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Original article

Upper Ordovician microphytoplankton of the Bill's Creek Shale and Stonington Formation, Upper Peninsula of Michigan, U.S.A.: Biostratigraphy and paleogeographic significance

Microphytoplancton du Shale de Bill's Creek et de la Formation de Stonington (Ordovicien Supérieur), Péninsule supérieure du Michigan, États-Unis : biostratigraphie et signification paléogéographique

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Abstract

An abundant, diverse, and well-preserved organic-walled microphytoplankton assemblage is described from the Upper Ordovician Bill's Creek Shale and the lower Stonington Formation (Bay de Noc Member) in the Upper Peninsula of Michigan, U.S.A. Based on graptolite and conodont evidence, the Bill's Creek Shale and Stonington Formation are Richmondian (=Ashgill) in age. The assemblage is dominated by acritarchs, which comprise 29 species (including the enigmatic palynomorph *Gloeocapsomorpha prisca*) assigned to 20 genera. The prasinophyte phycomata are represented by undifferentiated species of *Leiosphaeridia* and *Tasmanites*. In addition, chitinozoans are abundant, and scolecodonts and graptolite fragments are common. Paleontologic-palynologic and sedimentologic evidence indicates that the Bill's Creek Shale was deposited in a low-energy, shallow, nearshore marine environment. The overlying Bay de Noc Member of the Stonington Formation also accumulated in a low-energy, normal marine environment, but in a more offshore, somewhat deeper water setting. Both formations experienced minor transgressive and regressive episodes as indicated by fluctuations in the composition of the palynoflora. The combined Bill's Creek/Stonington acritarch assemblage closely resembles those described from the Richmondian-aged Maquoketa Shale (Missouri and Kansas), Sylvan Shale (Oklahoma), and Vauréal Formation (Anticosti Island, Québec, Canada). The overall composition of the acritarch assemblage from these four formations reflects a distinctive, recognizably Laurentian character. Nonetheless, many of the Bill's Creek/Stonington acritarchs have been reported from Upper Ordovician localities elsewhere, providing additional evidence for Late Ordovician cosmopolitanism of the marine microphytoplankton community. Additionally, the restricted stratigraphic range of many of the taxa further enhances their biostratigraphic application, both regionally and globally, and reaffirms the Richmondian (=Ashgill) age of the Bill's Creek Shale and Stonington Formation.

Résumé

Un assemblage de microphytoplancton à paroi organique abondant, diversifié et bien préservé est décrit dans l'Ordovicien Supérieur du Shale de Bill's Creek et de la Formation Stonington inférieure (Membre Baie de Noc) dans la Péninsule supérieure du Michigan, États-Unis. D'après le contenu en graptolites et conodontes, le Shale de Bill's Creek et la Formation Stonington sont d'âge Richmondien (=Ashgill). L'assemblage est dominé par des acritarches, comprenant 29 espèces (dont le palynomorphe énigmatique *Gloeocapsomorpha prisca*) réparties dans 20 genres. Les prasinophytes phycomata sont représentés par des espèces indifférenciées de *Leiosphaeridia* et *Tasmanites*. De plus, les chitinozoaires sont abondants et les fragments de graptolites et scolécodontes sont communs. Les résultats sédimentologiques et paléonto-palynologiques indiquent que le Shale de Bill's Creek s'est déposé dans un environnement marin proximal, peu profond et de faible énergie. Le Membre Baie de Noc de la Formation Stonington susjacent s'est également accumulé dans un environnement marin normal de faible énergie mais dans des eaux plus distales et plus profondes. Les deux formations ont connu des épisodes transgressifs et régressifs mineurs, indiqués par les fluctuations dans la composition de la palynoflore. L'assemblage à acritarches de Bill's Creek et Stonington ressemble à ceux décrits dans le Shale de Maquoketa (Missouri et

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Kansas), le Shale de Sylvan (Oklahoma) et la Formation Vauréal (Île d'Anticosti, Québec, Canada) d'âge Richmondien. La composition générale de l'assemblage à acritarches de ces quatre formations reflète un caractère Laurentien distinctif et reconnaissable. Cependant, la plupart de ces acritarches de Bill's Creek et Stonington ont été signalés dans d'autres localités de l'Ordovicien Supérieur, ce qui constitue une preuve supplémentaire du cosmopolitisme de la communauté microphytoplanctonique marine de l'Ordovicien Supérieur. De plus, la répartition stratigraphique restreinte de la plupart des taxons renforce leur application biostratigraphique à la fois au niveau régional et global et réaffirme l'âge Richmondien (=Ashgill) du Shale de Bill's Creek et de la Formation Stonington.

Keywords: Acritarchs; Bill's Creek Shale; Biostratigraphy; Paleoenvironment; Paleogeography; Stonington Formation; Upper Ordovician

Mots clés : Acritarches ; Shale de Bill's Creek ; Biostratigraphie ; Paléoenvironnement ; Paléogéographie ; Formation de Stonington ; Ordovicien Supérieur

1. Introduction

Organic-walled microphytoplankton have been widely used for stratigraphic correlation both regionally and globally for several decades, and their utility in dating Proterozoic and Paleozoic marine sedimentary rocks is widely recognized (Playford, 2003). Additionally, these palynomorphs are being applied increasingly in paleoenvironmental studies (Vecoli, 2000; Li et al., 2004), and more recently, as they relate to global biodiversification, and to paleoclimatic and paleogeographic changes (e.g., Servais et al., 2004; Vecoli and Le Hérissé, 2004).

Acritarchs and prasinophyte phycomata are the major components of Proterozoic and Paleozoic microphytoplankton communities. Acritarchs (from the Greek *akritos*, uncertain, confused; and *arche*, origin) are an informal and undoubtedly polyphyletic group of organic-walled microfossils of unresolved biologic affinities. Most palynologists accept that acritarchs are probably the cysts of various marine microphytoplanktonic groups, and that many of them are pre-dinoflagellates (Playford, 2003). The Prasinophyceae are an extant class of marine green algae, whose fossil record consists of the cyst-producing (or phycomata) stage in their life cycle.

Acritarchs and prasinophytes were the primary producers of the Proterozoic and Paleozoic oceans. Thus, being at the base of the marine food web, fluctuations in their diversity and abundance would, presumably, have influenced to some extent the evolution of the marine ecosystem. The Ordovician Period was a time when acritarchs experienced their greatest radiation (more than 1500 species are known from the Ordovician) and also mirrored the provincialism of marine invertebrates during the Early and Middle Ordovician, as well as the cosmopolitanism of the Late Ordovician (Vecoli and Le Hérissé, 2004).

Although the Lower Ordovician has been more intensively studied palynologically than the Upper Ordovician, a fairly extensive literature exists regarding the taxonomy, biostratigraphy, and paleogeographic distribution of Upper Ordovician organic-walled microphytoplankton taxa. A profuse and varied assemblage of acritarchs and prasinophytes from two Upper Ordovician (Richmondian = Ashgill) localities in Michigan's Upper Peninsula is described here, following preliminary observations by Wicander and Playford (1999). The assemblage is compared to three other coeval Laurentian acritarch suites, and the biostratigraphic, paleoenvironmental, and paleogeographic significance of the assemblage is discussed in both regional and global contexts.

2. Stratigraphy and age

2.1. Stratigraphy

The Bill's Creek Shale, Stonington Formation, and Big Hill Formation are the three uppermost Ordovician marine lithostratigraphic units exposed successively in the Upper Peninsula of Michigan, northern U.S.A. (Catacosinos et al., 2001).

Hussey (1926: p. 121) named the Bill's Creek beds (=Bill's Creek Shale) for thinly bedded shales and argillaceous limestones exposed along the banks of Bill's Creek in Michigan's Upper Peninsula and placed them in the Richmond portion of the Cincinnatian series. Hussey (1952: p. 41) later described an outcrop of Bill's Creek beds at Haymeadow Creek, also in the Upper Peninsula. However, he noted that "the lower Bill's Creek beds, exposed at the falls on Haymeadow Creek, may not belong to the Richmond. It now seems best to correlate these lower beds, at least, with the Collingwood [Middle Ordovician]... (p. 43)." Hussey (1952: p. 45) remarked that these lower beds differed lithologically from the typical Bill's Creek beds at Bill's Creek in being darker and not weathering to a light gray color. He termed them the Haymeadow Creek Member, which he stated "was formerly the basal part of the Bill's Creek beds of Richmond age" (Hussey, 1952: p. 13). The Haymeadow Creek Member is not formally recognized, the beds exposed at Haymeadow Creek being considered the lowermost portion of the Bill's Creek Shale (Catacosinos et al., 2001).

The Bill's Creek Shale consists of up to 26.8 m of mostly thin-bedded gray shale and calcareous shale, with numerous alternations of shale and argillaceous limestone near its top (Hussey, 1926, 1952). It rests disconformably on limestone of the Gross Quarry Member of the Middle Ordovician Trenton Formation (Catacosinos et al., 2001).

A disconformity also separates the Bill's Creek Shale from the overlying Stonington Formation, which is divided into two members (Hussey, 1926: p. 132; Catacosinos et al., 2001). The lower Bay de Noc Member comprises ca. 3.1 m of massive grayish-brown argillaceous limestone and gray calcareous shale, succeeded by ca. 4.6 m of alternating, thinly bedded gray argillaceous limestone and gray calcareous shale. The 0.9 to 6.1 m-thick Ogontz Member conformably overlies the Bay de Noc, and consists largely of gray to dark brown, massive and irregularly bedded cherty limestone with some lenses of argillaceous limestone.