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O NIEKTÓRYCH RÓŻNICACH W MORFOLOGII *PALAEODICTYON* HEER
(Tabl. XXXV, XXXVI)

Some morphological variants of Palaeodictyon Heer
(Pl. XXXV, XXXVI)

STRESZCZENIE

Fragmenty siatki *Palaeodictyon* znajdują się często na małych wyniosłościach powierzchni spągowej piaskowców fliszowych, odsłoniętych w potoku Białej Wody, w pobliżu Szczawnicy (Pieniny). Te wyniosłości odpowiadają pierwotnym zagłębieniom, które znaczą obszary najgłębiej żłobiącego prądu. Stosunek między morfologicznymi różnicami siatek i pierwotnymi nierównościami spągu bywa taki, iż większe i bardziej symetryczne sieci można z zasady znaleźć na szczytach nierówności spągu, a natomiast mniejsze sieci, wykazujące stosunkowo wysoki stopień zróżnicowania, odbiegające od sześciokątnej postaci, znajdujemy zwykle w zagłębieniach. Siatki *Palaeodictyon* zostały utworzone przez zwierzęta żerujące w poziomie odpowiadającym mniej więcej obecnej granicy między łupkiem a piaskowcem. Nastąpiło to po wyżłobieniu przez prąd śladów na zerodowanej powierzchni dna morskiego, a po wypełnieniu tychże śladów przez piasek przyniesiony prądem.

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Abstract: Fragments of *Palaeodictyon* networks, preserved on the lower surfaces of sandstone layers in a Cretaceous flysch sequence exposed in the Biała Woda stream-section, near Szczawnica (Pieniny), frequently coincide with small--scale elevations of the soles, which mark the areas of deepest current-scouring. The relationship between variations in network morphology and primary irregularities of the sandstone soles is such that the larger and more symmetrical meshes are commonly found on the crests of positive features of the soles, while smaller meshes showing relatively high degrees of departure from the commonly occurring hexagonal form tend to occur in hollows between the elevations. It is concluded that the *Palaeodictyon* networks were generated by a sediment-eating organism in a plane corresponding roughly to the present shale/sandstone interface, after the formation of current markings in the erosional upper surface of the bottom muds, and at a time later than the filling of these latter features during the deposition of the sandy part of the succeeding bed.

A flysch sequence, comprising alternating sandstone and shale units of lower Senonian age, is exposed in the stream Biała Woda, Szczawnica, in the eastern part of the Pieniny region of southern Poland. Lithological profiles of the beds exposed in this stream are given in a detailed study made by Birkenmajer (1963, Plate XXIII, Figs. 2—5, explanation pp. 377—378). The lower surfaces of the flysch sandstones are characterized by the frequent preservation of numerous „trace fossils" (S. Simpson, 1957, p. 477) as positive structures forming interfering patterns with the current-produced sole markings, which latter give rise to widespread unevenness of the shale/sandstone interfaces. The purpose of this note is to account for the morphological variation frequently observed in one group of trace fossils, *Palaeodictyon* Heer (fide Häntzschel, 1965, p. 65), in terms of the disposition of the different configurations with respect to small-scale, primary irregularities in the lower surfaces of sandstone layers.

Palaeodictyon is most commonly seen on the lower surfaces of sandstone layers as retiform patterns of ridges, frequently with hexagonal or nearly hexagonal interstices, and is known to occur in beds ranging in age from Silurian to Tertiary. Seilacher (1954) attributed the formation of the networks of *Palaeodictyon* to burrowing at the mud/sand interface, but later (Seilacher, 1962) supported an origin „predepositional" with respect to the sandstone part of the bed, at the base of which they are found. According to this latter view, stated in general terms by Kuenen (1957, p. 234) and Seilacher (1962, p. 232), the following sequence of events is envisaged: 1.) Formation of the *Palaeodictyon* network in sea-bottom muds as a system of interconnected tunnels, filled with faecal material; 2) Erosion of the muds to the level of the *Palaeodictyon* network by a sand-laden turbidity current, which in removing the faecal infilling modifies the delicate network only slightly, if at all, and deposits sand within excavated areas of the tunnel-system so that these will be later preserved as positive structures on the sandstone sole.

In support of a predepositional origin, „partly eroded" networks are mentioned by ten Haaf (1959, p. 53), and Seilacher includes a photograph of *Palaeodictyon* (Seilacher, 1962, Plate 2 : 3, explanation on p. 229) which he considers to show fluting of the meshes and also eroded areas elongated parallel to the current direction as deduced from sole markings. Seilacher (1962, Plate 2 : 4) also records an occurrence of *Palaeodictyon* as „flattened tube fillings" in shale. Dżułyński and Sanders interpret a sandstone sole figured by them (Dżułyński and Sanders, 1962, Plate IA) as recording the partial obliteration of *Palaeodictyon* networks by current-formed grooves and prod marks, and accordingly consider the organic markings to be of predepositional age with respect to the sandstone layer. However, it is here emphasised that the commonly seen cross-cutting relationships existing between sets of structures respectively of organic and inorganic origins, occurring as mixed assemblages on sandstone soles, at the best offer no more than a choice between two conflicting and equally probable interpretations of the order of formation. The processes envisaged by Seilacher (1962) are nevertheless of great importance in the preservation of a great number of sole trails, for unequivocal evidence of predepositional burrowing activity is provided by certain „painted" trace fossils (for example, Seilacher, 1962, Plate 2 : 2), by scour-modified traces which are connected to, or associated with, similar but relatively unmodified forms (ten Haaf, 1959, Fig. 40, p. 55) on the same bedding surface, and by occurrences on the soles of sandstones of paired, meandering trails displaying a coarse-grained infilling (Książkiewicz, 1960, p. 739, and Plate II, Fig. 8). Vialov (1964, p. 665), on the basis of taxonomic analysis of a large number of specimens of *Palaeodictyon* from sandstone soles, considers the networks to be formed at the sediment/water interface as a series of grooves in the bottom muds, arranged in the form of connecting series of channels, with each separate system surrounding an „elevated central part", hexagonal in outline. This view fails to take into account erosion of the bottom muds, prior to, or during the deposition of the sandy material.

In a sedimentological study of Upper Llandoverian turbidites in North Wales, Wood and Smith (1959, p. 167) describe relatively large-sized meshes of *Palaeodictyon* networks, occurring both on the soles of greywacke units as positive structures, and in the uppermost parts of the underlying mudstones in the form of rounded tubes exhibiting a distinct branching (Wood and Smith, 1959, Fig. 3, p. 167). In either mode of occurrence, the tube-like components are filled with sandy material, which in composition and grain-size does not differ from that seen at the base of the overlying greywacke unit. The authors conclude that the structure was formed as a result of burrowing activity at the sand/mud interface, and is thus postdepositional in relation to the greywacke layer. Similar conclusions concerning the time-relations between depositional episodes and burrowing activity were reached by Książkiewicz (1960, p. 738), in his study of the branched, meandering trace fossil *Protopalaeodictyon* Książkiewicz. A postdepositional origin is favoured by Nowak (1959, p. 118) as a result of considerations of occurrences in which *Palaeodictyon* is seen as a negative sole feature.

On the soles of flysch sandstones exposed in Biała Woda, inorganic hieroglyphs, seen as closely spaced, small-scale irregularities, are mainly those attributable to the infilling of marks made on a mud surface by the short-lived contact of current-borne objects. Prod and groove moulds are common, the latter most frequently occurring as fine, short ridges, which together with low, narrow flute moulds, form a prominent lineation on lower bedding surfaces. In addition, there are long, continuous groove moulds, seen as ridge-like elevations of the sole, less than one centimetre in width, and themselves marked by sets of longitudinal striations showing abrupt termination, overlapping, twisting and other features suggestive of incision by crenulated tools undergoing rotation during transport. As pointed out by M. Książkiewicz (personal communication, 1966), such grooves may have been cut by current-transported fragments of *Inoceramus* shells common in these beds. Other tools likely to have contributed to the formation of the assemblage of current-formed sole markings are isolated mineral grains of coarse-sand size, found on the sandstone soles, and plant fragments evidenced by finely comminuted carbonaceous debris concentrated on internal parting surfaces. It is emphasized that the entrainment of particles of bottom sediment is evidenced by interfacial structures occurring over the entire surface of soles displaying *Palaeodictyon* (Plate XXXV, Fig. 1). Furthermore, the sandstones are fine-grained and composed of horizontal laminae occurring to the very base of each layer.

In the Biała Woda specimens, *Palaeodictyon* varies in morphology from symmetrical patterns of ridges arranged in perfect hexagons, through a variety of rounded forms, to networks consisting of compressed, elongate meshes, roughly elliptical in shape. These different retiform ridge-configurations are frequently joined together so that the larger and more regular hexagons are seen on elevations of the sole corresponding to areas of deepest erosion of the bottom muds (Plate XXXV, Figs. 1—3; Plate XXXVI, Figs. 1—3), while asymmetrical meshes of small size tend to occur in depressions (Plate XXXV, Figs. 3, 4). Where meshes of varying size are joined together in the same network, changes in size and shape of meshes of similar relief are not as a rule accompanied by changes in the thickness of the constituent ridges (Plate XXXV, Fig. 3).

The ridges making up a given network may vary considerably in micro-relief and in degree of separation from the sandstone sole. In some cases, portions of the network situated on the central parts of relatively flat, positive features of the sole comprise ridges so low in elevation as to be barely discernible (Plate XXXVI, Fig. 4). These indistinct areas of the network frequently terminate in incomplete hexagons (Plate XXXVI, Fig. 4), and presumably mark regions of the sole where the network enters the sandstone layer. Other parts, situated on the edges of positive areas of the sole and in relatively flat hollows, are seen as systems made up of tube-like components of high relief, which may be detached from the base of the sandstone layer. Where the network is in high relief, it may follow irregularities of the sole so closely as to give the appearance of encrusting the structures of inorganic origin (Plate XXXV, Figs. 1, 2, 4).

Only the acceptance of a postdepositional origin of *Palaeodictyon* with respect to the sandstone layers beneath which it occurs can provide a satisfactory explanation for the sand-filled systems of branching tubes in mudstones, described by Wood and Smith (1959), and the observation in the Biała Woda specimens of Palaeodictyon networks which follow closely the relief of current-formed sole markings. Distortion of the network, accompanying changes in the relief of the sole, marks modification in the structure of the burrow of a sediment-eating organism, made to accomodate relatively sharp irregularities in the mud/sand interface. The *Palaeodictyon*-forming animal may have burrowed in sand or followed the mud/sand interface in preference to burrowing in mud, because of the relatively strong cohesion of the latter, which property had evidently caused sporadic resistance to scouring during the earlier formation of primary current markings. Local differences in consistency of muds at the mud/sand interface may be reflected in *Palaeodictyon* networks comprising meshes of variable size and shape, in the absence of interfacial irregularities.

It is generally accepted that trace-fossil „species" occupy a special place in taxonomy, in so far as they are not taken to imply specific designations for the animals active in their formation. Though the possibility of subdividing *Palaeodictyon* and similar forms into a number of genera and species on the basis of network morphology has been presented (see, for example, Wiałow and Golew, 1966; an extensive bibliography is given by these authors), the present author feels that the usefulness of such a rigorous taxonomic treatment has yet to be demonstrated. The existence of individual networks showing considerable morphological variation suggests that new species should not be based upon specimens displaying only a small numbers of meshes.

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OBJAŚNIENIA TABLIC
EXPLANATION OF PLATES

W każdym przypadku strzałka wskazuje kierunek prądu wyznaczonego na podstawie zespołów hieroglifów prądowych. Skala w centymentrach. Miejscowość: Biała Woda, Szczawnica. Wiek: dolny senon.

In each case, arrow indicates current direction determined from assemblages of interfacial markings. Scale in centimetres. Locality: Biała Woda, Szczawnica. Age: Lower Senonian.

Tablica — Plate XXXV

Fig. 1. Spąg drobnoziarnistego piaskowca ukazujący blisko osadzone jamki wirowe i ślady przedmiotów z siatkowymi naroślami *Palaeodictyon*. *„Cylindrites"* również postdepozycyjna forma w postaci rozgałęzionych i przerywanych linijnych hieroglifów

Fig. 1. Sole of fine-grained sandstone, showing closely spaced flute moulds and moulds of tool markings with retiform overgrowths of *Palaeodictyon* Heer. *„Cylindrites"* also a postdepositional form, present as branching and intermittent linear reliefs

Fig. 2. Wycinek z fig. 1. *Palaeodictyon* z sieciami o stosunkowo dużych rozmiarach rozwiniętymi na odlewach jamek wirowych

Fig. 2. Detail from Fig. 1. *Palaeodictyon* meshes of relatively large size developed on flute moulds

Fig. 3. Wycinek z fig. 1. Siatka *Palaeodictyon* przylegająca do powierzchni spągu. Oczka sieci o niewielkich rozmiarach (u góry i w części środkowej) w zagłębieniach spągu

Fig. 3. Detail from Fig. 1. *Palaeodictyon* network following irregularities in lower surface of bed. Small mesh-sizes (top, centre) in negative areas

Fig. 4. Wycinek z fig. 1. Ślady rozmywania i przedmiotów „inkrustowane" siatkami *Palaeodictyon*. Małe, podłużne sieci w zagłębieniach struktur spągu

Fig. 4. Detail from Fig. 1. Moulds of scour and tool markings „encrusted" by *Palaeodictyon* networks. Meshes on negative sole structures small, elongate

Tablica — Plate XXXVI

Fig. 1. *Palaeodictyon*, ślady rozmywania i przedmiotów na spągu piaskowca. Prawa strona i środek: ślad przedmiotu otoczony siatką *Palaeodictyon*. Linia intersekcyjna przecinających się śladów pozostawionych przez zwierzę żerujące, które wchodziło lub wychodziło z piasku

Fig. 1. *Palaeodictyon* and moulds of scour and tool markings on sandstone sole. Right, centre: mould of tool mark surrounded by *Palaeodictyon* network; line of intersection of organic and inorganic structures is locus of points where animal passed from mud into sand, and vice versa

Fig. 2. Spąg piaskowca z *Palaeodictyon* występującym w postaci narośli na śladach rozmywania

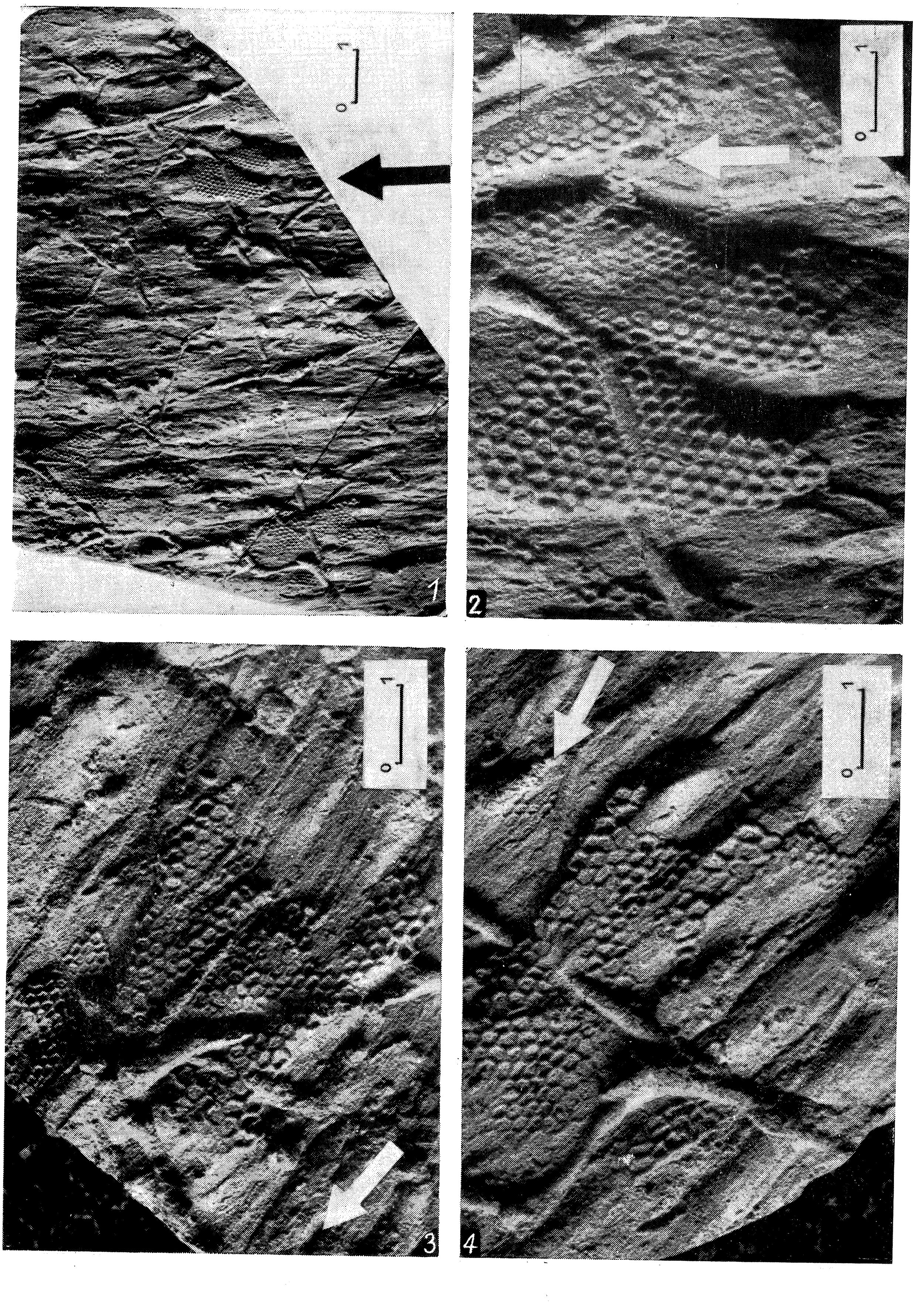
Fig. 2. Sandstone sole with *Palaeodictyon* as „overgrowth" upon moulds of low scour structure

Fig. 3. Spąg piaskowca przedstawiający „inkrustację" *Palaeodictyon* na śladach rozmywania i rozdzielonych stosunkowo płaskimi powierzchniami

Fig. 3. Sandstone sole with *Palaeodictyon* „encrusting" both the moulds of scours and the relatively flat areas between

Fig. 4. Spąg piaskowca. Lewy róg: całkowicie wykształcone siatki *Palaeodictyon* na wyniosłości nawiązujące do niewyraźnych sześcioboków zakończonych przerwanymi oczkami sieci

Fig. 4. Sandstone sole. Top, left: complete ridge-systems of relatively high relief joined to systems of lower relief which end in incomplete meshes



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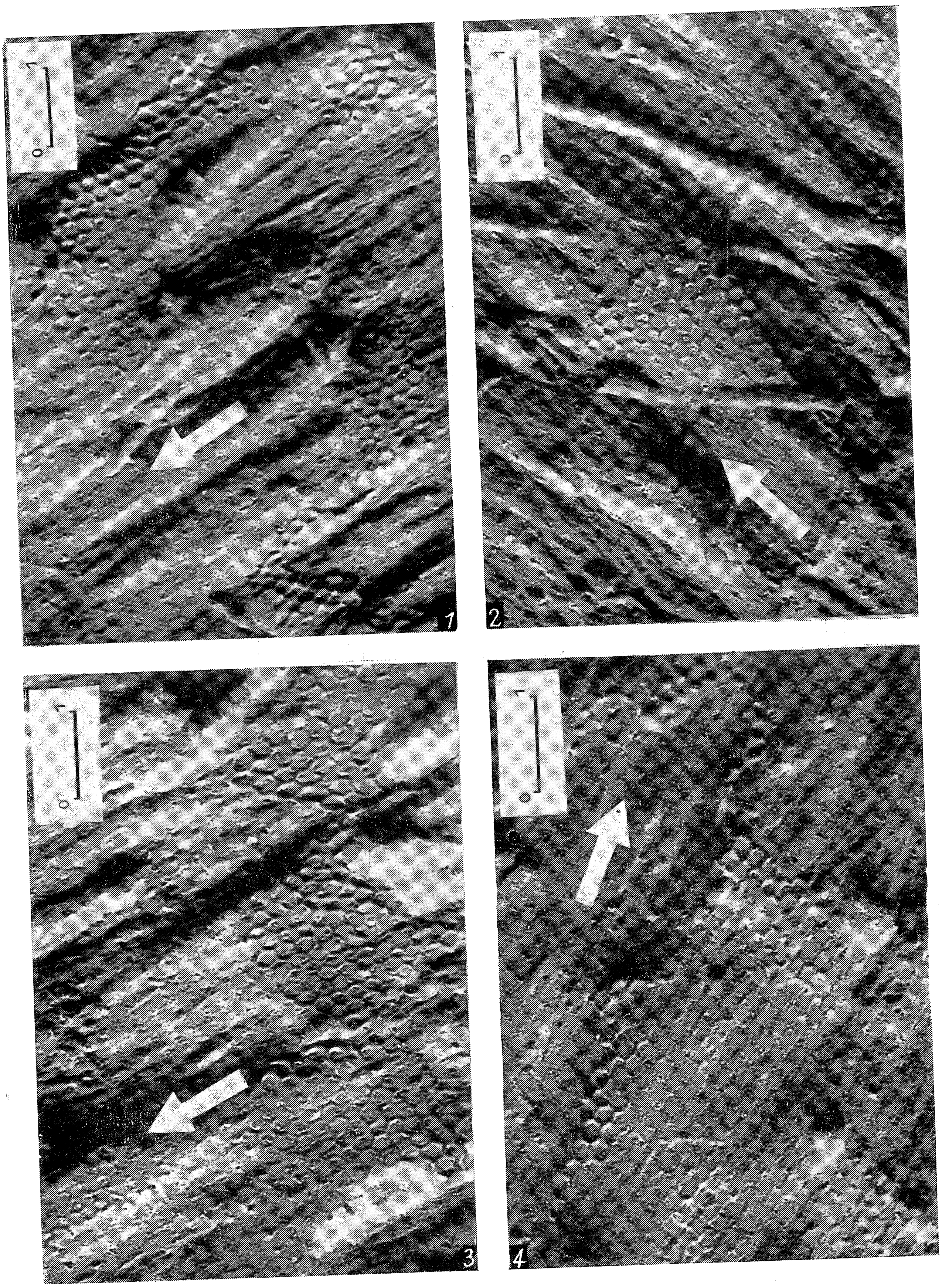

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