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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＊

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A meniscate backfilled burrow from the Upper Jurassic Arimine Formation of the Kuzuryu Group, southeastern Toyama Prefecture

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A horizontal meniscate backfilled burrow occured in the shallow marine Arimine Formation (Upper Jurassic Kuzuryu Group) distributed in the Arimine area, southern Toyama Prefecture. The trace fossil is characterized by 1) convex epirelief preservation, 2) shuffled arrangements of arcuate and subrectangular menisci (horizontal view), 3) anteriorly dipping non-compartmentalized backfill (lateral view), and 4) longitudinal striated thin lining slightly horizontally extending into the host sandstone.

These characteristics are partly comparable with the already described meniscate burrows such as *Ancorichnus*, *Beaconites*, *Scoyenia* and *Taenidium*, however, the latter two structures are unique to the Arimine specimen.

１．はじめに

メニスカス状の後方充填構造をもつ化石棲管が，東坂森谷中流域（富山県南東部，有峰地域; Fig. 1）に露出する，浅海成の上部ジュラ系九頭竜層群有峰層から産出したので，ここに報告する．

化石棲管は，埋在性底生生物の形成した巣穴の生痕化石である．底質環境の影響を受けた原地性の化石であるため，堆積環境を考察する上で化石棲管が有用であることは一般的に認識されている（例えばKnaust and Bromley, 2012）．ところが，有峰層産の生痕化石に関する知見は，1950年代から蓄積されてきた軟体動物化石のそれと比べると，2000年代初頭においてもなお不十分である（平澤，2016）．

そこで本稿では産出した化石棲管の特徴を記載し，有峰層の生痕化石群集および堆積環境を解明するための一資料とする．なお記載した標本は，富山市科学博物館に保管されている（標本番号TOYA-Fo．7375）．

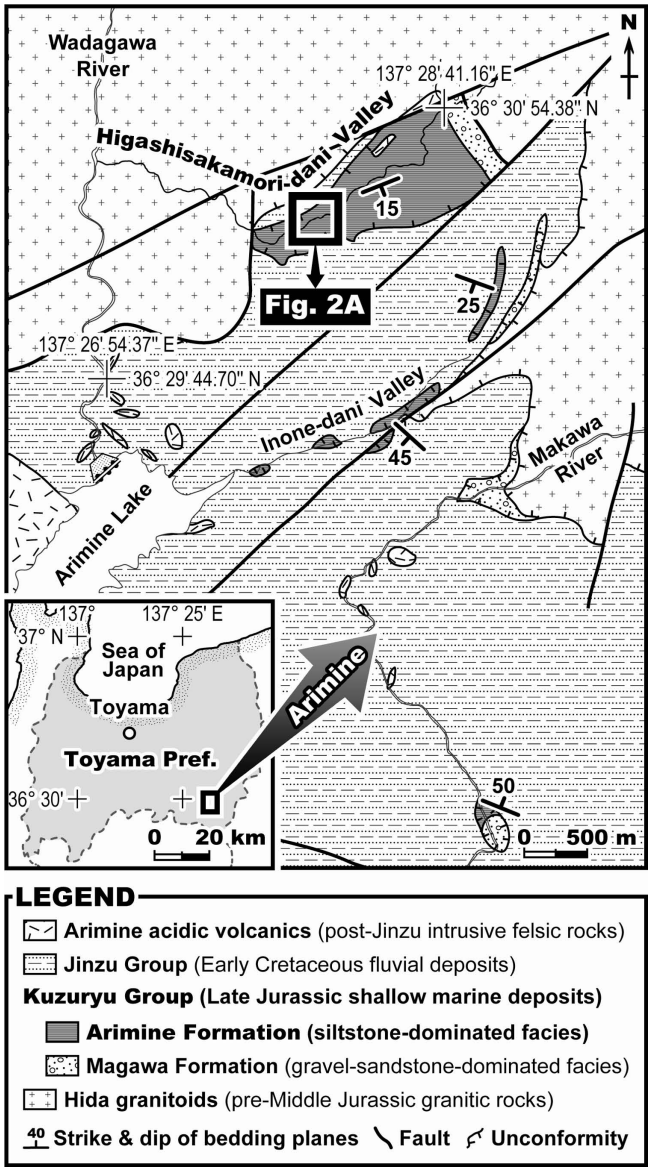

Fig. 1 Index and simplified geological maps showing the sampling locality (southeastern Toyama Prefecture). Modified after Kawai and Nozawa (1958), Takenami and Maeda (1959), and Nozawa and Sakamoto (1960).

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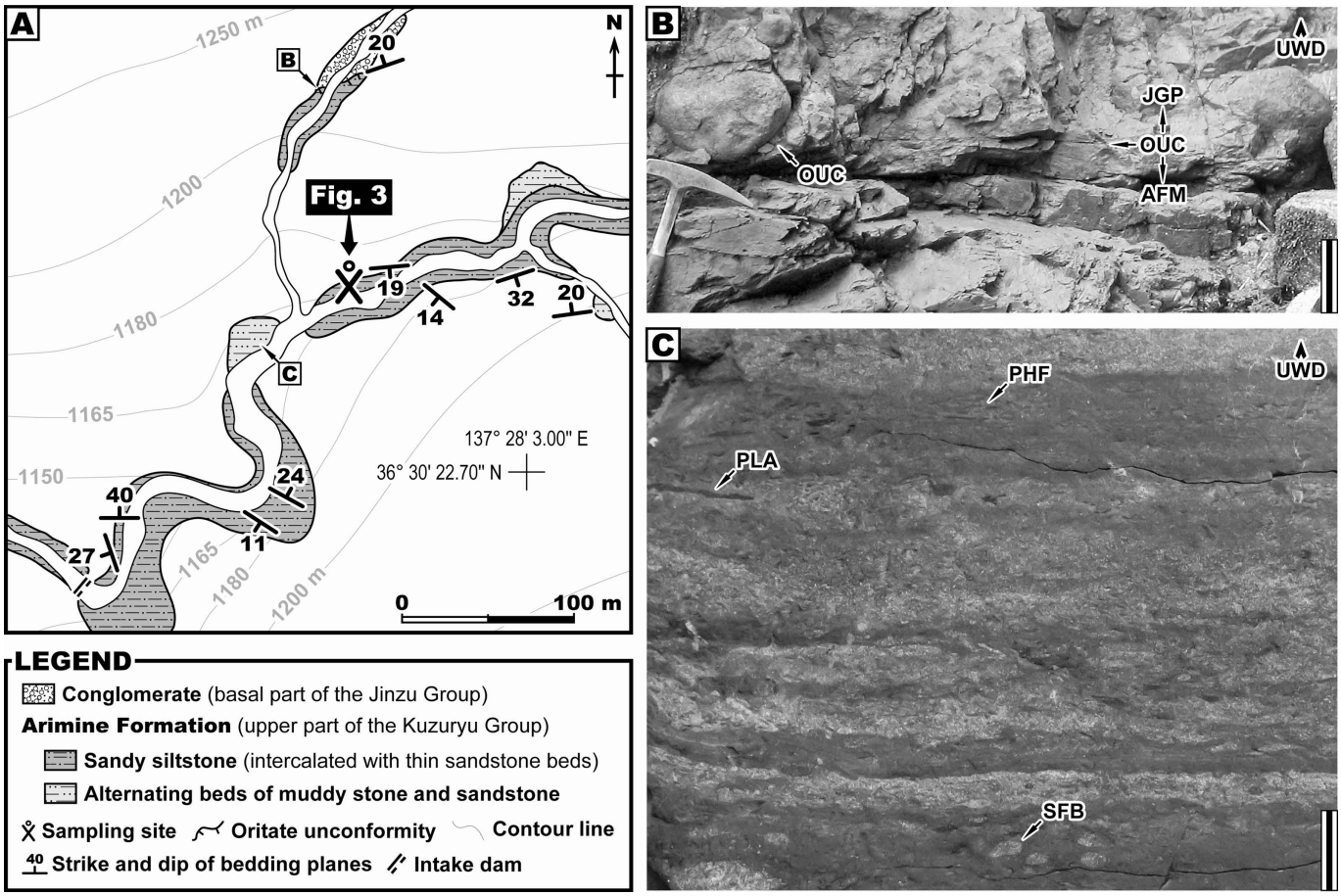


Fig. 2 Route map and outcrop photographs around the sampling site. (A) Route map. Sandy siltstone successively crops out along the Higashisakamori-dani Valley. Attitudes of beddings are highly variable. (B) Oritate unconformity. Sandy siltstone (Arimine Formation) is erosionally overlain by the basal conglomerate of the Jinzu Group. Scale bar equals to 10 cm. (C) Thin alternation of siltstone (darker intervals) and sandstone (lighter intervals). Both the deposits exhibit bioturbated lithofacieses due to phycosiphoniform, *Planolites* and unidentified mud- or sandstone-filled burrows. Scale bar indicates 1 cm. Abbreviations: AFM, Arimine Formation; JGP, Jinzu Group; OUC, Oritate unconformity; PHF, phycosiphoniform; PLA, *Planolites*; SFB, sandstone-filled burrow; UWD, upward direction.

2．地質概説

九頭竜層群（Sano，2015）は，中～後期ジュラ紀（後期Bathonian 期～Oxfordian 期）にかけて堆積した海進期の地層であり，福井県東部の九頭竜川上流域や富山県南東部の有峰地域，および南部の桐谷地域に分布する（佐野ほか，2013; Sano，2015; 山田，2017）．本層群は，基盤岩である飛騨帯および飛騨外縁帯の古生界・下部中生界と不整合や断層で接し，下部白亜系の手取層群や神通層群により不整合に被覆される（前田，1961; 松川ほか，2014; Sano，2015）．このような地質学的背景をもつため，九頭竜層群は後期中生代の東アジア地域における古環境や古生物地理，さらに日本列島の構造発達史を解明する際に重要である（前田，1961; 松川ほか，2007; Matsukawa *et al.*, 2008; 佐野ほか，2013; Sano，2015）．その堆積の場は全体として，堆積速度・堆積物供給量ともに高く，しばしば暴浪の影響を受けた沿岸域であったと解釈されている（前田・武南，1957a; 前田，1961; Masuda *et al.*, 1991; Sato and Yamada，2014; 平澤，2016，2017）．

有峰地域の九頭竜層群（＝前田・武南，1957bの「手取層群九頭竜亜層群」）は，下位より真川層（砂岩と礫岩主体で黒色泥質岩を伴う）と，有峰層（黒色泥質岩の優勢な泥質岩砂岩互層を主とし礫岩を挟在する）に区分され，東坂森谷，猪根谷および真川中・上流域に分布する（河合・野沢，1958; Takenami and Maeda，1959; 野沢・坂本，1960; 松川ほか，2014; Sato and Yamada，2014; Fig. 1）．本域の九頭竜層群は，基盤の飛騨花崗岩類（先中部ジュラ系）と不整合ないし断層で境され，河川成である下部白亜系神通層群の基底部（＝前田・武南，1957bの「手取層群石徹白亜層群」）により不整合に覆われる（松川ほか，2014）．また，分布域の一部で神通層群堆積後の有峰酸性火山岩類（大村，1973）に貫入される．

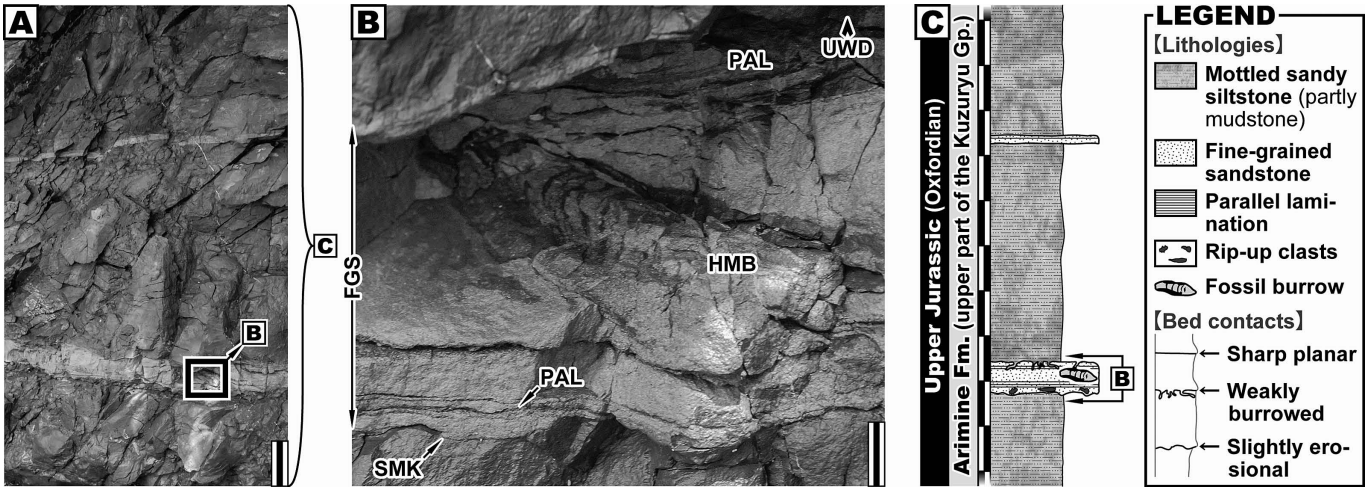


Fig. 3 Outcrop photographs and a columnar section of the sampling site. (A) Alternating beds of sandy siltstone and fine-grained sandstone. Sandy siltstone (darker intervals) is dominant in this succession. Scale bar indicates 10 cm. (B) Mode of occurrence of the meniscate burrow. The trace fossil is preserved as convex epirelief on a bedding surface in a middle horizon of the host sandstone bed. Sandstone layer below the burrow has an erosional base and parallel lamination in ascending order, which lithofacies exhibits Bouma T_{ab} divisions. Slightly oblique view to bedding plane. Scale bar equals to 1 cm. (C) Columnar section of the left photographed interval. Thin turbidites are intercalated with the silty succession. The sandy siltstone is intensely bioturbated in contrast to the turbidites. Scale bar is in 10 cm divisions. Abbreviations: FGS, fine-grained sandstone; HMB, horizontal meniscate backfilled burrow (fossil material); PAL, parallel lamination; SMK, sole mark; UWD, upward direction.

真川層では化石に乏しいものの，有峰層からはアンモノイド類（Sato，1962; Matsukawa *et al.*, 2008; Sato *et al.*, 2012; Sato and Yamada，2014; Goto *et al.*, 2018）や，二枚貝類（前田・武南，1957b; Maeda，1962; Maeda and Kawabe，1963，1966），植物（原山ほか，1991; Yamada，2018）といった大型化石に加えて，放散虫類などの微化石も産出する（平澤・柏木，2008; 平澤ほか，2010）．また生痕化石として，*Cylindrichnus* 様の垂直棲管，*Ophiomorpha*，phycosiphoniform，*Planolites* および *Skolithos* が本層より知られる（平澤ほか，2010; 平澤，2016; Goto *et al.*, 2018）．

有峰層の時代は，*Perisphinctes matsushimai* 群集帯（Sato and Westermann，1991）に属するアンモノイド類の産出から，後期ジュラ紀のOxfordian 期と考えられている（Sato and Yamada，2014）．

3．化石棲管産出露頭の岩相

東坂森谷の中流域には，有峰層の主部をなす黒色砂質シルト岩層と暗色泥質岩砂岩互層が河岸沿いに連続的に露出する（Fig．2A）．これらの層理面の姿勢は，小褶曲や小断層により頻繁に変化する．有峰層の下限は河床部においても露出していない．一方，上限は山腹に認められ，神通層群の基底をなす大～巨礫岩層と不整合（折立不整合；前田・武南，1957b）関係にある（Fig．2B）．泥質岩層と薄い砂岩層は一般にphycosiphoniform や *Planolites* などによる生物攪拌を受けており，斑状あるいは叢雲状の岩相を示す（Fig．2C）．

メニスカス構造のある化石棲管は，右岸に露出した黒色砂質シルト岩細粒砂岩互層から得られた（Fig．3）．砂質シルト岩の優勢な互層であり，その層厚は40 cm以上と砂岩層厚（2～10 cm程度）よりも非常に厚い（Fig．3A）．化石棲管は，露頭下部に見られる細粒砂岩層（層厚7 cmほど）の中部層準に，凸状の上面浮き彫り痕 convex epirelief として保存されていた（Fig．3B，C）．

砂質シルト岩層は強い生物攪拌（Taylor and Goldring，1993におけるBI = 5）によって初生的な堆積構造をほぼ失っており，Fig．2B に類似した，phycosiphoniform-*Planolites* 生痕ファブリックを示す．

細粒砂岩層はシート状で，上下とも比較的平坦かつ明瞭な層理面を示す．基底面はやや侵食的であり，ごく浅いソールマークを伴う（Fig．3B）．また，基底部にシルト岩質のリップアップクラストが認められる（Fig．3C）．砂岩層の下部と上部では，暗灰色でやや泥質な極細粒砂岩からなる平行葉理が発達する（Fig．3B）．砂岩層上部は弱い生物撹拌（BI 1 - 2相当）を被っており，基底面よりもやや不明瞭な層理面となっている．細粒砂岩は，円磨度・淘汰ともに良好な長石類と石英粒子を主とする岩質である．露頭面では風化により黄褐色を呈する．

このような岩相から，静穏な泥質底にしばしば極細～細粒砂が混濁流として供給され，Bouma T_{ab} ないし T_{abd}

タービダイトとして堆積したと解釈される．また，泥底質における生物攪拌の速度は，泥質物の堆積速度と平衡していたか，あるいはそれ以上であったと推定される．

生痕化石の記載
Description of the trace fossil

Ichnological terms follow those of Frey *et al.* (1984), Keighley and Pickerill (1994), and Retallack (2001). Stratigraphy and geological age are referred from Matsukawa *et al.* (2014), Sato and Yamada (2014), Sano (2015), and Yamada (2017).

Horizontal meniscate backfilled burrow
Fig. 4

Material: One specimen (TOYA-Fo. 7345) reposited in the collections of the Toyama Science Museum, Toyama City.

Preservation: Convex epirelief on a bedding surface within a weakly bioturbated (BI 1-2), fine-grained sandstone bed showing Bouma T_{ab} or T_{abd} divisions.

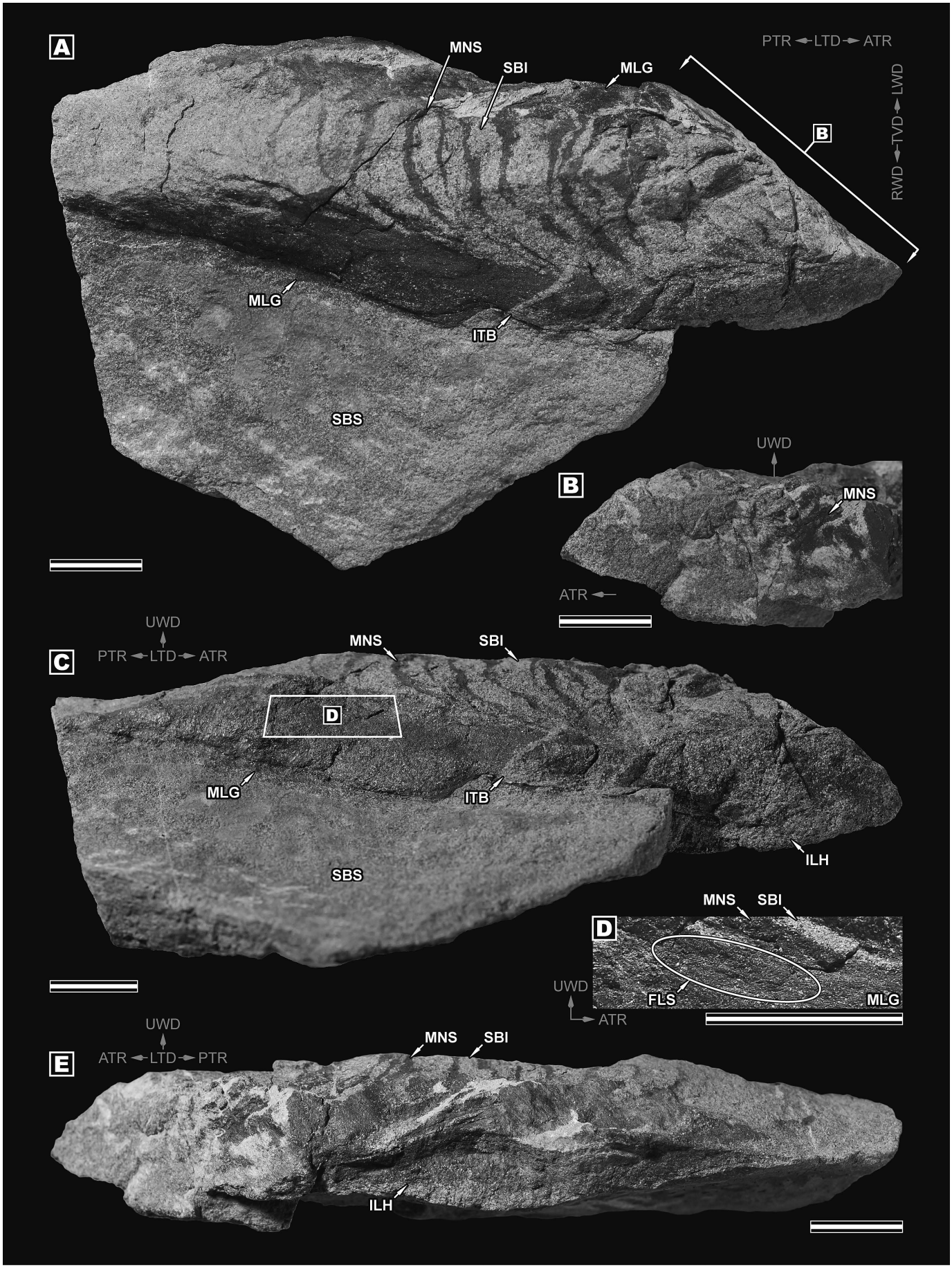
Description: TOYA-Fo. 7345 is an unbranched, slightly sinuous horizontal burrow with meniscate backfill and lining structures (Fig. 4A), containing neither fecal pellets nor bioclasts. Any internal structures, such as normal- or inverse grading, are not recognized in the transverse-oblique fracture surface in contrast to horizontal and lateral views (Fig. 4B). Preserved maximum length and width are 9.6 cm and 2.9 cm, respectively. When a concave side of a meniscus (direction of burrowing; Keighley and Pickerill, 1994) is defined here as anterior, burrow width slightly decreases toward posterior. Except for a posterior broken portion, burrow height is almost constant (approximately 1.7 cm). Surface of the burrow is smooth because of lacking transverse bellows-like ornaments, scalariform ridges, annulations or selective weathering of the infilled materials (Fig. 4C). Transverse view shows a convex semielliptical morphology whose height / width ratio is approximately 0.6.

The backfill structure consists of texturally heterogeneous coarse-to-fine alternations exhibiting a dense-to-well spaced shuffled pattern, that is, irregularly spaced, asymmetrical arrangements about the median line of the burrow (Fig. 4A). But intervals of the alternations have a faint tendency to be more spaced posteriorly. The burrow infill also displays an imbricated or anteriorly dipping structure (dips ranging from 10° to 50°), when viewed in the lateral side (Fig. 4C-E).

Menisci composed of black mudstone are parenthesis-like, shallow arcuate or tortoise shell bracket-like, subrectangular in their horizontal shapes (Fig. 4A). Transverse width and thickness highly vary even in a single meniscus. Several menisci extend into the lining, but others pinch out not to extend fully across the burrow width. Moreover, the menisci often intersect or merge into each other.

Irregularly spaced, often pinched-out menisci result in an irregular succession of incompletely bounded non-compartmentalized packets and meniscate segments (Fig. 4A), which are composed of yellowish-brown, massive fine-grained sandstone

Fig. 4 (next page) Horizontal meniscate backfilled burrow (TOYA-Fo. 7345) from the shallow marine, Upper Jurassic Arimine Formation. (A) Upper bedding plane view. The burrow is characterized by irregularly spaced, heterogeneous non-compartmentalized backfill and a thin lining slightly horizontally extending into the host sandstone. A thin burrow filled with structureless sandstone intersects along the lining of the meniscate trace fossil. (B) Oblique transverse view of an anterior fracture surface. Structureless sandy infill with fragments of muddy menisci is observed. Lighter gray portions are intensely weathered. (C) Right lateral view showing convex epirelief preservation. The backfilled structures display anteriorly dipping, imbricated arrangements. (D) Close-up of the lining, oblique bedding plane view of a right lateral surface. Note faint longitudinal striations dipping anteriorly. (E) Left lateral view. Floor of the burrow and the host rock are indistinctly bounded. All scale bars equal to 1 cm. Abbreviations: ATR, anterior; FLS, faint longitudinal striation; ILH, interface between the lining and the host sandstone; ITB, intersecting thin burrow; LTD, longitudinal direction; LWD, leftward; MLG, mudstone lining; MNS, meniscus (mudstone packing); PTR, posterior; RWD, rightward; SBI sandstone burrow infill; SBS, sandstone bedding surface; TVD, transverse direction; UWD, upward direction.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showing an almost similar (or very slightly muddy) lithology to the host sandstone. The sandstone infill has inconstant thickness owing to the irregularly and not parallelly arranged muddy menisci. Though thickness varies even within a single sandstone packing likewise the meniscus, it tends to be rather shorter than the transverse width.

The lining is mostly weathered out, only well-preserved from middle to posterior parts of the right lateral side (Fig. 4A, C). This structure covers not only the burrow infill, but also very slightly extends horizontally into the host rock with nearly constant width (about 2 mm; Fig. 4A, C). The lining is a considerably thin, simple wall structure made up of black mudstone similar in lithology to the meniscus (Fig. 4A). Very faint longitudinal striations, which dip anteriorly at the same angles to the imbricated infill, run on the lining surface (Fig. 4D). Interface between the lined burrow floor and the host sandstone is indistinct and somewhat irregular (Fig. 4C, E).

As a co-occurring trace fossil, a posteriorly oblique thin burrow containing structureless fine-grained sandstone intersects along the lining at a right anterior part of the meniscate burrow (Fig. 4A, C).

Remarks: Ichnotaxonomy of the meniscate trace fossils are based on their wall characters and presence or absence of branching (D'Alessandro and Bromley, 1987). In the light of this criteria, TOYA-Fo. 7345 is difficult to be identified at and below ichnogenus levels because its preservation is too patchy to confirm whether originally branching or non-branching. However, though insufficient preservation, the Arimine specimen is partially comparable with the already known meniscate traces on the basis of their backfill and lining structures.

Adhesive meniscate burrows (AMB; Hasiotis and Dubiel, 1994), *Ancorichnus* Heinberg, 1974, *Beaconites* Vialov, 1962, *Scoyenia* White, 1929 and *Taenidium* Heer, 1887 are typical meniscate backfilled traces whose ichnotaxobases have been discussed in a large number of literature (e.g. Frey *et al.*, 1984; D'Alessandro and Bromley, 1987; Keighley and Pickerill, 1994; Uchman, 1995; Retallack, 2001; Smith *et al.*, 2008). Brief comparisons are attempted between the exemplified burrows and TOYA-Fo. 7345.

AMB are characterized by sinuous burrows consisted of a series of ellipsoidal packets filled with densely arranged, fine meniscus (Smith *et al.*, 2008). Such features are never confirmed in the Arimine specimen.

Ancorichnus is a horizontal, weakly sinuous and cylindrical meniscate burrow with a marginal structure (Frey *et al.*, 1984; Keighley and Pickerill, 1994). In transverse section, the burrow shows a subelliptical morphology (Frey *et al.*, 1984). Menisci do not always transversely extend into the wall but sometimes are more or less abruptly discontinued (Frey *et al.*, 1984). These characteristics are also observed in TOYA-Fo. 7345. But the Arimine specimen dose not have smooth, structured mantle which is one of the diagnostic characters of the ichnogenus (Frey *et al.*, 1984; Keighley and Pickerill, 1994). Endo- and hyporelief preservation of *Ancorichnus* (Frey *et al.*, 1984) also differs from TOYA-Fo. 7345.

Beaconites resembles the Arimine specimen in respect to a horizontal, sinuous and walled meniscate burrow containing heterogeneous materials (Keighley and Pickerill, 1994). *B. antarcticus* Vialov, 1962 and *B. coronus* (Frey et *al.*, 1984) have gently to moderately arcuate menisci (Keighley and Pickerill, 1994), likewise TOYA-Fo. 7345. However, sometimes strongly arcuate meniscate packets and unornamented linings diagnosed for this ichnogenus (Keighley and Pickerill, 1994) are not identical with the Arimine specimen.

Scoyenia occurs as a gently curved burrow consisted of heterogeneous backfilled materials with a distinct longitudinal striated wall lining (Frey et al., 1984; D'Alessandro and Bromley, 1987). Such features can be also recognized in TOYA-Fo. 7345. But as pointed out by Frey *et al.* (1984), endo- and hyporelief preservation, conspicuous annulations and chevron-like menisci characterized *Scoyenia* are quite different from the Arimine specimen.

Sinuous, cylindrical *Taenidium* shears many diagnostic characters proposed in D'Alessandro

and Bromley (1987), and Keighley and Pickerill (1994) with TOYA-Fo. 7345. For example, stacked, longitudinally short non-compartmentalized backfill (*T. barretti* (Bradshaw, 1981)), epirelief of a horizontal burrow composed of packets considerably shorter than wide (*T. satanassi* D'Alessandro and Bromley, 1987), and arcuate menisci (*T. satanassi* and *T. serpentinum* Heer, 1887). Although not all of the morphologies in each ichnospecies correspond to the Arimine specimen. Specifically, an unwalled burrow containing deeply arcuate backfill (*T. barretti*), equally spaced and pelleted backfill (*T. satanassi*), annulations in the burrow boundary (*T. satanassi* and *T. serpentinum*), and well-spaced homogeneous menisci (*T. serpentinum*) are not recognized in TOYA-Fo. 7345.

In summary, the Arimine specimen has several but not all of the corresponding characteristics with the compared ichnogenera and ichnospecies. The anteriorly dipping non-compartmentalized backfill and the striated lining slightly horizontally extending into the host rock are in particular unique to TOYA-Fo. 7345.

Associated trace fossils: Sparsely occurring, unidentified horizontal-to-vertical burrows filled with dark sandy siltstone (other than the intersecting thin burrow).

Locality: Right bank of the middle stream of the Higashisakamori-dani Valley (36° 30' 25.42" N, 137° 27' 59.43" E; 1166 m in altitude), Arimine, southeastern Toyama Prefecture (Figs. 1, 2).

Stratum: Arimine Formation, upper part of the Kuzuryu Group.

Age: Oxfordian (early Late Jurassic).

5．まとめ

富山県南東部の有峰地域に分布する，浅海成の上部ジュラ系有峰層（九頭竜層群上部）から産出した化石棲管を記載し，類似する既知の生痕化石と比較した．化石棲管は，細粒砂からなるタービダイト砂岩層内に上面浮き彫り痕として保存されていた．その主な特徴は以下の5点である．

1）水平な棲管であり，メニスカス状の後方充填物（交互に配列した泥岩および砂岩）と，それを被覆するごく薄い泥岩の裏打ちをもつ．

2）水平面観において，メニスカス構造は不規則な間隔で配列し，また尖滅あるいは互いに斜交する左右非対称な配列を示す．

3）側方面観において，充填物は前方に傾斜した覆瓦構造をなす．

4）裏打ち表面には，覆瓦構造と平行する微細な線状構造がみられる．

5）裏打ちは充填物を被覆するだけでなく，母岩の水平方向にもわずかに拡張する．

有峰標本には，*Ancorichnus*，*Beaconites*，*Scoyenia* および *Taenidium* といった生痕属と共通する特徴が認められる．しかし，3）～5）は本標本に特有な構造といえる．

6．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．ここに記して深謝申し上げる．

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