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資　料

上部ジュラ系九頭竜層群有峰層（富山県南東部）から産出したメニスカス状後方充填構造をもつ化石棲管（補遺）－生痕化石*Archaeozostera* Koriba and Miki, 1958［コダイアマモ（郡場・三木, 1931）］との比較

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A Comparison Between the Horizontal Meniscate Backfilled Burrow from the Upper Jurassic Arimine Formation and the Trace Fossil *Archaeozostera* Koriba and Miki, 1958－Supplement for the Bulletin of the Toyama Science Museum 43 (2019) 77-85.

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Supplementary information on the horizontal meniscate backfilled burrow from the Upper Jurassic Arimine Formation (HMBA: TOYA-Fo. 7345), in the southeastern Toyama Prefecture, is added here. HMBA is compared to a branched meniscate trace fossil *Archaeozostera* Koriba and Miki, 1958 observed in the Upper Cretaceous Izumi Gorup exposed at southwestern Osaka Prefecture. Although overall morphologies of the two trace fossils are quite different from each other, their modes of occurrences and single burrow structures enable comparison between HMBA and *Archaeozostera*. In sum, 1) both HMBA and *Archaeozostera* are meniscate backfilled trace fossils preserved as convex epirelief on turbidite sandstone beds, 2) an imbricated backfilled structure showing non-compartmentalized and shuffled patterns are shared between HMBA and highly weathered *Archaeozostera* tunnels, and 3) differing from HMBA, *Archaeozostera* forms a branching system whose tunnels are bordered by lateral grooves in less or moderately weathered preservation modes. The above comparison shows an important fact that the differences and similarities between the trace fossils profoundly depend on their modes of preservation. In addition, the structural similarities between the each backfilling imply HMBA was probably formed by an endobenthic detritus feeder.

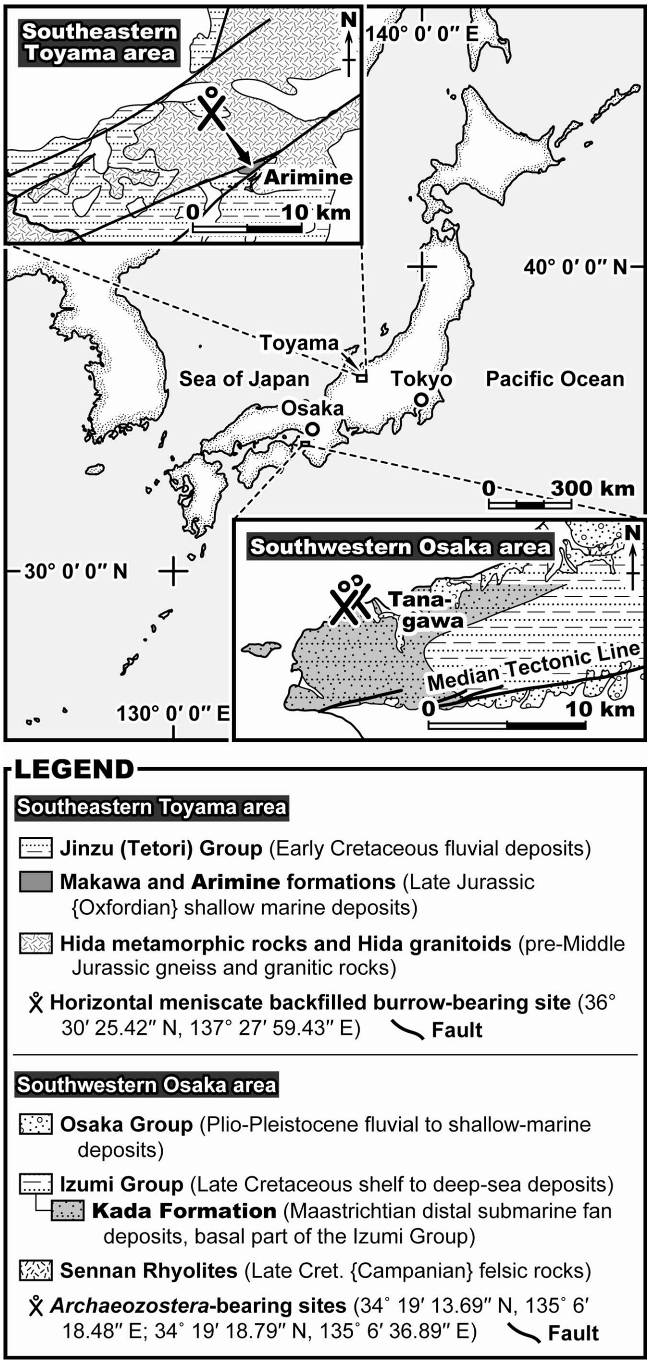


Fig. 1 Index and simplified geological maps showing the trace fossils sites in the Arimine (southeastern Toyama) and Tanagawa (southwestern Osaka) areas. The geological maps are modified after Kawai and Nozawa (1958), Nozawa and Sakamoto (1960), Kuzugiza *et al.* (2004) and Miyata *et al.* (1993).

1．はじめに

本報告は，平澤（2019）で記載した上部ジュラ系有峰層産の生痕化石に関する追記情報である．タービダイト砂岩から産出する後方充填構造をもつ化石棲管として，有峰標本（TOYA-Fo．7345: horizontal meniscate backfilled burrow）と上部白亜系和泉層群から産する生痕化石*Archaeozostera*の産状と形態を比較し，両生痕化石の相違点および類似点について述べる．

*Archaeozostera*は，郡場・三木（1931）によりアマモ属およびエビアマモ属の祖先にあたる水中顕花植物「コダイアマモ」として報告された化石である．特徴的な産状と形態を示すことから郡場・三木（1931）以来，*Archaeozostera*を植物化石とする解釈と，生痕化石とみなす見解が並立し度々議論されてきた（例えば，那須，1983; 徳橋・両角，1983）．結論として，*Archaeozostera*は埋在性のデトリタス食者の形成した巣穴の化石であったことがKotake *et al.* (2016) によって明らかにされた．

2．地質概説

生痕化石TOYA-Fo. 7345 および比較対象の*Archaeozostera*は，それぞれ上部ジュラ系有峰層と上部白亜系和泉層群加太累層から産出した（Figs. 1，2）．平澤（2019）では，有峰層を上部ジュラ系九頭竜層群（Sano，2015）の構成層として扱った．しかし，九頭竜層群の層序単元がYamada and Sano (2018) により再定義されたため，本稿ではTOYA- Fo.7345 の産出層を上部ジュラ系（オックスフォーディアン階）有峰層とする．また，サルヴァドール，日本地質学会（訳編）(2001) の地層命名指針に従い，加太累層（石上・吉松，1972; 宮田ほか，1993 再定義）を加太層と表記する．

有峰層（松川ほか，2014）は富山県南東部の有峰東方地域に局在し，後期ジュラ紀オックスフォーディアン期の軟体動物や放散虫類の化石を産する浅海成層である（前田・武南，1957; 河合・野沢，1958; 原山ほか，1991; Matsukawa *et al.,* 2008; 平澤ほか，2010; Sato and Yamada，2014; Figs. 1，2）．本層は砂質シルト岩の優勢な砂質シルト岩砂岩互層を主体とし，タービダイト砂岩層を頻繁に挟む（Goto *et al.,* 2018）．有峰層は下位の真川層（同じくオックスフォーディアン階の海成層）を整合に被覆し，河川成の下部白亜系神通層群（前田，1961 の手取層群．議論はNagata *et al.,* 2018を参照）で不整合に覆われる（松川ほか，2014）．また，これらのオックスフォーディアン階は基盤岩である先中部ジュラ系飛騨花崗岩類を不整合に被覆するか，あるいは断層で接する（前田・武南，1957; 河合・野沢，1958; 椚座ほか，2010; 松川ほか，2014）．

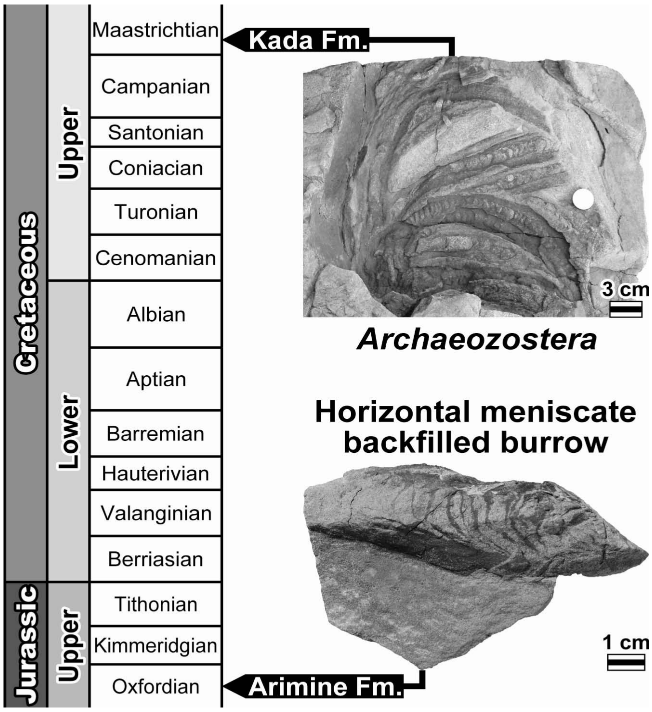


Fig. 2 Stratigraphic positions of the trace fossil-bearing beds. Stages of the Arimine Formation yielded the horizontal meniscate backfilled burrow and the Kada Formation hosting *Archaeozostera* are cited from Sato and Yamada (2014) and Hashimoto *et al.* (2015), respectively. The late Mesozoic chronostratigraphy is based on International Commission on Stratigraphy (2019).

上部白亜系（カンパニアン階〜マーストリヒチアン階）の和泉層群（平山・田中，1955）は，中央構造線の北側に沿って四国西部から近畿地方西部にかけて分布する横ずれ堆積盆の埋積物であり，陸棚相〜深海成タービダイト相を示す（宮田ほか，1993，2012; Hashimoto *et al.,* 2015; Fig. 1）．大阪府南西部において，本層群は上部白亜系カンパニアン階の泉南流紋岩類を不整合に覆い，また鮮新ー更新統大阪層群（河川〜浅海成層）によって不整合に被覆される（市原ほか，1986; 宮田ほか，1993; 坂本ほか，2001）．この地域では，加太層が和泉層群の基底部をなしている（宮田ほか，1993）．加太層は下部層および上部層に区分され，それぞれ砂岩泥岩厚互層・礫岩砂岩厚互層，および砂岩礫岩優勢互層・泥岩優勢砂岩泥岩中ー薄互層・砂岩優勢砂岩泥岩厚互層で特徴づけられるほか，多数の酸性凝灰岩層を挟む（宮田ほか，1993）．本層の時代は，凝灰岩に含まれるジルコンのFT年代に加え，アンモノイド類や放散虫類などの示準化石に基づいて，上部白亜系マーストリヒチアン階に対比されている（宮田ほか，1993; Hashimoto *et al.,* 2005; Fig. 2）．下部層は横ずれ堆積盆内のチャネル相およびその末端相を示すタービダイトとみなされている（Tanaka，1989）．また，泉南郡岬町多奈川の北西部海岸沿いでは，下部層から*Archaeozostera*が頻繁に発見されている（徳橋・両

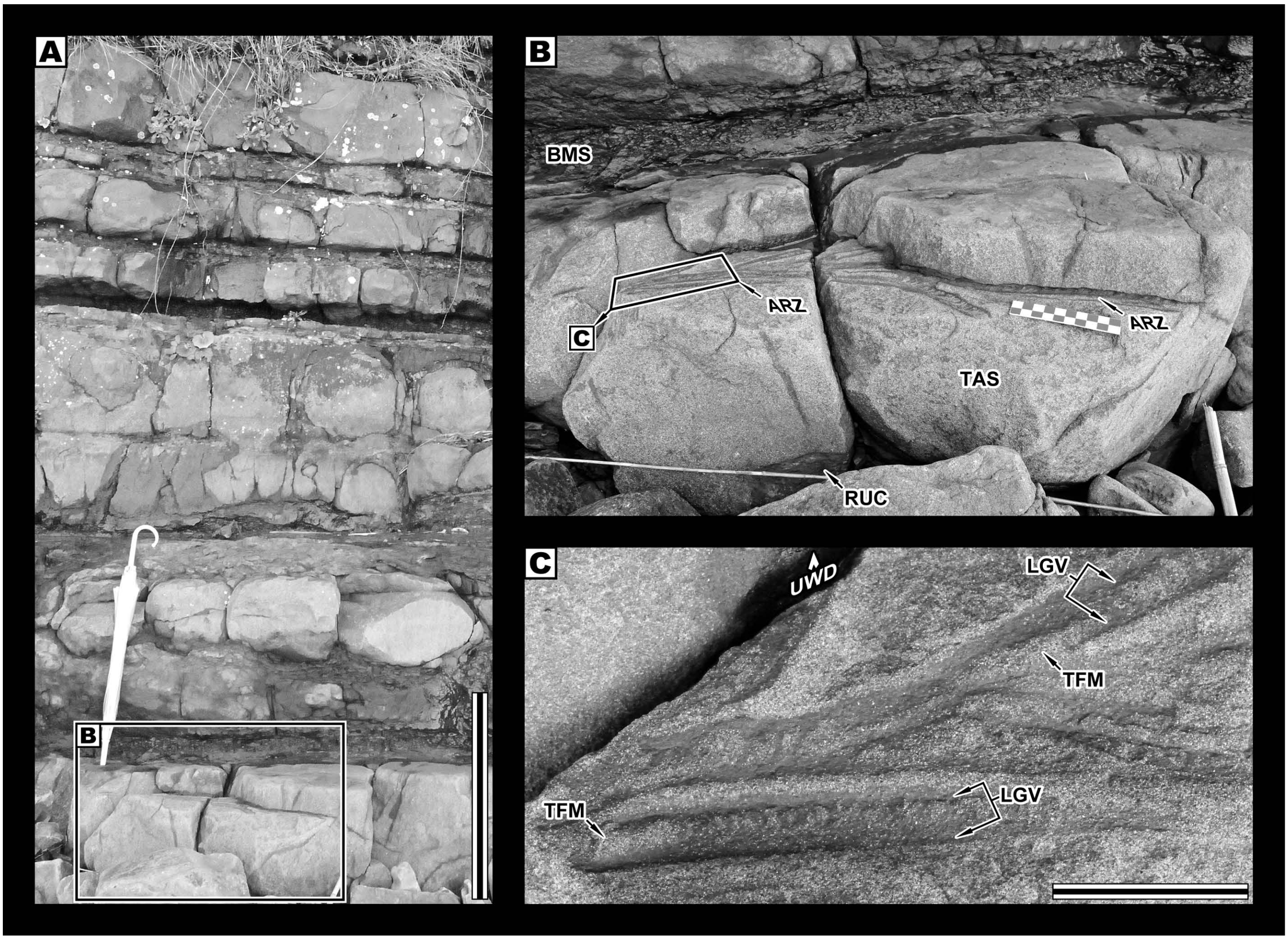


Fig. 3 *Archaeozostera*-bearing beds and mode of occurrence of the trace fossil observed in the lower member of the Maastrichtian Kada Formation (basal part of the Upper Cretaceous Izumi Gorup) exposed along northwestern coast of Tanagawa, southwestern Osaka Prefecture. The outcrop is located at 34° 19′ 18.79″ N and 135° 6′ 36.89″ E. (A) Sandstone-dominated alternation of turbidite sandstone (thicker light beds) and mudstone (thinner dark beds) showing the typical lithofacies of the member. *Archaeozostera* is recognized in the lowermost turbidite bed of the outcrop. (B) Massive coarse- to medium-grained sandstone bed preserved *Archaeozostera* in its upper horizon. The sandstone contains rip-up clasts at lower part and slightly normally grades, which displays the Bouma T_a division. (C) Mode of occurrence of *Archaeozostera*. Its tunnel-filled materials laterally bordered by shallow grooves are preserved as shallow convex epirelief. Oblique view to bedding plane. Scales indicate 50 cm (A), 10 cm (B) and 5 cm (C). Abbreviations: ARZ, *Archaeozostera*; BMS, black mudstone; LGV, lateral groove; RUC, rip-up clast; TAS, Bouma T_a sandstone; TFM, tunnel-filled materials; UWD, upward direction.

角，1983; 宮田ほか，1993，2012）．多奈川北西域の本部層は砂岩優勢な砂岩泥岩互層から構成されており，有峰層産標本と比較した*Archaeozostera*もこの分布域で観察された（Figs. 1，3A）．*Archaeozostera*の産出層は，下部に黒色泥岩の偽礫を含み，粗粒砂から中粒砂に正級化する砂岩からなり，Bouma T_aタービダイトの岩相を示す（Fig. 3B）．

３．生痕化石の記載

Description of the trace fossils

Ichnological terms representing the backfilled structures follow those of Frey *et al.* (1984), Keighley and Pickerill (1994), and Retallack (2001). Because concave sides of menisci indicate the burrowing direction of the tracemaker (Keighley and Pickerill, 1994), the anterior direction of the backfilled trace fossils is defined as the concave sides of menisci, and the opposite as posterior. Detail morphology of the horizontal meniscate backfilled burrow from the Arimine Formation (HMBA: TOYA-Fo. 7345) is described in Hirasawa (2019).

Archaeozostera Koriba and Miki, 1960

Archaeozostera was originally designated as a genus of a fossil seagrass yielded from the Upper Cretaceous sandstone distributed in some restricted areas of Japan (Koriba and Miki, 1958). Later, Kotake *et al.* (2016) demonstrated that *Archaeozostera* did not belong to a seagrass group but a trace fossil produced by a sedentary endobenthic detritus feeder. The following is a summary on morphology of the trace fossil described in Fu (1991) and Kotake *et al.* (2016).

Archaeozostera generally occurs on the bedding plane of a turbiditic sandstone bed as a strongly compressed large trace fossil which is characterized by systematically dichotomous and radial tunnels exhibiting considerable morphological and size variations.

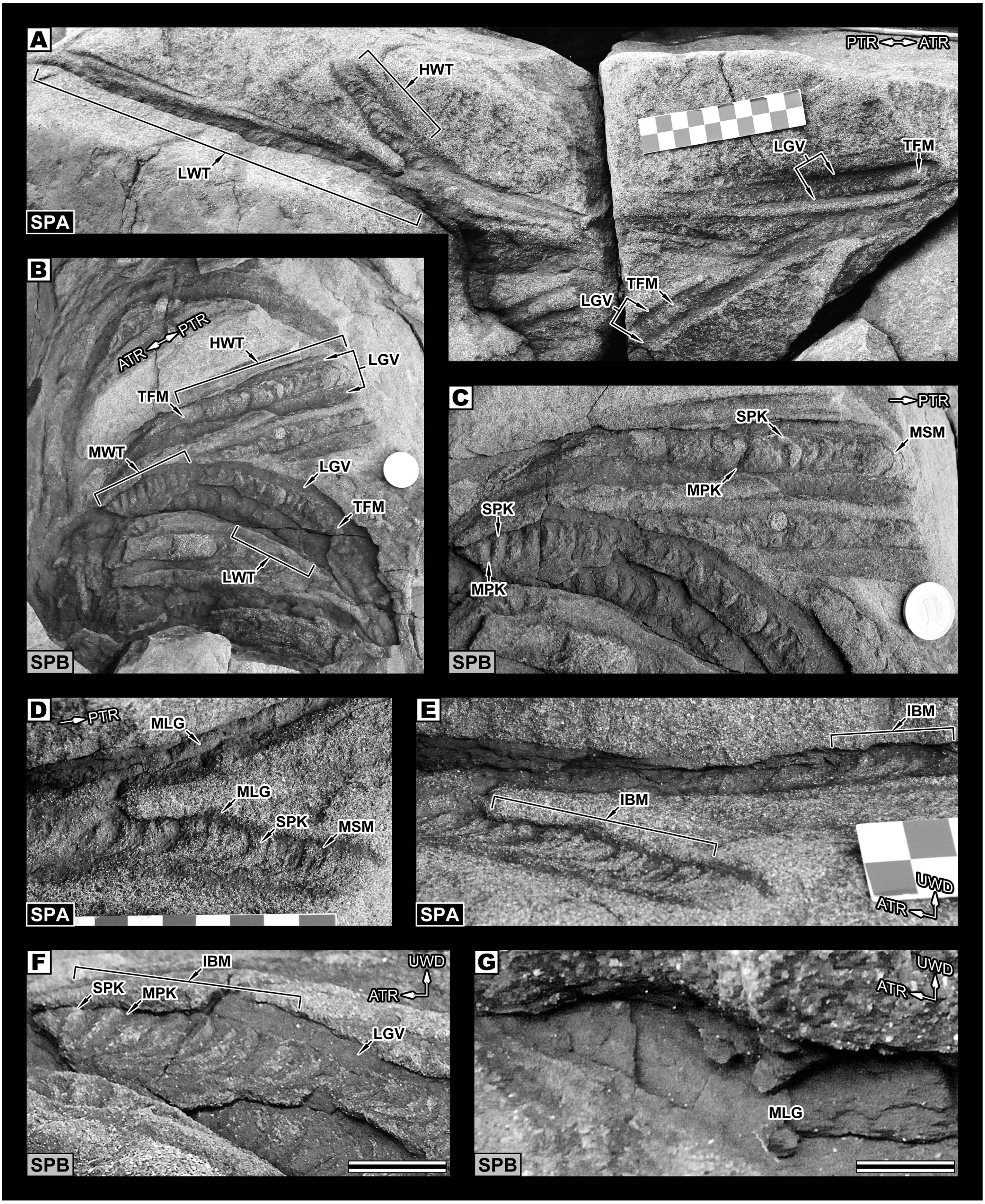
Overall morphology of the trace fossil is divided into the proximal Stage-I, middle Stage-II and distal Stage-III portions. The Stage-I portion forms an inclined axial tunnel with few strongly curved, very small dichotomous tunnels (length and width from 1 to 5 cm and 0.1 to 1 cm, respectively). The axial tunnel starts from the overlying mudstone base, and subsequently runs oblique to the bedding plane. In the Stage-II, the axial and the dichotomous tunnels become parallel to the bedding plane. The dichotomous tunnels increase in size toward the Stage-III portion. The axial tunnel of the Stage-III distally varies into straight or slightly curved, densely branching radial tunnels which overlap or cross-cut each other. The radial tunnels show almost invariant size up to 50 cm in length, 5 cm in width and 0.5 cm in thickness.

The dichotomous tunnel is filled with black muddy material, while the radial tunnel consists of a sandstone core (the same material as the host sandstone) lined by mudstone. When the mudstone lining is weathered out on bedding surface, the radial tunnel displays a trilobate structure that the convex sandstone core bordered on each lateral side by a groove. Meniscate backfilled structure develops within the tunnel. No fecal pellets are contained in the tunnel-filled material.

Archaeozostera observed in the Tanagawa coast

Any observed *Archaeozostera* specimens in the northwestern Tanagawa coast are the Stage-III radial tunnels preserved on bedding planes of turbidite sandstone beds or sandstone floats (Figs. 3C, 4). The radial tunnels are straight to gently curved in constant width, or very slightly widened posteriorly (Fig. 4A, B). The tunnel consists of an alternation of meniscate sand- and mudstone packets or mudstone segments lined by mudstone (Fig. 4C, D). Internal structures are not recognized within the packets. Both sides of the single tunnel are bordered by shallow lateral grooves sometimes wider than the tunnel (Fig. 4A, B). Modes of preservation of the tunnels quite differ even in a

Fig. 4 (next page) Modes of preservation and the Stage-III morphology of *Archaeozostera* from the Kada Formation, northwestern Tanagawa. (A) Bedding plane view of *Archaeozostera* (specimen A) preserved on the turbidite bed shown in Figure 3B. The radial tunnels partly with the lateral grooves are less or highly weathered. (B) Typical radial tunnel system of *Archaeozostera* (specimen B) exposed on a bedding plane of a sandstone float (found at 34° 19′ 13.69″ N and 135° 6′ 18.48″ E). Less-to-highly weathering modes of the tunnels with the lateral grooves. (C) Moderately- and highly weathered tunnels showing transverse bellows-like ridges and irregularly spaced backfill, respectively. The tunnels are filled with alternations of sandstone packets and mudstone packets or menisci. Middle part of figure B. (D) Meniscate backfilled structure recognized in a highly weathered tunnel lacking the lateral grooves (left upper part of figure A). Irregularly spaced, non-compartmentalized sandstone packets and mudstone menisci constitute the structure. Note the shuffled arrangement of the menisci locally cross-cutting or merging into each other. Thin mudstone lining laterally bordered the backfilled materials. (E) Anteriorly imbricated backfilled structure within the moderately- and partly highly weathered tunnels (left upper part of figure A). Oblique view to bedding plane. (F) Imbricated tunnel-filled materials displaying the bellow-like ridges due to selective weathering of the mudstone packets. A moderately weathered tunnel (left center of figure B). Oblique view to bedding plane. (G) Smooth surface of mudstone lining without striations or ornaments. Nearly bedding-parallel view of a less weathered tunnel. Scale bars in cm (A, D, E), and 1 cm in length (F, G). Coin for scale in figures B and C is 2 cm in diameter. Abbreviations: ATR, anterior; HWT, highly weathered tunnel; IBM, imbricated backfilled materials; LGV, lateral groove; LWT, less weathered tunnel; MLG, mudstone lining; MPK, mudstone packet; MSM, mudstone segment; MWT, moderately weathered tunnel; PTR, posterior; SPA, specimen A; SPB, specimen B; SPK, sandstone packet; TFM, tunnel filled materials; UWD, upward direction.



single tunnel system, that is, the tunnels of fully enveloped by the lining and not displaying the backfilled structure (less weathered), selectively weathered mudstone infill resulting in accentuated transverse bellows-like ridges reflecting the sandstone infill (moderately weathered) and the backfilled mudstone-sandstone alternations with the grooves clearly recognized by lining erosion (highly

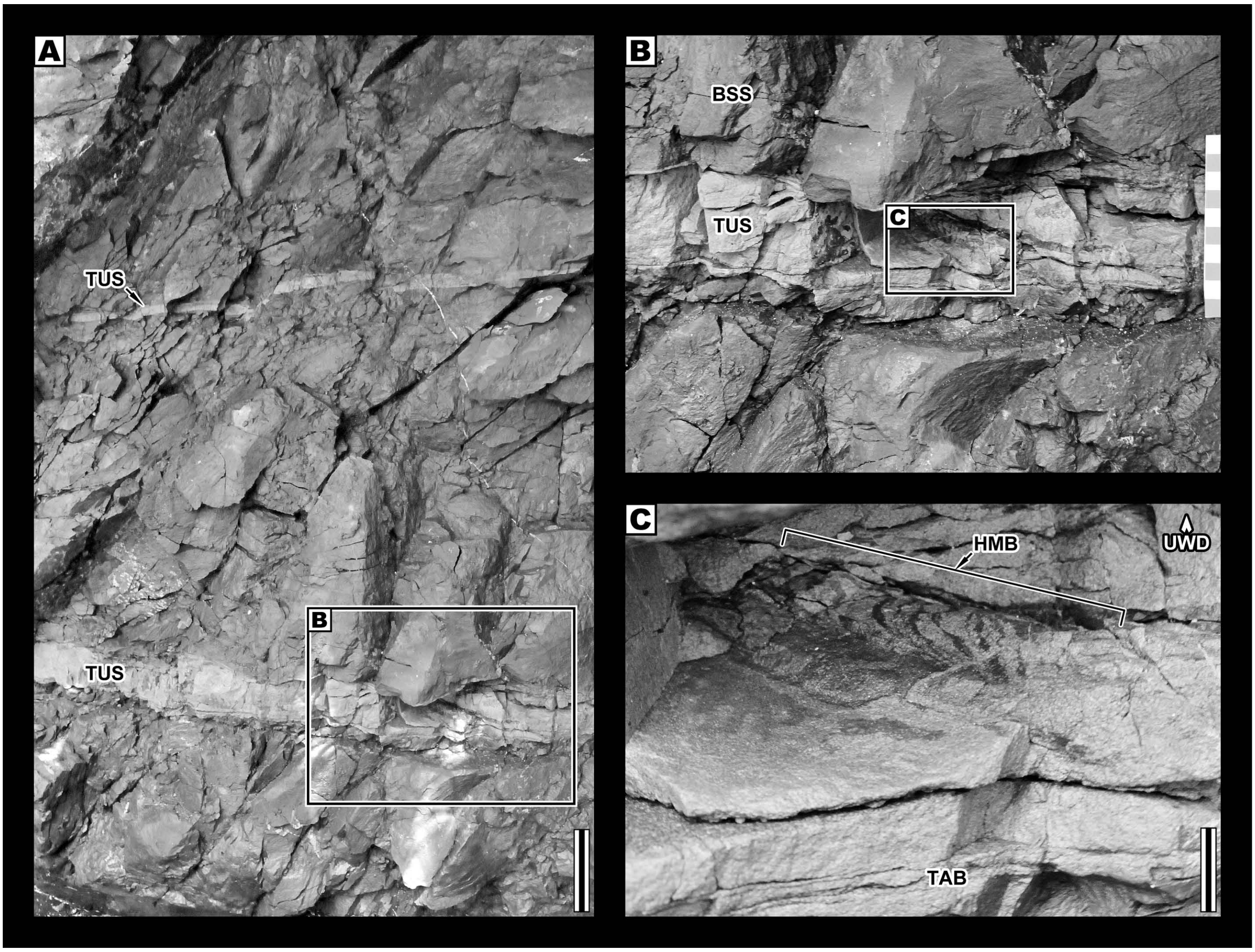


Fig. 5 Horizontal meniscate backfilled burrow-bearing bed and mode of occurrence of the trace fossil observed in the Upper Jurassic (Oxfordian) Arimine Formation distributed in southeastern Toyama Prefecture. (A) Alternation of sandy siltstone and turbiditic fine-grained sandstone cropped out at 36° 30′ 25.42″ N and 137° 27′ 59.43″ E. The siltstone (darker intervals) are much predominant than the sandstone. (B) Turbiditic sandstone bed preserved the backfilled burrow on its middle horizon. (C) Mode of occurrence of the burrow preserved as shallow convex epirelief on the Bouma T_{ab} turbidite. Oblique view to bedding plane. Scales indicate 10 cm (A, B) and 1 cm (C). Abbreviations: BSS, black sandy siltstone; HMB, horizontal meniscate backfilled burrow; TAB, Bouma T_{ab} bed; TUS, turbidite sandstone; UWD, upward direction.

weathered) (Fig. 4A, B). In any weathering modes, the sandstone packings are preserved as shallow convex epirelief on upper surfaces of the sandstone beds, or semirelief on the floats (Figs. 3C, 4B). Length and width of the preserved tunnels are up to 25 cm and from 1.5 to 2.5 cm, respectively.

Apparent backfill pattern varies depending on the weathering mode of the lining which is a thin, simple wall structure made up of black mudstone similar in lithology to the menisci (Fig. 4C-F). The moderately weathered tunnel shows a simple backfill pattern which consists of a comparatively regular spaced, equal-thickness alternation of sand- and mudstone packets extending fully across the tunnel (Fig. 4C). Boundaries of the each packet are liner, shallow- to-deep arcuate geometries at and around the median lines of the tunnel, and then the mudstone packets strongly curve anteriorly to merge into each other at somewhat annulated tunnel margins (Fig. 4C, F). While in the highly weathered tunnel, the backfill pattern displays an irregularly spaced alternation of the sand- and mudstone packets and/or mudstone segments (Fig. 4C, D). Locally the mudstone infills are not parallelly arranged, so that they form the shuffled menisci pattern (Fig. 4C, D). Thickness and width of both

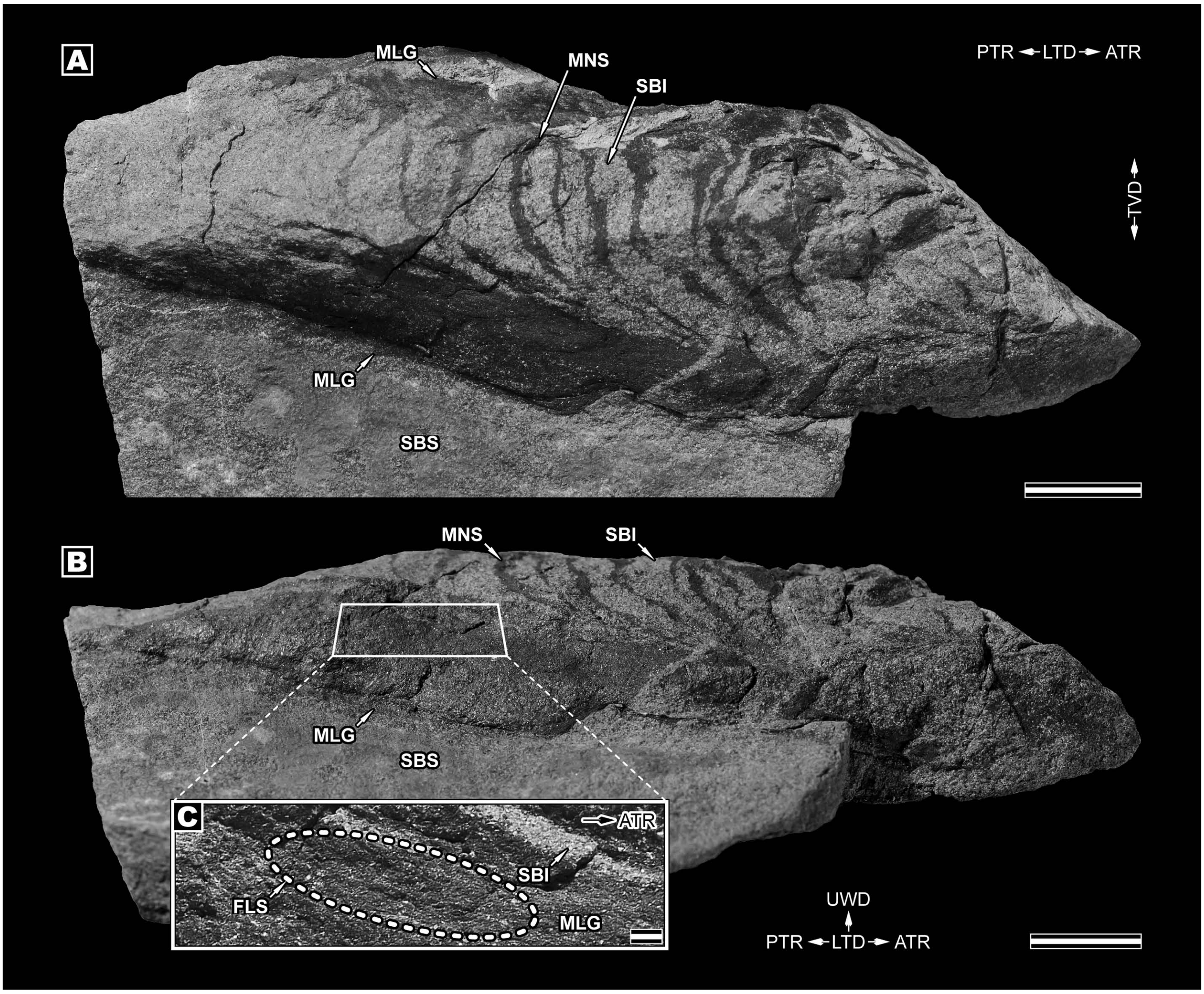


Fig. 6 Horizontal meniscate backfilled burrow (TOYA-Fo. 7345) from the Arimine Formation, southeastern Toyama Prefecture. This figure is modified after Hirasawa (2019). (A) Upper bedding plane view. The burrow is characterized by shuffled arrangement of heterogeneous non-compartmentalized backfill materials with thin mudstone lining slightly horizontally expanding into the host sandstone. (B) Lateral view showing shallow convex epirelief preservation. The backfilled structure displays an anteriorward imbrication. (C) Close-up of the lining surface with faint longitudinal striations dipping anteriorly. Oblique bedding plane view. Scale bars equal to 1 cm (A, B) and 1 mm (C). Abbreviations: ATR, anterior; FLS, faint longitudinal striation; LTD, longitudinal direction; MLG, mudstone lining; MNS, meniscate mudstone; PTR, posterior; SBI, sandstone burrow infill; SBS, sandstone bedding surface; TVD, transverse direction; UWD, upward direction.

the sand- and mudstone packings do not have any tendencies in anterioroposterior direction, rather they are considerably inconstant even in a single packet or segment (Fig. 4C, D). However, the mudstone infills tend to be thinner than the sandstone packets (Fig. 4C). Boundaries of the packets and mudstone segments are almost the same geometries as those of the moderately weathered tunnel (Fig. 4C), but the segments often discontinue not to be fully across the tunnel, which results in the non-compartmentalized meniscate backfill structure (Fig. 4D). The tunnel margins are relatively smooth compared to the moderately weathered tunnel. The lateral grooves are often obscured in particularly weathered tunnels (Fig. 4D, E). In such specimens, the lining is thinly preserved at the stuffed material margins (Fig. 4D). When viewed in the lateral side, the backfilled materials obviously constitute an anteriorly dipping imbricated structure in both the moderately and highly weathered tunnels (Fig. 4E, F). Neither the tunnel- filled materials nor lining contain fecal pellets. The lining has a smooth surface without striations or ornaments (Fig. 4G).

Comparison between HMBA and *Archaeozostera*

HMBA and *Archaeozostera* are superficially quite different from one another in respect to whether branching or nonbranching, and with or without the lateral grooves (Fig. 2). However the mode of occurrence and individual radial tunnel structures of *Archaeozostera* are comparable to HMBA.

Both the trace fossils are yielded from turbidite sandstones overlain by dark muddy deposits (Figs, 3B, 4A, 5A, B). HMBA and radial tunnel of *Archaeozostera* are horizontal, lined and backfilled trace fossils preserved on the upper surfaces of the sandstone beds as shallow convex epirelief (Figs, 3C, 5C).

The radial tunnels are straight or curved in constant width to very slightly widened posteriorly (Fig. 4A, B), but the slightly sinuous HMBA tapers gently toward posterior (Fig. 6A). Dorsal side of HMBA is a smooth surface in contrast to the bellows-like ridges of the moderately or highly weathered tunnels (Figs. 4F, 6B). Tunnels height of *Archaeozostera* is inconstant because of selective weathering of the mudstone infill (Fig. 4F), which is different from HMBA. Very faint longitudinal striations sculpted on the lining surface of HMBA are not recognized on that of *Archaeozostera* (Figs. 4G, 6C). Burrow infill of HMBA dose not contain the mudstone packets with deep arcuate boundaries and is not bordered by the lateral grooves. Such features are different from the radial tunnels (Figs. 3C, 6A).

In the internal structure of the highly weathered tunnel, many characteristics are common to HMBA. First, the backfills consist of heterogeneous materials without fecal pellets, which are alternately arranged massive sandstone packets almost similar lithologies to the host rocks and black muddy stone segments with sometimes discontinuous, transversely shallow arcuate boundaries (Figs. 4A-D, 6A). Thickness (longitudinal length) of the packets is inconstant and the segments highly vary in their width (transverse length) (Figs. 4C, D, 6A). Secondly, the alternations exhibit the non-compartmentalized meniscate backfills which are dense-to-well spaced, irregularly arranged shuffled patterns in bedding plane view (Figs. 4D, 6A), and anteriorly imbricated when viewed in the lateral side (Figs. 4E, F, 6B). And lastly, remaining lining thinly envelopes the tunnel-filled materials (Figs. 4D, 6A).

In conclusion, the differences and similarities between HMBA and *Archaeozostera* strongly depend on the preservational modes of the latter trace fossil. The burrow structural characteristics of HMBA imply its tracemaker behavior was partly common to that of *Archaeozostera*, probably detritus feeding within a sandy substrate delivered by turbidity current(s).

４．まとめ

富山県南東部の上部ジュラ系有峰層から産出したメニスカス状の後方充填構造をもつ化石棲管（有峰標本TOYA-Fo．7345: 平澤，2019）と，大阪府南西部に分布する上部白亜系和泉層群加太層で観察された生痕化石*Archaeozostera*の産状と形態を比較し，両者の相違点および類似点を明らかにした．本報告の要旨は以下の４点である．

１）有峰標本と*Archaeozostera*はともにタービダイト砂岩層の層理面に上面浮き彫り痕として保存された化石棲管であり，メニスカス状の泥質岩とそれに区画された砂岩の小包からなる後方充填構造をもつ．

２）有峰標本は，分枝と棲管側方に溝状構造をもたない点で*Archaeozostera*と大きく異なる．

３）有峰標本と風化程度の強い*Archaeozostera*の棲管は，砂岩充填物を完全に区画しておらず互いに斜交することもある泥質岩のメニスカス，および前方に向かって覆瓦構造をなす充填物を有する点で共通する．

４）*Archaeozostera*と共通する棲管の内部構造から，有峰標本は埋在性のデトリタス食者によって形成された生痕化石と考えられる．

本研究の結果から，同一標本内においても各部の保存状態（風化の程度）が，生痕化石の形態の評価に大きく影響することに注意しなければならないといえる．

５．謝辞

本報告を作成するにあたり，富山県生活環境文化部自然保護課および北陸電力株式会社には地質調査と転石標

本の採取に関してご協力いただいた．また有峰林道の通行に際しては，富山県農林水産部森林政策課にご便宜をはかっていただいた．本稿は富山大学大学院理工教育部の大藤　茂教授によるご指摘と，富山市科学博物館の岩田朋文学芸員の編集より大きく改善された．以上の方々に深謝申し上げる．

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