Concretions (or nodules) are a very specific kind of sedimentary rocks, because they are usually not developed as continuous layers. They have captivating shapes resembling cannonballs, turtle shells, eggs, discs, pipes, radishes, carrots, grapes, blueberries, which draws attention of perceptive nature observers and Earth-science enthusiast around the World. Some of them are cut by a regular polygonal network of septarian cracks filled by colorful crystals, which make them gemstones valued by mineral collectors and used in jewelry. Many contain exceptionally well preserved fossils, so they are targets for paleontologists and fossil hunters. Supposed concretions called "blueberries" have also been observed on Mars, which are thought to have possibly formed via microbial processes and, therefore, may store traces of former primitive life forms. Similar concretions have been investigated on Earth as potential analogs for the Martian "blueberries". Other terrestrial concretions are huge, several meters in diameter, which stimulates imagination of fake researchers spreading absurd hypotheses about provenance of these rocks linking them to extraterrestrial sources of mysterious lost civilizations. Yet, common people publish photographs of spotted concretions in social media asking for explanation of their origin. Therefore, there is a need for dissemination of reliable information about concretions based on solid scientific knowledge to prevent misinformation.

Concretions form by precipitation of minerals in soft sediments, mostly at low temperature. Minerals originating this way are termed cements and they precipitate from fluids circulating within the sediments. What particularly intrigues people about concretions is their morphology, which is not that easy to explain, because scientists still have different opinions about processes shaping concretions. In short, cements precipitate when the fluid in the sediment contains dissolved ions and when the local chemical conditions, such as redox, allow precipitation of cements from these solutions. Among many factors affecting concretion morphology, permeability of the host sediment is particularly important. Concretions grow through cement precipitation preferentially in a direction allowing for efficient supply of fluid carrying proper chemical species and supporting proper redox conditions. If permeability of sediments is equal in all directions, spherical concretions will form, which is typical in sandy deposits. If permeability is higher in horizontal direction, which is typical for muddy deposits, disc-shaped concretions will form. In rare instances, concretions acquire complex shapes resembling pipes, radishes, carrots etc., which is related to vertical fluid flow mostly caused by the activity of benthic organisms, such as bivalves or crustaceans, which burrow within the soft sediment. This burrowing activity creates tubes with significantly higher permeability than that in the surrounding sediment, which promotes much more efficient fluid flow and alters local redox conditions. Both factors affect significantly the shape of concretions that form around these burrows.

This project is focused on such concretions with complex shapes and is aimed at exploring the interaction between benthic activity and physio-chemical conditions favorable for precipitation of cements composed of carbonate minerals. This will further the understanding how these strange shapes of concretions originate and how this knowledge can be applied to reconstruction of chemistry and circulation of fluids in ancient sediments. Samples will be collected during field work campaigns in different countries around the World, where these specific concretions occur. Then, they will be studied with a wide range of methods, including microscopic observations, analysis of chemical and mineralogical composition, and stable isotope measurements. This approach will allow to understand how elements and isotopes are distributed in the concretions, especially in relation to the tubes formed by burrowing organisms. Then, when knowledge about distribution of elements and isotopes is sediments affected by burrowing in present-day environments is applied, reconstruction of processes controlling fluid flow and chemical conditions in the ancient sediments will be carried out.

Concretions and bioturbational structures not only represent a scientific conundrum, but also they are useful indicators of past climate and environmental changes. Burrowing of benthic organisms in marine sediments enhances fluid transport, which may impact the climate. Such bioirrigation in sediments saturated with methane plays an important role in regulating emissions of methane to seawater and atmosphere, which is a much more efficient greenhouse gas than CO_2. Burrowing organisms are also susceptible to environmental conditions at the seafloor. Abrupt climate-induced changes of these conditions modify abundance and diversity of benthic biota, which in turn affect sediment bioirrigation. Thus, results of this research will show what can be the consequences of climate-induced changes in benthic activity and in environmental conditions on fluid circulation, carbon sequestration through precipitation of carbonate minerals, and methane emissions. One of the project outcomes will be setting up social media profiles devoted to concretions, which will provide a trusted transfer of knowledge from scientific sources to the publicity.