
Supplementary information

A late-Ediacaran crown-group sponge animal

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A late Ediacaran crown-group sponge animal

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14 **Supplementary Information: Phylogenetic Data and Analysis**

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1. Phylogenetic datasets

Our character dataset was mainly adapted from that of Dunn et al.¹, which includes representative taxa of the main metazoan clades and their characters (Character 1–175, 220–222 below). To improve the phylogenetic resolution of sponges, several sponge-specific characters were adapted from Dohrmann et al.² (Character 178–219), Manuel et al.³ (Character 223–230), and Alvarez et al.⁴ (Character 231). Six new characters were introduced to define the skeletal architecture of certain sponge-grade organisms: “Highly regular hierarchical reticulate skeleton (quadrate mesh)” (Character 176), “Shape of the space between the skeletal mesh” (Character 177); and to better reconstruct the relationships between fossil and extant sponges: “Biminerallic spicules” (Character 232), “Calcareous spicules” (Character 233), “Shape of the cross-section of the axial filament” (Character 234), and “Shape of the cross-section of the axial filament” (Character 235).

New sponge taxa that were added to the Dunn et al.¹ dataset included 6 genera of fossil sponges (*Diagoniella*, *Protospongia*, *Eiffelia*, *Cyathophycus*, *Minitaspongia*, and *Vauxia*) and 35 genera of extant sponges (*Agelas*, *Cymbastela*, *Metania*, *Oscarella*, *Plakortis*, *Sycon*, *Leucosolenia*, *Uteopsis*, *Hyalonema*, *Pheronema*, *Semperella*, *Sericolophus*, *Aphrocallistes*, *Heterochone*, *Tretodictyum*, *Hexactinella*, *Farrea*, *Iphiteon*, *Rhabdoplectella*, *Walteria*, *Euplectella*, *Acoelocalyx*, *Malacosaccus*, *Rossella*, *Rossellinae*, *Acanthascus*, *Aulosaccus*, *Bathydorus*, *Caulophacella*, *Crateromorpha*, *Lophocalyx*, *Clathrochone*, *Leucopsacus*, *Caulophacus*, and

Oopsacas). Among the 235 characters in the dataset, 211 were scored for *Diagoniella*, 214 were scored for *Protospongia*, 212 were scored for *Eiffelia*, 214 were scored for *Cyathophycus* (with the coding predominantly based on *Cyathophycus loydelli*, a well-documented and extensively studied species within the genus), 185 were scored for *Minitaspongia*, 217 were scored for *Vauxia*, and 67 were scored for *Helicolocellus*. Note that the Choanoflagellata was included only for the purpose of rooting the tree: it was coded as absent or unknown for all characters except character 1 (collar complex). The taxon coding (except for *Helicolocellus*) in this study relies exclusively on literature cited in this document (ref.¹⁻⁴ and others cited in the character list).

The marginal model likelihoods for the different rate models were:

- gamma distribution with symmetrical transition frequencies (-1816.26);
- gamma distribution with asymmetrical transition frequencies (-1792.39);
- lognormal distribution with asymmetrical transition frequencies (-1790.86);
- lognormal distribution with symmetrical transition frequencies (-1813.49);

The marginal likelihoods for each model were used to determine the best-fit model through Bayes factors⁵, i.e., values that signify the relative strength of statistical support for one hypothesis/model over another: $2\Delta\log_e L$, where L is likelihood. Bayes factors calculated in this study indicate that the model with lognormal distribution and asymmetrical transition frequencies is strongly supported over the models with

symmetrical transition frequencies, and reasonably supported over the model with gamma distribution⁵ (Table S1).

	GS	GA	LS	LA
GS	n/a	47.74	5.54	50.8
GA	-47.74	n/a	-42.2	3.06
LS	-5.54	42.2	n/a	45.26
LA	-50.8	-3.06	-45.26	n/a

Table S1. Bayes factor comparison of evolutionary models, with positive values meaning greater support for models listed in the top row. GS: gamma distribution with symmetrical transition frequencies; GA: gamma distribution with asymmetrical transition frequencies; LS: lognormal distribution with symmetrical transition frequencies; LA: lognormal distribution with asymmetrical transition frequencies. Interpretations of Bayes factors follow reference⁵.

The marginal model likelihoods for two different topological hypotheses with regard to *Helicolocellus* were:

- *Helicolocellus* is a stem-group sponge (-1540.46)
- *Helicolocellus* is a stem-group hexactinellid (-1532.55)

The Bayes factor indicates that the stem-group hexactinellid hypothesis is strongly supported over the stem-group sponge hypothesis (Bayes factor value equals 15.82).

In other words, *Helicolocellus* is strongly supported as a crown-group sponge.

These marginal model likelihoods (the average fit of a model to a data set⁶, with higher values meaning better fit) were computed using stepping stone sampling with

50 steps and 20,000,000 generations. The data best support the model with a lognormal distribution and asymmetrical transition frequencies, and the topology of the stem-group hexactinellid hypothesis.

Sensitivity tests have been conducted in order to assess whether the phylogenetic interpretation of *Helicolocellus* remains robust under different topologies for early metazoans. These include constraint of ctenophores as sister-group to all other animals⁷ (Extended Data Fig. 5a), and constraint of the relationships of sponge classes and the internal relationships within Hexactinellida to be consistent with recent molecular phylogenies^{2,8} (Extended Data Fig. 5b).

2. Character list

1. Collar complex

We infer homology between the choanocytes of sponges and choanoflagellates because of their shared microvillar collar surrounding an undulating flagellum.

0 – absent

1 – present

2. Multicellularity with extracellular matrix (ECM)

ECM is described in all animal groups. The large body size of *Helicolocellus* is incompatible with unicellular or coenocytic anatomy.

0 – absent

110 1 – present

111

112 3. Septate junctions

113 Presence of this character is contingent on multicellularity. Septate junctions are
114 present in Eumetazoa, excluding vertebrates and ctenophores, but are uncertain in
115 Placozoa and only present in calcarean poriferans.

116 0 – absent

117 1 – present

118

119 4. Tight junctions

120 Presence of this character is contingent on multicellularity. Tight junctions are present
121 in vertebrates and urochordates.

122 0 – absent

123 1 – present

124

125 5. Gap junctions

126 Presence of this character is contingent on multicellularity. Gap junctions are present
127 in eumetazoans, but absent in all cnidarian Classes (except Hydrozoa) and
128 echinoderms.

129 0 – absent

130 1 – present

131

132 6. Adherens junctions

133 Presence of this character is contingent on multicellularity. Adherens junctions are
134 present in all animal lineages.

135 0 – absent

136 1 – present

137

138 7. Hemidesmosomes

139 Hemidesmosomes are present in eumetazoans and connect epithelial cells to the basal
140 lamina.

141 0 – absent

142 1 – present

143

144 8. Differentiation of two epithelial layers

145 Placozoa differentiates two epithelial layers along with all eumetazoans, but
146 homoscleromorph sponges only differentiate one layer.

147 0 – absent

148 1 – present

149

150 9. Epithelia with basal laminae

151 Epithelia is present in all sponges but only homoscleromorph sponges are known to
152 possess basal laminae. Placozoa also lacks epithelia with basal laminae.

153 0 – absent

154 1 – present

155

156 10. Spermatogenesis

157 While many animals have the ability to reproduce asexually, most animal phyla
158 reproduce sexually. Placozoans have never been observed to reproduce sexually.

159 0 – absent

160 1 – present

161

162 11. Oogenesis

163 While many animals have the ability to reproduce asexually, all phyla produce sperm
164 and eggs.

165 0 – absent

166 1 – present

167

168 12. Collagen

169 0 – absent

170 1 – present

171

172 13. Aquiferous system with ostia and osculae

173 Defining the body of the poriferans, ostia are inhalant openings and osculae are
174 exhalant openings through which water flows. We did not directly observe them, so it
175 is marked unknown for *H. cantori*.

176 0 – absent

177 1 – present

178

179 14. Pinacocyte

180 Making up the pinacoderm of poriferan, but absent in Hexactinellida.

181 0 – absent

182 1 – present

183

184 15. Archaeocytes

185 Involved in the ingestion of food particles (from choanocytes) in poriferans.

186 0 – absent

187 1 – present

188

189 16. Skeletal elements contain silica

190 *Protospongia*⁹, *Eiffelia*¹⁰, *Cyathophycus*¹¹, and *Vauxia*^{12,13} are scored as present.

191 *Diagoniella* and *Minitaspongia* are assigned to siliceous sponges¹⁴⁻¹⁷, but their

192 spicules are always replaced by iron compounds or calcium carbonate¹⁴⁻¹⁷. Since the

193 original mineralogy is obscured, they are scored as unknown. The presence of silica in

194 the skeletal elements in *Helicolocellus* is also scored as unknown.

195 0 – absent

196 1 – present

197

198 17. True spongin

199 0 – absent

200 1 – present

201

202 18. Body tissue

203 Body tissues are present in all animals except Placozoa and Porifera (excluding
204 homoscleromorphs, which possess epithelia).

205 0 – absent

206 1 – present

207

208 19. Anatomical polarity

209 This character requires multicellularity and therefore is contingent on that character.

210 Body polarity is defined as the ability to polarise the body along one or more axes.

211 Body polarity is present in all animals and in *Helicolocellus*.

212 0 – absent

213 1 – present

214

215 20. Polarity type

216 This character does not differentiate between specific metazoan body axes (e.g.

217 dorsal–ventral or oral–aboral), but orders successive body axes on the understanding

218 that one must precede two, and two must precede three. *Helicolocellus* has one

219 principal body axis.

220 0 – one principal body axis

221 1 – two principal body axes

222 2 – three principal body axes

223

224 21. Intermediate body layer populated by fibre cells

225 Fibre cells are present only in placozoans. Fibre cells are reactive to some cnidarian

226 neurotransmitters, but nerve cells have not yet been found in placozoans.

227 0 – absent

228 1 – present

229

230 22. Crystal cells

231 These are present in placozoans. Crystal cells contain an aragonitic crystal and are

232 arranged around the perimeter of the organism. They mediate the organism's response

233 to gravity.

234 0 – absent

235 1 – present

236

237 23. Nerve cells

238 Present in all eumetazoans and contingent on the presence of monociliated sensory

239 cells.

240 0 – absent

241 1 – present

242

243 24. Acetylcholine used as neurotransmitter

244 Present in cnidarians and bilaterians, but absent in ctenophores.

245 0 – absent

246 1 – present

247

248 25. Gamma-acetylbutyric acid used as neurotransmitter

249 Present in cnidarians and bilaterians, but absent in ctenophores.

250 0 – absent

251 1 – present

252

253 26. Uniform, diffuse nerve net

254 0 – absent

255 1 – present

256

257 27. Hox/ParaHox genes

258 Present in Placozoa, Cnidaria and Bilateria

259 0 – absent

260 1 – present

261

262 28. Diploblasts made of two cell layers

263 0 – absent

264 1 – present

265

266 29. Endoderm and Ectoderm

267 0 – absent

268 1 – present

269

270 30. Mesoderm

271 Bilaterians are scored as possessing mesoderm to the exclusion of placozoans,

272 cnidarians and ctenophores.

273 0 – absent

274 1 – present

275

276 31. Monociliated sensory cells

277 Present in Cnidaria, Ctenophora and Bilateria but absent in Porifera and Placozoa.

278 0 – absent

279 1 – present

280

281 32. Triploblasts made of three germ layers

282 This is contingent on the presence of diploblasty and so an endoderm and an

283 ectoderm. Cnidaria is marked as absent for this character.

284 0 – absent

285 1 – present

286

287 33. Striated ciliary rootlets

288 0 – absent

289 1 – present

290

291 34. Spiral cleavage with 4d mesoderm

292 Spiral cleavage is present in many spiralian lineages, but is absent in Bryozoa,

293 Brachiozoa and Gastrotricha.

294 0 – absent

295 1 – present

296

297 35. Gastrovascular cavity

298 Present in cnidarians, ctenophores and bilaterians, but absent in placozoans, which

299 utilise an external digestive sole, and absent in sponges.

300 0 – absent

301 1 – present

302

303 36. Coelenteron

304 A blind gastrovascular cavity that is known in both cnidarians and ctenophores.

305 0 – absent

306 1 – present

307

308 37. Giant fibre nerve net in medusae

309 0 – absent

310 1 – present

311

312 38. Gastrulation

313 Present in all eumetazoans.

314 0 – absent

315 1 – present

316

317 39. Through-gut

318 0 – absent

319 1 – present

320

321 40. U-shaped gut

322 This is a modified through-gut and is therefore contingent on that character.

323 0 – absent

324 1 – present

325

326 41. Protonephridia (or homologous)

327 An excretory tube without an internal opening. It is found in Platyhelminthes, rotifers,

328 and some chordates.

329 0 – absent

330 1 – present

331

332 42. Fate of blastopore

333 0 – protostomy

334 1 – deuterostomy

335 2 – amphistomy

336

337 43. Epitheliomusculature

338 Epitheliomusculature is present in cnidarians, ctenophores and bilaterians.

339 0 – absent

340 1 – present

341

342 44. Myoepithelial sheets as the predominant muscle type

343 This is the predominant muscle type in cnidarians, but is restricted to organ systems in

344 ctenophores and bilaterians.

345 0 – absent

346 1 – present

347

348 45. Myocyte

349 Muscle cells with no epithelial involvement.

350 0 – absent

351 1 – present

352

353 46. Body cuticle with chitin

354 There is no evidence for a body cuticle with chitin in *Helicolocellus*. This character is
355 marked as absent.

356 0 – absent

357 1 – present

358

359 47. Body cuticle with alpha-chitin

360 This character is contingent on the presence of a body cuticle with chitin.

361 0 – absent

362 1 – present

363

364 48. Body cuticle with thick layer of collagenous fibres in the inner layer

365 0 – absent

366 1 – present

367

368 49. Body cuticle moulted

369 0 – absent

370 1 – present

371

372 50. Ecdysteroids

373 0 – absent

374 1 – present

375

376 51. Segmented body with jointed limbs

377 This character is inconsistent with the overall morphology of *Helicolocellus*, so we
378 consider it absent.

379 0 – absent

380 1 – present

381

382 52. Lobopods

383 This character is inconsistent with the overall morphology of *Helicolocellus*, so we
384 consider it absent.

385 0 – absent

386 1 – present

387

388 53. Slime papillae

389 This character is inconsistent with the absence of a ventral mouth and distinct head in
390 *Helicolocellus* and so we consider it absent.

391 0 – absent

392 1 – present

393

394 54. Extensive hemocoel

395 0 – absent

396 1 – present

397

398 55. Ventral mouth

399 We found no evidence of any aperture that may serve as a ventral mouth, so we

400 consider this character absent in *Helicolocellus*.

401 0 – absent

402 1 – present

403

404 56. Terminal mouth

405 All ecdysozoan phyla have a mouth positioned terminally in the organism. We found

406 no evidence of any aperture that may serve as a mouth, so we consider this character

407 absent in *Helicolocellus*.

408 0 – absent

409 1 – present

410

411 57. Telescoping mouth cone with protrusible stylets

412 We found no evidence of any aperture that may serve as a mouth, so we consider this

413 character absent in *Helicolocellus*.

414 0 – absent

415 1 – present

416

417 58. Lorica present at any life stage

418 0 – absent

419 1 – present

420

421 59. Respiration by metameric trachea and spiracles

422 This character is incompatible with the known anatomy of *Helicolocellus* and so we

423 consider it absent.

424 0 – absent

425 1 – present

426

427 60. Mixocoel (haemocoel) surrounded by segmented mesoderm

428 This character is incompatible with the known anatomy of *Helicolocellus* and so we

429 consider it absent.

430 0 – absent

431 1 – present

432

433 61. Teloblastic segmentation

434 This character is incompatible with the known anatomy of *Helicolocellus*, so we

435 consider it absent.

436 0 – absent

437 1 – present

438

439 62. Longitudinal ventral nerve cord(s)

440 This character is incompatible with the conical body of *Helicolocellus*, so we consider
441 it absent.

442 0 – absent

443 1 – present

444

445 63. Circum-pharyngeal, collar-shaped brain with anterior and posterior rings of
446 perikarya separated by a ring-shaped neuropil

447 *Helicolocellus* is not compatible with the presence of a pharynx or a circum-
448 pharyngeal brain and as such we consider this character absent.

449 0 – absent

450 1 – present

451

452 64. Introvert with scalid rings

453 This character is incompatible with the known anatomy of *Helicolocellus*, so we
454 consider it absent.

455 0 – absent

456 1 – present

457

458 65. Flosculi

459 This character is incompatible with the known anatomy of *Helicolocellus*, so we
460 consider it absent.

461 0 – absent

462 1 – present

463

464 66. Immunoreactivity of Horseradish Peroxidase (HRP)

465 0 – absent

466 1 – present

467

468 67. Trochophore larva

469 0 – absent

470 1 – present

471

472 68. Segmental metanephridia sacculus

473 This character is incompatible with the known anatomy of *Helicolocellus*, so we
474 consider it absent.

475 0 – absent

476 1 – present

477

478 69. Chitinous microvillar appendages (chaetae)

479 This character is absent in *Helicolocellus*.

480 0 – absent

481 1 – present

482

483 70. Parapodia with dorsal branches terminated by beta-chitinous chaetae

484 This character is incompatible with the known anatomy of *Helicolocellus*, so we
485 consider it absent.

486 0 – absent

487 1 – present

488

489 71. Radula

490 This character is incompatible with the known anatomy of *Helicolocellus*, so we
491 consider it absent.

492 0 – absent

493 1 – present

494

495 72. Extensible proboscis surrounded by rhynchocoel

496 This character is incompatible with the known anatomy of *Helicolocellus*, so we
497 consider it absent.

498 0 – absent

499 1 – present

500

501 73. Complex jaw apparatus in pharynx

502 We consider this character absent in *Helicolocellus* because of the absence of any
503 evidence for a macroscopic mouth or gut.

504 0 – absent

505 1 – present

506

507 74. Origin of mesoderm

508 0 – from the blastopore lips and as ectomesoderm

509 1 – from the walls of the archenteron or neural crest

510

511 75. Radial cleavage

512 0 – absent

513 1 – present

514

515 76. Coelom formation

516 0 – schizocoely

517 1 – enterocoely

518

519 77. Trimeric coelom

520 0 – absent

521 1 – present

522

523 78. Pharyngeal slits

524 This character is incompatible with the known anatomy of *Helicolocellus*, so we
525 consider it absent.

526 0 – absent

527 1 – present

528

529 79. Endostyle (or homologous)

530 This character is incompatible with the known anatomy of *Helicolocellus*, so we
531 consider it absent.

532 0 – absent

533 1 – present

534

535 80. Notochord

536 This character is incompatible with the known anatomy of *Helicolocellus*, so we
537 consider it absent.

538 0 – absent

539 1 – present

540

541 81. Stomochord

542 This character is incompatible with the known anatomy of *Helicolocellus*, so we
543 consider it absent.

544 0 – absent

545 1 – present

546

547 82. Haemal system with axial complex

548 0 – absent

549 1 – present

550

551 83. Calcareous endoskeleton composed of separate ossicles

552 This character is incompatible with the soft-bodied nature of *Helicolocellus*, so we
553 consider it absent.

554 0 – absent

555 1 – present

556

557 84. Tornaria-type larva

558 0 – absent

559 1 – present

560

561 85. Longitudinal dorsal nerve cord

562 This character is incompatible with the known anatomy of *Helicolocellus*, so we
563 consider it absent.

564 0 – absent

565 1 – present

566

567 86. Zig-zag myomeres

568 This character is incompatible with the known anatomy of *Helicolocellus*, so we
569 consider it absent.

570 0 – absent

571 1 – present

572

573 87. Endothelium that lines the inner-wall of the blood vessels

574 0 – absent

575 1 – present

576

577 88. Neural crest

578 0 – absent

579 1 – present

580

581 89. Neurogenic placodes

582 0 – absent

583 1 – present

584

585 90. Body symmetry

586 *Helicolocellus* possesses a conical body, and therefore radial symmetrical. It is coded

587 present for *Helicolocellus*.

588 0 – absent

589 1 – present

590

591 91. Symmetry state

592 *Helicolocellus* exhibits a conical body, and therefore radial symmetrical.

593 0 – bilateral

594 1 – biradial

595 2 – triradial

596 3 – tetraradial

597 4 – pentaradial

598 5 – hexaradial

599 6 – radial

600

601 92. Flattening of the body along the pharyngeal plane

602 0 – absent

603 1 – present

604

605 93. Flattening of the body along the tentacular plane

606 0 – absent

607 1 – present

608

609 94. Mesoglea

610 0 – absent

611 1 – present

612

613 95. Cells in mesoglea

614 The mesoglea of most animals is cellular, but that of hydrozoans, staurozoans and

615 cubozoans is known to be acellular.

616 0 – absent

617 1 – present

618

619 96. Cydippid larva

620 0 – absent

621 1 – present

622

623 97. Ciliary rosettes

624 0 – absent

625 1 – present

626

627 98. Lophophore

628 This is not compatible with the known anatomy of *Helicolocellus*, which lacks

629 evidence for any feeding structures that resemble a lophophore, and so this character

630 is coded as absent.

631 0 – absent

632 1 – present

633

634 99. Cushion rings or polster cells

635 0 – absent

636 1 – present

637

638 100. Ciliary rows paired

639 0 – absent

640 1 – present

641

642 101. Large compound cilia

643 0 – absent

644 1 – present

645

646 102. Large cilia fused to form locomotory plate

647 This character is incompatible with the known anatomy of *Helicolocellus*, so we

648 consider it absent.

649 0 – absent

650 1 – present

651

652 103. Uniformity of ciliary rows

653 0 – absent

654 1 – present

655

656 104. Oral macrocilia

657 0 – absent

658 1 – present

659

660 105. Oral lobes

661 0 – absent

662 1 – present

663

664 106. Morphology of tip of oral extension

665 0 – narrow

666 1 – voluminous

667 2 – manubrium-like

668 3 – as margin of creeping sole

669

670 107. Mouth as margin of creeping sole

671 0 – absent

672 1 – present

673

674 108. Tentacular canals

675 0 – absent

676 1 – present

677

678 109. Meridional canals

679 This character is incompatible with the known anatomy of *Helicolocellus*, so we
680 consider it absent.

681 0 – absent

682 1 – present

683

684 110. Diverticula of meridional canals

685 0 – absent

686 1 – present

687

688 111. Circumoral ring canal

689 We do not find any evidence for a mouth of any kind in *Helicolocellus* and so we
690 consider it absent.

691 0 – absent

692 1 – present

693

694 112. Termination of meridional and pharyngeal canals

695 0 – both terminate blindly

696 1 – branch to form a complex network

697 2 – united with the circumoral ring canal

698

699 113. Inter-radial canals

700 0 – absent

701 1 – present

702

703 114. Anal canals

704 0 – absent

705 1 – present

706

707 115. Anal pores

708 0 – absent

709 1 – present

710

711 116. Paired ctenophore tentacles

712 We find no tentacles in *Helicolocellus* and so we consider these absent.

713 0 – absent

714 1 – present

715

716 117. Tentilla

717 We find no tentilla in *Helicolocellus* and so we consider these absent.

718 0 – absent

719 1 – present

720

721 118. Mesoglea cellular

722 0 – absent

723 1 – present

724

725 119. Extracellular digestion

726 0 – absent

727 1 – present

728

729 120. Embryonic development

730 0 – direct

731 1 – indirect

732

733 121. Cnidae

734 0 – absent

735 1 – present

736

737 122. Cnidae in gastrodermis

738 0 – absent

739 1 – present

740

741 123. Cnidocil

742 0 – absent

743 1 – present

744

745 124. Structure of mitochondrial DNA

746 0 – circular

747 1 – linear

748

749 125. Actinopharynx

750 0 – absent

751 1 – present

752

753 126. Siphonoglyph (sulcus)

754 0 – absent

755 1 – present

756

757 127. Circular depression on basal disc

758 0 – absent

759 1 – present

760

761 128. Stenoteles

762 0 – absent

763 1 – present

764

765 129. Euryteles

766 0 – absent

767 1 – present

768

769 130. Desmonemes

770 0 – absent

771 1 – present

772

773 131. Mastigophores

774 0 – absent

775 1 – present

776

777 132. Basitrichousisorhiza

778 0 – absent

779 1 – present

780

781 133. Apotrichousisorhiza

782 0 – absent

783 1 – present

784

785 134. Isorhiza

786 0 – absent

787 1 – present

788

789 135. Heterotrichousanisorhiza

790 0 – absent

791 1 – present

792

793 136. Birhopaloids

794 0 – absent

795 1 – present

796

797 137. Rhopalnemes

798 0 – absent

799 1 – present

800

801 138. Spirocyst

802 0 – absent

803 1 – present

804

805 139. Ptyhocyst

806 0 – absent

807 1 – present

808

809 140. Periderm

810 0 – absent

811 1 – present

812

813 141. Medusoid phase

814 0 – absent

815 1 – present

816

817 142. Location of medusa formation

818 0 – lateral budding from an entocodon

819 1 – apical or oral

820 2 – direct development without polyp stage

821

822 143. Type of apical medusa formation

823 0 – strobilation

824 1 – without transverse fission

825

826 144. Propagation through lateral budding

827 0 – absent

828 1 – present

829

830 145. Planula

831 0 – absent

832 1 – present

833

834 146. Polypoid phase

835 0 – absent

836 1 – present

837

838 147. Polyp organisation

839 0 – solitary

840 1 – colonial

841

842 148. Polymorphic polyps

843 Contingent on polyps being colonial

844 0 – absent

845 1 – present

846

847 149. Gut partitioned by septa

848 0 – absent

849 1 – present

850

851 150. Septa in polyp

852 0 – absent

853 1 – present

854

855 151. Septa in medusa

856 0 – absent

857 1 – present

858

859 152. Pairing of mesenteries

860 0 – absent

861 1 – present

862

863 153. Number of perfect mesenteries

864 0 – absent

865 1 – present

866

867 154. Types of mesentery

868 0 – only perfect mesenteries

869 1 – perfect mesenteries not divisible

870 2 – perfect mesenteries and imperfect mesenteries

871

872 155. Directive mesentery

873 0 – absent

874 1 – present

875

876 156. Two-tentacle polyp stage

877 0 – absent

878 1 – present

879

880 157. Ephyrae
881 0 – absent
882 1 – present
883
884 158. Actinula
885 0 – absent
886 1 – present
887
888 159. Canal system
889 0 – absent
890 1 – present
891
892 160. Gastrodermic musculature
893 0 – not in bunches
894 1 – organised in bunches of gastrodermic origin
895 2 – organised in bunches of ectodermic origin
896
897 161. Pedalium of coronate type
898 0 – absent
899 1 – present
900
901 162. Rhopalia/rhopalioids

902 0 – absent

903 1 – present

904

905 163. Complex eyes in rhopalia

906 0 – absent

907 1 – present

908

909 164. Nerve ring in medusa

910 0 – absent

911 1 – present

912

913 165. Number of rings

914 Contingent on a nerve ring being present in the medusa.

915 0 – absent

916 1 – present

917

918 166. Gastric filaments

919 0 – absent

920 1 – present

921

922 167. Coronal muscle

923 0 – well developed

- 924 1 – marginal and tiny
- 925
- 926 168. Radial canals
- 927 0 – absent
- 928 1 – present
- 929
- 930 169. Circular canal
- 931 0 – absent
- 932 1 – present
- 933
- 934 170. Velarium
- 935 0 – absent
- 936 1 – present
- 937
- 938 171. Adult medusoid shape
- 939 0 – bell
- 940 1 – pyramidal
- 941 2– cubic
- 942 3 – actinuloid
- 943
- 944 172. Shape of horizontal cross-section
- 945 0 – circular

946 1 – four-part symmetry

947

948 173. Anterior-posterior axis

949 *Helicolocellus* exhibits polarity from a basal disc to an apical conical body, and so this
950 character is scored as present.

951 0 – absent

952 1 – present

953

954 174. Dorsal-ventral axis

955 This character is coded as absent for *Helicolocellus*.

956 0 – absent

957 1 – present

958

959 175. Fate of blastomeres

960 0 – determinate or mosaic

961 1 – indeterminate and regulative

962

963 176. Highly regular hierarchical reticulate skeleton (quadrate mesh)

964 This character is well documented in some extant glass sponges: *Farrea*¹⁸, *Walteria*¹⁸,
965 *Euplectella*¹⁹; and fossil sponges: *Diagoniella*^{14,15}, *Protospongia*²⁰, *Cyathophycus*²¹,
966 *Minitaspongia*¹⁷. We also document it in *Helicolocellus*, as evidenced in the main text.

967 0 – absent

968 1 – present

969

970 177. Shape of the space between the skeletal mesh.

971 This character is scored as box-like in fossil sponges *Diagoniella*^{14,15}, *Protospongia*²⁰,

972 *Cyathophycus*²¹, *Minitaspongia*¹⁷, and *Helicolocellus*; irregular in *Eiffelia*¹⁰ and

973 *Vauxia*²².

974 0 – box-like

975 1 – circular or oval

976 2 – irregular

977

978 178. Demospongiac acids

979 This character is coded as unknown for all fossil taxa considered in this study, since

980 we cannot infer its existence or absence in the fossil taxa.

981 0 – absent

982 1 – present

983

984 179. Cytoplasmic production of siliceous spicules along protein filament

985 This character is coded as unknown for *Helicolocellus*, because siliceous spicules

986 have not been directly observed in *Helicolocellus*.

987 0 – absent

988 1 – present

989

990 180. Tissue organisation
 991 This character is coded as unknown for *Helicolocellus*.
 992 0 – cellular
 993 1 – largely syncytial
 994
 995 181. Triaxonic symmetry of biomineralised spicules, and its derivatives, e.g., planar
 996 cruciform (stauractin-like) skeletal elements
 997 This character is well documented in extant glass sponges^{23,24} and also found in fossil
 998 sponges: *Diagoniella*^{14,15}, *Protospongia*²⁰, *Eiffelia*¹⁰, *Cyathophycus*^{21,25},
 999 *Minitaspongia*¹⁷. *Helicolocellus* is interpreted to have organic cruciform elements, but
 1000 the possibility of light biomineralisation cannot be ruled out. Hence, *Helicolocellus* is
 1001 scored as unknown. For the same reason, characters 182–184 are also scored as
 1002 unknown for *Helicolocellus*.
 1003 0 – absent
 1004 1 – present
 1005
 1006 182. Spicule fusion
 1007 Spicule fusion has not been observed in the fossil sponges included in the data matrix
 1008 of this study.
 1009 0 – absent
 1010 1 – present
 1011

1012 183. Organisation of biomineralised skeletons

1013 This character is coded as unknown for *Helicolocellus* and is coded as 0 for fossil

1014 sponges *Diagoniella*^{14,15}, *Protospongia*²⁰, and *Minitaspongia*¹⁷. *Vauxia*²⁶ has a

1015 chitinous, semi-regular grid pattern, therefore, scored as inapplicable.

1016 0 – an unfused regular grid pattern that is held together by organic tissue

1017 1 – a fused rigid three-dimensional scaffold.

1018

1019 184. Dictyonal framework pattern

1020 The fossil sponges are scored as absent, because they do not exhibit dictyonal

1021 framework. *Helicolocellus* is scored as unknown because of the uncertainty regarding

1022 its skeletal composition.

1023 0 – absent

1024 1 – eurentoid

1025 2 – farreoid

1026 3 – other

1027

1028 185. Mode of attachment to substrate

1029 Lophophytous: the sponge is anchored by tufts of protruding spicules (basalia);

1030 basiphytous: attached to hard substrates by a ‘basidictyonal plate’ composed of fused

1031 spicules^{27,28}. Fossil sponges *Diagoniella*^{14,16}, *Protospongia*²⁹ and *Cyathophycus*³⁰ are

1032 coded as lophophytous. *Helicolocellus* exhibits a basal disc and likely inhabited a

1033 firm, microbially-bound substrate, implying a basiphytous type of attachment.

1034 However, this character is coded as unknown for *Helicolocellus* since fused spicules
1035 have not been observed in *Helicolocellus*. It is also coded as unknown for
1036 *Minitaspongia*¹⁷ because its basal part was not preserved. *Eiffelia* and *Vauxia* do not
1037 exhibit any attachment structures^{10,26}, so they are coded as inapplicable.

1038 0 – lophophytous

1039 1 – basiphytous

1040

1041 186. Long peduncle formed of anchorate basalia

1042 A peduncle contains choanosome, in contrast to the basal tufts of “naked” spicules².

1043 This character is not present in the Palaeozoic sponges^{14,16,29,30}, but it is coded as

1044 unknown for *Minitaspongia*¹⁷ since its basal part was not preserved. Characters 186–

1045 188 are coded as unknown for *Helicolocellus* due to the uncertainty about its skeletal

1046 composition in the stem.

1047 0 – absent

1048 1 – present

1049

1050 187. Anchorate spicules supplemented by tauactins

1051 Tauactins are T-shaped spicules². This character is not present in the Palaeozoic

1052 sponges^{14,16,29,30}, but it is coded as unknown for *Minitaspongia*¹⁷ since its basal part

1053 was not preserved.

1054 0 – no

1055 1 – yes

1056

1057 188. Long tubular peduncle composed of fused diactins

1058 This character is not present in the Palaeozoic sponges^{14,16,29,30}, but it is coded as

1059 unknown for *Minitaspongia*¹⁷ since its basal part was not preserved.

1060 0 – absent

1061 1 – present

1062

1063 189. Amphidiscs.

1064 Microscleres are rarely encountered in the fossil record³¹. However, for those sponges

1065 well-documented in shale with numerous specimens, i.e., *Diagoniella*^{14,16,32},

1066 *Protospongia*^{16,20}, *Eiffelia*^{10,16}, *Vauxia*^{16,33,34} and *Cyathophycus*¹¹, the quality of skeletal

1067 preservation is high, such that it could be inferred that microscleres were not present.

1068 Therefore, microscle-re-specific characters (characters 189–205) are scored as absent

1069 for these sponges. *Helicolocellus* and *Minitaspongia*¹⁷, on the other hand, are less well

1070 documented with fewer specimens, preserved as moulds and casts in limestone and

1071 nodules in mudstone, respectively. These taphonomic windows have less potential for

1072 preserving microscleres. Therefore, characters 189–205 are scored as unknown for

1073 *Helicolocellus* and *Minitaspongia*.

1074 0 – absent

1075 1 – present.

1076

1077 190. Hexasters.

1078 Microscleres exclusively occurring in Hexasterophora.

1079 0 – absent

1080 1 – present

1081

1082 191. Channelisation of dictyonal framework

1083 This character has not been observed in the fossil sponge taxa, and is scored as

1084 unknown for *Helicolocellus*.

1085 0 – absent

1086 1 – schizorhyses

1087 2 – diarthyses

1088 3 – if present, epiarthyses and/or aparthyses.

1089

1090 192. Sceptres

1091 A monaxonic spicule type restricted to Pheronematidae^{28,35}.

1092 0 – absent

1093 1 – present

1094

1095 193. Uncinates

1096 Thorned diactins characteristic for Amphidiscophora and Sceptrulophora²⁷.

1097 0 – absent

1098 1 – present

1099

1100 194. Uncinates perpendicularly arranged to dermal surface

1101 This character is scored as inapplicable for taxa (*Diagoniella*^{14,16,32}, *Protospongia*,

1102 *Eiffelia*, and *Cyathophycus*) that were scored as absent for character 193, and scored as

1103 unknown for taxa (*Helicolocellus* and *Minitaspongia*) that were scored as unknown for

1104 character 193.

1105 0 – no

1106 1 – yes

1107

1108 195. Scepтрules

1109 0 – absent

1110 1 – present

1111

1112 196. Scopules

1113 0 – absent

1114 1 – present

1115

1116 197. Oxyhexasters

1117 0 – absent

1118 1 – present

1119

1120 198. Onychohexasters

1121 0 – absent

1122 1 – present

1123

1124 199. Tylohexasters

1125 0 – absent

1126 1 – present

1127

1128 200. Discohexasters

1129 0 – absent

1130 1 – present

1131

1132 201. Microdiscohexasters

1133 0 – absent

1134 1 – present

1135

1136 202. Graphiocomes

1137 0 – absent

1138 1 – present

1139

1140 203. Sigmatocomes or drepanocomes

1141 0 – absent

1142 1 – present

1143

- 1144 204. Floricomes
- 1145 0 – absent
- 1146 1 – present
- 1147
- 1148 205. Calyccomes
- 1149 0 – absent
- 1150 1 – present
- 1151
- 1152 206. Plumosely arranged dermal diactins/uncinates
- 1153 Arrangement of diactins or uncinates in bundles perpendicular to the outer surface of
- 1154 the sponge.
- 1155 Plumosely arranged dermal diactins/uncinates have not been observed in the fossil
- 1156 sponge taxa included in this study. Characters 206–219 are scored as unknown for
- 1157 *Helicolocellus* because of the uncertainty regarding its skeletal composition.
- 1158 0 – absent
- 1159 1 – present
- 1160
- 1161 207. Diactins as major dermal megascleres
- 1162 Diactins as major dermal megascleres have not been observed in the fossil sponge
- 1163 taxa included in this study.
- 1164 0 – absent
- 1165 1 – present

1166

1167 208. Pentactins as major dermal megascleres

1168 Pentactins as major dermal megascleres have not been observed in the fossil sponge
1169 taxa included in this study.

1170 0 – absent

1171 1 – present

1172

1173 209. Hexactins as major dermal megascleres

1174 This character is scored as present for fossil sponges *Eiffelia*¹⁰, *Cyathophycus*³⁰, and
1175 *Minitaspongia*¹⁷.

1176 0 – absent

1177 1 – present

1178

1179 210. Stauractins as major dermal megascleres

1180 This character is scored as present for fossil sponges *Diagoniella*^{14,15}, *Protospongia*²⁰.

1181 0 – absent

1182 1 – present

1183

1184 211. Pentactins as major hypodermal megascleres

1185 These characters are scored as absent for the fossil sponges. *Minitaspongia* may have
1186 pentactins¹⁷, but unlikely to be the major hypodermal megascleres.

1187 0 – absent

1188 1 – present

1189

1190 212. Diactins as major choanosomal megascleres

1191 Choanosomal spicules are not developed in fossil sponges *Diagoniella* and

1192 *Protospongia*³⁶. This character is scored as unknown for *Cyathophycus*³⁰ because it

1193 may have an inner layer of monaxonid spicules, but whether it is choanosomal and

1194 whether the monaxonid spicules are diactins cannot be determined.

1195 0 – absent

1196 1 – present

1197

1198 213. Stauractins as major choanosomal megascleres

1199 Choanosomal spicules are no found in fossil sponges *Diagoniella* and *Protospongia*³⁶.

1200 Stauractins have been found in *Eiffelia*¹⁰ and *Minitaspongia*¹⁷, but it is unknown

1201 whether they are the major choanosomal megascleres.

1202 0 – absent

1203 1 – present

1204

1205 214. Pentactins as major choanosomal megascleres

1206 Choanosomal spicules are not developed in fossil sponges *Diagoniella* and

1207 *Protospongia*³⁶. Pentactins have been found in *Minitaspongia*¹⁷, but it is unknown if

1208 they are the major choanosomal megascleres.

1209 0 – absent

1210 1 – present

1211

1212 215. Hexactins as major choanosomal megascleres

1213 Choanosomal spicules are not developed in fossil sponges *Diagoniella* and

1214 *Protospongia*³⁶. Hexactins have been found in *Eiffelia*¹⁰ and *Minitaspongia*¹⁷, but it is

1215 unknown if they are the major choanosomal megascleres.

1216 0 – absent

1217 1 – present

1218

1219 216. Pentactins as major hypatrial megascleres

1220 Pentactins have been found in the fossil sponge *Minitaspongia*¹⁷, but it is unknown if

1221 they are the major hypatrial megascleres.

1222 0 – absent

1223 1 – present

1224

1225 217. Diactins as major atrial megascleres

1226 This character is scored as unknown for the fossil sponge *Cyathophycus* because it

1227 may have an inner layer of monaxonid spicules³⁰, but whether they are atrial cannot

1228 be determined.

1229 0 – absent

1230 1 – present

1231

1232 218. Pentactins as major atrial megascleres

1233 Pentactins have been found in the fossil sponge *Minitaspongia*¹⁷, but it is unknown

1234 whether they are the major atrial megascleres.

1235 0 – absent

1236 1 – present

1237

1238 219. Hexactins as major atrial megascleres

1239 Hexactins have been found in fossil sponges *Eiffelia*¹⁰ and *Minitaspongia*¹⁷, but it is

1240 unknown whether they are the major atrial megascleres.

1241 0 – absent

1242 1 – present

1243

1244 220. First order branches derive from one another.

1245 First order branches are the highest branching rank in frondose organisms, and they

1246 may derive directly from one another. This is an autapomorphy of *Charnia* and so all

1247 other multicellular taxa are scored as absent¹.

1248 0 – absent

1249 1 – present

1250

1251 221. First order branches comprise multiple other branching orders.

1252 First order branches are constructed of at least three branching orders. This character

1253 is dependent on character 220, so all groups except *Charnia* are scored as

1254 inapplicable.

1255 0 – absent

1256 1 – present

1257

1258 222. Expanded surface area to volume ratio via fractal branching.

1259 An expanded surface area to volume ratio is achieved by fractal construction of the

1260 multi-scale branches. This character is not considered present in any organism other

1261 than *Charnia* included in this matrix¹.

1262 0 – absent

1263 1 – present

1264

1265 223. Larval type

1266 Coeloblastula and amphiblastula larvae are found in calcareous sponges³ and

1267 cinctoblastula larvae are found in Homoscleromorpha³⁷.

1268 0 – coeloblastula

1269 1 – amphiblastula

1270 2 – cinctoblastula

1271 3 – parenchymella

1272 4 – trichimella

1273

1274 224. Tracts of storage cells

1275 0 – absent

1276 1 – present

1277

1278 225. Aspicular calcareous skeleton

1279 Characters 225 and 226 have not been observed in *Helicolocellus* or the other fossil

1280 sponges included in this analysis.

1281 0 – absent

1282 1 – present and reticulate

1283 2 – present and consisting of a compact basal mass of calcite

1284

1285 226. Giant longitudinal diactines.

1286 0 – absent

1287 1 – present

1288

1289 227. Microdiactines

1290 Microscopic spicules are rarely preserved, for this character and character 229

1291 (diapasons) we adopt the same coding approach as that used for the microscleres

1292 above.

1293 0 – absent or present only in the cortex

1294 1 – abundant in the whole body of the sponge or at least in the choanoskeleton

1295

1296 228. Shape of triactines and basal system of tetractines

1297 Triactine spicules with unequal angles are called sagittal triactines³. Triactines have

1298 not been described in the fossil taxa.

1299 0 – all equiangular

1300 1 – at least some are not equiangular.

1301

1302 229. Diapasons

1303 Diapasons are also called tuning-fork spicules and are sagittal triactines with parallel

1304 paired rays³

1305 0 – absent

1306 1 – present

1307

1308 230. Oxeas in the axial skeleton.

1309 Possible oxeas have been reported from *Diagoniella*¹⁵.

1310 0 – absent

1311 1 – present

1312

1313 231. Strongyle megascleres

1314 0 – absent

1315 1 – present

1316

1317 232. Biminerallic spicules

1318 Silica spicules combined with an outer layer of calcite secreted within an organic

1319 sheath³¹. Biminerallic spicules have been reported from *Eiffelia*¹⁰, but are unknown in

1320 *Minitaspongia*¹⁷ and *Helicolocellus*.

1321 0 – absent

1322 1 – present

1323

1324 233. Skeletal elements contain calcium carbonate

1325 Calcareous material has been recorded in spicules of *Protospongia*³⁸ and *Eiffelia*¹⁰.

1326 Spicules of *Diagoniella* may be composed of calcium carbonate¹⁵, but a diagenetic

1327 origin cannot be ruled out. Therefore, this character is coded as unknown for

1328 *Diagoniella*. It is also difficult to rule out the presence of calcium content in the

1329 skeletal elements in *Helicolocellus*, so it is also scored as unknown.

1330 0 – absent

1331 1 – present

1332

1333 234. Shape of the cross-section of the axial filament.

1334 The cross-section of the axial canal and filament show various shapes among different

1335 sponge clades: square or round in hexactinellids^{39,40}; triangular, hexagonal, round, or

1336 irregular in demosponges⁴¹; irregular in homoscleromorphs⁴¹. However, in fossil

1337 sponges, the axial canal is often reshaped and enlarged by later mineral dissolution.

1338 Organically preserved axial filaments, on the other hand, provide more reliable

1339 information about their biological precursors⁴². For example, *Cyathophycus loydelli*

1340 shows cylindrical axial filaments (Fig. 3i in ref.¹¹) but hexagonal axial canals (fig.

1341 3C–D in ref.¹¹); in this case, one may argue that the original shape of the axial

filament may have been hexagonal, because hexagonal axial canals are unlikely to be a result of dissolution. Therefore, *Cyathophycus* is coded as 1 (round) and 3 (hexagonal). *Helicolocellus* is scored as unknown because the details of its skeletal elements are not preserved.

0 – absent

1 – round

2 – square

3 – hexagonal

4 – triangular

5 – irregular

235. Chitin in skeletal elements

Chitin is common in sponge skeletons and has been found in *Sycon*, *Farrea*, *Rossella*, *Euplectella*⁴³ and *Vauxia*²⁶. There are no reports in the literature about the existence of chitin in skeletons of other sponges included in this research. However, considering the ubiquity of chitin in sponges and the relatively small number of sponges that have been examined, we scored the rest of sponges as unknown for this characteristic.

0 – absent

1 – present

3. Topological constraints

Poriferan inter-relationships following recent molecular phylogenies:

1364 constraint sponge1 partial = Hyalonema Pheronema Semperella Sericolophus

1365 Aphrocallistes Heterochone Tretodictyum Hexactinella Farrea Iphiteon

1366 Rhabdopectella Walteria Euplectella Acoelocalyx Malacosaccus Rossella

1367 Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella Caulophacus

1368 Crateromorpha Lophocalyx Clathrochone Leucopsacus Oopsacas Sycon

1369 Leucosolenia Uteopsis Agelas Cymbastela Metania Oscarella Plakortis :

1370 Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida Hexacorallia

1371 Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa Echinodermata

1372 Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata

1373 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha

1374 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda

1375 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;

1376

1377 constraint sponge2 partial = Hyalonema Pheronema Semperella Sericolophus

1378 Aphrocallistes Heterochone Tretodictyum Hexactinella Farrea Iphiteon

1379 Rhabdopectella Walteria Euplectella Acoelocalyx Malacosaccus Rossella

1380 Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella Caulophacus

1381 Crateromorpha Lophocalyx Clathrochone Leucopsacus Oopsacas Agelas

1382 Cymbastela Metania : Oscarella Plakortis Sycon Leucosolenia Uteopsis

1383 Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida Hexacorallia

1384 Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa Echinodermata

1385 Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata

1386 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1387 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1388 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1389
 1390 constraint sponge3 partial = Hyalonema Pheronema Semperella Sericolophus
 1391 Aphrocallistes Heterochone Tretodictyum Hexactinella Farrea Iphiteon
 1392 Rhabdoplectella Walteria Euplectella Acoelocalyx Malacosaccus Rossella
 1393 Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella Caulophacus
 1394 Crateromorpha Lophocalyx Clathrochone Leucopsacus Oopsacas : Agelas
 1395 Cymbastela Metania Oscarella Plakortis Sycon Leucosolenia Uteopsis
 1396 Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida Hexacorallia
 1397 Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa Echinodermata
 1398 Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata
 1399 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1400 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1401 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1402
 1403 constraint sponge4 partial = Hyalonema Pheronema Semperella Sericolophus :
 1404 Aphrocallistes Heterochone Tretodictyum Hexactinella Farrea Iphiteon
 1405 Rhabdoplectella Walteria Euplectella Acoelocalyx Malacosaccus Rossella
 1406 Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella Caulophacus
 1407 Crateromorpha Lophocalyx Clathrochone Leucopsacus Oopsacas Agelas

1408 Cymbastela Metania Oscarella Plakortis Sycon Leucosolenia Uteopsis
 1409 Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida Hexacorallia
 1410 Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa Echinodermata
 1411 Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata
 1412 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1413 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1414 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1415
 1416 constraint sponge5 partial = Aphrocallistes Heterochone Tretodictyum Hexactinella
 1417 Farrea Iphiteon : Rhabdopectella Walteria Euplectella Acoelocalyx
 1418 Malacosaccus Rossella Rossellinae Acanthascus Aulosaccus Bathydorus
 1419 Caulophacella Caulophacus Crateromorpha Lophocalyx Clathrochone
 1420 Leucopsacus Oopsacas Hyalonema Pheronema Semperella Sericolophus
 1421 Agelas Cymbastela Metania Oscarella Plakortis Sycon Leucosolenia Uteopsis
 1422 Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida Hexacorallia
 1423 Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa Echinodermata
 1424 Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata
 1425 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1426 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1427 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1428
 1429 constraint sponge6 partial = Rhabdopectella Walteria Euplectella Acoelocalyx

1430 Malacosaccus Rossella Rossellinae Acanthascus Aulosaccus Bathydorus
 1431 Caulophacella Caulophacus Crateromorpha Lophocalyx Clathrochone
 1432 Leucopsacus Oopsacas : Hyalonema Pheronema Semperella Sericolophus
 1433 Aphrocallistes Heterochone Tretodictyum Hexactinella Farrea Iphiteon Agelas
 1434 Cymbastela Metania Oscarella Plakortis Sycon Leucosolenia Uteopsis
 1435 Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida Hexacorallia
 1436 Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa Echinodermata
 1437 Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata
 1438 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1439 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1440 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1441
 1442 constraint sponge7 partial = Agelas Cymbastela Metania : Oscarella Plakortis
 1443 Hyalonema Pheronema Semperella Sericolophus Aphrocallistes Heterochone
 1444 Tretodictyum Hexactinella Farrea Iphiteon Rhabdopectella Walteria
 1445 Euplectella Acoelocalyx Malacosaccus Rossella Rossellinae Acanthascus
 1446 Aulosaccus Bathydorus Caulophacella Caulophacus Crateromorpha
 1447 Lophocalyx Clathrochone Leucopsacus Oopsacas Sycon Leucosolenia
 1448 Uteopsis Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida
 1449 Hexacorallia Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa
 1450 Echinodermata Pterobranchia Enteropneusta Urochordata Cephalochordata
 1451 Vertebrata Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida

1452 Gastrotricha Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda
 1453 Nematoda Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1454
 1455 constraint sponge8 partial = Sycon Leucosolenia Uteopsis Oscarella Plakortis :
 1456 Agelas Cymbastela Metania Hyalonema Pheronema Semperella Sericolophus
 1457 Aphrocallistes Heterochone Tretodictyum Hexactinella Farrea Iphiteon
 1458 Rhabdopectella Walteria Euplectella Acoelocalyx Malacosaccus Rossella
 1459 Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella Caulophacus
 1460 Crateromorpha Lophocalyx Clathrochone Leucopsacus Oopsacas
 1461 Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida Hexacorallia
 1462 Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa Echinodermata
 1463 Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata
 1464 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1465 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1466 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1467
 1468 constraint sponge9 partial = Sycon Leucosolenia Uteopsis : Agelas Cymbastela
 1469 Metania Oscarella Plakortis Hyalonema Pheronema Semperella
 1470 Sericolophus Aphrocallistes Heterochone Tretodictyum Hexactinella Farrea
 1471 Iphiteon Rhabdopectella Walteria Euplectella Acoelocalyx Malacosaccus
 1472 Rossella Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella
 1473 Caulophacus Crateromorpha Lophocalyx Clathrochone Leucopsacus

1474 Oopsacas Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida
 1475 Hexacorallia Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa
 1476 Echinodermata Pterobranchia Enteropneusta Urochordata Cephalochordata
 1477 Vertebrata Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida
 1478 Gastrotricha Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda
 1479 Nematoda Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1480
 1481 constraint sponge10 partial = Oscarella Plakortis : Sycon Leucosolenia Uteopsis
 1482 Agelas Cymbastela Metania Hyalonema Pheronema Semperella Sericolophus
 1483 Aphrocallistes Heterochone Tretodictyum Hexactinella Farrea Iphiteon
 1484 Rhabdopectella Walteria Euplectella Acoelocalyx Malacosaccus Rossella
 1485 Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella Caulophacus
 1486 Crateromorpha Lophocalyx Clathrochone Leucopsacus Oopsacas
 1487 Choanoflagellata Placozoa Cydippida Lobata Beroida Cestida Hexacorallia
 1488 Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa Echinodermata
 1489 Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata
 1490 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1491 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1492 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1493
 1494 constraint sponge11 partial = Hyalonema Pheronema Semperella Sericolophus
 1495 Aphrocallistes Heterochone Tretodictyum Hexactinella Farrea Iphiteon

1496 Rhabdopectella Walteria Euplectella Acoelocalyx Malacosaccus Rossella
 1497 Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella Caulophacus
 1498 Crateromorpha Lophocalyx Clathrochone Leucopsacus Oopsacas Sycon
 1499 Leucosolenia Uteopsis Agelas Cymbastela Metania Oscarella Plakortis
 1500 Choanoflagellata : Placozoa Cydippida Lobata Beroida Cestida Hexacorallia
 1501 Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa Echinodermata
 1502 Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata
 1503 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1504 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1505 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera;
 1506
 1507 **Ctenosis (Ctenophore sister to all other animals):**
 1508 constraint Ctenosis partial = Choanoflagellata Cydippida Lobata Beroida Cestida :
 1509 Sycon Leucosolenia Uteopsis Agelas Cymbastela Metania Oscarella Plakortis
 1510 Placozoa Hexacorallia Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa
 1511 Echinodermata Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata
 1512 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1513 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1514 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera Hyalonema Pheronema
 1515 Semperella Sericolophus Aphrocallistes Heterochone Tretodictyum Hexactinella
 1516 Farrea Iphiteon Rhabdopectella Walteria Euplectella Acoelocalyx Malacosaccus
 1517 Rossella Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella Caulophacus

1518 Crateromorpha Lophocalyx Clathrochone Leucopsacus Oopsacas;
 1519
 1520 4. Matrix
 1521 #NEXUS
 1522 BEGIN TAXA;
 1523 DIMENSIONS NTAX=79;
 1524 TAXLABELS
 1525 Helicolocellus Diagoniella Protospongia Eiffelia Cyathophycus
 1526 Minitaspongia Vauxia Charnia Sycon Leucosolenia Uteopsis Choanoflagellata Agelas
 1527 Cymbastela Metania Oscarella Plakortis Placozoa Cydippida Lobata Beroida
 1528 Cestida Hexacorallia Octocorallia Staurozoa Cubozoa Scyphozoa Hydrozoa
 1529 Echinodermata Pterobranchia Enteropneusta Urochordata Cephalochordata Vertebrata
 1530 Nemertea Bryozoa Brachiopoda Phoronida Mollusca Annelida Gastrotricha
 1531 Gnathifera Platyhelminthes Entoprocta Onychophora Arthropoda Nematoda
 1532 Nematomorpha Priapulida Tardigrada Kinorhyncha Loricifera Hyalonema Pheronema
 1533 Semperella Sericolophus Aphrocallistes Heterochone Tretodictyum Hexactinella
 1534 Farrea Iphiteon Rhabdopectella Walteria Euplectella Acoelocalyx Malacosaccus
 1535 Rossella Rossellinae Acanthascus Aulosaccus Bathydorus Caulophacella Caulophacus
 1536 Crateromorpha Lophocalyx Clathrochone Leucopsacus Oopsacas
 1537 ;
 1538 END;
 1539 BEGIN CHARACTERS;

```

1540     DIMENSIONS  NCHAR=235;

1541     FORMAT DATATYPE = STANDARD  GAP = - MISSING = ? SYMBOLS = "

1542     0 1 2 3 4 5 6 7";

1543     MATRIX

1544     Helicolocellus      ?1????????????????10????????????????????????0--

1545     -?000?000?0000000?0000000???0000?0?00???16--???0???0?-----

1546     00????????????????????????????????????????????????-??????-?10?10????????????????

1547     ????????????????????????????0-0?00?-?00???

1548     Diagoniella        1100010??1111?1?010000---0-0-?-?00--0--0---0---00000---

1549     00-0--0000000000-0---00000000---16--1???0--0-----0-???00-?-----00-

1550     --00-----10-10???1000000000000-0000000000000000100?0000000-

1551     0??000-0?00???

1552     Protospongia       1100010??1111?11?010000---0-0-?-?00--0--0---0---00000--

1553     -00-0--0000000000-0---00000000---16--1???0--0-----0-???00-?-----

1554     00---00-----10-10???1000000000000-

1555     0000000000000000100?0000000-0??000-00001??

1556     Eiffelia          1100010??1111?11?010000---0-0-?-?00--0--0---0---00000---

1557     00-0--0000000000-0---00000000---16--1???0--0-----0-???00-?-----00-

1558     --00-----10-02???1000-00000000-0000000000000000000?0?000?0-

1559     0??000-00011??

1560     Cyathophycus      1100010??1111?11?010000---0-0-?-?00--0--0---0---00000-

1561     --00-0--0000000000-0---00000000---16--1???0--0-----0-???00-?-----

```

1562 00---00-----10-10???1000000000000-
1563 0000000000000000100?0000?000-0??000-00000(1 3)?
1564 Minitaspongia 1100010??1111?1??010000---0-0-?-?00--0--0---0---00000--
1565 -00-0--0000000000-0---00000000---16--1???0--0-----0-???00-?-----
1566 00---00-----10-10???1000?????0????????????0001000????0??0-
1567 0??00?-?000???
1568 Vauxia 1100010??1111?11?010000---0-0-?-?00--0--0---0---00000-
1569 --00-0--0000000000-0---00000000---16--1???0--0-----0-???00-?-----
1570 00---00-----10-02???00-0-00000000-
1571 00000000000000000000000000000-0??000-0000001
1572 Charnia ?1?????????????0?111?????????????0-??--0????0--
1573 -?000?000?0000000?0000000???0000?0?00???17--???00-?0-----0-???????--
1574 -?????????????0?????0---?----?????????????????1??0-?-?-----??-??-?????????????----
1575 -----111??00?-?-0---
1576 Sycon 11100100011111100010000---0-0-0-000--0--0---0---
1577 00000---00-0--0000000000-0---00000000---16--11000-0-----0--0100-1-----
1578 -----00---00-----10-0200000-00000000000-
1579 00000000000000000000000000000-01000010000101
1580 Leucosolenia 11100100011111100010000---0-0-0-000--0--0---0---00000-
1581 --00-0--0000000000-0---00000000---16--11000-0-----0--0100-1-----
1582 00---00-----10-0200000-00000000000-
1583 00000000000000000000000000000-0100001000010?

1584 Uteopsis 11100100011111100010000---0-0-0-000--0--0---0---00000-
1585 --00-0--0000000000-0---00000000---16--11000--0-----0--0100-1-----
1586 00---00-----10-0200000-0000000000-
1587 00000000000000000000000000000-0?00101000010?
1588 Choanoflagellata 10000000000000000000-00000000000000000000-
1589 00000000000000000000000000000-0-0000000000000000-00000000000000000-
1590 00000000000000000000000000000--000-000000-00000-000000-000--00-0-00-00-0-
1591 00000000-00000000000000000000000000000-0000-0000000
1592 Agelas 1100010001111111010000---0-0-0-000--0--0---0---
1593 00000---00-0--0000000000-0---00000000---16--11000--0-----0--0100-0-----
1594 -----00---00-----10-0211000-0000000000-
1595 00000000000000000000000000000-030000-00000(1 3 4 5)?
1596 Cymbastela 1100010001111111010000---0-0-0-000--0--0---0---
1597 00000---00-0--0000000000-0---00000000---16--11000--0-----0--0100-0-----
1598 -----00---00-----10-0211000-0000000000-
1599 00000000000000000000000000000-030000-01000(1 3 4 5)?
1600 Metania 1100010001111111010000---0-0-0-000--0--0---0---
1601 00000---00-0--0000000000-0---00000000---16--11000--0-----0--0100-0-----
1602 -----00---00-----10-0211000-0000000000-
1603 00000000000000000000000000000-030000-01100(1 3 4 5)?
1604 Oscarella 11000100111111100110000---0-0-0-000--0--0---0---00000--
1605 -00-0--0000000000-0---00000000---0---11000--0-----0--0100-0-----

1606		00---00-----10-0211000-0000000000-
1607		000000000000000000000000000000-020000-000005?
1608	Plakortis	1100010011111111110000---0-0-0-000--0--0----0---00000---
1609		00-0--0000000000-0---00000000---0---11000--0-----0--0100-0-----00-
1610		--00-----10-0211000-0000000000-00000000000000000000000000000-
1611		020000-000005?
1612	Placozoa	01?001010001000-0011110---100-0-100--0--0----0-0-
1613		00000---00-0--0000000000-0---00000000---0---0-000--0-----0-----0--100--0-----
1614		-----00---00-----1?-0-0-0-----00-00-000000000000-----0-
1615		00-000-0-0----
1616	Cydippida	010011111111000-01110010010110101011-1000-1010-
1617		000000000000-00000000000000-0--0000000000001101111011110000111(0 1)00(0 1
1618		2)111(0 1)1100--000-----00---00--0-----1?-0-0-0-----00-00-
1619		000000000000-----0-00-000-0-0----
1620	Lobata	010011111111000-01110010010110101011-1000-1010-
1621		000000000000-00000000000000-0--00000000000011101111011111010011(0 1)(0
1622		1)2211111100--000-----00---00--0-----1?-0-0-0-----00-00-
1623		000000000000-----0-00-000-0-0----
1624	Beroida	010011111111000-01110010010110101011-1000-1010-
1625		000000000000-00000000000000-0--000000000000111-11010111101010-11120000-
1626		1100--000-----00---00--0-----1?-0-0-0-----00-00-
1627		000000000000-----0-00-000-0-0----

1628 Cestida 010011111111000-01110010010110101011-1000-1010-
 1629 000000000000-000000000000-0--00000000000111011110111110000110(0
 1630 1)2211111100--000-----00--00-0-----1?-0-0-0-----00-00-
 1631 000000000000-----0-00-000-0-0----
 1632 Hexacorallia 011001111111000-01110011111110101011-10-0-1100-
 1633 000000000000-000000000000-0--0000000000-01(0 5)0-110000-0--00-0-0-0-0000-
 1634 1111110110000100(0 1)0001(0 1)00--011(0 1)011-0(1 2)(0 1 2)(0 1)0000(0 1)-----
 1635 ---1?-0-0-0-----00-00-0000000000-----0-00-000-0-0----
 1636 Octocorallia 011001111111000-01110011111110101011-10-0-1100-
 1637 000000000000-000000000000-0--0000000000-0100-110000-0--00-0-0-0-0000-
 1638 111111011000000010000000--0111011-100100001-----1?-0-0-0-----00-00-
 1639 000000000000-----0-00-000-0-0----
 1640 Staurozoa 011001111111000-01110011111110101011010-0-1100-
 1641 000000000000-000000000000-0--0000000000-0110-100000-0--00-0-0-0-0000-
 1642 01111?100001000010000011111110-111----100120100-11000111?-0-0-0-----00-
 1643 00-000000000000-----0-00-000-0-0----
 1644 Cubozoa 011001111111000-01110011111110101011110-0-(0 1)(0
 1645 1)10-000000000000-000000000000-0--0000000000-0110-100000-0--00-0-0-0-
 1646 0000-011110100011010010000011111110-111----100120111010101211?-0-0-0-----
 1647 00-00-000000000000-----0-00-000-0-0----
 1648 Scyphozoa 011001111111000-01110011111110101011110-0-1110-
 1649 000000000000-000000000000-0--0000000000-0130-110000-0--00-0-0-0-0000-

1694 110--000-----00--00--0-----1100-0-0-----00-00-000000000000-
 1695 -----0-00-000-0-0----
 1696 Mollusca 011011111111000-01120011101-11111110-1101(0 1
 1697 2)101(0 1)00000000100000010000101010000000000000000000000100-0-000--0--00-0-
 1698 0-0-0000--110--000-----00--00--0-----1100-0-0-----00-00-
 1699 000000000000-----0-00-000-0-0----
 1700 Annelida 011011111111000-01120011101-11111110-1101(0 1
 1701 2)1010-00000001000001100001011000000000000000000000000100-0-000--0--00-0-0-0-0-
 1702 0000--110--000-----00--00--0-----1100-0-0-----00-00-
 1703 000000000000-----0-00-000-0-0----
 1704 Gastrotricha 011011111111000-01120011101-11111110-110101010-
 1705 000000010000-0100000000000000--000000000000100-0-000--0--00-0-0-0-0-0000--
 1706 100--000-----00--00--0-----1100-0-0-----00-00-
 1707 000000000000-----0-00-000-0-0----
 1708 Gnathifera 011011111111000-01120011101-11111110-110101010-
 1709 000000010000-0100000000000100--000000000000100-0-000--0--00-0-0-0-0-0000--
 1710 100--000-----00--00--0-----1100-0-0-----00-00-
 1711 000000000000-----0-00-000-0-0----
 1712 Platyhelminthes 011011111111000-01120011101-11111110-10-001010-
 1713 000000010000-0100001000000000--000000000000100-0-000-?0--00-0-0-0-0-0000--
 1714 110--000-----00--00--0-----1100-0-0-----00-00-000000000000-
 1715 -----0-00-000-0-0----

1738		0-0000--110--000-----00--00--0-----1100-0-0-----00-00-
1739		000000000000-----0-00-000-0-0----
1740	Tardigrada	011011111111000-01120011101-11111010-
1741		11010101110110101011001?100010000000000000000000000000000000100-0-000--0--00-0-
1742		0-0-0000--100--000-----00--00--0-----1100-0-0-----00-00-
1743		000000000000-----0-00-000-0-0----
1744	Kinorhyncha	011011111111000-01120011101-11111010-
1745		1101?10110011000001000-111111000000000--000000000000100-0-000--0--00-0-0-
1746		0-0000--100--000-----00--00--0-----1100-0-0-----00-00-
1747		000000000000-----0-00-000-0-0----
1748	Loricifera	011011111111000-01120011101-11111010-
1749		1101?10110011000001010-011111000000000--000000000000100-0-000--0--00-0-0-
1750		0-0000--110--000-----00--00--0-----1100-0-0-----00-00-
1751		000000000000-----0-00-000-0-0----
1752	Hyalonema	11000100011110110010000---0-0-0-000--0-0----0---
1753		00000---00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------
1754		-----00---00-----10-
1755		0211110000000100010000000000000001001100110100-040000-00000(1 2)?
1756	Pheronema	11000100011110110010000---0-0-0-000--0-0----0---
1757		00000---00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------
1758		-----00---00-----10-
1759		0211110000000100110000000000000001001001010100-040000-00000(1 2)?

1760 *Semperella* 11000100011110110010000---0-0-0-000--0--0---0---00000-
1761 --00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?-
1762 00---00-----10-0(0
1763 2)1111000000010011000000000000001001001010100-040000-00000(1 2)?
1764 *Sericolophus* 11000100011110110010000---0-0-0-000--0--0---0---00000-
1765 --00-0--0000000000-0---00000000---0---11000--0-----0-0---0--0100-?-
1766 00---00-----10-
1767 021111000000010011000000000000001001001010100-040000-00000(1 2)?
1768 *Aphrocallistes* 11000100011110110010000---0-0-0-000--0--0---0---00000---
1769 00-0--0000000000-0---00000000---0---11000--0-----0-0---0--0100-?-
1770 00---00-----10-
1771 021111111100001201111101000000001100000101000-040000-00000(1 2)?
1772 *Heterochone* 11000100011110110010000---0-0-0-000--0--0---0---
1773 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?-
1774 -----00---00-----10-
1775 021111111100001201111100100000000100000100010-040000-00000(1 2)?
1776 *Tretodictyum* 11000100011110110010000---0-0-0-000--0--0---0---00000-
1777 --00-0--0000000000-0---00000000---0---11000--0-----0-0---0--0100-?-
1778 00---00-----10-0(1
1779 2)1111111100001101111100000000101000000100000-040000-00000(1 2)?
1780 *Hexactinella* 11000100011110110010000---0-0-0-000--0--0---0---00000--
1781 -00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?-

1782 00---00-----10-

1783 02111111100001101111100100000101000000100100-040000-00000(1 2)?

1784 Farrea 11000100011110110010000---0-0-0-000--0--0---0---

1785 00000---00-0--0000000000-0---00000000---0---11000--0-----0-0----0--0100-?------

1786 -----00---00-----10-

1787 101111112100001301110101100000001000000100100-040000-00000(1 2)1

1788 Iphiteon 11000100011110110010000---0-0-0-000--0--0---0---00000-

1789 --00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------

1790 00---00-----10-

1791 021111113100001000000101100000001000000100100-040000-00000(1 2)?

1792 Rhabdopectella 11000100011110110010000---0-0-0-000--0--0---0---00000-

1793 --00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------

1794 00---00-----10-

1795 001111100100101000000010100010000100111100100-040000-00000(1 2)?

1796 Walteria 11000100011110110010000---0-0-0-000--0--0---0---00000-

1797 --00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------

1798 00---00-----10-

1799 121111100100001000000010101010000100100000100-040000-00000(1 2)?

1800 Euplectella 11000100011110110010000---0-0-0-000--0--0---0---00000--

1801 --00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------

1802 00---00-----10-

1803 101111100000001000000100101110000100010000100-040000-00000(1 2)1

1804 Acoelocalyx 11000100011110110010000---0-0-0-000--0--0----0---
1805 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------
1806 -----00---00-----10-
1807 021111100011001000000010100010000100000100010-040000-00000(1 2)?
1808 Malacosaccus 11000100011110110010000---0-0-0-000--0--0----0---
1809 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------
1810 -----00---00-----10-
1811 021111100011001000000110100010000100000100010-040000-00000(1 2)?
1812 Rossella 11000100011110110010000---0-0-0-000--0--0----0---00000-
1813 --00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------
1814 00---00-----10-
1815 021111100100001000000100110001001001100000010-040000-00000(1 2)1
1816 Rossellinae 11000100011110110010000---0-0-0-000--0--0----0---00000--
1817 -00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------
1818 00---00-----10-
1819 021111100000001000000100110000001001100000010-040000-00000(1 2)?
1820 Acanthascus 11000100011110110010000---0-0-0-000--0--0----0---
1821 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0----0--0100-?------
1822 -----00---00-----10-0(0
1823 2)111110010000100000010011000001111100000110-040000-00000(1 2)?
1824 Aulosaccus 11000100011110110010000---0-0-0-000--0--0----0---
1825 00000---00-0--0000000000-0---00000000---0---11000--0-----0-0----0--0100-?------

1826 -----00---00-----10-

1827 001111100100001000000100110000011111100000010-040000-00000(1 2)?

1828 Bathydorus 11000100011110110010000---0-0-0-000--0--0----0---

1829 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?------

1830 -----00---00-----10-

1831 021111100100001000000110000000011111100000010-040000-00000(1 2)?

1832 Caulophacella 11000100011110110010000---0-0-0-000--0--0----0---00000-

1833 --00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?------

1834 00---00-----10-0(0

1835 2)1111100100101000000100000000001001100110100-040000-00000(1 2)?

1836 Caulophacus 11000100011110110010000---0-0-0-000--0--0----0---

1837 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?------

1838 -----00---00-----10-0(0

1839 2)1111100100101000000110100001001101100110110-040000-00000(1 2)?

1840 Crateromorpha 11000100011110110010000---0-0-0-000--0--0----0---

1841 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?------

1842 -----00---00-----10-

1843 021111100100101000000100110100001011100010100-040000-00000(1 2)?

1844 Lophocalyx 11000100011110110010000---0-0-0-000--0--0----0---

1845 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?------

1846 -----00---00-----10-

1847 001111100100001000000100110000001101100101110-040000-00000(1 2)?

1848 Clathrochone 11000100011110110010000---0-0-0-000--0--0---0---00000-
1849 --00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?-----
1850 00---00-----10-
1851 0211111001000010000000000110000001000100000010-040000-00000(1 2)?
1852 Leucopsacus 11000100011110110010000---0-0-0-000--0--0---0---
1853 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?-----
1854 -----00---00-----10-
1855 0211111001000010000000000100100001000000100010-040000-00000(1 2)?
1856 Oopsacas 11000100011110110010000---0-0-0-000--0--0---0---
1857 00000---00-0--0000000000-0---00000000---16--11000--0-----0-0---0--0100-?-----
1858 -----00---00-----10-
1859 0211111001000010000000000100000001000000100010-040000-00000(1 2)?;
1860 begin mrbayes; lset rates = lnorm coding = informative; prset Symdirihyperpr =
1861 fixed(1.0);
1862 outgroup Choanoflagellata; mcmcp ngen = 6000000 relburnin = yes burninfrac = 0.25
1863 printfreq = 1000 samplefreq = 1000 nchains = 4 savebrlens = yes filename = log-
1864 a.nex; mcmc; sumt; sump; END

1865

1866 [Supplementary References](#)

1867

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