Russian Geology and Geophysics © 2020, V.S. Sobolev IGM, Siberian Branch of the RAS
Vol. 61, No. 2, pp. 214–223, 2020 *DOI:10.15372/RGG2019083* *Geologiya i Geofizika*

Rosselia Trace Fossil in Lower Jurassic Sediments from Cape Airkat (Northern Siberia)

A.Yu. Popov[a,b,✉], B.N. Shurygin[a,b]

[a] *Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Sciences, pr. Akademika Koptyuga 3, Novosibirsk, 630090, Russia*

[b] *Novosibirsk State University, ul. Pirogova 1, Novosibirsk, 630090, Russia*

Received 28 June 2018; received in revised form 20 August 2018; accepted 17 September 2018

Abstract—We study the morphology and sedimentary facies of trace fossils formerly identified as *Arctichnus* found at the base of the Jurassic section near Cape Airkat (northern Siberia). They are most often found in shoreface silty sand and are similar to *Rosselia socialis* ichnospecies in morphology, taphonomy, and depositional environments. On the basis of this similarity, the Airkat trace fossils should be identified as *Rosselia socialis* Dahmer, 1937. Analysis of the type collection of *Arctichnus arcticus* has revealed new morphological features of the taxon.

Keywords: trace fossil, lithology, facies, Lower Jurassic, Siberia

INTRODUCTION

Mesozoic tidal and shallow-marine clastic sediments widespread in northern Central Siberia contain various trace fossils. However, the published evidence on their ichnofacies has been very limited: most of publications on Siberian Mesozoic stratigraphy and paleogeography only mention the presence of traces left by detritus feeders or sand dwellers. Triassic and Lower Jurassic sediments rich in trace fossils are exposed in natural outcrops in the western coast of the Anabar Bay (Laptev Sea) near Cape Airkat (Fig. 1). The presence of *Arctichnus* and *Rhizocorallium* genera was reported mainly from lowermost Jurassic shelf deposits (Saks, 1976; Levchuk, 1985; Knyazev et al., 1991).

A large collection of samples was obtained during the field trip of 2015 from the Hettangian-Sinemurian Cape Airkat section assigned to the lower Zimnyaya Formation (Shurygin, 1978; Nikitenko et al., 2013). Comprehensive lithofacies analysis of the sediments provided details on their compositions and structure, with implications for deposition environments (Popov and Nikitenko, 2017) (Fig. 2). The paleoenvironments were described using the classification suggested for coastal areas of clastic deposition (Reading, 1978).

The stratigraphic boundaries in the sampled section remain poorly constrained because of limited amount and controversial interpretation of fauna data. We use the stratigraphy suggested earlier by Knyazev et al. (1991) and Nikitenko et al. (2013) and apply our own numeration of beds.

The features of trace fossil assemblages have bearing on wave energy, physical properties of sediments, depth, and other parameters of depositional environments (Buatois and Mángano, 2011). The study of Popov and Nikitenko (2017) included detailed ichnofacies analysis of sediments and allowed identifying an assemblage of Skolithos and Cruziana ichnofacies (Ekdale et al., 1984; Collinson and Thompson, 1989): *Skolithos*, *Palaeophycus*, *Teichichnus*, *Rhizocorallium*, *Planolites*, or less often *Diplocraterion*, *Thalassinoides*, and *Chondrites* species, as well as numerous trace fossils that were previously attributed to *Arctichnus* genus

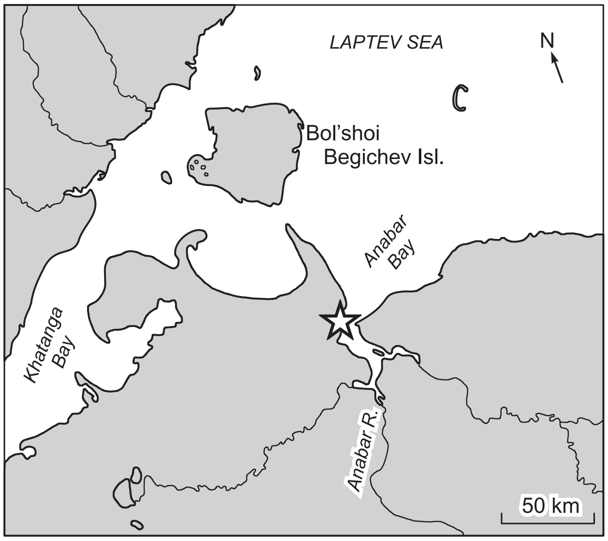

Fig. 1. Location map of the sampling area (asterisked).

✉ Corresponding author.
E-mail address: PopovAY@ipgg.sbras.ru (A.Yu. Popov)

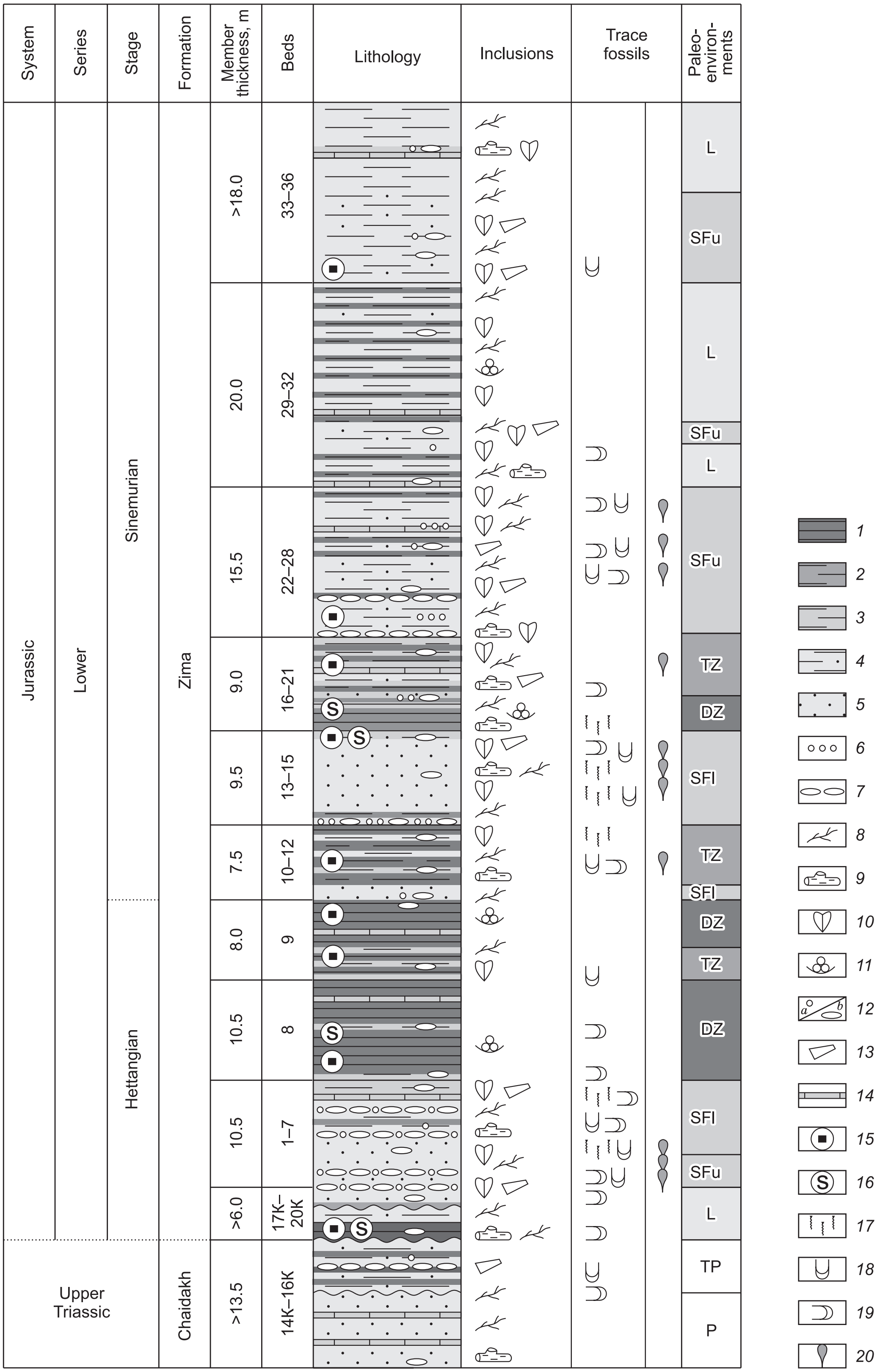

Fig. 2. Stratigraphy of lowermost Jurassic sediments at Cape Airkat. *1–7*, sedimentary rocks: mudstone (*1*), silty mudstone (*2*), silt (*3*), silty sand (*4*), sand (*5*), gravelstone (*6*), conglomerate (*7*); *8–13*, inclusions: plant detritus (*8*), coarse plant fragments (*9*), bivalves (*10*), foraminifera (*11*), gravel and pebbles (*12a* and *12b*, respectively), mud intraclasts (*13*); *14–16*, carbonate (*14*), pyrite (*15*), and siderite (*16*) concretions; *17–20*, trace fossils: heavily bioturbated horizons (*17*), vertical burrows (*18*), horizontal burrows (*19*), *Rosselia* (*20*). Abbreviations stand for deposition paleoenvironments: DZ, distal zone, below storm wavebase; TZ, transitional zone, between normal and storm wavebase; SF, shoreface above normal wavebase (*l* and *u* mean lower and upper shoreface, respectively); L, lagoonal flat; B, beach; TP, tidal plain.

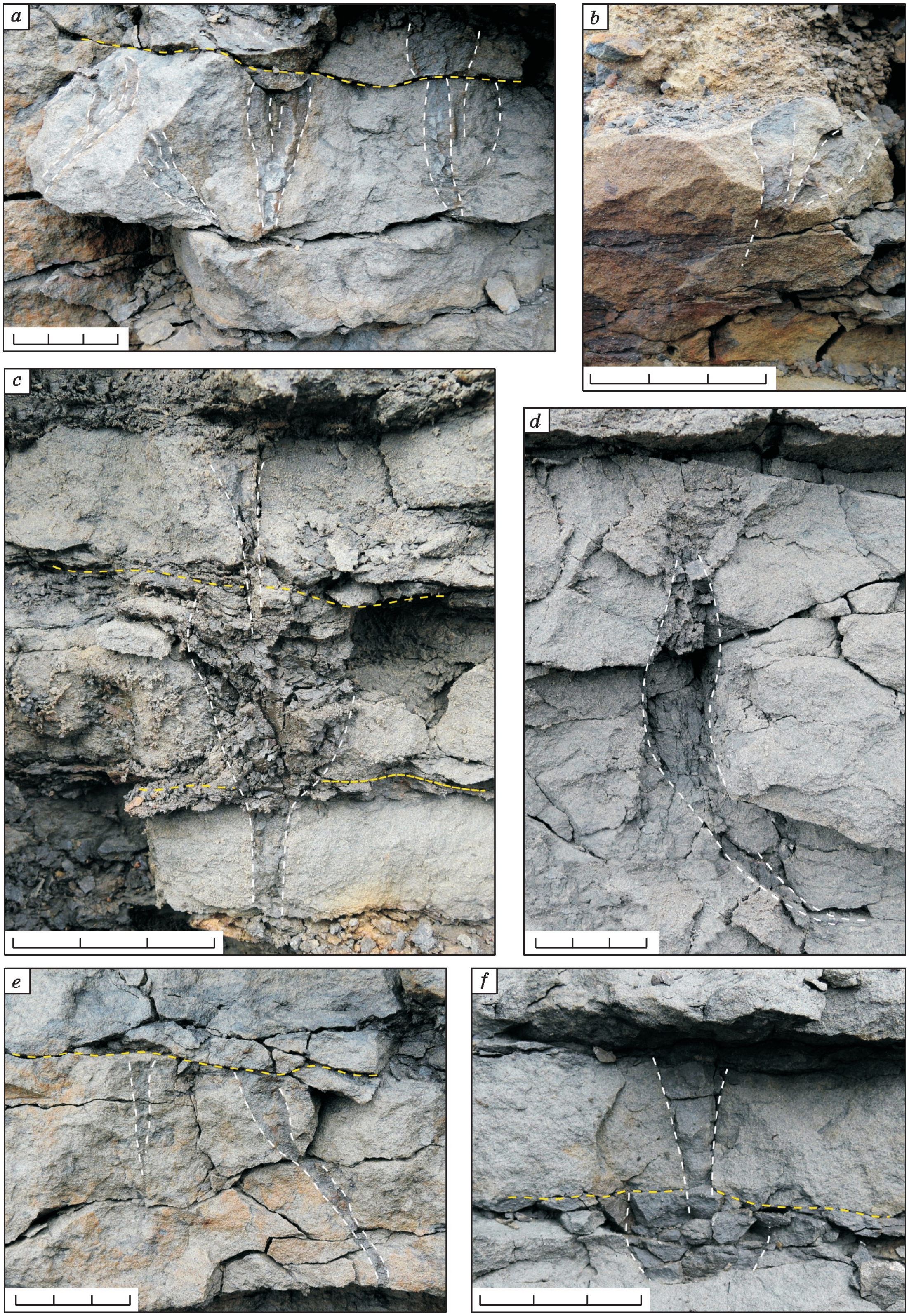

Fig. 3. Trace fossils from Lower Jurassic deposits of Cape Airkat identified previously as *Artichnus*. Scale bar is 3 cm. White dash line contours burrows; yellow dash line delineates eroded surfaces of silt-sand sets. *a*, Group of fusiform burrows with well pronounced inner structure (bed 14); *b*, central shaft (bed 13); *c*, erosionally truncated and stacked structure (bed 25); *d*, narrow spindle-shaped burrow in fine sandstone (bed 2); *e*, truncated narrow ends of burrows (bed 14); *f*, erosionally truncated and stacked structure (bed 14).

(Saks, 1976). This paper focuses on the morphology of the latter and the facies of the host sediments.

Zakharov (1972) was the first to describe *Arctichnus* in Beriasian–Lower Hauterivian successions from northern Siberia and report details of the typical species *Arctichnus arcticus* Zakharov. He discussed the variability, facies, taphonomy, and ecology of the burrowers and noted that their occurrence was restricted to the Arctic zoogeographic area. We rather consider that the Airkat vertical burrows belong to *Rosselia socialis* Dahmer, 1937 ichnospecies which was first discovered by Dahmer, and have to be identified correspondingly.

TRACE FOSSILS FROM THE AIRKAT CAPE OUTCROP

Morphology. Trace fossils from the basal beds of the Lower Jurassic Zimnyaya Fm. near the Airkat Cape, which were previously identified as *Arctichnus* genus (Saks, 1976), are vertical or slightly oblique curved quasi-cylindrical burrows with spindle- or funnel-shaped upper portions and narrow lower ends (Fig. 3). The spindles and cones are most often 2.5–3.0 cm or up to 5 cm in diameter and gradually thin out downward to a few mm. The lengths of the burrows reach 10–15 cm and vary depending on the preservation of the wide fusiform segments.

The burrows are composed of dark gray mud and have rather smooth clearly delineated outer walls. The inner structure is often poorly pronounced because of erosion but shows detectable concentric layering detectable in most strongly lithified areas. The cylindrical tube (central shaft) of the burrows is most often less than 1 cm in diameter (to a few mm) and thickens upwards. The tube has distinct boundaries and is filled with silt-sand material similar to the substrate (Fig. 3*a*, *b*).

The variability of ichnofabric in the sampled section shows up in the preservation/erosion of the fusiform burrow segments, in different relative diameters and stacking patterns of the wide and narrow segments, verticality of burrows, and in curvature of their narrow ends. The variations are related with sedimentary lithofacies and record the energy of environments and rates of deposition.

Taphonomy and assemblages. The trace fossils are buried *in situ* and are most often stacked within rhythmic silt-sand bedsets of a continuous decimeter-scale thickness (or less often thicker). Many burrows are erosionally truncated from the top (Fig. 3*a*, *c*, *f*) and some keep only the narrow lower ends (Fig. 3*e*) locally penetrating into the underlying horizons. Some burrows are brunched in the lower portion (Fig. 4*a*), which may reflect attempts of the trace maker to find a better way to the sediment surface. Some structures consist of stacked truncated segments sharing a single shaft (Fig. 3*c*, *f*) and apparently represent burrowing by a single producer while new sediment layers were deposited.

The described trace fossils in the lower Jurassic Airkat section coexist with other species, most often *Rhizocorallium jenense* which is typical of Cruziana ichnofacies (Fig. 4*b*, *c*). Cruziana is known to form in low-energy littoral and shelf environments (Buatois and Mángano, 2011; Collinson and Thompson, 1989; Ekdale et al., 1984; Schlirf, 2005). Skolithos ichnofacies, such as *Skolithos* or *Diplocraterion* (Fig. 4*d*, *e*), more often appear in higher-energy tidal environments (Ekdale et al., 1984; Collinson and Thompson, 1989; Buatois and Mángano, 2011).

The sediments that host the trace fossil assemblages often bear bivalves. Epifaunal and shallow burrower infaunal bivalves are commonly found as shell clasts or single valves at the base of large silt-sand bedsets, while deeply burrowing infaunal bivalves are buried in alive positions. The community lacks representatives of collectors/detritus feeders but is dominated by dwellers of shallow well aerated biotopes (*Myophopia, Tancredia, Pleuromya*) and eurybionts (*Homomya*), or less often species that prefer moderate-energy environments (*Meleagrinella*, *Otapiria*). The results of detailed biofacies analysis of the Airkat Lower Jurassic sediments were published earlier (Zakharov and Shurygin, 1979; Nikitenko, 2009).

Lithofacies of host sediments. The Airkat trace fossils occur in tens of meters thick successions of meter-scale sandy silt intervals at the base of the Lower Jurassic section (Fig. 2) which, in their turn, consist of several continuous dm-scale bedsets. The sediments are massive and locally show poorly pronounced differently directed low-angle cross stratification. They enclose mud intraclasts, plant fragments, and fine pebbles or gravel at the base of the bedsets, as well as randomly scattered plant detritus, pebbles, and bivalve shells. The beds bear signatures of erosion and have weakly undulated eroded tops, sometimes marked by thin mud layers (Fig. 3*c*, *f*). According to genetic analysis (Popov and Nikitenko, 2017), the sediments were deposited in a high-energy shoreface environment.

Note that burrows with large fusiform or conical segments occur in finer-grained silt deposited in moderate-energy settings which allowed the animals to expand the burrow space.

The trace fossils previously identified as *Arctichnus* are especially abundant in the upper parts of silt-sand bedsets with a weak progressive trend. The relatively deep-water silty tops of the bedsets are often bioturbated and rich in *Rhizocorallium*-type burrows (Fig. 4*b*, *c*) or locally contain *Teichichnus* (Fig. 4*f*). The lower parts of the bedsets are quite often composed of coarse sandy material with thin or thick differently directed cross stratification and with numerous gravel and conglomerate lenses that enclose abundant plant detritus. Such sediments were deposited in lower shoreface environments. Quite high contents of gravelly material were unfavorable for burrowers.

Few trace fossil specimens were found in tempestite dm-scale silt-sand beds alternating with silt-clay beds deposited in transitional zones near the normal wavebase.

Thus, the Airkat trace fossils we study demonstrate distinct lithofacies relations. They are most abundant in shoreface environments (mainly upper shoreface) and disappear in high-energy tidal zones, in the presence of coarse sediment fractions. The burrows reduce in number seaward to disappear completely in the middle part of the transitional zone below normal wave base.

AIRAK CAPE TRACE FOSSILS COMPARED TO *ARCTICHNUS* AND *ROSSELIA*

Studies of the typical collection of *Arctichnus articus* Zakharov, 1972 (including the holotype) stored at the Central Siberian Geological Museum (Novosibirsk) revealed some additional morphological features of the taxon (Fig. 5).

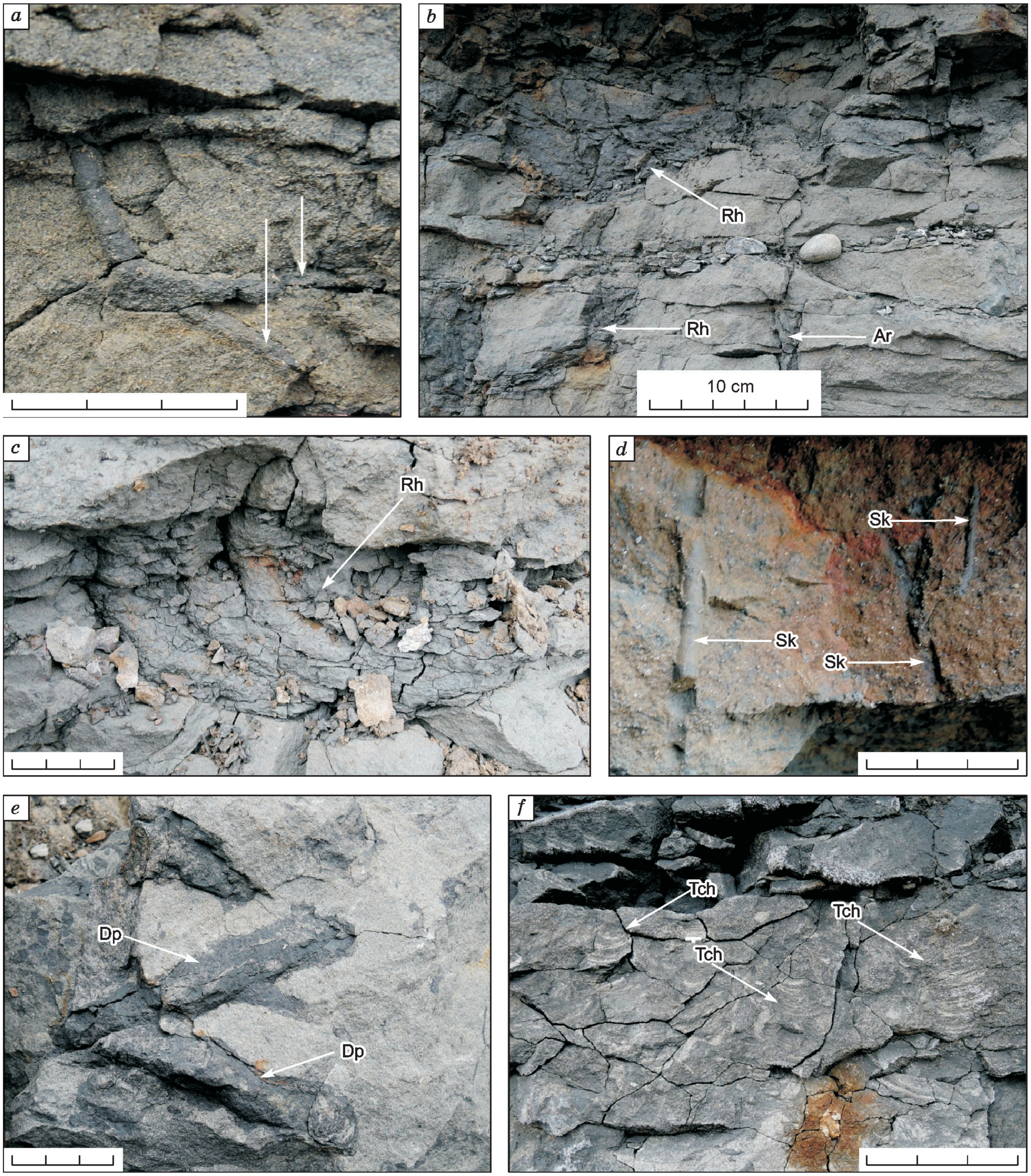

Fig. 4. Trace fossils from Lower Jurassic sediments of Airkat Cape. Scale bar is 3 cm. *a*, Branching lower end of a burrow attributed previously to *Artichnus* (bed 25); *b*, Airkat trace fossils (Ar) together with *Rhizocorallium* (Rh) (bed 2); *c*, *Rhizocorallium* (Rh) (bed 2); *d*, *Skolithos* (Sk) (bed 4); *e*, *Diplocraterion* (Dp), view from bedding plane (bed 3); *f*, *Teichichnus* (Tch) (bed 15).

Fig. 5. *Arctichnus* from Zakharov's collection stored in the Central Siberian Geological Museum (Novosibirsk). Scale bar is 3 cm. *a*, Specimen 370/1, holotype, with well pronounced spindle-like shape; *b*, specimen 370/2, with costate wall; *c*, specimen 370/3, with well pronounced spindle-like shape; *d*, specimen 370/4, with concentric layering in mud; *e*, specimen 370/5, with well pronounced spindle-like shape and a costate wall; *f*, specimen 370/8, with well pronounced spindle-like shape.

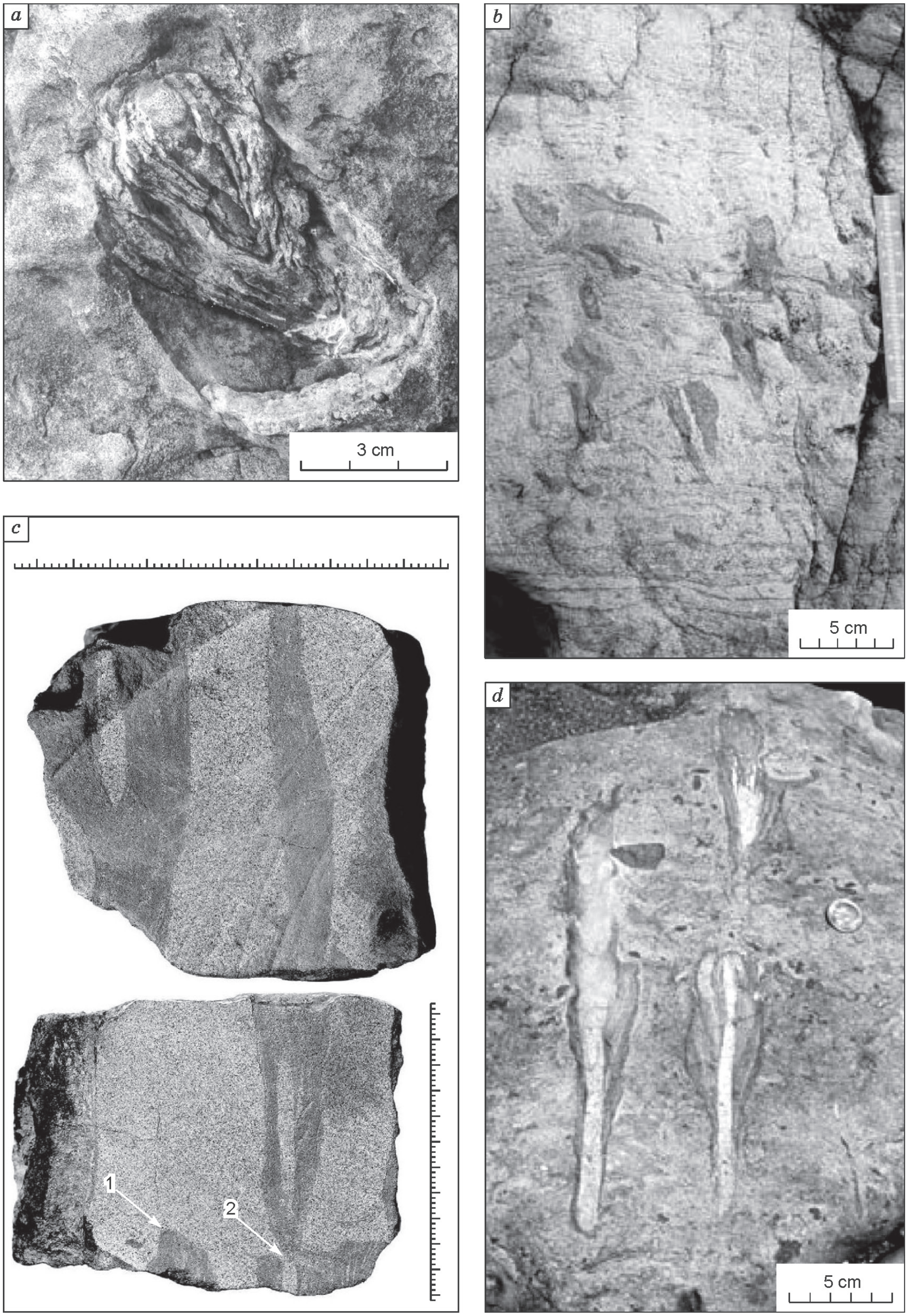

Fig. 6. Examples of *Rosselia socialis. a*, Type section (Gessen, Germany), photograph borrowed from (Schlirf, 2005); *b*, Middle to Upper Ordovician Castro Formation of Asturias, northern Spain (Buatois et al., 2016); *c*, Miocene Upper Marine Molasse (Frieling, 2007), scale bar is in cm, arrows show truncated (1) and stacked (2) burrows; *d,* Pliocene shelf sequences in Washington State, USA (Campbell et al., 2006).

The burrows have costate mud walls, which leads to believe that the animals pressed their worm-like bodies into the sediment and produced grooves simulating the body shape. The grooves on the mud walls may also result from activity of some small organisms (Zakharov, 1972). The wide burrow segments have a concentric structure (Fig. 5*d*).

Almost all samples in the collection, including the holotype, have spindle shapes and sometimes continuously traceable costate mud walls. This fact disagrees with the predominance of funnel-shaped structures mentioned by Zakharov (1972) which he interpreted as traps.

Thus, the morphology of the vertical burrows from the Airkat Lower Jurassic section generally corresponds to that of *Arctichnus articus* Zakharov, 1972. However, it appears more reasonable to identify the taxon as *Rosselia socialis* Dahmer, 1937, which was first reported (Dahmer, 1937) from Devonian sediments of the Rhenish Slate Mountains in Germany (Fig. 6*a*). Later the ichnospecies was found in Paleozoic, Mesozoic, and Cenozoic shelf and deltaic deposits from different areas worldwide (Frey and Howard, 1985, 1990; Nara, 1995, 1997, 2002; Uchman and Krenmayr, 1995, 2004; Lech et al., 2000; Schlirf et al., 2002; MacEachern et al., 2005; Campbell et al., 2006; Frieling, 2007; Zorn et al., 2007; Bradshaw, 2010; Buatois et al., 2016) (Fig. 6*b–d*) and interpreted as a component of Skolithos and Cruziana ichnofacies (Ekdale et al., 1984; Collinson and Thompson, 1989; Pemberton et al., 1992; Buatois and Mángano, 2011) (Fig. 7).

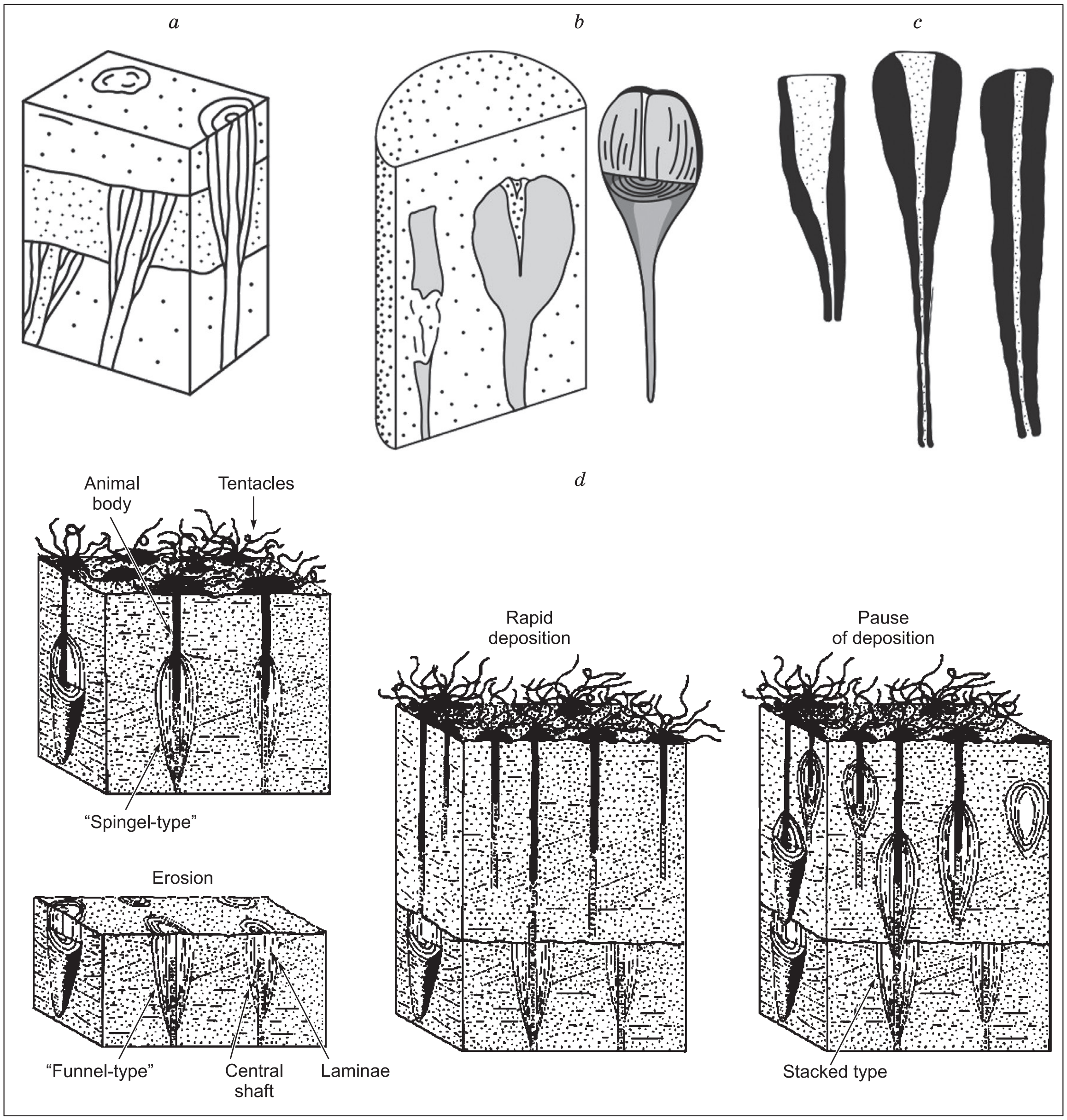

Fig. 7. Sketch of trace fossils. *a*, *Rossalia* in Cruziana ichnofacies (Ekdale et al., 1984); *b*, *Rossalia* in Skolithos ichnofacies (Collinson and Thompson, 1989); *c*, cross cut of *Arctichnus* (Zakharov, 1972); *d*, idealized model of ichnofabric showing the development of stacked *Rosselia* (Nara, 1995).

The trace fossils from the Airkat Jurassic section share much similarity with *Rosselia socialis* Dahmer, 1937 in morphology, taphonomy, and sedimentary environments. According to published descriptions, *Rosselia socialis* is a vertical fusiform or conical mud-lined burrow, with a cross section of 0.5–16.0 cm filled with the substrate silt-sand material (burrow proper). The traces occur mainly in laterally continuous silt-sand bedsets with variable clay contents, which are often massive or have poorly pronounced bedding. The sets are quite often separated by relatively thin quasi-horizontal mud intercalations. The trace makers could continue burrowing in newly deposited sediments and move in different directions (Figs. 6*c*, *d,* 7*d*). Both the Airkat and known *Rosselia socialis* communities show similar ichnofabric variations associated with changes in deposition environment.

Rosselia and *Arctichnus* (Figs. 5–7) are obviously similar, except for the presence of distinct lamination in conical *Rosselia* burrows which was not mentioned in the original description of *Arctichnus*. However, irregular concentric bands of different colors in mud walls were observed in thin sections, and additional investigation of Zakharov's collection (Novosibirsk) revealed prominent concentric layering of mud walls in some burrows (Fig. 5*d*).

Rosselia also shares some similarity with *Monocraterion tentaculatum* Torell, 1870 (Nara, 2002; Schlirf et al., 2002), with some features of difference which the cited authors attributed to the modes of life of the trace makers.

CONCLUSIONS

A detailed morphological study of trace fossils from the base of the Lower Jurassic section near the Airkat Cape, which were previously identified as *Arctichnus*, and the lithofacies of their sedimentary substrate revealed well pronounced relation of the burrows to certain facies. The trace fossils are especially abundant in shoreface silt-sand deposits.

The Airkat burrows are of the same type as *Rosselia socialis* Dahmer, 1937, and the two are much alike in morphology and taphonomy. Thus, the Airkat trace fossils can be identified as *Rosselia socialis* Dahmer, 1937 known from numerous publications for a long time.

The morphology of the Airkat burrows was also compared with that of similar trace fossils from stratigraphically higher (Jurassic) and lower (Triassic) strata, as well as from Triassic and Lower Jurassic outcrops in the Eastern Taimyr Peninsula. Their similarity indicates broad occurrence of *Rosselia* genus in lower and middle Mesozoic sediments of Siberia.

Arctichnus arcticus from Cretaceous deposits in northern Siberia likewise resembles *Rosselia socialis* in some morphological features. The final conclusions require further investigation of *Arctichnus* in typical Cretaceous sections of Siberia.

The study was supported by grants 18-17-00038 from the Russian Science Foundation and 18-05-70074 from the Russian Foundation for Basic Research.

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Editorial responsibility: N.V. Sennikov