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

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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*? s*hianenesis* (Reed 1912) to be the dasycladacean 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.

GEOLOGICAL SETTING AND LITHOSTRATIGRAPHY

Rocks of Neoproterozoic to Early Cretaceous age are exposed in the Spiti region in the state of Himachal Pradesh (India) (Hayden 1904; Bhargava & Bassi 1998). In the northwest direction these strata extend further to the Baralacha La (Lahaul Valley) and to the Zanskar Valley (Jammu and Kashmir), to the southeast they are known from the Kinnaur and Kumaun regions (Bhargava & Bassi 1998). In the Spiti region the lower Palaeozoic successions are exposed in the Pin and Parahio valleys in the southeastern part of Spiti (Fig. 1A).

The lower Palaeozoic succession of the Spiti region has been known since the late nineteenth century when F. Stoliczka and C. L. Griesbach visited the area (Stoliczka 1866; Griesbach 1891). Later on, Hayden (1904) provided the first detailed descriptions of the Palaeozoic–Mesozoic succession. Reed (1912) provided the palaeontological record of the Hayden (1904) collection. Srikantia (1977, 1981) and Srikantia et al. (1977) proposed the term 'Takche Formation' for the succession above the Thango Formation (Early–Middle Ordovician) and below the Muth Quartzite (Devonian). Goel & Nair (1977) classified the Ordovician–Silurian succession in the Spiti region as Shian Quartzite, Pin

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Limestone, Thannam limestone, Unnamed quartzite transitional and Unnamed 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 Srikantia (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. Srikantia & 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 neither representative nor 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; Srikantia 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).

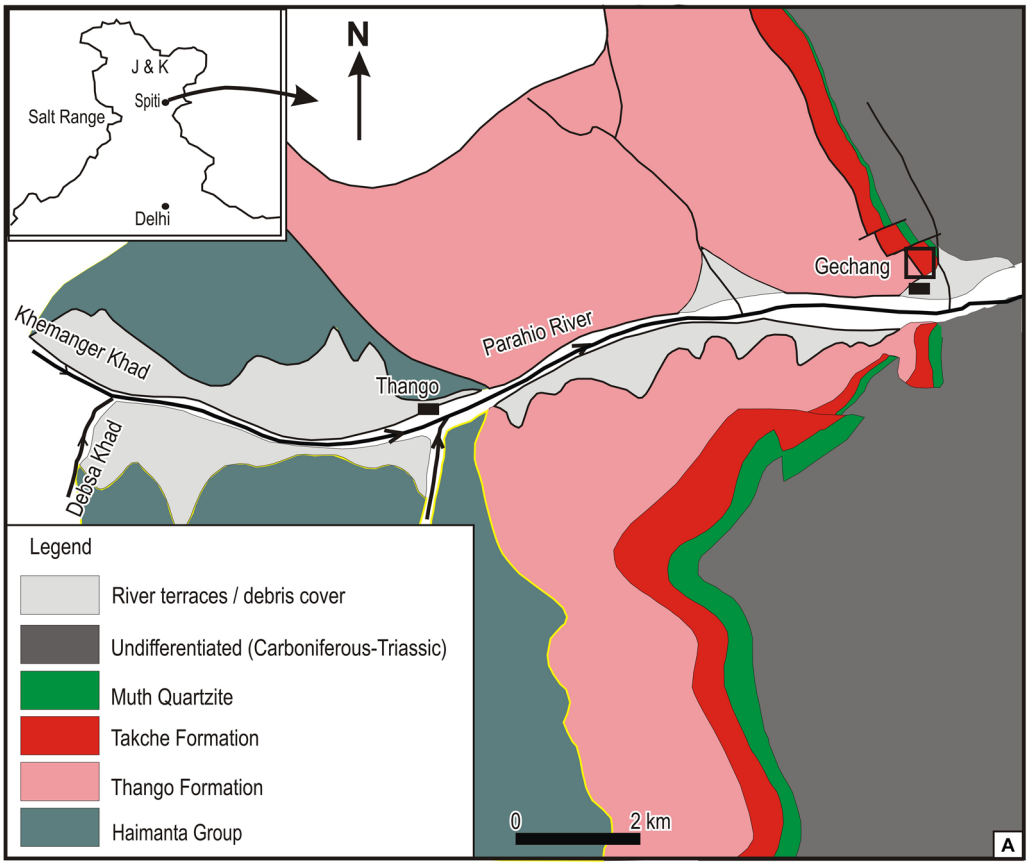
GECHANG SECTION (PARAHIO VALLEY)

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*, *Cochlichnus*, *Monomorphichnus*, *Catenichnus*, *Thalassinoides*, *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 *Nereites*, *Helminthopsis*, *Cruziana*, *Lockeia*, *Cochlichnus*, *Arenicolites*, *Archaeonassa*, *Aulichnites*, *Phycodes* 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).



Groups	Formations	Lithology	Broad age
Kanawar	Muth Quartzite	Sandstone/Quartzite	Early Devonian
Disconformity			
Sanugba	Takche	Limestone, Sandstone, Shale	Late Ordovician-early Silurian
	Thango	Conglomerate	?Early-Middle Ordovician
Angular unconformity			
Haimanta	Kunzam La Batal	Sandstone, Shale, Limestone	Early-Middle Cambrian

B

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.

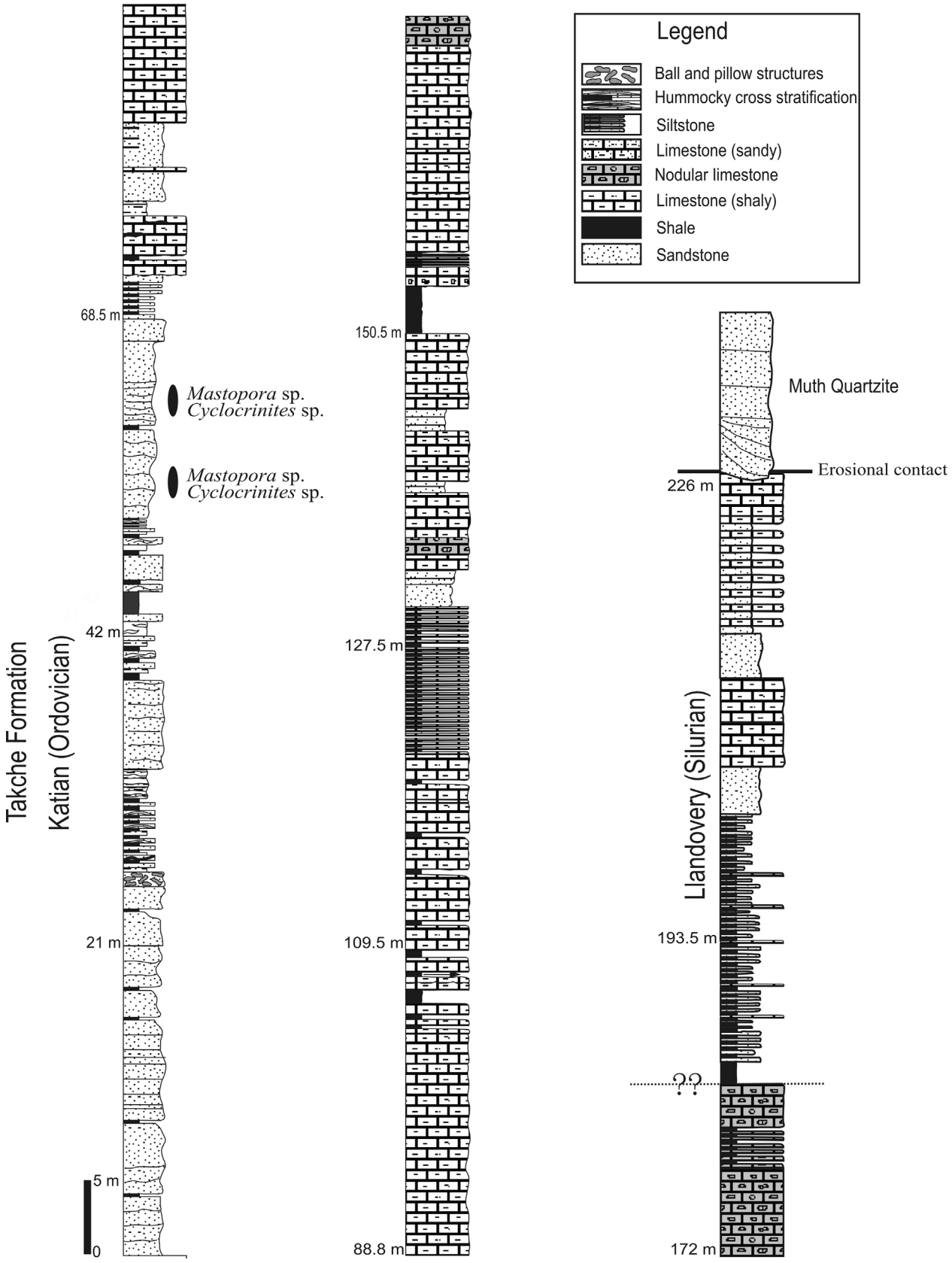


Fig. 3. Lithology of the Takche Formation measured at the Gechang locality in the Parahio Valley, Spiti, Himalaya.

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

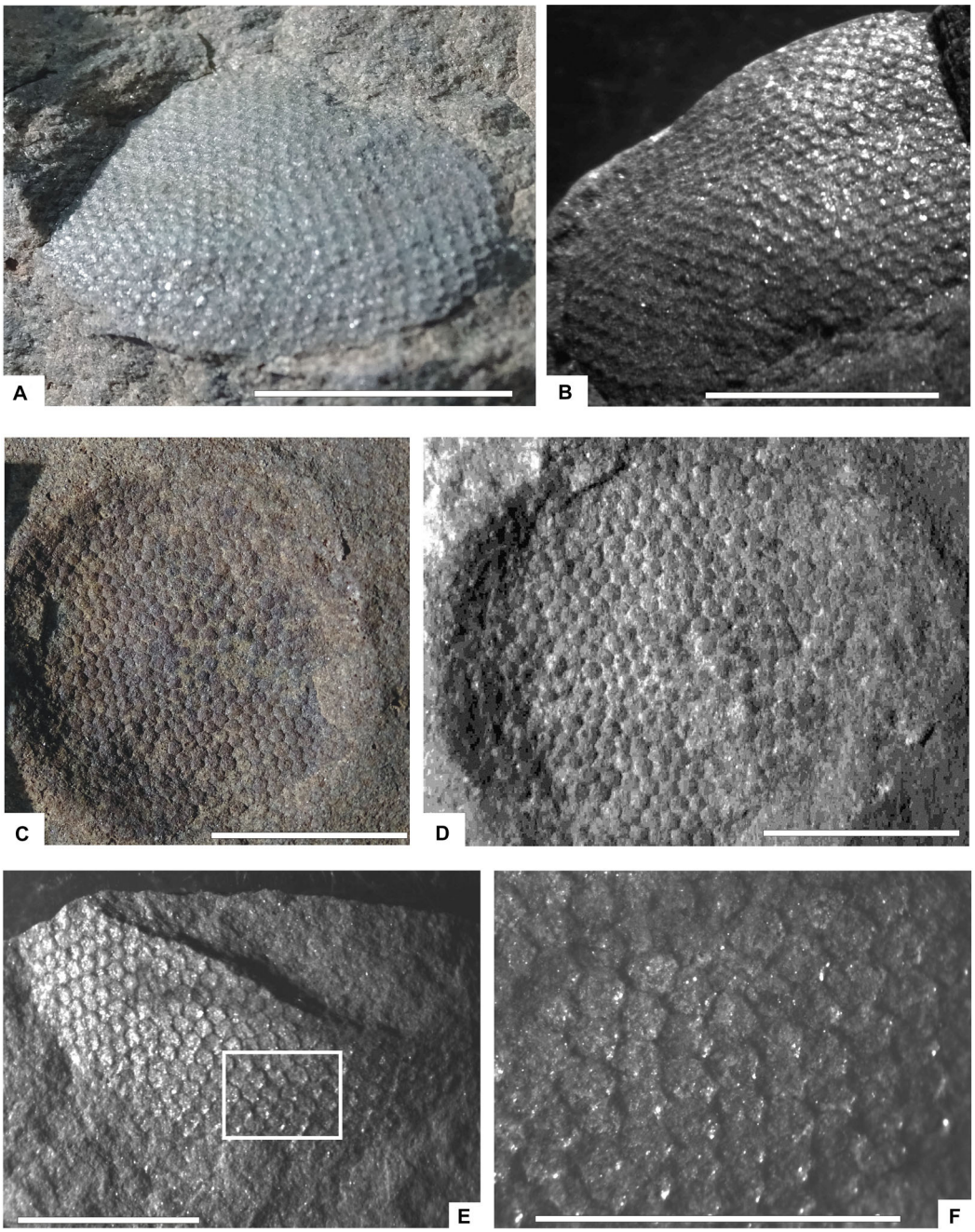


Fig. 4. Dasycladaceae algae *Mastopora* sp. (**A**–**F**) from the Takche Formation, Gechang locality, Parahio Valley, Spiti, Himalaya. F, magnification of E. All scale bars = 1 cm.

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

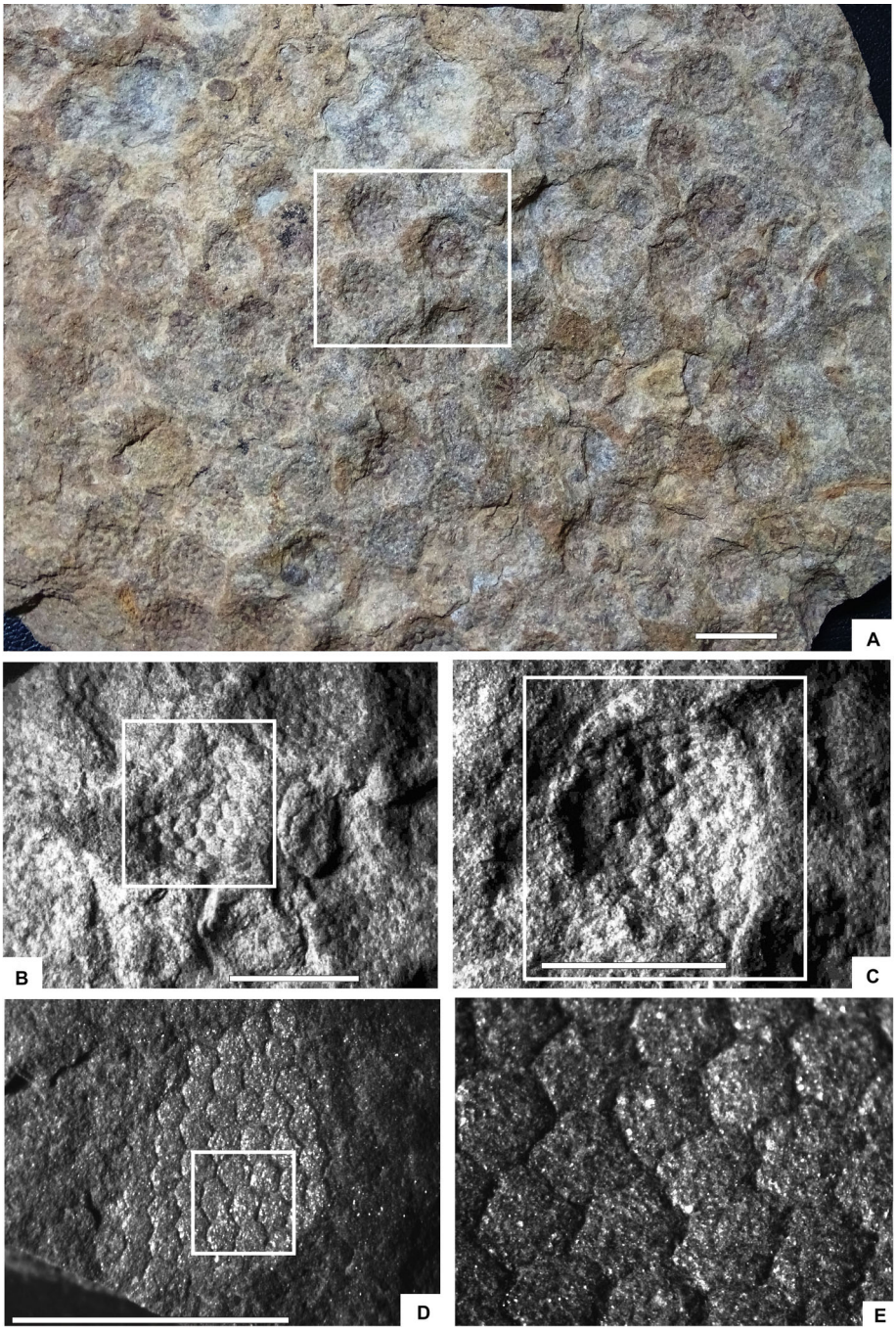


Fig. 5. Dasycladaceae algae *Cyclocrinites* sp. (**A**–**E**) from the Takche Formation, Gechang locality, Parahio Valley, Spiti, Himalaya. B, magnification of A; C, magnification of B; E, magnification of D. All scale bars = 1 cm.

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 specimens is from 0.9 to 1.1 cm. The body is covered by small polygonal cup-shaped facets having four to six sides. The exterior of each facet is deeply concave. The facets are surrounded at the surface by well-developed rims which are 0.05 to 0.1 mm thick. The diameter of facets varies from 1.1 to 1.2 mm, with the average diameter being 1.1 mm. The facets are about 0.2 mm deep.

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 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 the cooling and glaciations (Beadle 1988). They inhabited seas in low latitudes within 30º 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).

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Soojaveelised Dasycladaceae vetikad India Parahio oru Hilis-Ordoviitsiumis

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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 kivistised Takche Kihistus näitavad, et Spiti piirkond Himaalajas asus Hilis-Orodiviitsiumis 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.