	
5. Orthoquartzite; grayish red purple to dusky red purple; weathers dusky red purple; fine- to medium-grained.	10
Lower Subunit	
4. Covered interval, pits reveal grayish green to dark yellowish orange orthoquartzite; fine-grained; and pale green, fissile shale.	57
Total middle member	67
Lower Member Upper Subunit	
3. Covered interval (thick vegetation).	105
2. Covered interval, pits reveal grayish olive to dark gray shale and minor dark yellowish orange to grayish orange sandstone with <u>Orthambonites</u> sp., <u>Leperditia</u> sp.	76

Section G. Continued

	Thickness, in feet
Lower Subunit	
1. Siltite; medium gray; weathers light olive gray; very fine grained; calcareous; irregularly bedded.	19
Total lower member	200
Minimum total Swan Peak Formation present	462

Garden City Formation

SECTION H

Location: Western slope of a small hill at the northern end of Copenhagen Basin, in NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 5, and NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 6, unsurveyed T. 13 S., R. 42 E., Franklin and Bear Lake Counties, Idaho.

Top of section removed by erosion.

Swan Peak Formation

Upper Member — Thickness, in feet

9. Orthoquartzite; white to pinkish gray; weathers light gray to grayish orange, locally, moderate orange pink; fine- to medium-grained; parallel laminae; locally churned; beds 0.15-1.00 ft. thick, average 0.45 ft. — 43
8. Covered interval, talus of very light gray orthoquartzite; weathers grayish orange pink; fine-grained. — 91
7. Orthoquartzite; white to very light gray; weathers very light gray to moderate orange pink; fine-grained; burrows common, 0.01-0.05 ft. wide, 0.05-0.12 ft. long; beds 0.15-1.55 ft. thick, average 0.75 ft. — 21
6. Covered interval, no talus of brown orthoquartzite as below; talus consists of large boulders of white, locally very light gray orthoquartzite; weathers light gray; fine-grained; churned; parallel laminae. <u>Laevicyclus</u> common in talus blocks in lower part of unit. Contact placed at a change in slope (becomes much steeper) and in vegetation. — 364

Total upper member present — 519

Middle Member

5. Covered interval, unit begins at a change in slope and in vegetation (slope becomes steeper). No outcrops, float of brown and purple orthoquartzite typical of the middle member elsewhere. — 95

Total middle member — 95

Lower Member

Upper Subunit

4. Covered interval; yellowish brown quartzite in float. — 87

Lower Subunit

3. Siltite; light gray; weathers moderate reddish brown to moderate red; very fine-grained; parallel bedded; beds 0.05-0.15 ft. thick, average 0.09 ft.; <u>Cruziana</u>(?). — 19

Section H. Continued

		Thickness, in feet
2.	Dolomite; light gray; and siltite; light gray; weathers moderate brown; very fine-grained; interbedded.	5
1.	Covered interval, contact placed at last talus of Garden City Formation; moderate brown-weathering siltite occurs as float.	14
	Total lower member	125
	Total Swan Peak Formation present	739

Garden City Formation

SECTION J

Location: Eastern slope of Midnight Mountain, in E ½, SE ¼, Sec. 21, unsurveyed T. 13 S., R. 42 E., Bear Lake County, Idaho.

Top of section faulted.

Swan Peak Formation
Upper Member

		Thickness, in feet
11.	Orthoquartzite; white to very light gray; weathers light gray; fine-grained; sample MM-A from top of unit.	97
10.	Covered interval.	39
9.	Orthoquartzite; white to very light gray; weathers light gray; fine- to medium-grained; large burrows; beds 0.80-0.88 ft. thick, average 0.83 ft.; sample MM-145 from 5 feet below top of unit.	50
8.	Orthoquartzite; white to very light gray; weathers light gray; fine- to medium-grained; parallel laminae; low-angle, bottom-tangent, east-dipping cross-laminae; churned; beds 0.25-1.05 ft. thick, average 0.68 ft.; partly covered; sample MM-22 from base of unit.	40
7.	Orthoquartzite; very light gray to very pale orange; weathers light gray to pinkish gray; fine-grained; parallel laminae; churned; "knobby" burrows; oscillation ripples, wave length 3.6 ft., amplitude 0.2 ft., in middle of unit; beds 0.25-2.20 ft. thick, average 0.87 ft.; sample MM-17 near base of unit.	60
6.	Covered interval, minor outcrops of very light gray orthoquartzite; weathers light gray; fine-grained; churned; beds 0.25-1.75 ft. thick, average 1.03 ft.	150
5.	Orthoquartzite; very light gray; weathers light gray; fine-grained; low-angle, bottom-tangent, southwest-dipping cross-laminae; simple, vertical burrows; sample MM-15 from top of unit.	5
	Total upper member present	441

Middle Member
Upper Subunit

4. Orthoquartzite; dusky red purple; weathers grayish red purple; fine- to medium-grained; and shale partings; pale green; minor white to moderate brown orthoquartzite; parallel and wavy parallel laminae; oscillation (?) ripples and southwest-migrating current ripples; Annelidichnus common on bottoms of some beds; hydroxylapatite; rare Orthambonites sp.; beds 0.10-0.50 ft. thick, average 0.23 ft.; lateral changes in beds common. Uppermost part of unit covered; green, brown and red shales occur

Section J. Continued

	Thickness, in feet
just below the contact with the upper member.	25
Lower Subunit	
3. Orthoquartzite; yellowish orange to yellowish brown, locally, light gray to greenish gray; weathers grayish orange to dusky yellow, locally light gray to greenish gray; very fine-grained; and shale; pale green; interbedded; wavy parallel laminae; churned; *Annelidichnus* abundant on the bottoms of some orthoquartzite beds; low-angle, bottom-tangent, northeast-dipping cross-laminae near top of unit; beds lenticular; 0.05-0.80 ft. thick, average 0.35 ft.	27
2. Covered interval, slope becomes steeper, and vegetation less dense, than in unit below.	63
Total middle member	115
Lower Member	
1. Covered interval, unit begins at highest limestone talus of the Garden City Formation. Thick soil and vegetation cover.	195
Total lower member	195
Total Swan Peak Formation present	751

Garden City Formation

SECTION K

Location: Southwestern slope of hill southwest of Paris Peak, in N $\frac{1}{2}$, SW $\frac{1}{4}$, Sec. 20, unsurveyed T. 14 S., R. 42 E., Bear Lake County, Idaho.

Fish Haven Dolomite

Swan Peak Formation

Upper Member

		Thickness, in feet
10.	Orthoquartzite; white to light gray; weathers light gray to yellowish gray; fine- to medium-grained; very well developed low-angle, bottom-tangent, southeast-dipping cross-laminae in middle of unit; beds 0.1-1.8 ft. thick, average 0.8 ft.; Laevicyclus common.	22
9.	Covered interval.	11
8.	Orthoquartzite; white to very light gray; weathers light gray, locally, orange brown; fine-grained; parallel and wavy parallel laminae; low-angle, bottom-tangent, east- and northeast-dipping cross-laminae; simple horizontal burrows; beds 0.8-3.4 ft. thick, average 1.8 ft.; Laevicyclus.	85
7.	Orthoquartzite; white to very light gray, locally, grayish orange; weathers light gray, locally, grayish orange; parallel laminae; low-angle, bottom-tangent, south-dipping cross-laminae in lower half of unit; Laevicyclus common to abundant; beds 0.30-1.60 ft. thick, average 0.88 ft.	85
6.	Covered interval, thick vegetation, large talus blocks of very light gray orthoquartzite containing Laevicyclus.	186
5.	Orthoquartzite; very light gray to light gray; weathers light gray to grayish orange; fine-grained; parallel laminae; locally churned; vertical protection burrows common; beds 1.15-2.50 ft. thick, average 1.50 ft.	52
4.	Covered interval, vegetation becomes thicker than in unit below, no talus of brown or purple orthoquartzite.	37
	Total upper member	478

Middle Member

3.	Covered interval, unit begins at a change in slope and in vegetation, abundant float of moderate brown and dusky red purple orthoquartzite similar to middle member orthoquartzites elsewhere, Annelidichnus common.	73
	Total middle member	73

Section K. Continued

	Thickness, in feet
Lower Member	
Upper Subunit	
2. Covered interval, thick soil, light red orthoquartzite in float, fragments of Eleutherocentrus petersoni occur occasionally.	173
Lower Subunit	
1. Covered interval, talus of medium gray siltite, weathers moderate yellowish brown to moderate red, similar to lower subunit of the lower member elsewhere.	33
Total lower member	206
Total Swan Peak Formation	757

Garden City Formation

SECTION L

Location: Ridge near the head, and along the southwest side, of Hilyards Canyon, in SE $\frac{1}{4}$, Sec. 23, and NE $\frac{1}{4}$, Sec. 26, unsurveyed T. 15 S., R. 41 E., Franklin County, Idaho.

Fish Haven Dolomite

Swan Peak Formation

Upper Member

	Thickness, in feet
7. Orthoquartzite; white to very light gray; weathers very light gray, locally, moderate orange brown; fine- to medium-grained; some beds poorly indurated; southeast-dipping cross-laminae near middle of unit; beds 0.10-2.33 ft. thick, average 0.70 ft.; a few burrows (<u>Laevicyclus</u> ?) near base and near top of unit.	73
6. Covered interval.	42
5. Orthoquartzite; white to grayish yellow; weathers light gray to yellowish orange; fine-grained; parallel laminae; southeast-dipping cross-laminae near top of unit; some beds poorly indurated; beds 0.25-2.00 ft. thick, average 0.64 ft.; horizontal burrows common in some beds; <u>Laevicyclus</u> locally common.	50
4. Covered interval, from near bottom of a small valley on the southwest side of the main ridge.	59

Section repeated by faulting.

3. Orthoquartzite; speckled white and moderate red; weathers reddish brown to dark yellowish brown; medium-grained; impure; contact with middle member based on abrupt change in talus.	20
Minimum total upper member present	244

Middle Member

2. Covered interval, pits reveal dark yellowish orange sandstone and pale green shale; reddish brown and brown sandstone and pale green shale founs in float throughout unit.	95
Total middle member	95

Section L. Continued

Thickness, in feet

Lower Member

1.	Covered interval, pits reveal black shaly material; talus of light gray siltite near base of unit probably is the lower subunit.	85
	Total lower member	85
	Minimum total Swan Peak Formation present	424

Garden City Formation

SECTION M

Location: Side of small cirque, 750 yards southwest of Boy Scout Camp Wilderness, in NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 14, unsurveyed T. 16 S., R. 41 E., Franklin County, Idaho.

	Thickness, in feet
Swan Peak Formation	
Upper Member	
Not measured, see VanDorston (1969, p. 119).	250
Middle Member	
Upper Subunit	
3. Orthoquartzite; grayish red purple; weathers dusky red purple; medium-grained; hydroxylapatite.	14
Lower Subunit	
2. Orthoquartzite; moderate yellowish brown; weathers moderate brown; very fine-grained; and shale; pale green; interbedded; beds one to two inches thick.	80
Total middle member	94
Lower Member	
1. Covered interval to base of cirque wall; pits reveal thick, clayey soil, minor yellowish brown sandstone talus, no limestone of the Garden City Formation.	89
Minimum lower member present	89
Minimum total Swan Peak Formation present	433

Garden City Formation

SECTION N

Location: Crest of ridge between Steam Mill canyon and White Pine Creek, in SE ¼, Sec. 20, T. 14 N., R. 3 E., Cache County, Utah.

Fish Haven Dolomite

Swan Peak Formation

Upper Member

		Thickness, in feet
12.	Covered interval, contact with Fish Haven Dolomite located by digging pits.	5
11.	Orthoquartzite; white; weathers very light gray to light gray, locally, light brown to light red; fine-grained; some Liesegang banding; locally churned; simple branch-type and pinhole (*Laevicyclus* ?) burrows in lower one-fourth of unit, pinhole burrows more abundant in middle one-half of unit, decreasing in abundance in upper one-fourth of unit; beds 0.1-0.7 ft. thick, average 0.4 ft.; poorly indurated beds occur locally.	34
10.	Orthoquartzite; white; weathers light gray, locally, moderate yellowish brown to moderate red; fine- to medium-grained; parallel laminae; locally burrow-churned; local Liesegang banding.	21
9.	Covered interval, talus of orthoquartzite; white; weathers light to moderate brown to light red; fine-grained; some churning; local Liesegang banding; *Skolithos*-type burrows.	60
	Total upper member	120

Middle Member

Upper Subunit

8.	Orthoquartzite; light brown to white; weathers light brown; fine- to medium-grained; and pale green shales.	3
7.	Orthoquartzite; grayish red purple; weathers dusky red purple; medium-grained; contains hydroxylapatite and *Annelidichnus*.	18

Lower Subunit

6.	Orthoquartzite; light brown; weathers moderate brown; very fine-grained; and shale; pale green; interbedded; contains *Annelidichnus* and *Protocycloceras debilis*.	18
	Total middle member	39

Section N. Continued

		Thickness, in feet
	Lower Member	
	Upper Subunit	
5.	Shale; black; minor lenses of sandstone near top of unit.	33
4.	Shale; black; minor interbedded lenses of limestone and siltite.	27½
3.	Limestone; bluish gray; coarse grained; fossiliferous.	½
2.	Shale; black; minor amount of dark greenish gray shale; minor amount of sandstone.	26
	Lower Subunit	
1.	Siltite; medium gray; weathers light brown; greenish black shale at base.	7
	Total lower member	96
	Total Swan Peak Formation	255

Garden City Formation

SECTION P

Location: North side of St. Charles Canyon, in SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 23, unsurveyed T. 15 S., R. 42 E., Bear Lake County, Idaho.

Fish Haven Dolomite

Swan Peak Formation
Upper Member

		Thickness, in feet
18.	Mostly covered, small outcrops of orthoquartzite; light gray; weathers light gray; fine-grained; contact with Fish Haven Dolomite located by digging pits.	48
17.	Orthoquartzite; white to light gray; weathers light gray; fine- to medium-grained; some beds poorly indurated; Laevicyclus common throughout unit; unit partially covered.	76
16.	Covered interval, small outcrops of light gray orthoquartzite; weathers light gray; fine-grained.	43
15.	Orthoquartzite; pale yellowish orange; weathers dark yellowish orange; fine- to medium-grained; large "knobby" burrows weathered out in relief; beds 0.2-0.9 ft. thick, average 0.6 ft.	5
14.	Covered interval.	20
13.	Orthoquartzite; white to grayish yellow; weathers grayish yellow; fine- to medium-grained; poorly indurated; churned.	5
12.	Mostly covered, some small outcrops of orthoquartzite; white to light gray; weathers light gray, locally, moderate red to light brown; fine- to medium-grained; vertical burrows very abundant.	53
11.	Orthoquartzite; light gray; weathers light gray, locally dark yellowish orange; fine-grained; locally churned; vertical burrows abundant; outcrops are small and scattered in lower part of unit.	28
10.	Covered interval.	14
9.	Orthoquartzite; yellowish gray; weathers grayish orange pink; fine-grained; vertical burrows abundant.	20
8.	Covered interval.	48
7.	Orthoquartzite; white; weathers light gray; fine- grained; wavy parallel laminae; beds 0.3-0.9 ft. thick, average 0.5 ft.; churned.	14
	Total upper member	374

Middle Member
Upper Subunit

6. Orthoquartzite; dark yellowish orange to grayish orange pink; weathers medium greenish gray to moderate grayish brown;

Section P. Continued

	Thickness, in feet
fine- to medium-grained; contains hydroxylapatite; beds 0.1-1.0 ft. thick, average 0.5 ft.	30
5. Orthoquartzite; dusky red purple; weathers dusky red purple, locally, dark yellowish orange; fine- to medium-grained; parallel and wavy parallel laminae; westward-migrating current ripples; churned; hydroxylapatite; Annelidichnus, Eleutherocentrus petersoni, Leperditia sp.; beds 0.1-0.6 ft. thick, average 0.3 ft.	39
Lower Subunit	
4. Covered interval, pits contain light gray to dark yellowish orange orthoquartzite; weathers dusky yellowish orange; very fine-grained; and shale; pale green; interbedded; occurs both in place and as float. Outcrops 500 yards to the west (Plate 4).	49
Total middle member	118
Lower Member	
Upper Subunit	
3. Covered interval.	30
2. Shale; medium dark gray; weathers medium dark gray to dark gray; fissile; thin-bedded; minor dark green shale and brown, fissile silty sandstone.	29
1. Covered interval, base not exposed.	10
Total lower member exposed	69
Total Swan Peak Formation exposed	561

Base of formation not exposed.

SECTION Q

Location: (Upper member) west side of ridge, north of Swan Peak, in SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 10, T. 14 N., R. 4 E., and (middle and lower members) west side of Swan Peak, in SW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 3, T. 14 N., R. 4 E., Rich County, Utah.

Top of section eroded.

Swan Peak Formation Upper Member	Thickness, in feet
8. Orthoquartzite; white; weathers grayish orange; fine- to medium-grained; wavy and wavy parallel laminae; some cross-laminae; scoured.	4
7. Orthoquartzite; white; weathers very pale orange; medium-grained; planar, south-dipping cross-laminae common in lower part; beds are 2 inches thick.	10
6. Orthoquartzite; white; weathers light brown to light gray; fine- to medium-grained; medium-angle, planar, southeast-dipping cross-laminae in uppermost bed.	3
5. Mostly covered, small outcrops of orthoquartzite; white; weathers light brown to light gray; fine- to medium-grained; high-angle, planar, cross-laminae dipping both southeast and northwest.	24
Total upper member present	41
Middle Member Upper Subunit	
4. Orthoquartzite; pale red purple; weathers dusky red purple; fine- to medium-grained; southeast-migrating current ripples and planed-off ripples; fossils locally common include *Macluritella* sp., *Leperditia* sp., *Linguella* sp., *Eleutherocentrus petersoni*, *Protocycloceras debilis*, and *Annelidichnus*; rock is brown in upper 1 foot.	44
Lower Subunit	
3. Covered interval, break in slope separates unit from lower member, moderate brown orthoquartzite and pale green shale occur as float; contains *Annelidichnus*, *Eleutherocentrus petersoni*.	42
Total middle member	86

Section Q. Continued

	Thickness, in feet
Lower Member	
Upper Subunit	
2. Covered interval, greenish black to black shale in pits; locally interbedded limestone; dark bluish gray; weathers medium gray; contains ostracods, fragments of *Orthambonites* spp., *Protocycloceras debilis*.	59
Lower Subunit	
1. Siltite; medium gray; weathers light to dark brown; locally, moderate red; very fine-grained; calcareous; contains *Chondrites*, *Cruziana*. Includes 1 foot covered interval at base.	25
Total lower member	84
Total Swan Peak Formation present	171

Garden City Formation

SECTION R

Location: East side of Laketown Canyon, south side of an unnamed side canyon, in SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 6, T. 12 N., R. 6 E., Rich County, Utah.

Fish Haven Dolomite	Thickness, in feet
1. Covered interval, lithology undetermined, lies between last outcrop of limestone of the Garden City Formation and the first outcrop of dolomite of the Fish Haven Dolomite. No definite Swan Peak Formation lithologies were observed anywhere in talus.	15

Garden City Formation