Belemnites – a treasure-trove of information about Jurassic and Cretaceous environments

Climate Data Locked Away in Fossils

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They lived around 200 million years ago, and they resembled today's squids and cuttlefishes. Belemnites can reveal a wealth of fascinating information about climate in past geological eras

Belemnites (fossil cephalopods of the Belemnitida order) lived in Jurassic and Cretaceous oceans between 200 million and 66 million years ago. Their internal skeletons possessed elongated, spindle- or bullet-shaped elements called "rostra" (or "guards"). Belemnite rostra from the Jurassic can be found in clays, gaizes and limestones building the hills of the Kraków-Częstochowa Upland in central-southern Poland, and in marls, limestone and mixed rock from the Cretaceous near Annopol in southeastern Poland and chalk deposits near Mielnik in the northeast. They are also sometimes found in redeposited Scandinavian material, mainly sands and gravels, brought by glaciers during the Quaternary and originating from crushed older rocks.

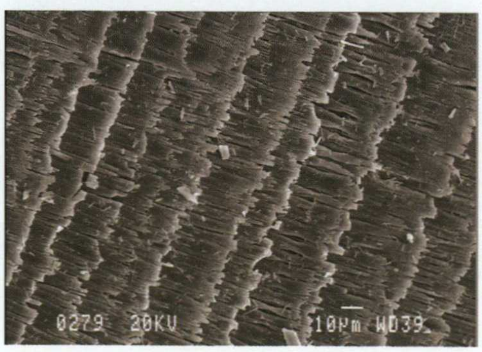
Life at great depths

Resembling present-day squids and cuttlefishes, belemnites were actively swimming cephalopods with ten arms studded with hooks for grasping prey, a mantle, a funnel for expelling water for propulsion, fins, a pair of gills, an ink sac, and large eyes. They also had an internal skeleton built partly of aragonite (a polymorphic form of calcium carbonate). The aragonite part comprised internal structures known as the proostracum and phragmocone. Belemnites also had a rostrum built of calcite (another polymorphic form of calcium carbonate). The heavy rostra acted as ballast for the air-filled phragmocone, giving belemnites stability and allowing them to swim in a position approaching the horizontal. In contrast to the rostra, the phragmocones and proostraca are rarely found in the fossil record. It is assumed that unlike present-day squids, which live in open waters, belemnites were mainly nektobenthic, swimming near the bottom of the sea and avoiding shallow waters. It was a lifestyle similar to that of today's cuttlefishes.

Rings of time

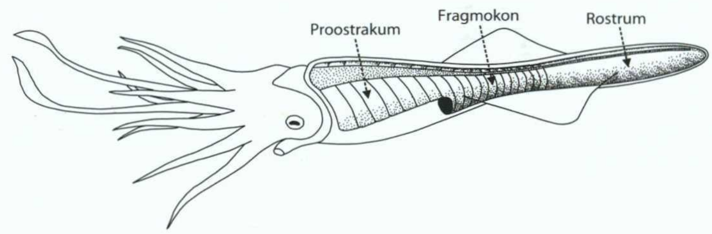
Belemnite rostra have long attracted the attention not of only fossil collectors and hobbyists interested in geology, but also paleontologists, geochemists and paleoclimatologists. They consist of elongated calcite crystals, which grew concentrically from the center of the rostrum. Due to the gradual accretion of the rostra, their cross-sections reveal rings similar to those found in the cross-sections of trees. The growth rings of rostra record the whole life story of these animals.

Studies have shown that in addition to the thicker rings macroscopically visible in rostra, there are also incremental micro-rings. These micro-rings have a diameter from 3 to 90 μm (averaging about 16 μm) in the rostra of Middle Jurassic belemnites and likely reflect daily increments. This is indicated by the similar daily cyclicity of the formation of growth micro-rings in the skeletons of modern cephalopods, which is associated with changes in lighting. Analysis of the incremental micro-rings has made it possible to track the speed and cyclical nature of belemnite growth and their life expectancy. Studies of Middle Jurassic belemnites from the Kraków-Częstochowa Upland have shown that their growth rate was high after hatching from the egg, in the early juvenile period, as well as in the adult one, before reaching sexual maturity. A significant slowdown of belemnite growth rate probably occurred during the spawning period, after which the belemnites died. The observed cyclicity (2-8 days) in the micro-ring thickness may be associated with periods of higher and



Incremental micro-rings arising in daily cycles, shown after digestion, in a cross-section of the rostrum of the belemnite *Hibolithes jurensis*, which comes from the Middle Jurassic clays of the Kraków-Częstochowa Upland

Belemnite rostra from the Middle Jurassic clays of the Kraków-Częstochowa Upland (genus *Hibolithes* - 2 specimens on the left, and genus *Pachybelemnopsis* - specimen on the right, from the Mesohibolitidae family)



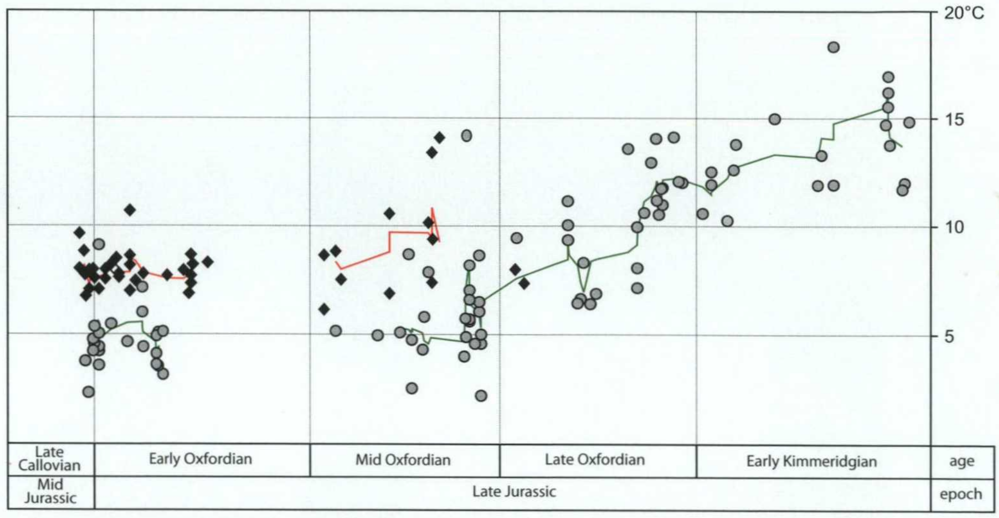
Reconstruction of the appearance and the internal structure of the Lower Cretaceous belemnite *Conobelus pseudoheres* sp. nov. (by Lukeneder, 2005)

lower activity in acquiring food, or with the cyclical formation of air-filled chambers in the phragmocone, which may have affected the belemnites' metabolism. Analysis of the number of growth rings indicates that the belemnites lived no longer than one and a half years, with an average life expectancy of about one year. This short lifespan among belemnites is not surprising, since a similar lifespan is seen in most modern cephalopods; for example squids, cuttlefishes, and common octopuses grow quickly after hatching from the egg, and die after about a year, after reaching sexual maturity and completion of spawning.

Reading the rostrum record

In addition to these incremental cycles, belemnite rostra also record information about the temperature and chemistry of ancient seawater. This is because of the fact that the fractionation of certain chemical elements and stable isotopes in calcite building the rostra in relation to the same components in the surrounding seawater is approximately constant and independent on temperature (e.g. stable isotopes of carbon and strontium), whereas the fractionation of other components varies with the temperature of the surrounding water (e.g. ratios of magnesium/calcium and strontium/calcium, and the oxygen isotopic composition).

In the former case, geochemical analysis of the rostra can provide information on the composition of ancient seawater, for example on the isotope composition of dissolved inorganic carbon, which consists of HCO_3^- and CO_2^{2-} ions and molecular CO_2. This is because dissolved inorganic carbon is the source of the carbonate group in calcium carbonate that is precipitated directly from seawater or by marine organisms. The isotopic composition of dissolved inorganic carbon in seawater, in turn, depends on the inflow and outflow of carbon to and from the oceans, thus being an indicator of the productivity of the water and perturbations in the global carbon cycle. Phenomena known as carbon isotope events, which are periods of growth or decline in the concentration of the heavy carbon isotope ^{13}C in seawater, are well reflected in the isotopic record of belemnite rostra. On the basis of the carbon isotopic composition of belemnite rostra from the Russian Platform, for example, we have been able to identify and determine the timeframe for a global increase in the concentration of the heavy ^{13}C isotope in the seas at the turn of the Middle and Late Jurassic. This increase is probably related to a restriction in the inflow of river-supplied organic matter enriched in the light ^{12}C isotope as a result of a global sea level rise which occurred at that time. This attests to a global-scale perturbation in the carbon cycle.



Temperature changes of bottom waters of the Middle Russian Sea at the turn of the Middle and the Late Jurassic as calculated on the basis of the oxygen isotopic composition of belemnite rostra. Grey circles – data from the rostra of belemnites of the family Cylindroteuthidae, black diamonds – data from the family Mesohibolitidae. These data indicate a strong increase in temperatures of bottom waters of the ancient sea during the Oxfordian period. Although this increase may be slightly overestimated (due to the progressive freshening of the seawater) and dependent on local causes (such as shallowing of the basin), it correlates well with the isotope records of other areas and other paleoclimatic proxies, offering evidence, at least partial, for global warming

The isotope or chemical signatures of marine calcite, which vary with the water temperature from which this mineral crystallizes, are extremely important sources of information about the past climate and its changes. Belemnite rostra are commonly used in Jurassic and Cretaceous climate research, because these animals were widespread in the seas and oceans, and the rostra often remain well-preserved in deposits. On the basis of the oxygen isotopic composition of belemnite rostra it is possible to calculate the temperature of ancient sea water, although the final outcome could also be affected by changes in salinity. Analyses of the oxygen isotopic composition of belemnite rostra has corroborated the theory of Jurassic climate fluctuations. They have evidenced the existence of a very warm period in the latest Early Jurassic (in the Toarcian period, from about 182 million years ago), followed by a cooling of the climate, including most of the Middle Jurassic (from the Aalenian to the Bathonian, i.e. from about 174 to about 166 million years ago), followed, in turn, by a successive warming, which occurred gradually at the turn of the Middle and the Late Jurassic (during the Callovian and Oxfordian periods, i.e. from about 166 to about 157 million years ago). The record of the latter warming can be observed on the basis of the isotopic composition of belemnite rostra from the Middle and Upper Jurassic boundary in the Russian Platform.

Hot – cold

Climate fluctuations in the Jurassic were not as strong as in the Tertiary and Quaternary. In addition to the isotopic changes noted in belemnite rostra, they manifest themselves as changes in the distributions of marine faunas and changes in land floras, or changes in sediment types. For example, siliciclastic sediments (sands, muds and clays) were deposited in central Poland during the Middle Jurassic period, and limestones during the warmer Late Jurassic. The cooler Middle Jurassic period was not cool enough to result in global glaciation; however, at that time the existence of periodic ice cover or drifting ice near the former North Pole in Siberia has been noted. The Boreal seas of this period also show poor and endemic fauna of cephalopods, including belemnites, testifying to the difficult life conditions. ■

Further reading:

Lukeneder A. (2005). First nearly complete skeleton of the Cretaceous duvaliid belemnite Conobelus. *Acta Geologica Polonica 55*, 147-162.

Wierzbowski H. (2013). Life span and growth rate of Middle Jurassic mesohibolitid belemnites deduced from rostrum microincrements. *Volumina Jurassica 11*, 1-18.

Wierzbowski H., Rogov M.A., Matyja B.A., Kiselev D., Ippolitov A. (2013). Middle-Upper Jurassic (Upper Callovian-Lower Kimmeridgian) stable isotope and elemental records of the Russian Platform: Indices of oceanographic and climatic changes. *Global and Planetary Change 107*, 196-212.