Warm-water Dasycladaceae algae from the Late Ordovician of the Parahio Valley, Spiti, India

Ravi S. Chaubeya, Olev Vinnb, Birendra P. Singha, Om N. Bhargavaa, Subhay K. Prasad and Naval Kishorea

a Center of Advanced Study in Geology (CAS), Panjab University, Chandigarh 160014, India
b Department of Geology, University of Tartu, Ravila 14A, 50411 Tartu, Estonia; olev.vinn@ut.ee

Received 13 December 2018, accepted 8 February 2019, available online 28 February 2019

Abstract. Warm-water Dasycladaceae algae Mastopora and Cyclocrinites were for the first time recorded from the Takche Formation (Upper Ordovician–lower Silurian), Parahio Valley, Spiti, India. They are preserved as external and internal moulds of the non-globular or possibly bulb-like cortical skeleton showing flattened thalli with a high degree of compaction. The occurrence of abundant cyclocrinitid remains in the Takche Formation indicates that the Spiti region of the northwestern Himalaya must have been located at about 30° palaeolatitude during the Late Ordovician and early Silurian. The cyclocrinitids were warm-water algae and their extinction at the end of the Ordovician is related to cooling and glaciations. The cyclocrinitids in the Ordovician are known from several localities in central and southern Asia, including Kazakhstan and western China.

Key words: Dasycladaceae algae, Mastopora, Cyclocrinites, palaeolatitude, Takche Formation, Parahio Valley, Spiti, India.

INTRODUCTION

The Caradocian (Ordovician)–Wenlock (Silurian) Takche Formation of the Spiti region, northwestern Himalaya, is a highly fossiliferous litho-unit which has yielded bryozoans, coral reefs, conodonts, algae, ostracods and trilobites (Hayden 1904; Reed 1912; Bhargava & Bassi 1986, 1998; Suttner 2003, 2007). One of the fossils, originally described from the Takche Formation as Pasceolus Billings (Reed 1912), was later described under other names. Reed (1912) described Pasceolus Billings (Pasceolus melliformis) and P. shianensis from the collection made by Hayden (1904) from the Ordovician–Silurian successions exposed in the Pin River section. Sahni (1953) and Maithy (1974) assigned it to the psilophytes and a lower group of plants, respectively. Kumar & Kashkari (1987) described similar fossils from the Pin and Parahio valley sections of the Takche Formation as a trace fossil Paleodictyon meneghini. Later, Kato et al. (1987) considered Pasceolus? shianensis (Reed 1912) to be the dasycladaceous alga Coelosphaeridium shianense (Reed). Our fresh collections of specimens from the Takche Formation, exposed along the Gechang section in the Parahio Valley, recorded Dasycladaceae algae cyclocrinitids, i.e. Mastopora sp. and Cyclocrinites sp.
Limestone, Thannam limestone, Unnamed quartzite transitional andUnnamed siliceous and flaggy limestone. Bhargava et al. (1984) and Bhargava & Bassi (1998) grouped the Thango and Takche formations in the Sanugba Group (Fig. 1B). Suttner (2007) proposed the term ‘Pin Formation’ for the Takche Formation of Srikanthia (1974, 1977, 1981) and Pin Limestone of Goel & Nair (1977); however, Bhargava (2008, 2011) contested the name Pin Formation and preferred Takche because of easy accessibility of the Takche type section, well-defined lithostratigraphy with the top and bottom and its mappability from Zanskar to Kinnaur. Srikanthia & Bhargava (2018) stated that the term ‘Pin Formation’ (Goel & Nair 1977; Suttner 2007) represents only a part of the Ordovician–Silurian siliciclastic carbonate sequence and is not either representative or mappable. Hence they rejected the term ‘Pin Formation’ and upheld the status of the Takche Formation. The terms ‘Takche Formation’ and ‘Pin Formation’ are widely used in the literature (Srikantia 1974, 1977, 1981; Goel & Nair 1977; Srikanthia et al. 1977; Sinha 1989; Bhargava & Bassi 1998; Negi 1998; Suttner et al. 2005, 2007; Vaidyanadhan & Ramakrisnan 2006; Suttner 2007; Suttner & Ernst 2007; Hubmann & Suttner 2008; Schallreuter et al. 2008; Chakrabarti 2016; Valdiya 2016; Raju 2017; Myrow et al. 2018; Roy & Purohit 2018; Shah 2018; Srikantia & Bhargava 2018). There is ongoing controversy on naming lithostratigraphic subdivisions of the lower Palaeozoic successions in the Himalaya (Srikantia & Bhargava 2018), but herein we prefer the term ‘Takche Formation’.

The Takche Formation (Upper Ordovician–lower Silurian) has gradational contact with the underlying Thango (Shian Quartzite) Formation (‘Early Ordovician) and is disconformably overlain by the ?Devonian Muth Quartzite (Bhargava & Bassi 1998; Draganits et al. 2001, 2002; Bhargava 2008, 2011).

The specimens of dasycladacean cyclocrinitid algae Mastopora and Cyclocrinites described herein were recovered from the Takche Formation exposed at the Gechang locality in the Parahio Valley (Fig. 1A). They occur abundantly in the lower part of the Takche Formation and particularly in the calcareous siltstone and sandstone units (Figs 2, 3).

GECHANG SECTION (PARAHIO VALLEY)

The Takche Formation is exposed along the Parahio River, but the exposure on the left bank of the Parahio River is more accessible near the Gechang village (Figs 1A, 2). The Gechang section (N 32°2′40.4″, E 077°59′31.11″) lies about 7 km WNW of the Sagnam and Ka Dogri villages on the left bank of the Parahio River in the Parahio Valley (Spiti). We measured ~226 m of the Takche Formation at the Gechang locality. It comprises fine to coarse sandstones, siltstones, argillaceous limestone, nodular limestone and fine to coarse crinoidal grainstone and marl (Fig. 3). The lower part (0–68 m) of the Takche Formation in the Gechang section consists of fine-grained sandstones and siltstones and to a lesser extent of shales. This interval contains ball and pillow structures, hummocky cross stratification, parallel and low-angle laminations, wavy and flaser bedding. The interval contains abundant trace fossils such as Skolithos, Cruziana, Cochlichmus, Monomorphychnus, Catenichnus, Thalassicnoides, Helminthodoichnites and Planolites. The dasycladacean algae Mastopora and Cyclocrinites are abundant through a 64.0 m interval. The first argillaceous limestone unit appears at ~70 m from the base of the section. The section from 70 to 185 m is dominated by argillaceous limestone, coralline and nodular limestone, and a subordinate calcareous sandstone–shale interval. This part of the Takche Formation contains abundant traces of Chondrites and Zoophycos, and brachiopod and cephalopod fauna. However, the top part (185–226 m) of the Takche Formation is dominated by the alteration of calcareous siltstone/sandstone with shale, grainstone and marl. The contact between the Takche Formation and the overlying Muth Quartzite is erosional in the Gechang section. Trace fossils Nerites, Helminthopsis, Cruziana, Lockeia, Cochlichmus, Arenicolites, Archaeonassa, Aulichnites, Phycolides and Planolites are found. Abundant Tentaculites and rugose corals have also been recorded from the argillaceous and crinoidal grainstone beds in the top part of the Takche Formation. Detailed sedimentological and chemostratigraphic analysis of the same section is presented by Myrow et al. (2018).

SYSTEMATIC DESCRIPTIONS

Order DASYCLADALES Pascher, 1931
Family CYCLOCRINACEA Maslov, 1956

Remarks. Nitecki (1970) regarded Mastopora as a synonym of Cyclocrinites (as are Nidulites Salter, Pasceolus Billings, Cerionites Meek & Worthen and Lunulites Owen), but due to the absence of ‘covering plates’ or ‘membrane’ and branching of laterals in Mastopora (Eichwald 1840; Maslov 1956; Korde 1963), we consider here Mastopora and Cyclocrinites as separate genera. These two genera also differ in the size of the thallus and in the degree of calcification (Maslov 1956; Korde 1963).
Fig. 1. Location and geological map of the Parahio Valley, Spiti, Himalaya, India. (A) detailed geological map of the Parahio Valley, Spiti, the inset showing the studied section near the village Gechang; (B) lithostratigraphic classification of the Ordovician–Silurian Sanugba Group in Spiti, Himalaya (after Bhargava & Bassi 1998; Srikantia & Bhargava 2018).

Fig. 2. Field photograph of the Gechang section in the Parahio Valley, Spiti, Himalaya.
Fig. 3. Lithology of the Takche Formation measured at the Gechang locality in the Parahio Valley, Spiti, Himalaya.
Genus *Mastopora* Eichwald, 1840

*Mastopora* sp.

**Figure 4**

*Description.* Our material contains partially preserved external and internal moulds of the non-globular, possibly bulb-like cortical skeleton. No trace of the original skeletal material was found. The external surface of the original skeleton is preserved by the dark, fine-grained mud which was moulded around it. The width of our partially preserved specimens is from 1.7 to 2.8 cm. The body is covered by relatively large polygonal, usually hexagonal cup-shaped facets. The exterior of each facet is moderately concave and marked off at the surface by sharp rims. The rims are 0.2 to 0.3 mm thick. The diameter of facets varies from 1.0 to 1.2 mm. The average

![Fig. 4. Dasycladaceae algae Mastopora sp. (A–F) from the Takche Formation, Gechang locality, Parahio Valley, Spiti, Himalaya. F, magnification of E. All scale bars = 1 cm.](image)
diameter of the facets is 1 mm. The facets are on average 0.2 mm deep.

Remarks. The described specimens resemble most closely *Mastopora concava* Eichwald 1860 (p. 84, fig. VI 7) by the size and shape of facets. However, the studied specimens are too fragmentarily preserved to be assigned to any *Mastopora* species with certainty.

Genus *Cyclocrinites* Eichwald, 1840
*Cyclocrinites* sp.

Figure 5

Description. Our material contains partially preserved external moulds of the globular cortical skeleton. The size and exact shape of the complete thallus are not known. No trace of the original skeletal material was

---

**Fig. 5.** Dasycladaceae algae *Cyclocrinites* sp. (A–E) from the Takche Formation, Gechang locality, Parahio Valley, Spiti, Himalaya. B, magnification of A; C, magnification of B; E, magnification of D. All scale bars = 1 cm.
Remarks. The described specimens resemble most closely *Cyclocrinites mickwitzi* Stolley 1896 (p. 49, fig. II 1–3) by the size and shape of facets. However, the studied specimens are too fragmentarily preserved and cannot be assigned to any *Cyclocrinites* species with certainty.

**SIGNIFICANCE OF CYCLOCRINITIDS IN THE TAKCHE FORMATION**

The cyclocrinitids (Middle Ordovician to early Silurian) are a small group of macrofossils and are usually regarded as an extinct tribe of dasycladacean algae (Beadle 1988). The tribe Cyclocriniteae was named by Pia (1920) and emended by Bassoullet et al. (1977). It includes *Cyclocrinites* Eichwald, *Mastopora* Eichwald, *Coelosphaeridium* Roemer and *Apidium* Stolley. Nitecki (1970) suggested that the cyclocrinitids are problematic algae related to receptaculitids.

The cyclocrinitids preserved in the Takche Formation have flattened thalli and show a high degree of compaction. The cyclocrinitids in the Ordovician are known from several localities in central and southern Asia including Kazakhstan (Gnilovskaya 1972) and western China (Mu 1982a, 1982b). The oldest cyclocrinitids have been reported from the lower part of the Middle Ordovician of California (Nitecki 1970) as *Cyclocrinites weller* Nitecki. They were most abundant and diverse during the Caradoc, became less common in the Ashgill and declined throughout the Llandovery (Beadle & Johnson 1986) becoming extinct by the end of the Llandovery (Silurian). The decline and end of these warm-water algae in the Ordovician may correlate with the end Ordovician cooling and glaciations (Beadle 1988). The cyclocrinitids occur in normal marine waters to highly saline restricted water settings (Johnson & Campbell 1980). The palaeogeographic reconstruction shows that most and perhaps all cyclocrinitids lived within 30° of the palaeoequator (Beadle & Johnson 1986; Beadle 1988). They probably lived on soft substrate by attaching themselves to small solid objects; living dasycladaceans are often found on soft bottoms attached to pebbles, shells and coral fragments. Cyclocrinitid thalli were relatively fragile and largely restricted to quiet-water environments, either below the wave base or in protected lagoons (Nitecki 1970; Beadle & Johnson 1986). The large accumulation of cyclocrinitids in the Takche Formation may be formed during a storm event which generated currents that penetrated into normally quiet water and swept thalli together (cf. Nitecki & Johnson 1978). The cyclocrinitids were most common at relatively shallow depths, below the wave base but within the photic zone. The comparison with living dasycladaceans suggests that they lived at a depth of less than 100 m (Beadle & Johnson 1986). The cyclocrinitids appear to be reliable indicators of low palaeolatitudes. The occurrence of abundant cyclocrinitid remains in the Takche Formation indicates that the Spiti region of the northwestern Himalaya must have been located in low palaeolatitudes. The cyclocrinitids were warm-water algae and their extinction at the end of the Ordovician is related to the cooling and glaciations (Beadle 1988). They inhabited seas in low latitudes within 30° of the palaeoequator (Beadle & Johnson 1986; Beadle 1988). Ordovician cyclocrinitids occur at several localities in central and southern Asia, including eastern Kazakhstan (Gnilovskaya 1972) and western China (Mu 1982a, 1982b).

**REFERENCES**

Bassoullet, J. P., Bernier, P., Deloffre, R., Genot, P., Jaddrezo, M., Poignant, A. F. & Segnozac, G. 1977. Classification criteria of fossil Dasycladales. In *Fossil Algae* (Flugel, E., ed.), pp. 154–166. Springer, Berlin.

Beadle, S. C. 1988. Dasyclads, cyclocrinitids, and receptaculitids: comparative morphology and paleoecology. *Lethaia*, 21, 1–12.

Beadle, S. C. & Johnson, M. E. 1986. Palaeoecology of Silurian cyclocrinitid algae. *Palaeontology*, 29, 585–601.

Acknowledgements. B. P. S. is grateful to the University Grant Commission (UGC) for financial support in the form of Startup Grant (No. F.20-1/2012(BSR)/20-8(12)/2012(BSR)). Financial support to O. V. was provided by the Estonian Research Council project IUT20-34. R. S. C. thanks the UGC for providing the financial grant as Junior Research Fellowship (2121220426, 23/12/2012(ii) EU-V). O. N. B. acknowledges financial support of the Indian National Science Academy. This paper is a contribution to IGCP 653 ‘The onset of the Great Ordovician Biodiversity Event’ and IGCP 668 ‘Equatorial Gondwanan history and early Paleozoic evolutionary dynamics’. We are grateful to journal reviewers Mark A. Wilson and Mikolaj Zapalski for the constructive comments on the manuscript. The publication costs of this article were partially covered by the Estonian Academy of Sciences.
Bhargava, O. N. 2008. An updated introduction to the Spiti geology. *Journal of the Palaeontological Society of India*, **53**, 113–129.

Bhargava, O. N. 2011. Early Paleozoic palaeogeography, basin configuration, paleoclimate and tectonics in the Indian Plate. *Memoirs of the Geological Survey of India*, **78**, 69–99.

Bhargava, O. N. & Bassi, U. K. 1986. Silurian reefal buildups, Spiti-Kinnaur, Himachal Himalaya, India. *Facies*, **15**, 35–52.

Bhargava, O. N. & Bassi, U. K. 1998. Geology of Spiti-Kinnaur, Himachal Himalaya. *Memoirs of the Geological Survey of India*, **124**, 1–188.

Bhargava, O. N., Bassi, U. K. & Chopra, S. 1984. Trace fossils from the Ordo-Silurian rocks of Kinnaur, Himachal Himalaya. *Journal of the Geological Society of India*, **25**, 175–186.

Chakrabarti, B. K. 2016. *Gondwanan coastal arthropod ichnofauna from the Muth Formation (Lower Devonian), Spiti Valley, Himachal Pradesh, India*. *Journal of the Palaeontological Society of India*, **32**, 47–52.

Maithy, P. K. 1974. Pre-Gondwanan land plants. In *Aspects and Appraisal of Indian Paleobotany* (Surange, K. R., Lakhanpal, R. N. & Bharadwaj, D. C., eds), pp. 47–51. Paleobotanical Society, Lucknow.

Maslov, V. P. 1956. Iskopaemye izvestkovye vodorosli SSSR [Fossil calcareous algae from USSR]. *Trudy Instituta Geologicheskikh Nauk, Akademiya Nauk SSSR*, **160**, 1–301 [in Russian].

Mu, X.-N. 1982a. Some calcareous algae from Xizang. In *Paleontology of Xizang* (Vol. 5), pp. 205–240. Science Press, Beijing [in Chinese, with English summary].

Mu, X.-N. 1982b. Discovery of Ordovician calcareous algae in Batang, Sichuan. In *Stratigraphy and Paleontology in West Sichuan and East Xizang, China*. Vol. 2, pp. 1–6. Sichuan People’s Press, Chengu [in Chinese, with English summary].

Myrow, P. M., Fike, D. A., Malmskog, E., Leslie, S. A., Zhang, T., Singh, B. P., Chaubey, R. S. & Prasad, S. K. 2018. Ordovician–Silurian boundary strata of the Indian Himalaya: record of the latest Ordovician Boda event. *Geological Society of America Bulletin*, https://doi.org/10.1130/B31860.1.

Negi, S. S. 1998. *Discovering the Himalaya, Vol. I*. Indus Publishing Company, New Delhi, 517 pp.

Nitecki, M. H. 1970. North American cyclocrinitid algae. *Fieldiana Geology*, **21**, 1–182.

Nitecki, M. H. & Johnson, M. E. 1978. Internal structures of *Cyclocrinites dactioloides*, a receptaculitid alga from the Lower Silurian of Iowa. *Fieldiana Geology*, **29**, 1–15.

Pascher, A. 1931. Systematische Übersicht über die mit Flagellaten in Zusammenhangstehenden Algenreihen und Versucheiner Einreihung di eser Algenstämme in die *Flagellaten* in Zusammenha ngstehenden Algenreihen. *Centralblatt für Beobachtungen in der Naturwissenschaft und Biologie*, **48**, 317–332.

Pia, J. von. 1920. Die Siphonoeavetticellatae vom Karbon bis zur Kreide. In *Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien*, **39**, 1–15.

Raju, D. S. N. 2017. Phanerozoic stratigraphy of India through charts and notes. *Bulletin ONGC*, K.D. Malviya Institute of Institute of Petroleum Exploration, Dehradun, **52**(3), 1–66; 5 Mega Charts, 52 Charts.

Reed, F. R. C. 1912. Ordovician and Silurian fossils from the central Himalayas. *Palaeontologica Indica, Ser.* ** XV**, **7**(2), 1–168.

Roy, A. B. & Purohit, R. 2018. *Indian Shield: Precambrian Evolution and Phanerozoic Reconstruction*. Elsevier, 398 pp.

Sahni, B. 1953. Note on possible psilophyte remains from Spiti, Northwest Himalaya. *Palaeobotany*, **2**, 1–3.

Schallreuter, R., Hinz-Schallreuter, I. & Suttner, T. 2008. New Ordovician ostracodes from Himalaya and their palaeobiological and palaeoecological implications: *Revue de Micropaléontologie*, **51**, 191–204.
Shah, S. K. 2018. *Historical Geology of India*. Scientific Publishers, New Delhi, 159 pp.
Sinha, A. K. 1989. *Geology of the Higher Central Himalaya*. John Wiley and Sons, U. K., 219 pp.
Srikantia, S. V. 1977. *Geological Survey of India*. Bishen Singh Mahendra Singh Dehra Dun.

Ravi S. Chaubey, Olev Vinn, Birendra P. Singh, Om N. Bhargava, Subhay K. Prasad ja Naval Kishore

**Soojaveelised Dasycladaceae vetikad India Parahio oru Hilis-Ordoviitsiumis**

Soojaveeliste Dasycladaceae vetikate *Mastopora* ja *Cyclocrinites*’e kivistisi leiti esmakordselt Takche Kihistust (Ülem-Ordoviitsium kuni Alam-Silur) Parahio orust Spitis Indias. Vetikad on säilinud väliste ja sisemiste valatistena ning nende ümar skelett on tugevasti kokkupressitud. Arvukad tsüklokriniitide kivistis Takche Kihistus näitavad, et Spiti piirkond Himalaajas asus Hilis-Ordoviitsiumis ja Vara-Siluris 30° paleolaiuskraadil. Tsüklokriniidid olid soojaveelised vetikad ja nende kadumine Ordoviitsiumi lõpul oli seotud kliima jahenemise ning jääajaga. Tsüklokriniite on leitud Kesk- ja Lõuna-Aasia, Kasahstani ning Lääne-Hiina Ordoviitsiumist.