

# 西藏南部堆纳地区上白垩统及下第三系 遗迹化石及其环境意义

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**提要** 描述我国西藏南部堆纳地区宗山组下部及基堵拉组中的遗迹化石。宗山组中的遗迹化石组合可归属于 *Zoophycos* 遗迹相, 该遗迹相可进一步划分成产于富氧条件下的 *Thalassinoides-Planolites* 遗迹亚相及产于贫氧条件下 *Zoophycos-Chondrites* 遗迹亚相。基堵拉组中的遗迹化石组合可归属于在高能的潮下带的临滨和潮间带的前滨环境下产生的 *Skolithos* 遗迹相。

**关键词** *Zoophycos* 遗迹相 *Skolithos* 遗迹相 宗山组 基堵拉组 西藏南部

## UPPER CRETACEOUS AND LOWER TERTIARY TRACE FOSSILS FROM TUNA AREA OF SOUTHERN TIBET AND THEIR ENVIRONMENTAL SIGNIFICANCE

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**Abstract:** This paper describes trace fossils from the lower part of the Zongshan Formation and Jidula Formation, Tuna area of Southern Tibet, China. The trace fossil assemblage of the Zongshan Formation is referred to the *Zoophycos* ichnofacies which can further be divided into the *Thalassinoides-Planolites* subichnofacies and the *Zoophycos-Chondrites* subichnofacies. The former was produced under aerobic conditions and the latter under dysaerobic conditions. The trace fossil assemblage of the Jidula Formation is referred to the *Skolithos* ichnofacies formed in high-energy subtidal shoreface and intertidal foreshore environments.

**Key words:** *Zoophycos* ichnofacies, *Skolithos* ichnofacies, Zongshan Formation, Jidula Formation, Southern Tibet

### INTRODUCTION

Progress in application of biogenic structures to environmental interpretation has been made in recent decades. Trace fossils as important criteria are widely used in interpretation of oxygen conditions of primary environments (Savrda and Bottjer, 1986; Bottjer and

Savrda, 1993; Sageman *et al.*, 1991), for example, *Chondrites* has been regarded as a trace fossil indicator of anoxia in sediment (Bromley and Ekdale, 1984). A general model of oxygen-dependent trace-fossil associations shows that the oxygen concentration of the interstitial water increases from unburrowed sediment through trace-fossil associations dominated by deposit-feeding structures to trace-fossil as-

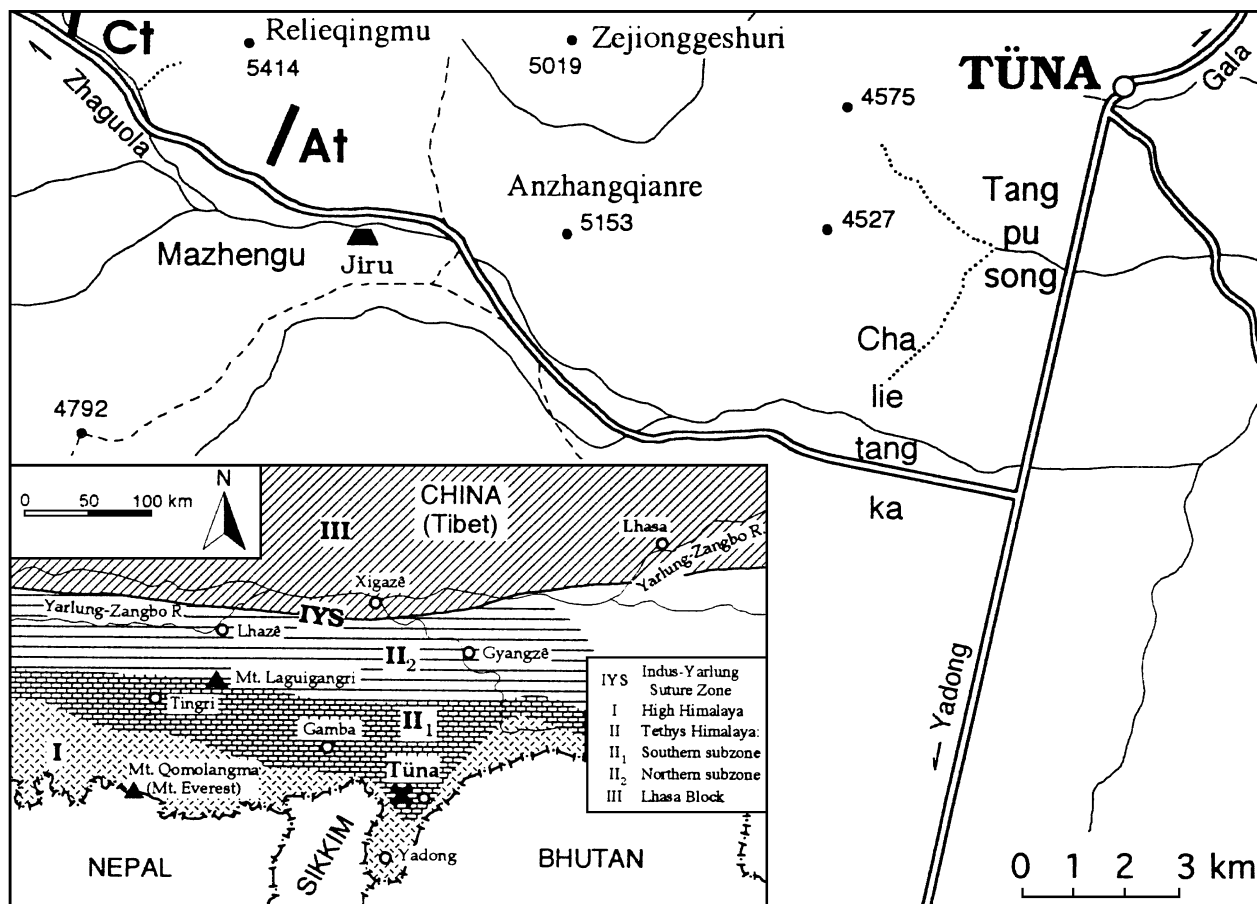
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sociations dominated by domichnia of suspension-feeders (Ekdale and Mason, 1988). Tiering of trace fossils can provide information on ecologic conditions, especially on oxygenation, benthic food content, sedimentation rate, and substrate consistency (Wetzel, 1991).

The trace fossil assemblage of the lower part of the Zongshan Formation is referred to the *Zoophycos* ichnofacies whereby a *Thalassinoides-Planolites* and a *Zoophycos-Chondrites* subichnofacies can be distinguished. The fluctuation of oxygen conditions during deposition was responsible for the alternation of the two subichnofacies in the vertical profile. The former was produced under aerobic conditions and the latter under dysaerobic conditions. The trace fossil assemblage of the Jidula Formation is very similar to that in the correspondent rock unit in the Gamba area. It is attributed to the *Skolithos* ichnofacies which was produced in well aerated high-energy and aerobic environments (Zhou Zhicheng, 1997).

## GEOLOGIC SETTING AND STRATIGRAPHY

The Himalaya is divided into 5 E-W extending zones: Subhimalaya, Lesser Himalaya, Higher Himalaya, Tethys-Himalaya/Tibet-Himalaya and Indus-Tsangpo Suture Zone by Gansser (1964). Later on, the Tethys-Himalaya has been further divided into two lithofacial subzones by Yin Jixiang (1988), which approximately border on the Laguigangri Mountains. The northern lithofacial subzone consists of siliciclastic and terrigenous sediments deposited under pelagic conditions during the Cretaceous. The southern lithofacial subzone is characterized by neritic terrigenous and carbonate sediments of Cretaceous and Early Tertiary age. It extends eastwards from the Tingri area through the Gamba area and then turns SEE to the Tüna area which is located between Karma County to the north and Yadong County to the south (Text-fig. 1).



Text-fig. 1 Map showing the section locality and geologic setting of a part of the Tibetan tethys Himalaya

The measured main section At lies on the southern flank of the Relleqingmu Mountain which is constructed by a syncline. The underlying Gamba Group crops out on the foot of the mountain. The measured Zongshan Formation and Jidula Formation are exposed on the slope and crest of the mountain. The complementary Section Ct is to the west of the Section At and 4.5 km away from it. Although there are some small gaps among the Gamba Group, the Zongshan Formation and the Jidula Formation, they are continuous and accessible (Text-figs. 1-5).

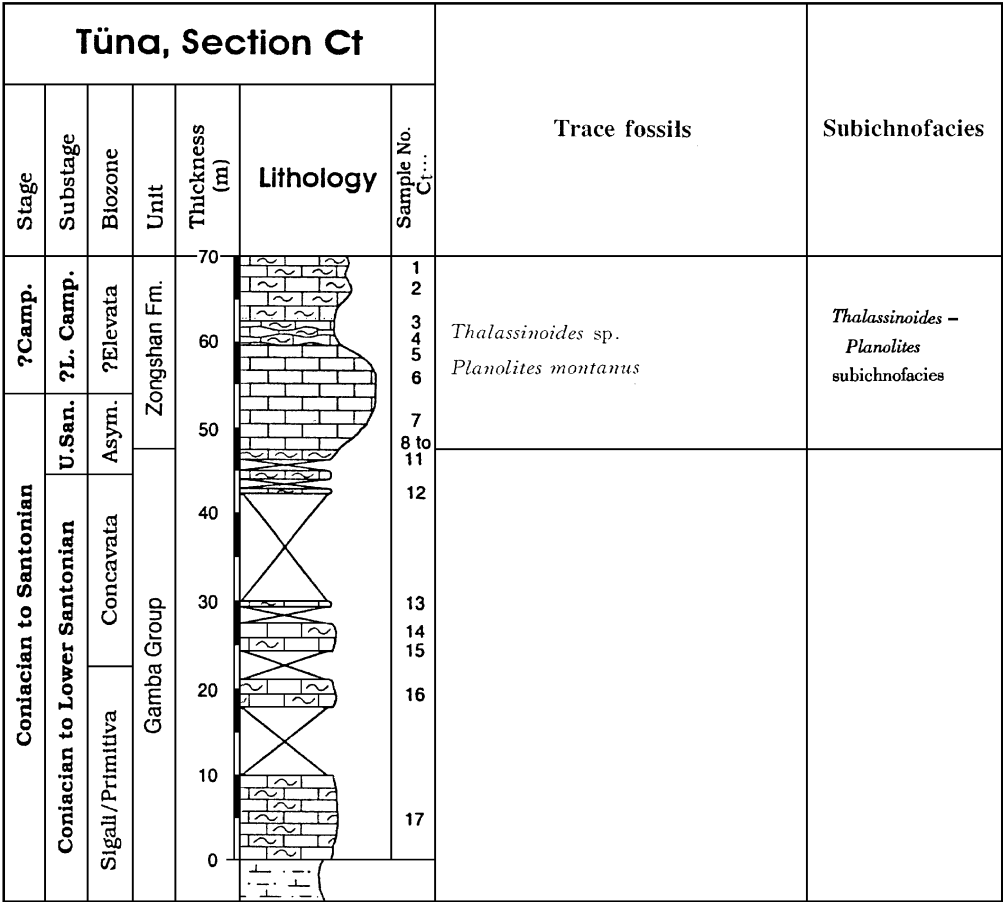
During the deposition of the Zongshan Formation and the Jidula Formation from the later Cretaceous to Early Tertiary, great paleogeographic and paleoenvironmental changes took place. The sedimentary environments changed from open sea shelf, carbonate platform slope, carbonate platform margin, carbonate platform to barrier sands deposited in the intertidal zone or the upper part of the subtidal zone.

The Santonian to Upper Maastrichtian Zongshan Formation is more than 350 m thick. In the Tuna

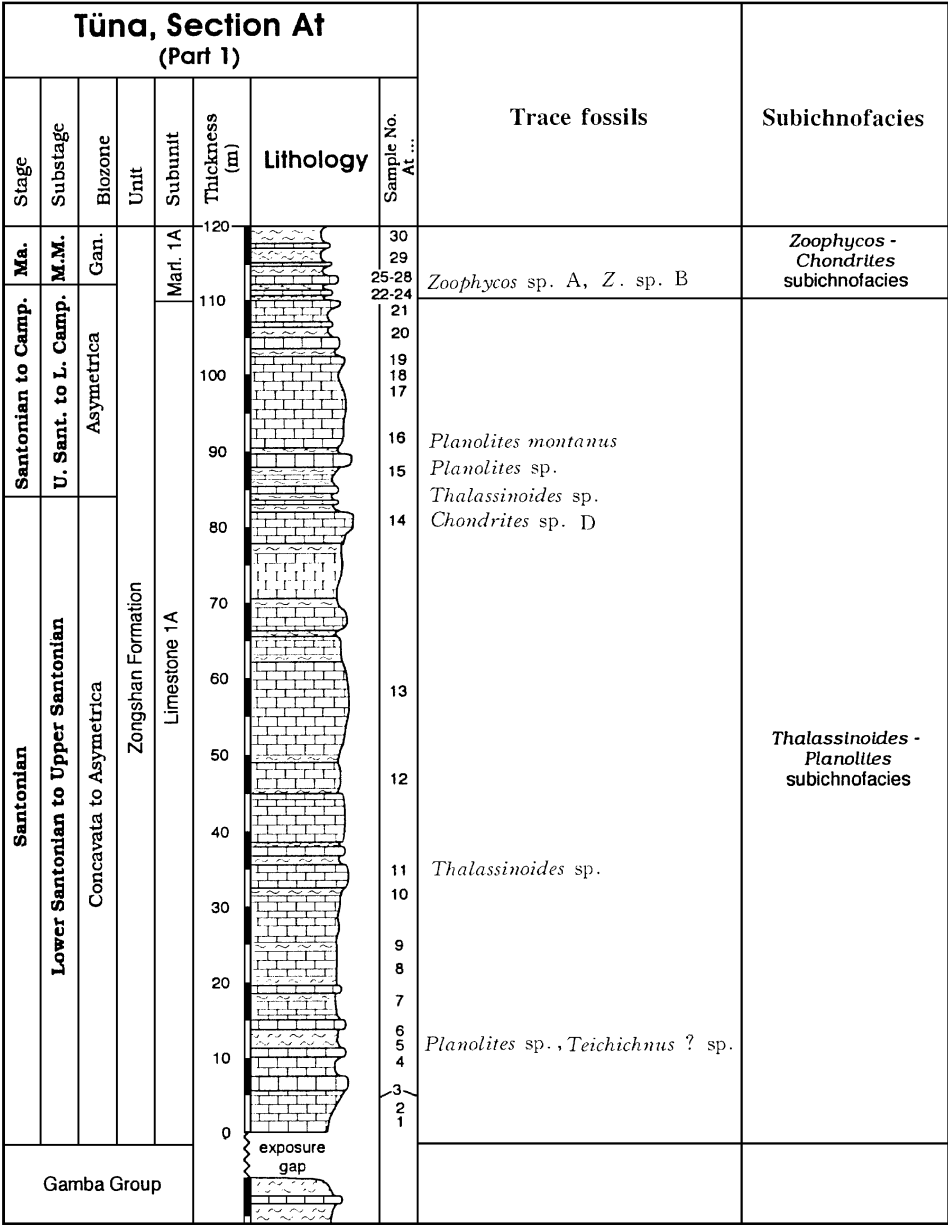
area, its lower part is, in comparison with adjacent Gamba and Tingri areas, more developed. The lithology of the Zongshan Formation and the Jidula Formation (from the Upper Maastrichtian to the Lower Paleocene) and the stratigraphic distribution of their trace fossils are briefly described as follows:

The Limestone <sup>1</sup> A of the Zongshan Formation is mainly composed of grey, regularly stratified and medium- to thick-bedded limestones and intercalated, thin-bedded marlstones and calcareous marlstones. The deposits show hemipelagic and pelagic characteristics. Calcspheres and planktic foraminifers predominate over body fossils in the sediments. The strongly bioturbated limestones contain graded beddings. The deposition of limestones was influenced by the distal turbidity currents. The main trace fossils include *Thalassinoides* sp., *Planolites montanus*, *Planolites* sp., *Rhizocorallium*<sup>2</sup> sp. and *Chondrites* sp. D. (Text-figs. 2, 3)

The Marlstone <sup>1</sup> A of the Zongshan Formation consists of marlstones and intercalated thin- to medi-



Text-fig. 2 Stratigraphic distribution of Upper Santonian to<sup>2</sup> Lower Campanian trace fossils in the Tūna area  
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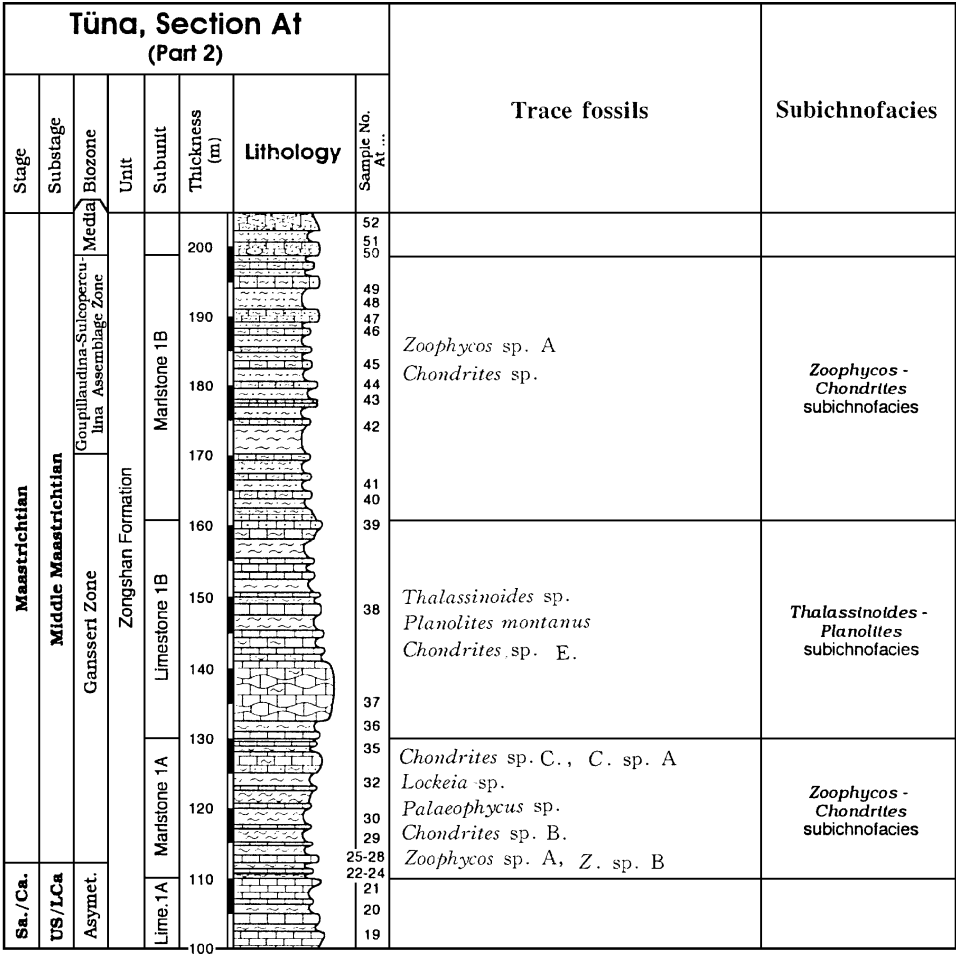
Text-fig. 3 Stratigraphic distribution of Santonian to Lower Campanian trace fossils in the Tüna area

um-bedded limestones. Main biota in the deposits are calcispheres, planktic foraminifers and smaller benthic foraminifers. The deposits display a considerable influence of terrigenous quartz and bioclasts derived from shallow-water environments. In comparison with the Limestone 1 A, the abundance of trace fossils and the degree of inoturbation are lower. Main trace fossils are *Zoophycos* sp., *Chondrites* sp. A, *C.* sp. B, *C.* sp. C, *Lockeia* sp., and *Palaeophycus* sp. (Text-fig. 4).

Medium- to thin-bedded limestones and intercalated marlstones comprise the Limestone 1 B. Nodular structures occur in the lower part of this unit. The

limestones are strongly bioturbated. Calcispheres dominate over planktic foraminifers. Other fossils are calpionellids, benthic foraminifers, echinoderms and bivalves. *Thalassinoides* sp., *Planolites montanus* and *Chondrites* sp. E are the main trace fossils in this unit (Text-fig. 4).

In the Marlstone 1 B, thin- to medium-bedded calcareous marlstones alternate with thick-bedded sandy marlstones. Biota in this unit are characterized by planktic and benthic fauna and flora. The larger foraminifers *Goupillaudina* and *Sulcoperculina* begin to appear in large quantities. Only few trace fossils *Zoophycos* sp. and *Chondrites* sp. have been



Text-fig. 4 Stratigraphic distribution of Middle Maastrichtian trace fossils in the Tüna area

found (Text-fig. 4).

The Limestone 1 C is mainly composed of thick-bedded nodular limestones and sandy limestones. Sandy limestones alternate with sandy calcareous marlstones at the bottom of this unit. With decreasing abundance of calcispheres and planktic foraminifers, benthic foraminifers increase upwards. Other benthic fossils such as ostracodes, echinoderms and bivalves prevail in this subunit. The trace fossils are *Palaeophycus* sp. and *Planolites* sp. (Text-fig. 5).

The Limestone 2 consists of thick-bedded to massive limestones. In the upper part of the massive limestones, rudist rud- and floatstone occur. Benthic faunal and floral elements dominate in this subunit including foraminifers (miliolids, nodosariids, rotalids, *Orbitoides* and *Omphalocyclus*), echinoderms, bivalves and red algae (Text-fig. 5).

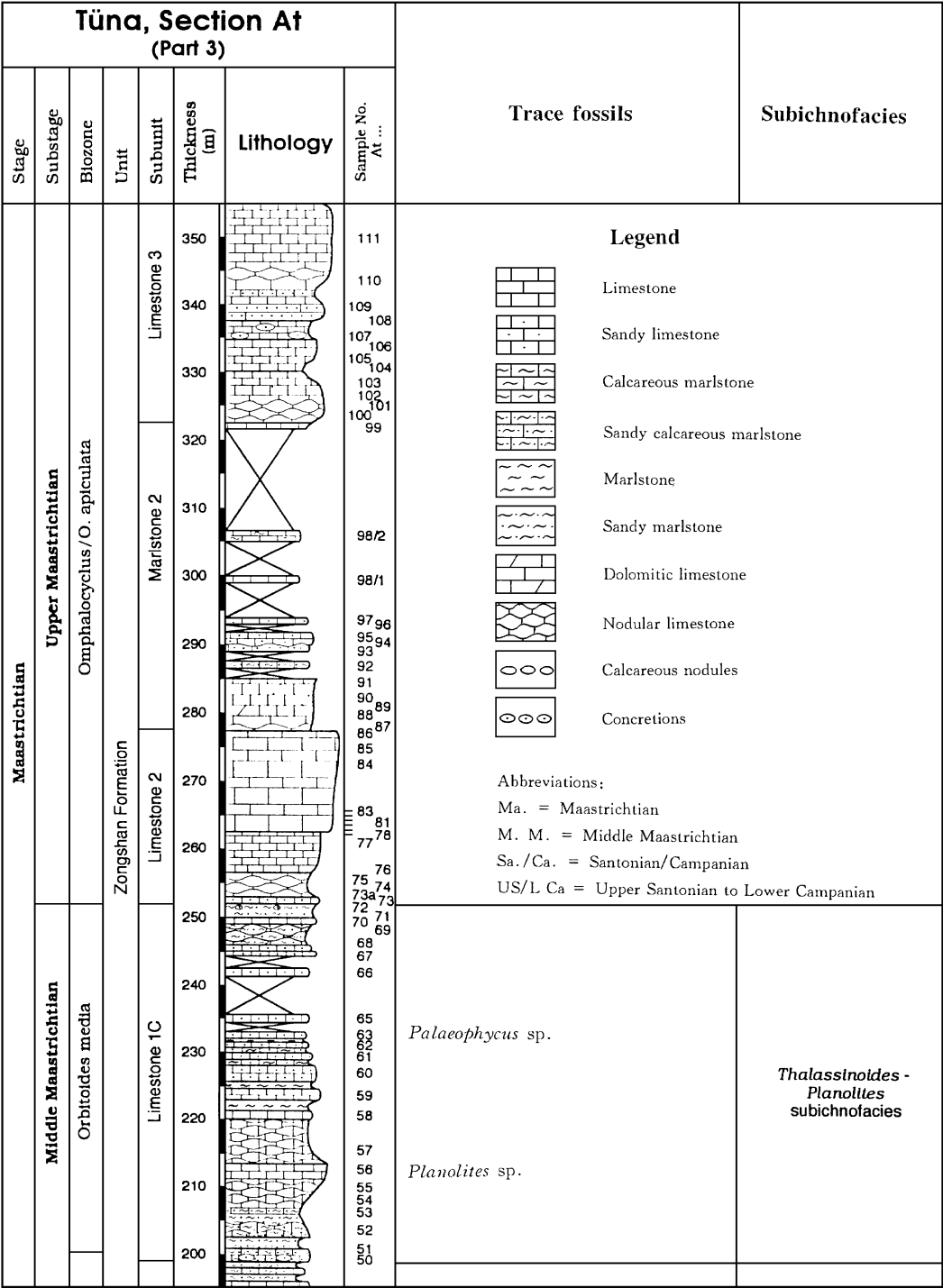
The Marlstone 2 is composed of medium- to thick-bedded limestones, calcareous marlstones,

marly limestones and sandy limetones. The main fossils are larger foraminifers (*Omphalocyclus*, *Orbitoides*) and calcareous algae (*Archaeolithothamnium*, *Ovulites*)(Text-fig. 5).

The Limestone 3 consists of thick-bedded and massive limestones, sandy limestones and nodular limestones. Foraminifers (*Omphalocyclus*, *Orbitoides*, and miliolids), echinoderms, rudists, gastropods and red algae are the main fossils in the limestone.

In contrast to the abundant trace fossils found in Limestone 1, no trace fossils have been found in the units Limestone 2, Marlstone 2, and Limestone 3 (Text-fig. 5).

The Jidula Formation is composed of yellowish-brown, massive, fine- to medium-grained sandstones with cross bedding of different dimensions. Trace fossils including *Skolithos* sp., *Skolithos linearis* and *Arenicolites* sp. are abundant. The trace fossil assemblage is very similar to that of the Jidula Forma-



Text-fig. 5 Stratigraphic distribution of Middle Maastrichtian to Upper Maastrichtian trace fossils in the Tūna area

tion of the Gamba area (Zhou Zhicheng, 1997).

SYSTEMATIC DESCRIPTIONS

Ichnogenus *Arenicolites* Salter, 1857

*Arenicolites* sp.

(Plate III, fig. 1)

**Description:** Simple U-tubes with funnel-shaped

opening, perpendicular to bedding plane, approximately symmetrical limbs about 9 cm in length, tube diameter about 4 mm; distance between two limbs about 2 cm.

**Toponymy-ethology:** Preserved as endichnia. Interpreted as dwelling structure of worms or worm-like organisms.

**Ichnogenus *Chondrites* Sternberg, 1833*****Chondrites* sp. A**

(Plate II, fig. 7)

**Description:** Asymmetrical ramifying burrow system more than 2.5 cm in length and more than 1.5 cm in width, individual tunnels about 1 mm in diameter, angles of branching  $30^{\circ}$ — $50^{\circ}$ .

**Toponymy-ethology:** Preserved as endichnia or epichnia. Interpreted as feeding structures of vermiform animals.

***Chondrites* sp. B**

(Plate II, figs. 1, 3)

**Description:** Asymmetrical burrow system more than 5 cm in length, more than 2 cm in width, with straight tunnels about 1.5 mm in diameter, angles of branching  $40^{\circ}$ — $50^{\circ}$ .

**Discussion:** *Chondrites* sp. B is distinguished from *C.* sp. A by having longer individual tunnels and larger tube diameter.

***Chondrites* sp. C**

(Plate II, fig. 6)

**Description:** Poorly developed branching burrow systems about 2 cm in length and 1 cm in width, tiny tunnel diameter about 1 mm, angles of branching about  $45^{\circ}$ .

***Chondrites* sp. D**

(Plate II, fig. 2)

**Description:** Asymmetrical tunnels inclined to bedding planes, tunnel diameter 1.5—2 mm. The second order branches radially diverge from the stem.

***Chondrites* sp. E**

(Plate I, fig. 4)

**Description:** Symmetrical tunnels about 3 mm in diameter, angles of branching about  $30^{\circ}$ .

**Discussion:** *C.* sp. E is characterized by the symmetrical, thick tunnels.

**Ichnogenus *Lockeia* U. P. James, 1879*****Lockeia* sp.**

(Plate I, fig. 2)

**Description:** Small almond-shaped trace fossils, tapering to sharp points at both ends, surface commonly smooth, mostly symmetrical, 5 mm in length

and 2 mm in width.

**Toponymy-ethology:** Preserved as hypichnia. Interpreted as resting structures of pelecypods.

**Ichnogenus *Palaeophycus* Hall, 1847*****Palaeophycus* sp.**

(Plate III, fig. 4)

**Description:** Preserved tube about 3—11 cm in length, tube diameter 7 mm, wall surface smooth. The sediment fill is the same as the enclosing sediment.

**Toponymy-ethology:** Preserved as endichnia, epichnia and hypichnia. Interpreted as dwelling structures.

**Ichnogenus *Planolites* Nicholson, 1873*****Planolites montanus* Richter, 1937**

(Plate I, fig. 3)

**Description:** Smooth, unlined and curved burrows, more than 2 cm in length and about 2 mm in diameter, horizontal or slightly inclined to bedding planes. The sediment fill is darker in color than the enclosing sediment.

**Toponymy-ethology:** Preserved as epichnia, endichnia and hypichnia. Interpreted as feeding structures.

***Planolites* sp.**

(Plate I, fig. 1b, 3; Plate III, fig. 6b)

**Description:** Unlined burrows horizontal or inclined to bedding planes, cross-sections of burrows round or oval, 7—15 mm in diameter, sediment fill lighter in color than that of the host stratum.

**Ichnogenus *Skolithos* Haldemann, 1840*****Skolithos linearis* Haldemann 1840**

(Plate III, figs. 3, 5)

**Description:** Exposed tube more than 15 cm in length, about 1 cm in diameter, slightly bent, perpendicular to bedding planes, shafts approximately parallel to each other.

**Toponymy-ethology:** Preserved as endichnia. Interpreted as dwelling structures.

***Skolithos* sp.**

(Plate III, fig. 2)

**Description:** Exposed tube, 6 cm in length and 7

mm in diameter, perpendicular to bedding planes, inner wall annulated.

### **Ichnogenus *Thalassinoides* Ehrenberg, 1944**

#### ***Thalassinoides* sp.**

(Plate I, fig. 1a)

**Description:** Horizontal burrow systems with slight swelling at points of branching. Burrow 6–12 mm in diameter.

**Toponymy-ethology:** Preserved as epichnia or endichnia. Interpreted as dwelling or feeding structures.

### **Ichnogenus *Zoophycos* Massalongo, 1855**

#### ***Zoophycos* sp.**

(Plate II, fig. 5)

**Description:** Tabular spreite structures more than 12 cm in diameter and 5 mm in thickness. The outline of the isolated lobe from the specimen is irregular, tongue-like.

**Toponymy-ethology:** Preserved as epichnia or endichnia. Interpreted as feeding structures.

## **ICHNOFACIES AND THEIR ENVIRONMENTAL SIGNIFICANCE**

Bromley and Ekdale (1984) described the oxygen-controlled tiering of trace fossils in selected examples of Mesozoic marine strata that represent oxic to anoxic depositional environments. When the oxygen content of bottom water decreases, the trace fossils *Planolites* and *Thalassinoides* disappear first, *Zoophycos* and *Chondrites* last. Therefore, *Chondrites* and *Zoophycos* are good indicators of dysaerobic or anaerobic conditions within the sediments whereas *Thalassinoides* and *Planolites* reflect aerobic conditions. Savrda and Bottjer (1986, 1989) used burrow size, ichnofaunal composition and the tiering concept as the main criteria to reconstruct the paleo-oxygenation history of Miocene Monterey Formation, California and Upper Cretaceous Niobrara Formation. Four trace fossil assemblages, namely the *Chondrites*, *Zoophycos*, *Planolites* and *Thalassinoides* assemblages are distinguished from the latter. The *Chondrites* and *Zoophycos* assemblages occur in marls and calcareous shales, while the *Planolites* and *Thalassi-*

*noides* assemblages in limestones. The alternation of the four trace fossil assemblages in the Niobrara Formation reflects the changes of paleo-oxygenation in bottom waters which were attributed to wet/dry climatic cycles driven by Milankovitch-like variations in the earth's orbital parameters. Wetter periods were characterized by increased input of fine-grained terrigenous clastic sediments and the formation of a brackish surface-water mass that reduced vertical circulation and induced oxygen-deficiency in deeper parts of the water column. During drier periods, clastic input was reduced and deterioration of brackish water cap led to the restoration of vertical circulation and, hence, reoxygenation of bottom waters (Savrda and Bottjer, 1989).

The trace fossils in the lower part of the Zongshan Formation include *Thalassinoides*, *Planolites*, *Lockeia*, *Palaeophycus*, *Zoophycos* and *Chondrites*. The trace fossil assemblage can be attributed to the *Zoophycos* ichnofacies. The main associated body fossils in the deposits are planktic foraminifers and calcispheres from the Limestone 1 A to the Limestone 1 B and a mixture of planktic and benthic biota from the Marlstone 1 B to the Limestone 1 C. The trace fossil assemblage and the associated body fossils document open shelf and carbonate platform slope environments in the Tüna area. The occurrence of trace fossils in the lower part of the Zongshan Formation is similar to that in the Niobrara Formation. The trace fossils in the limestones are strikingly different from those in the marlstones and calcareous marlstones. The former are characterized by high diversity and high abundance. The main elements are *Thalassinoides* and *Planolites*. Additional elements include *Palaeophycus*, *Rhizocorallium*? sp., *Chondrites* sp. D and C. sp. E. In contrast, the trace fossils in the marlstones and calcareous marlstones represent a deeper tier. The main members are *Zoophycos* and *Chondrites* sp. A, C. sp. B and C. This subassemblage is characterized by low abundance. It is assumed that the alternation of the two trace fossil subassemblages in Tüna area was caused by changes in the oxygen content of the bottom water. The *Zoophycos* ichnofacies in the Tüna area can be subdivided into a *Thalassinoides*-*Planolites* subichnofacies and a *Zoophycos*-*Chondrites* subichnofacies which were representative



of aerobic and dysaerobic condition of the original depositional environments respectively. The alternation of two trace fossil subassemblages as seen in Tüna section has not been observed in the correspondent strata of the Gamba area which is to the west of Tüna and 60 km away from it. It seems to be more convinced that the fluctuation of redox conditions in the Tüna area mentioned above was related to the activities of turbidity currents which influenced the deposition of limestones. The distal turbidity currents derived from shallow water environments produced an aerobic condition in the bottom waters. When the activities of turbidity currents ceased, the bottom water became dysaerobic. In this case, marls and calcareous marls were deposited. Episodic activities of turbidity currents resulted in the fluctuation of aerobic and dysaerobic conditions in the bottom waters.

The trace fossils in the Jidula Formation are mostly domichnia. They include *Arenicolites* sp., *Skolithos linearis* and *Skolithos* sp. The trace fossil assemblage is typical of the *Skolithos* ichnofacies. As Frey and Pemberton, 1984 indicated, the environments of *Skolithos* ichnofacies are characterized by shifting substrates, moderate to high-energy conditions and episodic erosion or deposition. Environments include the foreshore and shoreface zones of beaches, bars and spits (Howard, 1972, 1975). The Jidula Formation in the Tüna area mostly consists of fine- to medium-grained crossbedded sandstones. The *Skolithos* ichnofacies and the physical sedimentary structures indicate that the sandstones of the Jidula Formation were deposited in high-energy environments of barrier sands in the subtidal shoreface zone and intertidal foreshore zone.

## CONCLUSION

1. The trace fossil assemblage in the Limestone 1 of the Zongshan Formation can be attributed to the *Zoophycos* ichnofacies which represents open shelf and carbonate platform slope environments. The trace fossil assemblage in the Jidula Formation can be attributed to the *Skolithos* ichnofacies which represents barrier sands in the subtidal shoreface zone and intertidal foreshore zone.

Zongshan Formation in the Tüna area have much higher diversity and abundance than those from the Gamba area. The former can further be divided into two subichnofacies; *Thalassinoides-Planolites* subichnofacies and *Zoophycos-Chondrites* subichnofacies. The former indicates aerobic conditions whereas the latter indicates dysaerobic or anaerobic conditions.

3. The alternation of the *Thalassinoides-Planolites* subichnofacies and the *Zoophycos-Chondrites* subichnofacies was caused by changes in the oxygen content in bottom water. The trace fossil assemblages from Section At are, therefore, useful indicators of oxygen conditions of the original sedimentary environment.

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EXPLANATION OF PLATES

Plate I

1. *Thalassinoides* sp. (a) and *Planolites* sp. (b), Section At, Limestone 1 B, Middle Maastrichtian. 2. *Lockeia* sp., At 30, Marlstone 1 A, Middle Maastrichtian. 3. *Planolites montanus* (arrow), At16, Limestone 1 A, Upper Santonian-Lower Campanian. 4. *Thalassinoides* sp., *Planolites montanus* and *Chondrites* sp. E (arrow), Limestone 1 B, Middle Maastrichtian.

Plate II

1. *Chondrites* sp. B, At30, Marlstone 1 A. Middle Maastrichtian. 2. *Chondrites* sp. D (arrow), *Planolites* sp. and *Thalassinoides* sp., At16, Limestone 1 A, Upper Santonian-Lower Campanian. 3. *Chondrites* sp. B, At31, Marlstone 1 A, Middle Maastrichtian. 4. tunnel with backfill structures (arrow), Marlstone 1 A, Middle Maastrichtian. 5. *Zoophycos* sp. At22, Marlstone 1 A, Middle Maastrichtian. 6. *Chondrites* sp. C, At33, Marlstone 1 A, Middle Maastrichtian. 7. *Chondrites* sp. A, Marlstone 1 A, Middle Maastrichtian.

Plate III

1. *Arenicolites* sp., Jidula Formation, Upper Maastrichtian-Lower Paleocene. 2. *Skolithos* sp., Jidula Formation, Upper Maastrichtian-Lower Paleocene. 3. *Skolithos linearis*, Jidula Formation, Upper Maastrichtian-Lower Paleocene. 4. *Palaeophycus* sp., At31, Marlstone 1 A, Middle Maastrichtian. 5. *Skolithos linearis*, Jidula Formation, Upper Maastrichtian-Lower Paleocene. 6. *Rhizocorallim?* sp (a) and *Planolites* sp (b), At5, Limestone 1 A, Lower Santonian-Upper Santonian.