The Scoop on

How can we learn about the diet, health and parasites of animals which have long since gone extinct? One excellent, although perhaps slightly revolting way is to study pieces of fossilized excrement, known as coprolites.

Dr. Krzysztof Owocki

Institute of Paleobiology, Polish Academy of Sciences, Warsaw

Krzysztof Owocki, PhD is an Adjunct at the Department of Environmental Paleobiology, PAS Institute of Paleobiology. He studies the microtaphotomy, diagenesis, and geochemistry of fossilized bones and teeth of land vertebrates from the Mesozoic. He is a member of an international team studying coprolites from the Mesozoic in Poland and late Permian in Russia.

kowoc@twarda.pan.pl

Just like footprints, nests, burrows or marks of feeding, coprolites fall within a group known as trace fossils. The great majority of the original chemical composition of feces changes during fossilization, generally being replaced by calcium carbonate or tricalcium phosphate, silica, or siderite. Their surface may preserve traces of drying, adhesion, erosion or fracture, signs of what the surrounding environment was like prior to fossilization. Coprolites also provide information on the organism's physiological activity, and there is a high likelihood of their being preserved in the fossil record, since all animals leave behind a considerable volume of excrement.

Coprolites were first described in the literature in 1829 by the British geologist and paleontologist William Buckland; he discovered unusual stony structures containing fish bones in the abdominal parts of Jurassic ichthyosaurs, and identified them as fossilized feces.

Approach

In recent decades, coprolite research has advanced by leaps and bounds. Instead of regarding coprolites simply as a waste product left behind by extinct animals, researchers have started seeing them as time capsules concealing precious information on ancient ecosystems.

Basic coprolite analysis is straightforward and uses simple, inexpensive techniques. They are classified into different morphotypes based on their morphology, size, spiral shape, segmentation and length-to-width ratio. This makes it possible to distinguish coprolites of different species, and in certain circumstances even to identify the exact individual that produced them.

However, the most valuable paleobiological information comes from inclusions. Traditionally, in order to study coprolites, they need to be suspended or dissolved, or, if they are highly mineralized, a specimen needs to be prepared for examination under an optical microscope. Inclusions can also be examined using scanning electron microscopy, which visualizes details of the sample on a micrometric scale – this is by far the most commonly used technique of studying such structures as bone fragments or parasites found in coprolites. Dissolving coprolite samples in acid is effective when searching for traces of pollen, spores and parasites. Geochemical analysis, such as measuring concentrations of lanthanides, is a less common technique of studying coprolites, used to investigate taphonomic aspects – reconstructing the process of fossilization. We can also analyze stable carbon isotopes for evidence about the diets of herbivores. Such studies are expensive and invasive, because the samples are completely destroyed during analysis.

Analysis

In the early 21st century, the German paleontologist Adolf Seilacher and his team recognized coprolites as a new kind of *Konservat-Lagerstätten* (deposits known for the exceptional preservation of fossilized organisms or traces), into which various specimens held at museums should be classified.

WWW.PIXABAY.COM

Fossil Feces

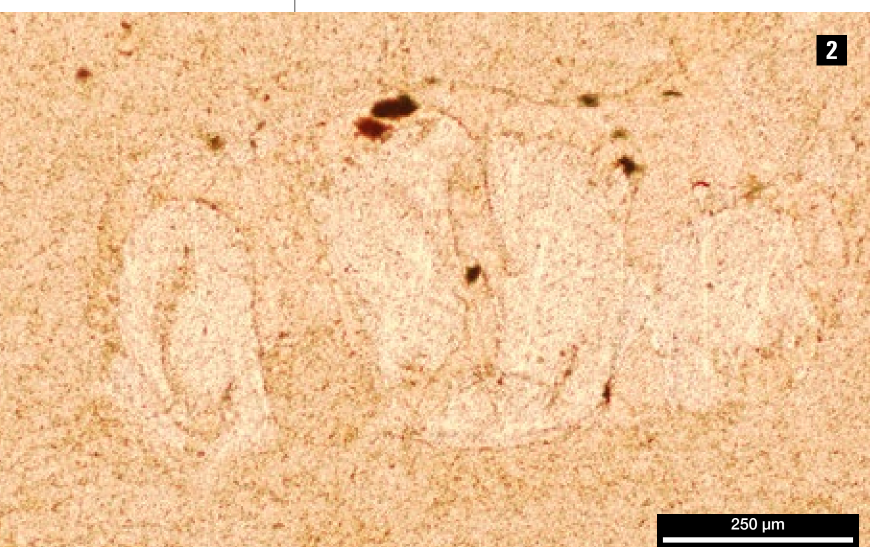
In recent years, researchers have been discovering that soft tissues of invertebrates and vertebrates are frequently very well preserved in coprolites. It is likely that the process is closely tied to early mineralization triggered by the bacteria present in feces. The abundance of phosphates in the feces of predators significantly increases the likelihood of fossilization, and means that any soft tissues found within are more likely to be preserved. In some cases, coprolites of predatory dinosaurs have been found to contain delicate structures such as muscle tissue. Tapeworm eggs complete with developing embryos were detected in the coprolites of Permian sharks, and the hairs of Paleocene mammals have been found in other coprolites.

In order for soft tissues to be preserved, it is essential that processes leading to the complete decomposition of organic matter are at least partially halted; this may happen due to environmental factors such as pH, oxidation or temperature, or due to biomineralizing microorganisms. The most commonly studied coprolites originate from predators, since they are far more numerous in the fossil record than those of herbivores. This is because predators' diet of meat and bones contains high levels of phosphates, which has a much higher fossilization potential than a diet rich in easily-decomposed vegetation. In the 19th century, due to their high phosphate content, coprolites were even treated as a valuable fertilizer.

Discovery

During the 1970s, the American paleontologist Robert T. Bakker suggested that certain fossil reptiles, known as Therapsids, had been endothermic and

SCANNING MICROSCOPE IMAGE



OPTICAL MICROSCOPE IMAGE

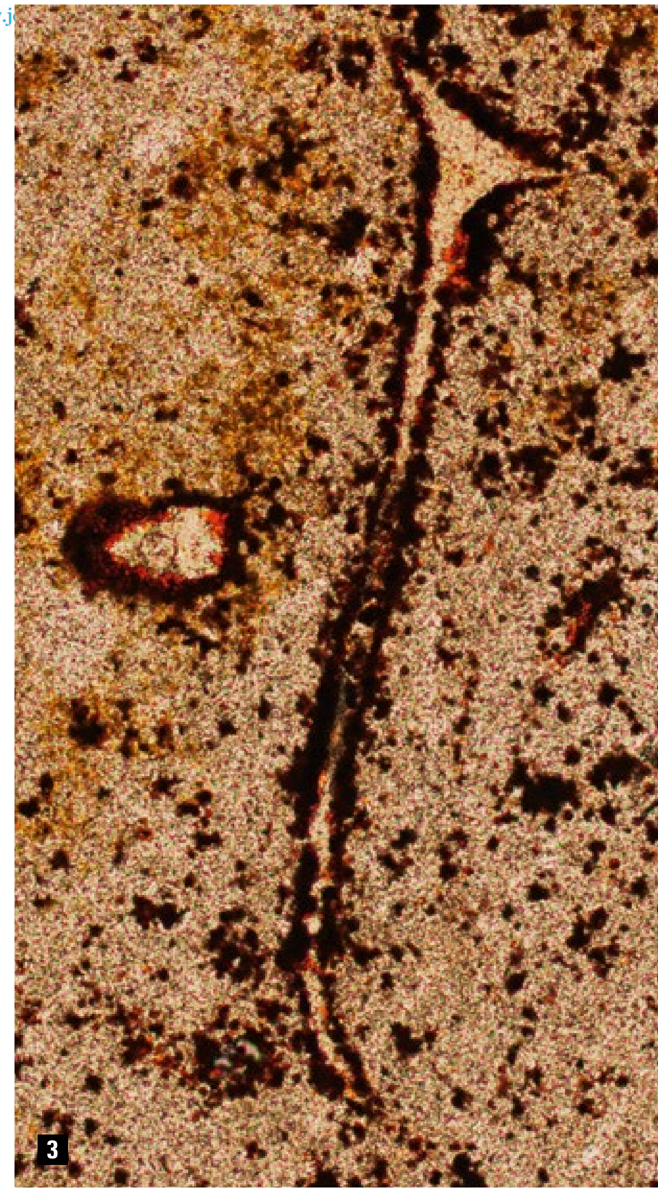


Fig. 1
Bone of an amphibian found in a coprolite (bone diameter approx. 0.7 mm).

Fig. 2
Elements in a coprolite interpreted as remains of parasitic behavior.

Fig. 3
Structures interpreted as hair remains.

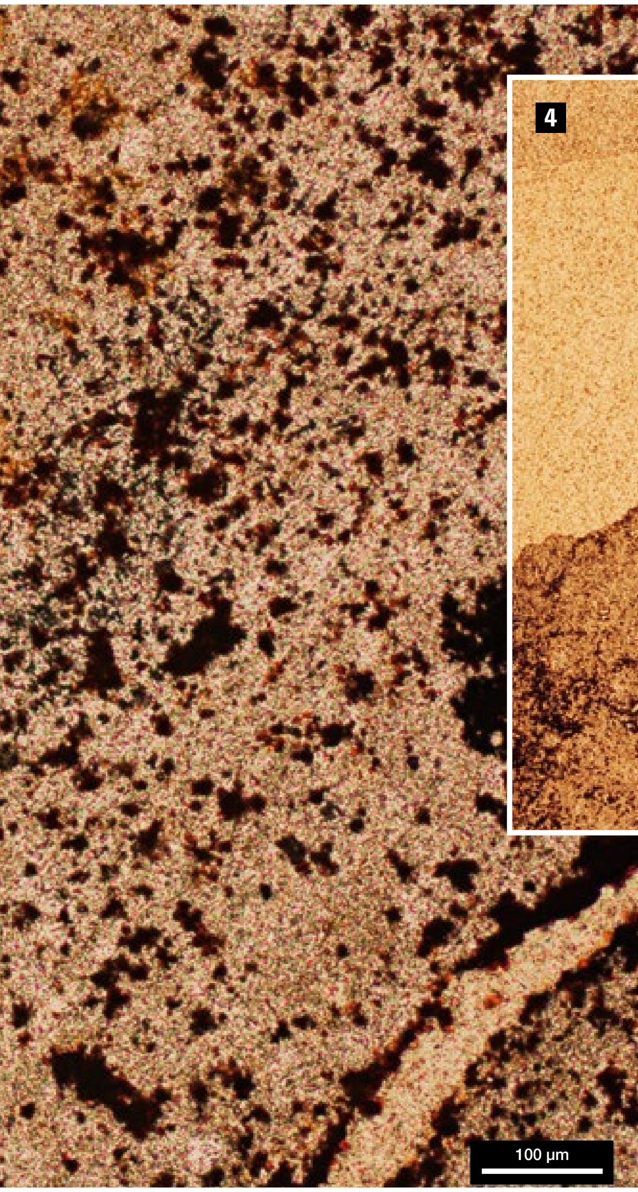
Fig. 4
Scale of a ray-finned fish in a coprolite.

covered in fur. He pointed out that Therapsid bones are highly vascularized, certain species inhabited climate zones too cool for animals with an extant reptile metabolism, and the ratio between predators and prey in their populations was similar to present-day mammals. However, his hypothesis remained unconfirmed.

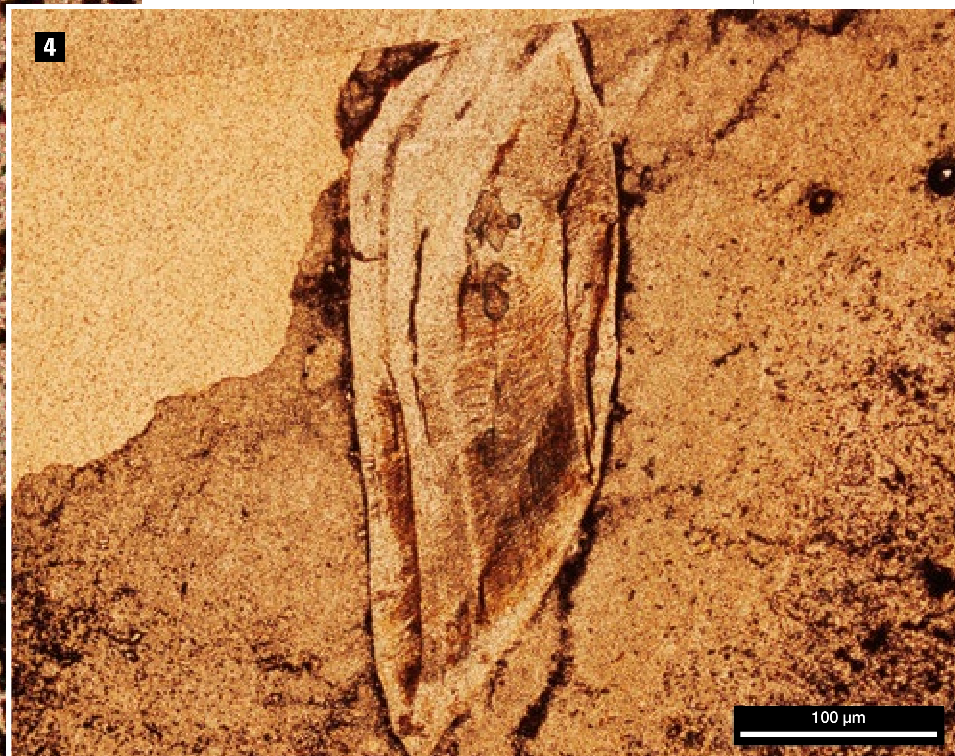
In recent years, research into coprolites has thrown new light on the physiology of the ancestors of mammals and their relatives. Researchers from South Africa Permian found coprolites to contain more than bones. Some samples contained enigmatic elongated structures a few millimeters long, about twenty micrometers in diameter. Roger M.H. Smith and Jennifer Botha-Brink from the Bloemfotein Paleosystems Centre suggested that these structures are fragments of plants or fungi, perhaps even hair.

Our own team studied coprolites from a late Permian site in Vyazniki in Russia. We described a total of nine different coprolite morphotypes, with our attention being drawn to the largest two. Undigested bone fragments can be found in Type A coprolites, while in Type B coprolites they are relatively rare and heavily digested. Reptiles such as crocodiles have a longer digestion process than mammals, and the bones they consume are almost entirely absorbed. Undigested bones are frequently found in mammal feces. Following this logic, we designated bone-rich coprolites of carnivorous Therapsids as Type A, and Archosauromorpha coprolites containing trace or no bone material as Type B. Both types can be found in the Vyaznik fossil record; Therapsids are more likely to have had a faster metabolism than early Archosauromorpha (ancestors of today's crocodiles and birds).

Inclusions in the coprolites we studied include fragments of large tooth crowns of Archosauromorpha, a digested tooth of a lungfish, fragments of ray-finned fishes (scales and small bone pieces) and fragments of bones of amphibians and reptiles. However, the most curious elements were tubular structures 4 mm long; we interpreted them as casts of hair-like objects, some of which even seem to have branched roots. Hairs are highly resistant to digestion and they are commonly found in feces of today's predators; they are also known in fossilized feces from the Paleocene. If our interpretation is correct, the structures described by our team are twice as old as the earliest currently known hair fossils of Jurassic and Creta-



OPTICAL MICROSCOPE IMAGE



OPTICAL MICROSCOPE IMAGE

Scatology, or coprology, is the science of feces and it is an important branch of medicine and zoology. Zoologists working with mammals do not necessarily work with actual animals, but often spend a lot of time studying their excrement. Feces of endangered species are so valuable they are recovered by specially trained sniffer dogs. In Russia, one such target species is the Siberian tiger.

ceous mammals. This suggests that certain Therapsids did indeed develop a hair-like covering as early as the late Paleozoic, before the appearance of the first mammals. This hair likely performed a thermoregulatory function. In the 1960s, some researchers were suggesting that mammalian hair might have its origins in tactile sensing, and perforations found in the skull of a late-Permian Therapsid *Olivera parringtoni* indicate the presence of tactile hairs. Discoveries made in South Africa and Russia suggest that predatory Therapsids from the late Permian had evolved thermal isolation (fur) and a fast metabolism. The results of oxygen isotope analysis of Therapsid bones and teeth, published in *Life* earlier this year, corroborate our theory.

A new look

The methods of analyzing coprolites described above are invasive and destructive, which frequently makes them unsuitable, especially when coprolites are rare at a given fossil site or when we are dealing with museum specimens. One alternative solution may lie in synchrotron-radiation microtomography (PPC-SRµCT), providing high quality 3D virtual reconstructions of coprolite inclusions, such as fragile fragments of beetles, remains of fish or fragments of mussels. Such scans are non-invasive and allow researchers to conduct precise studies on rare samples without damaging their physical or chemical composition. The full coprolite content can be recreated in 3D with incredible precision, which makes it possible to make statistically-significant estimates on questions such as diet and parasites and to identify the producers of the coprolites in question. It is also possible to conduct quantitative measurements of features such as gas bubbles and even study the internal structures of individual inclusions.

Since coprolites are similar to amber in that they act like miniature fossilized environments of the *Konservat-Lagerstatten* type, we can expect this state-of-the-art method to provide many fascinating discoveries. When the technique is used to study high numbers of coprolites from the same paleontological site, we can learn more about trophic pyramids of ancient ecosystems.

Krzysztof Owocki

Further reading:

Bajdek P., Qvarnstrom M., Owocki K., Sulej T., Sennikov A.G., Golubev V.K., Niedźwiedzki G. (2016). Microbiota and food residues including possible evidence of pre-mammalian hair in Upper Permian coprolites from Russia. *Lethaia* 49, 455–477.

Bajdek P., Owocki K., Sennikov A.G., Golubev V.K., Niedźwiedzki G. (2017). Residues from the Upper Permian carnivore coprolites from Vyazniki in Russia – key questions in reconstruction of feeding habits. *Palaeogeography, Palaeoclimatology, Palaeoecology* 482, 70–82.

Qvarnström M., Niedźwiedzki G., Tafforeau P., Žigaitė Ž. & Ahlberg P.E. (2017). Synchrotron phase-contrast microtomography of coprolites generates novel palaeobiological data. *Scientific Reports*, 7: 2723, DOI: 10.1038/s41598-017-02893-9