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Stratigraphy and Porifera of Ordovician Rocks Near Columbia Icefields Jasper National Park, Alberta, Canada

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ABSTRACT.—An excellent and readily accessible section of Lower and Middle Ordovician Mons to Mount Wilson Formations is exposed in creek banks immediately northeast of the campground at Columbia Icefields Chalet, Jasper National Park, Alberta. The Mons Formation is an argillaceous unit with interbedded bioclastic and intraformational conglomeratic limestone. It is overlain gradationally by abundantly fossiliferous limestone of the Sarbach Formation. Small sponge reefs occur in the basal beds of the Sarbach Formation.

Upper beds, pisolitic dolomite of the Skoki Formation and a laminated silty dolomite of an unnamed formation, are only sparingly fossiliferous. The boundary between dolomitic units is placed at a bed of large silicified gastropods.

The sandy to vitreous Mount Wilson Quartzite is the upper formation of the local Ordovician section and is unconformably overlain by the Devonian Fairholme Group.

Anthaspidellid, hexactinellid, and heteractinellid sponges occur in the section, but only anthaspidellid forms are abundant and these only in small reefs at the base of the Sarbach Formation. The anthaspidellid sponges are among the oldest known lithistid forms.

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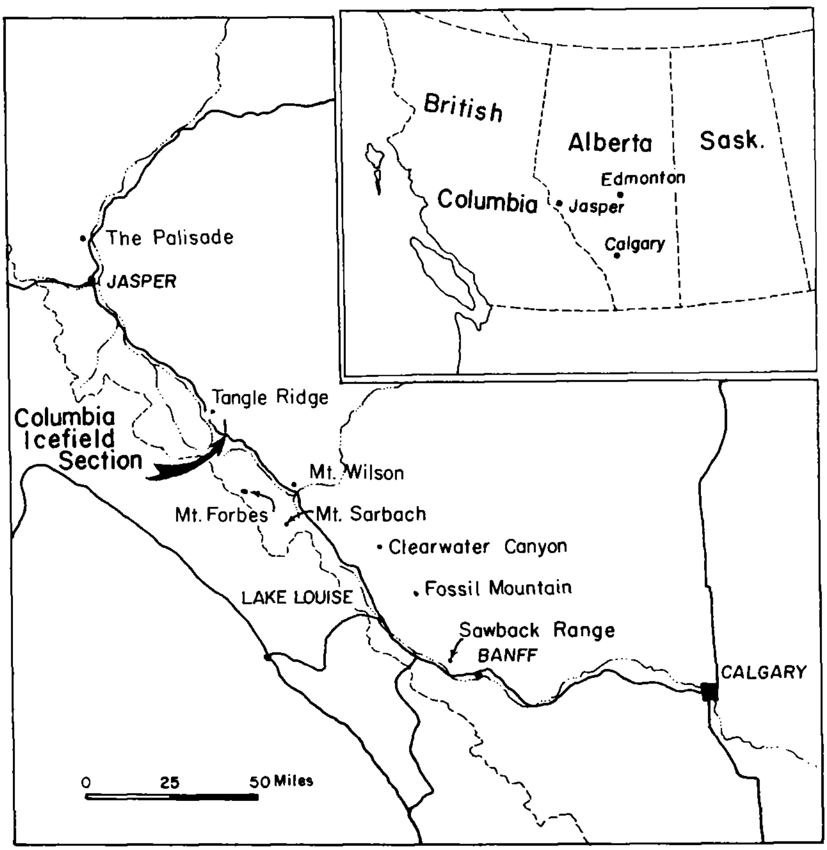
INTRODUCTION

Ordovician rocks are exposed in the Canadian Rocky Mountains in a northwesterly trending belt in some of the Front Ranges, Main Ranges, and Western Ranges (Norford, 1963, fig. 4-9). North and Henderson (1954, p. 62-68 and 196) have summarized known outcrops and thicknesses as part of a broad review of geology between latitudes 49°30' and 52°30' north and Norford (1963, p. 42-48) has done the same between latitudes 49° to 59°.

Few of these outcrops have been studied in detail, and published stratigraphic sections or paleontologic data are not common.

Walcott (1928) early subdivided the Lower Ordovician rocks of the Saskatechewan River Crossing region into the Mons and Sarbach Formations, largely because the Mons Formation contained an "Ozarkian" fauna, as contrasted with the "true Ordovician" fauna of the overlying Sarbach rocks. At the same time, he proposed the Skoki Formation for outcrops near Fossil Mountain (Text-fig. 1) to the southeast. It has been common practice to group the formations in regional field work. The Sarbach, Mons, and Skoki Formations are mappable at least from the Mount Wilson area at Saskatchewan Crossing to the vicinity of Sunwapta Pass and Columbia Icefields, more than 30 miles, some distance beyond Walcott's area of investigation.

Although Walcott's original reason for subdivision was faunal, various persistent lithologic units can also be utilized in subdivision of the section, at least in the area of consideration. Subsequent workers, in addition, have shown that the original Mons Formation includes not only Lower Ordovician rocks,



TEXT-FIGURE 1.—Index map of the measured section and of certain other sections referred to by Walcott and others.

but some Upper Cambrian as well, although in most sections the boundary between the two systems is difficult to place.

Allan (1938) discussed the Cambrian and overlying rocks of the Sunwapta Pass area, immediately southeast of the Columbia Icefields, and included some of the presently considered Ordovician in his sequence. Later, Severson (1950) mentioned Ordovician rocks below the Mount Wilson Quartzite as incidental to his paper on the Devonian sequence in the immediate area. A more recent paper concerning the geology in this vicinity is that of Hughes (1955), who described the areal geology of the Tangle Ridge area and described but did not name the Lower Ordovician rocks. Norford (1963) discussed the various units described here and gave thicknesses for Mount Wilson and other areas, as well as correlations of the various units.

Short papers by Greggs (1963, p. 1-3) and Pelzer (1963, p. 4-13) summarize the present status of stratigraphic nomenclature and zonation of the Mons and Sarbach Formations in the Sunwapta Pass region and in the Southern Rocky Mountains in general.

The present paper is an outgrowth of a regional study of conodonts by D. L. Clark and R. L. Ethington, and Early Paleozoic sponges by J. K. Rigby.

Locality and Method of Study

A complete section of the Lyell(?), Mons, Sarbach, Skoki, an unnamed Formation, and Mount Wilson Formations was measured during the summer of 1963, along a small stream which drains past the campgrounds, east of the Chalet, at the Columbia Icefields, Jasper National Park, Alberta (Text-fig. 1). The section is well exposed and readily accessible.

The section was measured with a tape. Thicknesses were calculated in the field using standard trigonometric techniques. Samples were collected for conodonts, sponges, and lithology.

ACKNOWLEDGMENTS

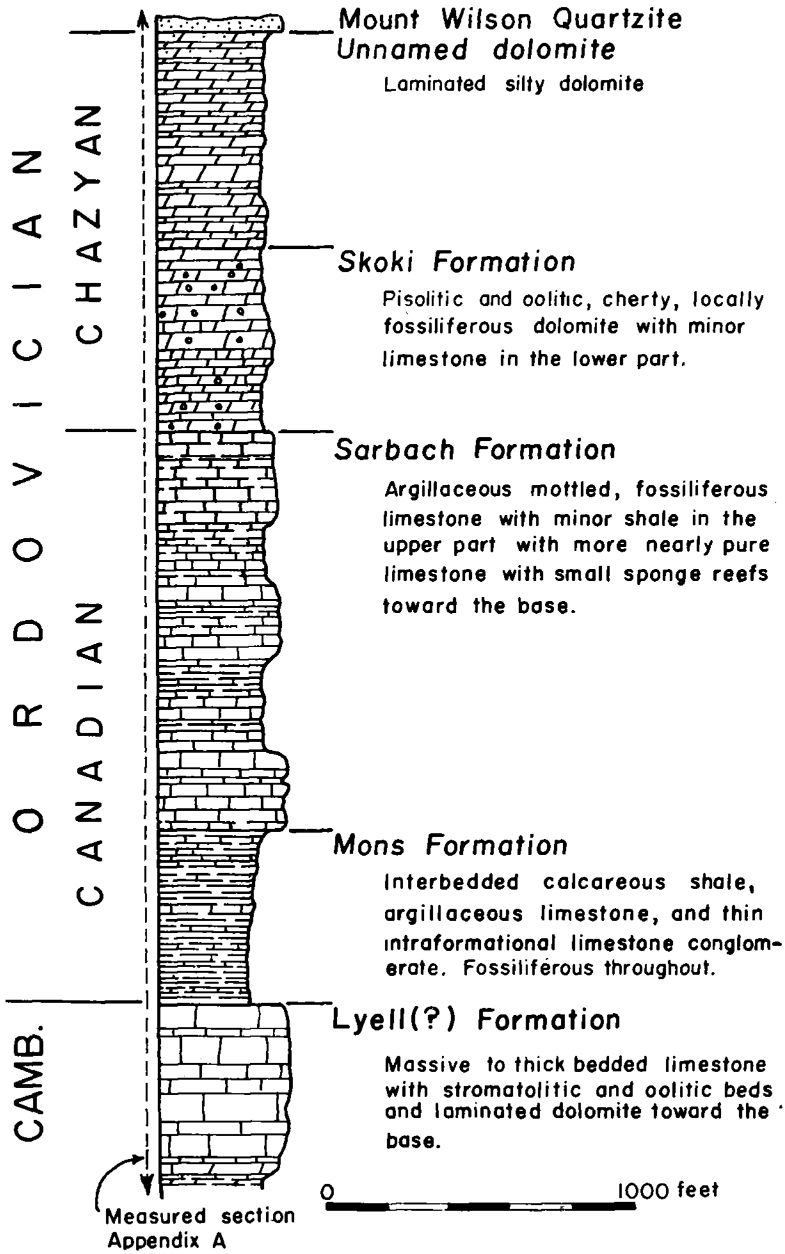
Permission to collect in Banff and Jasper National Parks is gratefully acknowledged. Cooperation of officers of both Jasper and Banff National Parks is sincerely appreciated. Robert Pinney, Robert Hinds, and J. Keith Rigby, Jr. assisted in the field and in preparation of some of the samples. Some costs of sample and manuscript preparation, and travel were supported by National Science Foundation Grant GB 1303. B. S. Norford criticized a preliminary manuscript.

STRATIGRAPHY

Cambrian System

LYELL (?) FORMATION

Walcott (1923, p. 15) named the Cambrian Lyell Formation from outcrops of massive, cliff-forming limestone near Glacier Lake, east of Mount Forbes. Massive limestone at the base of the section at Columbia Icefields Chalet are tentatively considered as Lyell carbonates. These massive to thick-bedded limestones are well exposed along the creek northeast of the campground and form prominent exposures behind the Icefields Chalet, and a nearly unbroken cliff on the southwest face of Mount Wilson (Plate 1, fig. 2).



TEXT-FIGURE 2.—Erosional log of the Columbia Icefields Section of the Lyell(?) Formation to the Mount Wilson Quartzite.

Dark-gray, massive, cliff-forming limestone which weathers to a medium blue-gray is the most characteristic lithology. Locally light gray, or gray-buff, laminated dolomitic beds are interbedded, but these are few and are most typical of basal beds. Black chert nodules are common throughout, as are irregular stromatolitic masses. Some beds are pisolitic and oolitic, particularly in the middle of the unit (Plate 3, fig. 2). Some of the upper beds are mottled with lenticular argillaceous partings which weather light-yellow or yellow-brown. Large isolated heads of *Collenia* occur in the upper beds, but other fossils are usually rare. Fragmental trilobites occur locally, but are commonly poorly preserved.

Base of the formation is not well exposed behind the Icefields Campground, but it is well exposed to the west behind the Chalet. Top of the formation is a pronounced topographic break produced by differences in weathering of the overlying shaly section and the resistant limestone of the formation. In the vicinity of the measured section, the top may be faulted, for outcrops of the overlying shale are crumpled in tributaries west of the main canyon.

Ordovician System

MONS FORMATION

Walcott (1923, p. 15; 1928, p. 224-226) proposed the Mons Formation for "Ozarkian" rocks exposed along the southeast side of Mons Glacier in the vicinity of Mount Forbes, west of the Banff-Jasper Highway (Text-fig. 1). As originally defined the formation consisted of an upper and lower section of shale and limestone with a medial massive limestone unit. Subsequent workers have pointed out problems with the Mons Formation, even at the type section, and have restricted the Mons to only the upper 225 feet, more or less, of the type section, excluding the underlying Cambrian rocks (Burling, 1955, p. 34; Hargreaves *et al,* 1960, p. 235-236; Norford, 1963, p. 46, text-fig. 4-11).

Base of the Mons Formation is well defined at the base of a slope-forming argillaceous limestone sequence above the massive limestone of the Lyell(?) Formation. The contact is well exposed in deep gullies along the creek section near Columbia Icefields Campground and is also well shown in cuts on the south slope of Mount Wilson (Plate 1, fig. 2).

Top of the formation is less distinct, for the upper shale is gradually replaced by limestone similar to that of the overlying Sarbach Formation. The transition is gradual and top of the Mons Formation is placed at the base of a dominantly limestone sequence, near the base of a moderately high waterfall on the creek along the section traverse.

The Mons Formation consists of interbedded micaceous shale, argillaceous limestone, and limestone intraformational conglomerate. Most of the shale beds are medium gray-green to medium gray and weather to a light gray or gray-green. Micaceous flakes produce a sheen on weathered surfaces which take on a silvery appearance from a distance. Most of the shaly units are fissile, but some of the more calcareous units become very thin-bedded.

Beds of bioclastic limestone (Plate 3, fig. 3), usually only one to three inches thick, occur throughout the unit, and lenses up to eighteen inches thick occur in the upper part. Fossil detritus is common in the limestone units. Brachiopods, trilobites, and gastropods are the most common. They are not silicified and are poorly preserved. Limestone beds are usually medium to dark-gray, and weather to a medium-gray.

Flat-pebble conglomerate beds are common in the upper part of the shale unit (Plate 3, fig. 4). Fine-grained, laminated limestone beds became disrupted and produced pebbles up to 6 inches in diameter, but usually only about one to two inches across their long dimension. Most of the pebbles are discoidal, commonly less than half an inch thick, with rounded edges.

Graptolites and isotelid trilobites are common in the upper part of the unit, from near the base of the transition zone into the overlying Sarbach Formation. Small trilobites and brachiopods are relatively rare in the upper beds, but abundant in limestone of the lower part of the unit.

The entire shale unit of the Mons forms a broad slope between ledges of the overlying Sarbach Formation and the massive Lyell(?) Limestone. On Mount Wilson, the formation forms a grassy slope above the Mons ledge, and below the sheer cliffs of the overlying Sarbach Formation (Plate 1, fig. 2).

Age and Thickness

Conodonts (Ethington and Clark, 1965) and trilobites indicate the Cambrian-Ordovician boundary occurs near the base of the Mons Formation. Distinctive basal Ordovician conodonts occur in limestones of the shale a few feet above Lyell(?) Limestone in unit 17. Bostock *et al* (1957, p. 327) indicated that slightly less than half the thickness of the Mons Formation as originally defined is Upper Cambrian. Difficulty of placing the Cambrian-Ordovician boundary is pointed up by North and Henderson (1594, p. 64), who indicated that most of the critical interval is frequently unfossiliferous. Little error would be introduced in stratigraphic work if here the top of the massive Lyell Limestone is considered the top of the Cambrian System.

The Mons Formation is 584' thick in the measured section.

SARBACH FORMATION

The Sarbach Formation was proposed by Walcott (1923, p. 459; 1928, p. 220-222) from the Mount Sarbach area near Saskatechewan River Crossing on the Banff-Jasper Highway (Text-fig. 1), to include the post-Ozarkian rocks of the Ordovician. In the type area it consists of thick-bedded, siliceous gray limestone, shale, and argillaceous limestone.

In the type area, and to the northwest, at least to the Jasper Park boundary, the formation is overlain by dolomite of the Skoki Formation. The upper boundary is thus easily established. The lower boundary is less marked, however, and is gradational into the underlying argillaceous limestone and calcareous shale of the Mons Formation. For the present paper, the boundary between the Mons and Sarbach Formations is drawn as the base of the lowest consistent limestone above the dominantly interbedded shale and limestone of the Mons beds. The boundary is undoubtedly time transgressive and various workers will differ in its placement.

Sarbach Formation is well exposed along headwaters of the small creek northeast of Columbia Icefields Campground southwest of Nigel Peak. A measured section from here is summarized in Appendix A.

Limestone of the lower part of the formation is medium-gray to dark-gray, and varies from medium-grained to coarsely fragmental (Plate 4, figs. 2-4). Bedding varies from massive to medium-bedded, and the unit forms a semiresistant ledgy zone. Small algal and sponge reefs occur in the lower part

(Plate 2, fig. 2). The entire unit weathers light-gray and forms a distinctively light colored band of outcrops.

The upper part of the formation is a brownish gray to greenish brown-weathering unit of concretionary, argillaceous limestone. Dark brown-green shale cccurs in the lower part of the unit and separates it from the light colored lower limestone. Limestone, typical of the upper units, is dark gray, fine- to medium-grained, and commonly in concretionary bands. Limestone often weathers away more readily than the enclosing argillaceous fretwork, to form a peculiar netted weathered surface, where lenses of limestone form pits (Plate 2, fig. 1). Chert is common in the unit, and in some beds near the top, white chert forms up to one third of the rock volume. Chert of the lower part is usually brownish gray or black. Bedding is variable, commonly appearing thin-bedded on ridges where beds have become splintery, but massive in creek bottoms where rocks are less deeply weathered.

Age and Thickness

The Sarbach is of Canadian age, judging from conodonts reported by Ethington and Clark (1965, p. 185-6) from limestones of the formation. North and Henderson, (1954, correlation table) equate the upper part of the Sarbach Formation with didymograptid-bearing Glenogle Shale. Similar graptolites are common in the Chazyan Kanosh Shale of Utah. Norford, (1963, p. 46, text-fig. 4-11), however, considered the Sarbach Formation as entirely Canadian, along with Clark and Ethington (1965).

The formation is approximately 1337 feet thick in the Columbia Icefields section, and a reported 1120 feet thick at the type locality and 1,172 feet thick in Clearwater Canyon (Walcott, 1928, p. 220).

SKOKI FORMATION

Dolomite of the Skoki Formation is exposed in Wilcox Pass, and for some distance to the southeast and northwest near Columbia Icefield. Appendix A summarizes the section as exposed southeast of the pass, north of Columbia Icefields Campground in Jasper National Park. Here the formation forms a distinctly light-gray band of outcrops, but elsewhere it forms bold ledges beneath the overlying dolomite unit and the Mount Wilson Quartzite.

Oolitic and pisolitic dolomite occurs throughout, in coarse-grained beds interbedded locally with fine-grained laminated, frequently cross-laminated, dolomite. Silicified gastropods and brachiopods are common in limited beds near the top of the formation.

Lower beds of the Skoki Formation contain some interbedded bioclastic limestone with cherty dolomite. Ghosts of fossils are apparent, but detail has been destroyed in the coarsely crystalline mosiac. Light- to medium-gray beds dominate, and most chert is white to light-gray. Bedding is variable, but medium- to thin-bedded units dominate throughout.

Age and Thickness

Norford (1963, p. 46, text-fig. 4-11) placed the Skoki Dolomite within the middle Chazyan. Later Norford (1965, p. 116) reported three brachiopod zones within the formation and concluded that the upper two, the *Anomalorthis* and *Orthidiella* zones, correlate with the Whiterock zone of the Antelope Valley Limestone of Nevada. A new zone from the lower part of the Skoki sequence may be uppermost Canadian, in part equivalent to the *Pseudocybele* trilobite zone (Zone J) of the Wahwah Limestone in western Utah.

The formation is 605 feet thick in the Columbia Icefields section at Wilcox Pass and 459 feet thick at Mount Wilson (Norford, 1963, p. 45).

UNNAMED FORMATION

An unnamed dolomite occurs above the pisolitic Skoki Formation and below the sandy Mount Wilson Quartzite. It is laminated and, according to Norford (1963, p. 45), represents a shallow restricted environment. In the section measured at Columbia Icefields, the formation is a fine-grained siliceous dolomite which weathers to a smooth porcellaneous surface. Silt grains are common, and white chert is locally abundant. It forms light yellow-gray to tan, low outcrops, punctuated periodically by more resistant ledgy units of mottled gray and gray-brown dolomite. Lower beds are darker gray or brown than upper beds, and the darkest beds are only irregularly laminated.

Base of the formation is drawn above a fossiliferous gastropod-rich unit, above the dominantly pisolitic Skoki beds. Top of the formation is easily drawn at the base of the sandy Mount Wilson Quartzite.

No fossils were collected from the unit during the present study. Norford (1963, p. 46, fig. 4-11) places the unit as upper Chazyan. It is approximately 719 feet thick in the Columbia Icefields section and 614 feet thick at Mount Wilson (Norford, 1963, p. 45).

PALEONTOLOGY

Sponges have not been commonly reported from Ordovician rocks of Western Canada. Walcott (1928, p. 330) reported *Receptaculites* (?) sp. from the upper part of the Sarbach Formation in the Clearwater Canyon region. From the same section he reported *Calathium* (?) sp. and *Receptaculites* (?) sp. from the lower part of the same formation. North and Henderson (1954, p. 68) cite the occurrence of sponges as reported by Walcott, presumably referring to the *Receptaculites* (?) and *Calathium* (?) from the Clearwater sequence. There is some doubt that either of these forms should be included with true sponges.

Several small sponge and algal reefs occur in the lower part of the Sarbach Formation in Unit 30 of the measured section (Appendix A). Outcrops of the reefs are best seen in the creek bed at the top of a major waterfall above gray shale slopes of the Mons Formation. Individual reef masses range up to six feet in diameter, but are exposed in cross section only, wedging in and out between less massively bedded clastic limestone (Plate 2, fig. 2).

Individual organic elements are not well shown on weathered surfaces, but the fabric is clearly seen on either polished surfaces or in thin sections. Only rarely do these sponges have a surface expression in the field, for they are apparently filled with matrix sufficiently similar to the country rock that the sponges do not weather with relief. Not until thin sections were made did their abundance become apparent.

Class DEMOSPONGEA Sollas
Order LITHISTIDA Schmidt
Family ANTHASPIDELLIDAE Ulrich
New Genus and Species A
Plate 5, figs. 4, 5; Plate 6, fig. 1

Description.—Moderate to small sponges ranging from obconical to conicocylindrical, probably with a smooth exterior, except for canal openings. No weathered exteriors are present in the collection so lack of surface ornamentation is reconstructed from various tangential, transverse, and diagonal thin sections. Sponges range from 5 to 15 mm. in diameter and may be up to at least 60 mm. long. In characteristic samples of forms with diameters approximating 15 mm., the centrally located spongocoel is from 4.5 to 5.0 mm. across. In some smaller forms with diameters of 10 to 11 mm., the spongocoel has a similar range. The spongocoel seems to be a deep, simple opening throughout the length of the sponge. The manner of termination at the base is unknown, but it is apparently not subdivided into rising excurrent canals as in some related genera.

The canal system appears to be relatively simple, with a main series of radiating straight canals, arranged nearly horizontally within the sponge. There may be smaller vertical canals within the coarse spicule net in addition to the skeletal pores which rise as gently outward curved rectangular openings. Horizontal canals are from 0.46 to 0.52 mm. in diameter and are roughly circular to slightly elliptical, elongate vertically. Spicules are gently arched around the canals when seen in vertical tangential sections. Determination of canal numbers in a single radiating series is difficult, but some sponges show at least six canals per quarter of circumference.

Spicules are typical of the family, relatively long-shafted dendroclones. The long shaft or rhabdome is smooth, nearly cylindrical and averages approximately 0.40 to 0.45 mm. long and 0.02 to 0.04 mm. in diameter. Clads are short, usually less than 0.04 mm. long, and terminate in an arborescent complex structure which, by union with other spicules, forms irregular rods by mutual interlocking. The rhabdomes thicken slightly before the nearly equal diameter cladomes bifurcate. Where the arborescent part of the cladome is preserved in the somewhat coarsely calcified specimens, it is composed of minutely branching structures less than one fifth the diameter of the clad.

Complex major rods of the cladomes range from 0.08 to 0.16 mm. in diameter, but most are approximately 0.14 mm. in diameter where thickest and as thin as 0.10 between junctions of spicules. The rods are spaced from 0.28 to 0.40 mm. apart, locally up to 0.50 mm. apart where canals have disrupted the normal pattern of the structure.

The entire skeletal structure consists of ladder-like rows of spicules in which horizontal rhabdomes form rungs and arborescent cladome-formed rods are the uprights. Rhabdomes are spaced at irregular intervals of from two to five per millimeter in a vertical series. Gaps caused by canals are not readily apparent because of the relatively coarse spicule pattern, although in some areas rhabdomes are curved to accommodate the more elliptical canal openings.

The complex rods are initiated at the inner or spongocoel margin of the wall, and rise upward and outward in a gentle curve, steep toward the bottom, but more distinctly outward toward the top. They rise upward three or four times the wall width from their initial point on the inner margin to their termination on the outer margin of the wall.

From 4 to 6 rows of spicules join to form a single rod complex. Skeletal pores between the various rows range from 0.40 to 0.46 mm. across and are triangular or rectangular in cross section. Skeletal pores parallel the complex rods.

In some transverse sections the complex rods appear irregularly placed, particularly in the smaller diameter sections. In the upper part of the sponge, where canals are better defined, rods are more evenly spaced in radial lines with 7 to 10 rods per radial row.

There is no evident dermal or gastral specialization or differences in spicule spacing.

Foreign spicules are present within the sponge wall. Some are hexactine or heteractine and must have been emplaced during growth of the sponge, for the spicule net has adjusted, and it appears impossible to insert these complex shapes into the smaller body mesh of the sponge after death. Elsewhere long monactines occur in the wall and these could have been inserted either during the life span or after death of the individual, along with the fine calcareous matrix of the country rock.

A gently spread base of one sponge was sectioned and shows the spicule net extending into the attachment cone, as well as upward into the body of the sponge with little variation.

Discussion.—Identification of the specimens at hand is difficult for no free individuals were collected on which surface sculpture could be observed. Some comparisons can be made with other members of the family, as listed by Finks (1960, p. 59-60), however. These sponges are relatively simple, unbranched conicocylindrical or obconical forms whose shape most closely approximates *Nevadocoelia,* except that they are smooth, as the various sections have been interpreted.

The Canadian forms lack the surface sculpture of *Nevadocoelia* (Bassler, 1941, p. 94-96), and the more coarsely annulate *Archaeoscyphia* or *Rhopalocoelia* (Raymond and Okulitch, 1940, p. 210-212). The more coarse spicule net or ill defined canals also differentiate the specimens at hand from those genera.

Well developed vertical axial excurrent canals in the basal spongocoel, such as in *Zittelella* (Ulrich and Everett, 1890, p. 267-271) *Hudsonospongia* (Raymond and Okulitch, 1940, p. 203-208), *Streptosolen* or *Anthaspidella* (Ulrich and Everett, 1890, p. 256-267) are wanting in the Canadian specimens. Also wanting are the large, well defined canals that are characteristically developed in *Steliella* (Wilson, 1948, p. 19-21), *Exochopora* (Raymond and Okulitch, 1940, p. 208), *Rhopalocoelia* or *Calycocoelia* (Bassler, 1941, p. 96-97).

The relatively complex spongocoel of *Okulitchina* (Wilson, 1948, p. 21-22) and the highly irregular canal system of *Eospongia* (Raymond and Okulitch, 1940, p. 198-200) immediately separate these genera from the sponges at hand.

The present specimens probably represent a new genus, but will not be given separate status until more material with surface features preserved can be collected. These sponges are the oldest members of the family yet described, coming from low in the Canadian, from rocks equivalent to Zone C of Hintze (1952) and Ross (1951) from the Fillmore Limestone or the Garden City Formation. They are older than any Ordovician sponges yet collected in Utah and Nevada where the most complete sequence of Early Ordovician faunas known to date has been obtained.

Occurrence.—Sarbach Formation, Unit 30, Columbia Icefields Section, Jasper National Park, Alberta, BYU locality 11126.

Repository.—Brigham Young University Geology Department.

New Genus and Species B

Plate 5, figs. 1-3; Plate 6, fig. 3

Description.—An explanate sponge of medium size from 0.6 to 1.5 mm. thick and covering an area of at least 10 square centimeters. Where the sponge is thickest, an upper and lower densely spiculate region is clearly separable from an interior loosely spiculed area. Where the sponge is thin, the lower region is ill defined.

The more coarsely meshed interior is from 0.2 to 0.3 mm. thick and is the locus of large canals which more or less parallel the upper and lower surfaces of the sponge. In thicker parts of the sponge, the upper and lower dense regions are from 0.2 to 0.5 mm. thick and are perforated by numerous canals.

Canals are gently curved within the relatively open interior of the sponge, but curve abruptly near the boundary between the open and tight spiculed areas, until the canals emerge essentially normal to the upper or lower surfaces. Upper canals range from 0.12 to 0.16 mm. in diameter and are traceable through from 0.3 to 0.4 mm. of densely spiculed material. Lower canals are less well defined and are usually smaller than 0.12 mm. in diameter. In some areas very few lower canals are cut in the section, and in other areas the basal part of the sponge appears impervious.

A few transverse surfaces were cut and show both upper and lower canals are roughly circular or elliptical in cross section. Individual canals are separated by as much as 0.08 to 0.11 mm. of dense spicular material.

Particularly coarse-textured interior regions occasionally occur where large canals apparently trend at an angle to the slice. These coarse-textured areas usually arch the upper surface of the sponge, somewhat like a monticule in bryozoans.

Spicules are anthaspidellid dendroclones, typical of the family, but are much smaller than those of the associated cylindrical sponge. These spicules range up to 0.12 or 0.14 mm. long and from 0.01 to 0.02 mm. in diameter. Rhabdomes are smooth, generally cylindrical, and bifurcate into short cladomes. Cladomes are rarely longer than 0.04 mm. where best developed, but are complex. There are from 12 to 14 rhabdomes per millimeter in a vertical transverse row, much closer spaced than in the associated larger spiculed sponges.

Cladomes interlock to form complex rods as in other genera of the family. The rods are nearly horizontal in the central part of the sponge, but swing to nearly vertical at the upper surface, parallel to the canal system. The rods are poorly defined in the interior of the sponge, but thicken in outer regions.

Spiculation appears irregular, with the complex rods forming a dotted pattern, in some tangential slices of the sponge. The rods are connected by an irregularly rectangular or triangular spicule pattern. Only where the section cuts at an angle is there a linear pattern in the skeleton. Most regularity shows in vertical sections parallel to the vertically oriented spicule structure.

Some of the internal structure of this form is poorly preserved in the specimens at hand. Coarsely crystalline calcite replacement has obscured much of the detail.

Discussion.—These flat sponges are less common than the coarser textured forms within the small reefs of the lower Sarbach Formation, and they are less well preserved as well.

Patellispongia (Bassler, 1941, p. 97-98), *Hesperocoelia* (Bassler, 1941, p. 98-99), *Psarodictyum* (Raymond and Okulitch, 1940, p. 212-214), and *Anthaspidella* (Ulrich and

Explanation of Plate 1
VIEWS OF MONS AND SARBACH OUTCROPS

FIG. 1.—Limestone and shale of the upper Mons Formation along the creek northeast of Columbia Icefields Campground. Dendroid graptoloids are common in shale shown in the lower left of the picture. Limestone beds are coarse bioclastic or flat-pebble conglomerate units.

FIG. 2.—Mount Wilson from the south. Om, Mount Wilson Quartzite; Osk, Skoki Formation; Os, Sarbach Formation; Om, Mons Formation; Cl, Lyell Formation.

Explanation of Plate 2
EXPOSURES OF SARBACH LIMESTONE

FIG. 1.—Characteristic argillaceous limestone of the upper Sarbach Formation. Relatively pure limestone lenses weather away leaving a fretwork of hornfels-appearing argillaceous material. Photograph is along traverse of Icefields section, unit 48.

FIG. 2.—Small reef mounds of algae and sponges in basal beds of the Sarbach Formation. Massive, dense reefs of relatively pure limestone are surroundsd by thin-bedded bioclastic limestone. Draped bedding is common around the reef mounds. Creek bed exposure of Unit 30, Icefields section.

Explanation of Plate 3
PHOTOMICROGRAPHS OF MONS AND LYELL(?) LIMESTONES

FIG. 1.—Bioclastic limestone of the lower Mons Formation from Mount Wilson. Crinoidal debris and trilobite fragments compose most of the recognizable particles. Some pebbles of fine-grained limestone occur throughout the unit. Plain light, x4.

FIG. 2.—Oolitic and pelletoid limestone of the Lyell(?) Formation from Columbia Icefields region, BYU locality 11017. Large pellets are often compound and frequently contain smaller oolites and hexactinellid sponge spicules. Oolitic limestone such as this is interbedded with stromatolitic limestone in the middle of the formation. Plain light, x4.

FIG. 3.—Coquinoid limestone from the Mons Formation from Columbia Icefields section, unit 21. Trilobites, brachiopods, and echinoderm fragments comprise most recognizable fragments. Fossiliferous limestone such as this forms a small part of the formation. Plain light, x4.

FIG. 4.—Flat-pebble conglomerate from the Mons Formation from Columbia Icefields section, unit 19. Limestone beds such as this are interbedded throughout. Pebbles are composed of fine-grained limestone, commonly with many sponge spicules. Plain light, x4.

EXPLANATION OF PLATE 4

PHOTOMICROGRAPHS OF SARBACH AND YOUNGER CARBONATES

FIG. 1.—Laminated dolomite from upper part of an unnamed formation above the Skoki Formation, Columbia Icefields section, unit 61. Some quartz silt is scattered throughout. Lamination is a function of grain size and organic content. Silt grains are most abundant in light units. Plain light, x4.

FIG. 2.—Poorly sorted bioclastic limestone, from the lower Sarbach Formation, Columbia Icefields section, unit 35. Crinoid, gastropod, and brachiopod fragments form most coarse clasts. Fragments of fine-grained limestone form coarse pebbles. Matrix is silty, fine-grained limestone. Plain light, x4.

FIG. 3.—Argillaceous bioclastic limestone, from middle of the Sarbach Formation, Columbia Icefields section, unit 40. Trilobite and brachiopod fragments occur in pure limestone lenses between argillaceous stringers and partings. Plain light, x4.

FIG. 4.—Sparry bioclastic limestone from the upper Sarbach Formation, Columbia Icefields section, unit 49. Partially silicified trilobites, brachiopods and echinoderm debris are frequently encrusted with stromatolites. Large pellet and algal masses are common in the unit as well. Plain light x4.

EXPLANATION OF PLATE 5

SPONGE PHOTOMICROGRAPHS

FIG. 1.—Explanate sponge in longitudinal vertical section. Dense packing of vertical complex rods of aulocopid spicule structure shows well at left, and the central canals and arched vertical canals show well at right. Sarbach Formation, Unit 30, plain light, x 10.

FIG. 2.—Explanate sponge, diagonal transverse section showing spacing of vertical complex rods and canals. Sarbach Formation, Unit 30, plain light, x 10.

FIG. 3.—Explanate sponge, diagonal transverse section showing poor preservation of the lower and interior spicule pattern. Weak development of axial rods and ill defined canals are characteristic. Sarbach Formation, Unit 30, plain light, x 10.

FIG. 4.—Conico-cylindrical aulocopid sponge in transverse section. The radial pattern, coarse spiculation, spongocoel and radial canals show well. Complex rods of the ladder-and rung spicule pattern are oriented at high angles to the slice, but the rungs show well in the upper right of the specimen. Sarbach Formation, Unit 30, plain light, x 10.

FIG. 5.—Conico-cylindrical and explanate sponges. The explanate form is the same as shown in Fig. 1, but shows the thickened margin of the sponge. The conico-cylindrical form is cut slightly diagonal to transverse but shows the spicule character well in the right part of the specimen. Sarbach Formation, Unit 30, plain light, x 10.

EXPLANATION OF PLATE 6

SPONGE PHOTOMICROGRAPHS

FIG. 1.—Aulocopid spicule pattern of the conico-cylindrical sponge. Complex rods formed by union of cladomes show well with the ladder rung-like rhabs between. Bifurcation of the cladome shows well even in these rather poorly preserved calcified spicules. Sarbach Formation, Unit 30, plain light, x 80.

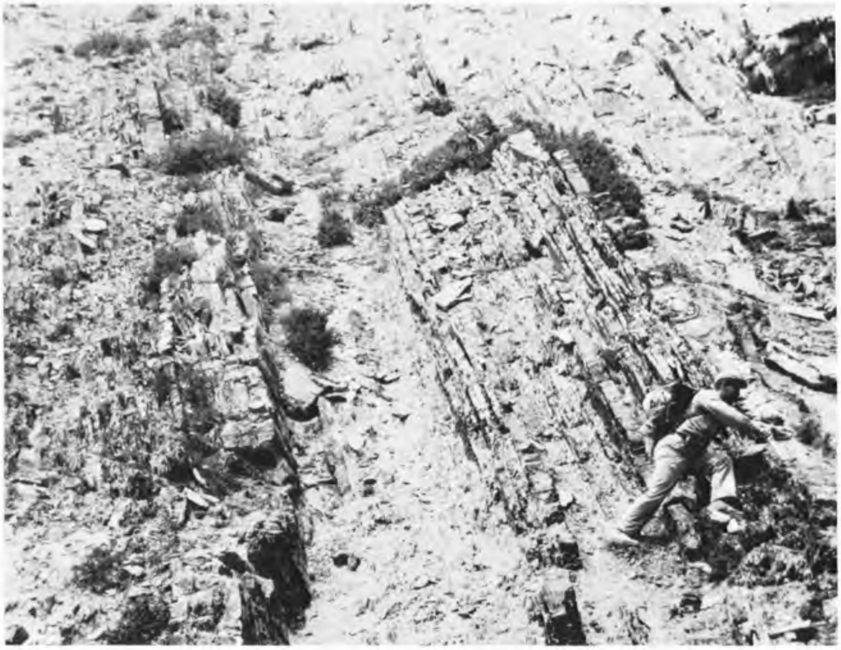
FIG. 2.—Isolated polyactinal spicule from Sarbach Formation, Unit 30, plain light, x 10.

FIG. 3.—Poorly preserved aulocopid spicule pattern of the explanate sponge. The complex rods of the ladder-and-rung pattern are ill defined, but the rungs are still well enough preserved to outline the pattern. Large canals show in the interior of the sponge at the left, and the vertical canals through the upper surface of the sponge at the right. Sarbach Formation, Unit 30, plain light x 80.

FIG. 4.—Poorly defined sponge spicules in a large coprolite, Lyell(?) Formation, BYU locality 11017, Columbia Icefields Campground, west of measured section. Plain light, x 10.

FIG. 5.—Cluster of hexactinellid spicules which may represent a single sponge, Sarbach Formation, Unit 41, plain light, x 10.

PLATE I — J. KEITH RIGBY



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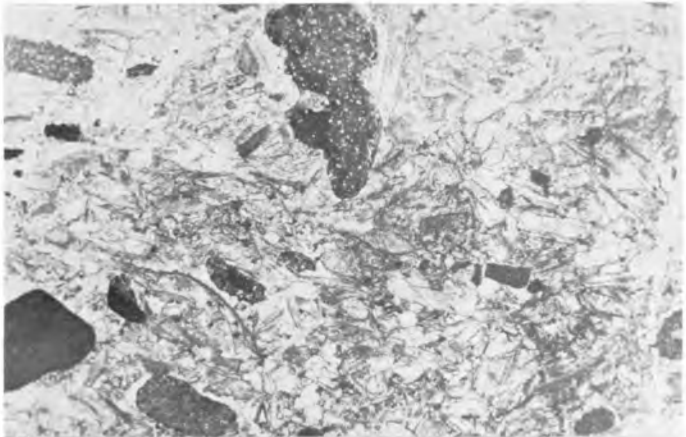

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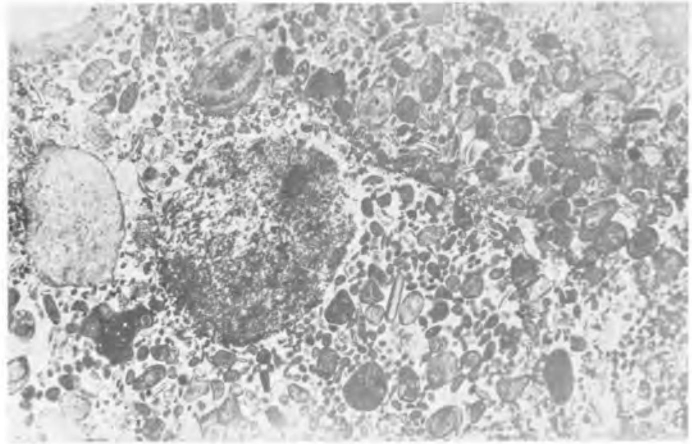

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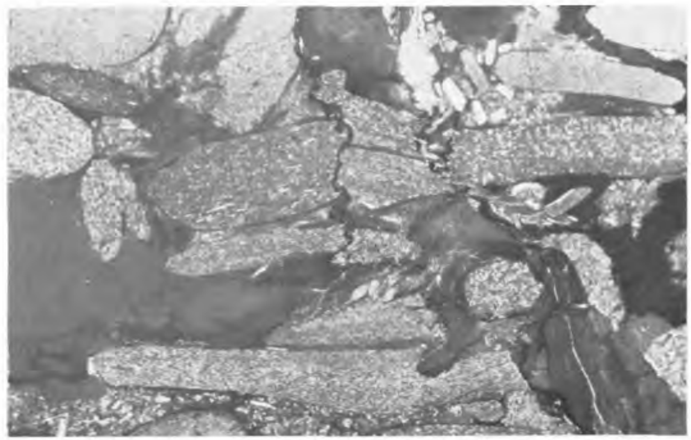

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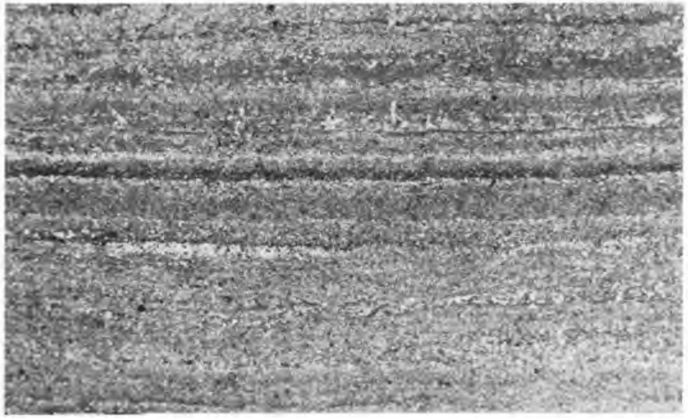

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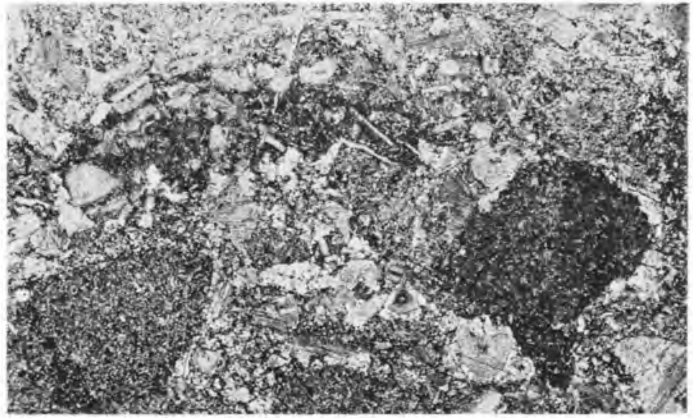

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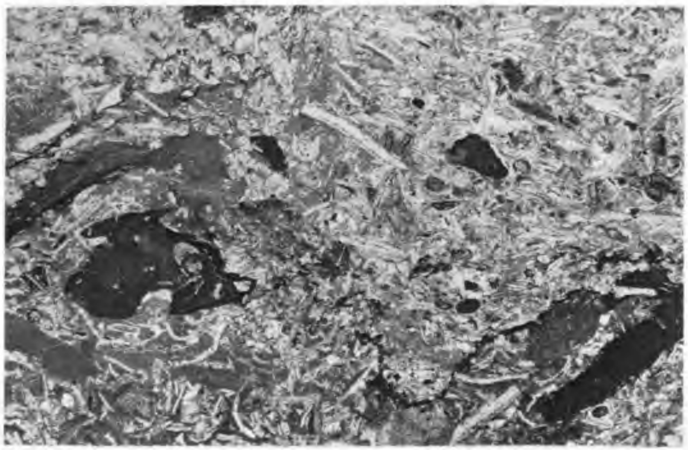

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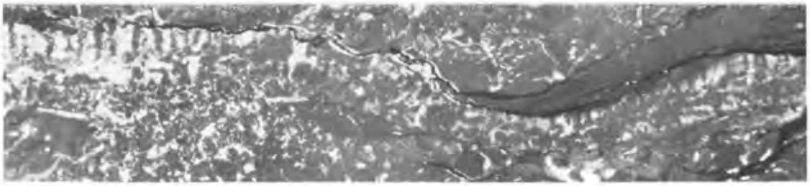

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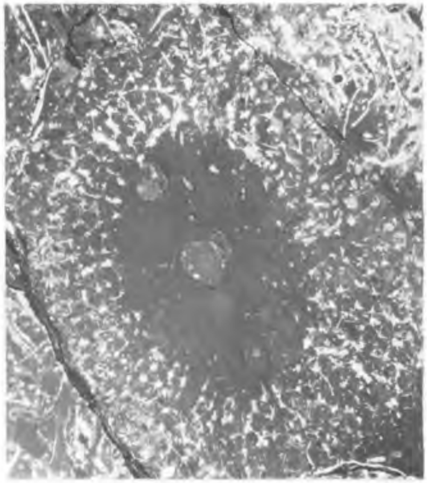

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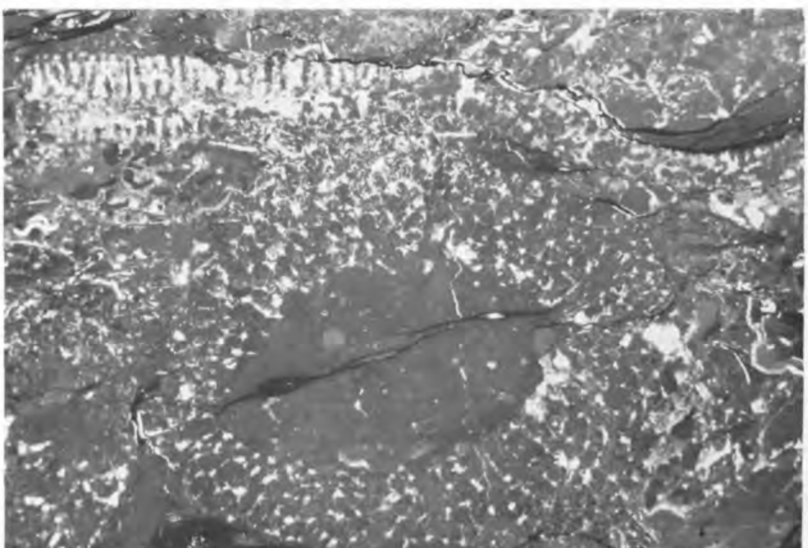

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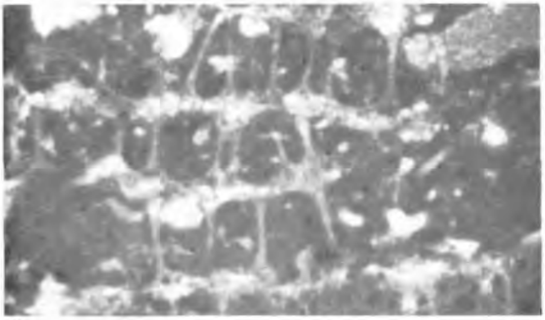
PLATE 6 – J. KEITH RIGBY



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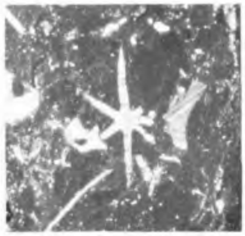

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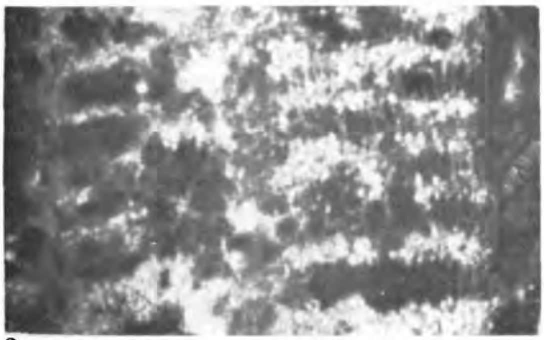

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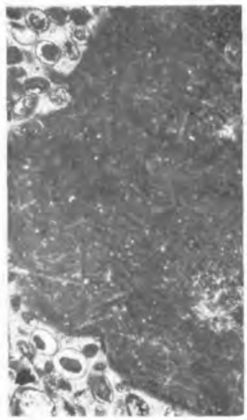

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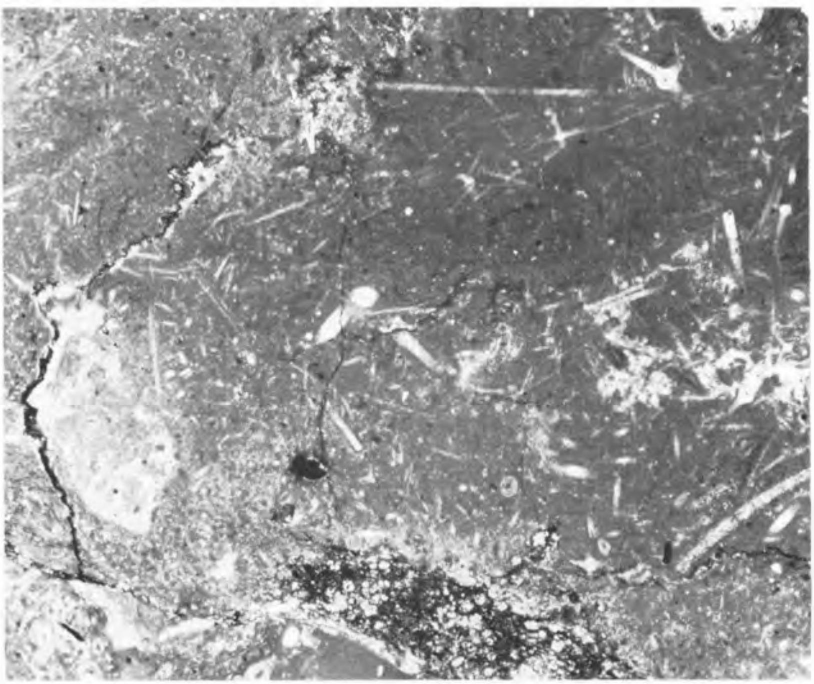

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Everett, 1890, p. 256-267) are the low conical to explanate older sponges of the family and all appear related to the specimens at hand, though distinct from them.

Patellispongia and *Psarodictyum* are most similar to the present form, but are coarser spiculed and much more regular. In addition these genera lack the well defined thick outer dense spiculed regions, although in both there may be thin dermal specialization.

Hesperocoelia is a thin bladed form with multiple spongocoels and a differentiated inner region. The Canadian specimens lack the well defined spongocoels although they do have regions of loose spiculation with larger canals. The multiple shallow spongocoel development and complex, but well defined, canal system of *Anthaspidella* differentiate that genus from the present specimens.

The Canadian specimens represent a new sponge related to the above genera, but it will not be named here because additional better preserved material is needed for adequate description.

Occurrence.—Sarbach Formation, Unit 30, Columbia Icefields Section, Jasper National Park, Alberta, BYU locality 11126.

Repository.—Brigham Young University Geology Department.

Class HEXACTINELLIDA Schmidt
Order LYSSAKIDA Zittel
Genus and species undetermined
Plate 6, fig. 5

A single hexactinellid spicule cluster was cut in one thin section. The cluster is 3.0 mm. in diameter with a central nonspiculate spongocoel (?) 1.5 mm. in diameter. The section cuts the cluster at an angle and produces an ellipse. Dimensions above are through the short diameter of the body.

Hexactines and monactines (?) occur, but with no apparent pattern, either in their arrangement or in their clustering. The dominant spicule type is a thin-rayed hexactine with rays at least 1.3 mm. long and only 0.04 mm. in diameter. Rays taper slowly and could easily be two or three times as long as seen in the slide. Most long rays, of all but coarsest spicules, parallel the long axis of the sponge ellipse, and would presumably have been parallel the walls in a nearly vertical direction. Some of this may be more apparent than real, however, since this is the direction of the slice diagonal. There is no evidence of a firm union of the spicules.

All the spicules have been calcified, but in some, the central canal left an impression.

Minor spicules are larger hexactinellids with ray diameters up to 0.10 mm. Since these spicules are large, they are rarely seen except as random cuts through rays. In one more centrally cut, there is a swelling at the ray junctions of 0.16 mm. diameter. Rays up to 0.8 mm. long are present in some diagonal cuts. The more abrupt taper of these spicules separate them from the finer associated forms.

Occurence.—Sarbach Formation, Unit 41, Columbia Icefields Section, Jasper National Park, Alberta Canada, BYU Locality 11126.

Repository.—Brigham Young University Geology Department.

Isolated Hexactines
Plate 6, fig. 4

Several isolated hexactine siliceous spicules are seen in thin section of pisolitic limestones of the Lyell(?) Limestone at Columbia Icefield localities. These are frequently concentrated in spheroidal coprolites which range up to 1 cm. in diameter, but average usually less than half that size in most beds. Individual spicules are often visible as single rays or as two rays in many masses. Rarely the intersection of the rays is evident. Pellets of oolites are often formed in the same beds and usually are of about the same diameter as the spicule masses. Spicules rarely extend beyond the sharp limits of the mass and often terminate at the darkened dense margin, while still of large diameter. Some masses occur in which oolites have adhered to the main spiculed mass, or some also occur with rare isolated oolites inside the spicule concentration.

Isolated spicules, some of which are hexactines, occur in fine-grained limestone sediments in the Ordovician Mons Formation, where small spicules are scattered though several beds. In some instances fine-grained spiculitic limestones form most of the flat-pebbles in some of the coarse conglomeratic beds of the upper shales of the formation. Most of the spicules are less than 0.04 mm. in diameter. There is no apparent fabric to their irregular occurrences in the pebbles or beds.

Occurrence.—Lyell (?) Formation; BYU Locality 11017 and Unit 8, Columbia Icefields Section, BYU Locality 11126.

Root tufts

Several aligned spicule clusters occur in various thin sections. These are oriented diagonal to the section in each instance. Spicules range in diameter from less than 0.05 to more than 0.10 mm. Smaller diameters are probably tips of adjacent spicules. The central axial canal shows well, and ranges from 0.01 to 0.04 mm. in diameter. The remainder of the spicule is annular ringed and characteristic, even though most have been calcified. These assemblages are considered as *in situ* root tufts.

Occurrence.—Upper Sarbach Formation, Unit 46, Columbia Icefields Section, Jasper National Park. Alberta, Canada, BYU Locality 11126.

Order HETERACTINIDA Hinde
Family ASTRAEOSPONGIIDAE de Laubenfels
Genus and Species Undetermined
Plate 6, fig. 2

Two polyactinal spicules occur in thin sections of the sponge reefs of Unit 30, the lower part of the Sarbach Formation. One of these consists of six equally spaced, smooth rays. The longest ray in the section is 0.9 mm. long and 0.1 mm. wide. All the rays are of the same general diameter, but are shorter because of the angle which the section cut through the spicule. Three of the rays show a central canal, typical of siliceous spicules, as relatively fine grained, darker gray material, perhaps one-tenth the diameter of the spicule.

The other spicule is imbedded in the body of a conicocylindrical aulocopid sponge. It consists of four rays and bits of two additional ones. Rays appear to be in the same plane. The longest ray is 0.7 mm. long, and individual rays are 0.04 mm. in diameter at the base. The central canal is well defined in one ray.

Both spicules appear light brownish gray, and are of the same general shape, although of slightly different sizes.

Although the spicules are sufficiently different to place them in a distinctive family, generic identification is impossble because of the manner of preservation and discovery. They appear most similar to *Astraeospongium* and *Eiffelia,* but are older and smaller than known *Astraeospongium* and are younger and smaller than *Eiffelia.*

Occurrence.—Sarbach Formation, Unit 30, Columbia Icefields Section, Jasper National Park, Alberta, BYU Locality 11126.

Repository.—Brigham Young University Geology Department.

APPENDIX A

Columbia Icefields Stratigraphic Section

Section was measured up the creek, northeast of the campground at Columbia Icefields, east of the Icefields Chalet and north of the main Jasper-Banff Highway, starting at the upper (northeast) end of the campground at the first bedded exposures in the creek above the coarse rubble fan. The section was measured along the creek bed or along the gully wall, except for the upper dolomite which was measured across uplands beneath the Mount Wilson Quartzite.

Unit	*Description*	*Thickness Unit Total (in feet)*
68	*Fairholme Group undifferentiated* Dolomite, dark- to medium-gray and gray-brown, medium to thick-bedded, poorly exposed above lower 20 feet because of cover by	

APPENDIX A (Continued)

	Palliser limestone rubble. Abundant *Amphipora* and some colonial corals in darker brownish units.	20+	4026
67	*Top Mount Wilson Quartzite* Quartzite, vitreous, light-gray to very light-gray in medial and upper part. Lower part sandy, complexly cross-bedded with much small scale rippled bedding. Medium-grained, clean quartz sand in slightly calcareous matrix in basal part. Quartzose matrix in middle and upper part. Forms light colored ledges above light colored dolomite slopes.	119	4006
	Total Thickness Mount Wilson Quartzite	119'	
66	*Top Unnamed dolomite* Dolomite, light- to medium-gray, weathers tan to light yellow-tan, thick- to medium-bedded silty, orange cherty laminae in upper part. Some beds show weak cross-lamination, particularly where more resistant ledge zone is formed. Medium crystalline and homogeneous throughout.	60	3887
65	Dolomite as unit 64, but laminated light-gray and light yellow-gray, thick- to medium-bedded, with 2-foot mottled medium- and light gray-brown band at top of lower one half. All finely crystalline, dense.	128	3827
64	Dolomite, medium-gray, weathers light-gray with minor (1 to 10) 1' - 2' units of medium gray dolomite. Top forms prominent ledge zone in pass and flat. Medium to thick-bedded throughout, and all finely crystalline.	142	3699
63	Dolomite, light medium yellow-gray, fine-grained, and flaky, forms shaly saddle of yellow-stained rubble in section traverse, mainly covered to east and west.	28	3457
62	Dolomite, light gray as 61, but some irregular white chert bands and flaky medium-gray units.	83	3429
61	Dolomite, light to light medium-gray, laminated, weathers light yellow-gray, medium-bedded, some irregular silty partings, dense, fine-grained, homogeneous.	67	3346
60	Dolomite as 59, interbedded with dark-gray and dark medium-gray dolomite, all laminated, but dark-gray beds irregularly so. Some irregular white blotches, may be ghosts of fossils in dark units.	91	3279
59	Dolomite, laminated light and medium-gray, weathers light medium-gray, thin-bedded, fine-grained, blocky weathering. Some cross-laminae in lower part, homogeneous.	20	3188
	Total unnamed dolomite	719'	
58	*Top Skoki Formation* Dolomite as 57, but gastropods rare.	70	3168
57	Dolomite, light-gray, laminated, abundant silicified palliserid gastropods, medium to thin-bedded, in upper part, finely crystalline to medium-crystalline in fossiliferous beds.	60	3098
56	Dolomite, dark to medium-gray, weathers medium-gray, algal pisolites common, medium-bedded to thin-bedded in upper part, poorly preserved brachiopods and other fossils, medium-crystalline.	63	3038
55	Dolomite, medium to light medium-gray, weathers light-gray and light brown-gray, abundant algal pistolites up to ½" in diameter. Thin to medium-bedded, medium-crystalline becomes medium-gray and finely crystalline toward top of unit.	77	2975
54	Dolomite, light to medium-gray, weathers light yellow-gray, slightly calcareous, medium-bedded, forms ledges where first exposed in grassy flats on either side of small gully where section measured.	88	2898
53	Limestone, light to medium-gray and some dark-gray thin units. Thin-bedded, weathers yellow-gray. Brachiopods in massive zone. Some concretionary massive blue-gray limestone at top. Dolomite fretwork and minor thin chert throughout weather slightly lighter than limestone.	96	2810

APPENDIX A (Continued)

52	Dolomite as 51, but chert concretionary and vuggy. Upper part poorly exposed in gully.	62	2714
51	Dolomite, light medium-gray, medium-crystalline, abundant lenticular white chert, thin-bedded. Chert 1/3 volume, weathers buff to light yellow-gray. Whole unit forms broad slope zone.	58	2652
50	Dolomite, medium-gray, weathers light-gray to light yellow-gray, abundant ragged white chert masses. Dolomite is medium-crystalline, medium-bedded. Has 2' limestone bed at top of unit.	31	2594
	Total Skoki Formation	605'	
49	*Top Sarbach Formation* Limestone, medium-gray, weathers light-gray, abundant 1/2"-1" dark-gray to medium-gray chert stringers. All unit is coarse-grained, medium-bedded, forms small ledges in creek where section measured, but grassy slope on either side of creek. In middle of unit chert weathers white and forms up to 1/3 volume of rock.	57	2563
48	Limestone, concretionary and shaly as unit 44 but with 1/3 hashy blue-gray limestone with much irregular cherty lamination and yellow-stained matrix blotches.	62	2506
47	Limestone, concretionary and banded with yellow-brown argillaceous partings and stringers. Massive in gully. Some weak chert nodules and blotches. Becomes thin-bedded in upper part and grades from medium to coarse-grained and hashy from top down.	102	2444
46	Limestone, concretionary, medium-bedded to irregularly concretionary thin-bedded, dark-gray, weathers medium-gray with yellow stringers and fretwork throughout. Hashy in lower part.	42	2342
45	Limestone as 42, Forms strike valley to West. Unit spans bend in gully. From here to top of section traverse follows small side gully to northeast.	44	2300
44	Shale and concretionary limestone. Concretionary lenses about 1/3 volume. Matrix is brown, shaly, often laminated and siliceous. Grades up from unit 43.	73	2256
43	Limestone as below, but with more silica in matrix. Weathers with "eyes" where concretionary limestone dissolved away from cherty and siliceous shaly matrix. Upper part is massive with light blue-gray "eyes" in medium brown-gray matrix on weathered surfaces in creek.	92	2183
42	Limestone, concretionary and lenticular wavy bedded. Massive along creek, but medium-bedded on ridges. Limestone lenses medium-gray, weather light blue-gray, matrix is dark green-gray, weathers medium greenish brown-gray. Forms cascades near bend in creek to west (just below bend) where creek is along weak strike valley. On ridge to east, unit forms crest of small hill.	162	2091
41	Limestone, dark-gray, weathers brown-green, medium-bedded, cherty with minor green-brown shaly bands and concretionary layers in lower 10'. Becomes dominantly limestone above where it forms brown semi-ledge. Hashy material in upper part where some thin beds of flat-pebble conglomerate occur.	94	1929
40	Shale as 39 with abundant concretionary limestone zones and much flat-pebble conglomerate beds in lower part. Forms flat between cascades in creek.	36	1835
39	Shale, dark brown-green and dark green-gray, siliceous, with abundant medium-gray limestone nodules. Becomes argillaceous cherty limestone in upper part. Looks like weak hornfels.	57	1799
38	Limestone, massive bedded in creek, flaky and concretionary where weathered on slopes. Dark-gray, weathers medium-gray with siliceous cherty green-brown and orange-brown "chicken-wire" mosiac in part. Unit extends to base of small cascades. Upper part of unit has dark green-gray argillaceous bands and mottling.	87	1742

APPENDIX A (Continued)

37	Limestone as 36, but with calcareous shaly beds 3"-8" thick in lower 5'.	17	1655
36	Limestone dark to dark medium-gray, fine to medium-grained, medium-bedded, hashy limestone with minor 1" to 2" shale partings.	58	1638
35	Mainly covered here, but to east, down strike valley, is as 34, but medium-bedded. Forms gully and strike valley to east along deeply incised creek. Section offset to east one-quarter mile on top of unit 34 to where creek cuts across lower beds at nearly right angles again. This is the top of the dominantly pure limestone unit and is a marked break as well. The top of this unit forms one of the easily mappable horizons because of topographic control to east and west.		
34	Limestone as unit 33, forms hogbacks through which creek cuts to top of 33. Top of unit forms gorge down creek-bottom strike valley.	42	1545
33	Limestone, coarse-grained hashy bioclastic crinoidal unit. Medium-bedded, medium-gray, weathers light blue-gray, forms shear cliff at bend in creek. Black chert nodules are common.	44	1493
32	Limestone, medium-gray, medium-grained to very fine-grained, lower and upper thirds massive, middle one-third medium-bedded. Forms ledges and sharp bend in creek above falls. Some reefoidal algal crusts, but not as pronounced as in Unit 30. Weathers light blue-gray where massive, very light-gray where thin and medium-bedded.	62	1449
31	Limestone, dark-gray, weathers medium-to light-gray, medium-bedded, pure beds with minor argillaceous streaking. Non-reefoidal, medium-grained, hashy in thin beds.	29	1387
30	Limestone, *small algal and sponge bioherms* with thin-bedded hashy limestone in interreef areas. Small reefs 2'-4' thick and 3' to 10' long of medium to dark blue-gray, fine-grained porcellaneous, pure limestone. Interreef limestone is coarse to medium-grained, medium-gray to dark-gray, hashy, thin bedded to medium bedded. Reefs have 2' high "*Collenia*" colonies. Unit is in bend at upper lip of cascades above major falls in creek, at head of barren shaly zone above campground.	64	1358
29	Limestone, medium-gray, weathers light medium-gray with some local yellow-brown mottling and fretwork. Forms basal ledges of cascade above a long falls and rubble slope. Forms part of prominent cliff zone above shales. Thick-bedded to massive. All unit siliceous and has yellow-gray chicken-wire pattern of mottling. Makes a yellow-gray slope in part.	60	1294
28	Limestone, interbedded medium-gray, fine to medium-grained, thin to medium-bedded, with 6" to 1' beds of flat-pebble limestone conglomerate, with minor gray-green weathering, black, calcareous shale. Forms lip at tip of bluff on east side of barren gray shale slope on creek. Fossils very rare fragmental. Limestone all fine-grained.	65	1234
	Total Sarbach Formation	1337'	
27	*Top Mons Formation* As unit 26, but shale and shaly limestone dominant.	86	1169
26	Interbedded limestone and shale. Limestone medium-gray, fine to medium-grained in 6" to 1-foot beds, weathers light medium brown-gray. Forms lowest part of gray slope zone below falls and above brown slope zone. Shale dark-gray, weathers light-gray, calcareous, flaky with abundant light-gray concretionary limestone throughout.	92	1083
25	Interbedded black siliceous, slightly calcareous shale and hashy flat-pebble conglomerate limestone in 3" to 1' beds. Forms yellowish ledgy zone on west side gully. Abundant inarticulate brachipods like small *Westonia*. Forms yellowish shale zone. Trilobite fragments in hashy limestone. Some limestone as ½" x 3" x 6" concretionary beds in brown-green shale.	52	991

APPENDIX A (Continued)

	Section offset to east side of gully beneath falls and ledge on brown limestone. Starts with *O* painted on ledge on east outcrops.		
24	Limestone, dark-gray, flaky, very argillaceous, concretionary in one-half inch or less beds. Forms crest of spur on west side gully. One half is very calcareous medium-gray shale that weathers light-gray, hashy fragments of trilobites very common. Abundant large isotelid trilobites and dendroid graptolites in upper part.	53	939
23	Limestone and shale interbedded. Limestone as 22, shale light green-gray-weathering from medium-green and brownish gray, calcareous and flaky, in 1' to 3' units. Limestone flat-pebble units 6" to 1' resistant flaky, hashy. Some non-conglomeratic units present, but not resistant because of shale stringers and partings.	33	886
22	Interbedded flat pebble conglomerate and very calcareous medium-gray shale. Conglomerate is of medium blue-gray limestone pebbles in yellow-brown matrix. Limestone dominant throughout, but shale and flat-pebble limestone about equal in upper part in 18" to 1' beds. Bedded dark-gray limestone, shaly, recessive, lenticular and wavy bedded dominant toward top. Unit forms first outcrop on east side of creek above gray shale slope zone.	42	853
21	Shale as 19, but one third interbedded hashy limestone. Trilobites, small orthid brachiopods common in hashy limestone.	50	809
20	Shale as 19, but with abundant trilobite fragments and with 3 limestone beds at top of unit, each forming a 1' ledge.	25	759
19	Shale as 18, but with 2" to 4" flat-pebble conglomerate limestone beds every 1' to 3' in upper half. Some limestone lenses in upper part up to 18" thick. All limestone beds very lenticular. Contain ostracodes, nautiloids, trilobite fragments.	35	734
18	Shale, medium green-gray, weathers very light silver-gray, fissile, a few limestones from one inch to six inches 5' from base, all shale calcareous.	27	699
17	Shale, medium gray-green, weathers light green-gray, flaky, calcareous, micaceous sheen on surface, with 1" to 2" hashy trilobite beds of medium-gray limestone every 2' to 3'. Some rare 6" beds of flat-pebble conglomerate throughout. All unit forms broad slope zone.	32	672
16	Covered, probably shale as 17 from rubble.	55	640
	Section offset along southwest bank of creek. Some evidence of minor faulting.		
	Total Mons Formation	584'	
15	*Top Lyell (?) Formation*		
	Limestone as Unit 14, but thick to medium-bedded, weathers medium blue-gray from dark-gray, with some weak yellow mottling, forms upper ledges in creek bed.	29	585
14	Limestone as Unit 10, but less resistant, top forms top of massive ledge in creek near sharp bend to northwest along strike.	42	556
13	Limestone as Unit 10, abundant brown-weathering, black chert nodules at base. Forms ledges at top of second cascade. (Red painted number of feet at top).	59	514
12	Limestone, dark gray, with abundant yellow-brown mottling, concretionary bedded, medium to thick-bedded, with some small black chert nodules and lenses, abundant trilobite fragments, black, somewhat siliceous, coarse grained.	28	455
11	Limestone, medium-gray, coarse-grained, hashy, abundant trilobite fragments, medium-bedded.	23	427
10	Limestone, dark-gray, massive 1' to 5' beds with some 2" to 6" partings of dolomite as in Unit 7. Forms basal ledges of upper cascades Rare brown and light-gray chert lenses, with some irregular chicken-wire-appearing irregular laminated chert 1 to 3 mm. thick in some massive units. Abundant large colonies of *Collenia*.	53	404

APPENDIX A (Continued)

9	Covered except for rare limestone as Unit 8.	125	351
8	Limestone dark-gray, weathers medium blue-gray, massive, fine-grained except for fossil horizons where trilobites and gastropods common. Forms upper ledges of first series of cascades before covered interval.	38	226
7	Limestone, buff-weathering from medium-gray, laminated and with flat-pebble conglomerate, weak ripple marked and with mud cracked polygons. Silty, upper part dark-gray, weathers buff and light yellow-gray.	3	188
6	Limestone as below in Unit 5, but has 12' buff laminated unit as 7 in upper part. Rare black chert nodules and stringers. Thick-bedded.	52	185
5	Limestone, dark-gray, weathers medium blue-gray, thick to medium-bedded with common black chert nodules and lenses. Weathers to ledges, some hashy chertified beds, particularly in thin-bedded middle part. Mainly fine-grained, some hashy coarse-grained beds, however, some weak irregularly rippled lenses.	45	133
4	Limestone, dark to dark medium-gray, medium to thick-bedded, weathers in 18" to 1½" units, a 1' to 1½' dark gray to dark green-gray shale at base with none in upper half of cliff unit. Upper part silicified and dolomitized ribbons and nodules common.	38	88
3	Limestone, dark-gray to medium-gray, weathers medium blue-gray with shale 3" to 1' thick every 1' to 2'. Flat-pebble conglomerate common in middle medium-bedded limestone. Pitted surface. Not noticeably concretionary as unit below.	12	50
2	Limestone and shale interbedded with 5' shale at base which grades up to dominantly limestone at top. Limestone dark to medium-gray, ledgy and nodular throughout. Shale medium dark-gray to medium green-gray, cleaved. Limestone weathers light medium-gray.	24	38
1	Shale, medium gray-green, flaky, with ¼" to 1" medium gray limestone lenses and beds. Forms semislope. Limestone ribbons form rough surface. Lowest exposed beds in upper part of eastern end of campground in creek bed.	14	14
	Total exposed Lyell (?) Formation	585	

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