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Reconstruction of brackish-water systems using an ichnological framework [1]

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Abstract

This paper provides an overview of the history of ichnology from both Russian and international perspectives. However, the main purpose of the paper is to review how trace fossils can be used to discern the brackish-water sedimentary environments from their open-marine counterparts. A number of modern studies are presented, including: (1) Kouchibouguac Bay, New Brunswick, Canada; (2) Willapa Bay, Washington, USA; (3) Ogeechee River Estuary, Georgia, USA; and (4) Petitcodiac River estuary, New Brunswick, Canada. Cretaceous examples from the Western Canada Sedimentary Basin (i.e., McMurray Formation, AB, Canada and Gething Formation, British Columbia, Canada) are provided to test the models derived from the modern estuaries.

Keywords: ichnology; trace fossils; sedimentology; brackish-water systems; estuaries

Introduction

Ichnology worldwide: historic background

Ichnology (paleoichnology) studies vestiges of animal behavior (ichnofossils). Trace fossils furnish important evidence of living conditions, mainly of nonskeletal bottom-dwelling organisms, and are markers of respective deposition environments.

Traces of past vital activity have attracted attention of scientists all over the world since long ago. For most of the 19th century, ichnofossils were interpreted as fucoids or lithified algal remnants, including benthic and pelagic algae. Since the 1880s, ichnofossils have been considered as markers of locomotion and burrowing recorded in sedimentary archives. This interpretation was first suggested by A. Nathorst (1881) who concluded that fucoids were traces of moving worms rather than algal remnants. The interpretation of fucoids as trace fossils had been broadly accepted by the beginning of the 20th century. In the first half of the 20th century, trace fossils were recognized to have important paleoecological implications. In 1929 R. Richter headed a special station *Senckenberg am Meer* set up on the North Sea coast to study the behavior and ecology of bottom dwellers, as well as burial of organic remnants in the shallow-water marginal-marine zone. The station was a cradle of research by prominent ichnologists and paleonologists, such as V. Häntzschel, W. Schaefer, H.-E. Reineck, and A. Seilacher. Häntzschel (1975), in his well known overview, reviewed and compared all trace fossils ever mentioned in the literature. The *Senckenberg am Meer* station became a model for other world laboratories of this kind, including the Marine Institute at Sapelo Island, University of Georgia, USA. Seilacher (1953) published his ethological classification of trace fossils and then suggested a model of bathymetric control on systematic changes in trace fossils (Seilacher, 1964). The idea behind Seilacher's philosophy was that organisms have a limited number of behavioral styles and can adapt to different physicochemical environments. That ichnological model of became the starting point on the way of ichnology to its modern state and has been still in broad use (Seilacher, 2007). Nowadays ichnofacies analysis mostly serves as a check for obtaining more rigorous constraints on deposition environments (Knaust and Bromley, 2012).

The science of ichnology is currently booming. The results have been reported in a special journal of *Ichnos* published since the 1990s which deals with ecological and ethological aspects of ichnofossils, animal-sediment interactions, sequence stratigraphic implications of ichnology, etc. Ichnologists can meet to share new data and ideas at various conferences: the

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International Ichnological Conferences *Ichnia* organized every several years by the International Association of Ichnology; International Ichnofabric Workshops held by the Paleontological Association; the International Congress on Ichnology; as well as AAPG and GSA international conferences.

Ichnology in Russia: historic background

The Russian school of paleontology and ichnology originated early in the 19th century when the Russian government invited professors of natural history from Germany: Johann Gotthelf Fischer von Waldheim (1771–1853), who laid the foundations for progress of paleontology in Russia (Shapovalov and Tesakova, 2007) and Karl Eduard von Eichwald (1795–1876) who was the first to teach paleontology as a separate scientific discipline at the Mining Institute. The first Russian paleontologists were G. Romanowski (1830–1906) famous for his years-long research in geology and faunas of Turkestan and V. Bogachev (1881–1965) known by studies of vertebrates, mainly fishes and mammals.

In the Soviet Union, ichnology has developed as an independent science since the 1930s due to the work by N. Vassoevich in the Caucasus Mountains who appreciated the major and diverse values of hieroglyphs (mechanoglyphs and bioglyphs) and argued for their deposition implications (Vassoevich, 1932, 1948, 1951). Interesting hieroglyphs in the Caucasus flysch were also documented by Grossheim (1946, 1961).

In postwar time, R. Gekker and O. Vyalov became the leaders of the Soviet ichnlogical school. Gekker (1954, 1957) was among the founders of paleoecology in the USSR, though he himself considered V. Kovalevsky (1842–1883) to be at the origins of paleoecological analysis. According to Gekker, paleoecology should aim primarily at reconstructing the life conditions of fossil organisms and their traces with respect to the inhabited space and deposition environments. He noted abiotic controls by currents, salinity, temperature, and depth of water, and sediment properties on the mode of life and behavior of organisms: feeding, motion, predating, attack/defence, and reproduction patterns. He also suggested to use the integrated paleoecological-lithological method, especially taking into account that soft-body animals constitute a large part of many biocenoses and often leave no other signatures but trace fossils. L. Zenkevitch, a prominent Soviet scientist, oceanographer, zoologist, and hydrobiologist, studied the structure and activity of macro- and meyozoobenthos, including invertebrates of the Barents Sea, White Sea, Kara Sea, Black Sea, Caspian Sea and Sea of Azov (Zenkevich, 1956, 1968a,b,c). O. Vyalov (1966) was the first in the USSR to publish a book on paleoichnology, where he summarized years of ichnological research and suggested a nomenclature and systematics of trace fossils. A special focus was on trace fossils in flysch and molasse from the Carpathian foothills and the Caucasus, as well as from Eocene deposits in the Volga region where he did a lot of field work. Vyalov was in correspondence with many paleoichnologists worldwide, including V. Häntzschel (Hamburg), A. Seilacher (Tübingen), A. Desio (Milan), K. Kester (Cincinnati), M. Ksiazkiewicz (Krakow), D. Ager (London) and others. Later he pointed to controversy in the classification of trace fossils and in its principles, proposed to use some bioglyphs (ichnofossils) as index taxa for stratigraphy, and considered the implications of ichnology for deposition environments (Vyalov, 1978, 1993a,b). He appreciated the neoichnological research, especially on coasts, in the tidal zone, and on the sea bottom, with submarine photographing. After the 4th Russian Workshop on trace fossils in Apatity (Kola Peninsula), Vyalov wrote a few papers (Vyalov et al., 1976, 1977, 1978) on neoichnological research on the Tersky Coast of the White Sea and on the Barents Sea coast (Dalnie Zelentsy). Since the 1980s, M. Fedonkin has published more than 200 papers on Precambrian soft-body organisms and trace fossils (Fedonkin, 1987), and thus gave a new impetus to paleoichnology.

Review of recent Russian publications shows that applied ichnology has aroused much interest among Russian geologists after a long pause, though the publications are still few (Yanin and Baraboshkin, 2010). At present, paleoichnology has been applied to reconstructions of deposition conditions by a team from the A.A. Trofimuk Institute of Petroleum Geology and Geophysics (Novosibirsk), namely, the lab of Sedimentology for Jurassic sediments in the West Siberian basin (Popov et al., 2014; Vakulenko and Yan, 2001; Vakulenko et al., 2005; Yan, 2002, 2003; Yan and Vakulenko, 2011; Yan et al., 2003) and the lab of Precambrian Paleontology and Stratigraphy for Vendian and Cambrian deposits of the Arctic and East Siberian areas (Grazhdankin and Krayushkin, 2007; Martin et al., 2000; Marusin, 2015, 2016; Rogov et al., 2012). Zakharov et al. (1998) and Eder et al. (2003) wrote about trace fossil discoveries in the Bazhenov Formation shales of West Siberia while Bekker (2013) reproted ichnostratigraphy results from the Southern Urals. A. Dronov and his colleagues from the Geological Institute (Moscow) investigated the Paleozoic and Mesozoic ichnology of the Russian East European Craton (Dronov and Knaust, 2013; Dronov et al., 2002; Fedonkin and Dronov, 2011; Natalin et al., 2010). Mikulás and Dronov (2006) published the first and unique ichnology texbook in Russian. E. Baraboshkin and his disciples from Moscow University studied trace fossils in Cretaceous sediments of the Crimea Peninsula (Baraboshkin and Zibrov, 2012; Yanin and Baraboshkin, 2010, 2012).

The fundamentals of ichofacies analysis are currently taught at several universities (in Moscow, Novosibirsk, Tomsk, Kazan, etc.) and used at R&D centers of oil companies, at institutions of the Ministry of Natural Resources, at the *Rosgeologiya* state oil company, some private companies, etc.

Problem formulation

Trace fossils are known to be suitable for reconstructions of ecological stresses on biocenoses, which may result from (1) water salinity fluctuations in space and time; (2) hydrodynamics (direction and strength of currents); (3) mechanic properties of sediments; (4) oxygen availability variations; (5) rapid sedimentation rates, (6) sealevel change and related sediment solidification, etc. For instance, brackish