First report of *Sporolithon ptychoides* (Sporolithales, Corallinophycidae, Rhodophyta) for the Atlantic Ocean.

Ricardo G. Bahia¹, Rafael Riosmena-Rodriguez², Gavin W. Maneveldt³ and Gilberto M. Amado Filho¹*

¹ Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Diretoria de Pesquisa Científica, Rua Pacheco Leão 915, CEP 22460-030, Rio de Janeiro, RJ, Brasil. Tel.: 55 21 32042150; Fax: 55 21 32042148; e-mail: gfilho@jbrj.gov.br.

² Programa de Investigación en Botánica Marina, Departamento de Biología Marina, Universidad Autónoma de Baja California Sur, Apartado postal 19-B, La Paz, B.C.S. 23080, Mexico.

³ Department of Biodiversity and Conservation Biology, University of the Western Cape, P. Bag X17, Bellville 7535, South Africa.

(*) Corresponding author

**SUMMARY**

Samples corresponding to *Sporolithon ptychoides* Heydrich were collected in the mesophotic zone (50 m depth) south of Espírito Santo State, Brazil. The collected material presented features characteristic of the species namely: tetrasporangia of 75-105 x 40-55 µm grouped into sori that are raised above the surrounding vegetative thallus surface; presence of a basal layer of elongate cells in areas where the tetrasporangia develop; presence of buried tetrasporangial compartments deep in the thallus; and 3-5 cells in the tetrasporangial paraphyses. These same features said to collectively characterise *S. ptychoides*, were all observed in a representative specimen and the type specimen of *Sporolithon dimotum* (Foslie & Howe) Yamaguishi-Tomita ex M.J Wynne.

This latter species is thus conspecific with *S. ptychoides* and is therefore considered a heterotypic synonym thereof as *S. ptychoides* has nomenclatural priority. This study expands the known geographical distribution of the species and may give insight into the origin of the species into other geographical regions.

**Key words:** Coralline algae, rhodolith, *Sporolithon dimotum*, taxonomy

**Running title:** *Sporolithon ptychoides* from the Atlantic.

**Introduction**

*Sporolithon ptychoides* Heydrich, the type species of the genus *Sporolithon*, is one of five extant species of *Sporolithon* for which detailed taxonomic information exists (Verheij 1993, Townsend et al. 1995, Braga and Bassi 2007). The species has been confirmed for the Mediterranean Sea (Alongi et al. 1996), Red Sea (Verheij 1993), Indian Ocean (Keats and Chamberlain 1993, Verheij 1993) and Pacific Ocean (Verheij 1993, Keats and Chamberlain 1993).

Here we report, for the first time, the presence of *S. ptychoides* in the Atlantic Ocean and provide a comparative taxonomic analysis of plants from the Atlantic against those from other known populations around the world. Also we compare the present record against some of the closely related *Sporolithon* species for which detailed modern information exists and in relation to the
records of *Sporolithon dimotum* (Foslie & M.A. Howe) Yamaguishi-Tomita ex M.J. Wynne that has been recorded for the same area (Tomita 1976).

**Materials and Methods**

Two techniques for coralline red algae identification were applied to check both reproductive and vegetative characters, one using scanning electron microscopy (SEM), following the procedure of Keats and Chamberlain (1993), and the other using light microscopic examination through embedding and sectioning (see Amado Filho et al. 2007 for further details).

Material for examination was collected during June of 2006 at 50 m depth in the southern region of Espírito Santo State, Brazil (21º02’972’’S; 40º17’824’’W, GM Amado-Filho, 17.vi.2006, RB 476940). Additional material from the same region (20º10’ S; 40º02’ W, 60 m depth), described as *Sporolithon dimotum* (Foslie & Howe) Yamaguishi-Tomita ex M.J Wynne by Tomita (1976) (SP 113211), as well as the holotype specimen of *S. dimotum* from Puerto Rico (NY 2667) (Foslie and Howe 1906) were analyzed due to their taxonomic similarity with *S. ptychoides*.

**Results**

Based on our observations we have found that our record of *S. ptychoides* (Figures 1-8) is the first record for Atlantic Ocean and we also are proposing the synonymy of *S. dimotum* as a heterotypic synonym of *S. ptychoides* (Figures 9-13).

**Species account**

*Sporolithon ptychoides* Heydrich, 1897: 67-69, figs 2, 3, pl. III: figs 20-23

Figures 1-13, table 1.

LECTOTYPE: TRH (not seen, considering that Verheij 1993 has presented descriptions), El Tor, Red Sea, no number (as *Sporolithon ptychoides* f. *dura*) designated by Woelkerling and Townsend (in Woelkerling 1988, p.204, Figure 239). SYNONYMS: *Sporolithon mediterraneum* Heydrich, 1899 (based on Alongi et al. 1996) *Archaeolithothamnion mediterraneum* (Heydrich) Foslie, 1900 *Archeolithothamnion dimotum* Foslie & M.A. Howe, 1906 *Sporolithon dimotum* (Foslie & Howe) Yamaguishi-Tomita ex M.J. Wynne, 1986 MATERIALS EXAMINED: Espírito Santo State, Brazil (21º02’972’’S; 40º17’824’’W, 50 m, *GM Amado-Filho*, 17.vi.2006, RB 476940); Espírito Santo State, Brazil (20º10’S; 40º02’W, 60 m, *NY Tomita*, unknown date, SP 113211, as *Sporolithon dimotum*); Lemon Bay near Guánica, Puerto Rico (*MA Howe*, 27.vi.1903, *NY 2667*, as *Archeolithothamnion dimotum*).

Plants encrusting to warty, forming rhodoliths up to 15 cm in diameter (Fig. 1). Thallus pseudoparenchymatous; internal organization monomorous in crustose portions (Fig. 2) and radial in warty protuberances. Epithallus comprising a single layer of flattened cells with flared corners measuring 1-4 µm long and 3-8 µm in diameter (Fig. 3). Subepithallial initials, 4-12 µm long and 5-10 µm in diameter, are squarish and are as short or shorter than their inward derivatives (Fig. 3). Perithallus mainly composed of elongated cells measuring 8-18 µm long and 3-10 µm diameter (Fig. 2). Hypothallus formed by 3-4 layers of cylindrical cells measuring 15-20 µm long and 7-9 µm in diameter (Fig. 2). Cells of adjacent perithallial and hypothallial filaments
joined by both secondary pit connections and cell fusions (Fig. 4); secondary pit connections, however, predominate with a ratio of secondary pit connections to cell fusions being 2:1.

Tetrasporangia measuring 75-105 µm long and 40-55 µm in diameter, are grouped into so that are raised (Figs. 5 and 6) 2-4 cells above the surrounding vegetative thallus surface. Tetrasporangial compartments are separated from each other by 1-3 calcified filaments (paraphyses) bearing 3-5 cells each and a basal layer of elongated cells. Tetrasporangia show cruciately arranged tetraspores measuring 55-65 µm long and 35-45 µm in diameter, and are supported by a single large stalk cell measuring 8-10 µm long and 20-23 µm in diameter (Fig. 7). Tetrasporangial compartments bear apical plugs (Fig. 7) with a pore 10-14 µm in diameter and surrounded by 10-11 rosette cells (Fig. 8). Old and empty tetrasporangial compartments become buried in the thallus. Gametangial plants were not seen.

The features observed for our material correspond to Sporolithon ptychoides described by Verheij (1993), Keats and Chamberlain (1993), and Alongi et al. (1996) (Table 1). Sporolithon ptychoides identified in this study differs from other species of Sporolithon by the following combination of characters: 1) the size of the tetrasporangia (75-105 x 40-55 µm); 2) the presence of buried tetrasporangial compartments deep in the thallus; 3) the presence of 3-5 cells in the tetrasporangial paraphyses; 4) the ratio of secondary pit connections to cell fusions (2:1, respectively); 5) the position of tetrasporangial sori relative to the surrounding vegetative thallus surface; and 6) the presence of a basal layer of elongate cells in areas where tetrasporangia develop (Table 1). The features considered diagnostic of S. ptychoides were also observed in specimens designated as S. dimotum by Tomita (1976) as well as in the holotype of S. dimotum (Figs. 9-13) (Table 1). Consequently, we consider S. dimotum to be conspecific with S. ptychoides and thus a heterotypic synonym thereof, the latter taxon having nomenclatural priority.

In Brazilian waters, only one species of Sporolithon, namely Sporolithon episporum (M.A.Howe) E.Y.Dawson, has been consistently identified and described (Nunes et al. 2008), although the doctoral dissertation of Tomita (1976) reports eight species from this genus: S. africanum (Foslie) J.Afonso-Carillo, S. australasicum (Foslie) N.Yamaguishi-Tomita ex M.J.Wynne, S. dimotum, S. episporum, S. erythraeum (Rothpletz) Kylin, S. howei (Lemoine) N.Yamaguishi-Tomita ex M.J.Wynne, S. mediterraneum Heydrich and S. pacificum E.Y.Dawson. However, the identifications and descriptions of the Tomita (1976) specimens were mainly based on the size of the tetrasporangial chambers, the tetrasporangial pore densities, the number of hypothallial cells layers and the thallus texture. According to modern concepts of coralline red algal taxonomy, these characters are no longer sufficient for precise identification; some are also too variable for use in species delimitation (Verheij 1993). Although S. mediterraneum is regarding as a heterotypic synonym of S. ptychoides (Alongi et al. 1996), the specimens identified by Tomita (1976) as S. mediterraneum (SP 138576, SP 114638, SP 114641, and SP 114642) do not agree with the description of S. ptychoides. The Tomita (1976) specimens have larger tetrasporangia (150-175 X 95-120 µm) and a greater number of cells in the tetrasporangial paraphyses (8-9) (pers. obs.). Futhermore, much of the herbarium specimen collection from Tomita (1976) are not fully available and also lack representative specimens from some species. A new review with extensive
inventory of the genus *Sporolithon* in Brazil is needed to assess the real number of species in order to solve these nomenclatural issues.

This is the first report of *S. ptychoides* from the Atlantic Ocean. Our study has expanded the known geographical distribution of the species and may give insight into the origin of the species into other geographical regions. In a study on the Neogene history of *Sporolithon* from the Mediterranean region, Braga and Bassi (2007) assumed that representatives from the genus *Sporolithon* disappeared from the Mediterranean region during the Messinian Salinity Crisis. They went on to conclude that later on, in the Early Pliocene, a single species of *Sporolithon*, *S. ptychoides*, re-invaded the Mediterranean Basin and continues to inhabit this sea till today. Braga and Bassi (2007) suggested that the most probable source of the Mediterranean re-invasion was the Atlantic Ocean, the only open ocean to which the Mediterranean Sea has been connected since the Mid Miocene. Till now, no evidence to support this suggestion was forthcoming and so the discovery of *S. ptychoides* in the Atlantic Ocean represents an important finding, one that possibly validates the Braga and Bassi (2007) hypothesis.

**Acknowledgements**

Sincere thanks are due to the New York Botanical Garden Herbarium (NY) and the Herbarium of the Instituto de Botânica (SP) for the loan of type and herbarium specimens. Financial support provided by CNPq (Brazilian Science Council) is also gratefully acknowledged. GWM acknowledges research support from the South African National Research Foundation.

**References**


**Figure captions**

**Figs 1-8. Sporolithon ptychoides** (RB 476940): vegetative and reproductive features. 1. A rhodolith bearing many species including a somewhat warty S. ptychoides specimen (ellipse). 2. Vertical section of the vegetative thallus showing the monomeroius internal construction. 3. Vertical section of the vegetative thallus showing a flared epithallial cell (e) and squarish subepithallial initial (i). 4. SEM image of a fracture showing secondary pit connections (arrows) and a cell fusion (arrowhead) between cells of adjacent perithallial filaments. 5. Transverse
section of the thallus showing tetrasperangial compartments both raised above the surrounding vegetative thallus surface and buried deep in the thallus. 6. Surface view of sori in stereomicroscopy. 7. Vertical section of the outer thallus showing a tetrasperangium bearing a pore plug (arrow) and cruciately arranged tetraspores (1, 2, 3 and 4), subtended by a single large stalk cell (arrowhead). 8. SEM image of the thallus surface showing a tetrasperangial compartment pore (p) surrounded by 10 rosette cells.

Figs 9-13. Holotype specimen of *Sporolithon dimotum* (NY 2667): vegetative and reproductive features. 9. General view of the holotype. 10. Vertical section of outer thallus showing a single layer of flared epithallial cells. 11. Vertical section of the outer thallus showing calcified filaments (paraphyses) (arrows) between two tetrasperangial compartments. 12. Vertical section of the thallus showing tetrasperangial compartments buried deep in the thallus. 13. SEM image of a fracture showing secondary pit connections (arrows) and a cell fusion (arrowhead) between cells of adjacent perithallial filaments.
Table 1. Comparative analysis of species of *Sporolithon* for which detailed descriptions are available. Information sources are cited at the bottom of the table.

<table>
<thead>
<tr>
<th>Character</th>
<th><em>S. ptychoides</em> (present study)</th>
<th><em>S. ptychoides</em>¹</th>
<th><em>S. ptychoides</em>²</th>
<th><em>S. ptychoides</em>³</th>
<th><em>S. dimotum</em>⁴</th>
<th><em>S. dimotum</em>⁵ (holotype)</th>
<th><em>S. durum</em>⁶</th>
<th><em>S. episporum</em>¹ &amp;²</th>
<th><em>S. episoredion</em>¹</th>
<th><em>S. molle</em>¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Locality</strong></td>
<td>Southwest Atlantic (Brazil)</td>
<td>Red Sea, Indian Ocean and Hawaii</td>
<td>Indian Ocean (South Africa)</td>
<td>Mediterranean Sea</td>
<td>Puerto Rico (Caribbean)</td>
<td>Southern Australia</td>
<td>Panama (Caribbean coast) and Indian Ocean</td>
<td>Hawaii and Indonesia</td>
<td>Red Sea and Indian Ocean</td>
<td></td>
</tr>
<tr>
<td><strong>Tetrasporangia length</strong></td>
<td>75 -105 µm</td>
<td>85-105 µm</td>
<td>77-108 µm</td>
<td>85 µm</td>
<td>88-125 µm</td>
<td>70-85 µm</td>
<td>92-105 µm</td>
<td>70 – 96 µm</td>
<td>180 - 220 µm</td>
<td>70 – 85 µm</td>
</tr>
<tr>
<td><strong>Tetrasporangia diameter</strong></td>
<td>40-55 µm</td>
<td>35-45 µm</td>
<td>29-53 µm</td>
<td>40 -60 µm</td>
<td>35-50 µm</td>
<td>40-60 µm</td>
<td>38-54 µm</td>
<td>30 – 55 µm</td>
<td>100 - 135 µm</td>
<td>70 – 45 µm</td>
</tr>
<tr>
<td><strong>Tetrasporangial compartment pore diameter</strong></td>
<td>10-14 µm</td>
<td>No data</td>
<td>10-14 µm</td>
<td>12-15 µm</td>
<td>No data</td>
<td>No data</td>
<td>13–21 µm</td>
<td>16-20 µm</td>
<td>No data</td>
<td>No data</td>
</tr>
<tr>
<td><strong>Number of rosette cells surrounding tetrasporangial</strong></td>
<td>10-11</td>
<td>No data</td>
<td>8-11</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
<td>14-15</td>
<td>8-12</td>
<td>No data</td>
<td>No data</td>
</tr>
<tr>
<td>Description</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present †</td>
<td>Present †</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>-----------</td>
<td>-----------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>--------</td>
</tr>
<tr>
<td>Layer of elongate cells at the base of tetrasporangia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of paraphyses between tetrasporangial compartments</td>
<td>1-3</td>
<td>1-2</td>
<td>1-several</td>
<td>1-2</td>
<td>1-3 †</td>
<td>1-3 †</td>
<td>No data</td>
<td>1-several</td>
<td>3-5</td>
<td>1</td>
</tr>
<tr>
<td>Number of cells in paraphyses between tetrasporangial compartments</td>
<td>3-5</td>
<td>3-5</td>
<td>7-9</td>
<td>4-6</td>
<td>3-5 †</td>
<td>4-6 †</td>
<td>6-7</td>
<td>3-8</td>
<td>6-9</td>
<td>3-4</td>
</tr>
<tr>
<td>Buried tetrasporangial compartments</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present †</td>
<td>Present †</td>
<td>Absent</td>
<td>Present</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Position of tetrasporangial compartments relative to surrounding vegetative surface (number of cells)</td>
<td>Raised (2-4 cells)</td>
<td>Raised (1-2 cells)</td>
<td>Raised (2-3 cells)</td>
<td>Raised (3-5 cells)</td>
<td>Raised (3-4 cells) †</td>
<td>Raised (2-3 cells)</td>
<td>Raised (1-4 cells)</td>
<td>Raised (3-5 cells)</td>
<td>Sunken</td>
<td></td>
</tr>
</tbody>
</table>

1 Verheij (1992, 1993); 2 Keats and Chamberlain (1993); 3 Alongi et al. (1996); 4 Tomita (1976); 5 Foslie & Howe (1906); 6 Townsend et al. (1995); † This study.