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Sedimentary facies, ichnofossils and storm deposits in the Lower Permian Taiyuan Formation, Jiaozuo city, Henan Province, central China

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ABSTRACT:

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Five sedimentary facies – neritic carbonate platform, lagoon, tidal flat, swamp and barrier island facies – are recorded in the Lower Permian Taiyuan Formation along with abundant ichnofossils. Common ichnofossils in this formation include *Zoophycos villae, Zoophycos brianteus, Nereites* cf. *missouriensis*, *Chondrites* isp., *Gordia marina, Taenidium* isp., *Thalassinoides* isp., *Palaeophycus* isp., *Planolites* isp. and a kind of bifurcation trail. From observations of the morphology of *Zoophycos* spreiten in approximately vertical sections, at least three kinds of spreite laminae are distinguished: ligular, crescentic and rectangular forms. Four types of storm deposits (coded as A, B, C, D) are recognised in the carbonates of the Taiyuan Formation and can be explained forming in shallow marine environments, which are distributed in order from near storm wave base to near fair weather wave base respectively.

Key words: Lower Permian; Ichnofossils; Storm deposits; Taiyuan Formation; Carbonates; Shallow marine environments.

INTRODUCTION

The carbonates of the Lower Permian Taiyuan Formation are well exposed in the northern part of Jiaozuo city, which is located at the southern foot of the Taihang Mountain (with a summit of 1100 m) in northwestern Henan Province. The studied outcrop section is located near Liu village, about 15 km from Jiaozuo city, on the southeast border to the North China plain (with an altitude of up to 200 m) (Text-fig. 1).

In the Jiaozuo area, the Taiyuan Formation has conformable contacts with both the underlying Upper Carboniferous Benxi Formation (C_{2b}) and the overlying Middle Permian Shanxi Formation (P_{2sh}). The Benxi Formation, 30–40 m in thickness, mainly consists of red hematite ores, pale grey to white bauxite and bauxitic claystone, light-grey, thin- bedded, fine sandstone and siltstone, in which the hematite and bauxite ore beds are laterally impersistent and commonly lenticular. The Shanxi Formation, about 60 m thick, consists of a set of coal-bearing deltaic sedimentary systems made up of sandstones, mudstones, silty mudstones and coal seams.

The Taiyuan Formation (P_{1t}), 70–90 m thick, which is widely distributed and laterally persistent in the Jiaozuo area, is composed of limestones intercalated with nodular, flaggy or banded flints, claystones, siltstones, sandstones and thin coals, and this unit generally contains nine layers of limestone (from bottom to top, coded L1, L2, ... L9) commonly with abundant

ichnofossils. The calcareous tempestites mainly occur in L3, L4 and L5 (Text-fig. 2).

In addition, body fossils are also very abundant, such as fusulinids (*Quasifusulina, Schwagerina, Sphaeroschwagerina*), brachiopods (*Dictyoclostus, Choristites, Chonetes*) and both rugosan and tabulate corals (*Caninia, Lophophyllum, Syringopora*) among others.

According to its lithologic and sedimentologic characteristics, the Taiyuan Formation in the study area can be divided into three units (Text-fig. 2).

(1) The **lower limestone unit (A)** is marked by shore and shallow marine deposits, containing five limestone layers (from L1 to L5) intercalated with thin bedded sandstone, siltstone, sandy mudstone and coal seams. The total thickness of carbonates in this unit is greater than that of clastic interlayers.

(2) The **middle clastic unit (B)** is dominated by deposits of a lagoon and barrier system, between top of L5 and bottom of L7. It consists of medium- to fine-grained sandstone, siltstone and mudstone, intercalated with a bed of limestone (L6). The aggregate thickness of carbonate in this unit is less than that of the clastic rocks.

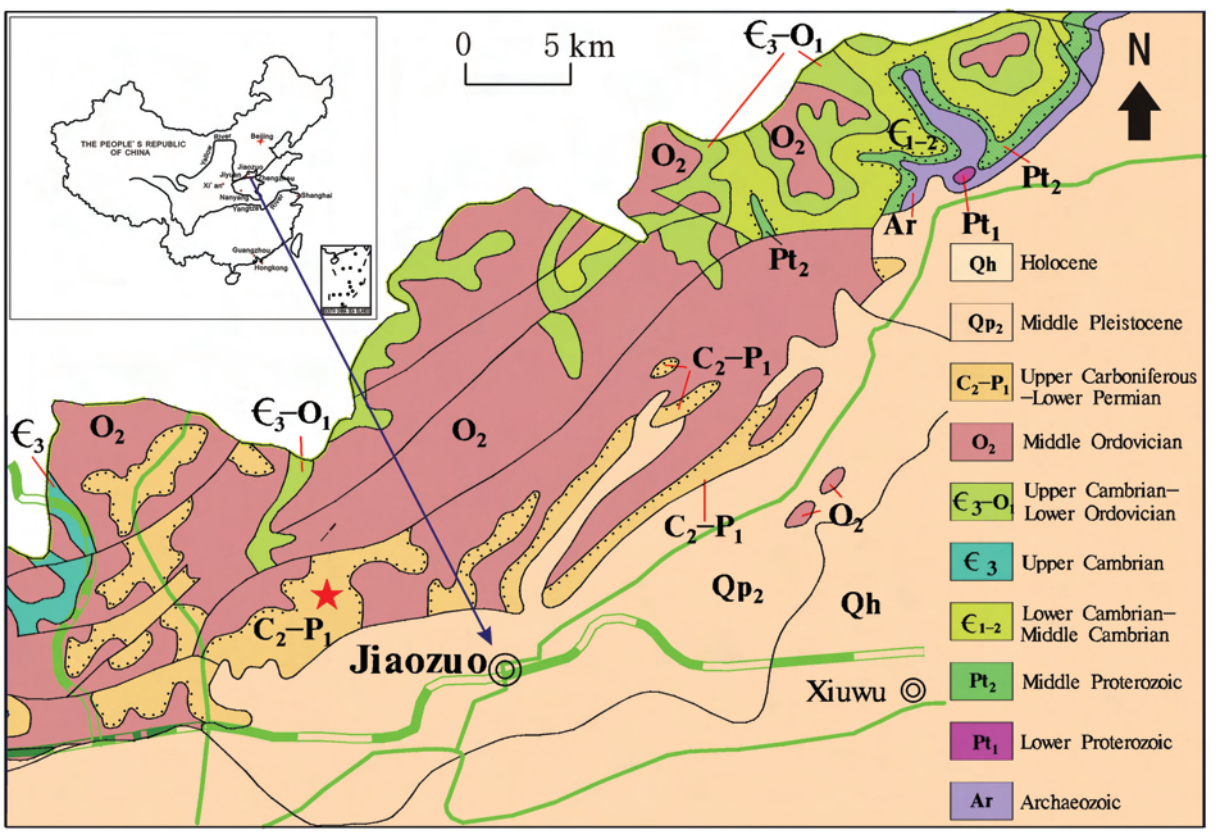
(3) The **upper limestone unit (C)** is made up of shallow marine and shore deposits and is composed of three limestone layers (L7, L8 and L9) intercalated with thin bedded sandstone, siltstone, and siliceous mudstone. The carbonate thickness of this unit is much greater than that of the clastic rock.

SEDIMENTARY FACIES AND ICHNOFOSSILS

In the Jiaozuo area, the Taiyuan Formation is mainly composed of carbonate, clastic and coal strata deposited in such sedimentary settings as carbonate platform, barrier-lagoon, tidal flat, shore swamp and barrier islands (sandy shoal and bar). Based on analysis of sedimentary characteristics, it can be divided into the following five types of sedimentary facies:

Neritic carbonate platform facies

This facies is marked by grey to dark grey, medium-bedded limestone with bioclastic and micritic limestone with abundant body fossils including corals, crinoids, brachiopods, algae and bryozoans, as well as abundant ichnofossils, such as *Nereites* cf. *missouriensis* (Pl. 1, Fig. 1a), *Chondrites* isp. (Pl. 1, Fig. 1b), *Thalassinoides* isp. (Pl. 1, Fig. 2), *Gordia marina* (Pl. 1, Fig. 4), *Taeni-*



Text-fig.1. Geological map of Jiaozuo area, northwest Henan, with star showing location of the outcrop section of the Taiyuan Formation

dium isp., *Palaeophycus* isp., *Planolites* isp., *Zoophycos villae* (Pl. 2, Fig. 7), *Zoophycos brianteus* (Pl. 3, Fig. 4) and a kind of bifurcation trail (Pl.1, Fig. 3). With the exception of the bifurcation trail and *Gordia* preserved as epichnia, most ichnofossils are preserved as endichnia. In particular, *Zoophycos* is pervasive in every marly limestone, and can be clearly divided into three types of *Zoophycos* with ligular (Pl. 2, Figs 1–6), crescentic (Pl. 3, Figs 1–3) and rectangular (Pl. 4, Figs. 1–5) spreite structures according to the morphology of their laminae in approximately vertical sections. *Zoophycos* and commonly associated ichnofossils have been widely recorded in diverse carbonates (limestones) and their morphology, occurrence, ethology, ichnofabric, palaeoecology, palaeoenvironments and ichnotaxonomy have been discussed by many workers (e.g., Ellenor 1970; Bromley and Ekdale 1984; Ekdale and Lewis 1991; Miller 1991; Olivero and Gaillard 1996; Hu and Qi 2000; Olivero 2003; Knaust 2004).

Lagoon facies

The sediments of this facies are dominated by grey to greyish black mudstone to silty mudstone, intercalated with thin bedded siltstone and fine sandstone. In mudstone, horizontal bedding and gently wavy bedding are developed. Siderite concretions and pyrite particles are commonly distributed along the bedding planes. Animal body fossils are characteristic of brackish water, but intact plant fossils are rare, though plant debris are common. *Chondrites* and *Nereites* are common in some dark grey marly limestone beds and sparse in the mudstone. In sum, the lithologic and palaeontologic features indicate suboxic, brackish sedimentary environments.

Tidal flat facies

This facies is characterized by frequently interbedded thin mudstone, siltstone and fine sandstone, in which flaser bedding, lenticular bedding and fine, wedge-like cross bedding are developed, with vertical and inclined burrows, abundant bioturbation structures and plant remains. Generally, the tidal flat facies is associated with lagoon and swamp facies.

Swamp facies

Typical sediments of the coastal swamp facies are the greyish black mudstone, carbonaceous shale, siltstones and coal beds, commonly associated with tidal flat, lagoon, coastal bar deposits. Horizontal bedding, gently wavy bedding and plant fossils are common in the mudstones and siltstones.

Barrier island facies

Barrier deposits in this study area**,** also including sandy shoal and bar deposits, mainly consist of grey, fine quartzose sandstone and detrital quartzose sandstone with wedge-shaped, wavy, tabular cross bedding, regularly associated with tidal flat and lagoon deposits.

To summarize the analysis of Early Permian sedimentary evolution in the Jiaozuo area, the lower and upper units of the Taiyuan Formation are characterized by neritic carbonate platform facies intercalated with shore swamp mudstone and coal beds, and the middle unit is marked by barrier island, lagoon and tidal flat facies containing thin coal layers. Thus, from bottom to top, this sequence reflects a complete cyclic deposition of transgression—regression—transgression (Text-fig. 2).

STORM DEPOSITS

Storm deposits or tempestites have been recorded in the shallow marine carbonates of the Taiyuan Formation in the Jiaozuo area (Wu *et al*. 1987). The thickness of an individual bed is generally 10–30 cm, in some cases up to 50 cm. A typical stratification sequence within a single storm event deposit includes four units from bottom to top (Text-fig. 3):

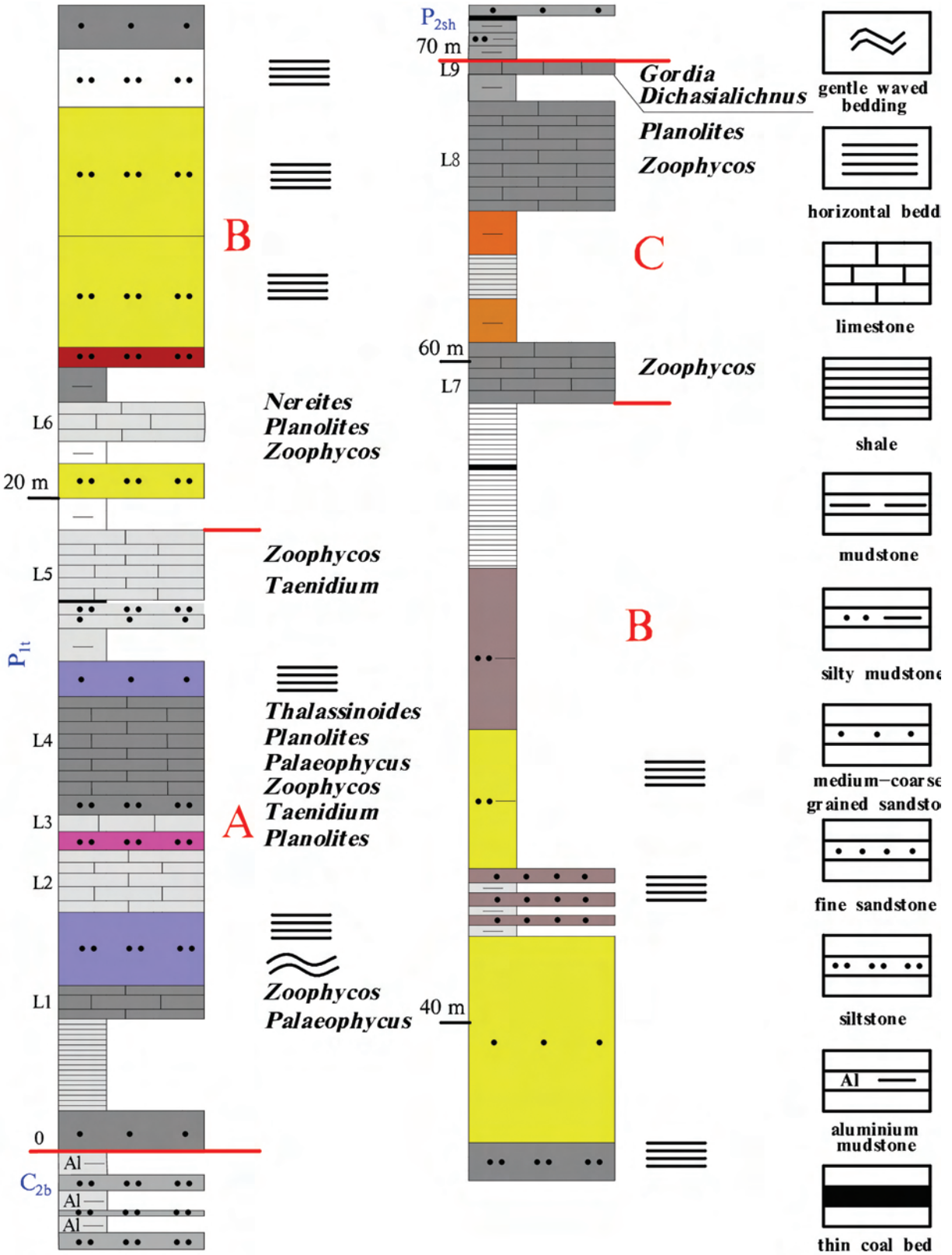
(1) Erosional base, truncated or undulating atop the underlying sediments, induced by storm wave and turbulence and showing irregular variations. The wavelength of the undulatory sole is about 16–40 cm with an amplitude of 2–9 cm. Gutter cast-like structures occur on some soles.

(2) Basal bioclastic lag with normally graded limestone. The lag deposits are mainly composed of bioclastics including brachiopods, corals, crinoids, fusulinids and other fossils.

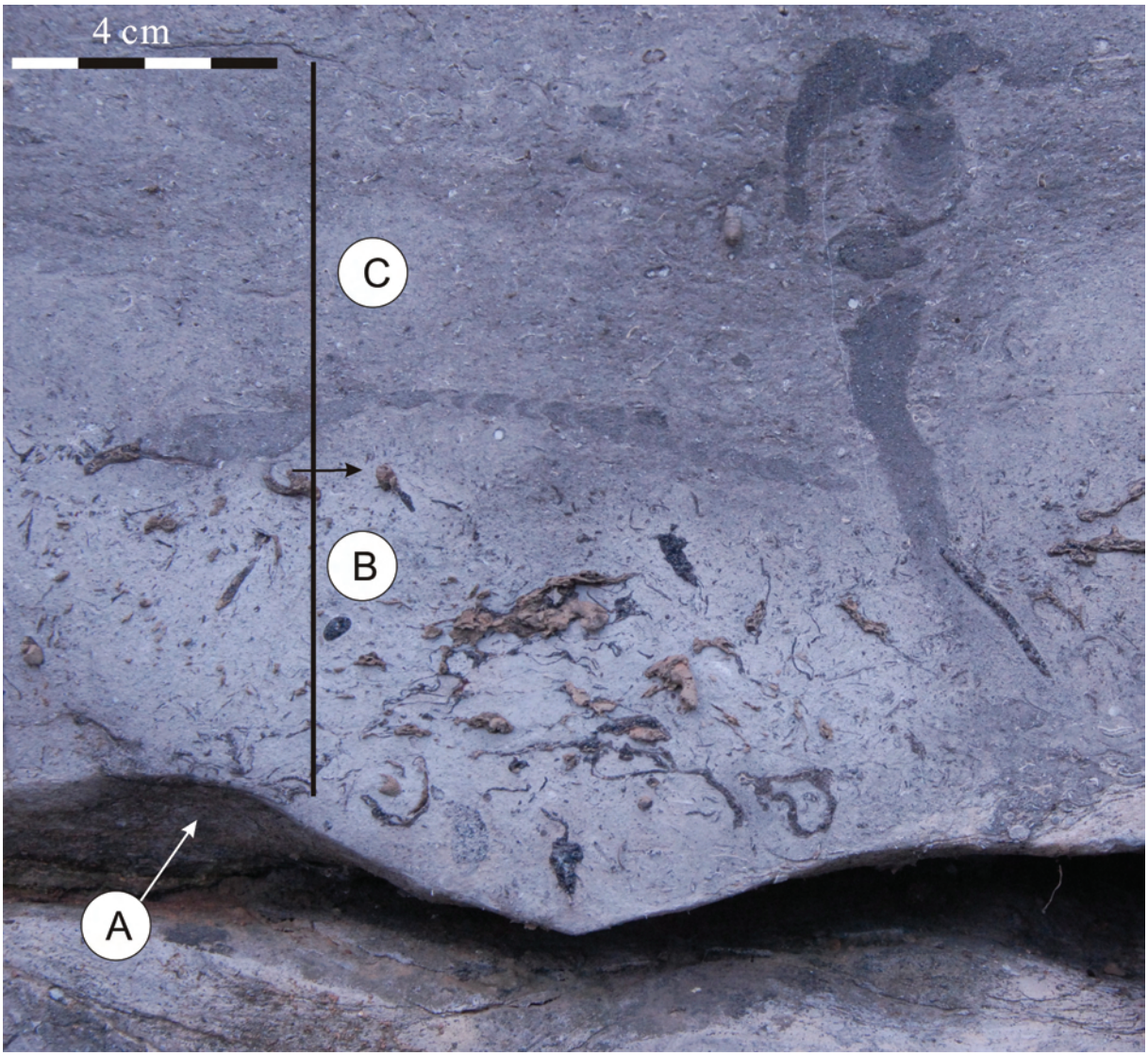
(3) Laminated unit. One or two kinds of characteristic storm sedimentary structures such as nearly parallel and low-angle lamination, irregular wave cross-lamination or hummocky cross-bedding are displayed in the vertical sections in each bed, but strictly speaking, these laminations are irregular and diverse in different depositional types.

(4) Wackestone or mudstone with trace fossils. This usually constitutes the top unit of an individual storm deposit bed. *Zoophycos* is the typical ichnofossil in this unit and commonly associated with *Planolites, Palaeophycus* and *Taenidium,* in some cases with *Rhizocorallium*.

Generally, the stratification sequence of the tempestites in the Taiyuan Formation consists of three parts as lower graded bed, middle laminated bed and upper



Text-fig. 2. Section of the Taiyuan Formation with distribution of trace fossils. A – Lower limestone unit; B – Middle clastic rock unit; C – Upper limestone unit



Text-fig. 3. Photograph showing the longitudinal sedimentary succession of storm deposit in the limestone (L5) of the Taiyuan Formation, Jiaozuo area
A – Wavy erosional base; B – Basal bioclastic lag and laminated unit; C – Wackestone unit with trace fossils

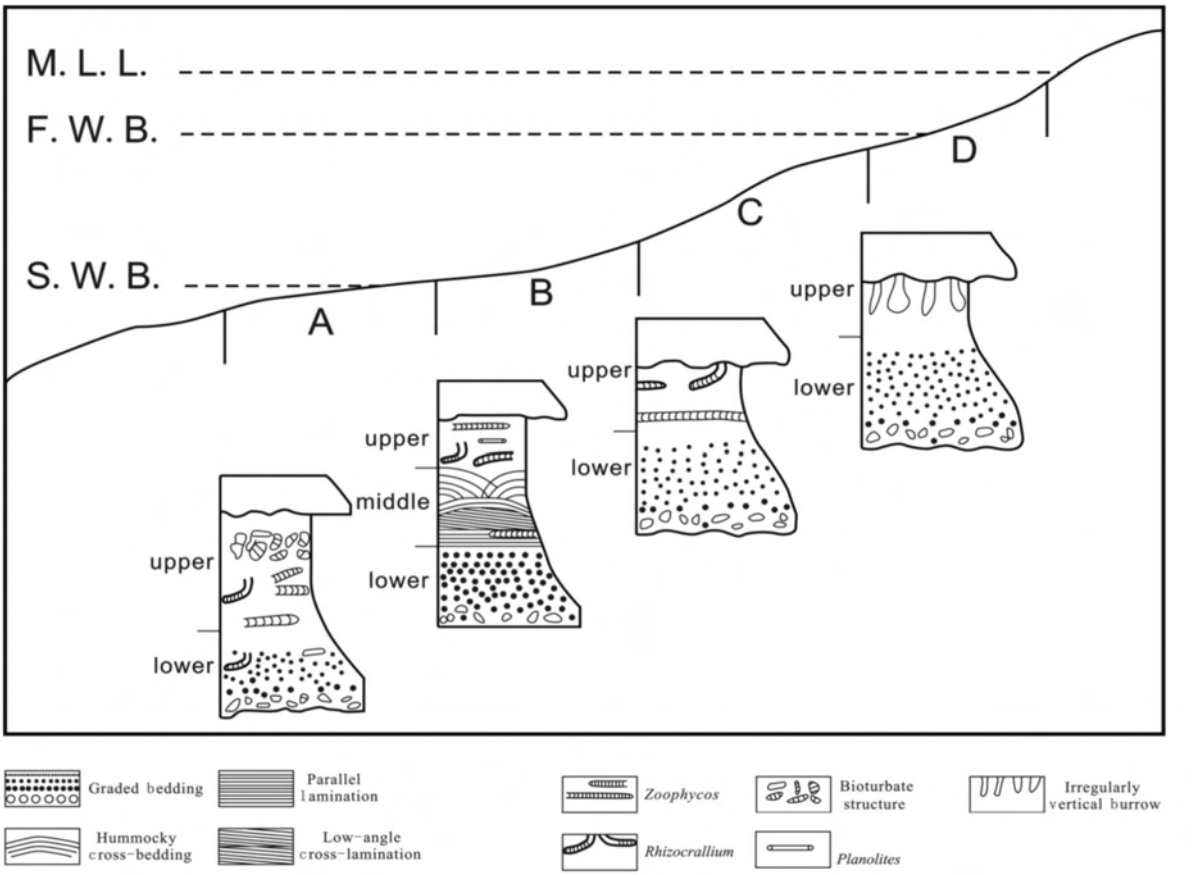
marl bed (wackestone) with ichnofossils (Text-fig. 3). This sedimentary succession is similar to those described by Aigner (1982) from Upper Muschelkalk (Middle Triassic) limestones in Germany. However, the characteristics of the laminated unit in the Jiaozuo area may be different. In particular, the typical hummocky cross-stratification (Duke 1985; Frey 1990) has been not found.

Based on the sequence features, sedimentary structures and biogenic structures, four depositional types of tempestites can be distinguished in the Taiyuan Formation (Text-fig. 4).

In Type A, the lower subunit consists of a basal lag and limestone with graded bedding whose thickness is usually 2–6 cm, the upper subunit is mainly composed of wackestone (about 22 cm thick) with intensive bioturbation (commonly 6–10 cm thick). This type of tempestite lacks of lamination and was probably generated near storm wave base (Text-figs 4A, 5).

Type B is tripartite, including a lower subunit (3–8 cm thick) recognized by its basal lag and graded limestone, a middle subunit (2–25 cm thick) with irregular cross-bedding or nearly parallel lamination and an upper subunit (about 12 cm thick) characterized by wackestone or mudstone and moderate bioturbation as well as abundant *Zoophycos* and other trace fossils. Type B sequences were presumably formed in the middle to lower part between fair weather wave base and storm wave base (Text-figs 3, 4B).

Type C is made up of a lower subunit (about 5 cm thick) with basal lag and normal graded limestone and



Text-fig. 4. The four types of storm deposits generated in the limestones of the Taiyuan Formation in their environmental context. M.L.L. – Mean low tide level; F.W.B. – Fair weather wave base; S.W.B. – Storm Wave base

Text-fig. 5. Photograph showing the longitudinal sedimentary succession of storm deposit Type A in the Taiyuan Formation (L5), Jiaozuo area. A – Wavy erosional base; B – Basal bioclastic lag; C – Wackestone unit with intensive bioturbation

Text-fig. 6. Photograph showing the longitudinal sedimentary succession of storm deposit Type C in the Taiyuan Formation (L5), Jiaozuo area. A – Wavy erosional base; B – Basal bioclastic lag; C – Wackestone unit with few trace fossils

an upper subunit of wackestone with few trace fossils, but lacking of both the laminated and bioturbated zones. The sedimentary water depth at which Type C was generated appears to be progressively shallowing and might be located in the middle to upper part between fair weather wave base and storm wave base (Text-figs 4C, 6).

Finally, Type D (about 25 cm thick) only includes a lower deposit with normally graded lag and an upper wackestone. Trace fossils are rare or even absent, reflecting further shallowing of the water probably close to the fair weather wave base (Text-fig. 4D). Therefore, the traces made by living animals might be easily destroyed by waves or currents in this sedimentary setting.

CONCLUSION

The observations made on the Lower Permian Taiyuan Formation in the northern part of Jiaozuo city (including previous works, Wu and Hu *et al*. 1987; Hu and Qi 2000) confirm that the neritic carbonate platform, lagoon, tidal flat, swamp and barrier island facies are recorded and abundant *Zoophycos* occurred in the carbonates of shallow marine environments. Observation of the morphology of *Zoophycos* spreiten in vertical and oblique sections shows at least three kinds of spreite laminae, here termed ligular, crescentic and rectangular forms. Other trace fossils associated with *Zoophycos* together are *Nereites, Chondrites, Gordia, Taenidium, Thalassinoides, Palaeophycus* and *Planolites,* in some cases with *Rhizocorallium*.

Four depositional types of tempestites are recognized within the carbonates of the Taiyuan Formation, distributed in depositional environments from near storm wave base to near the fair weather wave base.

Acknowledgments

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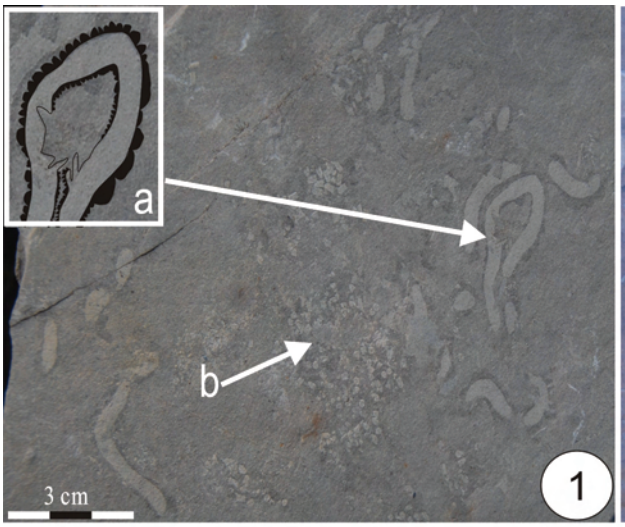
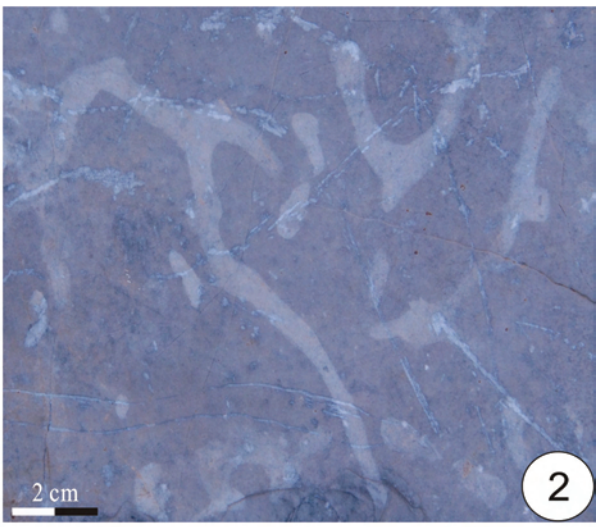
PLATES 1–4

PLATE 1

Ichnofossils preserved in the Taiyuan Formation, Jiaozuo area

1 – *Nereites* cf. *missouriensis* (a) with *Chondrites* isp. (b) from the L6 limestone
2 – *Thalassinoides* isp. from the L4 limestone
3 – A bifurcation trail atop the L9 limestone
4 – *Gordia marina* atop the L9 limestone


a
b
3 cm
1


2 cm
2


4 cm
3

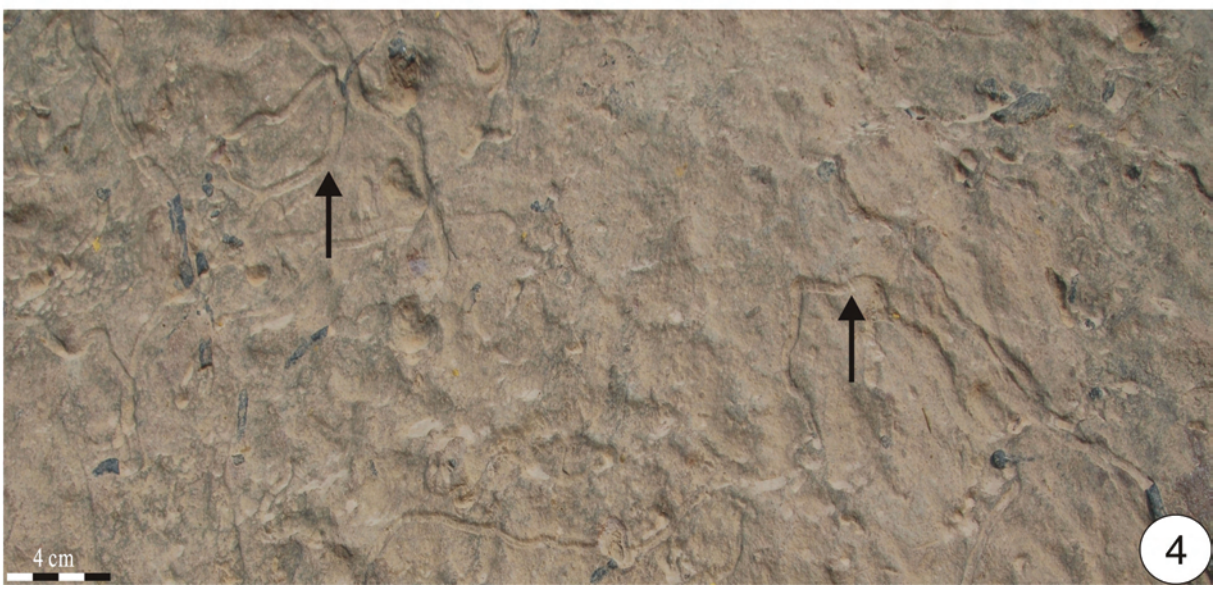
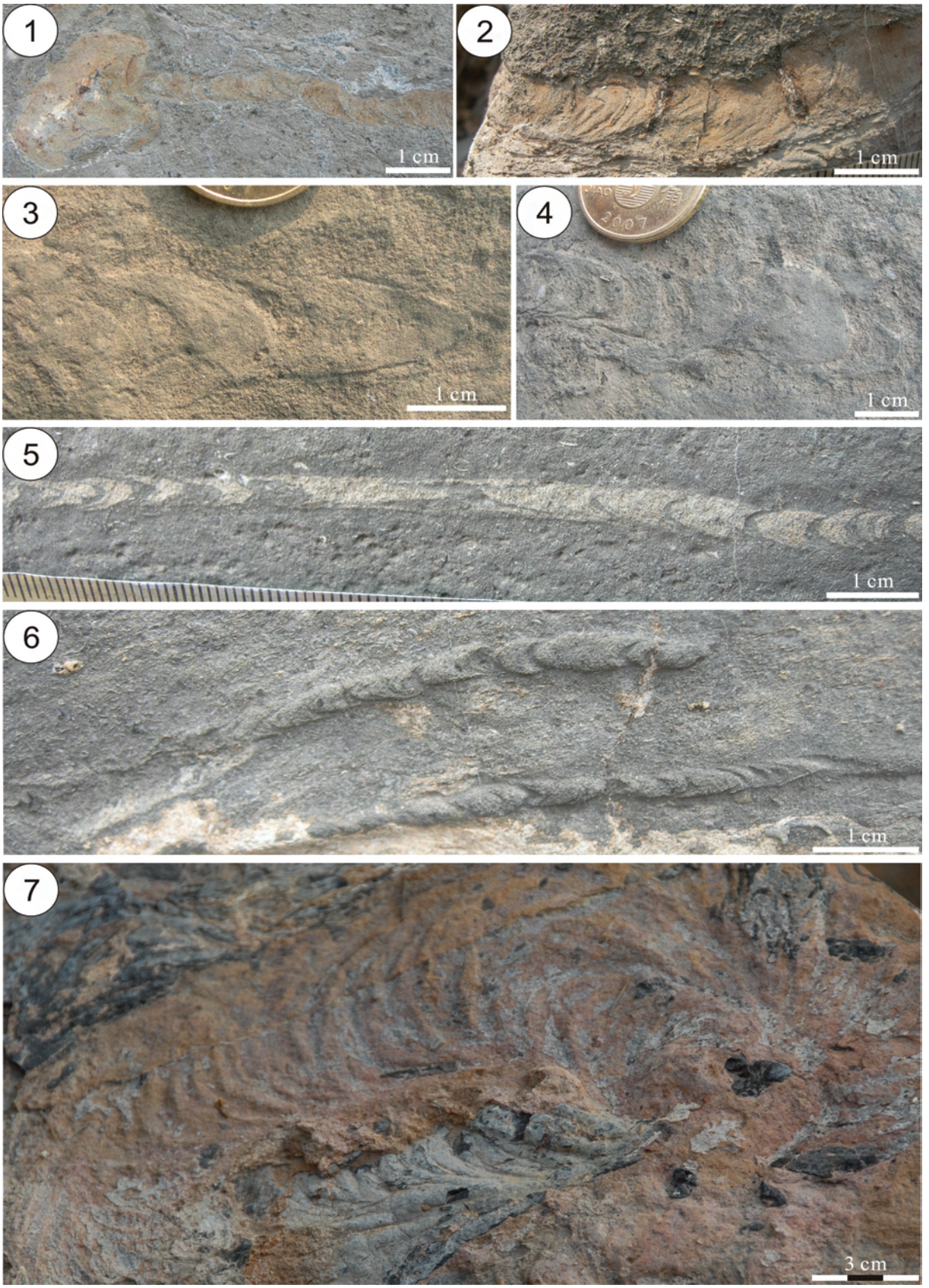

4 cm
4

PLATE 2

1-6 – Vertical section of *Zoophycos* with ligular lamellae preserved in the limestones from the Taiyuan Formation, Jiaozuo area. Figs 1–3. *Zoophycos* from the L6 limestone; Figs 4–6. *Zoophycos* from the L5 limestone

7 – *Zoophycos villae* Massalongo, 1855 in the L7 limestone, common distribution along the bedding planes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4
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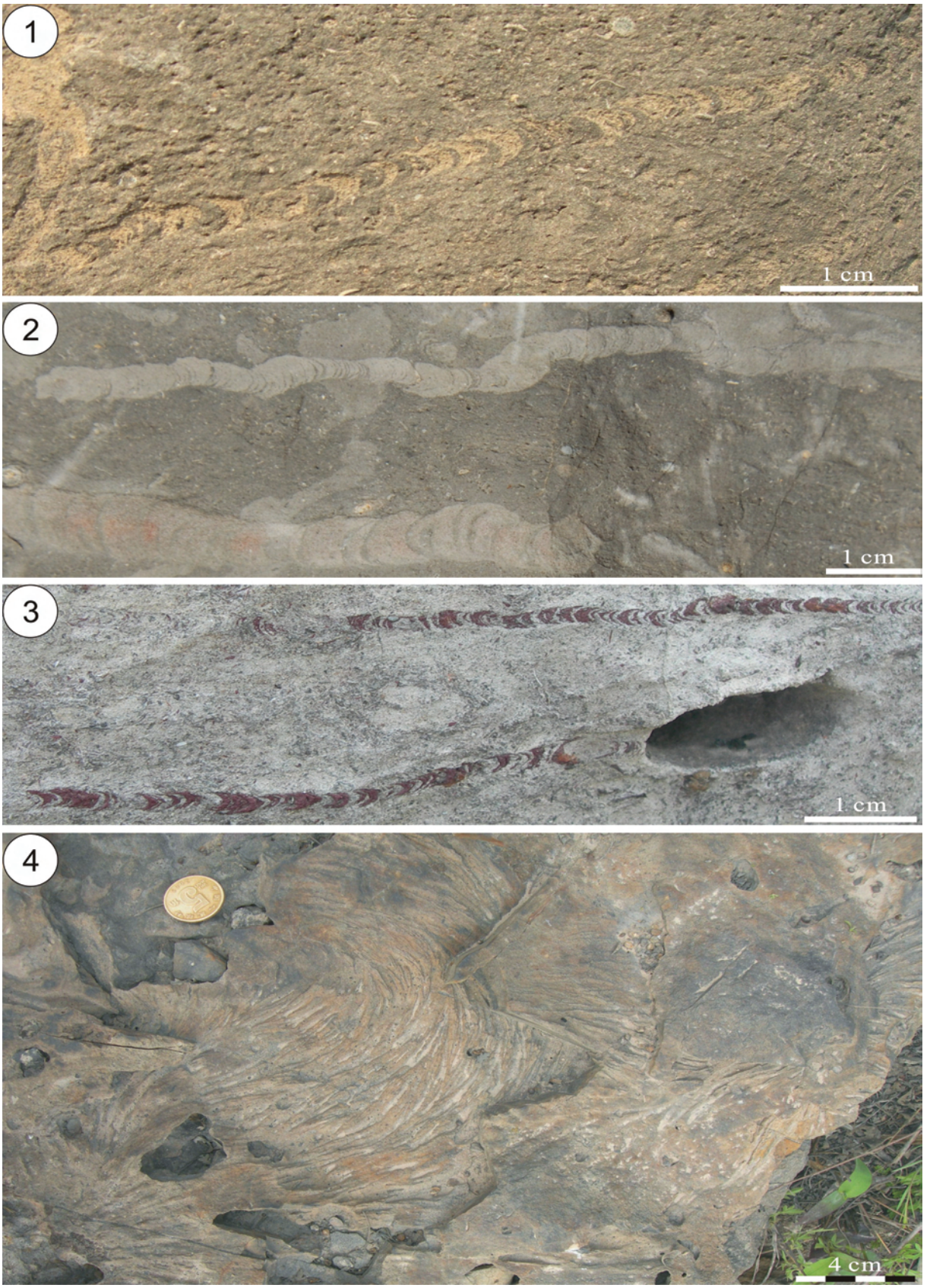
1 cm
5
1 cm
6
1 cm
7
3 cm

PLATE 3

1-3 – Vertical section of *Zoophycos* with crescentic lamellae preserved in the limestones in the Taiyuan Formation, Jiaozuo area. Fig. 1 from L6, Fig. 2 from L4 and Fig. 3 from L7

4 – *Zoophcos brianteus* Massalongo, 1855 in the L7 limestone, common distribution along the bedding planes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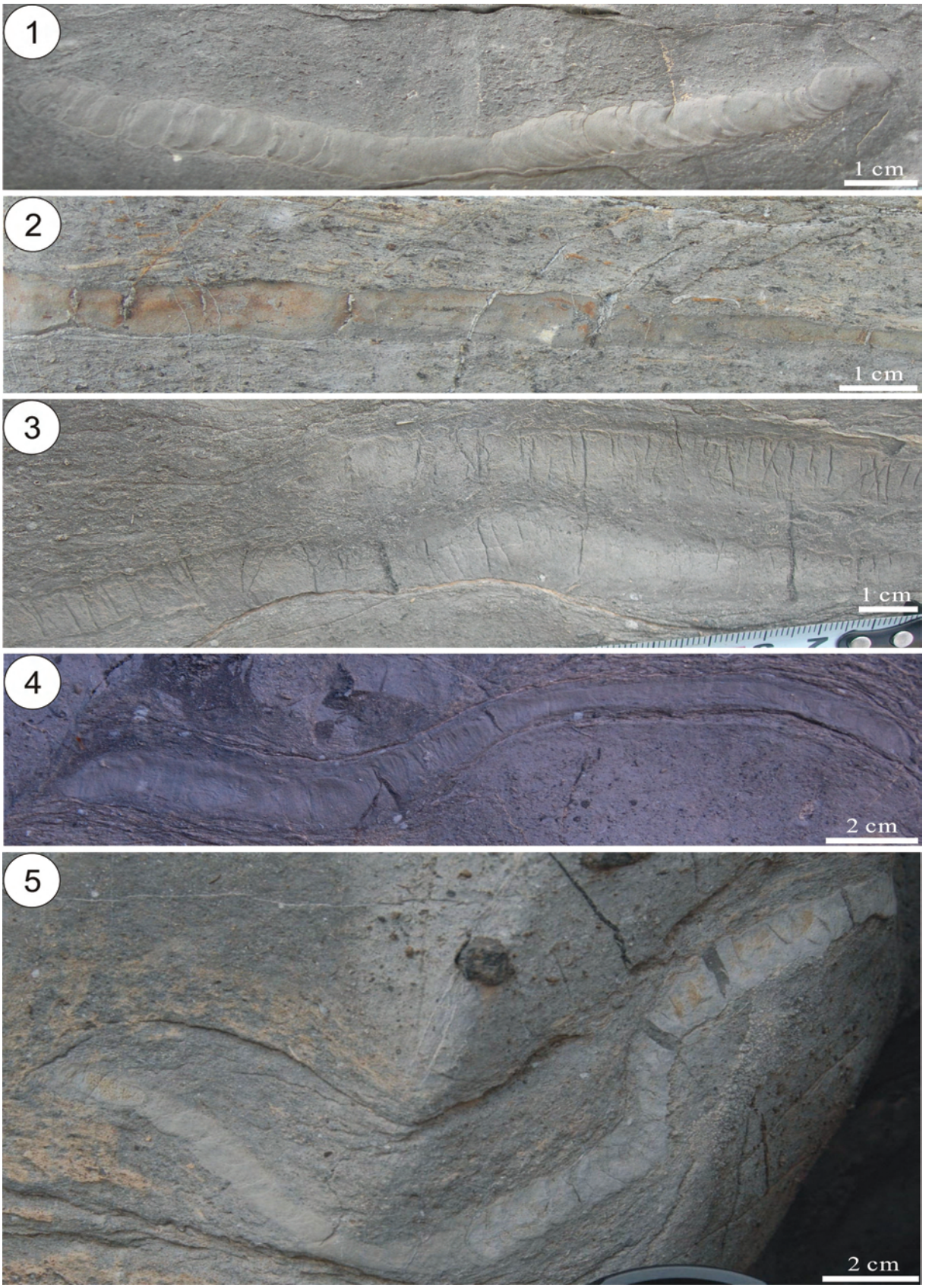
1 cm
3
1 cm
4
4 cm

PLATE 4

Vertical section of *Zoophycos* with rectangular lamellae in the Taiyuan Formation, Jiaozuo area. Figs 1–3 from L5, Fig. 4. from L4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