BSPE 00321－535－5

오르도비스기 해양퇴적층(문곡층 및 막골층)에 분포하는 흔적화석과 이들의 지화학적 특징에 관한 연구

Trace Fossils and Geochemical Characteristics of the Ordovician Marine Sediments

(Mungok and Maggol Formations)

1993. 3.

한 국 해 양 연 구 소

제 출 문

한국해양연구소장 귀하

본 보고서를 "오르도비스기 해양퇴적층(문곡층 및 막골층)에 분포하는 흔적화석과 이들의 지화학적 특징에 관한 연구" 사업의 최종보고서로 제출합니다.

1993년 3월

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요 약 문

I. 제 목

오르도비스기 해양퇴적층(문곡층, 막골층)에 분포하는 흔적화석과 이들의 지화학적 특징에 관한 연구

II. 연구내용 및 결과

한국에 분포하는 후기 고생대층에 관한 연구는 주로 속성작용을 포함한 퇴적학, 층서학 및 고생물학적 관점에서 수행되어져 왔다. 그러나 야외조사에서의 관찰에도 불구하고 흔적화석에 관한 연구는 전혀 이루어지지 않았다. 본 보고서는 한반도에 분포하는 후기 고생대층, 특히 강원도 영월 및 태백지역에 분포하는 오르도비스기층인 문곡층과 막골층에서 산출되는 흔적화석들에 대한 최초의 연구로 흔적화적의 기재 및 이들에 의한 퇴적환경 해석에 주안점을 두었다.

문곡층은 주로 돌로마이트질 석회암과 돌로마이트로 이루어져 있으며, rippled-lenticular 상의 층리가 연속적으로 발달하고 있다. 문곡층은 주로 flat-pebble conglomerate, trough cross-bedded packstone 및 grainstone, laminated mudstone, 그리고 소량의 bedded chert 로 구성되어져 있다. 비

록 문곡층중 일부 퇴적층에서는 생물기원의 퇴적구조(biogenic sedimentary structure)가 인지되지 않았으나, 대부분의 퇴적층에서는 흔적화석이 확인되었다. 이들 흔적화석과 암상으로 볼때 문곡층은 rippled bed의 표면에 수직으로 발달하는 bioturbation 구조가 우세하게 발달하는 것으로 대표되는 Skolirhos ichnofacies에 속한다. 수평으로 발달하는 burrow (예, Planolites) 들은 주로 horizontal bedding plane 또는 rippled facies 내에 발달하는 mud flaser에 한정되어져 나타난다.

Skolirhos ichnofacies는 조석간만의 차이에 의해 지배되는 고에너지 환경에서 발달한다. 이러한 사실은 여러학자들에 의해 연구된 문곡층의 퇴적환경해석을 보다 공고히 할수있는 자료가 될것이다. Bioturbation은 문곡층 전반에 걸쳐 비교적 그 정도가 낮으며, 이는 높은 퇴적률과 조간대 환경과 연관된 환경적인 요인에 의한 결과로 사료된다.

막골층에 분포하는 흔적화석에 대한 연구결과는 전반적인 흔적화석의 종류 및 이들의 분포상태의 경우 문곡층과 유사함을 보여주나 bioturbation의 정도는 문곡층에 비해 전반적으로 높게 나타났다. 이는 막골층의 퇴적환경이 문곡층에 비해 보다 조용한 환경, 즉 조하대 환경에서 퇴적작용을 진행시킨 것으로 사료된다.

SUMMARY

Previous workers of Lower Paleozoic strata in Korea have focused on body fossils, sedimentology, stratigraphy, and diagenesis, but trace fossils have not been examined specifically. This report is the first to provide detailed descriptions and interpretations of trace fossils from Paleozoic rocks in the Korean peninsula, specially from the Lower Ordovician Mungok Formation of the Yeongweol region and Maggol Formation of the Taeback region, Kangweondo.

The Mungok Formation in this region is composed primarily of dolomitic limestones and dolomites that show a continuum of rippled-lenticular bedforms; flat-pebble conglomerates, trough cross-bedded packstones and grainstones, laminated mudstones, and bedded chert are less common. Trace fossils are evident in most of the formation, although some lithofacies lack identifiable biogenic sedimentary structures. Trace fossils and lithofacies represent a Skolithos ichnofacies: the ichnocoenose is composed mostly of small, vertically oriented dwelling structures that originated at rippled bed tops. Small horizontal burrows (e.g., Planolites) are restricted mostly to horizontal bedding planes or mud flasers within rippled facies. The

Skolithos ichnofacies indicates shifting, high-energy conditions typical of tidally dominated regimes, which corroborates and augments some environmental interpretations made by previous investigators of the Mungok Formation. Bioturbation was relatively low throughout deposition of Mungok sediments, probably as a result of high sedimentation rates and other environmental stresses associated with intertidal environments.

The results of trace fossil and lithofacies of Maggol Formation are similar to those of Mungok Formation. Howerer, bioturbation was relatively higher than that of Mungok Formation. probably as a result of lower sedimentation rates and/or deposition in the relatively lower energy conditions typical of subtidal environments.

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PART I

MUNGOK FORMATION

I. INTRODUCTION

Recent focus on lower Paleozoic carbonate strata in Korea has generated detailed reports on the body fossils, sedimentology, stratigraphy, and diagenesis of these rocks, particularly those from the Cambrian and Ordovician (Woo and Park, 1989; Paik and Lee, 1989; Woo et al., 1990; Paik et al., 1991). However, very little information in these reports has been related to paleoichnology, the study of trace fossils, despite the international prominence that this field has gained in the past several decades (Frey and Pemberton, 1990; Maples and West, 1992). Neoichnology, the study of modern traces made by organisms, has been represented by several studies in Korea (Frey et al., 1986, 1987a, b; 1989). The few mentions of trace fossils in Korea have dealt mainly with vertebrate traces in Mesozoic and Cenozoic strata (Kim, 1986; Lim et al, 1989; Chough and Sohn, 1990), although reports on Paleozoic rocks include references to "burrows," "borings," or "bioturbation" (Paik and Lee, 1989; Woo and Paik, 1989; Paik et al, 1991). This report represents the first detailed trace fossil study in Paleozoic strata of the Korean peninsula. The Lower Ordovician Mungok Formation of Yeongweol, Kangweondo, was the specific subject of our study.

II. STUDY AREA AND STRATIGRAPHY

The Mungok Formation is located in part of the western outcrop area of the Choseon Supergroup, termed the Yeongweol Type Sequence. The study area is located in the Yeongweol region of the Kangweondo province of eastern Korea (Fig. 1). The Mungok Formation was dated by Won and Lee (1977) as Lower Ordovician (Tremadocian-Arenigian; Table 1). Formation thickness in most places is 70-200 m and consists mostly of dolomite and dolomitic limestone. Lithofacies, physical sedimentary structures, and fragments of body fossils (echinoderms, trilobites, ostracods, brachiopods, and algae) have been described in detail by these previous investigators, but trace fossils were only mentioned as "dolomite mottling" or "burrows and borings" (Paik and Lee, 1989; Paik et al., 1991).

Paik et al. (1991) recognized six lithofacies and corresponding sedimentary environments in the Mungok Formation: (1) grainstone facies (shallow subtidal); (2) quartzose packstone facies (subtidal); (3) ribbon rock facies (high intertidal to subtidal); (4) flat-pebble conglomerate facies (supratidal to subtidal); (5) stromatolite facies (shallow subtidal to low intertidal); and (6) mudstone facies (intertidal). Paik et al. (1991) also discerned four associations of these facies and their respective environments: (1) grainstone and flat-pebble conglomerate facies (subtidal flat with oolitic patches); (2) ribbon rock and flat-pebble conglomerate facies (intertidal influenced by storms); (3) stromatolite and grainstone facies (low intertidal to subtidal); and (4) mudstone and flat-pebble conglomerate facies (tidal ponds and creeks). Changes in vertical and lateral distributions of facies, such as shallowing-upward sequences, were attributed to sediment accumulation on a subsiding carbonate platform or sea-level fluctuations (Paik et al., 1991), but storm sedimentation also influenced the formation of some lithofacies (Paik and Lee, 1989).

Our descriptions of lithofacies in the Mungok Formation are similar to those of Paik and Lee (1989) and Paik et al. (1991), but we recognized that the term "ribbon rock" used by Paik et al. (1991) was applied to lithofacies that showed a continuum of rippled to flaser to lenticular bedding, similar to that described by Reineck and Wunderlich (1968) in terrigenous sediments. Because many physical sedimentary structures in carbonate and terrigenous environments are formed by identical processes (Davis, 1992, p. 458), we prefer to designate these "ribbon rocks" as rippled, flaser, and lenticular bedding.

The most common lithofacies we described include rippled-flaser-lenticular bedforms, flat-pebble conglomerates, trough cross-bedded packstones and grainstones, laminated mudstones, and bedded chert. Stromatolites, described by Paik et al. (1991), seem to be uncommom in the Mungok Formation: we experienced difficulty in finding convencing examples at each of the outcrops examined.

III. METHODS

Trace fossils were described in terms of their toponomy, morphology, ethology, and systematic ichnology. Toponomy refers to the preservation of trace fossils with respect to the host rock (i.e., epichnia are preserved on bed tops, hypichnia on bed bottoms) and toponomic descriptions conformed to terms by Martinsson (1970). Trace fossils morphology was described according to guidelines provided by Simpson (1975). Ethological (behavioral) categories were applied in accordance with inferred behavior, such as feeding structures (fodinichnia) or dwelling structures (domichnia) using modifications of terminology by Frey (1973) and Pemberton et al. (1992). Systematic ichnology, which involves the use of specific names for trace fossil species and genera (e.g., Skolithos lineris, Cruziana isp.), was applied to all identifiable trace fossils.

Trace fossils were described in the context of their paleoenvironmental settings by correlating trace fossil assemblages with lithofacies and associated physical sedimentary surutures. This combination of data helped to insure a more accurate assessment of the ichnofacies represented by the Mongok trace fossil assemblage. Ichnofacies were discerned by comparison to archetypal assemblages defined by other workers in Phanerozoic strata (Frey and Seilacher, 1980; Pemberton et al., 1992).

IV. TRACE FOSSILS AND ICHNOFACIES OF THE MUNGOK FORMATION

Trace fossils and other biogenic sedimentary structures are present in most of the Mungok Formation but comprise a relatively low-diversity assemblage. The assemblage is composed primarily small, vertically oriented dwelling burrows, such as Skolithos, Arenicolites, and Monocraterion (Table 2). These vertical traces originate at the tops of rippled beds and are most common in the rippled-flaser-lenticular facies. Their toponomic expression is mostly endichnial but some exichnial forms are readily observable as tan-colored burrows: the latter are apparently filled with a mixture of clay minerals and silt distinctive from the surrounding rippled beds, but identical to material composing flaser beds (Fig. 2). Burrows were likely passively filled by sediments from the flaser beds, which aided in preservation of the trace fossils as identifiable structures. Burrow depths of both Skolithos and Arenicolites range from < 1.0 to 3.0 cm and seem to be controlled by the thickness of individual rippled beds. Because rippled facies represent shifting substrates, vertical burrows originating at the tops of the rippled beds may have undergone slight erosion and thus had greater original depths (e.g., Bromley and Asgaard, 1991). Burrow widths are also comparatively small and most range from 2–4 mm, but some are as small as 1 mm or as large as 7 mm. Rare examples of transported vertical burrows are evident in some of the flat-pebble conglomerate facies: one specimen of Skolithos cross-cuts a clast in conglomerate bed, indicating a initially unconsolidated substrate inhabited by the tracemaker before rip-up of the clast (Fig. 3).

Vertical burrows also provide supplementary evidence that bedded chert in the Mungok Formation at some localities was formed originally by hydrodynamic processes. Evidence for this initial unconsolidation is indicated by lenticular to rippled bedforms, preserved ripple laminations in lenticular and rippled beds, and minute vertical burrows that originate at bed tops (Fig. 4). Bedded chert at Machari, Yeongweol–samgeori, and Baeil Jae were originally unconsolidated and composed of stratified silica grains, such as sponge spicules (Woo et al., 1990), before diagenetic formation of chert.

Horizontal traces, such as Planolites and Palaeophycus, are also diminutive (1–3 mm diameter) and restricted mostly to very thin muddy flasers in rippled–flaser–lanticular facies and horizontal bedding planes of other lithofacies (Fig. 5). Planolites probably represents deposit–feeding activity within relatively muddy bed interfaces (i.e., flasers) that provided more nutrients than surrounding sediments. Palaeophycus, a lined burrow that has been interpreted by some workers as a combined feeding and dwelling burrow of a vermiform predator (Pemberton and Frey, 1982), is not as common as Planolites. Both trace fossil genera are endichnial or exichnial, the letter distinctive form surrounding host rocks by sediment fills similar to those described for the vertical burrows. However, some specimens of Planolites are evident as negative-relief epichnia or positive-relief hypichnia.

Some flat-pebble conglomerate beds have burrow mottling near the tops of beds, evident as silt-filled exichnia distinct from surrounding sediments. This mottling may represent post-storm colonization of beds by infauna, interpreted in some parts of the Mungok Formation by Paik and Lee (1989). However, interstitial silt, located between clasts in the conglomerates, causes a similar weathering pattern that could be confused with burrow mottling (Fig. 6). Burrow mottling was discerned by the following characteristics: (1) cross-sections of burrow mottling are circular to ovoid or show linear trends, whereas interstitial silt has angular outline; and (2) burrow mottling cross-cuts pebbles as discrete trace fossils in some places.

In a broad sense, bioturbation was limited throughout deposition of Mungok sediments. Amounts of bioturbation in the Mungok Formation were estimated by tabulating semiquantitative categories of percent biogenic disturbance of physical sedimentary structures (Table 3), similar to methods used by Howard and Reineck (1972), Droser and

Bottjer (1986), and Martin (1993). Compilations of these categories revealed that much of the Mungok Formation is unbioturbated: 130 m of section examined for bioturbate-texture data, measured at Machari (Fig. 7) and Yeongweol-samgeori, had 43.8% of the stratigraphic thickness composed of unbioturbated beds (Table 4). Strata primarily show vertical transitions of unbioturbated to very slightly bioturbated horizons, followed by unbioturbated horizons. This pattern of bioturbation is typical of high-energy environments with constantly shifting substrates, which caused intermittent and limited colonization by infaunal organisms and few epifauna (Howard, 1975, 1978; Pemberton et al., 1992). Overall, physical sedimentary structures are dominant over biogenic sedimentary structures; all of the strata examined are unbioturbated to moderately bioturbated, pointing toward relatively high-energy conditions and frequent reworking of sediments by physical processes (Howard and Reineck, 1972; Howard, 1975). Intertidal zones can be inhospitable for preservation of body and trace fossils through sandy, shifting substrates, abrupt changes in salinity, and acidic waters (Howard and Frey, 1975; Dalrymple and Makino, 1989). Indeed, very few macroscopic body fossils are observable at outcrops of the Mungok Formation, although fragments of marine invertebrates are commonly observed in thin sections (Woo et al., 1990; Paik et al., 1991).

The trace fossil assemblage and associated lithofacies in the Mungok Formation are typical of a Skolithos ichnofacies. Trace fossils of this ichnofacies are composed primarily of: (1) vertical burrows representing domichnia of suspension feeders (dwelling structures: Skolithos, Arenicolites); (2) comparatively fewer examples of horizontal traces, which represent fodinichnia of deposit feeders (feeding traces: Planolites); and (3) low diversity (Pemberton et al., 1992). The Skolithos ichnofacies typically indicates substantial current or wave activity and develops in clean to slightly muddy, well-sorted, shifting sediments (Frey and Pemberton, 1984; Frey et al., 1990; Pemberton et al., 1992), which results in a preferential preservation of physical sedimentary structures instead of biogenic structures. Depositional environments that might have a Skolithos ichnofacies include the foreshore and shoreface of beaches, estuarine points bars, spits, bars, submarine fans, or tidal deltas (Pemberton et al., 1992). Carbonate intertidal zones can also contain elements of a Skolithos ichnofacies (Curran, 1992; Pratt et al., 1992), although relatively few examples have been reported from Paleozoic carbonates, possibly because most ichnologists have shown preferred interest in terrigenous rocks (Narbonne, 1984; Pickerell et al., 1984; Curran, 1992).

V. DEPOSITIONAL ENVIRONMENT OF THE MUNGOK FORMATION

Previous interpretations of intertidal environments in the Mungok Formation (Paik and Lee, 1989; Paik et al., 1991) seem to be supported by the ichnologic evidence, although specific information revealed by trace fossils provide a more detailed picture of the paleoenvironments. For example, the relatively small sizes of the Mungok trace fossils may be related to tidal range, height of the low water table, and instability of the substrate. Organisms in intertidal settings often will burrow deeply to stay within sediments below the marine water table, which prevents desiccation and buffers against major salinity or temperature fluctuations (Pemberton et al., 1992). Thus, a large tidal range, such as that found along the mordern Inchon tidal flats (Frey et al., 1987a, b, 1989), would have more periodic exposure of organisms to the environmental extremes of high and low tide, necessitating some deep burrowing for infaunal organisms. In contrast, shallow burrows may indicate near-constant submergence of a tidal flat (albeit by relatively shallow water), which provides a reason for organisms not to burrow as deeply. Thus, smaller tidal ranges (i.e., microtidal, mesotidal) might be indicated by smaller burrows. Additionally, the relative instability of sediments in the Mungok is suggested by the predominance of small burrows that originate at bed tops: these burrows represent the incursion of opportunistic species that colonized the substrate immediately after physical disturbance and reworking of the sediment. Associated physical sedimentary structures, such as those in the rippled-lenticular-flaser facies and flat-pebble conglomerate facies, support the notion of continual physical reworking of sediments and trace fossils provide evidence of short periods of quiescence between reworking episodes. Responses by organisms were immediate, evidenced by the aforementioned vertical burrows as well as horizontal burrows: this type of opportunistic colonization by organisms into reworked sediments has been described in post-storm ichnofacies by Frey (1990). However, shifting substrates typical of a Skolithos ichnofacies increased the likelihood that some burrow tops may have been eroded (Bromley and Asgaard, 1991), thus the measured depths of some vertical burrows actually might represent truncated depths that were originally greater. Nevertheless, burrow widths are also relatively small and somewhat proportional to burrow lengths of extant ichnospecies. Consequently, Mungok trace fossils seem to be representative of paleoenvironmental conditions despite any preservational controls that affected the assemblage.

VI. CONCLUSIONS

Trace fossils have been inadequately documented by previous workers in lower Paleozoic rocks of Korea. However, the Lower Ordovician Mungok Formation of the Yeongweol region provides an example of a Skolithos ichnofacies in most lithofacies. Mungok trace fossils are represented mainly by small, vertical burrows of suspension feeders (Skolithos, Arenicolites) and relatively fewer horizontal burrows of deposit feeders (Planolites). Most trace fossils are associated primarily with rippled-lenticular-flaser facies, although some burrow mottling is evident near tops of flat-pebble conglomerate beds. Trace fossils are in most of the formation, but some lithofacies exhibit little or no evidence of biogenic disturbance. The low diversity and small sizes of trace fossils may be the result of physical reworking, high sedimentation rates, and other stresses typical of intertidal regimes. This ichnologic information supplements lithologic data about paleoenvironments of the Mungok Formation.

We hope that this study will provide the incentive for other workers to seek and include more ichnologic information in their studies of Paleozoic rocks in Korea. The paucity of previous work on paleoichnology is regrettable but not irreversible: the extensive outcrops of Paleozoic strata in Korea provide ample opportunity for future workers to contribute to the ever-broadening scope of international ichnology.

VII. ACKNOWLEDGEMENTS

Fundings for this project was provided by the Basic Research Project (PE00321) of Korea Ocean Research and Development Institute (Moon) and an Emory University Summer Research Grant from the University Research Committee (Martin). The authors wish to thank Dr. Jeong-Keuk Kang and Dr. Byong-Kwon Park of the KORDI for encouragement during the study.

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Table 1. Stratigraphic setting for Mungok Formation (after Lee, 1987).

Age		Kim, O.J., et al. (1973)	Lee, H.Y., (1980) Lee, et al.(1986)
ORDOVICIAN	Ashigilian		
	Caradocian	Yonghung Fm.	Yonghung Fm.
	Landeilian	Samtaesan Fm. (Mungog Fm.)	
	Llanvirnian		
	Arenigian	Hungwolri Fm. (Wagok Fm.)	Mungog Fm.
	Tremadocian		
CAMBRIAN	Upper	Machari Fm.	Wagog Fm.
	Middle	Sambangsan Fm.	Machari Fm.
	Lower	Taegi Fm.	

Table 2. Ethologic categories and relative abundance of major trace fossil genera in Mungok Formation, Yeongweol region. Location key: MC=Machari; YS=Yeongweol-samgeori; BJ= Baeil Jae; CS=Changweon-samgeori.

Trace Fossil	Ethology	Relative Abundance	Location
Arenicolites	Domichnion	Moderate	MC, YS, BJ, CS
Monocraterion	Donichnion	Rare	YS
Palaeophycus	Domichnion	Rare	MC, YS
Planolites	Fodinichnion	Abundant	MC, YS, BJ, CS
Skolithos	Domichnion	Abundant	MC, YS, BJ, CS

Table 3. Semiquantitative categories based on amounts of biogenic disturbance of physical sedimentary structures.

Category	Percent Biogenic Disturbance	Description
1	0 %	Unbioturbated
2	1 - 25 %	Slightly bioturbated
3	25 - 50 %	Moderately bioturbated
4	50 - 75 %	Substantially bioturbated
5	75 - 99 %	Intensely bioturbated
6	100 %	Completely bioturbated

Categories 1 + 2 + 3 = physical sedimentary structures dominant

Categories 4 + 5 + 6 = biogenic sedimentary structures dominant

Table 4. Total thicknesses and percentage thicknesses of semiquantitative categories estimating amounts of bioturbation. None of the beds examined were Categories 4, 5, and 6.

	Category 1 (0 %)	Category 2 (1-25 %)	Category 3 (25-50 %)
Machari	7.17 m	41.38 m	1.23 m
Yeongweol-samgeori	49.70 m	29.80 m	-
Total Thickness	56.87 m	71.63 m	1.23 m
Percentage of Thickness	43.8 %	55.2 %	1.0 %

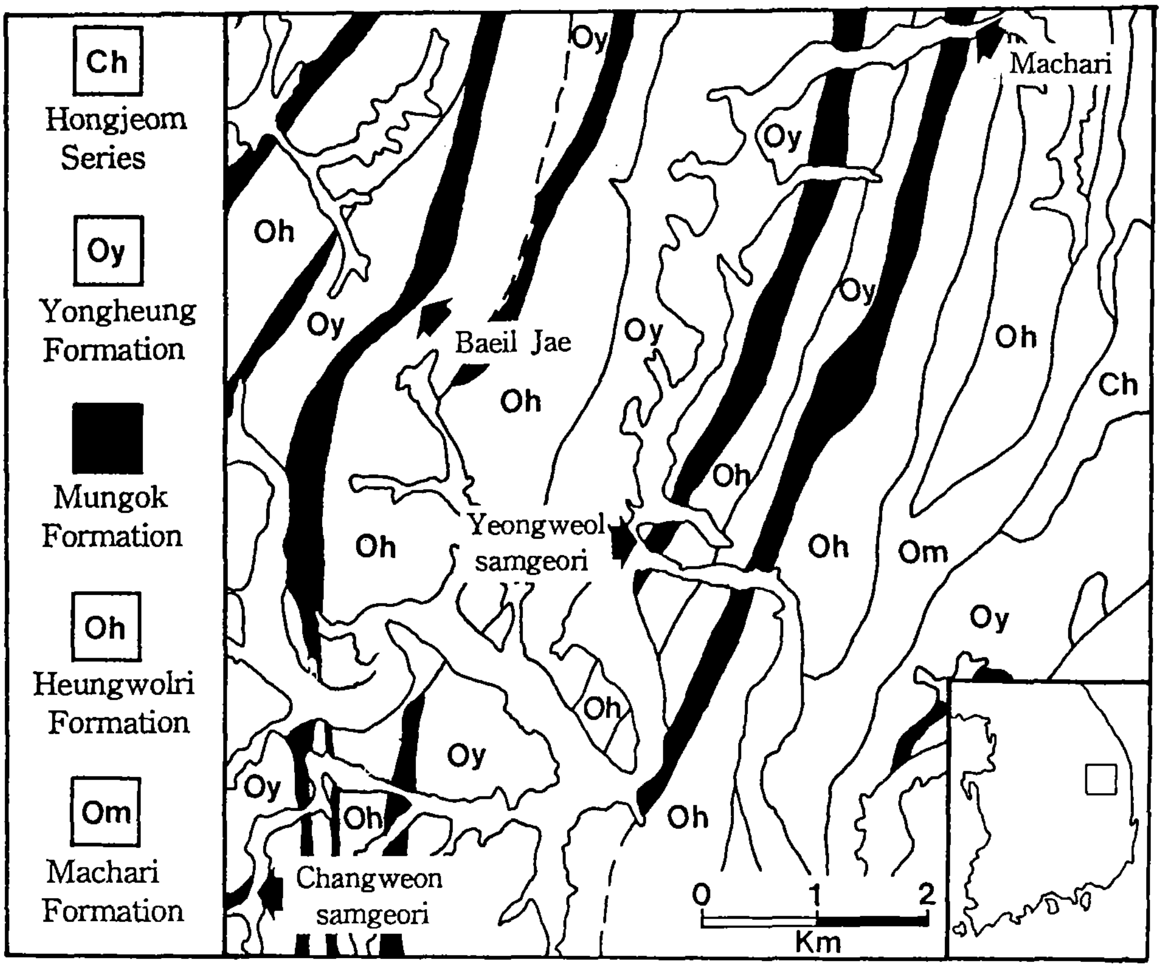

Fig. 1. Study area with indicated localities of Mungok Formation (after Choi, 1991).

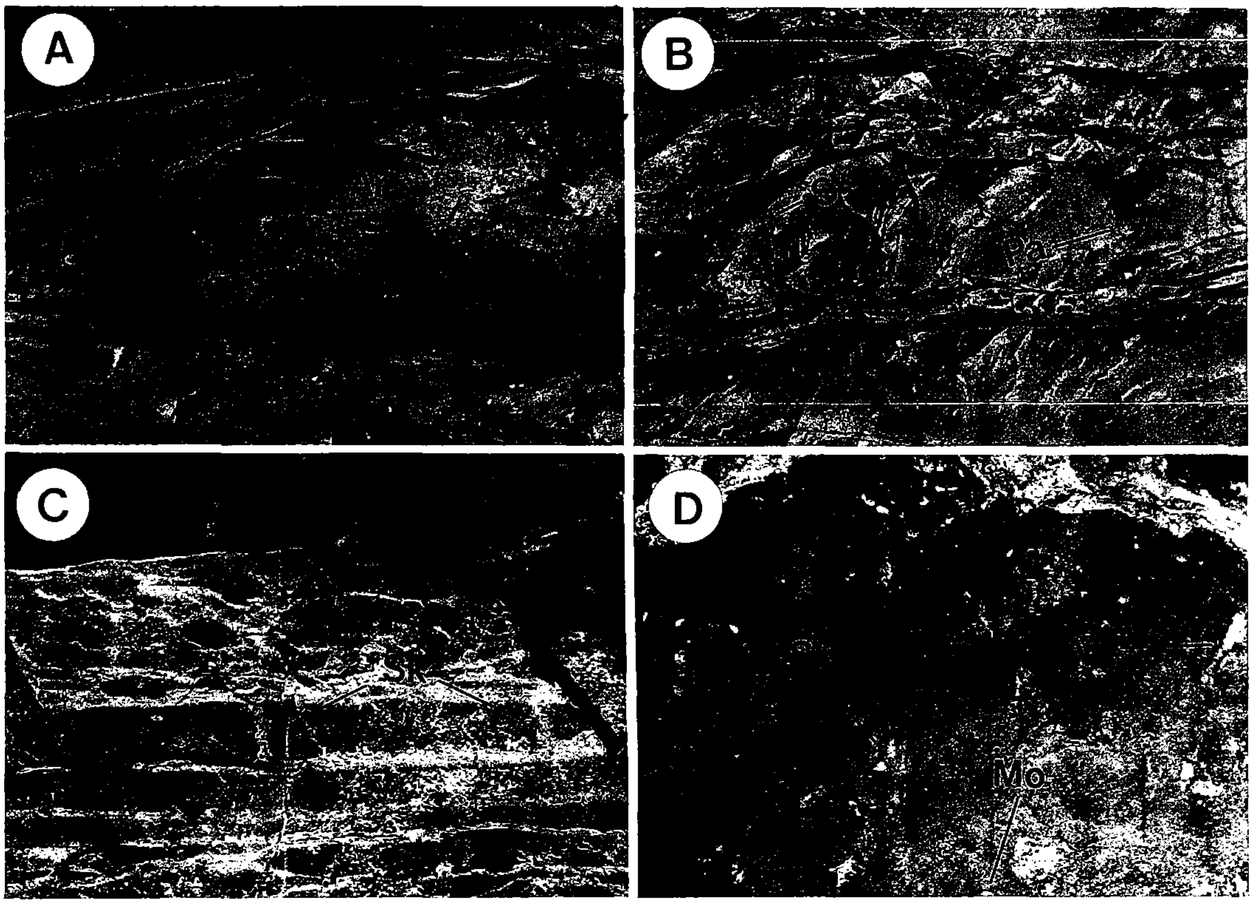

Fig. 2. Vertical burrows in rippled and flaser beds. A) Skolithos isp. 1 (Sk) and Arenicolites isp. 1 (Ar) in rippled beds, Machari. B) Skolithos isp. 1, showing origination at rippled bed tops, and Palaeophycus (Pa), in rippled beds, Machari. C) Skolithos isp. 2, penetrating entire bed thickness and infilled with same material as flaser interbed, Baeil Jae. D) Skolithos, Arenicolites, and Monocraterion (Mo) on top of rippled bed, Yeongweol-samgeori. Scale bars are 5 cm.

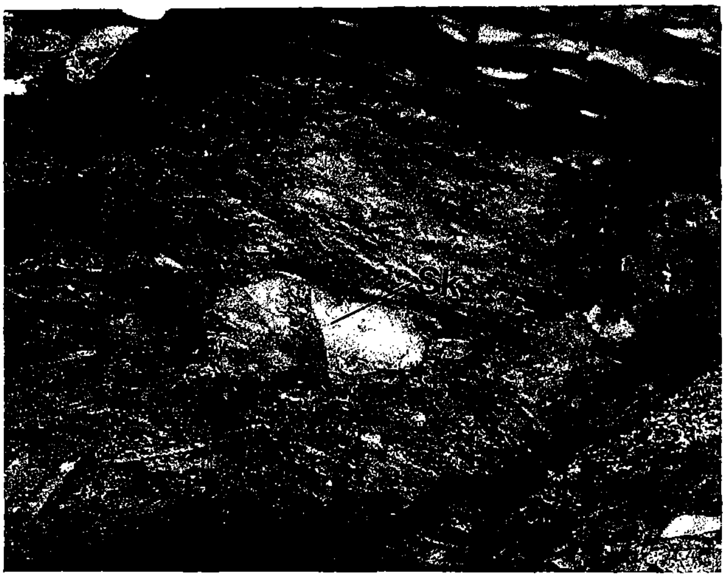

Fig. 3. Skolithos isp. 3 cross-cutting clast in flat-pebble conglomerate Machari. Unit scale is 1 cm.

Fig. 4. Small vertical burrow (square mark) originating at top of ripple-laminated chert bed, Baeil Jae. Unit scale is 1 cm.

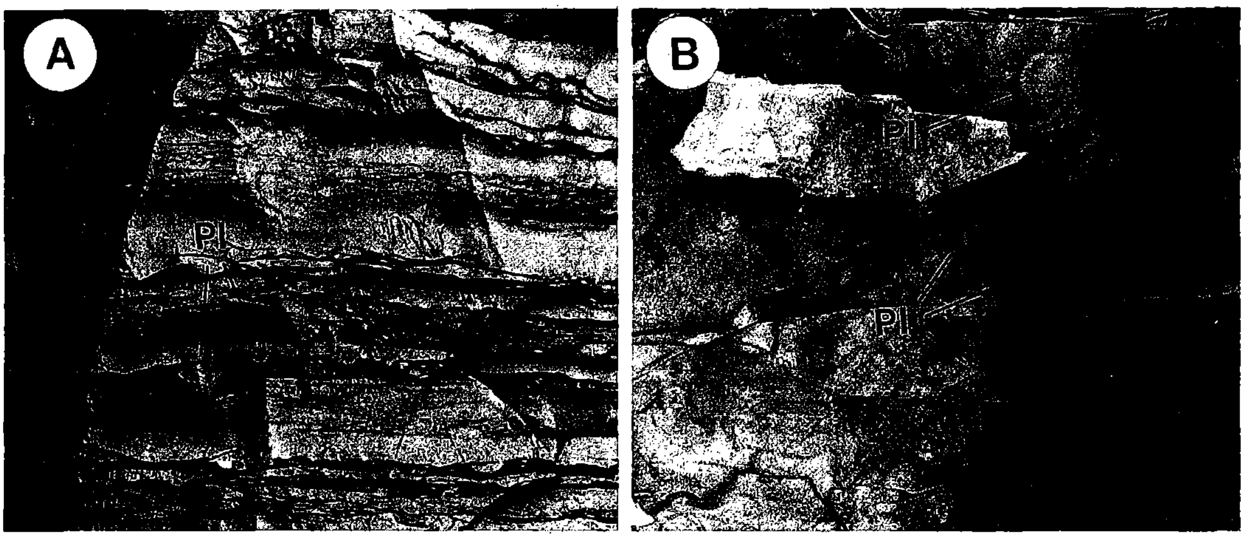

Fig. 5. Horizontal burrows in rippled and flaser beds. A) Planolites isp. 1 (Pl), evident as hypichia, Machari. B) Bedding plane surface (top) of Planolites isp. 2, Baeil Jae. Scale bars are 5 cm.

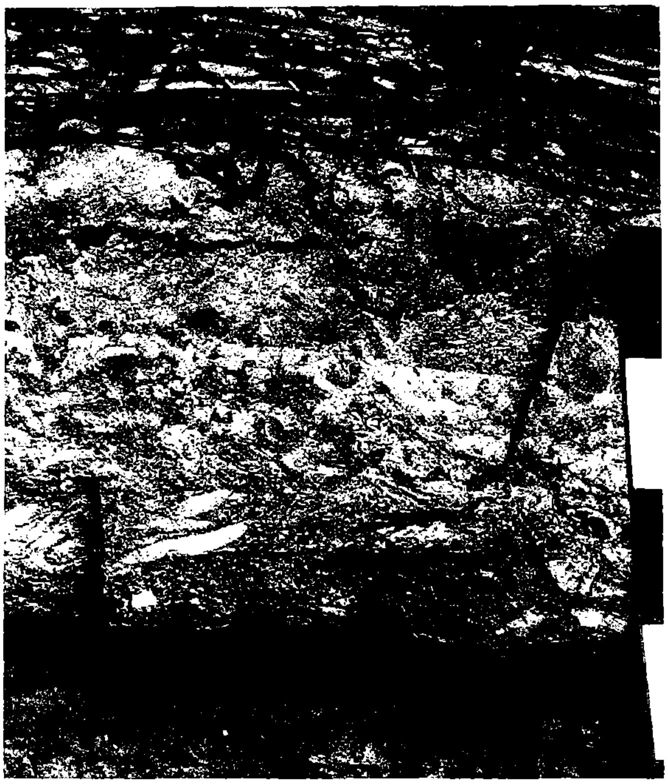

Fig. 6. Burrow mottling in top part of flat-pebble conglomerate bed, Machari. Unit scale is 5 cm.

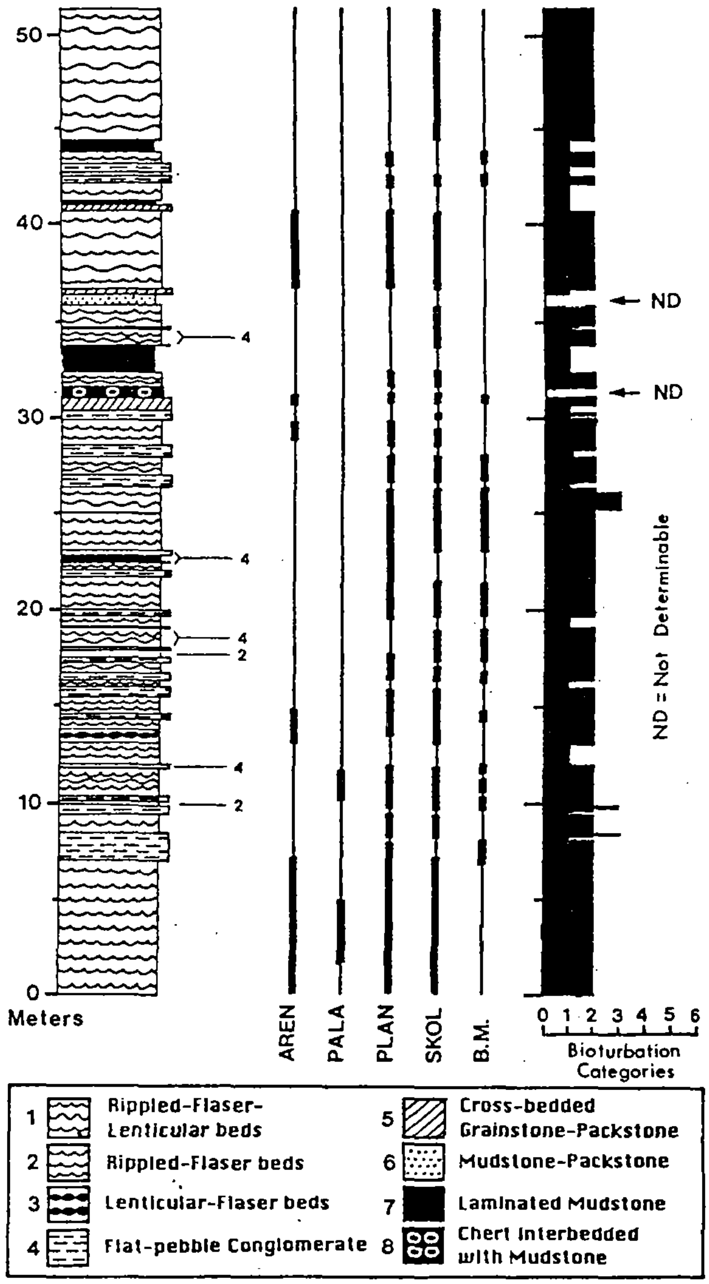

Fig. 7. Stratigraphic section of upper part of Mungok Formation exposed at Machari, including lithofacies, presence of ichnogenera and burrow mottling (indicated by thicker bars), and relative amounts of bioturbation. All lithofacies are dolomitic limestone or dolomite. Ichnogenera key: AREN=Arenicolites; PLLA=Palaeophycus; PLAN=Planolites; SKOL=Skolithos; B.M.=Burrow Mottling. Bioturbation categories are explained in Table 3.

APPENDIX I : Field Localities

Machari Section

P'yongch'ang Quacrangle, within Sections 418 and 151: 37 degrees 15' N, 128 degrees 27' E; roadcut on north side of Highway 413, across from stream parallel to road. Only thhe upper 52 of 120 meters of the Mungok Formation is exposed here - the lower part is covered.

Yeongweol-samgeori Section

Yongwol Quadrangle, within Sections 412 and 149: 37 degrees 12' N, 128 degrees 25' E; section on north side of river along trail, just east of Highway 31. About 70 meters of discontinuous section (out of about 130 meters total thickness) of the Mungok Formation is exposed here.

Baeil Jae Section

Yongwol Quadrangle, within Sections 413, 414, and 146: 37 degrees 13' N, 128 degrees 24' E; roadcut on north side of Highway 402 is continuous but winding outcrop leading up to scenic overlook; continuous section of Mungok Formation but much of the section has been affected by structural deformation.

Changweon-samgeori Section

Yongwol Quadrangle, within Sections 409 and 145: 37 degrees 11' N, 128 degrees 23' E; roadcut on north side of Highway 38 at bend in road, south of railroad tracks and immediately west of railroad bridge over Highway 38; small outcrop, only about 30 meters of Mungok Formation exposed.

APPENDIX II : Systematic Ichnology

FEEDING TRACES (FODINICHNIA)

Palaeophycus isp.

Morphological Description: Horizontal to slightly oblique to bedding (mostly horizontal); simple unbranched and meandering burrows; burrow lining $\leq$1 mm thick, burrow diameter 2-3 mm, elliptical cross-section but nearly circular, flattened slightly parallel to bedding; total length indeterminable, occurs about 1-2 cm within 3-4 cm thick beds.

Toponomic Description: Exichnia, silty infillings, weathered out as positive relief in dolomitic limestone. Seems to be same silty material composing flaser beds between wavy-bedded dolomitic limestone.

Comments: Rare at all localities, only observed at a few horizons.

Planolites isp. 1

Morphological Description: Horizontal to slightly oblique to bedding (mostly horizontal); simple unlined and unbranched meandering burrows; width 3-7 mm with elliptical cross-section, flattened parallel to bedding; length indeterminable, occur about 1–2 cm within 3–4 cm thick beds.

Toponomic Description: Exichnia, silty infillings, weathered out as positive relief in dolomitic limestone. Burrow fill seems to be same silty material composing flaser beds between ripple-bedded dolomitic limestone.

Comments: This ichnospecies is represented by small-scale feeding traces associated with vertical burrows in same beds, thus they may represent secondary colonization by deposit feeders after initial colonization by opportunistic species.

Planolites isp. 2

Morphological Description: Horizontal to slightly oblique to bedding (mostly horizontal); simple unlined and unbranched meandering burrows; width 2–3 mm, length 6–8 cm.

Toponomic Description: Positive and negative epichnia, silty infillings, weathered out as positive relief in dolomitic limestone. Concentrated within hematitic flasers of cross-bedded packstones.

Comments: Because most outcrops of the Mungok Formation have few bedding plane exposures, epichnial or hypichnial specimens of Planolites in the Mungok Formation are difficult to describe. These specimens of Planolites, which occur at Yeongweol-samgeori, provide more precise information about thhe horizontal extent of the burrows. Their concentration within flasers is very similar to the same stratigraphic occurrence of Planolites in the Machari section, including a similarity in feeding stratege.

Burrow Mottling

Morphological Description: Horizontal to oblique to bedding, few vertical components; possibly branched but two-dimensional surface mitigates more accurate assessment (may be separate but intersecting burrow); width 3-10 mm.

Toponomic Description: Exichnia, silty infillings, weathered out as positive relief in dolomitic limestone.

Comments: Most mottling is probably assignable to Planolites, but is difficult to define as only one ichnogenus. Most common in top parts of storm beds (flat-pebble conglomerates), but can be easily confused with interstitial silt between clasts in conglomerate.

DWELLING TRACES (DOMICHNIA)

Arenicolites isp. 1

Morphological Description: Vertical to bedding; simple unlined and unbranched U-shaped burrow with no visible sperite; width of burrow 4 mm, length/depth into bed 1.0 cm, breadth of "U" 1.2 cm.

Toponomic Description: Exichnia, silty infillings, weathered out as positive relief in dolomitic limestone. Seems to be same silty material composing flaser beds between wavy-bedded dolomitic limestone.

Comments: Relatively uncommon at this locality, may be associated with Skolithos as an opportunist burrow, representing initial colonization of the substrate.

Arenicolites isp. 2

Morphological Description: Vertical to bedding; simple unlined and unbranched U-shaped burrow with no visible spreite; width of burrow 3 mm, length/depth into bed probably 2.5 cm (penetrating entire thickness of rippled bed), breadth of "U" 3.0 cm (Yeongweol-samgeori example, burrow width 3 mm, vertical extent unknown, breadth of "U" 3.9 cm). Burrow top evident on top of rippled bedding plane.

Toponomic Description: Exichnia and epichnia, both evident as silty infillings, weathered out as positive relief in rippled dolomitic limestone.

Comments: Occur in rippled beds in float samples near lower part of Machari and Yeongweol-samgeori sections, clearly visible in association with Skolithos in abundance on tops of rippled beds.

Monocraterion isp.

Morphological Description: Vertical to bedding; simple lined burrow with funneled aperature surrounded by deformed concentric laminae in host sediment; width of funnel 0.8-1.0 cm, width and length of underlying part of burrow undeterminable.

Toponomic Description: Epichnia, deformed laminae distinct from surrounding material by silty infill.

Comments: Only a few specimens were observed on bed tops at Yeongweol-samgeori; the ichnogenus was interpreted on the basis of the deformed concentric laminae, but othher views of the burrow were not observed. Erosion of the funneled aperature of Monocration would create a burrow similar to Skolithos, thus examples of Skolithos, common at all localities, may actually represent a more abundant occurrence of Monocraterion than what was preserved.

Skolithos isp. 1

Morphological Description: Vertical to bedding; simple unlined and unbranched burrow; width of burrow 1–2 mm, length/depth into bed 1.0 cm, some specimens show origin on bed top, circular cross-section at top.

Toponomic Description: Exichnia, silty infillings, weathhered out as positive relief in dolomitic limestone. Seems to be same silty material composing flaser beds between wavy-bedded dolomitic limestone.

Comments: Smaller variety of two very similar species of Skolithos; may represent first colonizers of sediment in intertidal environment.

Skolithos isp. 2

Morphological Description: Vertical to bedding; simple unlined and unbranched burrow; width of burrow 2–5 mm, length/depth into bed 1.1–1.3 cm, some specimens show origin on bed top, circular cross-section at top.

Toponomic Description: Exichnia, silty infillings, weathered out as positive relief in dolomitic limestone. Seems to be same silty material composing flaser beds between wavy-bedded dolomitic limestone.

Comments: Large variety of two very similar types of Skolithos; may represent second colonizers of sediment in intertidal environment, after Skolithos sp. 1.

Skolithos isp. 3

Morphological Description: Vertical to bedding; simple unlined and unbranched burrow; width of burrow 3-4 mm, length/depth 2.0-3.0 cm.

Toponomic Description: Exichnia, silty infillings, weathered out as positive relief in rippled dolomitic limestone. Seems to be same silty material composing flaser beds between wavy-bedded dolomitic limestone.

Comments: Rare larger form of Skolithos that occurs in some beds, one specimen cross-cuts a clast within a flat-pebble conglomerate bed.

PART II

MAGGOL FORMATION

(Field Description)

I. DANYANG SECTION

1. Location and General Description

Outcrop examined but not measured or described along highway adjacent to Danyang. Burrow mottling observed in relative lower, middle, and upper parts of Maggol Formation, according to positions of previously mapped area.

Burrow mottling consisted of large (< 1.0 cm width) burrows, mostly paralled to bedding. Bedding was rippled to microrippled, some flasers, mottling concentrated in between ripples in parts where physical sedimentary structures are dominant over biogenic sedimentary structures. Bioturbated zones range from Bioturbation Category (BTC) 2 (1-25%) to BTC 5 (75-99%). Mottling seems to increase in size proportionally with thickness of ripples and interbedded flasers.

Field check of lithology and burrow infill material revealed that the lithology is dolomitic limestone, and burrow infills react about the same to acid as thhe host lithology, but some silt in burrows causes different fill and exichnial appearance, weathering to light gray to tan mottling in outcrop.

Burrow mottling seems to be the same in type and preservation throughout the upper, middle, and lower parts of the Maggol Formation in this area.

2. Section Description

Samples (designated by MG-DY-#)

(1) MG-DY-1 : burrow mottling of top of zone photographed in MG-DY-1, upper part of Maggol Formation.

(2) MG-DY-2 : rippled bed showing bedding-plane parallel burrow mottling, at same locality as MG-DY-1.

(3) MG-DY-3 : burrow mottling, sample taken next to place photographed in MG-DY-2, middle of Maggol Formation.

(4) MG-DY-4 : burrow mottling in lower part of Maggol Formation, near intersection leading to cave, next to place photographed in MG-DY-4.

Photos

(1) MG-DY-1 : burrow mottling in upper part of Maggol Formation.

(2) MG-DY-2 : burrow mottling in middle part of Maggol Formation.

(3) MG-DY-3 : burrow mottling in middle part of Maggol Formation.

(4) MG-DY-4 : burrow mottling of lower part of Maggol Formation.

II. DONGJEOM (STREAMCUT) SECTION

1. Location and General Description

Changsong Quadrangle, within Sections 399 and 204: 37 degrees 5' N, 129 degrees 3' E; streamcut of the Maggol Formation was examined, and a measured section was initiated. The streamcut is located just to west of a natural bridge (composed of the Maggol Formation, eroded by the stream) and intersection, and is parallel to Highway 35. The position of the outcrop, when compared to a geologic map of the area, probably exposes the lower part of the Maggol Formation, but the lower contact was not observed. The probable upper contact is nearly underneath but just several meters to the east of a small bridge, but was not exposed.

Strike and dip of beds (Strike = 54 NE, dip = 46 NW) in the streamcut are fairly consisstent through much of the exposure, but beds were more folded near the probable upper contact. Base of measured section was designated at the break in slope at the entrance of the natural bridge, on the south side of the stream (near to the road).

The lower part of the Maggol Formation is characterized by extensive exichnial burrow mottling that weathers to a light tan, contrasting with the gray host rock. Most of the burrow mottling consists of probably just two ichnogenera: Thalassinoides and Planolites (although both were designated as Planolites in the field), and is so pervasive in some zones that interrelationships between burrows and identification is difficult to impossible. Because of this difficulty, burrow mottling is noted simply as "burrow mottling" unless identifiable genera were distinguished.

2. Section Description

(1) Wackestone, few flasers and ripples, few bedding planes preserved, 5.0 m thick; BTC = 5 (75-99%), burrow mottling.

(2) Wackestone, more flasers/ripples, 30 cm thick; BTC = 4(50-75%), burrow mottling.

(3) Wackestone, few flaser/ripples, 3.0 m thick; BTC = 5 (75-99%), burrow mottling.

(4) Wackestone, ripple/flaser/lenticular bedding, lenticular beds 0-3 cm thick, 1.0 m thick; BTC = 3 (25-50%), burrow mottling.

(5) Wackestone, ripple/flaser bedding, 2.7 m thick; BTC = 4(50-75%), burrow mottling.

(6) Wackestone, may have remnants of ripples but obscured by mottling, 80 cm thick; BTC = 6 (100%), burrow mottling.

(7) Wackestone, some bedding planes defined by bedding-parallel mottling, 90 cm thick; BTC = 5 (75-99%), burrow mottling, very densely populated but concentrated in bedding plane zones.

(8) Flat-pebble conglomerate, some ripples discernible in lower 10 cm, 40 cm thick; BTC = 4 to 5 (50-80%), gradual increase upward in burrow mottling, especially in top 30 cm of bed.

(9) Wackestone, few ripples or flasers, some internal bedding in unit is discernible as 30-40 cm thick beds, bedding may be related to bioturbation depth, 4.4 m thick; BTC = 5 (75-99%), burrow mottling.

(10) Wackestone, ripple/flaser bedded, 50 cm thick; BTC = 2 (15-20%), some burrow mottling.

(11) Wackestone, few flasers, 40 cm thick; BTC = 4 (50-75%).

(12) Wackestone, ripple/flaser bedded, 80 cm thick; BTC = 3 (25-50%).

(13) Wackestone, possible rippled beds, 15 cm thick; BTC = 4 (50-75%).

(14) Wackestone, rippled beds, 20 cm thick; BTC = 2 (10-20%), ?Skolithos, burrow mottling.

(15) Wackestone, few flasers, 1.35 m thick; BTC = 5 (75-99%), burrow mottling.

(16) Flat-pebble conglomerate, 25 cm thick; BTC = 2 (10%), burrow mottling.

(17) Wackestone/packstone, ripple/lenticular bedding, 40 cm thick; BTC = 2 (15-20%), burrow mottling, ?Skolithos.

(18) Packstone, rippled with megaripples (0-25 cm thick), 65 cm thick; BTC = 2 (15-20%), burrow mottling, ?Skolithos.

(19) Packstone/wackestone, ripple/flaser/lenticular bedding, lensoidal form (convex on base and more flat on top), truncation of underlying strata and lateral association with underlying megaripples, ripples and flasers within lens, possible abandoned channel showing some lateral migration, 1.1 m thick; BTC = 3 (25-50%), burrow mottling, bioturbation of ripples and flasers may demonstrate that channels were abandoned and became low-energy environments for infaunas.

(20) Wackestone/packstone, ripple/flaser/lenticular, 90 cm thick; BTC = 2 (10-25%), burrow mottling.

(21) Flat-pebble conglomerate, 20 cm thick; BTC = 2 (5-10%).

(22) Wackestone/packstone, ripple/lenticular/flaser bedding, 1.8 m thick; BTC = 2 (5-10%), burrow mottling.

Section was stopped at end of outcrop on the south side of the stream. Approximately 10 meters separate the top of this part of the outcrop and remaining outcrop on the north side of the stream. 10 meter gap was recorded and section was resumed on north side of stream.

(23) Wackestone/packstone, ripple/flaser bedding, 1.0 m thick; BTC = 3 (25–50%), burrow mottling.

(24) Wackestone/packstone, ripple/flaser bedding, 1.2 m thick; BTC = 4 to 5 (50–99%), burrow mottling, gradually increases upward.

(25) Wackestone/packstone, ripple/flaser bedding, 3.0 m thick; BTC = 3 (25–50%), Skolithos, burrow mottling, trace fossils have more vertical components than underlying burrowed units.

(26) Flat-pebble conglomerate, 10 cm thick; BTC = 3 (25–50%), burrow mottling.

(27) Wackestone/packstone, ripple/flaser bedding, 3.0 m thick; BTC = 3 (25–50%), Skolithos, burrow mottling. Unit is a continuation of unit 25, but is interrupted by conglomerate in unit 26.

(28) Flat-pebble conglomerate, graded bedding, 10 cm thick; BTC = 1 (0%).

(29) Wackestone, few lenticular/rippled beds, 1.0 m thick; BTC = 5 (75–99%), burrow mottling.

(30) Wackestone/packstone, small (1-2 cm thick) rippled and lenticular beds, 1.7 m thick; BTC = 2 (10-25%), burrow mottling.

(31) Wackestone, few flasers, 1.0 m thick; BTC = 5 (75-99%), bioturbate textures, discrete burrow mottling or trace fossils not discernible.

(32) Wackestone, few flasers, 50 cm thick; BTC = 5 (75-99%), bioturbate textures.

(33) Wackestone, few flasers, 50 cm thick; BTC = 5 (75-99%), bioturbate textures.

(34) Wackestone, few flasers, rippled beds in top 30 cm, 1.4 m thick; BTC = 5 (75-99%) in first 1.1 m, 4 (50-75%) in remaining 30 cm, bioturbate textures.

(35) Wackestone, few flasers, 1.2 m thick; BTC = 5 (75-99%), bioturbate textures, some smaller burrows structures (several mm's diameter) evident in some fresh fractured surfaces.

(36) Wackestone, few flasers, 1.7 m thick; BTC = 5 (75-99%), bioturbate textures.

(37) Wackestone/packstone, few wavy bedding planes (possibly rippled), 1.6 m thick; BTC = 4 (50-75%), bioturbate textures.

(38) Wackestone/packstone, few wavy bedding planes (possibly rippled), 2.6 m thick; BTC = 5 (75-99%), bioturbate textures.

(39) Wackestone/packstone, few wavy bedding planes (possibly rippled), 20 cm thick; BTC = 5 (75–99%), bioturbate textures.

(40) Wackestone/packstone, few rippled beds (about 10–20 cm thick), 1.6 m thick; BTC = 5 (75–99%).

(41) Wackestone/packstone, few rippled beds (about 10–20 cm thick), 90 cm thick; BTC = 4 (50–75%).

(42) Wackestone/packstone, few rippled beds (about 10–20 cm thick), 50 cm thick; BTC = 4 (50–75%).

(43) Wackestone/packstone, few rippled beds (about 10–20 cm thick), 30 cm thick; BTC = 4 (50–75%).

(44) Wackestone/packstone, few rippled beds (about 10–20 cm thick), 1.0 m thick; BTC = 4 (50–75%).

(45) Wackestone/packstone, few rippled beds (about 10–20 cm thick), 15 cm thick; BTC = 4 (50–75%).

(46) Wackestone/packstone, few rippled beds (about 10–20 cm thick), 85 cm thick; BTC = 4 (50–75%).

(47) Wackestone/packstone, ripple/flaser bedding in lower part, few ripples in upper part, 2.8 m thick; BTC = 2 (10–25%) for lower 80 cm, 4 (50–60%) in upper 2.0 m of unit, bioturbate textures.

(48) Wackestone/packstone, ripple/flaser bedding, 2.0 m thick; BTC = 3 (25–50%), bioturbate textures.

(49) Wackestone/packstone, few flasers, 40 cm thick; BTC = 5 (75-99%), bioturbate textures, burrow mottling.

(50) Wackestone/packstone, few flasers, 1.0 m thick; BTC = 5 (75-99%), bioturbate textures, burrow mottling.

(51) Wackestone/packstone, few flasers, 1.2 m thick; BTC = 5 (75-99%), bioturbate textures, burrow mottling.

(52) Flat-pebble conglomerate, graded bedding, 25 cm thick; BTC = 1 (0%).

(53) Wackestone/packstone, ripple/flaser bedding, fewer flasers toward top of unit, 25 cm thick; BTC = 2 (10%) to 3 to 4 (60%), gradual upward increase in burrow mottling and bioturbate textures.

(54) Packstone, possible lenticular/flaser bedding, 10 cm thick; BTC = 4 (50-75%), burrow mottling, bioturbate textures.

(55) Wackestone/packstone, ripple/flaser bedding, fewer flasers toward top of unit, 30 cm thick; BTC = 2 (10%) to 3 to 4 (60%), gradual upward increase in burrow mottling and bioturbate textures.

(56) Wackestone/packstone, few flasers or rippled beds, 90 cm thick; BTC = 4 (50-75%), burrow mottling, bioturbate textures.

(57) Wackestone/packstone, few flasers or rippled beds, 40 cm thick; BTC = 4 (50-75%), burrow mottling, bioturbate textures.

(58) Flat-pebble conglomerate, 50 cm thick; BTC = 2 (5-10%), burrow mottling, bioturbate textures.

(59) Wackestone/ packstone, ripple/flaser bedding, rippled beds 2-12 cm thick, 2.3 m thick; BTC = 3 (25-30%), burrow mottling, bioturbate textures.

(60) Flat-pebble conglomerate, graded bedding, 70 cm thick; BTC = 2 to 3 (5-30%), 2 in lower 60 cm, 3 in upper 10 cm, burrow mottling prominent in upper 10 cm.

(61) Wackestone/packstone, rippled (10-20 cm thick beds), 90 cm thick; BTC = 2 (1-5%), sparse burrow mottling.

(62) Wackestone/packstone, ripple bedded with cross-laminations, 40 cm thick; BTC = 2 (1-5%), sparse burrow mottling.

(63) Flat-pebble conglomerate, 50 cm thick; BTC = 1 to 2 (0-10%), bioturbate textures.

(64) Wackestone/packstone, ripple/flaser/lenticular bedding, lenticular and rippled beds 0-10 cm thick, some flasers develop into shaley beds, 0-3 cm thick, 90 cm thick; BTC = 2 (1-5%), Skolithos.

(65) Wackestone/packstone, ripple bedded, ripples 15-20 cm thick, 70 cm thick; BTC = 1 (0%).

(66) Wackestone/packstone, ripple bedded, ripples 2-10 cm thick, 40 cm thick; BTC = 1 (0%).

(67) Wackestone/packstone, ripple bedded, few flasers, rippled beds 4–10 cm thick, some graded bedding in rippled beds, 35 cm thick; BTC = 1 (0%).

(68) Packstone/grainstone, trough cross-bedded, some coarse lags in trough cross-bed sets, 35 cm thick; BTC = 2 (1–5%), Skolithos.

(69) Wackestone/packstone, ripple/flaser bedded, rippled beds 2–7 cm thick, well-developed rippled beds, 60 cm thick; BTC = 2 (1–5%), Skolithos.

(70) Wackestone/packstone, planar bedded, some flasers, beds 10–25 cm thick, 70 cm thick; BTC = 1 (0%).

(71) Flat-pebble conglomerate, 7 cm thick; BTC = 2 (1–5%), burrow mottling.

(72) Wackestone/packstone, planar bedded, some flasers, beds 10–25 cm thick, 43 cm thick; BTC = 1 (0%).

(73) Wackestone/packstone, ripple bedded with ripple laminations, rippledbeds 2–7 cm thick, few flasers, 2.0 m thick; BTC = 2 (5–10%), burrow mottling, Skolithos.

(74) Wackestone/packstone, planar bedded, well laminated, some flasers, 40 cm thick; BTC = 2 (1–5%), Skolithos.

(75) Wackestone/packstone, ripple bedded with ripple laminations, rippled beds 2–7 cm thick, few flasers, 50 cm thick; BTC = 1 (0%).

(76) Wackestone/packstone, planar to ripple bedded, ripples low amplitude, 30 cm thick; BTC = 1 (0%).

(77) Wackestone/packstone, ripple beds with silty flasers, flasers become gradually thinner upward (1.0 cm to several mm's thickness), 50 cm thick; BTC = 1 (0%).

(78) Stromatolite (boundstone), LLH (laterally-linked hemispheroids, low amplitude), 40 cm thick; BTC = 2 (1-5%), burrow mottling (mostly vertical), penetrate laminae of stromatolite.

(79) Flat-pebble conglomerate, probable rip-up of underlying stromatolite, 10 cm thick; BTC = 2 (1-5%), burrow mottling.

(80) Wackestone/packstone, ripple bedded, ripples low amplitude, 50 cm thick; BTC = 1 (0%).

(81) Stromatolite, LLH, ephermeral, 0-10 cm thick; BTC not recorded because of lack of lateral continuity.

(82) Wackestone/packstone, ripple/lenticular/flaser bedded, lenticular beds 0-3 cm thick, 70 cm thick; BTC = 2 (1-5%), hypichnial Planolites.

(83) Wackestone/packstone, ripple/flaser bedding, ripples 10-15 cm thick, 1.2 m thick; BTC = 1(0%).

(84) Flat-pebble conglomerate, 30 cm thick; BTC = 1 (0%).

(85) Wackestone, some visible ripple laminations in 20 cm, 40 cm thick; BTC = 1 (0%).

(86) Flat-pebble conglomerate, 40 cm thick; BTC = 1 (0%).

(87) Wackestone/packstone, well laminated, 60 cm thick; BTC = 1 (0%).

(88) Flat-pebble conglomerate, 20 cm thick; BTC = 1 (0%).

(89) Packstone, ripple-laminated, fine-grained, few bedding planes, 1.3 m thick; BTC = 1 (0%).

(90) Wackestone, some laminations, 40 cm thick; BTC = 2 (1-5%), bioturbate textures.

(91) Packstone, ripple-laminated, fine-grained, similar to unit 61, 50 cm thick; BTC = 1 (0%).

(92) Wackestone/packstone, ripple/flaser bedding, ripples 1-3 cm thick, 20 cm thick; BTC = 1 (0%).

(93) Wackestone, few bedding features, 40 cm thick; BTC = 5 (75-99%), bioturbate textures.

(94) Wackestone/packstone, ripple/flaser bedding, ripples 5-7 cm thick, 80 cm thick; BTC = 4 (50-75%), burrow mottling.

(95) Flat-pebble conglomerate, 20 cm thick; BTC = 2 (10-15%), burrow mottling.

(96) Wackestone/packstone, ripple/flaser lenticular bedding, ripples and lenticular beds 0-5 cm thick, 1.2 m thick; BTC = 3 (25-30%), burrow mottling.

(97) Wackestone/packstone, ripple/flaser lenticular bedding, ripples and lenticular beds 0–5 cm thick, 2.0 m thick; BTC = 4 to 5 (50–99%), gradual upward increase in burrow mottling, some Skolithos.

(98) Wackestone/packstone, ripple/flaser lenticular bedding, ripples and lenticular beds 0–5 cm thick, 70 cm thick; BTC = 3 to 4 (30–60%), gradual increase upward in burrow mottling, some Skolithos.

(99) Wackestone/packstone, ripple/flaser bedding, ripples 3–10 cm thick, bedding obscured by burrow mottling, 80 cm thick; BTC = 4 (50–75%), burrow mottling, Skolithos.

(100) Wackestone/packstone, ripple/flaser bedded, 70 cm thick; BTC = 5 (75–99%), burrow mottling.

(101) Wackestone/packstone, ripples/flasers barely discernible, 1.1 m thick; BTC = 5 (75–99%), bioturbate textures.

(102) Wackestone/packstone, ripples/flasers barely discernible, 1.3 m thick; BTC = 5 (75–99%) for lower 50 cm to 6 (100%) for next 60 cm to 5 (75–99%) for upper 20 cm, burrow mottling, Skolithos, bioturbate textures.

(103) Wackestone/packstone, possible megaripple, cross-laminated, 65 cm thick; BTC = 2 (5–10%), small Skolithos and Planolites.

(104) Wackestone/packstone, possible megaripple, cross-laminated, 45 cm thick; BTC = 1 (0%).

(105) Wackestone/packstone, lenticular bedded, 30 cm thick; BTC = 2 (1-5%), small Skolithos.

(106) Wackestone, ripple- to planar-laminated, few flasers, 90 cm thick; BTC = 2 (1-5%), small Skolithos.

(107) Packstone, ripple/flaser bedded, 40 cm thick; BTC = 2 (1-5%), small Skolithos.

(108) Wackestone, ripple- to planar-laminated, few flasers, similar to unit 78, 40 cm thick; BTC = 2 (1-5%), small Skolithos.

(109) Flat-pebble conglomerate, 15 cm thick; BTC = 2 (1-5%), small Skolithos.

(110) Packstone, rippled, high amplitude top surface, 35 cm thick; BTC = 2 (1-5%), small Skolithos.

(111) Wackestone/packstone, lenticular/ripple/flaser bedded, lenticular and rippled beds 0-7 cm thick, lenticular beds in lower 20 cm, 80 cm thick; BTC = 2 to 3 (5-30%), gradual upward increase in burrow mottling.

(112) Wackestone/packstone, ripple/flaser bedding, 30 cm thick; BTC = 5 (75-99%), burrow mottling, Skolithos.

(113) Wackestone, 30 cm thick; BTC = 6 (100%), burrow mottling.

(114) Wackestone/packstone, ripple/flaser bedded, ripples 3-5 cm thick, 50 cm thick; BTC = 2 to 5 (10-75%), gradual upward increase in burrow mottling.

(115) Wackestone/packstone, possibly rippled, 70 cm thick; BTC = 5 (75-99%), burrow mottling.

(116) Wackestone/packstone, possibly rippled, 20 cm thick; BTC = 6 (100%), bioturbate textures.

(117) Wackestone/packstone, ripple/flaser bedded, 20 cm thick; BTC = 4 (50-75%), burrow mottling.

(118) Wackestone, rippled/laminated, 90 cm thick; BTC = 2 (1-5%), small Skolithos.

(119) Wackestone, rippled/laminated, grades into overlying lenticular beds, 2.8 m thick; BTC = 3 (25-50%), burrow mottling, bioturbate textures.

(120) Wackestone, lenticular/flaser bedding, 20 cm thick; BTC = 2 (1-5%), burrow mottling, bioturbate textures.

Approximately 5 meters of missing section in the streamcut was encountered here. 5 meter gap was recorded and section was resumed.

(121) Wackestone/packstone, ripple/flaser bedding, rippled beds 2-5 cm thick, 4.5 m thick; BTC = 4 (50-75%) in lower 1.5 m, 5 (75-99%) in next 50 cm; 6 (100%) in next 60 cm; 5 (75-99%) in next 50 cm, 6 (100%) in upper 1.4 m, possible bedding planes in last part, burrow mottling, Skolithos.

Covered area, 1.4 m thick

(122) Wackestone/packstone, possible ripple/flaser beds, rippled beds 3-7 cm thick, some bioturbated beds 15-20 cm thick, 1.2 m thick; BTC = 5 (75-99%), burrow mottling, Skolithos.

(123) Wackestone/packstone, ripple/flaser beds, rippled beds 3-7 cm thick, 70 cm thick; BTC = 3 (25-50%), burrow mottling.

(124) Wackestone/packstone, ripple/flaser beds, rippled beds 3-7 cm thick, 60 cm thick; BTC = 5 (75-99%), burrow mottling.

(125) Wackestone/packstone, possibly rippled but obscured by burrow mottling, 60 cm thick; BTC = 6 (100%).

Streamcut on north side of stream ends here. Section was resumed at a roadcut of the upper part of the Maggol, on the south side of Highway 35, adjacent to the stream. The uppermost exposed beds of the Maggol were also described from below the road level in the stream, on the south side of the stream (same side as road). A 20 m gap between the previously described streamcut section and the roadcut/streamcut section was estimated and recorded.

(126) Wackestone, rippled beds (5–20 cm thick), ripple laminations in parts, 3.0 m thick; BTC = 2 (1–5%), small Skolithos.

(127) Wackestone/packstone, rippled beds (5–20 cm thick), ripple laminations in parts, 1.2 m thick; BTC = 2 (1–5%), small Skolithos.

(128) Wackestone/packstone, rippled beds (5–20 cm thick), ripple laminations in parts, 1.6 m thick; BTC = 2 (1–5%), small Skolithos.

(129) Wackestone/packstone, wavy bedded, thicker beds (12–30 cm thick), possible megaripples, 5.1 m thick; BTC = 2 (10–15%), epichnial Planolites and Skolithos.

(130) Wackestone/packstone, ripple/flaser/lenticular bedded, ripples and lenticular beds 0–3 cm thick, 1.9 m thick; BTC = 2 (1–5%), epichnial Planolites.

(131) Wackestone/packstone, wavy bedded, thicker beds (12–20 cm), 1.0 m thick; BTC = 2 (1–5%), epichnial Planolites.

(132) Wackestone, wavy bedded, light gray with birdseye structures throughout, ripple laminations in parts, 80 cm thick; BTC = 1 (0%).

(133) Flat-pebble conglomerate, 20 cm thick; BTC = 1 (0%).

(134) Wackestone/packstone, ripple/flaser bedding, thicker beds (10-20 cm), 1.5 m thick; BTC = 2 (1-5%), epichnial Planolites.

(135) Flat-pebble conglomerate, 30 cm thick; BTC = 1 (0%).

(136) Wackestone/packstone, ripple/flaser bedding, ripples 10-15 cm thick, 40 cm thick; BTC = 2 (1-5%), epichnial Planolites.

(137) Packstone, wavy bedded, megaripples (30-50 cm thick), 2.5 m thick; BTC = 2 (1-5%), endichnial and exichnial Planolites.

(All burrows observed in units 98-109 were small-scale, only several mm's in diameter, contrasting with burrows in lower part of formation.)

Covered interval - 10 m thick.

Section continued below road level in stream cut adjacent to the road.

(138) Wackestone/packstone, ripple/flaser bedding, some secondary brecciation, 2.0 m thick; BTC = 1 (0%).

(139) Limestone breccia (packstone), 60 cm thick; BTC = 1 (0%).

(140) Wackestone/packstone, ripple/flaser bedded, more shaley than previous units, 40 cm thick; BTC = 1 (0%).

(141) Limestone breccia (packstone), very large clasts (> 20 cm diameter), 1.8 m thick; BTC = 1 (0%).

(142) Wackstone/packstone, ripple/flaser beds, ripples 3-7 cm thick, 2.0 m thick; BTC = 1 (0%).

(143) Flat-pebble conglomerate, 40 cm thick; BTC = 1 (0%).

(144) Wackestone/packstone, ripple/flaser bedding, ripples 3-7 cm thick, 20 cm thick; BTC = 1 (0%).

(145) Flat-pebble conglomerate/breccia, 40 cm thick; BTC = 1 (0%).

(146) Wackestone/packstone, ripple/flaser beds, ripples 3-7 cm thick, 1.0 m thick; BTC = 1 (0%).

(147) Limestone breccia (packstone), 60 cm thick; BTC = 1 (0%).

(148) Wackestone/packstone, ripple/flaser bedding, ripples 3-7 cm thick, 10 cm thick; BTC = 1 (0%).

(149) Limestone breccia (packstone), 20 cm thick; BTC = 1 (0%).

(150) Wackestone/packstone, ripple/flaser bedded, ripples 3-7 cm thick 30 cm thick; BTC = 1 (0%).

Samples (designated by MG-DJ-#)

(1) MG-DJ-1 : oblique section of trace fossils, full to semi-relief exichnia in dolomitic limestone, Planolites and burrow mottling. Several close-up pictures taken of specific traces.

(2) MG-DJ-2 - taken at 13.0 m , perpendicular to bedding, showing intense burrow mottling at top of bed. One picture also taken on top of bedding plane.

(3) MG-DJ-3 - trace fossils on bedding plane, at about 22.5 m.

(4) MG-DJ-4 - channels and megaripples, at about 23.0 m.

(5) MG-DJ-5 - trace fossils, apparently filled with fecal pellets and curved, multibranched burrow mottling, vertical burrows (possible Monocraterion), on bedding plane, at about 26.0 m.

(6) MG-DJ-6 - trace fossils on bedding plane, multibranched burrow mottling (tan on gray rock).

(7) MG-DY-7 - stromatolites in unit 78, showing latterally linked hemispheroids.

(8) MG-DJ-8 - burrow mottling and trace fossils at about 100 m.

(9) MG-DJ-9 - burrow mottling, densely populated, just above 100.1 m.

(10) MG-DJ-10 - burrow mottling, very densely populated, at about 101.5 m.

(11) MG-DJ-11 - distinct differences in bioturbation in vertical sequence, 107.3-107.8 m interval.

(12) MG-DJ-12 - burrow mottling in zone just below 125.0 m.

Samples (designated as MG-DJ-#)

(1) MG-DJ-1 - taken from same zone as Photo MG-DJ-1, sample of burrow mottling.

(2) MG-DJ-2 - taken from same zone as Photo MG-DJ-2, sample of burrow mottling.

(3) MG-DJ-3 - taken from same zone as Photo MG-DJ-5, sample of trace fossils.

(4) MG-DJ-4 - taken from about 38.0 m.

(5) MG-DJ-5 - taken from same zone as Photo MG-DJ-8, burrow mottling.

III. DONGJEOM (ROADCUT) SECTION

1. Location and General Description

Changsong quadrangle, sections 399-400 and 204, 37 degrees, 5' N, 129 degrees, 3' E; Section parallel to railroad, adjacent to Highway 423, has a partial exposure of the lower part of the Maggol Formation. However, much of the outcrop is covered by human-made concretes that include large blocks of the Maggol Formation: these concretes have weathered to dark brown to black, making identification of actual outcrop of the Maggol impossible throughout much of the outcrop. Blocks of Maggol Formation in the concretes are easily identifiable because of the same burrow mottling pattern (tan burrow in light gray host rock) observed at other localities. Beds that are exposed show a fairly uniform strike and dip: strike = nearly E-W, dip = 60 S, but bedding is obscured by concretes in many places.

Near the base and in some parts of the middle of the railroad cut is the same suite of trace fossils and burrow mottling observed in the lower part of the Donjeong streamcut section.

Samples (designated by MG-R-#)

(1) MG-R-1 - burrow mottling near base of section at top of bed.

(2) MG-R-2 - burrow mottling near middle of section, top of bed.

IV. FOSSIL DESCRIPTIONS

1. FEEDING TRACES (FODINICHNIA)

Palaeophycus sp.

Location: Taebaksan region, Dongjeong outcrop. Outcrop located as a stream cut adjacent to road.

Morphological Description: Horizontal to oblique burrows, lined, simple or branched, branched examples have sharp acute angles between branches, 0.8–0.9 cm width, as much as 9 cm length, burrow lining 1–2 mm thick but barely visible in most places, implied in other places because of contrast of burrow infill material with host rock.

Toponomic Description: Exichnia, burrows filled with ovoid, medium to coarse sand-sized ooids or fecal pellets, filling distinct from surrounding finer grained host rock (dolomitic wackestone).

Comments: This trace fossil is tentatively assigned to Palaeophycus, but the possibility of the burrow infill being partially composed of fecal pellets makes it comparable to Tomaculum sp., or Granularia sp., which are described in the Treatise of Invertebrate Paleontology under the "Coproplites" and "Trace Fossils" sections, respectively. Another possible designation is Granularia sp., which is an elongated, branching burrow filling. Description of Tomaculum from the Treatise is: Tomaculum Groom, 1902, p. 127. Strands of elliptical fecal pellets (= "Coprulus" Richter and Richter, 1939a, p. 163), up to 10 cm long and 1 to 2 cm broad; lying on bedding planes; within strands pellets commonly lumped together in clusters; length of pellets 1 to 5 mm, diameter 0.5 to 1.5 mm. Occurs in the Ordovician. Description of Granularia from the Treatise is: Granularia Pomel, 1849, p. 333. Elongated fillings of burrows; long, diameter up to about 15 mm; twig-shaped, with rather regular branching; walls origianlly lined with clay particles. Silurian-Tertiary.

Phycodes sp.

Location: Taebaksan region, Dongjeong outcrop. Outcrop located as a stream cut adjacent to road.

Morphological Description: Horizontal to slightly oblique to bedding, single burrow trunk branching in broomlike pattern, branches slightly curved in interior of pattern but increase in curvature in most peripheral branches, spreiten or ornamentation of burrow not observed, main trunk slightly wider than branches, 0.7 cm width (branches 0.4-0.5 cm width), entire burrow about 12-15 cm length.

Toponomic Description: Exichnial, but burrow infill (dolomitic silt) only weathers slightly differently from host rock (dolomitic limestone).

Comments: Identified initially as a type of Planolites, the branching indicates another ichnogenus, and the broomlike pattern of the feeding trace is most akin to Phycodes.

Planolites sp. 1

Location: Danyang region, outcrop along road winding up and down mountain adjacent to Danyang.

Morphological Description: Horizontal to oblique burrows, simple, unlined, meandering to slightly curved to straight, burrow width 1.0-1.3 cm, length as much as 6 cm, many burrows cross-cut one another, giving appearance of "branching" in some places.

Toponomic Description: Exichnia, filled with dolomitic to calcareous silt in rippled dolomitic limestone, weathered as tan to light gray in darker gray limestone.

Comments: This trace fossil is only distinguishable from Teichichnus in the same burrow-mottled zones by its lack of spreiten and its restriction to primarily horizontal planes. Many of these traces seem to originate within flaser beds between rippled beds, thus indicating a preferential feeding strategy that probably concentrated on organics-rich material that accumulated in troughs of ripples (later forming flasers).

Planolites sp. 2

Location: Danyang region, outcrop along road winding up and down mountain adjacent to Danyang.

Morphological Description: Horizontal to oblique burrows, simple, unlined, meandering to slightly curved to straight, burrow width 0.2-0.3 cm, length as much as 6 cm, many burrows cross-cut one another, giving appearance of "branching" in some places.

Toponomic Description: Exichnia, filled with dolomitic to calcareous silt in rippled dolomitic limestone, weathered as tan to light gray in darker gray limestone.

Comments: This trace fossil is only distinguishable from the Planolites sp. 1 in the same burrow-mottled zones by its smaller size. Many of these traces seem to originate within flaser beds between rippled beds, thus indicating a preferential feeding strategy that probably concentrated on organics-rich material that accumulated in troughs of ripples (later forming flasers).

Planolites sp. 3

Location: Taebaksan region, Dongjeong outcrop. Outcrop located as a stream cut adjacent to road.

Morphological Description: Horizontal to slightly oblique to bedding (mostly horizontal), simple, unlined, and unbranched burrows, 0.4–0.8 cm width, as much as 10 cm length, elliptical to subcircular cross-sections, vertical connections to bed tops discernable in places.

Toponomic Description: Positive relief exichnial traces within beds, some connections of burrow to bed tops evident as positive relief epichnia, filled with dolomitic silt that weathers to tan within light gray to gray dolomitic limestone. Where bedding is definable, some remnants of rippled beds or flasers are associated with burrow mottling.

Comments: Initially, this trace fossil was put into the same category as the tentatively identified Thalassinoides, but is of a smaller diameter and is unbranched. However, Planolites is probably the second most abundant trace fossil in the burrow mottled sequences in this area.

Teichichnus sp.

Location: Danyang region, outcrop along road winding up and down mountain adjacent to Danyang.

Morphological Description: Horizontal to oblique burrows with some vertical extent, unlined, retrusive spreiten barely discernable as concentric lamellae underneath final (uppermost) burrow, total vertical distance of movement 1-3 cm, burrow width 1.0-1.3 cm, length undeterminable, many burrow systems cross-cut one another.

Toponomic Description: Exichnia, filled with dolomitic to calcareous silt in rippled dolomitic limestone, weathered as tan to light gray in darker gray limestone.

Comments: This trace fossil is only distinguishable from Planolites in the same burrow-mottled zones by its spreiten and its vertical extent. Many of these traces seem to originate within flaser beds between rippled beds, thus indicating a preferential feeding strategy that probably concentrated on organics-rich material that accumulated in troughs of ripples (later forming flasers).

Thalassinoides sp.

Location: Taebaksan region, Dongjeong outcrop. Outcrop located as a stream cut adjacent to road.

Morphological Description: Horizontal to slightly oblique burrow systems (primarily horizontal), 0.8–1.0 cm width, up to 17 cm horizontal extent, unlined, linear to slightly curved, simple to bifurcated (branching)burrows with some considerable horizontal extent to branches, vertical connection to bed tops obscure in most places but discernable in some places.

Toponomic Description: Positive relief exichnial traces within beds, some connections of burrow to bed tops evident as positive relief epichnia, filled with dolomitic silt that weathers to tan within light gray to gray dolomitic limestone. Where bedding is definable, some remnants of rippled beds or flasers are associated with burrow mottling.

Comments: Initially defined in the field as a varitey of Planolites, but the considerable branching of some specimens indicates a burrow system rather than a simple feeding burrow. This trace fossil is responsible for the majority of burrow mottling observed in the Maggol Formation in this area. Vertical extent of some burrow systems may be determined by observing the depth of penetration of individual burrows, but is probably better defined by the vertical extent of the tan dolomitic silt infills below identifiable bedding planes. Using this approximation, some systems may have penetrated as much as 50 cm, but most intensely bioturbated zones with this burrow mottling have vertical extents of 25–35 cm.

Annulated Burrow – Unidentified

Location: Taebaksan region, Dongjeong outcrop. Outcrop located as a stream cut adjacent to road.

Morphological Description: Horizontal to slightly oblique to bedding (mostly horizontal), unlined and unbranched burrows, crudely annulated exterior displaying "bumps", some bumps are similar to fecal pellets in shape and size, 0.8–1.0 cm width, 4–6 cm length, vertical connections to bed tops uncertain.

Toponomic Description: Positive relief exichnial traces within beds, filled with dolomitic silt that weathers to tan within light gray to gray dolomitic limestone. Where bedding is definable, some remnants of rippled beds or flasers are associated with burrow mottling.

Comments: This trace fossil is very similar to Planolites and Thalassinoides in overall appearance, but the burrow exterior is markedly more irregular than either of those two trace fossils. Possible identification might be yielded by comparing with other meniscate burrows, but ornamentation is also suggestive of burrows with fecal-pellet linings, such as Ophiomorpha.

(2) DWELLING TRACES (DOMICHNIA)

Skolithos sp.

Location: Taebaksan region, Dongjeong outcrop. Outcrop located as a stream cut adjacent to road.

Morphological Description: Vertical to slightly oblique burrows, simple, unlined, average width 0.6 cm (+/- 0.1 cm), average length 3.1 cm (+/- 0.8 cm) [n=18], circular cross-sections, most originate at tops of rippled beds.

Toponomic Description: Exichnial, burrows filled with dolomitic silt that weathers to tan in light gray to gray dolomitic limestone. Some epichnial traces are evident as circular cross-sections on the tops of rippled beds.

Comments: One of the few identifiable vertical trace fossils in the Maggol Formation. Size, orientation, and toponomic occurrence of this ichnospecies is consistent throughout the formation.

?Monocraterion sp.

Location: Taebaksan region, Dongjeong outcrop. Outcrop located as a stream cut adjacent to road.

Morphological Description: Vertical burrows, simple, possibly lined, circular cross-section, possible retrusive spreiten evident as concentric (2-3) lamellae within cross-section, width of cross-section 0.9-1.2 cm, vertical extent uncertain, silty exterior zone 0.3-0.4 cm thick, dolomitic interior zone 0.2-0.3 cm thick.

Toponomic Description: Epichnial, exterior zone of cross-section composed of dolomitic silt that weathers to tan (different from surrounding host rock, dolomitic limestone) and has negative relief, interior zone composed of same material as host rock and has positive relief, originate at tops of rippled beds.

Comments: Multiple funnels are implied by concentric lamellae in cross-section of burrow top, thus suggesting Monocraterion as the likely ichnogenus. However, the lack of vertical sections of this trace fossil, which was only found at one horizon within the Maggol Formation, precludes a more precise designation. The unusual toponomy of the trace fossil is also comparable to Laevicyclus sp., described in the Treatise of Invertebrate Paleontology. Description from the Treatise is: Laevicyclus Quenstedt, 1879, p. 577. Approximately cylindrical bodies standing at right angles to bedding plane; diameter variable in same specimen; perforated by central canal; visible on bedding planes as regular concentric circles with diameter of several cm; interpreted by Seilacher (1953c, p. 270) as feeding burrow comparable with dwelling shaft and scraping circles of Recent annelid Scolecolepis. Cambrian-Triassic.