BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

VOLUME 44 • 1999

BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

Volume 44, 1999

CONTENTS

A Publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Brigham Young University Geology Studies is published by the Department of Geology. This publication consists of graduate student and faculty research within the department as well as papers submitted by outside contributors. Each article submitted is externally reviewed by at least two qualified persons.

ISSN 0068-1016
6-99 650 29580

A Large *Protospongia Hicksi* Hinde, 1887, from the Middle Cambrian Spence Shale of Southeastern Idaho

STEPHEN B. CHURCH
Sinclair Oil Corporation, P. O. Box 30825, Salt Lake City, Utah 84130-0825

J. KEITH RIGBY
Department of Geology, Brigham Young University, S-389 ESC, P.O. Box 24606, Provo, Utah 84606-4606

LLOYD F. GUNTHER
28 North 200 West, Brigham City, Utah 84302

VAL G. GUNTHER
71 North 200 West, Brigham City, Utah 84302

ABSTRACT

The largest known specimen of *Protospongia hicksi* Hinde, 1887, a fragment with articulated spicule skeletal structure, has been collected from the lower Middle Cambrian Spence Shale in southeastern Idaho. It and associated smaller fragments and dissociated spicules came from a 2 m thick, deep-water, spicule-rich claystone located 2–4 m above the base of the Shale, at Oneida Narrows on the Bear River northeast of Preston, Idaho.

INTRODUCTION

A large and moderately intact fragment of skeletal mesh and many shale pieces containing net fragments and dissociated spicules of a protosponge hexactinellid have been collected recently from the Middle Cambrian Spence Shale in southeastern Idaho (Fig. 1).

Several decades ago similar, though loosely associated, hexactinellid sponge spicules collected from Cambrian rocks in southern Idaho were described by Walcott (1920, p. 306–307) as *Protospongia fenestrata* Salter, 1864. No specimens were found at that time that included pieces of intact skeleton, but the slender nature of the cruciform spicule rays led Walcott to identify the spicules as *Protospongia fenestrata.* Those spicules were collected from Walcott's Locality 5g, in the Middle Cambrian Spence Shale, 30.5 m above the Brigham Formation in Two Mile Canyon, 4.8 km southeast of Malad, Oneida County, Idaho. They came from rocks younger than those that contain the sponges described here.

A large rectangular fragment (13 x 20 cm) of relatively intact skeletal mesh of *Protospongia hicksi* Hinde, 1887, and additional net fragments and dissociated spicules were recently collected from the spiculitic layer, 2–4 m above the base of the Spence Shale at two Oneida Narrows localities. These localities are 38 km (24 miles) northeast of Preston, Idaho, in Sec. 6, T. 13 S., R. 41 E., on the Oneida Narrows Reservoir, 7.5′ quadrangle, Idaho (Fig. 1).

Church collected at Locality C (Fig. 1), from a road cut on the Maple Grove Hot Spring Road, 640 m (2100 feet) east and 790 m (2600 feet) south of the northwest corner of Section 6. The Gunthers collected from the same stratigraphic unit at Locality G (Fig. 1) in an upfaulted section approximately 70 m (230 feet) above the road, on a promontory on the ridge to the south of Locality C, at 580 m (1900 feet) east and 1010 m (3300 feet) south of the northwest corner of Section 6.

The large specimen, although a fragment, indicates the large size that some specimens of *Protospongia* attained. Discovery of the sponge also confirms Walcott's earlier determination (1920, p. 306–307), based on loosely associated spicules, that *Protospongia* does occur in the Spence Shale.

Some controversy has developed about the stratigraphic terminology used for the Spence Shale. Walcott (1908) originally defined the unit as a member of the Ute Formation, based on exposures in the Bear River Range near Liberty, Bear Lake County, Idaho. Lowe and Galloway (1993), on a map published by the Utah Geological Survey,

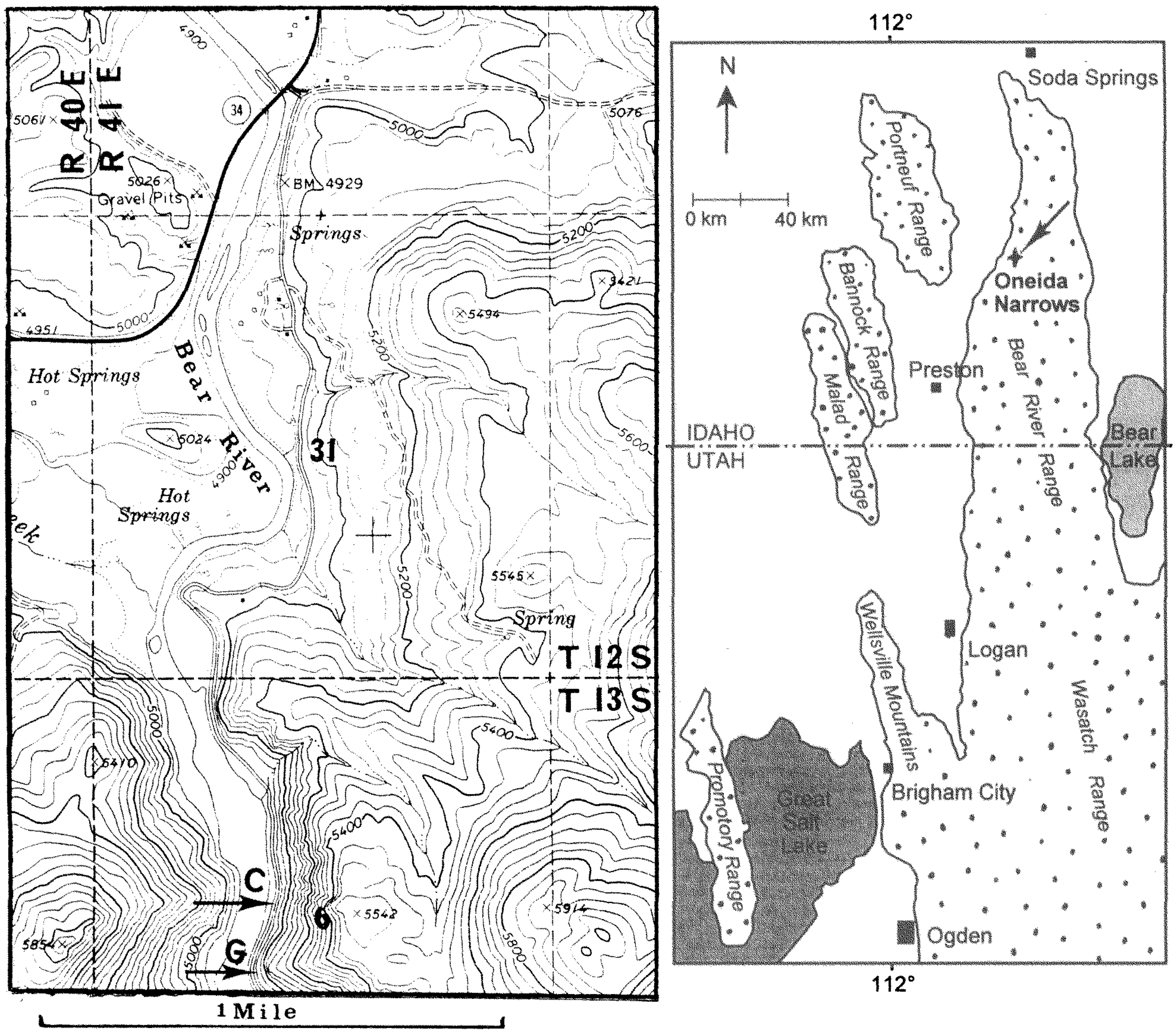


Figure 1. Index maps to the Oneida Narrows sponge localities. 1, *Localities are along the Maple Grove Hot Spring road, or on a ridge above the road, as indicated by the arrows (C, Church; G, Gunther), east of Oneida Narrows Reservoir on the Bear River, in the west-central part of Sec. 6, T. 13 S., R. 41 E., on the Oneida Narrows Reservoir 7.5′ quadrangle. Junction of the Maple Grove Hot Spring Road and Idaho State Highway 34 is 22 miles northeast of Preston, on Highway 34.* 2, *The general position of Oneida Narrows in southeastern Idaho. Mountainous regions are coarsely stippled (modified from Liddell, et al., 1997).*

used terminology proposed by Williams and Maxey (1941) and Maxey (1958), designating the Spence Shale as a member of the Langston Formation. Oriel and Armstrong (1971) had proposed that correlative beds above the Brigham Group in southeastern Idaho be called the Twin Knobs Formation and Lead Bell Shale (Fig. 3) and that the Spence Shale should be designated the Spence Tongue of the Lead Bell Shale. Trilobites collected from the Spence Shale are of Lochman-Balk's *Glossopleura* Trilobite Zone. Robison (1976) placed the sponge-bearing beds within the agnostoid *Peronopsis bonnerensis* Biochron. He also proposed (1991) that the Spence Shale be elevated to formation rank. Liddell, et al., (1997) have summarized the various stratigraphic nomenclatures proposed for the Spence Shale and equivalent units (Fig. 3). They included it as a member of the Langston Formation. Liddell, et al., (1997, fig. 5) show the lower beds of the Spence Shale as in the *Albertella* zone and apparently these sponge-bearing beds are of that age.

Liddell, et al., (1997), in a recent stratigraphic study of the Spence Shale, recognized at least seven shallowing upward, meter-scale, parasequences in the Spence Shale

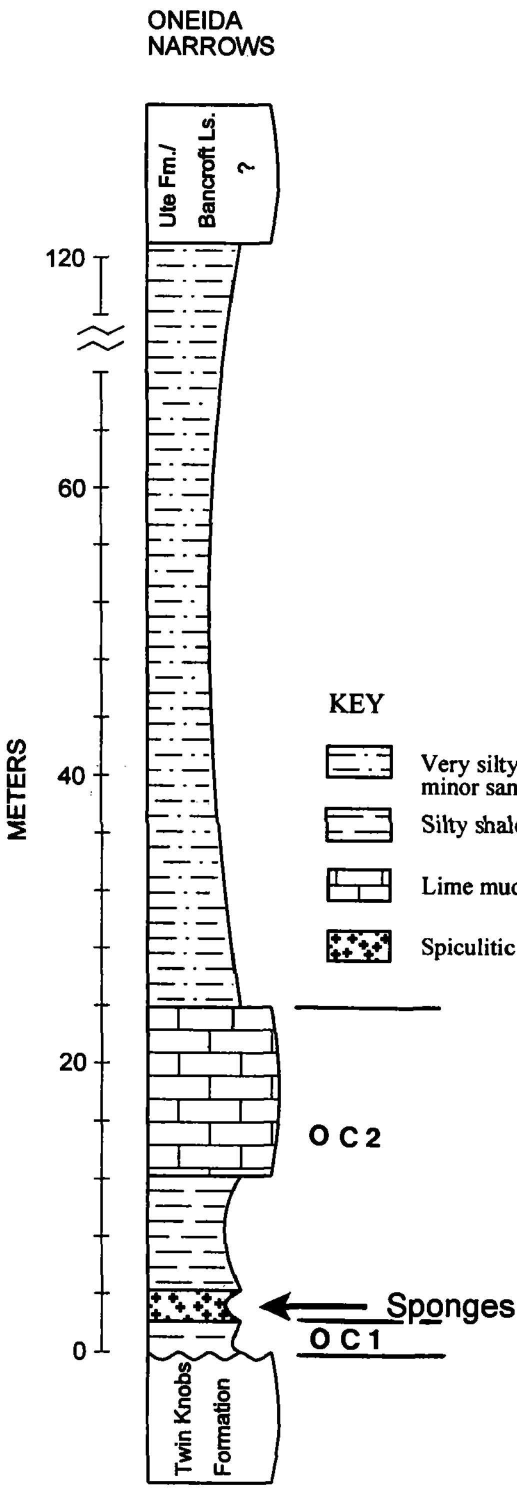


Figure 2. Stratigraphic section of the Spence Shale at Oneida Narrows, Idaho. The arrow indicates the sponge-bearing claystone near the base of the section (modified from Liddell, et al., 1997).

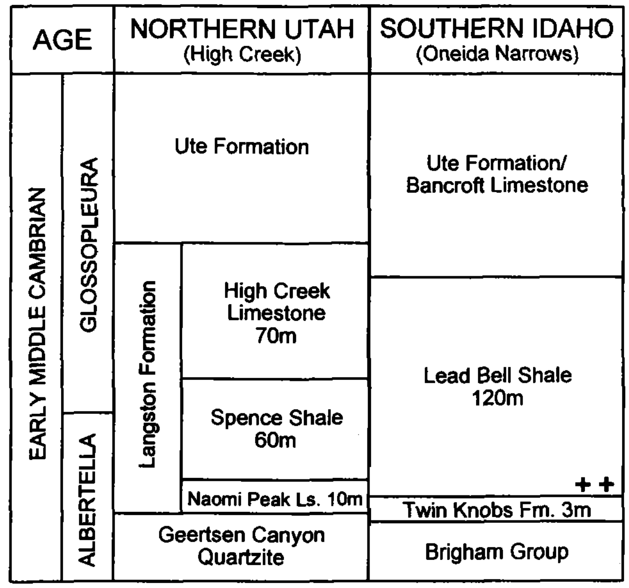


Figure 3. Correlation diagram showing stratigraphic relationships and nomenclature of Lower Middle Cambrian rocks in northern Utah and southern Idaho. The crosses in the lower right mark the position of the spiculitic layer (modified from Liddell, et al., 1997).

in their sequence stratigraphic and paleoecologic study. They delineated parasequence OC2 in the lowermost part of the section (Fig. 2), which hosts a rich sponge spicule accumulation in its base. They investigated a series of sections from northern Utah into southeastern Idaho and noted depositional settings that they interpreted as ranging from proximal to distal ramp positions. The Spence Shale at the Oneida Narrows locality, the collecting site for the *Protospongia hicksi* described here, accumulated in a deep ramp or basinal setting. Liddell, et al., (1997, p. 75) observed that, "At this locality the Spence/Lead Bell Shale differs greatly from all other sites described herein. The basal portions are very dark and generally lack limestone. These beds contain abundant sponge spicules and agnostoid trilobites, as well as a diminutive fauna of oryctocephalid trilobites, suggesting that this is the deepest environment represented by the basal Spence Shale."

The spicule-rich unit at the base of parasequence OC2 of Liddell, et al., (1997) is about 2 m thick and 2–4 m above the base of the formation. It is an argillaceous, blocky, dark-gray shale that weathers to a medium-gray. Overlying shales are dark-gray to black, thinly bedded, fissile, and brittle. The less fissile spiculitic zone is exposed in the near basal southern part of the road cut at the locality where Church collected (C of Fig. 1), where beds dip into the hillside in the northern and central part of the roadcut. The spicule-bearing zone is traceable along the outcrop for approximately 3 m, to where it is truncated at the southern end of the exposure by a fault. Vertical fracture sets disrupt the unit throughout the exposure because of proximity to the fault zone. Consequently, the shale tends to break along fractures rather than bedding planes. Three bedding planes in a relatively unfractured interval within the blocky shale contain skeletal wall mesh fragments of *Protospongia hicksi.* The lower two surfaces are separated by 2 cm and the upper one is 3.5 cm higher stratigraphically. These thin intervals suggest depositional pulses with rapid burial of organisms that left delicate skeletal sponge walls mostly intact and relatively undeformed. These episodic smothering events, possibly seasonal or storm-related, or ash falls, must have interrupted an otherwise favorable environment for sponge growth.

Preservation of sponge fossils at Locality C is generally poor. After the shale is split and bedding planes are exposed, the spicule meshes tend to disintegrate upon extended exposure to air. Positive molds of spicules crumble and counterpart impression surfaces also deteriorate with time. Spray lacquer was applied immediately after exposing fossil-bearing surfaces, to stabilize and protect the bedding plane surfaces and sponge body-fossil fragments.

The trilobite-bearing basal black shale of parasequence OC1 of Liddell, et al., (1997) is approximately 3.5 m thick and is exposed in a small quarry (Locality G, Fig. 1) above the ledge-forming top beds of the Twin Knobs Formation on the ridge crest. The gray, relatively massive, spiculitic claystone is approximately 1.5 m thick and is exposed in the upper trench of the quarry. The claystone is overlain by black fissile shale of the lower part of parasequence OC2 of Liddell, et al., (1997, Fig. 7).

Robison (1991) and Liddell, et al., (1997, p. 66) concluded that many of the classic Spence Shale fossil deposits represent tempestite accumulations. The relatively light gray-brown, argillaceous rocks, packed with sponge spicules, at the Oneida Narrows localities, may have accumulated as tempestite deposits in the deepest environments documented by the basal Spence Shale. Alternatively, the micaceous and clay-rich nature of the beds, their comparatively light color, plus their uniform texture, other than for the exotic sponge spicules, suggest these beds may represent volcanic ash accumulations. Liddell (personal communication, 1999) noted that the basal part of the Spence Shale represents a transgressive system tract where sedimentation rates were typically low, and that lower beds within parasequence OC2 generally reflect an interval of sediment starvation that resulted in the high concentration of spicules.

SYSTEMATIC PALEONTOLOGY

Class HEXACTINELLIDA Schmidt, 1870
Order RETICULOSA Reid, 1958
Superfamily PROTOSPONGIOIDEA Finks, 1960
Family PROTOSPONGIIDAE Hinde, 1887
Genus PROTOSPONGIA Salter, 1864
PROTOSPONGIA HICKSI Hinde, 1887
Figs. 4–5

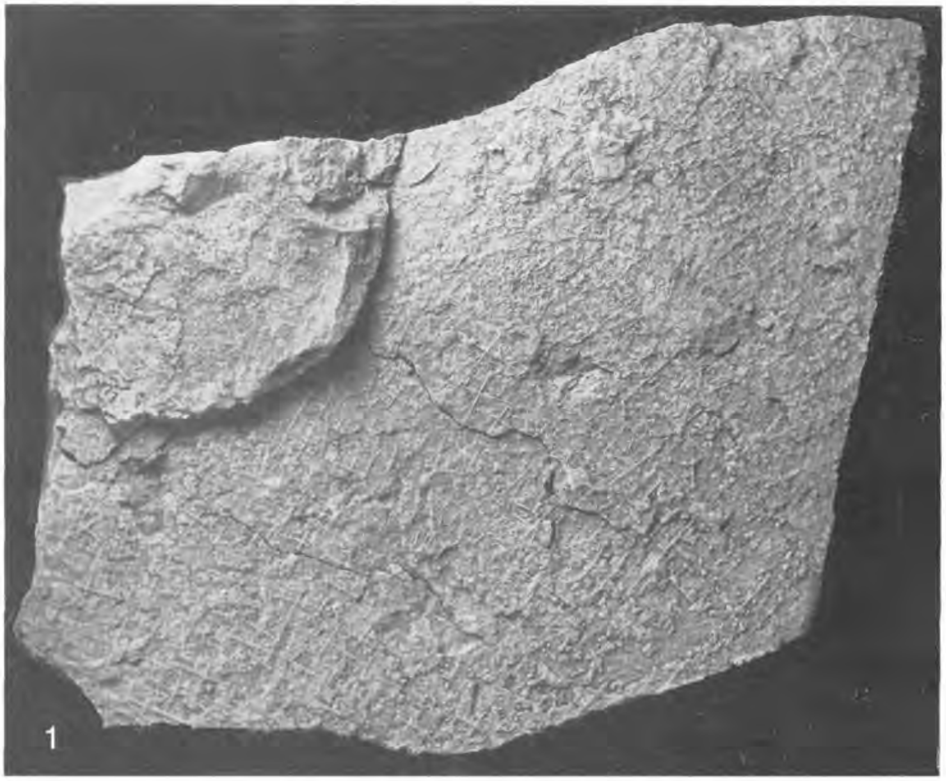
Protospongia fenestrata HICKS, 1871, p. 401, pl. 16, fig. 20; BRÖGGER, 1878, p. 36, pl. 6, fig. 14; ROEMER, 1880, p. 316, fig. 59b; SOLLAS, 1880 p. 362, fig. 1.

Protospongia hicksi HINDE, 1887, pl. 1, figs. 2, 2a; 1888, p. 107, pl. 1, figs. 2, 2a; RAUFF, 1894, p. 237, WALCOTT, 1920, p. 307–309, pl. 80, figs. 3, 3a–b; RIGBY, 1966, p. 549–554, pl. 66, figs. 1, 2; RUSHTON and PHILLIPS, 1973, p. 231–237, pl. 23, figs. 1–3; RIGBY, 1976, text-fig. 4; GUNTHER and GUNTHER, 1981, p. 69, pl. 55, figs. A–C; RIGBY, 1983, fig. 9; RIGBY, 1986, p. 53–54, pl. 18, figs. 1, 2.

Original description.—"Sponge probably vasiform; the portions preserved indicate that the type specimen was at least 100 mm. in height by 75 mm. in width, at the summit. The spicular mesh is composed of robust cruciform spicules, the rays are approximately rectangular, and nearly of a uniform thickness throughout their length. The centers of the spicules are slightly elevated so that they are not strictly horizontal. The rays of the smaller spicules in the majority of cases dip beneath those of the larger forms. Five series of squares are present in the complete mesh, the largest are 8 mm. in diameter and the smallest .5 mm.; the axes of the largest spicules are 16 mm. in length and .52 mm. in thickness, whilst the smallest are 1 mm. in length and .2 mm. in thickness. . . In no case in this species are the points of contact of the spicules with each other clearly shown, but the structure of the mesh appears to justify to me the view that the spicules are cemented together where they join each other; Prof. Sollas states, however, that they are separated and not limited either by development in a common coating or by ankylosis." (Hinde, 1888, p. 107).

Description.—One large fragment of skeleton, USNM 480564A and B, preserved as part and counterpart, covers a rhomboidal area, 13 x 20 cm, on which the delicate articulated skeletal mesh is preserved. Two other layers with articulated skeletal mesh occur in the same block a few centimeters apart. Growth fabric of the specimen is somewhat fan-shaped and suggests a sponge at least 23 cm tall from the preserved fragment. Whether the sponge was broadly obconical or vase-shaped is uncertain, but the material does represent a common large species.

Six orders of cruciform stauractines, or hexactines, occur in the impression. Six orders of spicules are preserved.



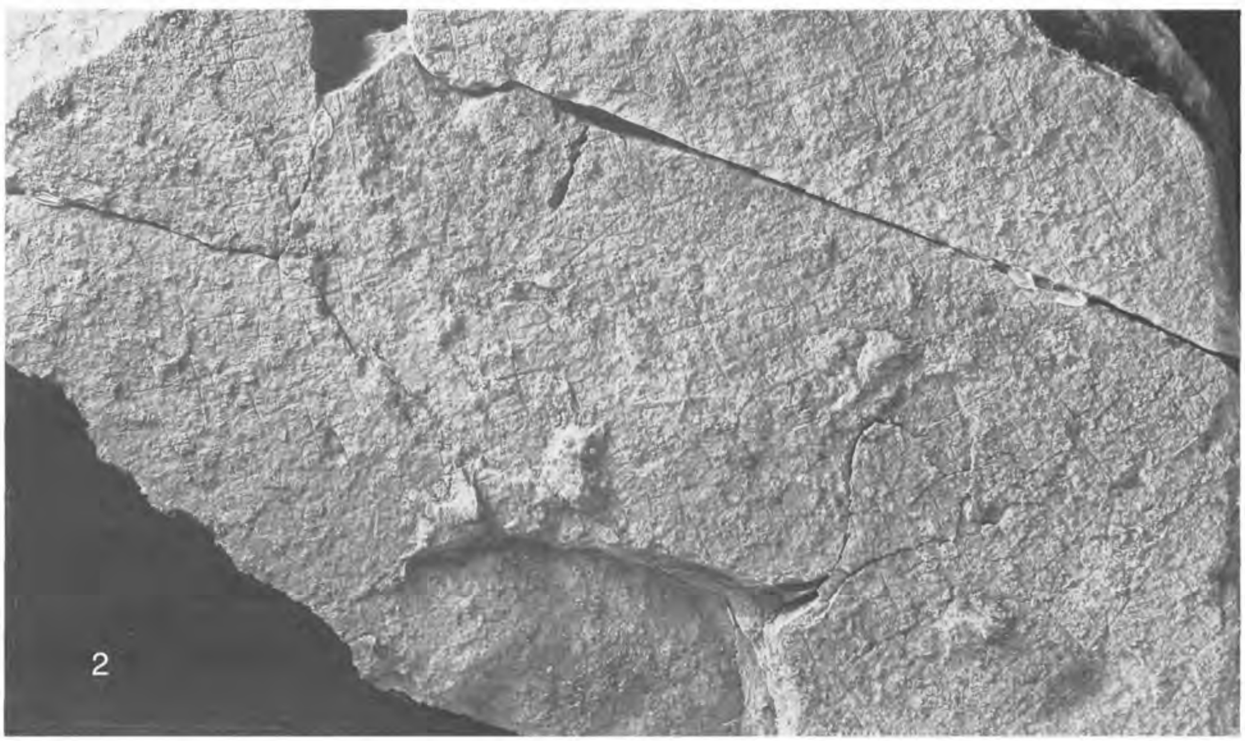


Figure 4. Protospongia hicksi *Hinde, 1887, from Locality C in the Spence Shale at Oneida Narrows, Idaho. 1, Counterpart surface showing the intact skeletal net, which expands toward the upper left. USNM 480564 B, x 1. 2, Large block, inverted from 4.1, with bedding plane surface showing the moderately intact skeletal mesh with first-order quadrules 9–13 mm across. This is the largest known fragment of the skeleton of the species. USNM 480564 A, x 1.*


1

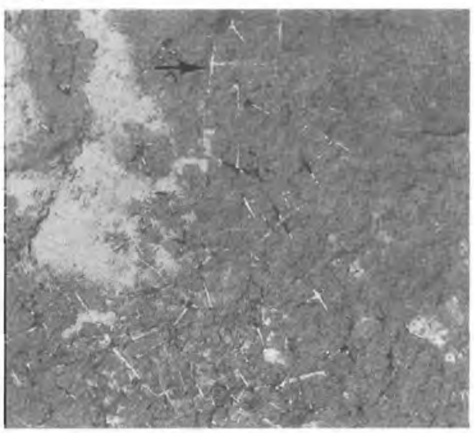

2


3


4


5


6


7


8


9

Largest first-order spicules have rays 14–15 mm long, where complete, and basal ray diameters of 0.40– 0.50 mm. These are commonly at mutual right angles, although some with angles of only approximately 60° do occur, presumably where flattened and somewhat modified. These large spicules occur at diagonal corners of first-order quadrules, which range 9–13 mm across and high with some regularity. The borders of quadrules are made by two long rays each of the two diagonally-positioned spicules, whose rays tips overlap and extend somewhat parallel to rays of adjacent spicules.

Those quadrules are subdivided by second-order spicules with rays 7–8 mm long that have basal ray diameters of 0.35–0.40 mm. These spicules subdivide first-order quadrules into second-order rectangular quadrules 5–7 mm across and high. These quadrules, in turn, are subdivided by third-order spicules into smaller openings that range 2–3.5 mm high and wide. These third-order spicules have rays 4.5–5.0 mm long and 0.30–035 mm in basal ray diameter. Fourth-order spicules, with rays 2.5–3.2 mm long and with basal ray diameters of 0.20–0.25 mm, subdivide third-order openings into fourth-order openings 1.2–1.5 mm across, but these and smaller quadrules are more irregular than the larger ones, for apparently the smaller spicules shifted more easily.

Fifth-order spicules have rays 1.2–1.3 mm long and basal ray diameters of 0.12–0.15 mm. They defined fifth-order quadrules approximately 0.5–0.8 mm in diameter, but these are the least well-preserved and least regular openings defined in the skeletal net. Sixth-order spicules do occur, but they are commonly loose and appear only as tiny spicules, either floating free in matrix of other samples or as irregular oriented spicules in the larger net fragment. These have rays 0.6–0.7 mm long and have basal ray diameters of 0.08–0.10.

Some spicules of first-order to fourth-order size show rudimentary knobs of probably radial rays. These are characteristically only a few tenths of a millimeter high and are only rarely preserved in the fossils. They do indicate, however, that many of the spicules are basically hexactines or modified stauractines. Generally speaking the spicules are either replaced with pyrite, now altered to limonite, or as calcareous structures. Others are preserved only as molds or impressions in the shaly surface.

Clusters of four or five straight rays suggest presence of root-tuft spicules and one large spicule (Fig. 5.4), with aborted rays at the upper end, occur as limonite impressions. The latter is approximately 20 mm long and has a basal ray diameter at the upper end of approximately 0.40 mm. The spicule is isolated in a cluster of irregularly oriented stauractines, but poor development of horizontal rays and the length of the spicule ray longer than that seen in first-order spicules in the intact skeletal mesh, suggests that it may have been a root-tuft element.

Fillings of small, axial canals (Fig. 5.1) are preserved in some of the calcareously replaced spicules (USNM 480566). The canals appear as dark, rod-like elements in the otherwise light gray rays. One such axial canal is a dark limonite rod approximately 0.03 mm in diameter near the base of the ray, which is approximately 0.2 mm in diameter. The ray and the rod appear to taper distally, although, only a relatively short segment of the ray, approximately 0.6 mm long, shows the well defined axial structure.

A small specimen, USNM 480569, appears to include a fragment of skeletal net from near the base of the sponge wall and is preserved in a block 40 x 52 mm across. It shows, in cast-and-mold impressions, much of an upward-expanding grid where first-order quadrules are 8.0–8.5 mm across and 7.0–7.5 mm high, in the lower part, and up to 9–10 mm wide and 10.5 mm high, in the upper part of the fragment. First- and second-order spicules are well preserved, but third-order spicules are less common, and fourth-order spicules are rare. Lateral rays curve in the

Figure 5. Protospongia hicksi *Hinde, 1887, from the Spence Shale at Oneida Narrows, Idaho localities.* 1, 7, *Specimen 480566, from Locality G;* 1, *The second-order spicule has the axial canal in one ray filled with dark limonite in the calcareous preservation, x 10,* 7, *position of the spicule in the block (arrow), which also shows some of the skeletal net in the lower part, x 2.* 2, 5, *Specimen USNM 480567, from Locality G, where spicules have been replaced by calcareous material, shows first- and sixth-order spicules well; a sixth-order spicule occurs in* 2 *as the small spicule in the upper center. The largest spicule is part of a first-order element. Position of* 2 *is indicated in* 5 *by the arrow, which points at the ray junction in the large spicule. Other spicules and part of an organized net show near the base.* 2, *x 10;* 5, *x 2.* 3, 6, *Part of a skeletal net showing ranked spicules in USNM 480568, from Locality G, where some elements are replaced by calcareous material and others are evident as casts and molds on the bedding plane. The dark area of partial limonite replacement in the lower center of* 3 *is indicated by the arrow in* 6, *with the specimen rotated 90° counter clockwise. Spicules in the left part of the fragment are irregularly oriented;* 3, *x 10,* 6, *x 2.* 4, *A long possible root tuft spicule is indicated by the arrow. It has short aborted rays at the top, near the edge of the fragment. Other spicules are irregularly oriented, USNM 480565, from Locality G, x 2.* 8, 9, *Part and counterpart of USNM 480569, from Locality C, showing the curved lateral margin of first-order quadrules and the upward divergence of rays of first-order spicules, to the right in* 8 *and to the left in* 9. *The fragment is from near the base of the sponge both x 1.*

flattened impression and vertical rays diverge upward in the regular expanding structure.

Discussion.—Protospongia hicksi Hinde, 1887, and *Protospongia fenestrata* Salter, 1864, are similar and very closely related sponges. Hinde (1888, p. 107–108) differentiated the two species based on dimensions of spicules and observed that ray diameters are significantly greater in *Protospongia hicksi* than they are in *Protospongia fenestrata.* Rauff (1894, p. 236–237) reached the same conclusion as Hinde and observed that the largest spicules in *Protospongia fenestrata* Salter, 1864, have rays 0.2 mm thick and up to 8 mm long, with those of associated orders with ray lengths of 4, 2, 1, and 0.5 mm respectively. He observed that in *Protospongia hicksi* Hinde, 1887, the coarsest spicules have basal diameters of 0.52 mm and rays approximately 16 mm long and range down to the smallest spicules that have rays 1 mm long and basal diameters of 0.2 mm, combining to make quadrules 8, 4, 2, 1, and 0.5 mm on the side. The latter are generally the dimensions of spicules in the sponges from the Spence Shale at the Oneida Narrows localities reported here.

A similar large fragment of *Protospongia hicksi* Hinde, 1887, described by Rigby (1966) from the Middle Cambrian Marjum Formation in the House Range in western Utah, has spicules of essentially the same dimensions as those in the Spence Shale specimens reported here.

Literally hundreds of individual sponges must be represented in the approximately 2 m of light gray-brown-weathering, relatively massive, claystone from which the specimens reported here were collected. Most fragments from the claystone show only irregularly oriented, disrupted, skeletal structure as a strew of spicules of various orders in irregular spacing and orientation. A few, however, show fragments a few centimeters across in which the quadruled skeletal structure is still preserved. The large specimen reported here, however, is the largest single specimen of the species yet recovered.

Material.—The large specimen USNM 480564A and B, plus five additional figured specimens, USNM 480565-480569, are all from the basal 2 m of parasequence OC2 of Liddell, et al., (1997), in the near-basal part of the Spence Shale at the Oneida Narrows localities. USNM 480564A and B, and 480569 and other fragments were collected by Church from the lower Locality C (Fig. 1), and USNM 480565–480568 and numerous additional fragments were collected by the Gunthers from the upper Locality G (Fig. 1).

ACKNOWLEDGMENTS

Minor costs of manuscript and figure preparation were partially covered by NSF Grant EAR-9116202 to Rigby. We appreciate the assistance of Glade Gunther in the collection of the sponges. Drafts of the manuscript were prepared by M. M. Lorz, and photographs were printed by C. B. Linford, both from the Department of Geology, Brigham Young University. Linford also constructed Figures 1–3, modified from Liddell, et al., (1997). W. D. Liddell and S. M. Ritter provided helpful reviews of the manuscript.

REFERENCES CITED

Brögger, W.C., 1878, Om paradoxides skifene ved Krekling, Separat-Abdruck aus Nyt Magazin for Natuurvidenskaberne, 24.20–21. [in Swedish]

Gunther, L.F., and Gunther, V.G., 1981, Some Middle Cambrian fossils of Utah, Brigham Young University Geology Studies, 28, part 1, 81 p.

Hicks, H., 1871, Description of new species of fossils from the Longmynd rocks of St. Davids, Quarterly Journal of the Geological Society of London, 27.401–402.

Hinde, G J , 1887, A monograph of the British fossil sponges, Part I, Sponges of Palaeozoic and Jurassic strata, Palaeontological Society, London, 40:1–92

______, 1888, Notes on sponges from the Quebec Group at Métis, and from the Utica Slate, *in* New species of fossil sponges from Little Métis, Province of Quebec, Canada, Notes on Specimens, Canadian Record of Science, 3:59–68, (reprint, 1888, Peter Redpath Museum, McGill University, Montreal, Notes on Specimens, p 59–68.)

Liddell, W.D., Wright, S H , and Brett, C E., 1997, Sequence stratigraphy and paleoecology of the Middle Cambrian Spence Shale in northern Utah and southern Idaho, Brigham Young University Geology Studies, 42(1):59–78.

Lowe, M., and Galloway, C L , 1993, Provisional geologic map of the Smithfield quadrangle, Cache County, Utah, Utah Geological Survey Map 143.

Maxey, G.B., 1958, Lower and Middle Cambrian stratigraphy in northern Utah and southeast Idaho, Geological Society of America, Memoir 114, p. 17–26

Oriel, S S., and Armstrong, G.C , 1971, Uppermost Precambrian and lowermost Cambrian rocks in southeastern Idaho, U S. Geological Survey Professional Paper 394, 52 p

Rauff, H., 1894, Palaeospongiologie, Palaeontographica, v 41, p 233–346

Rigby, J.K., 1966, *Protospongia hicksi* Hinde from the Middle Cambrian of Western Utah, Journal of Paleontology, 40.549–554

______, 1976, Some observations on occurrences of Cambrian Porifera in western North America and their evolution, *in* Robison, R.A , and Rowell, A J., eds , Paleontology and Depositional Environments Cambrian of Western North America, Brigham Young University Geology Studies, 23(2) 51–60

______, 1983, Sponges of the Middle Cambrian Marjum Limestone from the House Range and Drum Mountains of western Millard County, Utah, Journal of Paleontology, 57.240–270.

______, 1986, Sponges of the Burgess Shale (Middle Cambrian), British Columbia, Palaeontographica Canadiana, No 2, Canadian Society of Petroleum Geologists and Geological Association of Canada, 105 p.

Roemer, C F, 1880, Lethaea palaeozoica, Erste Lieferung, 324 p

Robison, R.A., 1976, Middle Cambrian trilobite biostratigraphy of the Great Basin, Brigham Young University Geology Studies, 23 93–109

______, 1991, Middle Cambrian biotic diversity; examples for four Utah Lagerstatten, p 77–98, *in* Simonetta, A.M , and Conway Morris, S , eds., The early evolution of metazoa and the significance of problematic taxa, Cambridge, Massachusetts, Cambridge University Press

Rushton, A W.A., and Phillips, W.E.A , 1973, A *Protospongia* from the Dalradian of Clare Island, Co. Mayo, Ireland, Palaeontology, 16 231–241

Salter, J.W., 1864, On some new fossils from the Lingula Flags of Wales, Quarterly Journal of the Geological Society of London, 20:233–441

Sollas, W.J., 1880, Structure and affinity of *Protospongia,* Quarterly Journal of the Geological Society of London, 36 362–366

Walcott, C.D., 1908, Nomenclature of some Cambrian Cordilleran formations, Smithsonian Miscellaneous Collections, 53.167–230.

______, 1920, Middle Cambrian Spongiae, Cambrian Geology and Paleontology, Smithsonian Miscellaneous Collections, 67(6):261–364.

Williams, J.S., and Maxey, G.B., 1941, The Cambrian section in the Logan quadrangle, Utah and vicinity, American Journal of Science, 239. 276–285.