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Statistical processing of the shape and attitudes of ellipsoidal objects with special reference to sedimentary grain fabric

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Grain orientations in sediments and metamorphic rocks have been used in Earth sciences as clues to (paleo) environments. Recent advancement of X-ray computed tomography enables us to capture three-dimensional shapes and orientations of grains in a rock. However, the conventional technique that was developed to deals with the major-axis orientations on two-dimensional surfaces, e.g., thin sections, is ineffectual to study such three-dimensional data, because shapes and orientations are inseparable information. This is highlighted by the fact that we can definitely describe the minor-axis orientations of oblate ellipsoids but their major axes are not clear. Grain orientations must be jointly dealt with grain shapes.

In this study, we developed the following statistical technique to recognize the peaks of joint probability of shapes and orientations of ellipsoids. The technique is applicable not only sedimentary and metamorphic shape fabrics but to other kinds of ellipsoidal objects including stress and strain ellipsoids and magnetic susceptibility ellipsoids. The parameter space that we devised is useful as a search space to fit ellipsoids in voxel data.

First, we defined a six-dimensional parameter space, where a point has a one-to-one correspondence with the size, aspect ratio, shape factor, and principal orientations of an ellipsoid. The factor indicated a shape in the spectrum between prolate and oblate ellipsoids. Neglecting sizes, we devised a five-dimensional parameter space by modifying the parameter space that we made for stress tensor inversion. The radius vector in this space equals the logarithm of the aspect ratio, and tangential components designate the shape factor and principal orientations.

Second, a clustering technique was used to recognize the joint frequency of the shapes and orientations of given ellipsoids. The joint frequency is represented by the density distribution of the data points in the parameter space corresponding to the ellipsoids. Once clusters are recognized, it is easy to calculate the mean shape and orientation of the members that correspond to the data points in a cluster.

We used the three-dimensional data of sand grains that were deposited in an experimental flume for testing our statistical technique. It was found that imbricated grains had preferred shapes and the transverse orientation to the paleocurrent was a preferred orientation for grains with particular shapes. It has been known that sedimentary grains have those preferred orientations, but the joint frequency was found for the first time. The preferred orientations had preferred shapes.