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Dinosaur Footprints and Other Indentation in the Cretaceous Sebayashi Formation, Sebayashi, Japan

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Abstract This paper describes some imprints on the surface of a cliff of the Lower Cretaceous Sebayashi Formation at Sebayashi, Nakazato-village, Tano-county, Gunma Prefecture, Japan, and interprets the cause of the formation of imprints on the basis of thier morphology and distribution with reference to the sedimentary environments of the Sebayashi Formation.

The imprints are made up of two groups: one consists of three deep imprints which stand in a row toward the strike in the central zone of the cliff surface (A group); the other consists of imprints of fairly shallow, depressive and various shapes which form a narrow zone from the lowest margin of the mid-breadth of the cliff to the right margin of the mid-height (B group).

These imprints are interpreted to be dinosaur footprints on the basis of their morphology, size, development of cracks around imprints, resemblance to some iguanodontid footprints, and the regular space between two prints of the same kind and the width of the tracks.

A few trackways consisting of these imprints are interpreted to be formed by three or more dinosaurs.

Introduction

In the Kwanto Mountains, the Lower Cretaceous strata are distributed in the Sanchu Terrane, in the middle part of the Chichibu belt. The Sanchu Terrane, defined as a narrow strucural zone 2–5 km wide and approximately 40 km long, extends longitudinally from the western part of Saitama Prefecture to the southeastern part of Nagano Prefecture.

The Cretaceous strata are characterized by a nonmarine to marine, thick cyclic sequence consisting of conglomerate or sandstone in the lower part, and alternating sandstone and shale or only shale in the upper.

The cliff showing numerous ripple marks and some peculiar imprints located in the mid-part of Sanchu Terrane. These sedimentary structures on the surface of the cliff were described by ARAI *et al.* (1958) in detail. These authors discussed the depositional environments on the basis of field observation and experimental study of ripple marks. The detailed observations and interpretation of the imprints, however, have not yet been worked out to our satisfaction. The purpose of this study is to describe these imprints based on new observations, and to interpret the cause of their formation on the basis of their morphology and distribution with special reference to the sedimentary environments of the Sebayashi Formation in the neighborhood of Sebayashi which were analyzed by MATSUKAWA (1983).

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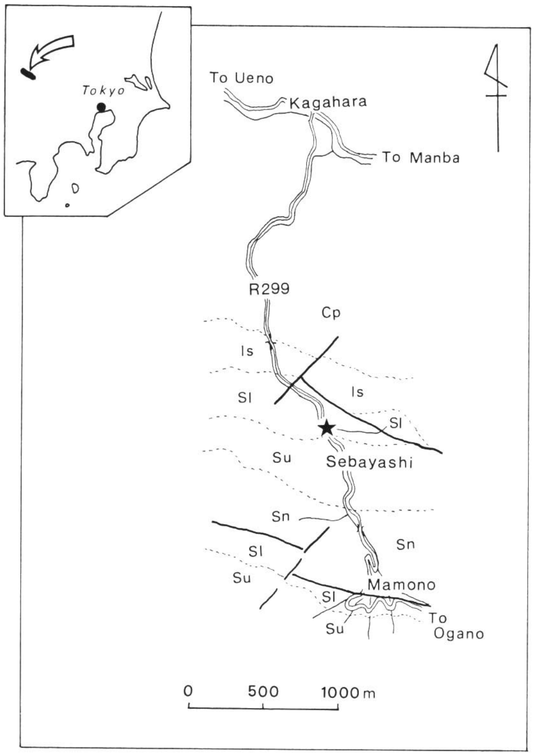
Geological Setting

The geology of the Sanchu Cretaceous Terrane was reported by TAKEI (1963), MATSUKAWA (1983), and others. According to MATSUKAWA (1983) the Cretaceous strata of the Sanchu Terrane comprise clastic rocks that are almost 2700 meters in thickness. These are characterized by three fining-upwards, thick-unit cyclic sequences, each of which attains more than several hundred meters in thickness and shows facies variations from nonmarine to marine beds. The Cretaceous is divided into four units named. In ascending order these are the Shiroi, Ishido, Sebayashi and Sanyama Formations. Some ammonoids occurred from the Ishido and Sanyama Formations. These ammonoids indicate that the Ishido Formation can be assigned to the Upper Hauterivian (?) to Barremian, and the Sanyama Formation to the Upper Aptian to Lower Cenomanian. Hence the Sebayashi Formation, which lies between these two formations, is probably referable to the Uppermost Barremian to Aptian.

Some peculiar imprints described in this paper are present in the fine sandstone belonging to the Sebayashi Formation. This is included in the second of three sedimentary cycles and is lithologically divisible into the Lower and Upper Members. The Lower Member overlies the shallow marine Ishido Formation conformably. It is composed of massive dark grey to light grey fine- to medium-grained sandstone, and contains a large number of fresh- and brackish-water bivalves and gastropods and terrestrial plant remains. In turn, the Upper Member conformably overlies the Lower Member. It consists mostly of shale and rhythmically alternating beds of sandstone and shale, and it contains occasional marine bivalves and foraminifers. Thus the formation suggests offlapping, deltaic, topset deposits in the Lower Member and renewed transgressive deposits on a shallow shelf or seaway in the Upper Member. Consequently, the deposits of the Lower Sebayashi at Sebayashi are interpreted as being deltaic and associated with prograding distributaries.

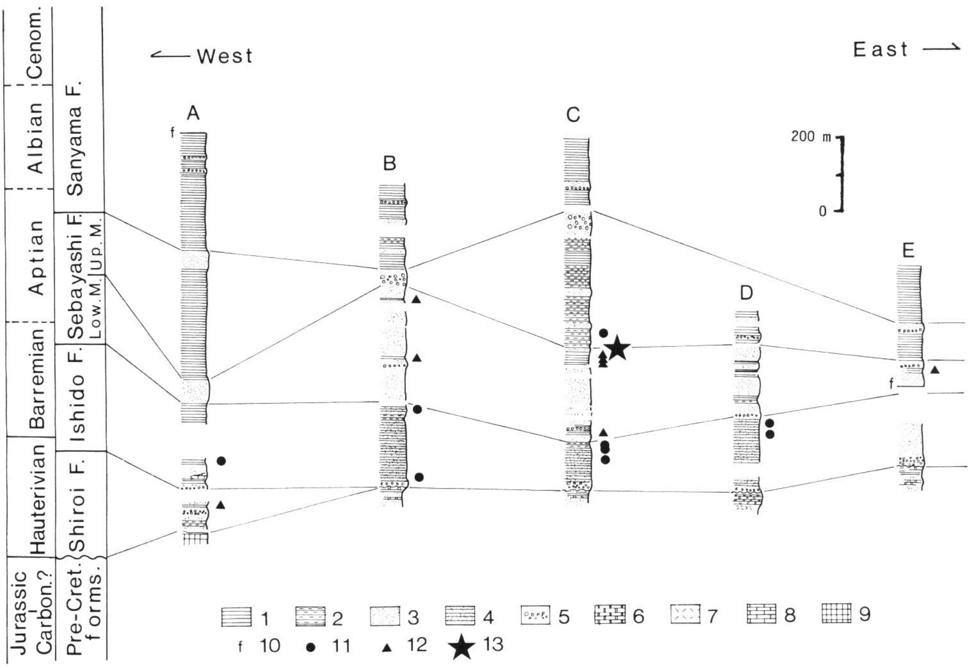
Some kinds of imprints with numerous ripple marks are observed on a bedding plane of the cliff of the Lower Sebayashi exposed at about 200 meters north of Sebabayashi hamlet (Nakazato-village, Tano-county, Gunma Prefecture) on the right



Text-fig. 1. Map showing locality of the cliff (star mark) containing some imprints at Sebayashi.

Cp: Pre-Cretaceous formations, Is: Ishido Formation, Sl: Lower Member of Sebayashi Formation, Su: Upper Member of Sebayashi Formation, Sn: Sanyama Formation, R299: highway No. 299.

side of a highway No. 299 along Mamonozawa River (Text-fig. 1). In the neighborhood of Sebayashi, the nonmarine Lower Member is characterized by thick sandstone with some shale interbeds yielding fresh or brackish water bivalves. The thick sandstone beds rapidly thin laterally (Text-fig. 2). This nonmarine wedge bed is interpreted as deltaic deposits prograded into the marine area of the Upper Member, probably due to a high rate of deposition, in excess to the rate of rising sea level. Moreover, the nonmarine bivalves (i.e. *Costocyrena radiatostriata*, *Protocyprina* sp. aff. *P. naumanni*, *Nipponoinaia ryosekiana* and others) are well preserved with a complete shell in the above-mentioned wedge bed and are associated with some allochtonously introduced marine bivalves (i.e. *Ostrea* sp., *Astarte* (*Yabea*) *shinanoensis*, and *Panopea* sp.). This fact suggests that the fossiliferous interbeds represent river-influenced bay sediments on a delta.



Text-fig. 2. Individual columnar sections with the indication of the horizon which preserved some imprints, and showing lithofacies change.

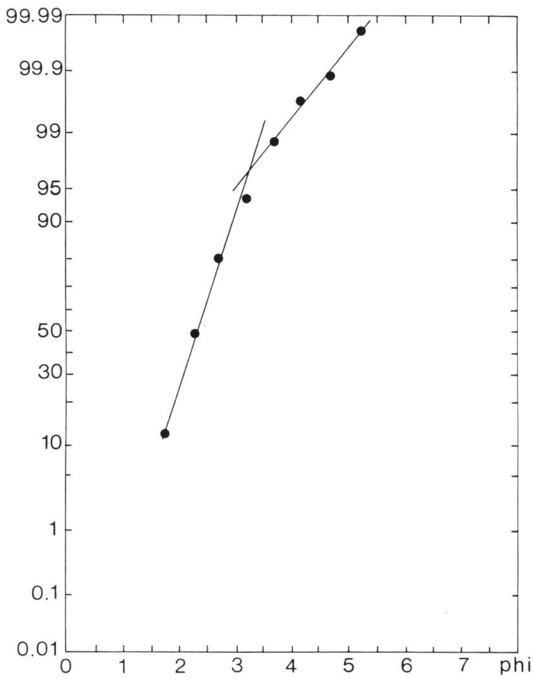
1: shale, 2: alternating beds of sandstone and shale, 3: sandstone, 4: muddy sandstone, 5: conglomerate, 6: chert, 7: pyroclastic rocks, 8: limestone, 9: ultramafic rocks, 10: fault, 11: marine molluscs, 12: nonmarine molluscs, 13: imprints.

A: Otchizawa-Kayorizawa, B: Myokezawa, C: Mamonozawa, D: Niheizawa, E: Kimyozawa.

Observations of the Cliff at Sebayashi

1) Outline

The cliff is of about 12 meters in height and 10 meters in width. The surface of the cliff represents a bedding plane which strikes N50°W and dips 75°S and consists of ill-sorted sandstone: average grain size is 3.74 phi, and mud content is 34.27% (Text-fig. 3). On the bedding plane a fairly depressive central zone which accompanies three imprints (A group) can be recognized. Many kinds of reliefs, i.e. ripple marks, "tiny pits," numerous lebensspuren, imprints and cracks, can be observed on the surface of the cliff (Text-figs. 4, 5). The ripple marks occupy the entire surface of the exposure. The "tiny pits" are scattered in the right lower part, and are also observable on a small isolated area in the left lower part. The imprints (B group) are shallow and medium in size and partly indistinct in outline. The joint system consists of strike and dip sets: the former are apparently cut by the latter.

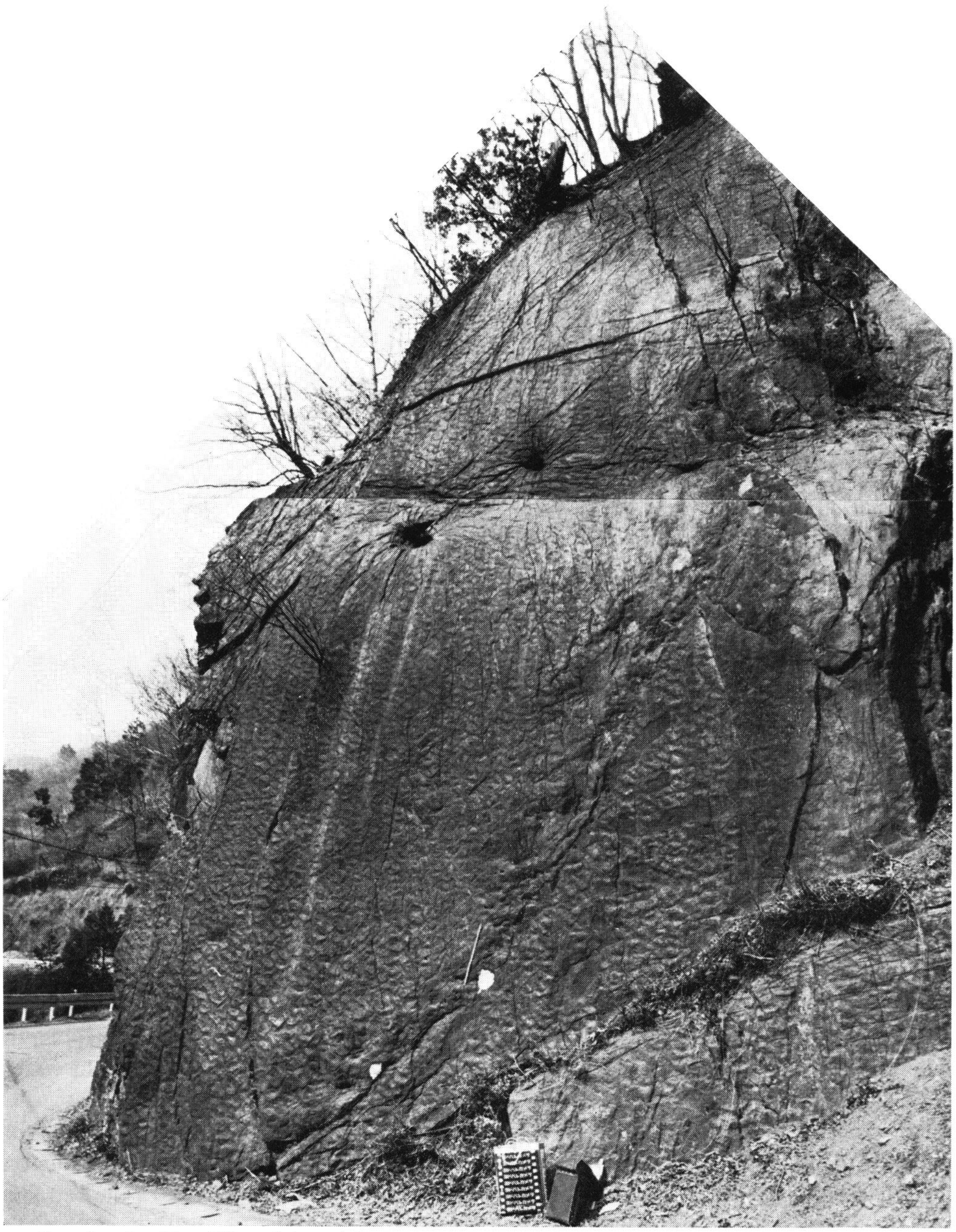


Text-fig. 3. Grain size distribution and log-probability curve of the sediments.

2) Ripple marks

The ripple marks are made up of asymmetrical current ripples which comprise a linguoid type (ALLEN, 1968) in the lower-half on the cliff and a sinuous type (ALLEN, 1968) in the upper-half. As to the former type the morphologic characters and the formative conditions were reported by ARAI *et al.* (1958). The linguoid ripples are ridges about 100 mm in length, approximately 150 mm in wave length, and nearly 5 mm in amplitude, indicating that the former current was from the upper to the lower part of the cliff. The same authors also mentioned that ripple marks almost the same as those seen in the Sebayashi Formation were produced by them experimentally under the following conditions: a grain size averaging about 0.3 mm, a water depth of 20 to 60 mm, and a velocity of the running fluid of 250 to 270 mm/sec at the water surface.

On the other hand, the ripple marks of sinuous type comprise two types: one of them runs obliquely and the other runs parallel to the strike of the bedding plane on the cliff surface. As to the former, the ripple ridges and the strike line of the bedding plane intersect at about 65 degrees. The ripple mark ridges are 110 to 170 mm in length, about 100 mm in wave length, and nearly 10 mm in amplitude. The stoss side of the ripples face upperwards on the surface of the cliff. Accordingly, the current direction is presumably towards the lower part of the cliff.

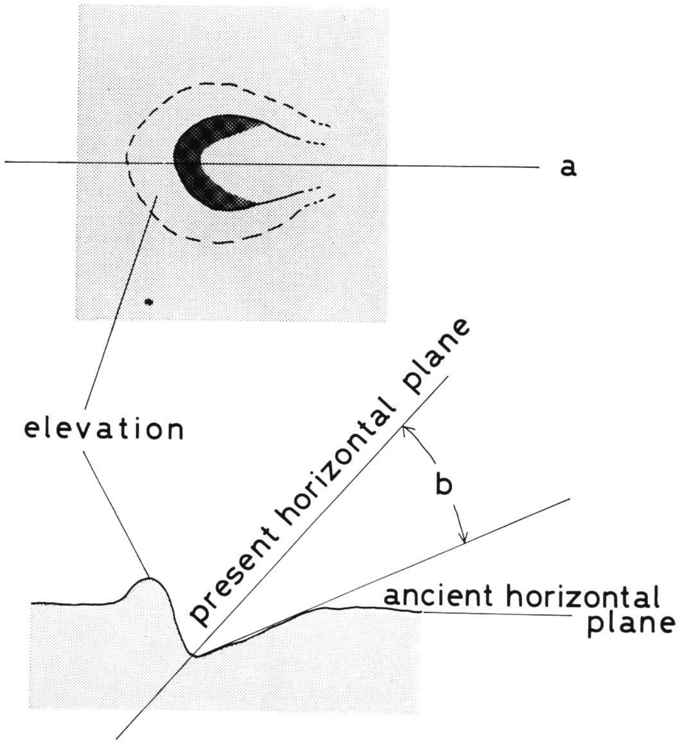


Text-fig. 4. The cliff at Sebayashi, Nakazato-village, Tano-county, Gunma Prefecture. White markings on the surface of the cliff are plaster casts of some of the imprints.

Text-fig. 5. Sketch of the cliff at Sebayashi.
1. imprints, 2. linguoid type ripple marks, 3. sinuous type ripple marks, 4. "tiny pits" on the linguoid type ripple marks and regularly spaced imprints, 5. non-relief.

3) "Tiny pits"

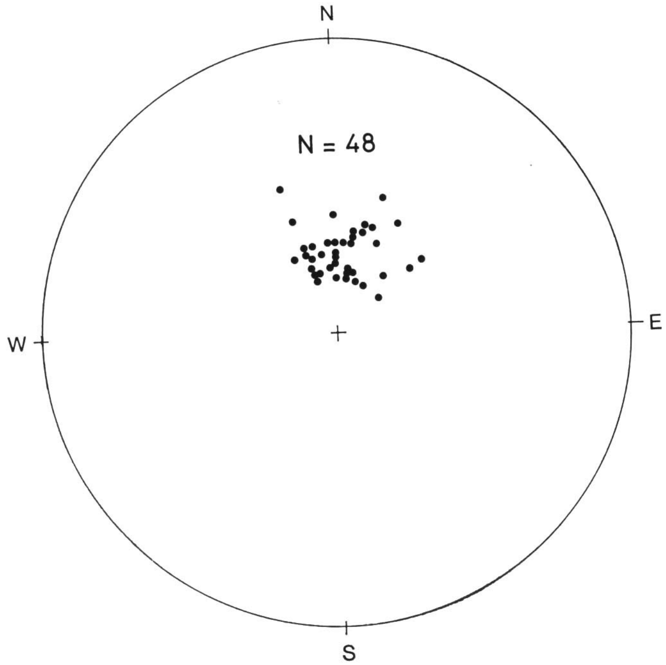
The rim of "tiny pits" consists of circular or elliptical forms, 3 to 5 mm in diameter. The shape of the pits is roughly that of inverted cones. Comparatively large pits accompany with a low and wide elevation around the rim, which is not visible at the one side of the rim, but is observable at the opposite side (Fig. 1 and 2 in Plate 2, Text-



Text-fig. 6. Diagrammatic upper view and cross section of "tiny pit."
a: the direction of pit, b: the degree of slope at the cavity along the long diameter of pit.

fig. 6). The direction of long diameter (a in Text-fig. 6) and the degree of slope at the cavity along the long diameter (b in Text-fig. 6) show roughly north and south, and 0° to 25° against the cliff surface respectively. As the surface of the cliff is a bedding plane that strikes N 50°W, and dips 75°S, the degree of slope above mentioned is convertible 50° to 75° when the surface of the cliff is restored at the depositional time (Text-fig. 7). The distributed density of "tiny pits" is not the same everywhere but varies from 78 to 89 per 150×150 mm^2. These pits were described and interpreted by ARAI *et al.* (1958) and HIRANO (1971). However, opinions concerning the origin of the pits have been divergent. One opinion is that they are rain drop imprints (HIRANO, 1971) and another denies this (ARAI *et al.* 1958).

Although the morphologic characters described above are somewhat similar to those of the hailstone impressions described by SHROCK (1948), the cross-section of the pits and the adjacent areas clearly proves an existence of a kind of lebensspuren (Text-fig. 8). They are possibly interpreted as somewhat horizontal fodinichnia made by crustaceans of the cruziana facies. Such "tiny pits" have some similarity, in the surface shape, size, and distributed density, with those made by recent amphipod crustaceans.



Text-fig. 7. Equal area projection of attitudes of "tiny pits," when the surface of the cliff is restored at the depositional time. (Lower hemisphere).

4) Lebensspuren

These were described and illustrated in detail by ARAI *et al.* (1958). According to them, the lebensspuren were classified into three types:

(1) Simple stick-like forms, including (a) long string like epichnia and hypichnia which suggest repichnia of Polychaeta (Fig. 4 in Plate 1); (b) rope-like epichnia which closely resembles repichnia of Polychaeta; (c) slender but short epichnia; and (d) fat but long epichnia.

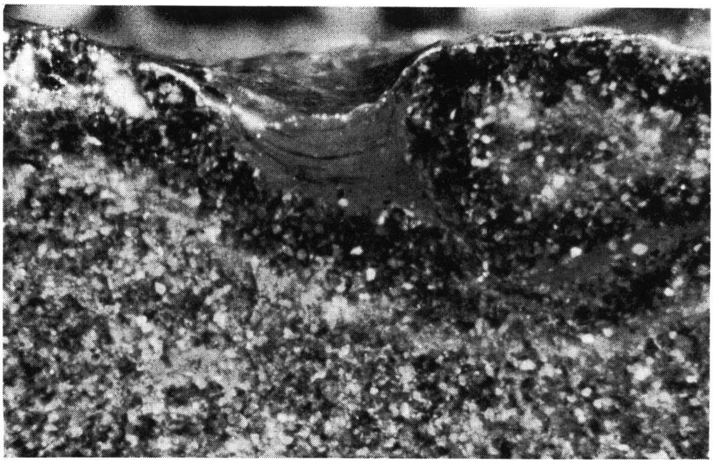
(2) Two types of regular and divergent forms of epichnia which suggest pascichnia accompanied by coprolites (Figs. 2, 3 in Plate 1).

(3) Irregular and divergent form of epichnia which suggests pascichnia accompanied by coprolites (Fig. 1 in Plate 1).

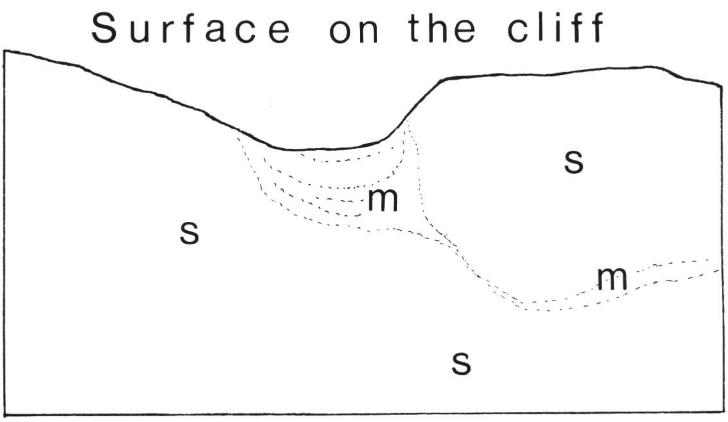
5) Imprints

Two sets of conspicuous imprints are observable on the cliff surface (Text-figs. 4, 5). The locations of each imprints are shown in Text-fig. 9. They are named the A and B groups. The A group consists of three deep imprints which stand in a row toward the direction of the strike of the bedding plane in the central zone on the cliff. The B group comprises shallow and various types of imprint.

A group: The size and depth tend to decrease from the left to the right of the cliff. At the marginal area of the imprints numerous radial cracks and rare con-



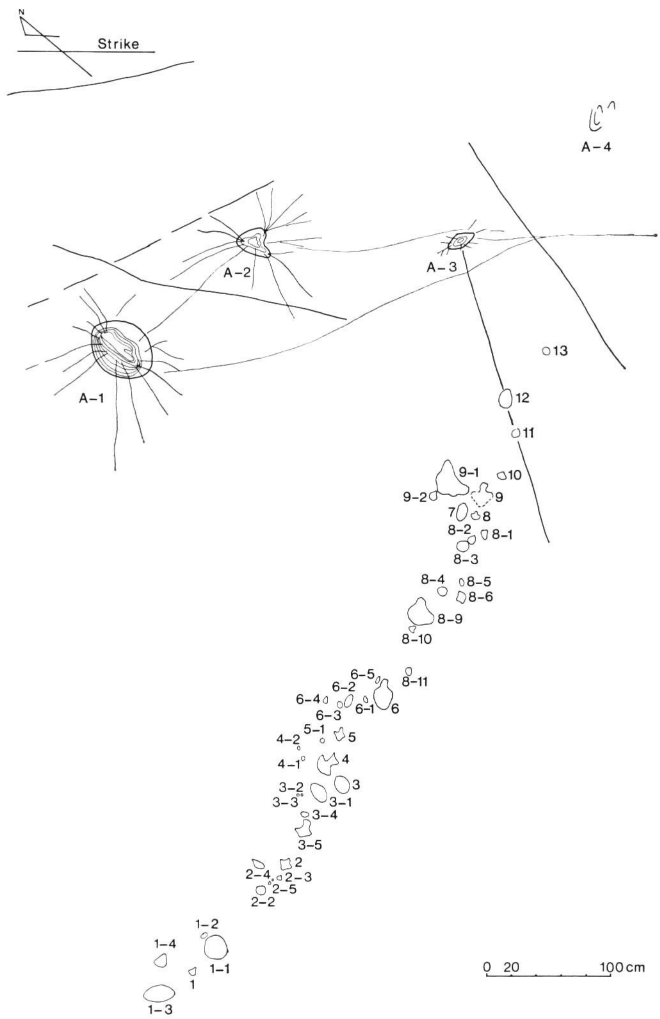
(A)



(B)

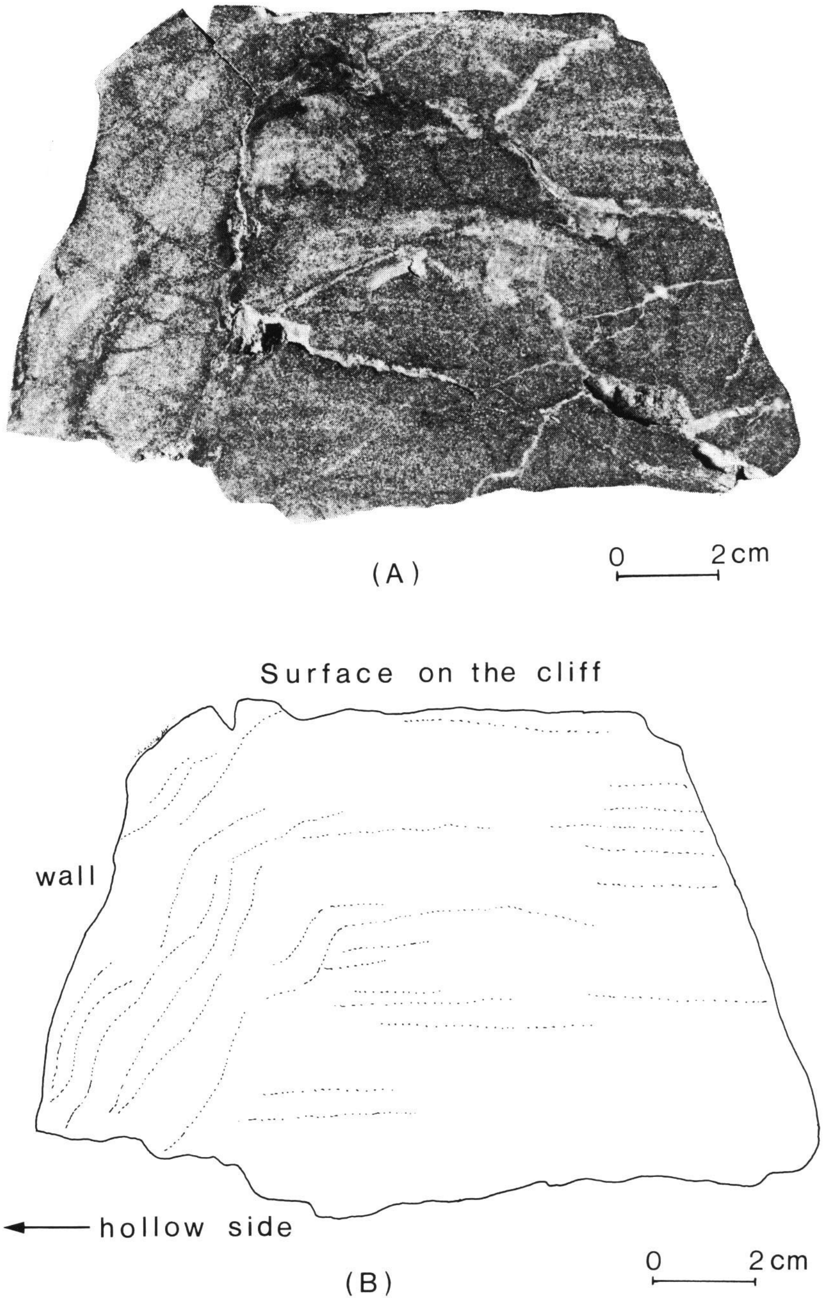
Text-fig. 8. (A). Polished cross-section of a "tiny pit". ×8. (B). The sketch is an idealized cross-section of "tiny pit," showing the occurrence of mudstone (m) and sandstone (s). Mudstone is exclusively observed under the bottom of "tiny pit."

centric ones are developed. The former are especially prominent, passing through the imprint margin and disappearing at the mid-wall. The left imprint (A-1 in Text-fig. 9) has an elliptical shape at the surface of the cliff. It measures 57 cm along the major axis, 39 cm along the minor axis, and 25 cm in depth. The major axis intersect the strike line of the bedding plane obliquely at about 40°. The wall is steep in the left half, while it is gentle at one-third the wall height, then steep again in the right half. The bottom is deepest in the left part and forms three branches which shorten from right to the left. The structure of the inside wall when observed in polished cross-section, shows numerous laminae which curve along the imprints (Text-fig. 10). The above observation is in accordance with that of ARAI *et al.* (1958)'s. The central imprint (A-2 in Text-fig. 9) is at 136 cm apart to the right-upperward direction

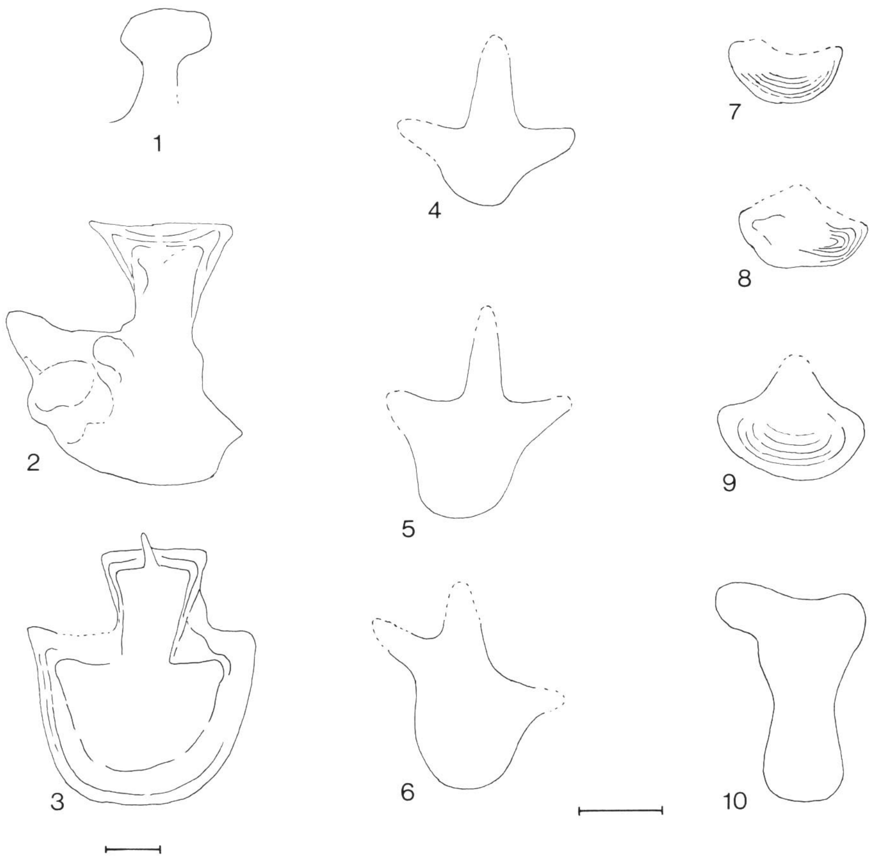


Text-fig. 9. Diagram showing the locality of imprints on the surface of cliff at Sebayashi. A-1 to A-4 show the A group, and 1 to 13 represent the B group.

from the left imprint (A-1). It is subtriangular in shape, 30 cm in median length, 24 cm in width, and 17 cm in maximum depth. The wall is steep, except for the right upper part which is characterized by a shallow concavity at the outer portion and a steepness at the inner portion. The bottom forms three branches, and the central one is the shortest among them. The right imprint (A-3 in Text-fig. 9) is at 164 cm apart to the rightward direction from the central imprint (A-2), and lies obliquely to the strike at 28° in a counter-clockwise direction. The outline of this imprint is nearly a half of rugby ball-like shape; it measures 23 cm along its major axis, 11 cm along its minor axis, and 8 cm in maximum depth. The wall shows a gentle slope, and



Text-fig. 10. (A) Polished cross-section of a part of the inside wall. (B) The sketch is an idealized cross section of the inside wall, showing the numerous laminae which curve along the imprint.



Text-fig. 11. Diagram showing the outline of imprints which are classified into five types: a-type is represented by 1, 2 and 3; b-type is 4, 5 and 6; c-type is 8 and 9; d-type is 7; and e-type is 10. The bar is 5 cm.

converges to the bottom. The outline of the bottom shape is in accordance with that of the mouth on the cliff surface. The U-shaped elevation (A-4 in Text-fig. 9) is measured at 110 cm apart to the right-upperward direction from the right imprint (A-3). This elevation is 30 cm in length and 22 cm in width; it intersects the strike at 60° in a counter-clockwise direction. No radial cracks accompany it. The central part surrounded by the U is fairly concave.

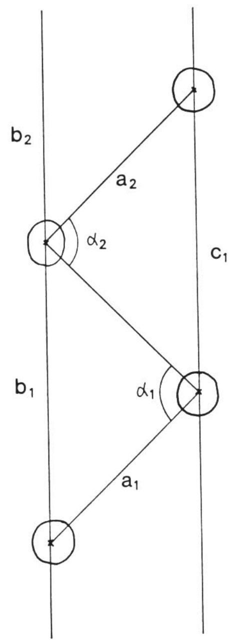
B group: This group is made up of 46 imprints, and forms a zone 70 cm in width. Each imprint is of 3 to 25 cm in maximum length. As these imprints are partly weathered, the original shape of the outline is obscure in some cases. The central area of each imprint is the deepest part of the imprint. Some imprints are accompanied by weak, radially oriented cracks in the marginal area, and by a low elevation at the rim in some cases. At least five types of imprints are distinguishable:

Table 1. Measurements of each imprint in B group (in cm).

type	loc	w_1	w_2	w	l	d
	1–1			20	20	
	1–3			16	24	
	3–5			15	19	
a-type	4	18.5	19.0	20?	21.5	3
	6	12.0	13.0	20	23	4
	9			20	25	4
	12			13	17	4
	1	8+	8+	10+	10.5+	2
b-type	2	8+	8+	12+	13+	3
	5	6+	9.5+	12+	12+	3.5
c-type	8	6	6	9	8+	1.7
	10	5	5	8.5	5.5	1.3
d-type	6–1			6.5	3	1.5
e-type	7			6.5	8.5	1.2

loc: locality of imprints (see Text-fig. 9)
w_1: distance between anterior point of the central and left finger like projections
w_2: distance between anterior point of the central and right finger like projections
w: maximum width of imprint
l: maximum length of imprint
d: maximum depth of imprint

a, b, c, d, and e types which are shown in 1–10 in Text-fig. 11. The a-type is the largest of these, and is represented by 4, 6 and 9 in Text-fig. 9. The outline of the a-type is made up of a subquadrilateral in the posterior part and a small subtrapezoid in the anterior part. It is 17 to 25 cm in length, 13 to 20 cm in width, and 3 to 4 cm in depth (Text-fig. 11, Table 1). In the case of No. 6 in Text-fig. 9, the wall is slightly steep except for the posterior part which forms a gentle slope. The direction of the subtrapezoidal, anterior part of each imprint is in accordance with the general direction of B group. The b-type consists of 1, 2 and 5 in Text-fig. 9. It is made up of three finger-like projections and a base. It is 10.5 to 13 cm in length, 10 to 12 cm in width, and 2 to 3.5 cm in depth (4–6 in Text-fig. 11, Table 1). The central projection is the longest among them. The direction of central projection is arranged in parallel to the general direction of B group. The distance between two imprints of the b-type is at interval of 114 cm. In the case of No. 1 in Text-fig. 9, the central point is the deepest in the concavity, and therefrom start three projections at an angle of 70 degrees between the central one and the others (4–6 in Text-fig. 11). The c-type is made up of 8 and 10 in Text-fig. 9. It is of subtriangular shape and measures 5.5 to 8 cm in length, 8.5 to 9 cm in width, and 1.3 to 1.7 cm in depth (8 and 9 in Text-fig. 11, Table 1). The d-type is shown in 6–1 in Text-fig. 9, and forms a crescent in outline, 3 cm in length and 6.5 cm in width (7 in Text-fig. 11, Table 1). The depth of the bottom increases toward the posterior arc and attains 1.5 cm. The e-type consists



Text-fig. 12. Measurements from successive imprints forming a zone (see Table 2). a_1, a_2 ---: the distance of next imprint; b_1, b_2 ---, c_1 ,c_2 ---: the distance of the next imprint but one; α_1, α_2 ---: the angle formed by the three imprints.

Table 2. Measurements of imprints in cm and in degree (see Text-fig. 12).

A group

a_1:	136	b_1:	288	α_1:	143
a_2:	110	c_1:	278	α_2:	140

B group
a-type

a_1:	58	b_1:	116	α_1:	167.5
a_2:	58	c_1:	120	α_2:	178
a_3:	60	b_2:	116	α_3:	163
a_4:	56	c_2:	124	α_4:	160
a_5:	72	b_3:	142	α_5:	167
a_6:	72	c_3:	178	α_6:	175
a_7:	106	b_4:	184	α_7:	165
a_8:	80				

b-type

a_1:	114	b_1:	226	α_1:	162
a_2:	114				

of 7 in Text-fig. 9. It is 8.5 cm in length, 6.5 cm in maximum width, and 1.2 cm in depth (10 in Text-fig. 11, Table 1). The measurement of each imprint and some relations between imprints are illustrated in Text-fig. 12 and data are shown in Table 1 and 2.

Interpretations

1) Sedimentary environments

The depositional environments of the strata will now be discussed based on the above observations. As the surface of the cliff is a bedding plane that strikes N50°W and dips 75°S, and is not overturned, the upper part of the surface on the cliff points to the north, and the lower part to the south. In the same way, the sinuous type ripple marks occupy the northern part of this plane, and the linguoid type the southern part. The stoss side of the ripples in cross-section faces north. Accordingly, the feature described above suggests that the current direction is from north to south with increasing speed of the running fluid, and with decreasing depth (ALLEN, 1968). From the above-mentioned interpretations and the sedimentary environments around Sebayashi (MATSUKAWA, 1983) the following conclusions are drawn: this area is presumed to

Table 3. Measurements of trackway (in cm and degree).

animal-A

Pace	Stride	Pace angulation	Trackway breadth
P_1: 136	S_L: 274	α_1: 143	T_1: 76
P_2: 110	S_R: 288	α_2: 140	T_2: 58
			T_3: 34
			T_4: 32

animal-Ba

Pace	Stride	Pace angulation	Trackway breadth
P_1: 58	L_1: 112	α_1: 167.5	T_1: —
P_2: 64	R_1: 118	α_2: 178	T_2: 8
P_3: 74	L_2: 120	α_3: 163	T_3: 0
P_4: 106	R_2: 130	α_4: 160	T_4: 8
	L_3: 144	α_5: 167	T_5: 10
	R_3: 174	α_6: 175	T_6: 8
	L_4: 180	α_7: 165	T_7: 2
			T_8: 12

animal-Bb

Pace	Stride	Pace angulation	Trackway breadth
P_1: 116	L_1: 226	α_1: 162	T_1: —
			T_2: 18
			T_3: —

Table 4. Measurement data of imprints (in cm and degree).

		N	$\bar{x}$	OR
A group	a	2	123	110–136
	b , c	2	283	278–288
	α	2	142	140–143
B group a-type	a	8	70	56–106
	b , c	7	140	116–184
	α	7	168	160–178
B group b-type	a	2	114	114
	b , c	1	226	—
	α	1	162	—

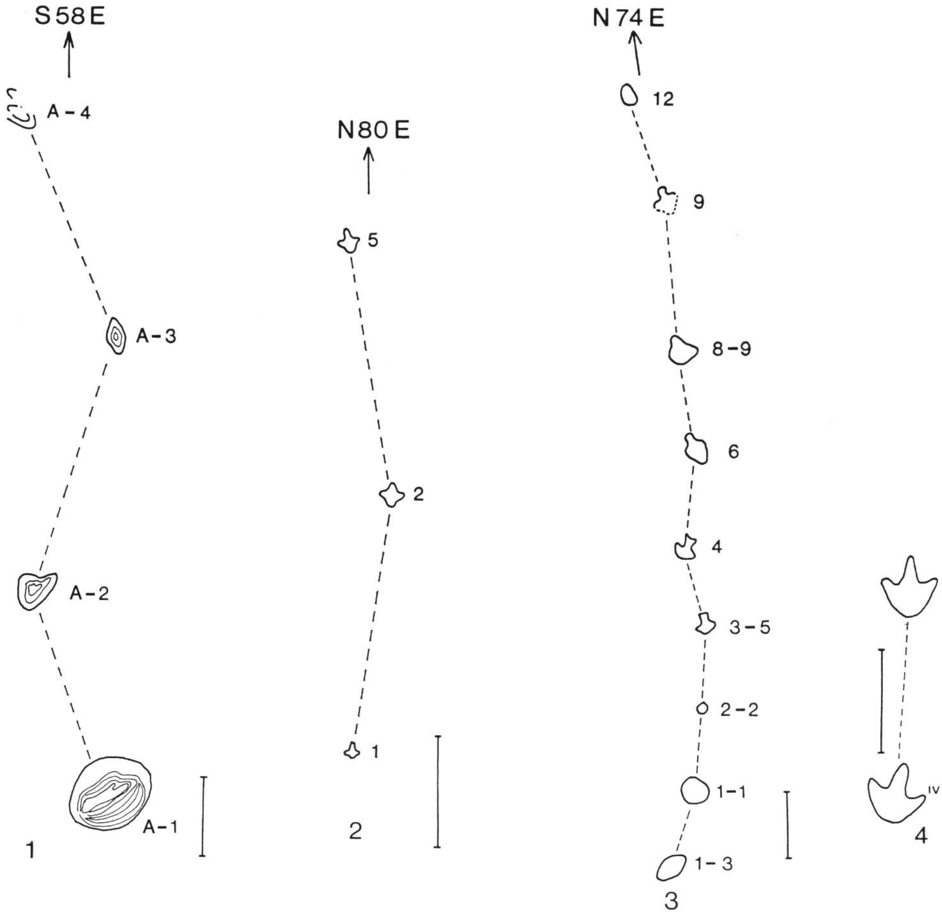
N : number of measurements
$\bar{x}$: arithmetic means
OR: observed range

have been a delta which probably represented a southerly flowing fluvial system, showing a southerly opened deltaic plain, and decreasing depth from north to south, which is caused by the mouth bar sediments. Furthermore, the pattern of the log-probability curve of the sandstone of the cliff (Text-fig. 3) is similar to that of delta distributary sands shown by VISHER (1969). As the linguoid type ripple marks are produced under the condition of 20 to 60 mm in depth (ARAI *et al.*, 1958), the mouth bar seems to dry up at least at ebb tide and/or at spring tide.

2) Imprints

The following three features are observed on the imprints: (1) the radial cracks developed around some imprints, (2) the concentric cracks recognizable in the A-1 and A-2 of A group, (3) the wall of A-1 and A-2 converging to the bottom at a steep angle, being probably caused by the sinking of some heavy material into the deposits. In fact numerous laminae into the inside of the wall of A-1 forms a curve along the imprint (Text-fig. 10). From the above observations the following conclusions can be reached: the imprints were not destructively formed after the concretion of the deposits, but they were made by a partial weighting or absorption which gives the bottom of the imprints before concretion. This opinion is quite in agreement with ARAI *et al.* (1958). But they mentioned a kind of load cast as the cause of boring and hardly recognized the possibility of footprints of mega-animals.

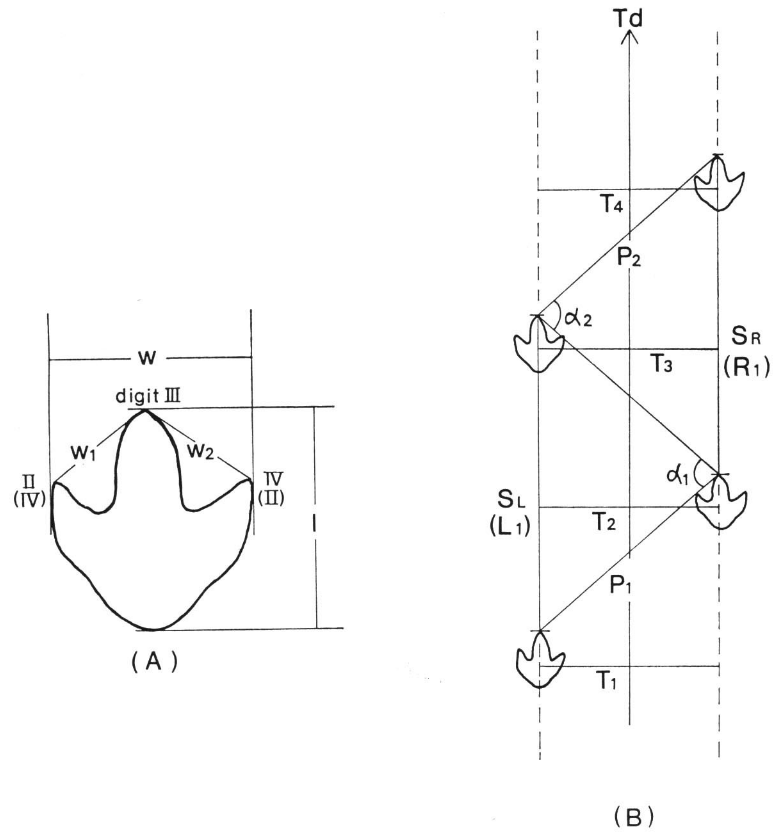
The following two features are worthy of notice: (1) the nearly equivalent form and size of imprint (Text-fig. 9 and 11, Table 1, 2, 3 and 4) is used to distinguish five types (Text-fig. 11). Besides, the imprints form a zone made up of regular spaces in a constant width (Text-fig. 13). Three groups are recognized (Text-fig. 13): the first A group containing A-1, A-2, A-3 and A-4 in Text-fig. 9 is 80 cm in width, 136 cm in distance between A-1 and A-2 (a_1 in Table 2),



Text-fig. 13. Successive and regular bipedal imprints. Trackway direction indicated by arrow. Scale bar is 50 cm.

1: *animal-A*, 2: *animal-Bb*, 3: *animal-Ba*, 4: *Gypsichnites pacensis* (after STERNBERG, 1932 in HAUBOLD, 1971). As to the number of each footprint refer to Text-fig. 9.

and 110 cm between A-3 and A-4 (a_2 in Table 2), and of 278 cm between A-2 and A-4 (c_1 in Table 2), 288 cm between A-1 and A-3 (b_1 in Table 2), and of 143° which is formed by A-1, A-2 and A-3 (α_1 in Table 2) and 140° by A-2, A-3 and A-4 (α_2 in Table 2). The second or B group of the a-type contains 1–3, 1–1, 2–2, 3–5, 4, 6, 8–9, 9 and 12 in Text-fig. 9 is 30 cm in width, 58 cm to 106 cm in distance between imprints (a_1 to a_8 in Table 2), 116 cm to 184 cm in distance between the next imprint but one (b_1 through c_1 and c_2 to b_4 in Table 2), and of 160° to 175° by three imprints (α_1 to α_7 in Table 2). The third B group, the b-type, contains 1, 2 and 5 in Text-fig. 9 and is 25 cm in width, 114 cm in distance between 1 and 2, and 2 and 5 in Text-fig. 9 (a_1, a_2 in Table 2), 226 cm in distance to the next imprint but one (b_1 in



Text-fig. 14. (A) Basic morphology and measurements of footprints.
W: maximum width of footprint, W_1: distance between the second and third toes, W_2: distance between the third and fourth toes, l: maximum length of footprint.
(B) Measurements from successive imprints in trackway.
S_L (L_1), S_R (R_1) ---: stride, P_1, P_2 ---: pace, T_1, T_2 ---: trackway breadth, Td: trackway direction, α_1, α_2 ---: pace angulation. (Adapted from HUENE, 1941; YANG, 1982).

Table 2), and of 162° by three imprints of 1, 2, and 5 in Text-fig. 9 (α_1 in Table 2). These three kinds of measurement are following (Text-fig. 12): (i) the distance to the next imprint (a), (ii) the distance to the next imprint but one (b and c), and (iii) the angle formed by three successive imprints (α). The measurements are rather stable respectively (Table 4), indicating that the imprints keep balance as to those location. The angle is most remakable among them, showing almost constant value. (2) the form of b-type in B group is similar to that of footprints of iguanodontid dinosaur in some respects (HAUBOLD, 1971, fig. 55). Accordingly, the feature described above suggests that the imprints are footprints impressed by some animals.

Furthermore, the following two facts are noteworthy: (1) a piece of vertebra of a

Table 5. Measurement data of trackway (in cm).

Trackway		N	x̄	OR
Animal A	Stride	2	281	274–288
	Pace	2	123	110–136
	Pace angulation	2	142	140–143
	Trackway breadth	4	52	42– 62
	Stride/Trackway breadth		5.58	
	Direction		N58°W to S58°E	
Animal Ba	Stride	7	140	112–180
	Pace	4	76	58–106
	Pace angulation	7	168	160–178
	Trackway breadth	7	5	0– 10
	Stride/Trackway breadth		25.9	
	Direction		N82°W to S82°E ⟶ S74°W to N74°E	
Animal Bb	Stride	1	226	—
	Pace	1	116	—
	Pace angulation	1	162	—
	Trackway breadth	1	18	
	Stride/Trackway breadth		12.6	
	Direction		S80°W to N80°E	

N : number of measurements
x̄ : arithmetic means
OR: observed range

dinosaur has been reported (HASEGAWA *et al.*, 1984) from the locality No. 295 of MATSUKAWA (1977, 1983), which is located at about 100 meters east of the cliff and corresponds to a somewhat lower horizon compared to the horizon of the cliff. (2) the sedimentary conditions of the Lower Member of the Sebayashi Formation in the neighborhood of Sebayashi are similar to those of the strata containing numerous dinosaur footprints in the Lower Cretaceous of Deogmyengri of Korea (YANG, 1982), the uppermost Triassic to lowest Jurassic of Connecticut Valley of U.S.A. (OSTROM, 1972) and others which were made up of shallow water deposits at dry season (SARJEANT, 1975; MOSSMAN and SARJEANT, 1983).

3) Restoration of the animal which made these footprints

As the imprints are suggested to be made by some animals, the animals which probably impressed the imprints are named the *animal-A* (corresponding to the imprints of the A group), the *animal-Ba* (to the imprints of the B group of a-type) and the *animal-Bb* (to the imprints of the B group of b-type). In this chapter the animals that probably made these footprints are reconstructed on the basis of the morphology and measurements of the imprints (Text-fig. 12, Tables 1, 2, 4), and the measurements from successive imprints along the trackway (Text-fig. 13, 14, Table 3, 5). The measurement methods are those of von HUENE (1941), SARJEANT (1975), and YANG (1982).

As the footprints of *animal-A*, *animal-Ba* and *animal-Bb* are made up of alternate left and right feet, these imprints are suggested to the bipedal trackway.

Furthermore, from the narrow trackway breadth, long pace and stride, and tridactyl footprints it may be inferred that the animals were dinosaurs, i.e. ornithopod or theropod.

animal-A

Bipedal: Tridactyl: Stride is 274 cm to 288 cm. Pace is 110 cm to 136 cm. Pace angulation is 140° to 143°. From the long stride it is suggested that the animal has long legs. It appears from the long stride and the pace that the animal has a strongly built body. According to ALEXANDER (1976)'s formula the walking speed is calculated as $1.60 \sim 1.74$ m/sec.

animal-Ba

Bipedal: Pes is made up of tridactyl and large heel (1–3 in Text-fig. 11), and is larger in length than width with about 20 cm in length and under 20 cm in width. Digit III (A in Text-fig. 14) is the stoutest of the three. The slender projection on the point of digit III may be claw (No. 3 in Text-fig. 11). Stride is 112 cm to 180 cm. Pace is 58 to 106 cm. As described above, from large foot and short stride it may be inferred that the animal is low in stature with fat legs, if the trunk of animal is not so long. Pace angulation is 160° to 178°, indicating that the animal seems to have been an effective walker. The walking or running speed is calculated as $1 \sim 2.3$ m/sec.

animal-Bb

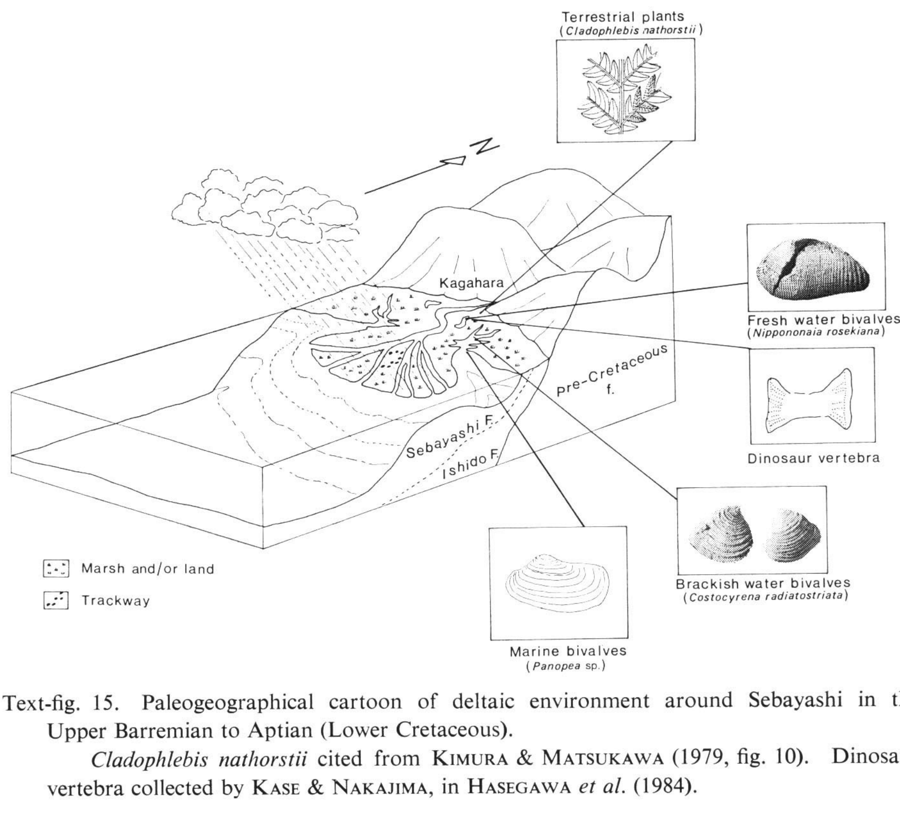
Bipedal: Pes is formed of tridactyl and heel (4–6 in Text-fig. 11), and is equal in length and width, which are about 12 cm. Heel is broad and round. Three digits are slender. Digit III is the most slender one of the three. Digit II and Digit IV (A in Text-fig. 14) form an angle of about 140°. Stride is 226 cm. Pace is 116 cm. Pace angulation is 162°. The specimen possibly belongs to the family Iguanodontidae MARSH 1884 (HAUBOLD, 1971, p. 86–88, fig. 54) in its pes form and size. It is especially similar to the specimen of *Gypsichnites pacensis* STERNBERG (STERNBERG, 1932: in HAUBOLD, 1971, p. 88, fig. 55–2) from the Lower Cretaceous of the Kootenai Formation in the Peace River Canyon, British Columbia, Canada in being equal in length and width, and the breadth and roundness of the heel. The stride of the former specimen is, however, longer than the latter specimen (the former is 226 cm: the latter is 200 cm). The pes of the former specimen is smaller than the latter (the length of the former is 12 cm; the latter is 29 cm). The angle between digits is greater in the former than in the latter (140° to 90°), suggesting that of some ostrich dinosaur. The running speed is calculated as 7.24 m/sec.

4) Restoration of animal behavior

As already stated, the two trackways are recognizable on the surface of the cliff. One is due to *animal-A*, and the another is caused by *animal-Ba*, *animal-Bb*, and others. The former is considered to be a result of the movement of one dinosaur (the *animal-A*) which goes on foot from northwest to southeast. The latter is interpreted to be that of the walking of two or more dinosaurs. *Animal-A*'s size and depth of imprint tend to decrease from northwest (left) to southeast (right) of the cliff. Besides, from the fine deposits (average grain size is 3.74 phi) and the obvious ripple marks that occur around the two imprints on the northwest (left) side, it may be that the deposits are covered by very shallow water, and contain much water within themselves. Therefore the feet of *animal-A* are considered to have sunk into the ground. Furthermore the *animal-A* is presumed to walk off in a flurry from the breadth of trackway which somewhat narrow with a forward walking (Table 3). On the other hand, the *animal-Ba* turns the course from N82°W–S82°E to S74°W–N74°E resulting in random trackway breadth (Table 3) and is interpreted to walk with a quick step on the basis of pace and stride which widen with a forward movement (Table 3). Then the footprints of *animal-Bb* break off on the way, so that the *animal-Bb* is considered to swerve from the course.

Conclusions

1. Some peculiar imprints on the cliff of the Lower Sebayashi Formation (as-



Text-fig. 15. Paleogeographical cartoon of deltaic environment around Sebayashi in the Upper Barremian to Aptian (Lower Cretaceous).

Cladophlebis nathorstii cited from KIMURA & MATSUKAWA (1979, fig. 10). Dinosaur vertebra collected by KASE & NAKAJIMA, in HASEGAWA *et al.* (1984).

signed to the Uppermost Barremian to Aptian) described in this paper are observed on a bedding plane with numerous ripple marks. They are divided into two groups. One consists of three deep imprints which stand in a row toward the direction of strike of the bedding plane in the central zone (A group). The other comprises shallowly and variously concave types and is called B group.

2. The surface on the cliff is characterized by many reliefs of ripple marks, numerous lebensspuren, imprints, and cracks. These structures are considered to have been formed under deltaic conditions which were probably with a southerly flowing fluvial system indicated by a southerly opening deltaic plane. Thus a paleogeographical cartoon around Sebayashi is presented (Text-fig. 15).

3. The imprints are suggested to be dinosaur footprints on the basis of their morphology, characteristics of form and size, development of cracks around imprint, resemblance to footprints of iguanodontid dinosaur, and to tracks of some vertebrates. Besides, there are some evidences: (1) a piece of dinosaur vertebra has been reported from Sebayashi; (2) the sedimentary conditions of the Lower Sebayashi Formation around Sebayashi were similar to those of other strata containing numerous dinosaur footprints.

4 Two trackways described in this paper were formed by three or more dinosaurs. One is due to the single animal which is considered to be carried off its feet. Another one is caused by two or more dinosaurs. One of them is interpreted as having walked with a quick step, while the other one is considered to swerve from the course.

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Explanation of Plates 1–4

Plate 1

All figures represent lebensspuren. Scale of finger is about 9 cm long, and of pen is approximately 12 cm long.

Fig. 1. Regular and divergent form of epichnia.
Figs. 2, 3. Irregular and divergent form of epichnia.
Fig. 4. Simple stick-like form of long string like epichnia.

Plate 2

Figs. 1, 2. Numerous "tiny pits" scattered on a part of the bedding plane. Scale bar of pen is about 12 cm.
Fig. 3. Imprints (hollows), as numbered 4, 6 and 8–9 in the Text-fig. 9, of the *animal-Bb* in the central bordered zone, "tiny pits" in the right part and ripple marks in the whole are shown. The *animal-Bb* walked from lower left to upper center.

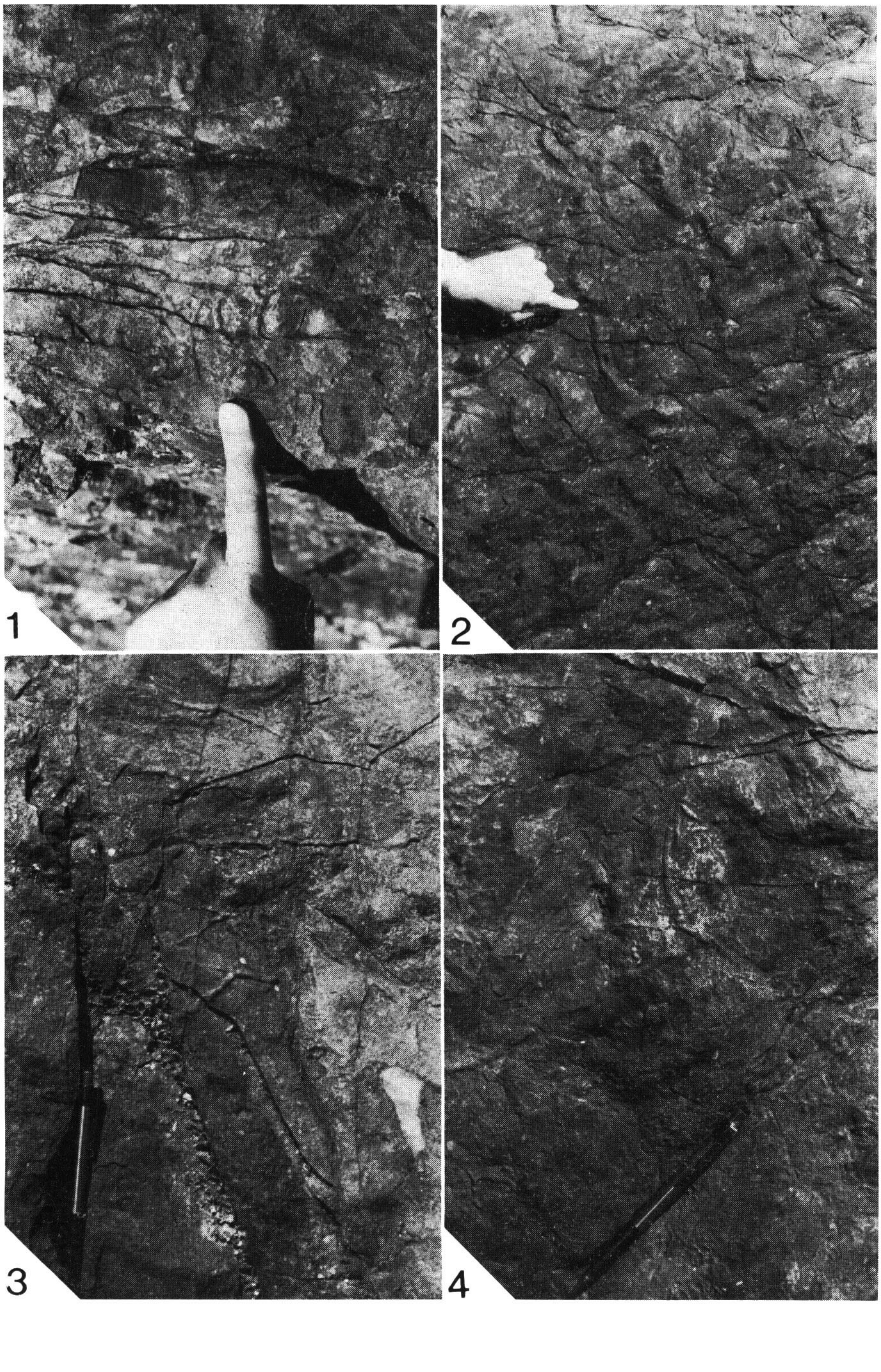
Plate 3

All figures represent the occurrence of three hollows (imprints) on the bedding plane.

Figs. 1, 2. Imprints by *animal-Ba* as numbered 2 and 1 respectively in the Text-fig. 9.
Fig. 3. Imprint by *animal-Bb* as numbered 6 in the Text-fig. 9.

Plate 4

Fig. 1. b-type of B group shown by 1 in Text-fig. 9, (a) rubber cast from external mould, (b) gypsum cast from external mould, ×0.38.
Fig. 2. b-type of B group shown by 2 in Text-fig. 9, gypsum cast from external mould, ×0.38.
Fig. 3. c-type of B group shown by 10 in Text-fig. 9, gypsum cast from external mould, ×0.38.
Fig. 4. a-type of B group shown by 6 in Text-fig. 9, gypsum cast from external mould, ×0.15.
Fig. 5. a-type of B group shown by 4 in Text-fig. 9, gypsum cast from external mould, ×0.15.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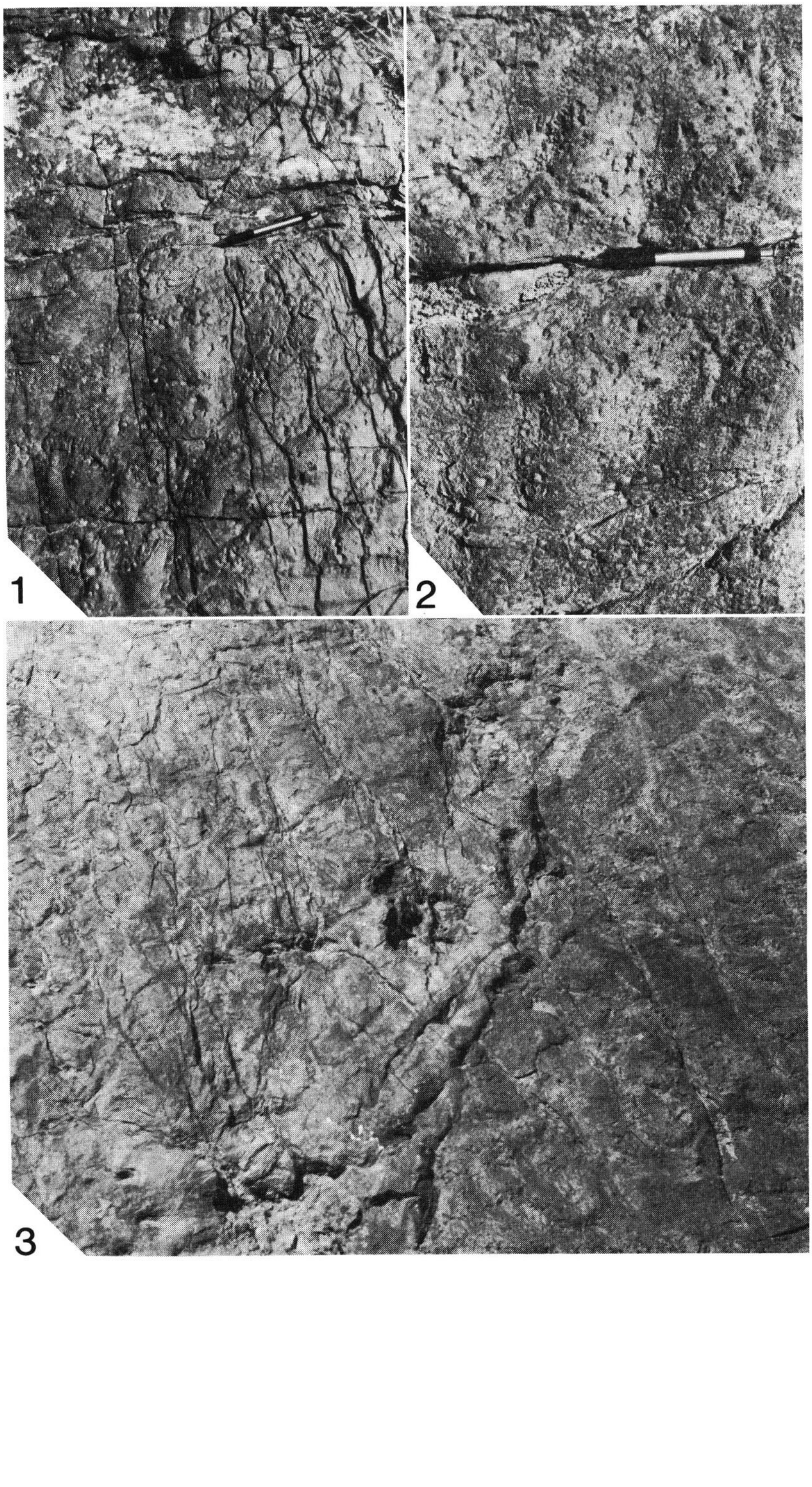
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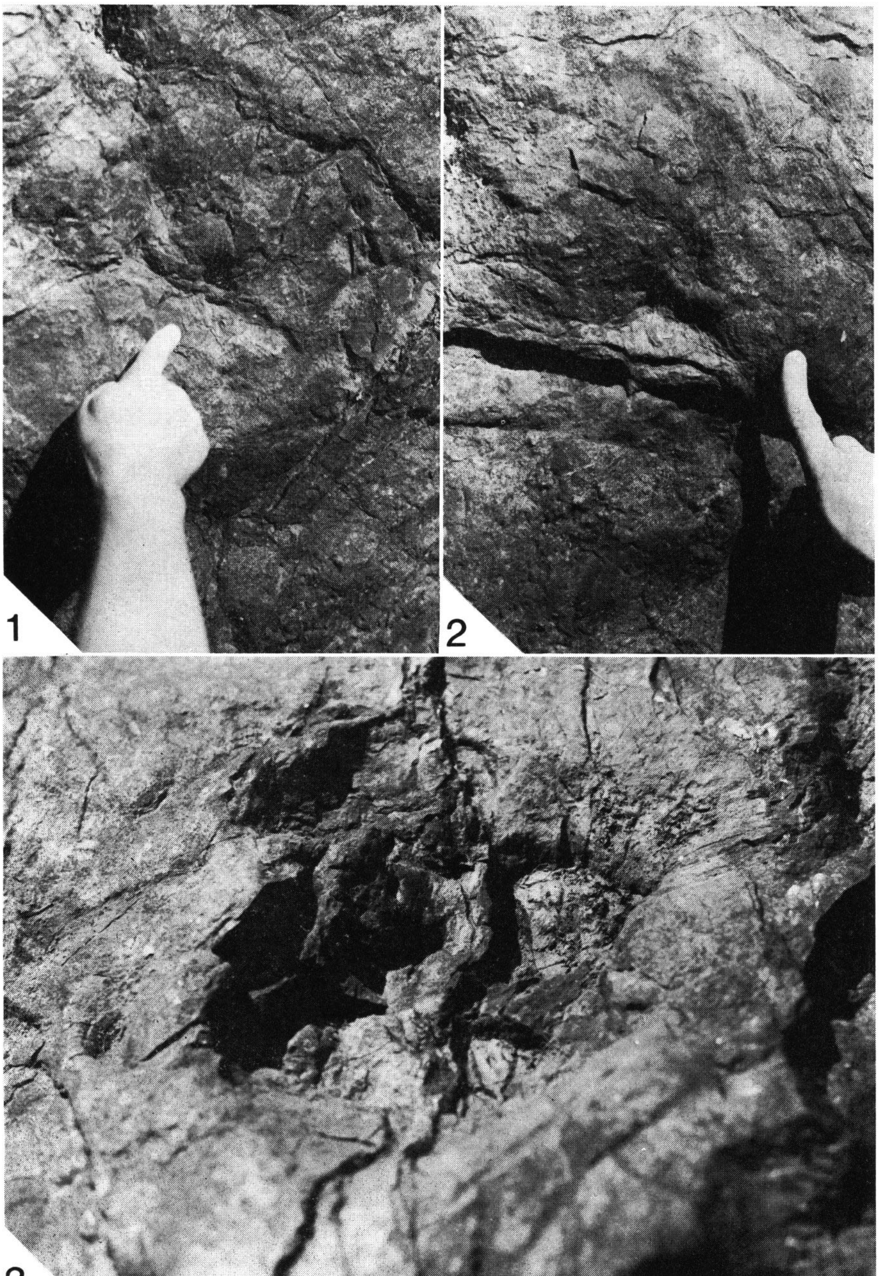
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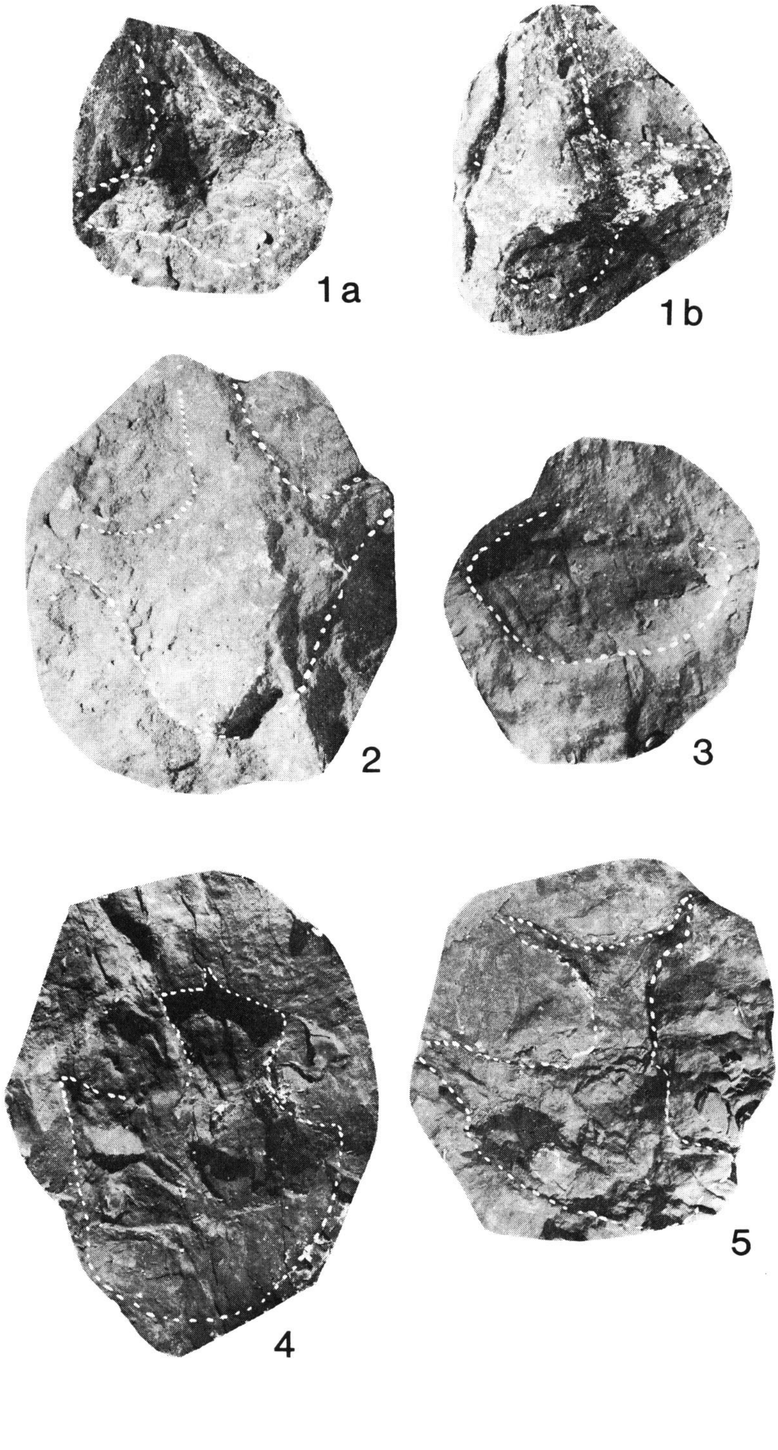
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