論文内容の要旨

Hydrodynamic properties of spiriferide (brachiopod) morphology: experimental and simulation approaches to generation of passive feeding flows

スピリファー形態型腕足類の殻形態における流体力学的特性：
流水実験および流体解析を用いた受動的採餌機構の解明

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A mechanism of generating passive feeding flow in the Devonian spiriferide brachiopods was experimentally and theoretically analyzed through flume experiments and fluid dynamics simulations for flow around the shells. Based on the obtained results, optimal spiriferid shell morphology to generate the passive feeding flow was demonstrated. In the flume experiments, two Devonian spiriferide brachiopods *Paraspirifer bownockeri* and *Cyrtospirifer* cf. *verneuli* were examined using transparent hollow models and a flowing water tank. The models were made of an acrylic plate by vacuum heat press method. Another model of *Paraspirifer* with a spiral brachidium was also made for the visualization of passive flow. The experimental results using the hollow models that were set in the ventral and dorsal directions to the water flow suggest that outflows were generated through lateral gapes of a shell whereas the inflows possibly occurred through a sulcus gape. The passive internal flows inside the models inevitably moved as a gyrating behavior, and the axis of the circle is similar to that of the spiral lophophore in spiriferides. Comparison between the results using the hollow and backbone models indicates that the internal structures, consisting mostly of spiral brachidium, aided to better adjust the gyrating flows around the brachidium, even if the lateral regions of the valves face upstream. Recent terebratullides are known to generate gyrating flows around the median coils of the major feeding area to guarantee the best relationship between the passive internal flows and the form of lophophore. As a consequence, the shell forms of spiriferides could generate the passive feeding flows of the gyrating movement, that are effective for feeding by the spiral lophophore. In the fluid dynamics simulations around rigid shell of *P. bownockeri*, the RANS model was used as a turbulent model, and the unsteady incompressible flow was solved using the finite volume method. Two directions of ventral and dorsal flows were investigated as typical cases where little exchange flow occurred inside the shells. The digital model was constructed using image processing of X-ray CT images of a shell replica made by molding a polycarbonate plate to a well-preserved fossil specimen of *Paraspirifer*. To examine the effect of flow velocity, three conditions of ambient flow velocity were adopted for both the ventral and dorsal flows. The pressure distribution along the gape showed that a relatively high pressure occurred around the sulcus in all simulated cases. This high pressure generated inflow from the sulcus and subsequent spiral interior flow, especially in fast ambient flows. This means that the sulcus generated the considerable pressure gradient around the gape passively and generated the stable intake of seawater and preferable interior flow for feeding. Given the results of flume experiments, the shell form of certain spiriferides could generate spiral flows so as to promote passive feeding, and the sulcus can be interpreted as an important form for the passive intake of water. Optimization of sulcus function to generate passive feeding flows in the Devonian spiriferide brachiopod *Paraspirifer bownockeri* was theoretically examined by means of fluid dynamics simulations. Under a preference direction of a ventral valve facing an upstream flow, the pressure distribution along the gape showed that the models with a deeper sulcus could generate a strong inflow through the sulcus gape with comparative high pressure difference between the gape, as opposed to the case of the sulcus lacking model. The inflow of the sulcus-bearing models formed a passive spiral flow with an axis of right-to-left direction inside the models, which seems to be favorable for a passive feeding because of its alignment on the spiriferid spiral lophophore. The passive flow inside the sulcus-bearing models behaved a similar movement as an outward spiral, but differed in its velocity. The model with a normal sulcus depth, whose form was same in original *Paraspirifer*, generated a stable and slow passive flow, unlike sensitively increased velocities in the deep and shallow sulcus models in the increasing velocity. The extant brachiopods appear to prefer a fairly slow and stable flow for their feedings, which is comparable with the present results of the original form. Ultimately, the hyperplastic sulcus may enhance function to generate a pressure difference along the gape, whereas the swift passive flow by an inflow through the sulcus gape seems to be unfavorable for passive feeding in spiriferides. These lines of evidence suggest that the morphology of sulcus was ecologically constrained from a lotic environment to generate effective feeding flow passively.