Calcimicrobes, Microbial Fabrics, and Algae in Mississippian Midale Beds, Midale and Glen Ewen Pools, Williston Basin, Southeastern Saskatchewan

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Shen, J.-W. and Qing, H. (2008): Calcimicrobes, microbial fabrics, and algae in Mississippian Midale Beds, Midale and Glen Ewen pools, Williston Basin, southeastern Saskatchewan; *in* Summary of Investigations 2008, Volume 1, Saskatchewan Geological Survey, Saskatchewan Ministry of Energy and Resources, Misc. Rep. 2008-4.1, CD-ROM, Paper A-5, 10p.

Abstract

The Midale Beds of the Mississippian Charles Formation were deposited in a shallow-water, periodically restricted, epeiric setting in southeastern Saskatchewan, and are characterized by a variety of shallow-water carbonate lithologies ranging from wackestone, to packstone, to grainstone with abundant calcimicrobes, algae, and related microbial fabrics. More than 300 thin sections from 35 wells that cored through Mississippian Midale Beds in the Glen Ewen and Midale pools of southeastern Saskatchewan were examined in order to study the contribution of calcimicrobes and algae to the sedimentation of Mississippian carbonate rocks. The calcimicrobes identified are mostly porostromate calcimicrobes and Garwoodia *sp.,* Ortonella *sp., as well as* Archaeolithoporella-*like,* Girvanella-*like,* Wetheredella-*like, and other forms of problematic calcimicrobes. The algae are mostly* Zidella maxima, Archaeolithophyllum *sp., phylloid algae, and a problematic algal group. Microbial fabrics are characterized by micro-stromatolites, microbial laminations, thrombolite, and clotted peloids and fenestrae. The fragmented algae commonly occur as bioclastic grains in the packstone and grainstone, whereas calcimicrobes and microbial fabrics are important components in the grainstones and microbial boundstone, and may be related to change of sea level, nutrient supply, and biotic assemblages.*

Keywords: *calcimicrobes, microbial fabrics, algae, Midale Beds, Mississippian, Saskatchewan.*

1. Introduction

The carbonate rocks of the Early Mississippian (Visean) Midale Beds, southeastern Saskatchewan (Figure 1), have long been studied for oil and gas exploration (Thomas, 1954; Smith, 1980; Fuzesy, 1983; Kent, 1984a, 1984b, 1987; Matiisen and Shehata, 1987; Wegelin, 1987; Keswani and Pemberton, 1993, 2006; Nimegeers and Qing, 2002a, 2002b; Nickel and Qing, 2004; Qing and Nimegeers, in press). The Midale Beds generally consist of, in ascending order, the Frobisher Evaporite, the Midale Vuggy limestones, and the Midale Marly dolostones (Fuzesy, 1960, 1983; Smith, 1980). Keswani and Pemberton (1993) and Keswani (1999) suggested that the Midale Vuggy limestones contain abundant algae, and Lake (2007) suggested that they contain calcimicrobes and microbial fabrics. Because few systematic investigations of the nature of these algal-microbial deposits and of their contribution to lithofacies development and to the porosity and permeability of these carbonate reservoirs have been carried out, this study was initiated. More than 300 thin sections from 35 wells in the Glen Ewen and Midale pools have been examined. Preliminary results with regard to the type and characteristics of calcimicrobes, algae, and related microbial fabrics identified in the thin sections, all of which are archived in the Saskatchewan Ministry of Energy and Resources Subsurface Geological Laboratory, are summarized in this paper.

2. Geological Setting

The Mississippian Midale Beds represent transgressive-regressive cycles characterized by a succession of shallow-marine carbonate-evaporite sediments deposited in a shallow ramp or an epeiric sea with an arid-climate setting (Nimegeers and Qing, 2002a; Nickel and Qing, 2004; Pendrigh, 2004; Qing and Nimegeers, in press). The Midale Beds can be subdivided into three units: the Frobisher Evaporite at the base, successively overlain by the Midale Vuggy limestones, and the Midale Marly dolostone (Kent, 1984a; Wegelin, 1984; Matiisen and Shehata, 1987), above which is the Midale Evaporite, the basal unit of the Ratcliffe Beds (Figure 2).

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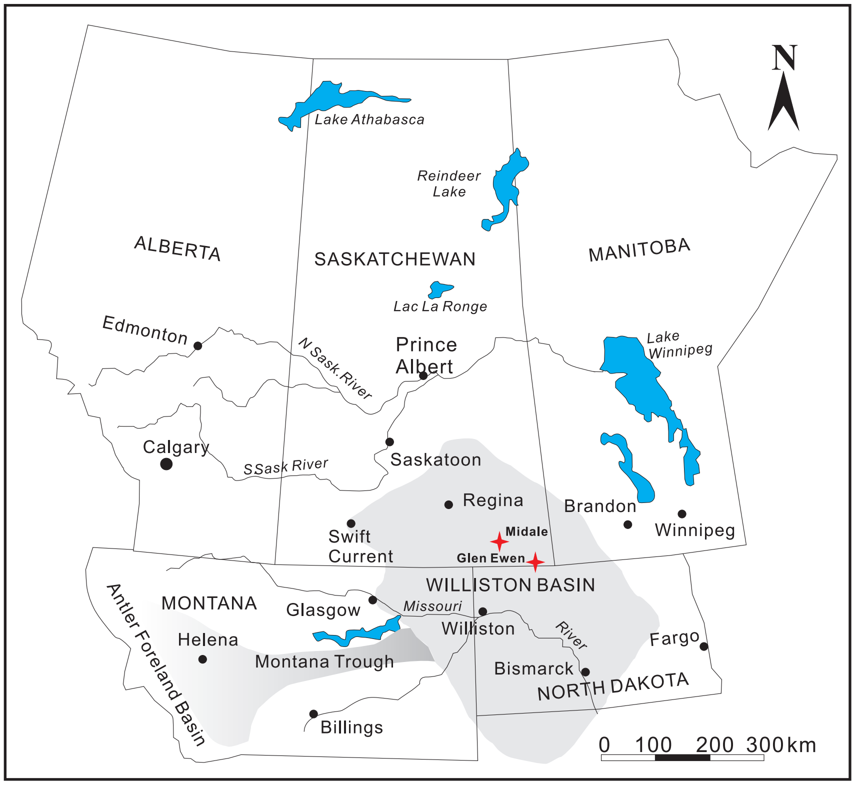

Figure 1 - Location map of the Williston Basin in central North America. Red stars represent the schematic locations of the Glen Ewen and Midale pools.

The Midale Vuggy unit is composed of a variety of limestones with abundant secondary porosity, some of which is filled or partially filled with anhydrite cement (Nimegeers and Qing, 2002a; Nickel and Qing, 2004; Pendrigh, 2004; Qing and Nimegeers, in press). The overlying Midale Marly unit is characterized by cryptocrystalline dolostones (wackestones and mudstones) that represent the onset of restricted, shallow-water conditions (Wegelin, 1987). The Midale Evaporite, deposited under an emergent, supratidal, highly restricted hypersaline sabkha setting, contains intercalated anhydrites and dolostones (Matiisen and Shehata, 1987; Churcher and Edmunds, 1994).

3. Algae and Calcimicrobes

Calcareous algae identified in the Midale Vuggy unit include dasycladales, *Zidella* sp. (Figure 3A), *Archaeolithophyllum* sp., phylloid algae, coralline red algae, green algae, and a problematic algal group (Figure 3B). Most of algae are fragmented and commonly occur as bioclasts (about 1 to 2%) in the host substrate of peloidal packstone in the lower "Vuggy" beds.

Different types of calcimicrobes occur in the Midale Vuggy carbonates, and locally played an important role in binding carbonate deposits and lithification. Calcimicrobes are generally closely associated with skeletal metazoans to form unique microfacies and varied microbial fabrics. The dominant type of calcimicrobes is related to the porostromate group with large, strongly calcified thalli such as *Garwoodia* sp. (Figures 3C, 3D, and 4A), *Ortonella* sp. (Figures 4B, 4C, and 4D) and porostromate calcimicrobes (Figure 5A). *Archaeolithoporella*-like (Figure 5B), *Girvanella*-like, *Wetheredella*-like, and problematic calcimicrobes (Figure 5C) were also locally identified. These calcimicrobes mainly occur in microbial limestone, micritized bioclastic wackestone, bioclastic wackestone, bioclastic grainstone, and peloidal grainstone.

Materials of the *Garwoodia* sp. in the Midale Beds belong to *Garwoodia gregaria*, which is characterized by the thalli diameter ranging from 0.25 to 8 mm (Figures 3C and 3D). The fragments of colonies and thalli were generally identified in the grainstones; they make up about 15 to 60% (by volume) of the bioclastic grains. The overall growth form is bush like (Figures 3C and 3D), generally 1 to 9 mm in width and 2.5 to 8 mm in height. Transverse sections of *Garwoodia* tubes are circular to ovate (Figure 4A).

A number of minute shrubs and masses of *Ortonella* sp. and *Garwood* sp. were identified in the wackestone of the Midale Beds, differing from the *Garwoodia* sp. that mostly occurs in the grainstone. *Ortonella* sp. is composed of various bifurcated tubes that are assembled into knob-like or encrusted forms (Figures 4B and 4C). No membranous parts are developed in the tubes. Filamentous tubes are oriented in parallel or radial patterns (Figure 4D). Growth layers could be observed in longitudinal section.

Porostromate calcimicrobes, distinctive tubular organisms, locally occur as tufts showing lobed projections in massive automicrite in the Midale Beds (Figure 5A). In the early growth stage, the filamentous tubes are closely spaced and share micritic walls. Then the filaments spread out in a fan shape and continue their growth with branching in their later stages. The filamentous tubes can be straight or slightly curved, or can show dichotomous branching.

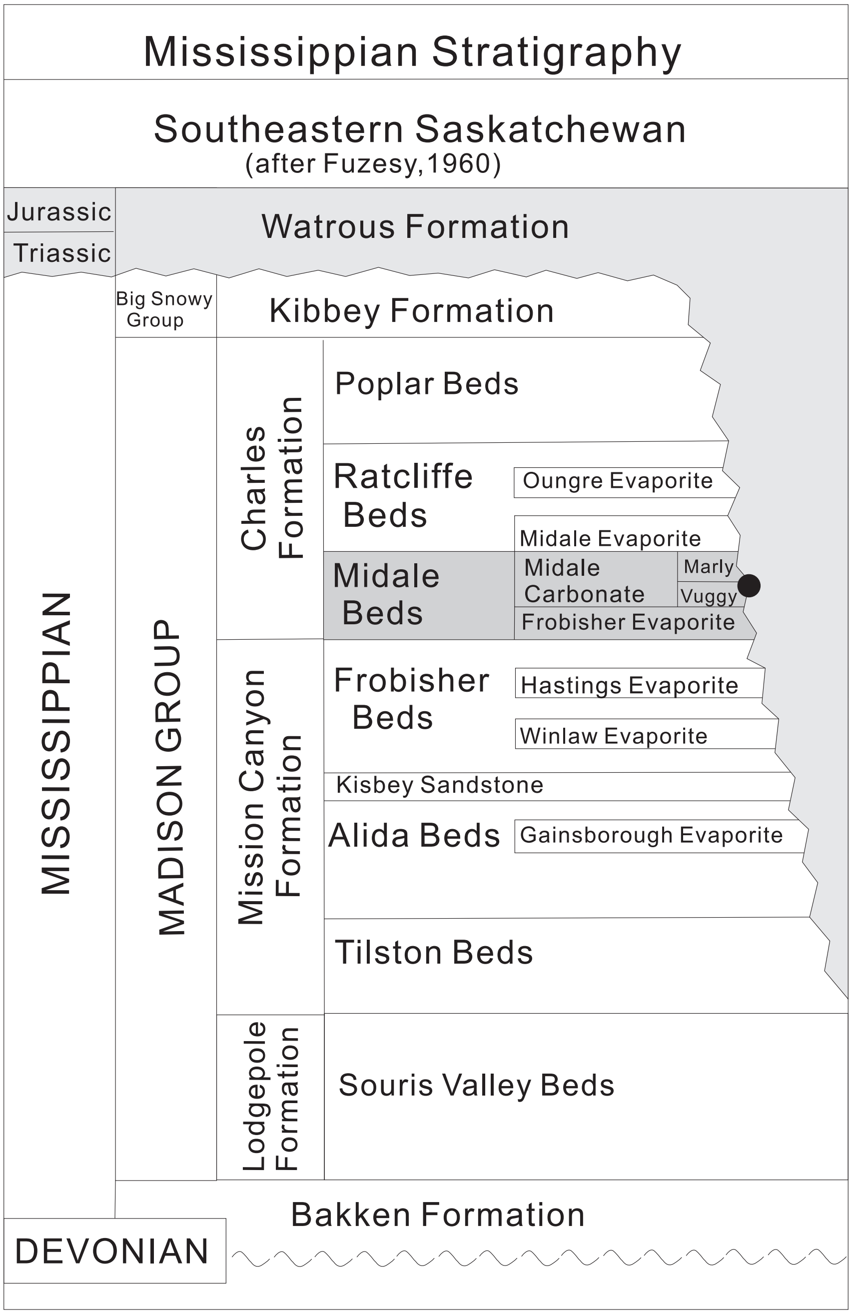

Figure 2 - Stratigraphic column showing Mississippian units along subcrop in southeastern Saskatchewan. Units within each formation are referred to as "Beds". The regional Mississippian (sub-Mesozoic) unconformity separates the units from the overlying Jura-Triassic Lower Watrous Member of the Watrous Formation (Fuzesy, 1960). The black dot represents the algal and microbial occurrence horizon.

Several problematic calcimicrobes also occur in the Midale Beds, including *Archaeolithoporella*-like (Figure 5B), *Girvanella*-like, *Wetheredella*-like, and other forms of problematic calcimicrobes (Figure 5C). *Archaeolithoporella*-like calcimicrobes are encrusting growth forms and interlaminated with synsedimentary marine cements, showing dark-coloured filaments and light coloured cements. These calcimicrobes can form nodular structures such as oncoids with variable sizes (Figure 5B).

4. Microbial Fabrics

Microbial fabrics are widespread in all the carbonate lithofacies in the Midale Vuggy carbonates, and include thrombolites, micro-stromatolites, microbial laminations, clotted peloids, and fenestrae. Thrombolites were formed by dark-coloured microbial carbonates that contain scattered, distinct, radiating filaments of *Ortonella* (Figure 5D).

Microstromatolites are stromatolite columns <1 cm in diameter with very fine lamination (Riding, 2000). In the Midale Beds, they commonly occur in bioclastic wackestone where they are generally developed on small gastropods, but also locally grew on ostracods, bryozoans, algae, bioclasts, and cavity walls. These microstromatolites are frequently columnar in form (Figure 6A) and are locally dichotomous. The stromatolitic fabric is commonly composed of fine lamination and form individual and compound columns (Figure 6B). The margins of microstromatolite columns are uneven and serrate.

Locally microstromatolitic structures can occur in grainstones, where they developed in bulbous and domal growth forms (Figure 6C). Domal growth forms were initiated on algal fragments or other bioclasts (Figure 6C). Upper surfaces of algal fragments are overgrown by inter-laminated microbial micrite, forming low domal microstromatolites. Fine-grained bioclasts are trapped in the dark-coloured laminae.

Lamination fabrics formed low-relief, wave-like or dome structures composed of dark-coloured thinner laminae and light- to dark-coloured layers with clotted peloids and irregular sparry pores (Figure 6D). Fenestral fabrics formed by clotted peloids are well developed; they resulted from grain bridging. Irregular, elongate, spar-filled voids in

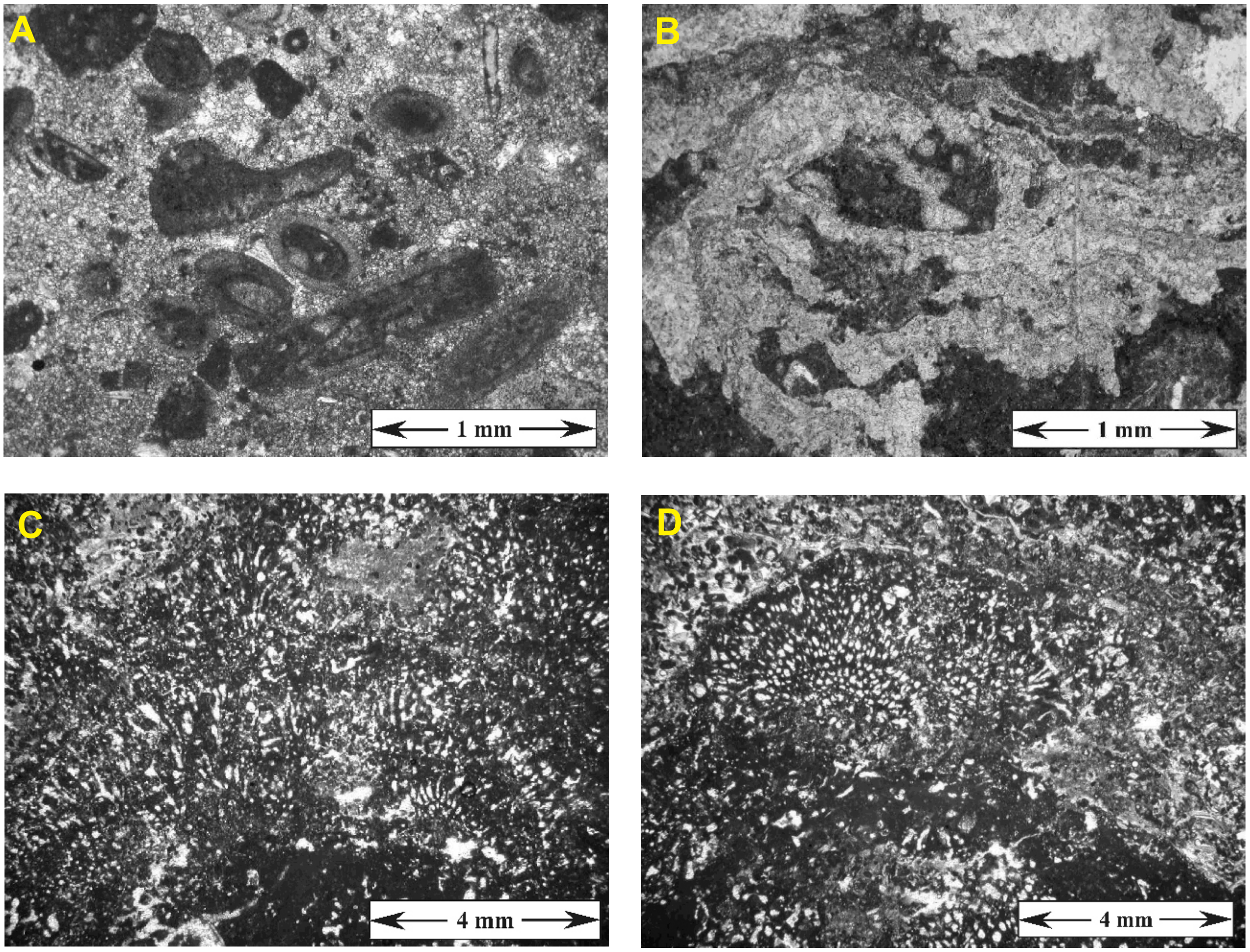

Figure 3 - Algal fragments and calcimicrobes in the Midale Beds. (A)* Zidella *sp. showing hollow tabular thallus with circular transverse section (3-12-3-1W2, 1275.2 m). (B) Problematic alga, showing encrusting growth form,* Rothpletzella*-like structure, but internal texture is indistinct (3-9-3-1W2, 1297 m). (C) Large* Garwoodia gregaria *colony showing typical flabellate shape in more or less oblique sections (3-28-6-9W2, 1257.3 m). (D)* Garwoodia *sp. with long, practically straight tubes (3-28-6-9W2, 1257.3 m).

micritic sediments (mostly clotted peloids), are fenestrae-like, but do not show geopetal sediments. Laminoid fenestral fabrics are characterized by a large amount of clotted peloids and pisoids. The alternation of fine and coarse-grained pisoids, cemented by micrite, formed different layers. Some pisoids are overgrown fragmented filamentous cyanobacteria.

5. Discussion

Algae have been abundantly preserved in restricted lagoonal Midale carbonates as fragments in bioclastic packstone and grainstone and, rarely, wackestone. Algal sediments in the lower Midale carbonate represent a landward lagoon or algal marsh setting (Nimegeers and Qing, 2002a; Qing and Nimegeers, in press).

Few studies and descriptions have been done on the calcimicrobes and microbial fabrics in the Midale Beds. Lake (2007) reported *Ortonella* sp. from the Mississippian Ratcliffe Beds of the Williston Basin and classified them as calcareous algae. Currently, *Ortonella* have been taxonomically put into cyanobacteria, and belong to the porostromate group because they were formed from synsedimentary calcification of calcimicrobes and bacteria (Pratt, 1984; Riding, 1991). Most of the calcimicrobes described from the Midale Beds belong to the porostromate group which is common in Mississippian reefs and shallow-water assemblages with thrombolites (Rich, 1974; Riding, 2000; Brenckle, 2004; Petty, 2005; Shen and Webb, 2005, 2008; Pickard *et al.*, 2006) and has many ambiguous names referred to as other fossils (Mamet and Roux, 1983; Riding, 1991).

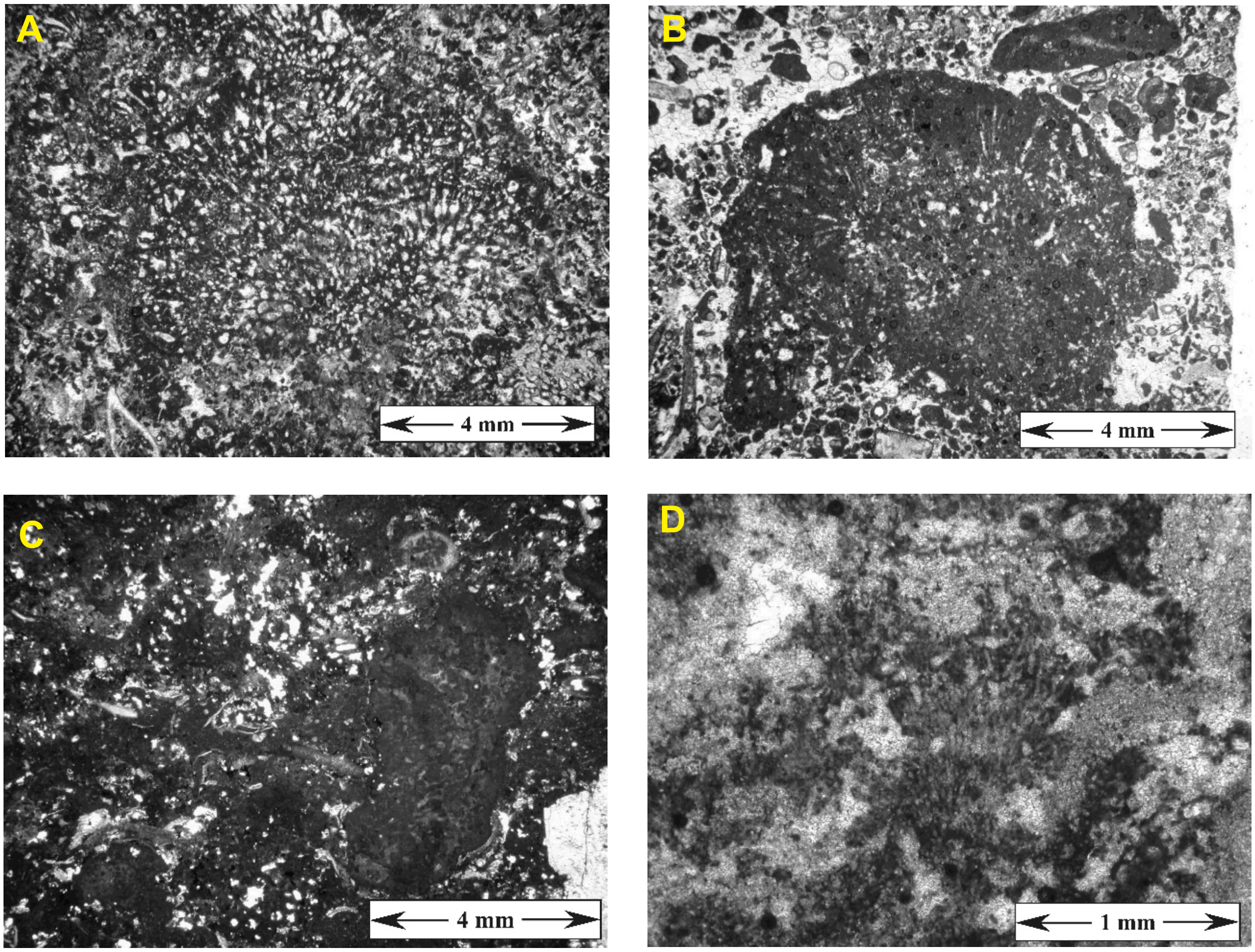

Figure 4 - Calcimicrobes in the Midale Beds. (A) Garwoodia colonies with four to five flabellate bushes, one growing on the top of another (3-28-6-9W2, 1257.3 m). (B) An Ortonella colony encrusted by microbial carbonates, showing radially, straight tubes (11-2-3-1W2, 1257.4 m). (C) The nodular thallus of Ortonella, showing relatively massive form in wackestone (13-7-3-1W2, 1322.2 m). (D) Ortonella occurring as fan-shaped masses in which micrite-walled filamentous tubes are radially sprayed (3-5-3-1W2, 1320.9 m).

Most common calcimicrobes in the Midale Beds are *Garwoodia* sp. *Garwoodia* was named by Wood (1941). It was assigned to porostromata by Senowbari-Daryan *et al.* (1993) and to Pseudoudotaceae by Mancinelli *et al.* (2004). This calcimicrobe is typical of shallow water (typically 0 to 2 m deep) in tropical to subtropical shelf settings (Vacard and Aretz, 2004), but is not lagoonal like the similar genus *Ortonella* (Vacard and Aretz, 2004). *Ortonella* in the Midale Beds closely resemble those from the Mississippian strata in Australia (Shen and Webb, 2005, 2008), Ireland (Pickard *et al.*, 2006), southern Scotland (Riding, 2000), the United States (Rich, 1974), and northwestern China (Brenckle, 2004) in growth form (in radial arrays), morphologies of filamentous tubes (tabular and non-septate), and branching patterns. Bush-like *Ortonella* are generally associated with thrombolitic fabrics as those from the thrombolitic-*Ortonella* reefs in the Upper Visean Clifton Down Limestone of southwestern England (Kirkham, 2005).

Porostromate calcimicrobes commonly occur within bioclastic-microbial wackestone and bafflestones together with other calcimicrobes and algae. Flügel (2004) indicated that the porostromate group includes calcimicrobes with close morphological similarity to recent calcified blue-green algae (cyanobacteria), as well as various green algae. Porostromate microbial fabrics reflect relatively still water in a low-energy environment and are of importance in lagoonal limestones.

Various problematic calcimicrobes of uncertain affinity occur as oncoids and encrusters in cavities and interstices between *Syringopora* corallites, and thrombolitic fabrics in the Midale Beds. Oncoids formed by *Archaeolithoporella*-like problematica may have a similar genetic interpretation to phosphatic oncoids formed at discontinuities (see Flügel, 2004, p131, Figure 4.16A).

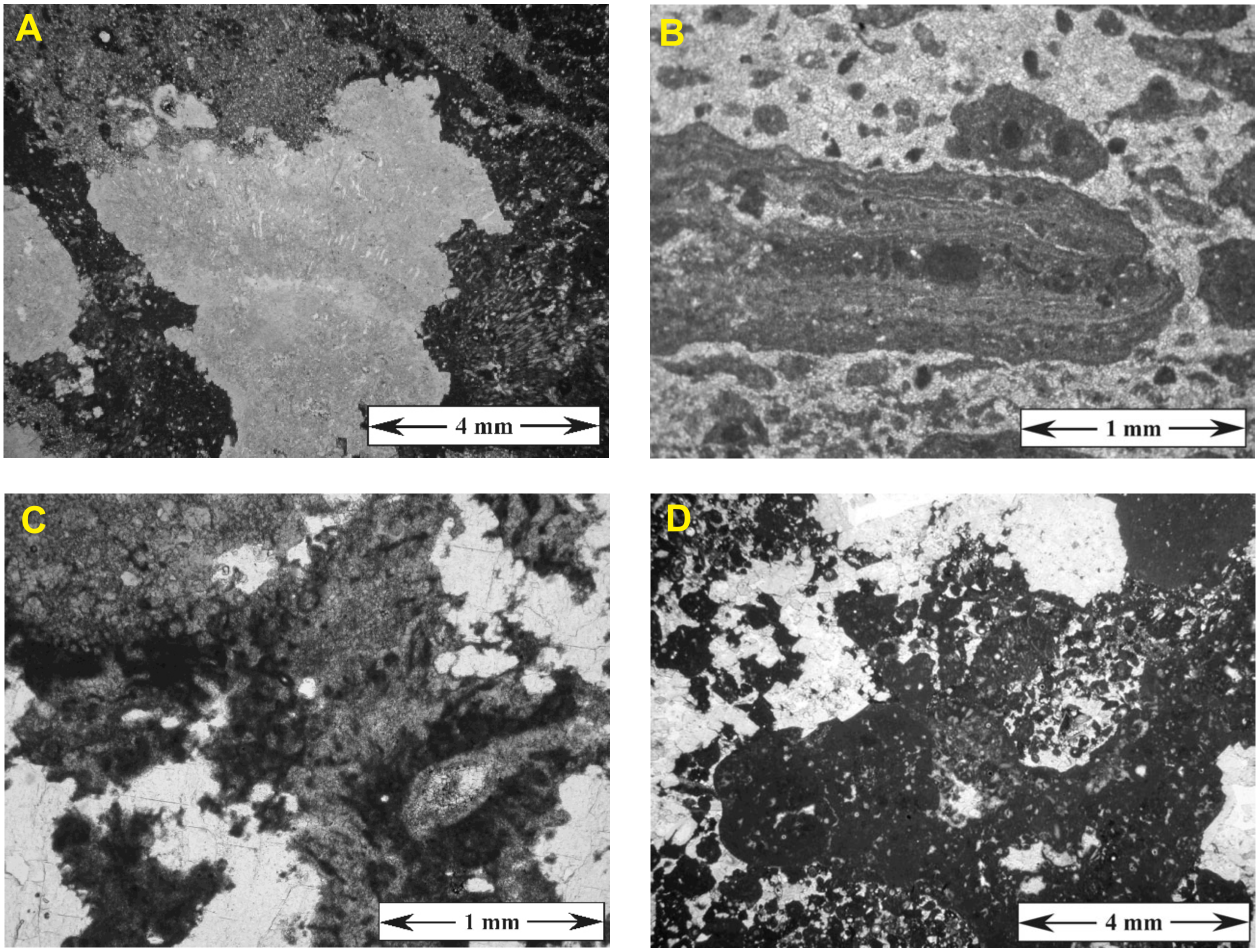

***Figure 5** - Calcimicrobes and microbial fabrics in the Midale Beds. (A) Porostromate calcimicrobe thalli as encrusting-style, erect, straight or slightly curved filamentous tubes showing dichotomous branching and differentiation into marginal tufts (13-16-6-9W2, 1370.4 m). (B)* **Archaeolithoporella**-*like problematica, forming oncoids (13-22-6-9W2, 1346.9 m). (C) Problematic calcimicrobes showing elongate, semicircular cross-section surrounded by comb-like textures (11-19-3-1W2, 1306.4 m). (D) Thrombolite formed by* **Ortonella** *colonies and encrusted micrite (13-19-6-9W2, 1381 m).*

Microstromatolites developed on ostracods and gastropods in the Midale Beds may indicate moderately deep-water, relatively restricted, more-or-less adverse, cold-seep related, microbially active environments (Peckmann *et al.*, 2002). Domal (or bulbous) microstromatolites may represent a shallow-water, slight to moderately agitated, semi-restricted to open environment because they occur in grainstones, trap fine-grained bioclasts in laminae, and are associated with normal marine faunas without accumulation of gastropods, ostracods, and other common marine biota.

Calcimicrobes can stabilize grains, and modify and create sediment (Mancinelli *et al.*, 2004), and the related syndepositional microbial fabrics may affect the development of porosity/permeability of the hydrocarbon reservoirs (Figures 4D and 5D). Microstromatolites and clotted fabrics formed by peloids and pisoids have well-developed porosity (Figure 7A), whereas laminated fabrics have low porosity (Figure 6D). Microbial activities also influenced cementation in the various carbonate depositional settings (Figure 7B) (Hillgärtner *et al.*, 2001).

6. Conclusions

1) Calcareous algae, calcimicrobes, and microbial fabrics are common in the Mississippian Midale Beds. Microbial fabrics include thrombolites, micro-stromatolites, microbial laminations, and clotted peloids and fenestrae.

2) The calcareous algae are mostly *Zidella* sp.; *Archaeolithophyllum* sp., phylloid algae, and a problematic group. They are abundant in the restricted lagoonal sediments of the Midale carbonate, and generally occur in peloidal packstone and grain-rich wackestone.

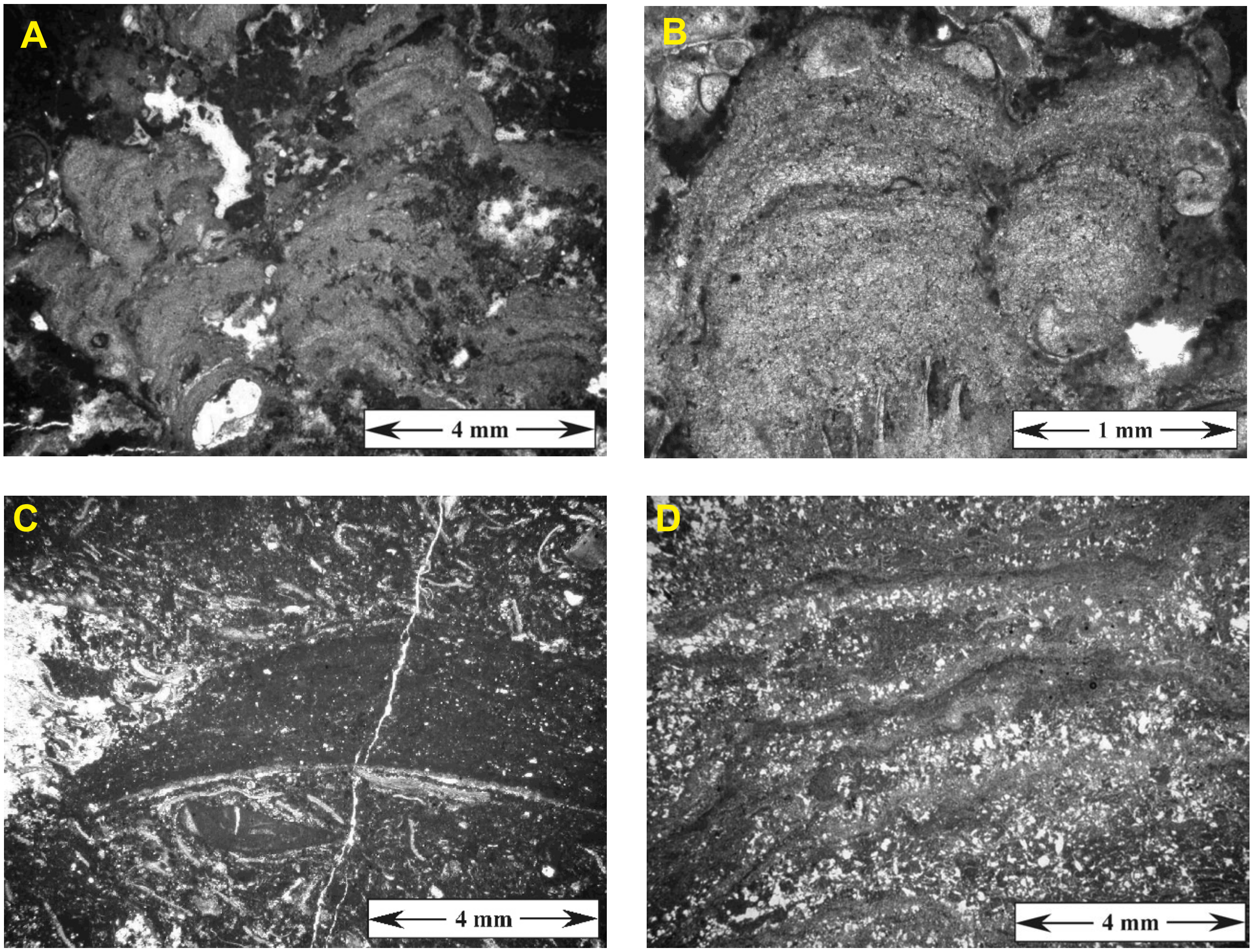

Figure 6 - Microbial fabrics in the Midale Beds. (A) Compound microstromatolites on gastropods and bioclasts, locally showing dichotomous or trichotomous branching (3-5-3-1W2, 1320.9 m). (B) Microstromatolite showing indistinct laminae, locally encrusting small gastropods (3-5-3-1W2, 1320.9 m). (C) Domal growth microstromatolite on bioclasts and algal fragments, indistinct microbial laminae trapping fine-grained bioclasts (11-28-2-1W2, 1333.3 m). (D) Laminations composed of dark-coloured thin laminae and light- to dark-coloured layers with clotted peloids and irregular sparry pores (9-35-2-1W2, 1288.5 m).

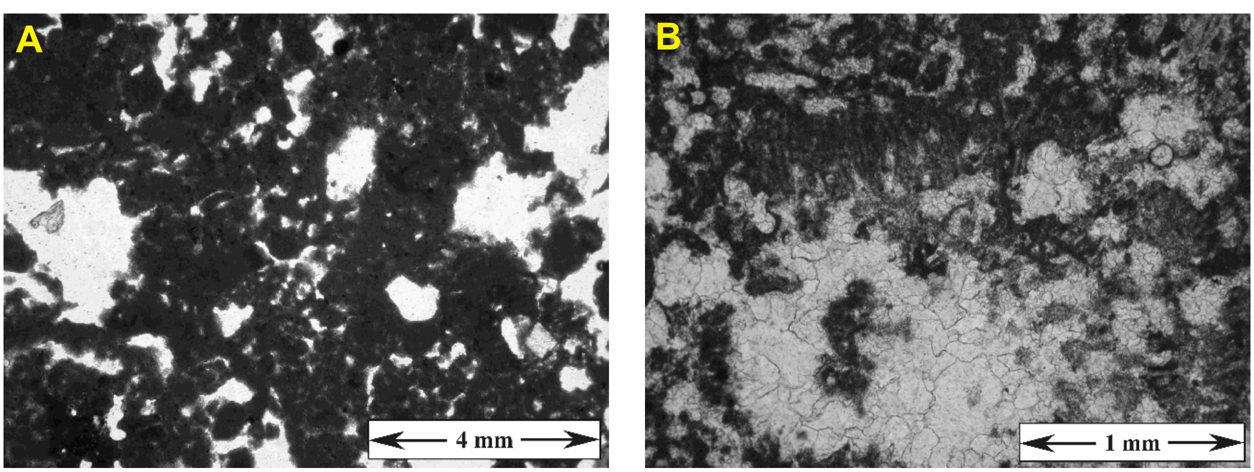

Figure 7 - Effect of microbial fabrics on development of porosity. (A) Well-developed porosities in clotted fabrics formed by peloids and pisoids (3-17-3-1W2, 1323.3 m). (B) Microbial activity (**Ortonella** *sp.) induced calcite cementation (7-10-3-1W2, 1267.7 m).*

3) Well-preserved calcimicrobes are abundant in the Midale Beds. Porostromate calcimicrobes with large, strongly calcified thalli such as *Garwoodia* sp. and *Ortonella* sp. are dominant; *Archaeolithoporella*-like, *Girvanella*-like, *Wetheredella*-like, and problematic calcimicrobes are also sporadically present. They mainly occur in microbial limestone, micritized bioclastic wackestone, bioclastic wackestone, bioclastic grainstone, and peloidal grainstone.
4) Microstromatolites in the Midale Beds commonly occur in wackestone or bioclastic wackestone and generally grew on gastropods, ostracods, bryozoans, algae, bioclasts, and cavity walls. Two types of microstromatolites are distinguished: microdigitate and domal (bulbous).
5) Calcimicrobes and related syndepositional microbial fabrics may influence the porosity and/or permeability of hydrocarbon reservoirs. Porosity developments in the reservoir may be affected through stabilization, agglutination and calcification of microbial mats comprising complex calcimicrobe communities associated with biofilms. Microbially induced cementation is also important in porosity development.

7. Acknowledgments

We thank the Saskatchewan Ministry of Energy and Resources Subsurface Geological Laboratory for providing free access to the cores, thin sections, and other examination facilities. Special thanks are extended to the Department of Geology at the University of Regina for providing research facilities. Jian-Wei Shen is financially supported by the Chinese Academy of Sciences Hundred Talents Program.

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