



A new Middle Ordovician reef assemblage from north-central China and its palaeobiogeographical implications



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ABSTRACT

A new Middle Ordovician microbial boundstone incorporating the problematic coralline fossil *Amsassia* is reported from the Jinghe Formation of north-central China, Sino-Korean Block. The reefs are dominated by microbial masses composed of aggregated peloids and micrites. The subordinate small-module favositoid coral-like organism *Amsassia*, characterized by phacelocerioid forms and module increase involving fission, was surrounded by peloidal layers. A few *Amsassia* are preserved in growth position and are occasionally attached to each other. The peloidal masses that make up these reefs are considered to be microbialite acting as a primary reef builder and binder, whereas *Amsassia* was a limited framework builder in these reefs. The Jinghe reefs have been previously described as “coral–stromatolite reefs” because of the superficial resemblance of *Amsassia* to *Lichenaria*, though their growth characteristics are fundamentally different. *Amsassia* and *Lichenaria* show markedly different patterns of palaeobiogeographical initiation and distribution, and all Middle Ordovician “*Lichenaria*” and “*Lichenaria*-bearing reefs” reported from north-central China apparently occur outside of the main palaeobiogeographical province of *Lichenaria*. This study demonstrates the need for re-evaluation of such reports of early corals from the Middle to Late Ordovician of the western margin of Gondwana to clarify the palaeobiogeographical distributions of early coralline organisms.

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1. Introduction

Reefs are biogenic structures resulting from the amalgamation of sessile benthic organisms. An understanding of reef-building biotas can provide valuable information on reef-forming processes and ambient environments (Wood, 1999) and the palaeoecology and evolution of reef constituents (Pandolfi, 2011), as well as biogeographical reconstruction (Webby, 1992a). Corals have been key participants in both modern and ancient reefs throughout the Phanerozoic (Flügel and Kiessling, 2002). Corals first emerged during the early Cambrian (Rowland and Shapiro, 2002; Scrutton, 2005), but none appear to be in the direct lineage of unequivocal tabulate or rugose corals, which first appeared in the Early Ordovician of Laurentia (Scrutton, 1997, 2005; Webby et al., 2004). Subsequent diversification of early corals during the Ordovician (Scrutton, 1997) coincided with the evolutionary radiation of the period (Droser and Finnegan, 2003; Webby et al., 2004).

Lichenaria Winchell and Schuchert, 1895 is commonly considered a representative of the most primitive stock of tabulate corals (Flower, 1961; Scrutton, 1979, 1997; Hill, 1981; Lee and Elias, 2004; Webby et al., 2004; Elias et al., 2008). It has been mainly reported from North America throughout the Ordovician (Table 1), and first appeared in the Early Ordovician reefs of Newfoundland, Canada (Pratt and James, 1982). From the 1960s onwards, reports of *Lichenaria* and *Lichenaria*-bearing reefs were made from the Middle Ordovician deposits of China, including Shaanxi (Fu, 1981; Li and Lin, 1982; Lin, 1983, 1984; Ye et al., 1995; Jiang et al., 2013), Gansu (Yu, 1961; Yi, 1974), Qinghai (Zhou and Dean, 1996), and Zhejiang (Lin and Webby, 1989) provinces, which dramatically expanded the palaeobiogeographical distribution of early corals and coral-bearing reefs (Webby, 2002). The recent study of Sun et al. (2014), however, evaluated the “*Lichenaria*” material (Lin, 1983; Ye et al., 1995) and concluded that probably all species from Shaanxi assigned to *Lichenaria* are actually *Amsassia*. *Amsassia* superficially resembles *Lichenaria* in the field in some respects, but they belong to separate taxonomic group: *Amsassia* is probably an alga (Sun et al., 2014). This study aims to describe and analyse constituents of the *Amsassia*-bearing microbial reefs from north-central China, and to discuss the palaeobiogeographical implications of early tabulate corals and coral-like organisms for Ordovician reef development.

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Table 1

Selected occurrences of *Lichenaria* in the Ordovician compiled by age and locality. The shaded rows indicate occurrences of *Lichenaria* within reefs. Note the predominant occurrences of *Lichenaria*-bearing reefs from Laurentia. The bold-faced *Lichenaria concava* from the Sino-Korean Block has been reassigned to *Amsassia shaanxiensis* by Sun et al. (2014). *Lichenaria typa** is the type species.

	Age	Occurrence	Location	Palaeocontinent	Species	Reference	
Late Ordovician	Late	Kozhym River	Polar Ural, Russia	Baltica	<i>Lichenaria</i> sp.	Antoshkina (1998)	
	Middle	Hermitage Fm.	Tennessee, USA	Laurentia	<i>Lichenaria grandis</i> <i>L. globularis</i> <i>L. parva</i>	Elias et al. (2008)	
	Early	Benjamin Ls.	Tasmania, Australia	Gondwana	<i>Lichenaria</i> sp.	Corbett and Banks (1974)	
		Anderken Fm.	Chu–Ili, Kazakhstan	Kazakhstan	<i>Lichenaria</i> sp.	Popov et al. (2002); Popov and Cocks (2006)	
		Yanwashan Fm.	Zhejiang, China	South China	<i>Lichenaria</i> sp. <i>L. jiangshanensis</i>	Yi (1974); Lin and Webby (1989)	
Middle Ordovician		Braeside bed	Ontario, Canada	Laurentia	<i>Lichenaria typa</i> *	Steele and Sinclair (1971)	
		Laval Fm.	Québec, Canada	Laurentia	<i>Lichenaria</i> sp.	Pratt (1989)	
		Mingan Islands	Québec, Canada	Laurentia	<i>Lichenaria</i> sp.	Desrochers and James (1989)	
		Southern Bobcaygeon	Ontario, Canada	Laurentia	<i>Lichenaria typa</i> *	Liberty (1969)	
		Bobcaygeon Fm.	Ontario, Canada	Laurentia	<i>Lichenaria</i> sp. <i>L. coboconkensis</i>	Liberty (1969)	
		Sinmard bed	Québec, Canada	Laurentia	<i>Lichenaria</i> sp.	Bolton (1988)	
		Day Point Fm.	New York, USA	Laurentia	<i>Lichenaria lamottensis</i>	Kapp and Stearn (1975)	
		Day Point Fm.	New York & Vermont, USA	Laurentia	<i>Lichenaria</i> sp. <i>L. heroensis</i>	Erwin (1957); Pitcher (1964)	
	Late		Carters Ls.	Tennessee, USA	Laurentia	<i>Lichenaria</i> sp.	Alberstadt et al. (1974)
			New Market Fm.	Maryland, USA	Laurentia	<i>Lichenaria</i> sp.	Wanless (1991)
			Daylesford Fm.	New South Wales, Australia	Gondwana	<i>Lichenaria</i> sp.	Semeniuk (1972)
			Fossil Hill Ls.	New South Wales, Australia	Gondwana	<i>Lichenaria</i> sp.	Webby (1992b)
			Gordon Ls.	Tasmania, Australia	Gondwana	<i>Lichenaria</i> sp.	Banks et al. (1962)
			Mole Creek succession	Tasmania, Australia	Gondwana	<i>Lichenaria</i> sp.	Banks and Burrett (1979); Webby (1979)
			Yaoxian Fm.	Yaoxian, China	Sino–Korean	<i>Lichenaria</i> sp.	Li and Lin (1982)
			Shaanxi–Gansu area	Shaanxi–Gansu, China	Sino–Korean	<i>Lichenaria</i> sp.	Yi (1974)
			Hengluanshan Fm.	Guangzhou, China	Tarim	<i>Lichenaria</i> sp.	Zhou and Dean (1996)
			Gulang Fm.	Gulang, China	Tarim	<i>Lichenaria</i> sp.	Zhou and Dean (1996)
		Yaomoshan Fm.	Yumen, China	Tarim	<i>Lichenaria cf. artica</i>	Zhao (1979) Zhou and Dean (1996)	
	Middle		Novaya Zemlya	Arctic Russia, Russia	Baltica	<i>Lichenaria</i> sp.	Nekhorosheva (1976)
		Jinghe Fm.	Yongshou, China	Sino–Korean	<i>Lichenaria concava</i>	Ye et al. (1995)	
		Beiguoshan Fm.	Longxian, China	Sino–Korean	<i>Lichenaria concava</i>	Ye et al. (1995)	
Early		Collierstown Ls.	Virginia, USA	Laurentia	<i>Lichenaria</i> sp.	Cooper and Cooper (1946)	
		Lehman Fm.	Nevada, USA	Laurentia	<i>Lichenaria</i> sp.	Ross (1970)	
		Antelope Valley Ls.	Nevada, USA	Laurentia	<i>Lichenaria</i> sp.	Ross (1970)	
Early Ordovician	Early	Tank Hill Ls.	Nevada, USA	Laurentia	<i>Lichenaria</i> sp.	Duncan (1958)	
		Tanyard Fm.	Maryland, USA	Laurentia	<i>Lichenaria</i> sp.	Sepkoski (1998)	
		Rockdale Run Fm.	Nevada, USA	Laurentia	<i>Lichenaria</i> sp.	Sepkoski (1998)	
		Appalachian	Virginia, USA	Laurentia	<i>Lichenaria</i> sp.	Bova and Read (1987)	
		Watts Bight Fm.	Newfoundland, Canada	Laurentia	<i>Lichenaria</i> sp.	Pratt and James (1982); Knight et al. (2008)	

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