AN ABSTRACT OF THE THESIS OF

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Title: STRATIGRAPHY OF THE SILURIAN AND DEVONIAN ROCKS, NORTHWESTERN PEND OREILLE COUNTY, WASHINGTON

Abstract approved: Redacted for privacy

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Silurian and Devonian rocks are exposed for approximately 8 square kilometers in the Kootenay Arc structural province of northeastern Washington. These Middle Paleozoic rocks overlie the Upper Cambrian Metaline Limestone and the Ordovician Ledbetter Formation, which includes slates, siltstones, and limestones.

Two Silurian units crop out in this area. Unit A is composed of Lower Silurian graptolitic argillites and siltstones and Upper Silurian siltstones and fossiliferous limestone. These lithologies represent a trend towards shallower water conditions than those operative during deposition of the Ledbetter Formation. Above Unit A lies the quartz granule conglomerate Unit. This unit consists of a silica rich granule conglomerate with associated beds of slate and is interpreted as an inner submarine fan deposit.

Devonian rocks are found locally at Limestone Hill. The polymictic Givetian limestone conglomerate crops out at the base of the hill. This conglomerate contains limestone clasts of Lower and lower Middle Devonian rocks, thereby documenting a break in the sedimentary record. The Givetian limestone occurs as float fragments of dark-gray limestone, which preserve a diverse conodont fauna. On the crest of Limestone Hill lies the Frasnian massive and bedded limestones, which are believed to represent a reef build-up.

The post-Paleozoic sedimentary record consists of Quaternary glacial deposits. An olivine trachybasalt of probable Tertiary age crops out for a short distance in the central portion of the map area.

The region has undergone several periods of deformation of probable Mesozoic age. The structure is dominated by northeast and northerly trending folds, and northeast and northerly trending steeply dipping normal faults.

Stratigraphy of the Silurian and Devonian Rocks,
Northwestern Pend Oreille County, Washington

by

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A great debt of gratitude is owed Dr. Brian D. E. Chatterton, who processed close to one ton of rocks for conodonts and then identified the microfossils. His information is crucial to understanding the stratigraphic relationships in the map area. Thanks is also given Dr. William B. N. Berry, who identified the very poorly preserved graptolites. Dr. A. R. Niem, Dr. R. D. Lawrence and Dr. J. G. Johnson offered advice at different stages of progress. Their ideas were helpful and very much appreciated. Mr. Dave Rohr kindly devoted many hours to developing and printing pictures.

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INTRODUCTION

Location and Accessibility

Silurian and Devonian rocks are exposed from Limestone Hill to Beaver Mountain, in the Selkirk Mountains of northeastern Washington. The map area is a narrow tract of land, approximately eight square kilometers, situated in northwestern Pend Oreille County and spans the Abercrombie Mountain and Boundary Dam 7-1/2 minute quadrangles. Metaline Falls is the nearest town, approximately eight kilometers south southeast of Beaver Mountain (Figure 1). The map area is included within sections 16, 21, 28, 29, and 33 of T 40 N and R 43 E, and section 4, T 39 N, R 43 E. This land is contained within Colville National Forest. A small portion of the area is privately owned.

The Boundary Dam paved road, which leaves Highway 31 between Metaline and Metaline Falls, forms convenient access to the area. This road is joined by several dirt and gravel roads which transect the map area.

Purpose and Methods of Investigation

The purpose of the investigation was to determine the

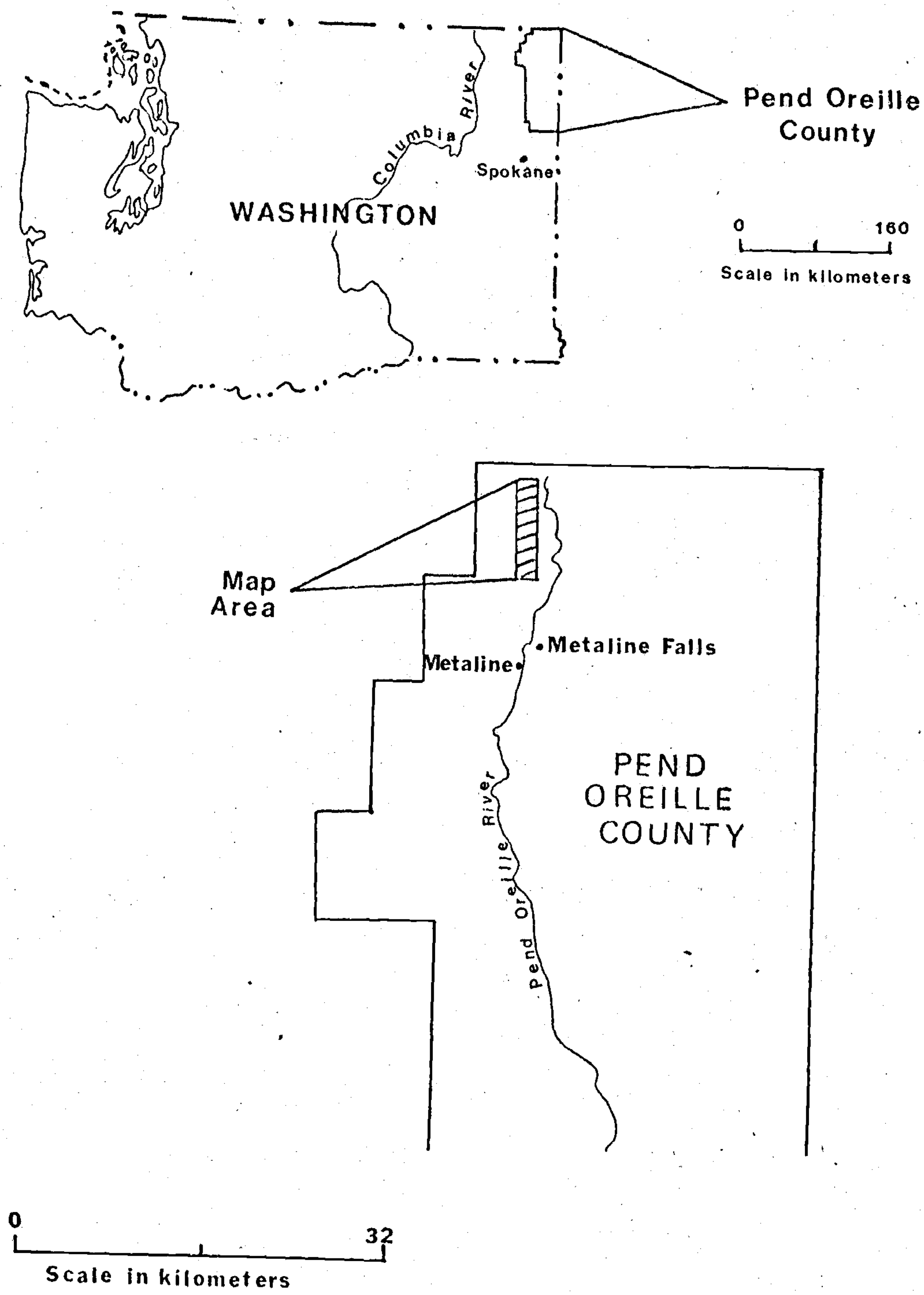

Figure 1. Index map of Washington showing location of the map area.

stratigraphic relationships of the Paleozoic rocks in the map area and form conclusions as to their depositional environments. Obtaining fossil data was of major importance, since, except for the Cambrian and Ordovician formations, the Paleozoic rocks in the area had previously been labeled as undifferentiated Silurian-Devonian.

Field work began in late June, 1975, and continued until mid-September. Mapping was done using 1966 U.S.G.S. Boundary Dam and Abercrombie Mountain 7-1/2 minute quadrangle maps, enlarged to 1:12000. Aerial photographs, flown in 1972, scale 1:15640, aided in establishing locations. The top of Limestone Hill was mapped by pace and compass techniques; the error held to $\leq$ 5 percent.

Approximately 1135 kg of rock were collected for conodont and petrographic study. Conodont samples averaged 9 kg and were processed by Dr. Brian D. E. Chatterton of the University of Alberta, who then identified the microfossils. Graptolites were identified by Dr. William B. N. Berry of the University of California, Berkeley; and brachiopods were identified by Dr. A. J. Boucot of Oregon State University. Thirty-eight thin sections were prepared for petrographic examination. Insoluble residue and heavy mineral analysis were performed for selected samples. Two acetate peels were made of slabbed rocks. In addition, several rocks were stained for feldspar and dolomite.

Classifications used in discussion of rock samples are: GSA rock color chart; classification of sandstones according to Williams, Turner, and Gilbert (1954), Dunham's (1962) and Folk's (1962) classification of limestones.

Topography, Climate and Vegetation

The map area has 470 m of relief between the highest and lowest elevations, 1207 m and 737 m, respectively. The topography can be described as rolling hills. Although tiring to climb, in no place were slopes forbiddingly steep.

The summer climate is moderate and pleasant for field work, with temperatures generally between 26-32° C. Winter temperatures below -16° C are not uncommon. The average annual precipitation is 69 cm, accumulating mostly as snow during the winter months.

Vegetation is quite lush and includes a variety of deciduous and coniferous trees. Hemlock, cedar, white and red fir, tamarac, birch, cottonwoods, and alders are common. Much of the area is timbered with second growth, due to logging or devastation by fire.

Exposures

Except on the upper portion of Limestone Hill, exposures are not very good. The contacts are everywhere concealed by vegetation and outcrops are discontinuous. The best exposures occur along ridges. Logging roads, when new, must have provided excellent outcrops, but many roads have since been reclaimed by vegetation and hillside slumping.

Previous Work

Geologic interest in the map area began around the turn of the century, but was confined to mineral exploration. In 1936 and 1937, Park and Cannon of the U.S.G.S. undertook pioneer regional mapping in the area. Their findings were subsequently published in 1943, and noted the presence of Devonian rocks at Limestone Hill. Another U.S.G.S. study, headed by Dings and Whitebread, was published in 1965. They reported one outcrop of definite Silurian age, as well as limestones containing fossils ranging in age from post-Ordovician to pre-Carboniferous.

More detailed efforts have focused on Limestone Hill. Enbysk (1956) and Sorauf (1972) have both published accounts of the fossils of this locale.

STRATIGRAPHY

Regional Stratigraphy

The map area lies within the Kootenay Arc, which dominates the structure of Pend Oreille County. This belt of folded and faulted rocks exposes the westernmost miogeosynclinal Paleozoic sedimentary rocks in northwestern United States (Yates, 1970, p. 22 and Figure 2, this text). The Metaline District, as used in this text, refers to the northern portion of Pend Oreille County and is notable for the occurrences of lead and zinc. Pre-Mesozoic rocks of the Metaline District range in age from Cambrian or older through early Late Devonian. The post-Paleozoic record comprises the Tertiary Tiger Formation, a localized olivine trachybasalt, and widely distributed Quaternary glaciofluvial and glacial till deposits.

Local Stratigraphy

Nine units are described from the map area, only two of which have been given formation names (Figure 3). These two units, the Cambrian Metaline Limestone and the Ordovician Ledbetter Formation, are widespread in northeastern Washington and British Columbia and are not described in detail in this report. Brief mention is given to the Tertiary (?) olivine trachybasalt and

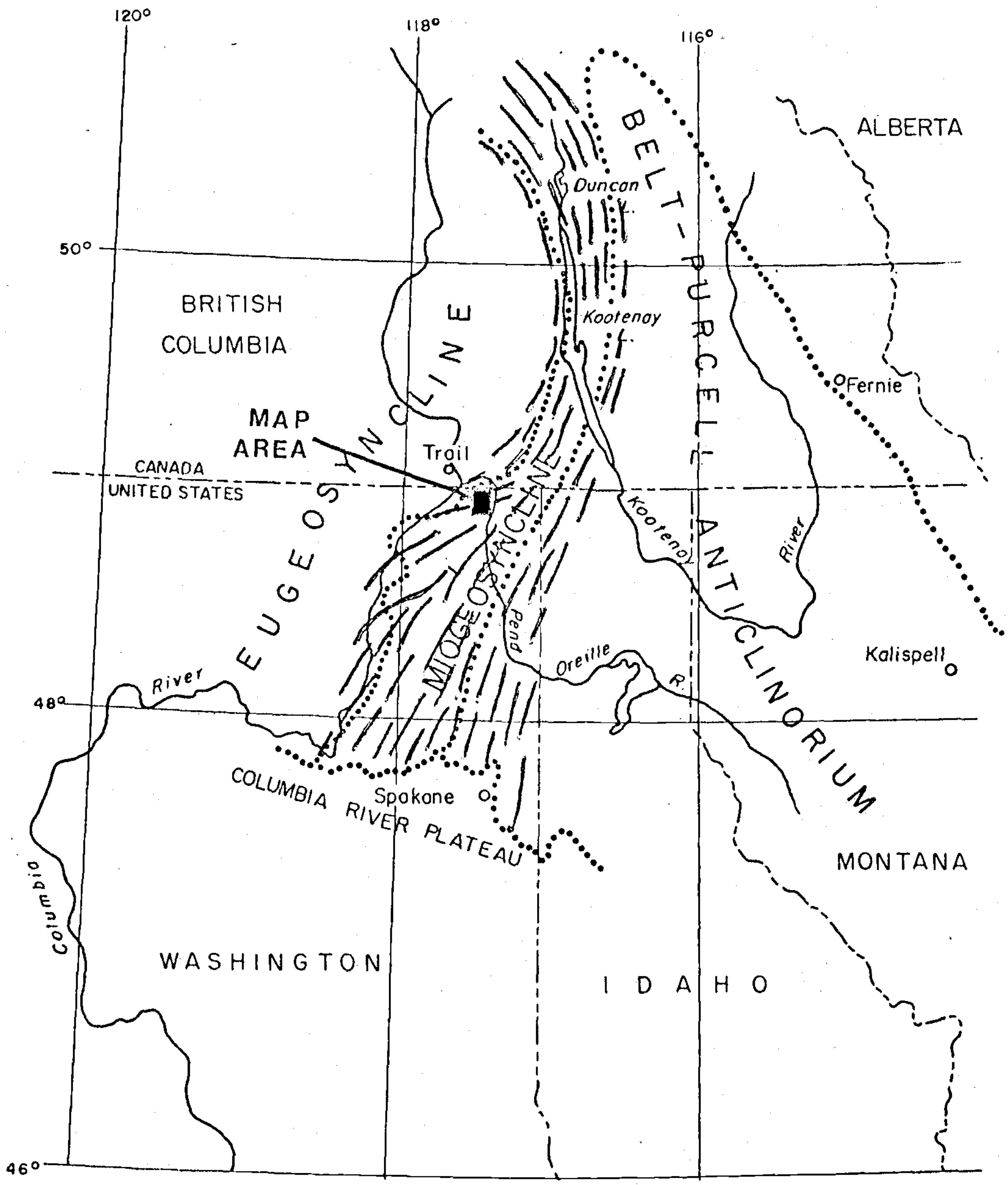

Figure 2. Index map showing location and trend of the Kootenay Arc. Structural trends indicated by dashed lines (after Yates, 1970).

Frasnian Limestone

Givetian Limestone

Givetian Limestone Conglomerate

. . . . Unconformity

Quartz Granule Conglomerate Unit
(Silurian)

. . . . Disconformity

Unit A
(Silurian)

Ledbetter Formation
(Ordovician)

Metaline Limestone
(Cambrian)

Figure 3. Stratigraphic relationships of the Paleozoic units described in this study.

Quaternary glacial deposits.

This paper focuses on five Silurian and Devonian units (Figure 3). These are localized accumulations of rocks that are unknown elsewhere in the Metaline District. Unit A, the oldest, is the most diverse unit. Within Unit A, the Early Silurian is represented by argillites and siltstones, which contain graptolites. Ludlow age siltstones are found in Unit A, although by this time, limestone deposition had become dominant, in the form of carbonate banks. The growth of these banks was terminated in Late Silurian time by the introduction of the clastic quartz granule conglomerate Unit.

Devonian rocks occur only at Limestone Hill, which is separated from the older rocks by a fault. The oldest Devonian unit is the Givetian limestone conglomerate. The rock contains limestone clasts of Early and Middle Devonian age. The Givetian limestone is possibly coeval with parts of the Givetian limestone conglomerate. At the crest of Limestone Hill lies the Frasnian limestone.

Stage names of the Devonian and Silurian used in the text appear in Figure 4.

Metaline Limestone

Name and Distribution

The Metaline Limestone is found extensively throughout the

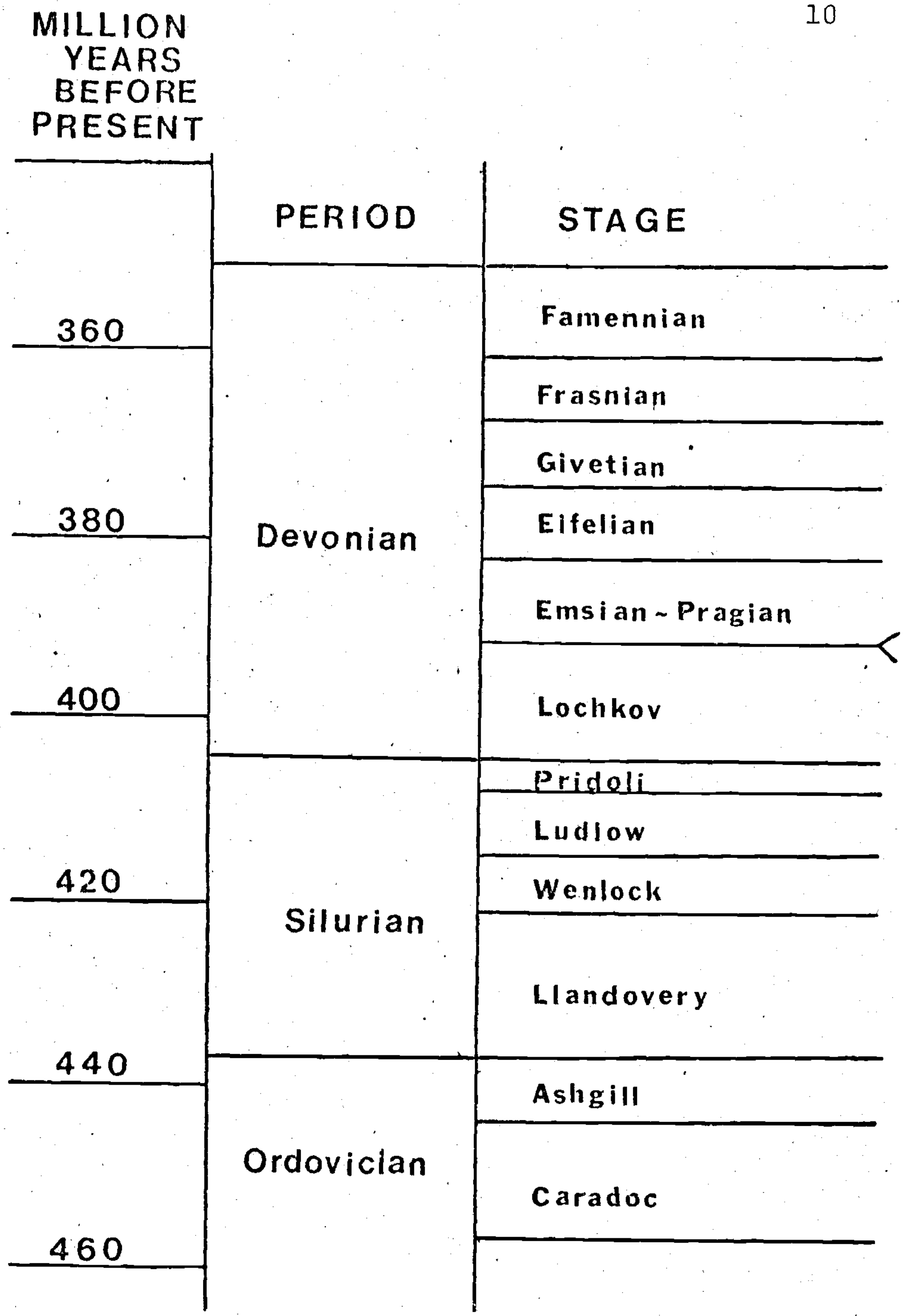

Figure 4. Geologic time scale including stage names of Late Ordovician, Silurian, and Devonian periods (after Boucot, 1975).

Metaline District. It was named by Park and Cannon (1943) for the rocks exposed near Metaline Falls. The equivalent of the Metaline is known in British Columbia as the Nelway Formation (Little, 1950). The Metaline Limestone is host to the lead and zinc deposits of the region, and the drill holes within the map area are probes to the ore horizon. Within the map area the Metaline Limestone crops out in three small exposures, each in fault contact with adjacent rocks. Two outcrops occur on the western slope of the hill west of Basalt Hill; another occurs on the western slope of Beaver Mountain (Plate 1).

Lithology

The Metaline Limestone appears locally in a roadcut at the base of the west side of Beaver Mountain. The occurrence consists of small, flaggy pieces of limestone which weather from the road surface. The limestone is fine-grained and homogeneous. The weathered rock is light-gray in color and very soft. Calcite veinlets transect the rock in many specimens.

This same rock type is found as float on the hill west of Basalt Hill. Thin sections show the rock consists of a non-porous composite of micrite and calcisiltite. Angular silt-sized grains of quartz and euhedral dolomite crystals form less than 1 percent of the rock. Minor clay minerals are concentrated as dark discontinuous laminae. The non-sutured appearance of these laminae suggests that they are primary, rather than concentrations along a pressure solution stylolite boundary.

Irregular patches of neomorphic recrystallized calcite are unevenly distributed in the rock. The larger grains are commonly 10 times the size of those in the groundmass, and the contact between the two regions is gradational. This texture suggests that the larger grains have grown at the expense of the smaller ones (Folk, 1965; Bathurst, 1975).

The exposures of Metaline Limestone within the map area are distinguished from Silurian limestones by the complete lack of fossils, although this absence may be due to insufficient sampling. Lithologic differences separate the Metaline from limestones of the Ordovician Ledbetter Formation. With the limited exposures available, however, it is prudent to realize that these variations may be quite localized. Dings and Whitebread (1965) recognized these small outcrops of limestone as gray massive limestone, the uppermost lithologic unit of the Metaline Limestone. This identification was made by lithologic correlation with limestones outside the map area.

Age

The bedded limestone unit of the Metaline Formation is dated by trilobites as Middle Cambrian (Park and Cannon, 1943). No dates have been obtained from the gray massive limestone; however, its stratigraphic position above the bedded limestone indicates a younger age.

Contacts and Thickness

On the hill west of Basalt Hill the Metaline Limestone is assumed to lie in fault contact with rocks of the Silurian quartz granule conglomerate Unit, based on the absence of the Ordovician Ledbetter Formation and Silurian Unit A (Plate 1). These faults have no topographic expression. At Beaver Mountain graptolitic slate and limestone of the Ledbetter Formation overlie the Metaline Limestone. A fault contact is indicated, here, because of the absence of part of the Ledbetter.

The thickness of the gray massive limestone was estimated by Dings and Whitebread (1965) to be between 380-440 m in the vicinity of Lead King Hills, east of the map area.

Ledbetter Formation

Name and Distribution

The Ordovician Ledbetter Formation is widely found in the Metaline District. It was named by Park and Cannon (1943) for rocks which crop out on the slope west of Ledbetter Lake and correlates with the Active Formation in British Columbia (Little, 1950). The siltstone and limestone lithologies in the map area are uncharacteristic of the type Ledbetter, 95 percent of which is dark carbonaceous slate or argillite (Dings and Whitebread, 1965). The Ledbetter crops out in the eastern portion of the map area and also occurs at Brush Ridge, Horsefly Hill, and Beaver Mountain (Plate 1).

Slate Lithology

The exposures of the Ledbetter Formation which are found in the eastern portion of the map area and at Beaver Mountain are the most representative of the unit. Cuts along the Boundary Dam Road west of Ledbetter Lake provide the best outcrops. The rock is a black slate which weathers to a rust or medium-gray color, depending on the iron content.

The resistance of the rock varies with the outcrop. Generally the slate will break with a conchoidal fracture into splintery pieces. Near Whiskey Creek, the weathered slate is sooty and crumbles easily at a touch.

Pyrite is very common in outcrops west of Ledbetter Lake. It occurs as small concretions and also replaces fossils, chiefly graptolites. Oxidation of pyrite produces a rusty, weathered appearance.

The slate is very homogeneous in texture and bedding is rarely obvious. Some faint color bands indicate gently dipping beds.

Graptolites are the most abundant fauna within the slate lithology. At most locations the organisms have been replaced with a white chalky-looking substance, which does not react with hydrochloric acid. In roadcuts opposite Ledbetter Lake, graptolites have been replaced by pyrite. One pyritized cephalopod was collected.

Siltstone Lithology

The siltstone of the Ledbetter Formation crops out on the slopes encircling Brush Ridge, on the western slope of Beaver Mountain, and in one locality on the southern slope of Horsefly Hill. Except at Horsefly Hill, the rock is associated, though not interbedded, with a silty limestone (Plate 1). The weathered rock is yellowish-gray at Horsefly Hill, and medium-gray to light-gray at other locations. The Ordovician and Silurian siltstones are lithologically indistinguishable.

Silty Limestone Lithology

Limestone is found with siltstone at Brush Ridge and on the western slope of Beaver Mountain. The rock is dark-gray, and weathers to a medium-gray color. Small brown mudstone laminae contribute a dark color to the fresh rock. The limestone is a homogeneous medium-grained packstone with no variation in grain size or mineralogy. At Brush Ridge, beds are outlined by thin fractures in the rock where vegetation has taken root. Where observable, the bedding surface is slightly undulating. It appears that some less resistant material, probably mudstone, has weathered from between the limestone layers. Bedding thickness varies between 15-25 cm.

Calcite veinlets are found intermittently throughout the limestone. Dark-brown staining along the edges of the veinlets is shown, in thin section, to be hematite. The limestone is more resistant where the pore-filling calcite is localized.

At Brush Ridge small bands of dark chert, no more than 25 cm in length, roughly parallel bedding. This chert is incorporated into a limestone breccia which forms the extreme northeastern outcrop.

The rock is composed of approximately 65 percent calcisiltite; 15 percent sparry calcite; 10 percent silica, as quartz grains $\leq$ .1 mm in diameter, chert, and cement; 7 percent mudstone as laminae; and 3 percent hematite. The quartz and calcite grains are rimmed with mud-sized grains and hematite, which gives the crystals a dirty appearance.

The sparry calcite forms patches with sutured crystal boundaries. This feature, plus the presence of clay-sized material as mudstone, suggests that some of the calcisiltite and spar are a product of aggrading neomorphism (Folk, 1965). A likely source for the silica cement would be from dissolution of the quartz grains.

The rock contains no trace of macrofossils. Conodonts have been recovered from limestones at Beaver Mountain.

Age

Graptolite collections recorded by Park and Cannon (1943) and Ruedemann (1947, p. 111-112) (Ruedemann, 1947, p. 111-112 discussed collections made by Prof. W. B. Bennett) indicate that the Ledbetter Formation ranges in age from the Early into the Middle Ordovician. In terms of graptolite zones recognized by Berry (1960), the age span of the formation based upon collections discussed by Ruedemann (1947) is at least from graptolite zone 3 or 4 through zone 12.

Schuster (1976, Open File Report, Washington Department of Natural Resources: "Geology of the Clugston Creek area, Stevens County, Washington") collected graptolites from the three members of the Ledbetter Formation that he recognized in the Clugston Creek area. The graptolites were examined by Berry. The collections from the lower and middle members of the formation in the Clugston Creek area are indicative of a latest Early and earliest Middle Ordovician age. The collection from the upper member in the Clugston Creek area includes dicellograptids, dicranograptids, and climacograptids indicative of a zone 11 age, which is mid-Middle Ordovician.

The graptolites contained in slates in the present study are indicative of zones 11-12 and 13, the latter part of the Middle Ordovician. A collection dated as zone 13 age was obtained from exposures west of Ledbetter Lake. One specimen collected by David Huffine Jr. of Metaline Falls, is significant because it is the first specimen of Diplograptus ingens T. S. Hall to be recorded in North America (Figure 5). The species has been previously known from eastern Australia. The graptolite collection from Beaver Mountain is slightly older than that from near Ledbetter Lake, bearing graptolites suggestive of a zone 11-12 age span. In addition, graptolites collected in siltstones at location G 972 (Plate 1) are dated as zone 15, latest Ordovician in age.

The age of the limestones at Beaver Mountain is bracketed by conodonts as being in the span of Middle Ordovician-Earliest Silurian. Lithologic correlation implies that the limestones at Brush Ridge fall in the same age span.

Contacts and Thickness

The contact between the Ledbetter Formation and overlying Silurian rocks of Unit A is concealed everywhere. The gradual lithologic transition from Ordovician to Silurian strata argues that

Figure 5. Diplograptus ingens T.S. Hall. This graptolite species has been previously recorded from Australia but is new to North America. The larger fossil is 33 mm long. Locality G 9211 (Plate 1).

the contact is conformable. On the eastern side of Horsefly Hill Ordovician slates grade into Silurian argillites of Unit A, and at Brush Ridge Ordovician limestones and siltstones are overlain by Silurian siltstones and calcareous sandstones.

Furthermore, siltstones collected from location G 972 (Plate 1) contain graptolites of zone 15 (latest Ordovician age). These Ordovician siltstones are lithologically identical to the surrounding Silurian siltstones and may represent the core of an anticline which has reached the surface. If this structural interpretation is correct, a facies change occurs between the Ordovician siltstones and the Ledbetter slates which crop out 350 m to the east.

The data suggest that sedimentation was probably continuous from Ordovician time into the Silurian, and it is worth considering that the age of the Ledbetter Formation, at least the strata contained within the map area, be extended upward to include Lower Silurian siltstones.

The contact on the eastern slope of Brush Ridge between Ordovician siltstones and limestone and Silurian siltstones and sandstones, is thought to be of fault origin, which would explain the tectonic breccia, which crops out at the northern-most outcrop, and the strike of the beds (Plate 1). Drill hole data (Pend Oreille Mines and Metals Co., 1964) recording the presence of black carbonaceous shales below till, help to define the fault trend.

At Beaver Mountain, the rocks of the Ledbetter Formation and the Metaline Limestone lie in fault contact (p. 13, this text). The contact with rocks of the Silurian quartz photographs as a lineament that stretches from the southern slope of Beaver Mountain to the southern slope of the hill west of Basalt Hill. A siltstone and limestone breccia is present at the extreme limits of the fault.

The entire Ledbetter sequence is not found within the map area. Dings and Whitebread (1965) have estimated the maximum thickness of this unit to be between 645-660 m.

Paleoenvironmental Interpretation

The Ledbetter Formation is generally considered to be a deep water deposit of euxinic muds (Yates, 1970). The dark color and fine-grained texture of the slate, the presence of pyrite, and the almost complete absence of fossils other than graptolites, indicate an anaerobic bottom environment.
Local variations in water circulation are suggested by the siltstones and limestones of the Ledbetter Formation. These lithologic differences may reflect facies changes, or deposition of silt and

micrite muds during stratigraphic intervals when stagnant conditions were subordinate.

With the abundance of graptolites and the good quality of preservation, further fossil sampling could serve to delineate depth zonation as well as stratigraphic horizons.

Unit A

Distribution

Unit A is divided into 3 main lithologic subunits: a gray fossiliferous limestone, a gray graptolitic siltstone, and a dark, thinly bedded argillite. The unit crops out mostly in the central portion of the map area and is also present on the western slope of Beaver Mountain (Plate 1). The subunits possess some stratigraphic meaning. No Lower Silurian limestones are present. However, the siltstones transgress Early and Late Silurian time.

Argillite Lithology

Argillite crops out on the eastern slope of Horsefly Hill and along the power line clearing. This lithology accounts for about 2 percent of the rock mapped as Unit A. The rock is dusky blue to black and weathers to a pale blue color. Limonite locally stains the rock yellow.

The argillite is thinly stratified, beds 1-4 cm in thickness are the rule, and contains lenses of pale yellowish-brown argillite. The lighter bands probably reflect differences in carbon content. The darker layers commonly have a fetid odor when struck, a characteristic not recognized in the lighter-color rock.

Black chert layers also appear within the rock. Their thickness is approximately the same as that of the argillite. The chert bands seem to be more continuous than the argillite lenses. On the surface of the fresh rock, the chert blends with the black argillite in color but is distinguished by its hardness and conchoidal fracture.

Small folds are routinely visible in hand specimen (Figure 6). This deformation has caused pronounced bedding plane parting in some rocks due to the differing strengths of individual rock layers.

Graptolites are found in two locations in the argillite (location G 981 and G 961, Plate 1). From fossils at locale G 981, Dings and Whitebread (1965) recognized rocks of Silurian age in the Metaline District. Preservation has been helped by the relatively resistant nature of the strata.

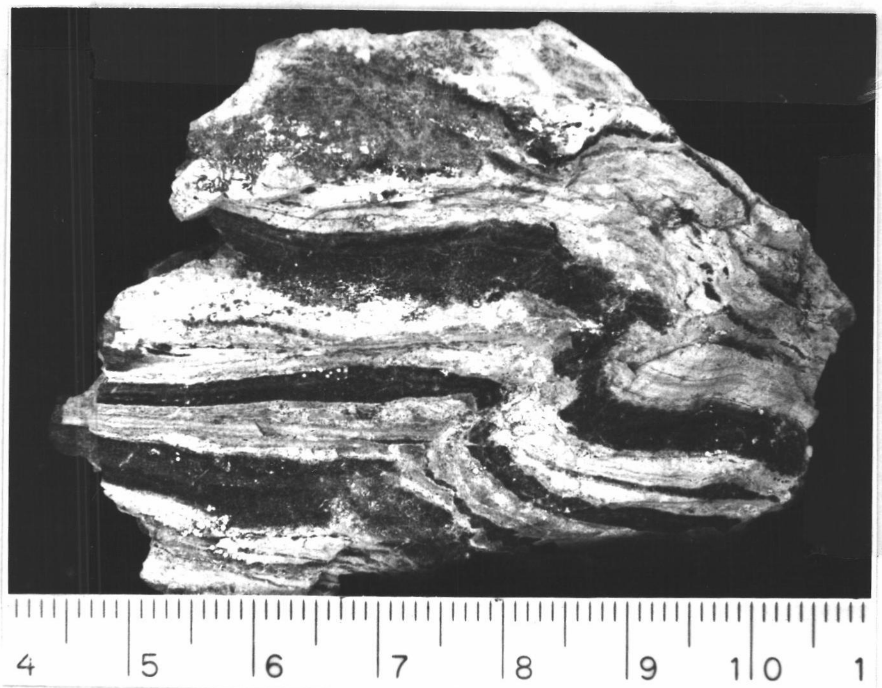

Figure 6. Interbedded light and dark argillite of Unit A showing folds. Scale in inches. Location: approximately 20 m north of G 981 (Plate 1).

Under thin section examination the rock is composed approximately of one third silt-sized angular quartz, while the remainder of the rock is undetermined argillaceous material. Sections cut normal to bedding show a uniform mass extinction pattern of minerals. Small dark pellets, about 1 mm in diameter, and microlaminations follow bedding. These structures are visible due to hematite coating along their edges.

Interbedded light and dark-colored argillite is absent in the Ledbetter rocks of the map area, but may be present elsewhere. Therefore, lithology should not be considered a diagnostic criterion for distinguishing between Silurian and Ordovician argillites.

Siltstone Lithology

Siltstone is found primarily in the central portion of the map area, and totals about 60 percent of the strata in Unit A. The rock is extremely weathered and forms slopes. Virtually all of the outcrops lie along unused dirt roads or in gullies. The color of the siltstone varies in outcrop from yellowish-gray to light bluish-gray to light-brown.

The thickness of beds ranges from 0.5-2 cm in most places, but along the power line clearing, thicker beds (5-15 cm) occur. Bedding planes are recognized by small bedding plane fractures, slight color variations in the rock, and the presence of graptolites on bedding surfaces. The beds weather to small chips which makes collecting a difficult process, lest the fragile samples become demolished in transport.

The rock contains a varying amount of calcite cement. Leaching of this material is responsible for the porous friable quality of the rock.

Graptolites occur profusely at Horsefly Hill and Beaver Mountain. The fossils are highly sheared and very poorly preserved. Their impressions are a light rust color.

In thin section angular and sub-angular silt-sized quartz grains and silica cement amount to 40-45 percent of the rock. Much of the quartz shows corroded grain edges which have been replaced by calcite. Broken quartz grains are infilled with hematite.

Calcite forms a continuous matrix as well as irregular interlocking crystals. This carbonate represents about 26 percent of the rock, in weight, as determined by solution in hydrochloric acid. The calcite is contaminated with argillaceous material, which gives it a very dirty appearance.

The remainder of the rock is mostly clay-sized material. Hematite forms microstylolites and pseudomorphs after pyrite.

Minor dolomite, as rhombs, floats within the calcite matrix. Minute mica flakes are the only other accessory mineral.

It is characteristic of the thicker-bedded siltstone to contain a much greater silica/carbonate ratio. The fraction of these rocks soluble in hydrochloric acid is negligible.

Limestone Lithology

Limestone crops out at Beaver Mountain, the hill west of Basalt Hill, the hill west of Horsefly Hill, and at the hill near the power lines (Plate 1). The rock is more resistant than the siltstone, and some outcrops form small ridges. At all locations except Beaver Mountain, the limestone contains fossils that are visible in hand specimen.

The texture of the limestone varies. A sparsely fossiliferous mudstone crops out on the hill west of Basalt Hill, and at the base of the hill near the power lines. The rock is dark-gray on a fresh surface, and weathers to a light bluish-gray. Calcite-filled fractures, averaging 102 mm in width, cut the mudstone. Thin sections show these fractures to be rimmed with hematite and infilled with large crystals of sparry calcite and irregular-shaped clasts of micrite. One unbroken gastropod shell was found, replaced by sparry calcite.

A medium-gray fossiliferous coarse-grained limestone crops out on the hill west of Horsefly Hill. Tabulate corals, crinoids, and bryozoa were recognized in hand specimen. In addition, stromatoporoids and brachiopods are present in thin section. This fossiliferous limestone contains approximately 65 percent fossil material, 25 percent calcisiltite and sparry calcite, 5-8 percent micrite, and 2-5 percent pyrite and quartz, as grains and authigenic quartz. The rock is a packstone. Coelenterates are the largest fossil fragments within the limestone. Some pieces are 3-5 cm in length. All of the fossils have recrystallized to sparry calcite. Commonly the remains of an organism are apparent only as grain-size differences in the sparry calcite matrix and the fossil. Minor replacement by authigenic quartz has also occurred.

Micrite forms small, 1 mm diameter, rounded pellets concentrated near coral fragments. Micrite rims, mostly converted to microspar, surround many fossils. Micrite also occurs as stylolites around larger fossils. As stylolitization results from pressure solution of connecting grains, the localization of micrite around fossils suggests that the calcite of the organisms' structure is more resistant to solution than calcite of the matrix. Significantly, the calcite of the matrix is finer grained, which is probably a factor in its relatively rapid dissolution.

Lenses of red quartz siltstone lie adjacent to the fossilferous limestone, and also crop out on the southeast side of the hill near the power lines. The siltstone has weathered to irregular shaped blocks, 10-20 cm in length. The rock is very porous due to numerous circular and elliptical cavities. In one sample the imprint of a rugosan coral was seen. This suggests that the rock contained calcareous fossils which have selectively dissolved from the silt-stone matrix during weathering.

At the crest of the hill near the power lines, an intraformational conglomerate crops out. The rock shows a reddish tinge, attributable to the amount of terrigenous siltstone and mudstone it contains. Quartz siltstone coats many of the corals, bryozoa, and crinoids in the rock, and has caused the fossils to stand out in relief.

The conglomerate forms beds 10-25 cm in thickness. Beds are outlined by small bedding plane fractures. Fossils and clasts are roughly aligned parallel to bedding. No pattern of grain size distribution is present throughout a bed.

Fossils compose approximately 50 percent of the conglomerate. The fragments are rounded, which is evidence of transport and abrasion by waves or currents. Bryozoa are the most abundant fauna. Their zooecia are filled with a mixture of sparry calcite and neomorphic microspar.

The rock contains about 10-15 percent terrigenous siltstone and mudstone. These constituents occur as rounded clasts and laminae. The mudstone clasts form the largest allochems in the conglomerate. No individual quartz grains are present; however, authigenic quartz appears as fossil replacements and interstitial cement.

Micrite rip-ups, averaging 1.25 cm in diameter, are common, composing approximately 10 percent of the intraformational conglomerate. Some of the clasts contain micro-fragments of calcareous organisms. In most cases, the micrite has begun recrystallization to microspar.

The matrix of the conglomerate consists of calcisiltite. No gradation of grain size exists in the matrix to suggest that the calcisiltite is actually neomorphic microspar. It is interesting, considering the amount of clay-sized material in the rock, that the thin sections showed no stylolites. Early diagenetic cementation may have prevented stylolite growth (Bathurst, 1975).

Age

Graptolites have been identified from siltstones and argillites of Unit A. The collections have all included monograptids, which place the age of these rocks as Silurian-Early Devonian. More specifically, at Horsefly Hill, the rocks are recognized as being late Llandovery and probable Wenlock in age.

Various limestone locales have yielded conodonts of Ludlow age (Appendix I). At location C 871 (Plate 1), the age has been restricted to the latialatus Zone. One float fragment from Horsefly Hill gave an age within the ploeckensis-siluricus Zone.

Contacts and Thickness

At one outcrop on the northern slope of Beaver Mountain, limestone of Unit A is observed in depositional contact with the quartz granule conglomerate Unit (Figure 7). Here, the beds strike nearly east-west and dip 62° to the north. This attitude may be influenced by nearby faults. However, if the beds are not overturned, Unit A underlies the conglomerate unit. The contact is sharp, and apparently disconformable, since little more than a meter of the limestone is present above graptolitic siltstone of possible Llandovery-Wenlock age (Appendix I).

All other contacts are concealed by cover. One lineament on the eastern side of Beaver Mountain extending to Everett Creek, is visible on aerial photographs and is interpreted as a fault. The fault separates limestones of Unit A from rocks of the quartz granule conglomerate Unit to the west. A fault separates these same lithologies on the southern slope of the hill west of Basalt Hill. From lack of contrary evidence, it seems that on the hill west of Horsefly Hill, the limestone of Unit A is in depositional contact

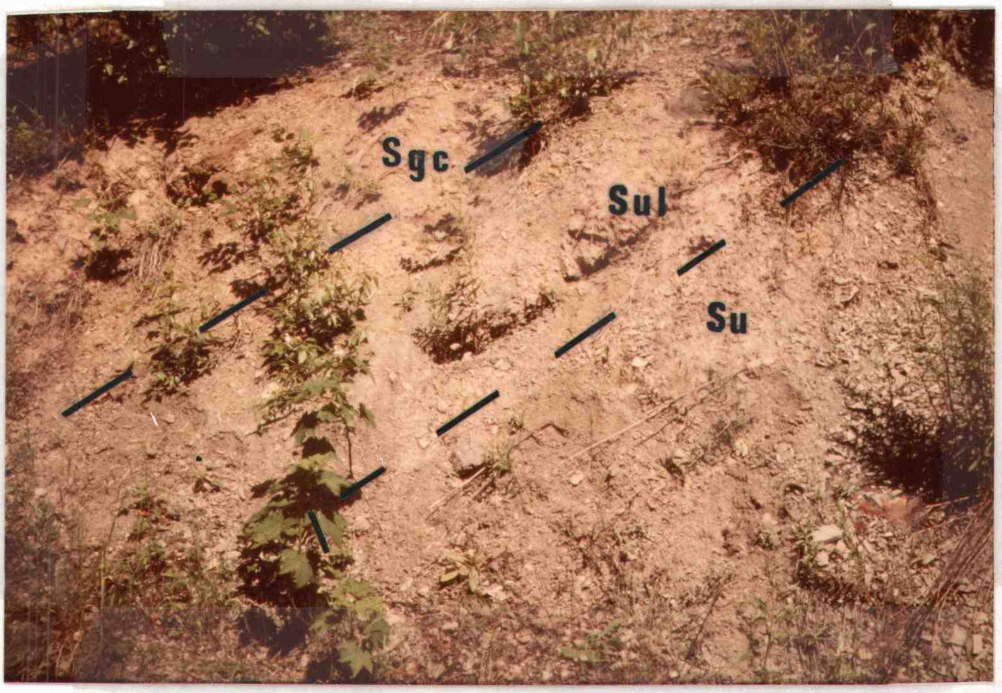

Figure 7. Contact between Silurian limestone (Sul) and siltstones (Su) of Unit A and the Silurian quartz granule conglomerate Unit (Sgc), Beaver Mountain, location G 9101 (Plate 1).

with the quartz granule conglomerate Unit.

The contact between Unit A and the underlying Ordovician Ledbetter Formation has been discussed (p. 20, this text).

The thickness of Unit A is approximately 255 m as estimated from cross-section A-A' (Plate 1).

Paleoenvironmental Interpretation

Unit A represents a continuation of the conditions prevalent during Late Ordovician time. The dark argillite of Unit A was deposited under conditions similar to those which influenced most of Ledbetter sedimentation. The influx of silt-sized quartz is possibly caused by shallowing, allowing stronger water currents and increasing the grain size transport competancy of the water. More oxidizing conditions imply that less organic matter would be preserved, thus the lighter color of the siltstones. The greater proportion of calcium carbonate in the Silurian rocks, as compared to most of the Ledbetter rocks is another indication of increased water circulation. A lateral facies change occurs between the siltstones and argillites at Horsefly Hill. Both lithologies are of late Llandovery age.

The fossiliferous limestones are of shelf depth origin as evidenced by the faunal assemblage. The mudstone formed in quiet water. A rapid change in water energy could have produced the intraformational conglomerate, which contains a large percentage of micrite clasts.

The packstone possibly existed as a carbonate bank, or small bioherm, while terrigenous silt formed contemporaneous lenses. As the packstone crops out only as dismembered blocks, this hypothesis is speculative.

Quartz Granule Conglomerate Unit

Distribution

The quartz granule conglomerate Unit includes a silica-rich granule conglomerate and an associated dark, non-calcareous slate. The conglomerate generally crops out as ridges while the slate is a slope former. Exposures occur on the slopes of Basalt Hill, the hills to the west and southeast of Basalt Hill, and the eastern slope of Beaver Mountain.

Quartz Granule Conglomerate Lithology

The fresh surface of the quartz granule conglomerate displays a dark-gray color, but is distinctly reddish in the presence of jasper. The reddish appearance is enhanced in the weathered rock, due to the occurrence of ferric iron oxide.

At most outcrops the rock is a granule conglomerate.

Siltstone and pebble conglomerates occur less frequently. Generally the coarser-grained exposures appear near the western margin of the map unit (Plate 1).

In hand specimen quartz and chert constitute the majority of the clasts. The chert is black, while the quartz ranges in color from white to dark-gray, to red jasper. Accessory constituents are composed of slate, phyllite and mudstone fragments, and clay minerals. The slate particles are a very light-gray, or pale blue color. The clay is present as soft, white powdery specks. It is possible that complete weathering of this substance is the cause for the pitted appearance of this rock. These pits account for the rock's only porosity.

The quartz granule conglomerate occurs as structureless rocks and as beds 33 to 150 cm in thickness. In instances where bedding is not apparent attitudes were measured from the crude alignment of clasts. In other localities, particularly on the eastern slope of Basalt Hill, distinct, sharply bounded beds are found. In some beds, a crude normal grading of grain size is observed and beds are bracketed between a pebble or granule-size fraction, and a clay-size fraction, which is metamorphosed to slate or phyllite. A few examples of reverse grading are also present (Figure 8). Phyllite and arenite ripups, up to 10 cm in length, are common in

Figure 8. Sample of the quartz granule conglomerate lithology containing non-calcareous mudstone clast. Location: approximately 10 m north of G 851 (Plate 1).

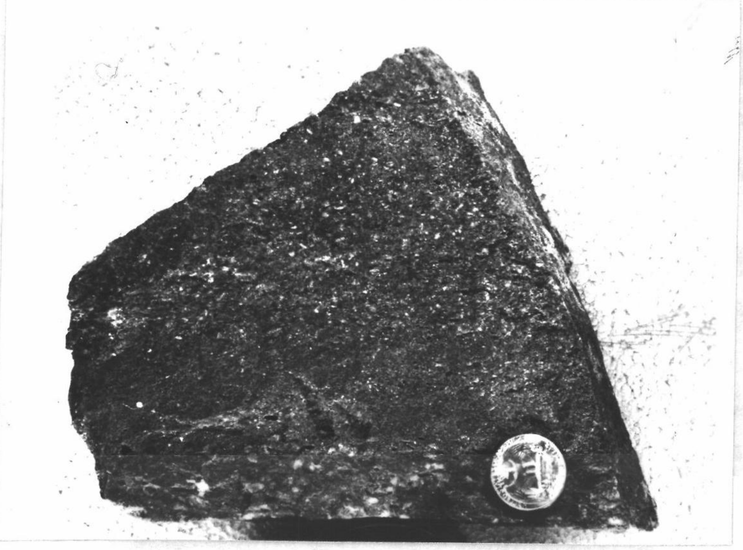

Figure 9. Sample of the quartz granule conglomerate lithology showing reversed grading. Location: approximately 660 m N5E of G 851 (Plate 1).

the coarser-grained beds (Figure 9). Flute marks and ropy sole markings are only seen in sandier beds.

In outcrops with a higher percentage of mudstone matrix, the rock assumes a foliated appearance. This foliation is distinguished as small partings within the rock, and may parallel the actual bedding plane. Bedding was not obvious in the outcrops which were examined.

Milky white quartz veins occur throughout the extent of the granule conglomerate lithology. They vary from tens of centimeters to several meters in thickness. Where the veins are located, the granule conglomerate is brecciated. These veins may have been introduced along fault fissures, although no displacement can be detected.

Thin section analysis confirms quartz and chert as the dominant grains (Table 1). Some chert fragments contain spheres which are filled with more coarsely crystalline silica, surrounded by microcrystalline chert matrix. These are thought to be silica-infilled molds of former radiolaria which underwent solution. In other clasts, small cubes have been plucked from the chert. The square outline is rimmed with hematite, suggesting the previous presence of pyrite. Micro-laminations are present in some larger clasts, where chert alternates with mudstone. Recrystallized chert is recognized by its larger crystal size.

Table 1. Modal analysis (500 points) of Quartz Granule Conglomerate Lithology.

Constituent	Percent of each thin section 8121	812
quartz	35.5	44
chert	28.1	.6
recrystallized chert	6.2	8.4
mudstone and phyllite fragments	5.2	5.8
opaques	2	---
orthoclase	---	Tr.
silica cement	4	16.6
matrix	19	24
Totals	100.0	100.0

Locality 8121: NE 1/4 NW 1/4 SW 1/4 sec. 33

Locality 812: SW 1/4 SW 1/4 NW 1/4 sec. 28

Minor orthoclase feldspar and sericite are identified only petrographically. Alteration of potassium feldspar has probably contributed to the formation of sericite and clay minerals.

The heavy mineral component of this lithology is extremely small, 0.05-0.25 percent, and is composed almost entirely of magnetite. The percentage of other heavy minerals is so minute that identification in grain mounts was not possible. One grain of monazite was tentatively recognized in thin section.

Matrix constituents fluctuate from sample to sample. In some localities mudstone and argillite laminae are pervasive so that the rock may be termed a wacke (Williams and others, 1954). Thin sections of samples from other outcrops reveal the matrix composition to be identical to that of the larger framework grains. Small angular fragments of chert and quartz are wedged among their larger, more rounded counterparts. Silica cement is also present, produced from dissolution of the abundant quartz.

Some dimensional orientation of grains is present. This is best seen in the alignment of chert clasts, which are more elongate than the quartz grains. In Figure 10, grain orientation is exaggerated by reaction of the framework clasts with the surrounding mudstone matrix. The degeneration of grains at their opposing sides lends the rock a stretched, foliated appearance. This phenomenon may be due to deep burial of the sediments or tectonic

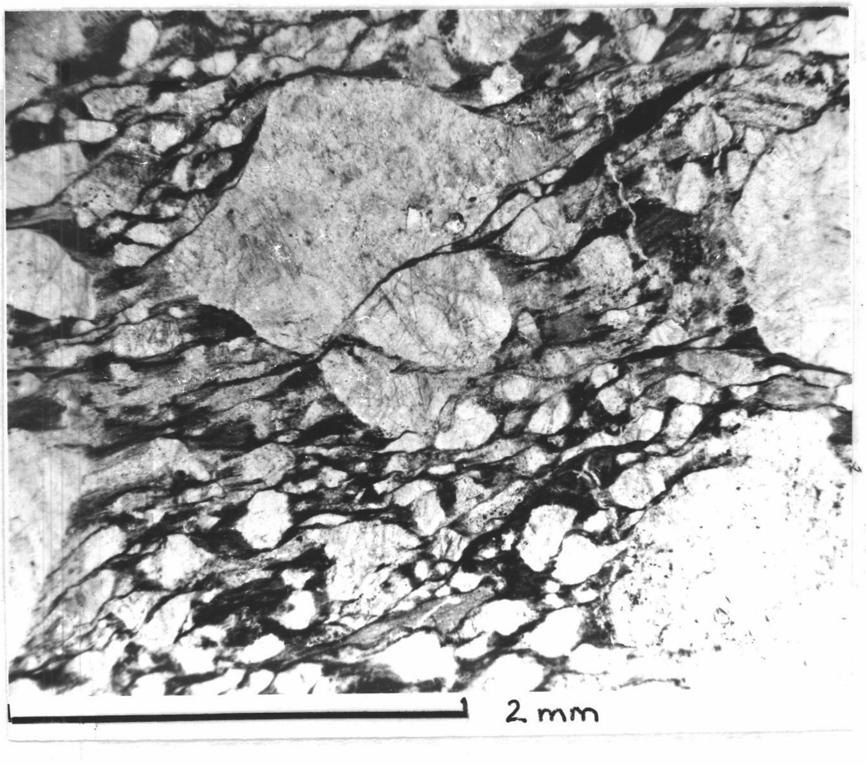

Figure 10. Quartz granule conglomerate lithology. Photomicrograph of quartz grains reacting with mudstone matrix, producing a foliated appearance. Location: approximately 1170 m west of Horsefly Hill.

shearing during low-grade metamorphism.

Texturally the rock is immature. Mineralogically, it is very mature, probably reflecting the quartz and chert source rather than the amount of transport. Sorting ranges from poor, in the conglomerate rocks, to moderate, in the sandstones. The degree of grain roundness varies from angular to well-rounded, but the mode falls within the subangular category. On the average, chert fragments tend to be better rounded than quartz grains.

Quartz is the most abundant mineral in the conglomerate lithology. Of the total number of quartz grains counted in 865 points, 69 percent were monocrystalline, 14 percent polycrystalline with straight boundaries, and 17 percent were polycrystalline with micro-sutured boundaries. Roughly three-fourths of the quartz grains extinguish in crossed-nicols within a 40° revolution of a flat stage. Quartz overgrowths are infrequent. More commonly the crystal boundaries of the grains blend with the mudstone or silica cement matrix. Although dimensional orientation of chert pebbles is well established, the quartz and chert grains are not optically oriented. Dust and acicular inclusions are regularly observed in the quartz grains.

In synthesis, the prevalence of monocrystalline quartz with undulose extinction suggests an acid plutonic source rather than volcanic or vein quartz. Polycrystalline quartz is characteristic of metamorphosed rocks: the grains with straight boundaries have undergone recrystallization while the ones with sutured edges have not (Folk, 1974; Blatt and others, 1972). The deficiency of clasts of composition other than quartz and chert argues that the immediate source rock was recycled chert and sandstone beds, the sandstone was ultimately derived from acid plutonic terrain. It is possible that a warm climate, low relief, and extreme chemical weathering at the source area contributed to the monotonous mineralogy of the quartz granule conglomerate lithology.

Slate Lithology

The slate weathers from a dusky blue to pale blue, rust, or yellow color. The tint probably relates to the presence of pyrite and magnetite.

In hand specimen, individual grains are indistinguishable. In a few outcrops from the eastern slope of Beaver Mountain, the rock did fizz when hydrochloric acid was applied. In all other places carbonate is either absent or a very minor constituent. No pyrite is visible in hand specimen.

The slate is found as interbeds with the quartz granule conglomerate lithology and as discrete slope forming outcrops. The rock is homogeneous, containing no internal structures or textures. In some outcrops, two cleavage surfaces are apparent. As interbeds, the slate ranges from 2.5-10 cm in thickness. In separate outcrops the thickness of beds is harder to ascertain, since cleavage generally parallels bedding, and obscures any bedding plane fractures that might be present.

Age

Fossils are unknown from the coarser portions of the quartz granule conglomerate Unit. However, at one location on the eastern slope of the hill southeast of Basalt Hill, (G 851, Plate 1), a few graptolites were recovered from a slate outcrop. These were recognized no more precisely than as probable monograptids. Peculiar blotches and lumps are found on samples of the same outcrop. Their appearance suggests an organic origin but their affinity is unknown. The graptolites and the stratigraphic position of this unit above Unit A limit the age of the quartz granule conglomerate Unit to post- late Ludlow through Early Devonian. The Givetian limestone conglomerate contains limestone clasts of Early Devonian age, implying that carbonate sedimentation was prevalent during that time. For that reason a Late Silurian age is favored for the quartz granule conglomerate Unit.

Contacts and Thickness

Contacts of the quartz granule conglomerate Unit and older rocks have been discussed (p. 13, 21, and 31, this text). On the hill southeast of Basalt Hill, slates of the quartz granule conglomerate Unit underlie Tertiary (?) basalt with angular unconformity, although the contact is concealed by talus. The thickness of the quartz granule conglomerate Unit is estimated to be 275 m, as determined by cross-section A-A' (Plate 1).

Paleoenvironmental Interpretation

The quartz granule conglomerate Unit is composed of coarse and fine-grained marine clastics. Within the coarse-grained lithology, the sandstone matrix, bedding thicknesses of 33-150 cm, normal and reversed graded bedding, and crude horizontal stratification defined by clast orientation coincide with diagnostic features of organized conglomerates, turbidite facies A2 of Walker and Mutti (1973). The slate lithology resembles facies G, which consists of pelagic and hemipelagic shales. Various small outcrops show scattered structures and lithologies observed in other turbidite facies of Walker and Mutti, but facies A2 and G best characterize the unit as a whole.

Walker and Mutti (1973) concluded that organized turbidite conglomerates and associated pelagic shales may represent an inner fan channel deposit. Thus, the quartz granule conglomerate Unit was possibly deposited in such a marine fan channel environment.

This conclusion may be moot, considering that other facies related to submarine fan deposits described by Walker and Mutti (1973) are absent. The granule conglomerate beds laterally adjacent to moderately thick slate units may depict a channel or channels enclosed by terrigenous muds formed on inner channel positions. The thick slate beds, lacking laminations, may have been part of a continuous rain of hemipelagic material.

The lack of paleocurrent indicators in outcrop make it impossible to determine paleodispersal patterns of the quartz granule conglomerate Unit. The abundance of chert fragments, some containing 'ghosts' of radiolaria, indicates a recycled deep marine sedimentary source for at least a part of the unit. The polycrystalline and monocrystalline quartz grains may have multiple source terrains but are probably of immediate sedimentary derivation. These scanty data permit the following conjecture: during Late Silurian time, a local uplift occurred near the depositional basin of the quartz granule conglomerate Unit. The elevated terrain included Early Paleozoic rocks. Lower Cambrian quartzites and Ordovician slates and cherts in the area may have provided material for the Middle Paleozoic conglomerate unit. Cannibalization of local uplifted strata within a basin of sedimentation is not unique (Danner, 1970).

The problems inherent in such an interpretation follow.

Within the map area there is no transition from shallow water Ludlow-age limestones to coarse-grained rocks of the conglomerate unit. Rapid subsidence of this region, in conjunction with proximity to the uplifted area, may explain the lack of gradation from carbonates to terrigenous silicate clastics. If the source of granule conglomerate sediments were Lower Paleozoic formations, some fragments of Upper Cambrian limestones, which stratigraphically interrupt the Cambrian quartzites and the Ordovician slates, would be expected within the conglomerate unit. No such fragments have been found; however, this absence could be due to their destruction by chemical weathering which had little effect on siliceous clastics.

Givetian Limestone Conglomerate

Distribution

The Givetian limestone conglomerate crops out at the base of Limestone Hill, approximately 95 m west of the Boundary Dam Road. The outcrop consists of one ridge exposure and its consequent talus. This lithology was previously described by Dings and Whitebread (1965, p. 28) as occurring in a roadcut which has since been overgrown.

Lithology

The Givetian limestone conglomerate is polymictic, containing angular and rounded clasts of limestone, siltstone and mudstone (Figure 11). The large clasts are flattened, with an average 5:1 length/width ratio and generally align with bedding. The beds dip gently and are 15-35 cm in thickness.

Clasts

The most prevalent clasts, approximately 92 percent, are composed of dark-gray very finely-crystalline limestone. The average size of these clasts is around 4.5 cm, and the largest cobble found measured 12 cm in length. Very few fossils occur in hand specimen. Thin sections, however, show fauna to be fairly abundant. Crinoid columnals, echinoderm plates, and brachiopod and gastropod shells are present. The maximum size of the organisms is 1.5 mm in length. The matrix of the clasts is micrite, partially recrystallized to microspar. Commonly, the fossil outlines are blurred due to the lack of distinction between the microspar in the matrix and the recrystallized shell fragments. The brachiopod

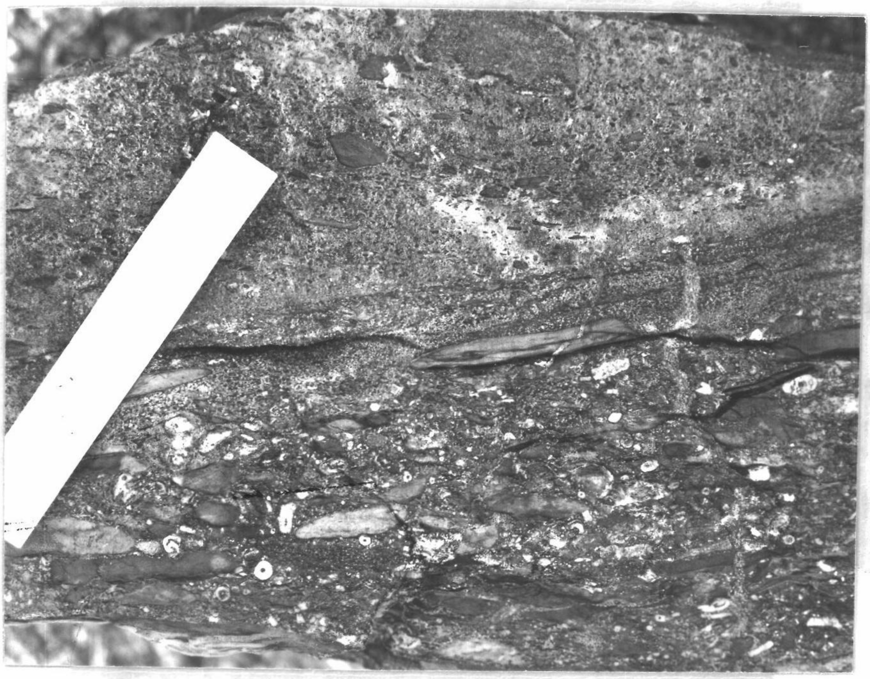

Figure 11. Sample of Givetian limestone conglomerate. Conglomerate bed with overlying cross-bedded calcareous sandstone. White strip is 15 cm long. Location: C 8224 (Plate 2).

shells and the crinoid ossicles are disarticulated but unbroken, possibly a result of current activity. The gastropod shells are whole. Elliptical pellets, approximately the same size as the shell material, are common.

Most of the limestone clasts contain no internal structure, but some pebbles are thinly laminated with quartz sand. Some thin laminae of brown mudstone are observable in thin section. Quartz grains and argillaceous material compose a 6 percent insoluble residue fraction.

Moderate-pink siltstone, brown mudstone and a few pebbles of dark-gray chert form the remainder of the clasts. The pebbles examined did not contain fossils.

Matrix

The matrix of the conglomerate is a light-gray quartz sand bioclastic limestone. The sand/carbonate ratio is approximately 3:2, in weight, as determined by the insoluble residue fraction. In some rocks the detrital sand and fossil debris has formed small clastic dikes which cross bedding planes.

Fossils in the matrix are larger than those found in the clasts, averaging 1 cm in length. Despite their more robust nature, the shells are still fragmented. The fauna is represented by crinoids, gastropods, brachiopods, fenestrate bryozoa, and tabulate coral fragments.

The sand particles are spherical frosted quartz grains, averaging 1/2 mm in diameter. Thin sections show that additional angularity of the grains has been generated by replacement of quartz by surrounding calcite cement. Calcite pseudomorphs after quartz are recognized, due to differing textures of the replacement calcite and the dirtier matrix calcite (Figure 12). This substitution process is the origin of the frosted appearance of the grains observed in hand specimen. Dissolution of silica and replacement by calcite will occur at warm temperatures and high pH levels, ≥ 9 (Walker, 1962). Biotite, as well as one euhedral zircon crystal, was identified as inclusions in the quartz. In addition, many grains display trails of globular opaque minerals.

The Givetian limestone conglomerate is interbedded with layers of dark-gray fine-grained limestone and calcareous sandstone. A gray non-fossiliferous mudstone crops out approximately 150 m to the north. Its relation to the conglomerate is unknown.

The calcareous sandstone is thinly bedded, and in some places cross-bedding is observable. Sparse fragments of crinoids

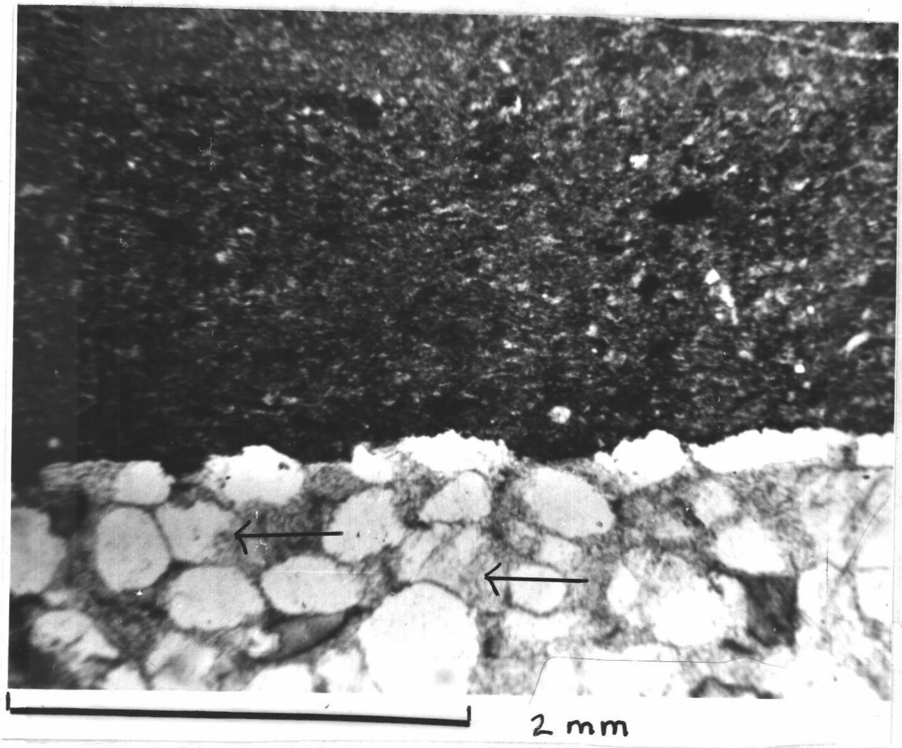

Figure 12. Givetian limestone conglomerate. Photomicrograph showing contact between a large structureless micrite clast (top of photo) and the sandy limestone matrix. Some quartz grains (indicated by arrows) show partial replacement by calcite. Uncrossed nicols. Location: C 8314 (Plate 2).

and brachiopods are seen in hand specimen.

Age

Conodonts recovered from the limestone clasts have diverse ages: Lochkovian, Emsian, and early Eifelian (Appendix I). No Silurian conodonts were reported from this unit. The sandy limestone matrix has produced conodonts of early Givetian age (Appendix I). The limestone conglomerate was deposited throughout the early and early late Givetian stage, incorporating erosional clasts of Lower and Middle Devonian rocks.

Contacts and Thickness

As part of the Limestone Hill block, the Givetian limestone conglomerate lies in fault contact with Ordovician rocks to the south. The nature of the contact between the conglomerate and the Givetian limestone is unknown. It is possible that parts of the conglomerate unit are gradational with the Givetian limestone.

The thickness of the limestone conglomerate is estimated at 80 m, based on the outcrop exposure and attitude of the beds.

Paleoenvironmental Interpretation

The Givetian limestone conglomerate provides insight into the Early to Middle Devonian. The clasts reveal that limestone sedimentation resumed at least as early as Lockhovian time and continued into the early Eifelian. The abundant micrite and unbroken small shell material in the clasts suggest quiet or low energy water conditions at shelf depths. An abrupt break in sedimentation occurred somewhere between early Eifelian and early Givetian time, at which point Lower and lower Middle Devonian rocks were eroded. Limestone deposition recommenced during the Givetian, as documented by the conglomerate.

Significantly, no limestone clasts containing Silurian conodonts were found. Rocks of this age escaped erosion, possibly protected by the resistant quartz granule conglomerate Unit.

The size of the eroded clasts (up to 12 cm), implies that these fragments were not transported a great distance from their source. Erosion of the quartz granule conglomerate Unit would furnish a ready supply of quartz. If this were the case, however, the limestone conglomerate would probably contain more chert fragments than it does.

Two related sequences of events may have produced the Givetian limestone conglomerate. It is possible that a local tectonic disturbance, similar to that which precipitated deposition of the quartz granule conglomerate Unit, elevated the terrain which had received limestone sedimentation throughout the Early and early Middle Devonian. This highland then experienced erosion.

Alternatively, exposure of the Lower and earliest Middle Devonian rocks might have arisen in response to a eustatic lowering in sea level unassociated with uplift. A combination of eustatic and tectonic movements may have acted on this region in the Middle Devonian.

Givetian Limestone

Distribution

The Givetian limestone unit occurs only as float and is mentioned, here, because of its age significance. The limestone appears as large blocks on the northern slope of Limestone Hill, topographically between the Givetian limestone conglomerate and the bedded limestone lithology of the Frasnian limestone.

Lithology

The Givetian limestone is a coarse-grained rock and weathers from a dark-gray color to light-gray. Differential solution weathering has left a ribbed surface on the limestone. This layering coincides with the orientation of fossils observed on a slabbed surface.

Examination of the rock in thin section reveals abraded and rounded allochems in grain support. Fragments range from 2-4 mm in length; consisting of approximately 51 percent fossil fragments, 40 percent sparry calcite cement, 5 percent micrite, 3 percent quartz, and a trace of opaques, such as pyrite.

The fossils are fragments of tabulate corals, crinoid ossicles, and other echinoderm parts, which were identified mainly from their property of uniform extinction of single crystals, disarticulated brachiopods, bryozoa, and rugosan calices. Monocrystalline carbonate overgrowths are in optical continuity with the fossil components.

Micrite occurs as subrounded clasts and as envelopes around particles. The latter phenomenon is indicative of the presence of relict boring algae or other boring organisms (Bathurst, 1975)

The sparry calcite cement and the monocrystalline calcite overgrowths around fossil fragments are a dirty gray color, producing an indistinct boundary between the cement and overgrowths in plane polarized light. The sparry calcite filling fractures is perceptibly lighter in color, suggesting that this cement is a later generation than the matrix and overgrowths. The presence of unaltered micrite in the rock denies the possibility that the spar is a product of aggrading neomorphism (Bathurst, 1975).

In thin section grains lose the semblance of orientation that appears in hand specimen. Among the larger grains, however, the long axes of the fossils are roughly aligned.

Both detrital and authigenic quartz is present in the Givetian limestone. Calcite cement replacement of the terrigenous grains is obvious, as evidenced by the embayed edges and pseudomorphs after quartz. It is likely that this substitution has released silica to contribute to authigenic quartz, which is sometimes found as chalcedony overgrowths on shell fragments, and replacing the centers in crinoid columnals.

The rock is poorly sorted, as determined by the method proposed by Folk (1962), where the standard deviation of grain size is greater than 1. There is no layering of grain size to suggest current transport. The Givetian limestone is labeled a grainstone or biosparite (Dunham, 1962; Folk, 1962).

Age

The Givetian limestone samples have yielded a rich conodont fauna, which place the age of this unit within the Polygnathus varcus Zone, which lies in the lower half of the Givetian stage. It is likely that the Givetian limestone is coeval with parts of the Givetian limestone conglomerate.

Paléoenvironmental

The sand and granule-size grains, poor sorting, rounding of allochems, fossil abundance, the spar:micrite ratio (8:1), and the presence of detrital quartz place the water energy level of deposition between moderately and strongly agitated (Plumley and others, 1962). Folk concurs (1962) that textural inversion involving rounding and poor sorting is produced at high energy levels. The fossils indicate clear normal marine waters of shelf depths. The evidence suggests that the Givetian limestone Unit was deposited at or near wave base. It is possible that parts of the underlying Givetian limestone conglomerate formed a carbonate bank and that the resulting shoaling waters acted as the transport medium.

Frasnian Limestone

Introduction

The Frasnian limestone Unit includes rocks which crop out of the crest of Limestone Hill. The name was so chosen because the outcrops have been dated by conodonts as Frasnian in age. The Frasnian limestone is the first known occurrence of Middle Paleozoic rocks in the Metaline District. The unit includes gray massive limestone and gray bedded limestone subunits.

Massive Limestone Subunit

Distribution

The massive limestone composes approximately 70 percent of the Frasnian limestone unit. This rock type forms prominent cliff exposures on the eastern side of Limestone Hill (Plate 2, Figure 13). Smaller outcrops occur on the southern and western

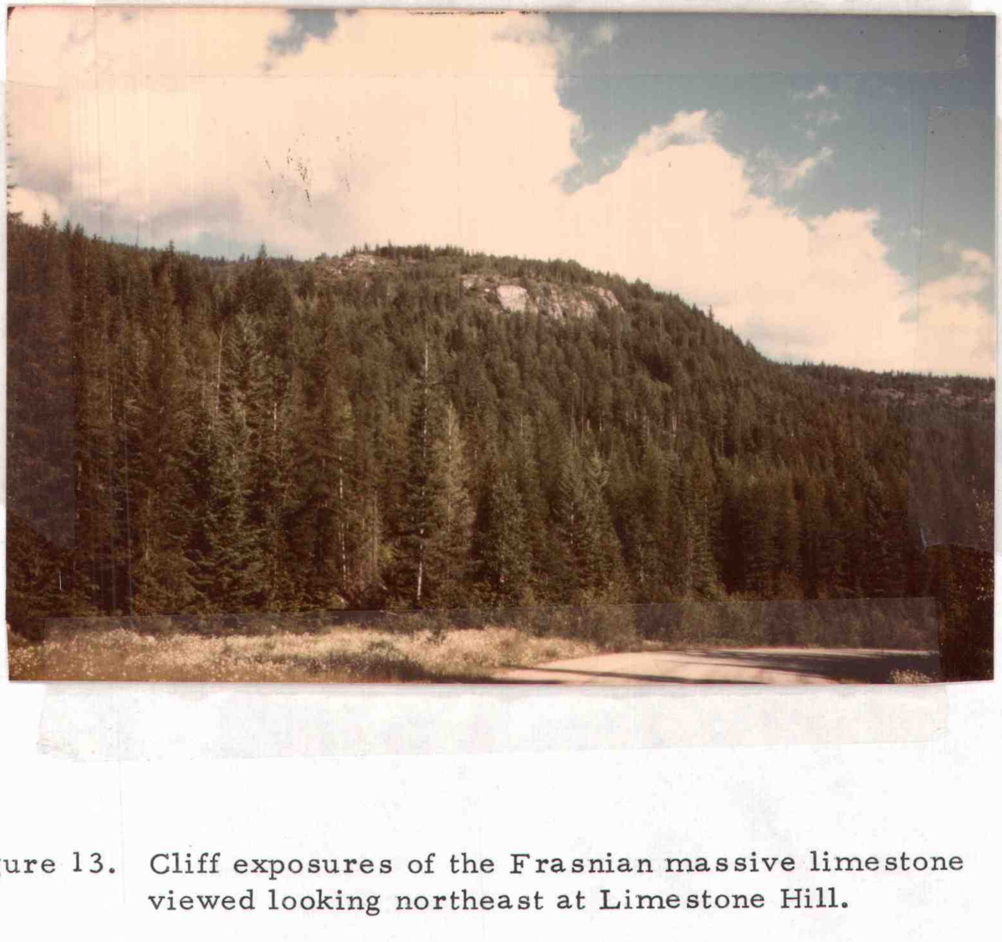

Figure 13. Cliff exposures of the Frasnian massive limestone viewed looking northeast at Limestone Hill.

sides of the hill.

Lithology

The color of the massive limestone is a monotonous medium-gray on both the fresh and weathered surfaces. Locally, argillaceous seams and veinlets of white calcite darken or lighten the shade of gray (Figure 14).

The limestone is coarse-grained and non-porous. Solution weathering has created a ribbed and bumpy surface on the rock. These bumps appear to be some resistant material, such as chert, but dissolve quickly when treated with dilute hydrochloric acid. Weathering and extensive diagenetic recrystalisation have left a minimum of recognizable sedimentary and biogenic features in the rock in outcrop. Macroscopic calcite crystals are clearly visible in hand specimen. Fossils are identifiable on weathered rock surfaces. Bryozoa are especially abundant near location C 7266 (Plate 2).

No distinct bedding features are present in the massive limestone. Thin argillaceous lenses suggest stratification in a few, widely scattered outcrops. The limestone is fractured prominently by steeply dipping NE and NW trending joints, producing a slabby appearance in many places.

Figure 14. Outcrop of the Frasnian massive limestone. Location: approximately 20 m south of C 7266 (Plate 2).

The massive limestone is a fairly pure carbonate rock. Samples from most locations yielded 1.5-5 percent insoluble residue fraction. The undissolved material is mostly clay minerals, mixed with a minor amount of authigenic quartz (Appendix II).

The limestone is grain supported and contains a variable amount of micrite and sparry calcite in the matrix (Table 2). Skeletal material makes up the majority of the grains. Whole sections of tabulate and rugosan corals, stromatoporoids, and bryozoa are visible in thin section. By contrast, brachiopods, foraminifera, echinoderms, trilobites, sponges, and coralinacean algae are recognized only as fragments, averaging 2 mm in length and are found within micrite. Ostracode shells are often preserved intact.

Where micrite or microspar is present, it contains pelletal material as well as shelly fossils. Angular and rounded micrite pellets are present in equal amounts. Except where micrite is visible, it is difficult to determine whether the microspar is neomorphic, recrystallized from micrite, or clastic, a calcisiltite.

Sparry calcite cement comprises a large portion of many rock specimens as observed in thin section. It is recognized as interstitial, rather than neomorphic, by the sharp boundaries between the fossil particles and the sparry calcite, and by the presence of plane interface boundaries between adjacent sparry calcite crystals

Table 2. Modal Analysis (500 points) of the Massive Limestone subunit of the Frasnian Limestone.

Constituent	Percent of each thin section		
	7267	9112	7142
Skeletal fragments	51.8	41.3	55.4
pellets	4.3	8.2	26
opaques	---	1.9	---
quartz	---	---	2.3
Micrite	---	9	8.2
calcisiltite or microspar	20.2	35.6	8.1
sparry calcite cement	23.7	4	---
Totals	100.0	100.0	100.0

Locality 7267: location C 7267, Plate 2.

Locality 9112 location C 7202, Plate 2.

Locality 7142: SW 1/4 NW 1/4 SW 1/4 sec. 16.

(Bathurst, 1975). Sparry calcite is also present as casts of shell material surrounded by micrite, and as cavity fillings within coral and bryozoa fragments.

Corals are most commonly imbedded in a matrix of calcisiltite or sparry calcite cement. In the instances where corals and stromatoporoids are found in contact with biomicritic or pelmicritic material, the coelenterates have acted as sediment traps. However, it is unclear just when this sediment accumulated. The association of corals and micrite may have occurred in a sheltered region protected from currents during growth, or in a post-growth stage.

The small southern-most outcrops contain a much higher percentage of silica and detrital clay minerals than the rest of the massive limestone exposures. Quartz sand commonly occurs as matrix enclosing larger fossils such as corals and crinoids. Small sandy detrital quartz lenses, less than 2.5 cm in thickness, can be traced up to 20 cm. Terrigenous siltstone and mudstone are present as clasts and as branching laminae within the rock. A count of 500 points from one slide shows the composition to be 28 percent sub-rounded and rounded medium sand-size monocrystalline quartz grains, 43 percent matrix of sparry calcite and silica cement, 12 percent chert clasts, 9 percent fossil fragments, 3 percent mud-stone, as pebbles, 2 percent dolomite, 2 percent hematite, and traces of mica and biotite.

Siltstone outcrops are present in two locales, lateral to the cliff outcrops on the north. Brachiopods were collected from red-brown calcareous siltstone at location B 751 (Plate 2).

Bedded Limestone Subunit

Distribution

The bedded limestone subunit of the Frasnian limestone grades into the massive limestone on the eastern side of Limestone Hill, and outcrops continue along the north side of the hill (Plate 2). All exposures are located at the break in slope.

Lithology

The bedded limestone weathers from a dark-gray color to medium-gray, light-gray, or white. The lighter-colored rocks are continually shaded and typically covered with thick green moss.

The grain size of the bedded limestone ranges from medium to coarse. Skeletal material constitutes the bulk of the rock, although terrigenous clastics are also very abundant, locally. In hand specimen bryozoa, crinoid fragments, tabulate corals, and solitary and colonial rugosan corals are easily recognized.

Bedding in the eastern-most outcrops is indicated by light brownish-gray layers of rock, 1-5 cm in thickness (Figure 15).

Figure 15. Outcrop of the calcareous sandstone within the Frasnian bedded limestone subunit. Location: southernmost outcrop of this unit, Limestone Hill (Plate 2).

Fossils are rare at these locales, and the rock may actually be classified as a calcareous sandstone. To the north, the sand content diminishes, but stratification is still obvious due to bedding plane fractures, and moderate pink siltstone lenses which parallel these cracks. Here, beds vary from 3-30 cm in thickness. The NE and NW fracture planes which prevailed in the massive limestone persist in the bedded limestone.

The insoluble fraction/total rock ratio is less consistent in the bedded limestone outcrops, as compared with the massive limestone. Insolubles fluctuate between 3 and 60 percent. Frosted quartz grains are recovered from the calcareous sandstone outcrops. The quartz is very similar to that which occurs in the Givetian limestone conglomerate (Figure 16). Most grains are well-rounded, averaging 1/2 mm in diameter. The grains are almost all monocrystalline and show fairly straight extinction. Many grains are micro-fractured and infilled with a brown substance, possibly an alteration of mafic minerals. Dust-sized particles and tiny needle-shaped inclusions cloud the quartz grain interiors. One inclusion each of hornblende and biotite was identified. The perimeters of the grains have corroded and been replaced by calcite.

Outcrops with less terrigenous clastic material contain fauna similar, although not in the same proportions, to that of the massive

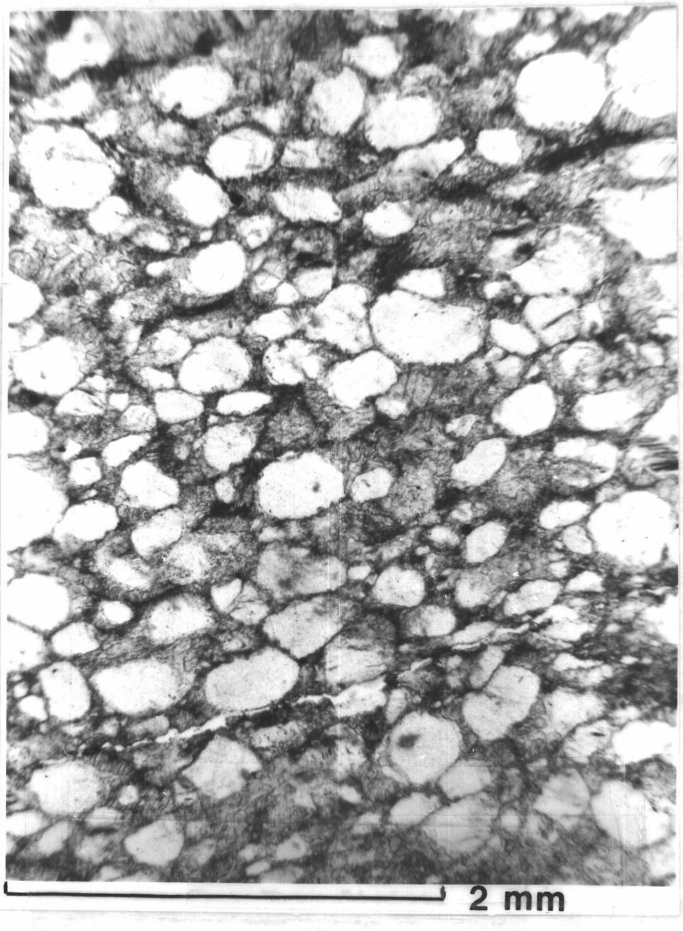

Figure 16. Photomicrograph of calcareous sandstone of the Frasnian bedded limestone subunit. Some quartz grains show replacement by calcite. Same location as as Figure 15.

limestone. Coelenterates are subordinate to crinoids and bryozoa. However, from the rocks examined, rugosan corals appear more abundant in the bedded limestone. In thin section, solitary rugosan corals are recrystallized and are identifiable by their shape, and the presence of tabulae, generally the only remaining recognizable internal structure. The fossils are not uniformly oriented, a result of disturbance during or soon after growth. All coelenterates collected were too recrystallized for specific identification (Oliver, 1976, personal communication).

Micrite also seems more common in the bedded limestone than in the massive limestone. It is usually found in the process of recrystallization to microspar. Suspended in this matrix are small fragments of brachiopod shells, echinoid spines, and crinoid ossicles. These micritic rocks are classified as wackestones or biomicrites (Dunham, 1962; Folk, 1962).

Age

A tabulation of fossils reported from the crest of Limestone Hill appears in Appendix I. Park and Cannon (1943) assigned rocks of Limestone Hill to the Devonian on the basis of fossils identified by G. H. Girty. Enbysk (1956) referred to corals collected from Limestone Hill and judged the age of the rocks to be Middle Devonian (Onondagan). Sorauf undertook field work in 1966. With the rugosan corals he collected and those from Enbysk's collection, he considered the top of Limestone Hill to be of probable Givetian age (Sorauf, 1972).

Dr. Brian Chatterton's study of conodonts from samples collected by the author during the summer of 1975, has shown that the age of the limestone is Late Devonian. Location C 7202 afforded a particularly diverse fauna and placed the age of this outcrop within the lower gigas Zone. Corals from the same exposure collected by Dr. Alan Pedder, support the Frasnian age determination (Pedder, 1976, personal communication).

Brachiopods were collected from location B 751 (Plate 2) and silicified brachiopods were retrieved from several float fragments. Dr. A. J. Boucot states that "the general aspect of the faunas is completely consistent with the Frasnian age indicated by the conodonts recovered from outcrop samples, but a Givet or even Eifel age could not be excluded from a consideration of the brachiopods alone".

Contacts and Thickness

The massive and bedded limestone subunits are laterally gradational. In some places massive limestone also overlies the bedded limestone. The transition may be prefaced by a small influx of clastic quartz in the massive limestone.

A fault between the Frasnian limestone and the older rocks at Limestone Hill is speculative, and drawn to explain the difference in bedding attitudes between the Frasnian limestone and the Givetian limestone conglomerate. It is very possible, considering the lack of pattern in the strike and dip readings, that slumping at the crest of the hill has influenced the attitudes now observed.

On Plate 2, the contact between the Frasnian limestone and Quaternary glacial sediments is drawn below the appearance of outcrops. The contact is placed on the basis of smaller outcrops which do not appear on the map. As do the older rocks at Limestone Hill, the Frasnian limestone lies in fault contact with Ordovician and Silurian rocks to the south.

Assuming that the rocks are nearly flat lying, the thickness of the massive limestone is estimated as 115 m. The accumulation of bedded limestone may reach 95 m in thickness.

Paleoenvironmental Interpretation

Enbysk (1956) termed the faunal assemblage at Limestone Hill 'reefoid'. Structural relationships and forest cover limit the extent to which a reef model may be measured at this locale. The massive limestone now stands topographically higher than the bedded limestone, but to imply that this was the situation during Devonian time would require more precise structural, stratigraphic and paleontologic data. Initial topographic relief would be established if one knew that the massive limestone were older than the bedded limestone. This would assume that erosion and faulting had not altered the picture.

Facies differences are apparent from the internal structure of the limestones. The massive limestone possesses no true bedding surface while the bedded limestone is so named because of its stratified nature. These subunits may exist as the reef core and reef flank facies.

A high degree of current activity is implied by the amount of coarse-grained clastic material and sparry calcite cement. The dominance of framework-building organisms, such as stromatoporoids, tabulate corals and bryozoa, rather than fragmented skeletal grains, suggests that the fauna formed a coherent structure that resisted wave energy.

Within the massive limestone brachiopods, crinoids, and ostracodes are mostly found in micrite or calcisiltite. The diminuitive size of these organisms, combined with the fine grain size of the matrix, indicates that these animals did not endure turbulent water conditions. Boucot states that 'the silicified brachiopods are dominated by articulated specimens of a finely ribbed species of *Atrypa*, which is consistent with a relatively quiet although far from still-water environment. . . The single siltstone sample consists entirely of an ambocoelid which indicates an ambocoelid community with relatively quiet water, Benthic Assemblage 4 or 5 indicated.' These quiet water organisms probably lived in regions sheltered by the framework-builders.

A firm substrate is advantageous, though not essential, to the inception of reef growth (Cloud, 1952; Steers, 1928). The accumulation of the Givetian limestone conglomerate and the Givetian limestone at the base of Limestone Hill might have provided a convenient foundation on which the Frasnian organisms began growth.

Olivine Trachybasalt

Distribution

Remnants of an olivine trachybasalt flow crop out for approximately 875 m at Basalt Hill and the small hill to the southeast (Plate 1). This is the only occurrence of basalt within the Metaline District. Rocks of similar lithology crop out in the Northport District, to the west.

Lithology

The basalt is aphanitic to finely crystalline and weathers from a dark gray-green color to orange-brown. Dings and Whitebread

(1965) report seeing vesicles in a part of the basalt at the northern end of the larger body at Basalt Hill.

The rock is very resistant and requires several hammer blows to break. The talus comprises blocky pieces of rock which conceal the contact between the igneous body and the Silurian rocks. The basalt supports very little vegetation.

Mineral composition includes "33% clinopyroxene and olivine, 22% sodic plagioclase, 16% glass, 13% palagonite, and 13% orthoclase, occurring interstitially or poikilitically enclosing plagioclase and clinopyroxene. The remaining few percent consists of magnetite and/or ilmenite, apatite, biotite and limonite" (Dings and Whitebread, 1965).

The trachybasalt is believed to be part of a localized flow that was emplaced along a northwest-trending zone of weakness related to faults of a similar trend which lie to the west. Dings and Whitebread state that the absence of bodies of trachybasalt in the higher hills to the west and elsewhere in the district suggests a local origin for these bodies, rather than that the rocks are remnants of a widespread flow that formerly covered a larger part of the district.

Age

The trachybasalt post-dates the Devonian rocks of the area, and is presumed to be Tertiary in age.

Contacts and Thickness

The trachybasalt overlies rocks of the Silurian quartz granule conglomerate with angular unconformity (p. 44, this text.)

The thickness of the unit is 60 m based on the assumption that the rocks are flat-lying.

Quaternary Glaciofluvial Deposits and Till

Distribution

Glacial debris is omnipresent in the map area, ranging in size from silty material to boulders. In cuts along the Boundary Dam Road, the sediments are weakly consolidated. These outcrops appear to be of glaciofluvial origin, as a crude grading of particle size indicates water transport.

Virtually every rock unit in northeastern Washington has been touched by Quaternary glaciers, as evidenced by a cursory examination of float. The largest boulders found, approximately 2 m in diameter, are of diorite and granodiorite.

Glacial debris is found at the highest elevations of the map area, although its presence is not so dominating as in the lowlands. Park and Cannon (1943), report finding a granitic boulder at Crowell Ridge (outside of the map area), at an elevation of 1900 m.

STRUCTURE

Introduction

The structure of the map area is probably more complex than the cross sections show. Several stages of deformation produced folding and faulting, as well as foliation in the more argillaceous rocks. The dominant trends of structures are NE-SW and N-S.

Folding

The few areas where bedding attitudes can be followed show these regions to be folded into structures measuring 300 m or more from crest to crest. The folds are pictured as symmetric (Plate 1), but locally, faults may influence the attitudes of the limbs. Small-scale folds are visible in hand specimens of the argillites of Unit A.

Folds are best illustrated around Basalt Hill and Horsefly Hill. Section A - A' (Plate 1) crosses synclinal structures whose axes trend N - S. In this region there are also a number of bedding attitudes striking E - W. This may indicate more than one period of folding or could result from the relative incompetence of slate beds, which were subject to more intense deformation between the conglomeratic beds of the quartz granule conglomerate Unit. Many cleavage planes parallel the trend of bedding, which is characteristic of axial plane cleavage. However, since slate of the quartz granule conglomerate displays two cleavage directions in some outcrops, it is likely that readings do not consistently record the same cleavage within the rock. Two cleavage directions tend to support the hypothesis of multiple folding episodes.

At Horsefly Hill the fold axes trend NE. At location G 972, Ordovician and Silurian graptolites were recovered from the same outcrop. Section B - B' (Plate 1) reveals the crest of an anticline at this locale. If the Ordovician rocks are the core of an anticline that has reached the surface, then a facies change occurs between this locale and Ordovician slates to the east.

The lithologies of the Ordovician rocks on the eastern slope of Brush Ridge change from limestone and siltstone on the north to black slate farther south. It is possible that the Brush Ridge region and Horsefly Hill are broadly warped in a N - S direction. Alternatively, the lithology difference may be another possible instance of facies change.

Faults

Faults within the map area are visible as lineaments on aerial photographs, or are inferred by the juxtaposition of different-aged rocks. Locally, tectonic breccias indicate some rock displacement. Steeply dipping normal faults characterize the region.

The major structures are briefly discussed with reference to Figure 17.

Fault 1 trends NNW from the southern slope of Beaver Mountain to the southern slope of the hill west of Basalt Hill. Ledbetter Formation limestones and siltstones are in contact with rocks of the Late Silurian quartz granule conglomerate. A calcareous siltstone breccia crops out at the extreme ends of the fault. Displacement along the fault is estimated to be between 250 and 670 m at Beaver Mountain, but is considerably less at the northern limit, where the contact is between Ludlow age limestones and the quartz granule conglomerate Unit.

Fault 2 is also visible on aerial photos and trends N-S from Beaver Mountain to Everett Creek. Topographic contours follow the trend of this fault. Strata of the quartz granule conglomerate Unit on the west lie adjacent to Ludlow age limestones of Unit A. Net slip along this fault is not very great and probably does not exceed 60 m.

Fault 3 trends nearly E - W and forms the northern boundary of Fault 2. Everett Creek follows this course. Fault 3 separates Llandovery and Wenlock age siltstones on the north from Ludlow age limestones on the south. Displacement may be as much as 175 m along this fault.

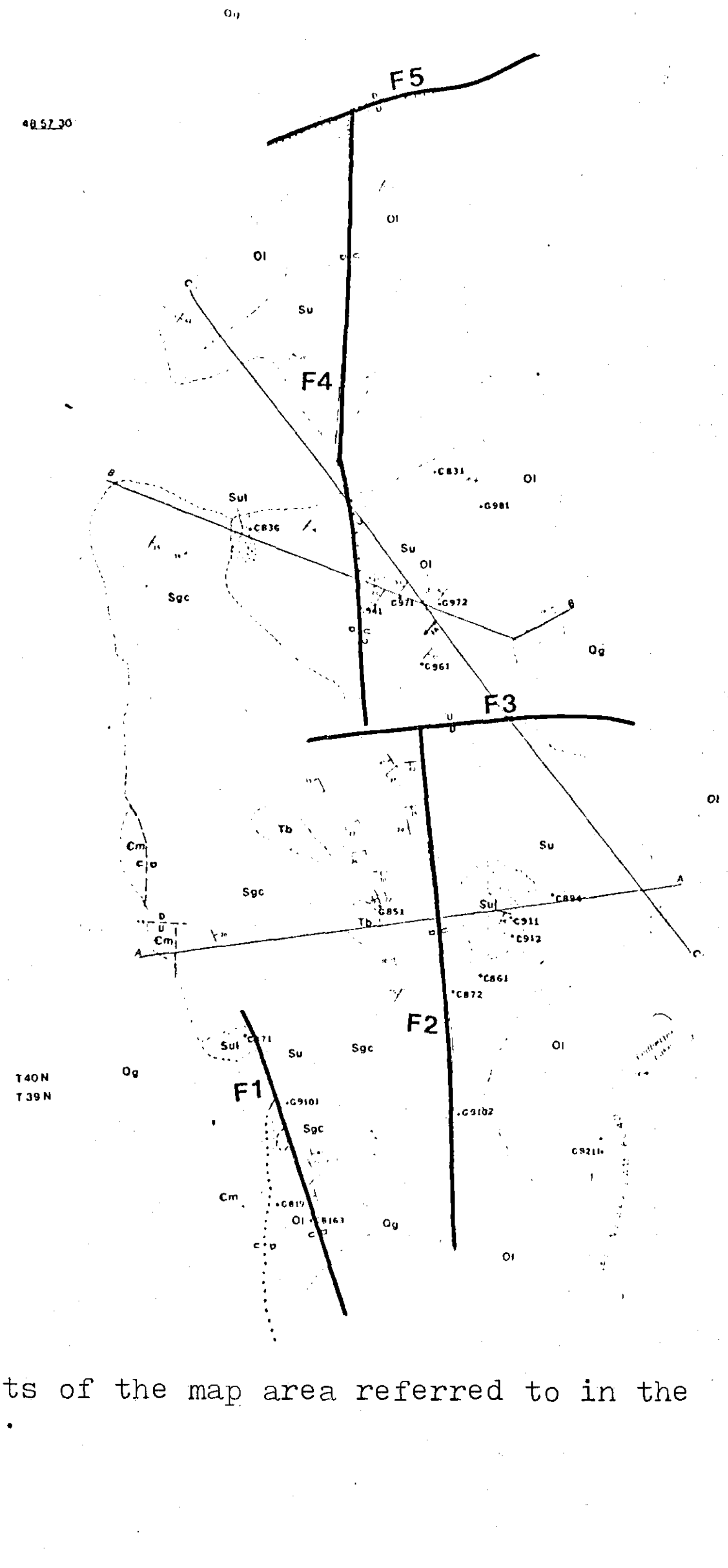

Figure 17. Faults of the map area referred to in the text.

At Brush Ridge Ordovician rocks are in contact with Silurian siltstones. Fault 4, trending N-S, is inferred to explain the attitudes of the rocks on either side of the contact. This fault is hypothetically extended southward where it parallels the trend of the valley between Horsefly Hill and the hill to the west. Fault 4 was possibly once connected with Fault 2, which follows the same general trend, and has since been offset by Fault 3. If extension of this fault is more than theoretical, proximity to this structure could have produced the abrupt change in bedding attitudes observed on the southwestern side of Horsefly Hill (Plate 1). Displacement on Fault 4 is about 25-145 m, considering that the fault juxtaposes Upper Ordovician and Lower Silurian rocks at Brush Ridge.

Limestone Hill lies within a downthrown block defined by E - W trending faults. Fault 5 separates Devonian rocks on the north from Ordovician rocks on the south. The northern extension of this fault block lies beyond the map area. Minimum displacement along Fault 5 is 670 m.

Structural History

Four stages of probable Mesozoic age deformation are recorded in the Metaline District (Dings and Whitebread, 1965). Folding is believed to be a product of the first stage of deformation, when compressive forces acted in a NW-SE direction. NW-SE tensional forces developed soon after, and it is speculated that Fault 5, bounding Limestone Hill with Ledbetter Formation rocks to the south, developed at this time.

Faults 1, 2 and 4 were active during the second pulse of deformation of the area. At this time, E-W tensional forces produced steeply dipping normal faults throughout the Metaline District (Dings and Whitebread, 1965).

If the structure witnessed around Basalt Hill were influenced by a second episode of folding, the folding occurred during the third stage of deformation, when N-S compressional forces were dominant. The hypothetical warping of the Brush Ridge rocks would have happened at the same time.

Fault 3 quite likely developed during stage 4. Faults of this age do not have a well defined trend, although most trend W to NW (Dings and Whitebread, 1965). It is possible that movement along Fault 5 was reinitiated during this stage.

Another theory which would explain the occurrence of Ordovician siltstones at Horsefly Hill, would have Ordovician siltstones from the Brush Ridge area thrust over Silurian siltstones to the south, and then subsequently eroded. The unique pod of Ordovician siltstones at Horsefly Hill would remain as a klippe. This idea would solve the lithologic dissimilarities between the Ordovician rocks at Horsefly Hill without relying on a facies change. The hypothetical thrusting would have occurred during the third stage of deformation of the Metaline District, when compressive forces acted in a N-S direction. This thrusting could also account for reactivation of movement along Fault 5.

SUMMARY AND CONCLUSIONS

The Silurian and Devonian rocks in the Limestone Hill-Beaver Mountain area represent gradually shoaling conditions, interrupted twice by tectonic and/or eustatic oscillations. As do the Ordovician strata, the Lower Silurian rocks contain graptolites, but the lithology is distinguished by a coarser grain size, lighter color, and an increased amount of carbonate cement, indicating more oxidizing environments of higher current activity. The Ludlow age carbonate banks are a manifestation of a shallowing trend, accommodating continental shelf faunal assemblage.

The quartz granule conglomerate Unit depicts a break with this pattern during Ludlow-Lochkov time. Local uplift nearby caused erosion of Lower Paleozoic rocks, subsequently redeposited in the map area as submarine fan deposits. This region probably subsided in harmony with the neighboring uplift.

The Givetian limestone conglomerate records another nearby tectonic uplift. The limestone clasts in the conglomerate reveal limestone deposition in Lochkovian-Eifelian time. During middle Eifelian-early Givetian time, uplift occurred, possibly concommitant with regression of the Middle-Devonian sea. Limestone deposition resumed sometime in the Givetian. This hiatus is temporally correlative with orogenies postulated to have affected southeastern

Alaska, western and central Washington, and the eastern Paleozoic belt of the California Klamath Mountains (Boucot and others, 1972). It is also analagous to the Eifelian-Givetian discontinuity found in southeastern British Columbia and Alberta, produced by a eustatic change in sea level (Belyea and Norford, 1967; Bassett and Stout, 1967).

The Frasnian buildup at Limestone Hill is coeval with some Upper Devonian reefs in southeastern British Columbia and Alberta (Belyea, 1958). A late Devonian rise in sea level may have contributed to reef growth (Johnson, 1971).

It has been suggested that the Silurian-Devonian rocks of the map area are allochthonous blocks, sliding in from Idaho during Late Paleozoic orogenesis (Yates, 1970). This idea seems unlikely, since, except where the rocks are fault bounded on the west (Dings and Whitebread, 1965), the stratigraphic succession is preserved: Ordovician, and Lower, Middle and Upper Silurian rocks occur in depositional contact. Limestone Hill is rather anomalous. The Givetian limestone conglomerate contains clasts of Lower Devonian rocks, whereas no Lower Devonian outcrops are present in the map area. However, if allochthonous, it would be conjecture at best, to attempt to restore Limestone Hill to its original locale. The closest known Lower Devonian rocks lie in the Fernie Map area, British Columbia (Leech, 1958; Figure 2, this text).

Paleogeographically, the rocks of the map area are consistent with Yates' conception of the Kootenay Arc rocks as a miogeosynclinal facies (Yates, 1970). No Paleozoic volcanics are present to imply the setting was a marginal basin or island arc environment.

Post-Devonian history is vague. Carboniferous limestones and dolomites occur to the south of the map area (Miller and Clark, 1975) and it is likely that deposition took place within the map area during at least part of the Late Paleozoic. Whatever rocks may have been deposited were eroded pre-Tertiary time, before a localized trachybasalt flow partially covered the map area.

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APPENDICES

APPENDIX I

Faunal Lists and Localities

FAUNAL LISTS AND LOCALITIES

All fossil localities lie within the Boundary Dam and Abercrombie Mountain 7.5 minute quadrangles, Washington. Specific samples are located with reference to Plate 1.

Identification and age assignments are as follows:

Conodonts: Dr. Brian D. E. Chatterton
Graptolites: Dr. William B. N. Berry
Brachiopods: Dr. A. J. Boucot
Corals: Dr. William A. Oliver

CONODONTS:

Unit: Ledbetter Formation

Sample: C 8163

Fossils: Amorphognathus sp. (1 poor and incomplete specimen)

Age and Comments: Middle Ordovician-Earliest Silurian

Unit: Unit A, limestone

Sample: C 836

Fossils: Panderodus simplex (Branson and Mehl)

Age and Comments: Silurian-Lower Devonian

Sample: C 861

Fossils: Ozarkodina confluens (Branson and Mehl)
Ozarkodina sp. indet.
Panderodus gracilis (Branson and Mehl)
Panderodus simplex (Branson and Mehl)
Delotaxis sp. indet.

Age and Comments: Ludlovian

Sample: C 871

Fossils: Pedavis latialata (Walliser)
Ozarkodina sp. indet.
Ozarkodina aff. O. excavata (Branson and Mehl)

Age and Comments: Ludlovian-latialatus Zone

Sample: C 872

Fossils: Ozarkodina confluens forma Klapper and Murphy, 1975
Ozarkodina aff. O. excavata (Branson and Mehl)
Panderodus gracilis (Branson and Mehl)
Panderodus simplex (Branson and Mehl)

Age and Comments: Ludlovian-? late Ludlovian

Sample: C 882

Fossils: Ozarkodina n. sp. B Klapper and Murphy, 1975
Ozarkodina aff. O. confluens (Branson and Mehl)
Delotaxis sp. indet.
Panderodus gracilis (Branson and Mehl)
Panderodus simplex (Branson and Mehl)

Age and Comments: Ludlovian-siluricus Zone or slightly younger

Sample: C 894

Fossils: Ozarkodina n. sp. B Klapper and Murphy, 1975
Ozarkodina aff. O. excavata (Branson and Mehl)
Delotaxis sp. indet.
Panderodus simplex (Branson and Mehl)

Age and Comments: Ludlovian-siluricus Zone or slightly younger

Sample: C 911

Fossils: Panderodus simplex
Ozarkodina excavata excavata (Branson and Mehl)

Age and Comments: P. simplex ranges from Silurian - Lower Devonian. O. excavata excavata, according to Klapper in Ziegler et al. (Catalogue of Conodonts), ranges from the Silurian (patula Zone) to the Lower Devonian (lower Emsian). This form may not range below the crassa Zone. The specimens look slightly more Devonian than Silurian, but since this species is highly variable, that does not mean much. The species is referred to as Spathognathodus inclinatus inclinatus (Rhodes) in form terminology (the P element).

Sample: C 912

Fossils: Ozarkodina confluens forma Klapper and Murphy, 1975.
Panderodus simplex (Branson and Mehl)

Age and Comments: Ludlovian-? Upper

Sample: C 981

Fossils: Ozarkodina n. sp. B Klapper and Murphy, 1975.
Kockelella variabilis Walliser
Delotaxis excavata (Branson and Mehl)
Panderodus simplex (Branson and Mehl)

Age and Comments: Ludlovian-ploeckensis to siluricus Zone (probably siluricus)

Unit: Givetian limestone conglomerate

Sample: C 8224 - probably from matrix

Fossils: Polygnathus aff. P. pennatus Hinde
Polygnathus parawebbi Chatterton
Polygnathus linguiformis linguiformis Hinde

Icriodus latericrescens latericrescens
(Branson and Mehl)

Age and Comments: early Givetian - probably varcus Zone

Sample: C 8224 - probably from clasts

Fossils: Belodella devonica (Stauffer)
Panderodus simplex (Branson and Mehl)
Ozarkodina remscheidensis? (Ziegler)
Polygnathus dehiscens Philip and Jackson
Pandorinellina expansa Uyeno and Mason
Polygnathus n. sp. A Klapper and Johnson, 1975

Age and Comments: O. remscheidensis? and P. dehiscens are possibly Lochkovian in age. P. expansa is is Emsian and Polygnathus n. sp. A Klapper and Johnson suggests an early Eifelian age.

Sample: C 8314

Fossils: fragments of Polygnathus aff. P. dengleri Bischoff and Ziegler

Age and Comments: Givetian - this specimen suggests a late rather than early Givetian age but since early Givetian conodont faunas are very poorly known in North America . . . I presume this form must range down into the varcus Zone.

Sample: C 8314 - clast

Fossils: Ozarkodina aff. O. johnsoni (Klapper)

Age and Comments: Lochkovian (Fauna 4)

Sample: C 8314 - clast

Fossils: Pandorinellina exigua exigua (Philip) transitional to
P. exigua philipi (Klapper)
Polygnathus inversus Klapper and Johnson

Age and Comments: Emsian

Sample: C 8314 - clast

Fossils: Icriodus huddlei Klapper and Ziegler
Polygnathus perbonus (Philip)
Pandorinellina optima (Moskalenko)
Icriodus bilatericrescens Ziegler

Age and Comments: Emsian

Sample: C 8314 - clast

Fossils: Pelekysgnathus glenisteri Klapper

Age and Comments: Emsian

Sample: C 8314 - clast

Fossils: Polygnathus perbonus serotinus Telford = P. perbonus n. subsp. D. Perry et al., Klapper and Johnson
Pandorinellina steinhornensis (Ziegler)

Age and Comments: Emsian / earliest Eifelian

Sample: C 8314 - clast

Fossils: Pandorinellina expansa Uyeno and Mason
Icriodus aff. I. expansus (Branson and Mehl)
Polygnathus linguiformis linguiformis forma Bultynck, 1970.

Age and Comments: early Eifelian

Sample: C 8314 - clast

Fossils: Polygnathus aff. P. angustipennatus

Age and Comments: Eifelian - ? mid to late

Sample: C 8314 - clast

Fossils: Panderodus unicostatus (Branson and Mehl)
Panderodus simplex (Branson and Mehl)
Panderodus gracilis (Branson and Mehl)
Belodella devonica (Stauffer)
Coelocerodontus sp.

Age and Comments: long-ranging forms

Comments on clasts: the conodonts from clasts of Emsian age are much more abundant than the oldest taxa; and Pandorinellina expansa, an early Eifelian form, is probably the most abundant taxon in these clasts (suggesting that most of the clasts are early Eifelian and they decrease in number toward older ages. The specimens of Polygnathus aff. P. angustipennatus is very well preserved, and probably came from a clast. This species is normally regarded as a late Eifelian form, but this specimen is not so close to the type specimen that it could not be an early form of this species (say, a late early Eifelian form).

Unit: Givetian limestone

Sample: C 9117

Fossils: Polygnathus linguiformis linguiformis Hinde
Polygnathus varcus Stauffer
Polygnathus xylus Stauffer
Polygnathus eiflius Bischoff and Ziegler
Polygnathus aff. P. decorosus Stauffer
Icriodus aff. I. expansus (Branson and Mehl)

Age and Comments: Givetian - Polygnathus varcus Zone

Unit: Frasnian limestone

Sample: C 7192

Fossils: *Polygnathus* aff. *P. xylus* Stauffer
Belodella devonica (Stauffer)

Age and Comments: Givetian to Frasnian

Sample: C 7201

Fossils: *Polygnathus xylus* Stauffer

Age and Comments: Givetian to early Frasnian

Sample: C 7202

Fossils: *Polygnathus decorosus* Stauffer
Polygnathus webbi Stauffer
Polygnathus normalis Miller and Youngquist
Ancyrodella lobata Branson and Mehl
Ancyrodella triangularis
Coelocerodontus aff. *C. klapperi* Chatterton
Palmatolepis delicatula delicatula Branson and Mehl
Palmatolepis foliacea Youngquist
Palmatolepis gigas Miller and Youngquist
Polygnathus unicornis Muller and Muller
Polygnathus brevis Miller and Youngquist

Age and Comments: Frasnian - lower *gigas* Zone

Sample: C 7231

Fossils: *Coelocerodontus* sp. indet. ozarkodinan element

Age and Comments: Ordovician - Devonian

Sample: C 7266

Fossils: Ancyrodella aff. A. rotundiloba (Bryant)
Icriodus symmetricus Branson and Mehl

Age and Comments: Frasnian - probably early

Sample: C 7267

Fossils: Polygnathus pennatus Hinde
Ancyrodella ? sp. indet.
Polygnathus sp. indet. ligonodiniform element

Age and Comments: probably early Frasnian

Sample: C 821

Fossils: Polygnathus xylus Stauffer
Icriodus symmetricus Branson and Mehl
Polygnathus decorosus s.l. Stauffer

Age and Comments: ? Givetian - probably Frasnian

Sample: C 951

Fossils: Ancyrodella aff. A. lobata Branson and Mehl

Age and Comments: Frasnian

Sample: C 961

Fossils: Polygnathus decorosus Stauffer
Icriodus nodosus s.l. (Huddle)

Age and Comments: probably Frasnian, possibly Givetian

GRAPTOLITES

Unit: Ledbetter Formation

Sample: G 819

Fossils: Climacograptus sp. cf. C. modestus
Dicellograptus sp. ? D. gurleyi
Diplograptus cf. D. multidens compactus
Glyptograptus sp. cf. G. teretiusculus type
Orthograptus sp. probably of the O. calcaratus type
leptograptid stipes?

Age and Comments: Middle Ordovician, in span of N. gracilis, C. bicornis zone

Sample: G 9211

Fossils: Dicranograptus cf. D. kirki
Glyptograptus sp.
Orthograptus sp. probably of the O. calcaratus type
Orthograptus sp. probably O. pageanus

Age and Comments: late middle Ordovician, zone 13

Sample: G 9211a

Fossils: Dicranograptus sp.
Orthograptus quadrimucronatus
Glossograptus sp., possibly hinksii
Diplograptus sp. cf. D. multidens compactus
Diplograptus ingens T.S. Hall

Age and Comments: approximately zone 13, Late Ordovician. D. ingens T.S. Hall, new to North America - previously recorded from Australia

Sample: G 972

Fossils: Climacograptus supernus
Climacograptus bicornis longispina
Climacograptus hvalross?
orthograptid

Age and Comments: latest Ordovician - zone 15

Unit: Unit A, argillite

Sample: G 981

Fossils: Cyrtograptus cf. C. lapworthi
Monograptus priodon
Monograptus spiralis
Monoclimacis sp.
retiolitid?

Age and Comments: Late Llandovery - zone of M. spiralis

Sample: G 961

Fossils: Monograptus spiralis
Monograptus priodon

Age and Comments: Late Llandovery - zone of M. spiralis

Unit: Unit A, siltstone

Sample: G 941

Fossils: Monograptus flemingii
Monoclimacis flumendosae ?
Pristiograptus sp. (possibly P. praedubius)
Monograptus sp. (possible streptograptid)

Age and Comments: Probably Wenlock

Sample: G 971

Fossils: Monograptus sp. (close to M. flemingii, and clearly of the M. flemingii-M. priodon group)

Age and Comments: Late Llandovery - Wenlock

Sample: G 9101

Fossils: monograptids - possibly monclimacids and M. priodon types

Age and Comments: Silurian - possibly in span of late Llandovery - Wenlock

Sample: G 9102

Fossils: monograptid

Age and Comments: Silurian - Early Devonian

Unit: Quartz granule conglomerate unit, slate

Sample: G 851

Fossils: probable monograptids

Age and Comments: Silurian - Early Devonian

BRACHIOPODS

Unit: Frasnian limestone

Sample: B 751

Fossils: ambocoelid

Silicified brachiopods from limestone float blocks

Sample: Block 1

Fossils: *Atrypa* (fine ribbed), rhynchonellid, smooth gypidulid, *Cyrtina*, dalmanellid

Sample: Block 2

Fossils: *Atrypa* (coarse-ribbed)

Sample: Block 3

Fossils: *Atrypa* (coarse-ribbed), rhynchonellid

Sample: Block 4

Fossils: tabulates, *Atrypa* (fine-ribbed). *Cyrtina*, *Leptaena* "*rhomboidalis*", *Carinatina*? or a douvillinid, rhynchonellid, orthotetacid, unidentified brachiopods, dalmanellids, *Teichertina*? sp.

Sample: Block 5

Fossils: unidentified brachiopods, gypidulid, Atrypa (fine-ribbed), dalmanellid, orthotetacid

Sample: Block 6

Fossils: rhynchonellid, gypidulid, Cyrtina, Atrypa (fine-ribbed), unidentified brachiopods, fenestellid, dalmanellid

Sample: Block 7

Fossils: Cyrtina, unidentified brachiopods, fenestellid, Carinatina? sp., rhynchonellid, Atrypa (fine-ribbed), tabulates

Sample: Block 8

Fossils: Atrypa (fine-ribbed), Atrypa (coarse-ribbed), unidentified brachiopods, gypidulid, rhynchonellid, dalmanellids, strophodontids, Cyrtina

Age and Comments: The brachiopods provide little in the way of precise age determination except to make it clear that a post-Frasnian age is impossible. The general aspect of the faunas is completely consistent with the Frasnian age indicated by the conodonts recovered from outcrop samples, but a Givet or even Eifel age could not be excluded from a consideration of the brachiopods alone. The brachiopods are not abundant, are tectonically sheared to a certain extent, and in general, are not good materials for age determination. The silicified brachiopods are dominated by articulated specimens of a finely-ribbed Atrypa, which is consistent with a relatively quiet, though far from still-water environment. Diversity of these silicified faunas is about six species each, but the small size of the samples precludes attaching much significance to this except as a lower limit. A Benthic Assemblage 3 or 4 seems reasonable with an Atrypa Community assignment. B 751 consists entirely of an ambocoelid which indicates an ambocoelid community with relatively quiet water, Benthic Assemblage 4 or 5 conditions indicated.

CORALS

Unit: Frasnian, bedded limestone

Sample: S 9131

Fossils: Ramose stromatoporoid?
Alveolites sp.
Favosites sp.
Pachyfavosites ? sp.
Thamnopora sp.

Age and Comments: a few of the tabulates are similar to forms occurring in Alaska and Siberia

Sample: S 9132

Fossils: tabulate fragments
Pachyfavosites? sp.

Sample: S 9133

Fossils: Ramose stromatoporoid? cf. _Stachyodes_

Sample: S 9134

Fossils: Ramose stromatoporoid ? cf. _Stachyodes_

Age and Comments: This is a large colony but preservation is poor. It is probably a stromatoporoid, and if so, is close to _Stachyodes_, a typically Middle-Upper Devonian genus.
Fragmental specimens in S 9133 and S 9135 are probably the same; fragments in S 9131 and S 9136 are possibly the same.

Sample: S 9135

Fossils: Ramose stromatoporoid? cf. Stachyodes
Rugose coral fragments (indet.)
Favosites sp.

Sample: 9136

Fossils: Ramose stromatoporoid
Thamnopora ? sp.
Bryozoan?

Unit: Frasnian, bedded limestone

Age and Comments: The samples from the north side of Limestone Hill, Pend Oreille County, Washington, contain few corals and almost no rugose corals. The tabulate corals are only informally identified, as they are virtually unstudied in western North America. However, with one or two possible exceptions, they are the common Silurian-Devonian genera, widely distributed in time and space.

Preservation ranges from poor to medium.

APPENDIX II

Insoluble Residue Results

Appendix Table 1. Insoluble - residue percentages from rocks in the Limestone Hill-Beaver Mountain area.

Collected from	Locality	Insoluble Residue Percentage
Unit A, calcareous siltstone	G 971	70
	G 9101	78.2
Unit A, limestone	C 836	9.3
	C 861	7
	C 872	11.9
Givetian Limestone Conglomerate	C 8314, clast	6
	C 8314, matrix	48.4
Frasnian Limestone, Massive	C 7256	1.9
	C 7202	4.4
Frasnian Limestone, Bedded	southern-most outcrop	57.8
	C 7231	2.7
	S 9131	3.3

Rocks were treated with 50% hydrochloric acid solution.