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Foreword : Image Analysis and Morphometry of Geological Objects

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This issue of Mathematical Geology is the outcome of the September 1999 BioGeoImages conference held in Dijon (France) at the University of Burgundy. The aim of this conference was to bring together people who did not have the opportunity to meet frequently, although they were working on different topics but using similar methods. Geologists, biologists (paleontologists), mathematicians, and computer scientists working on the shape and distribution of natural objects using image analysis, met during 3 days to exchange methods and points of view on rock forming features, from fossils to crystals.

Form is defined as the visible appearance of an object, the whole of the contours resulting from the structure of its parts. Biologists and geologists recognize that the form of an object concentrates a lot of information about its structures and its past evolution. However, as pointed out by Alain Boutot (1993, p. 23), form is an idea that is fundamentally *qualitative*. Form is a rupture, a break between the object and the space in which it evolves or exists. This discontinuity is the source of morphogenesis, and a discontinuity is measurable or at least observable. It is the abrupt transition from one state to another. Therefore form can be projected, highlighted, or illuminated in various ways. If the entire form cannot be manipulated, certain of its characteristics or features can be extracted in a metric space. This is the aim of morphometry, the study of shape.

Morphometry is not the measurement of the form itself but of its external and perceptible characteristics, i.e., in a first approximation, its shape or morphology. Morphology is defined as the study of the configuration and the external structure of the object, i.e., its appearance. The term comes from the Greek $\mu o\rho\phi\eta$ (form) and $\lambda o\gamma o\sigma$ (study). Form in Greek ($\mu o\rho\phi\eta$) makes reference to the mythological entity Morpheus, one of the many children of the god of sleep Hypnos. Morpheus causes his sleeping subjects to dream and captures

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the different forms that fill their unconciousness. Thus, since Antiquity, the imaginary cleverly related form to illusion. In the morphological disciplines, according to the expression of René Thom (1982), it is necessary to liberate oneself from illusion in order to perceive, measure, and in one word to characterize, the external structure, the morphology and thus, the projection of the form, i.e., its shape. This projection includes information related to the object's appearance as well as to its physical and diachronic constitution, i.e., throughout its evolution.

Nevertheless, the modelization of forms remains difficult because in general, physical models are not powerful enough to formalize empirical discontinuities (Boutot, 1993, p. 21). Modelization uses regular functions that are by nature continuous. This continuous approach to objects undoubtedly explains the lack of interest of physicists in the modelization of natural forms and their evolution. D'Arcy Thompson—"the phantom of biology" (Witkowski, 1998)—is the striking exception that confirms the rule. But this continuous and inappropriate conception of natural forms was dismissed at the end of the twentieth century with the arrival of computers and a geometry that took the opposite stance of continuity, called discrete geometry.

Morphometry is a descriptive discipline that consists of using methods and tools that can lead to the characterization of visual information contained in the form through shape. This characterization is expressed by symbolical mathematical relationships whose actual application allows numerical data (thus, testable and comparable) to be obtained. Generally, four types of morphometric quantitative approaches can be distinguished:

1. The multivariate approach is applied to a series of data acquired by linear or area measurements, of distances and angular properties;
2. Reference systems use coordinates and include all the geometrical transformations based on landmarks. This approach also uses distances, i.e., the object's spaces of deformation. However, it excludes all reference to the precise appearance of the contours or the curvature of the contour lines;
3. The spectral approach breaks down morphological contours into numerous coefficients. Belonging to this category are: Fourier descriptors (derived from conventional series or elliptical functions), wavelet transforms, etc.;
4. The textural approach is employed to define the appearance, the complexity of the state of the surface or the texture of an object. It uses the same types of transforms as the spectral approach but is applied to intensity images in two dimensions.

In all four approaches, the descriptors of the shape projected on the numerical space must, in order to be useable in conformity with the objectives of morphometry, satisfy what are called the seven laws of morphometry (Clark, 1981; Lestrel, 1997).

1. Numerical representation descriptors of a form must cover a unique description of its size, shape, and structure for each representation. This assumes that if two descriptors are equal, then the representations of the forms that they describe will be similar (or identical). Consequently, a good descriptor contains numerous arguments: the more that descriptor is precise and complex, the greater the chance of being unique for the given form.
2. Descriptors must be efficient in terms of numerical calculation time, in order to reduce the number of observation data necessary to a subgroup of variables with a minimum loss of morphological information. This aspect allows the first rule to be limited. Nevertheless, it is necessary to realize that the increased precision due to the addition of descriptors is not uniform. All the segregative information of a representation must be able to be contained in several well-chosen descriptors.
3. As much as possible, the descriptors must be independent. It must be possible to calculate each descriptor without having to go back to calculation of other descriptors. If one of them does not seem to add any additional information to the description of the object, it must be abandoned. This rule limits the redundancies that are always possible among descriptors. It also assumes that this possible redundance and the degree of pertinence of descriptors must be rigorously tested by the appropriate statistical tools.
4. The descriptors must allow a reconstitution of the shape with great precision. They can be useful for the compression of data. Resorting to reconstruction also allows the measurement and testing of the relevance of each new descriptor. The descriptors must be as accurate for the general representation of the appearance of the shape as for its smallest identifiable details. This permits the measurement of both morphological changes affecting the appearance on a small scale of the shape as well as those comprised in its variations in detail. Consequently, each of the differences must be able of being identified by the calculated parameters.
5. The descriptors must reflect a significant percentage of the variabiliy present in the form and be invariant in terms of translation, rotation, reflexion and, if possible, changes of scale. While it is difficult to give an orientation to an object, a good discriptor must be able to describe it in an identical manner, whatever the measurement's starting point. Nevertheless, in order to make rigorous comparisons, it is sometimes necessary to acquire the morphology of a series of objects starting from the highest point of their largest axis aligned horizontally and in the trigonometrical sense. A good descriptor must describe the object and its mirror reflection in the same way. In addition, the enlargement or reduction of a form must not change the value of the descriptor. However, there are numerous specific cases in biogeosciences in which the orientation, the chirality, and the size of the object must be taken into account in the measurement. Therefore,

the relevance and the qualities of the chosen descriptors must be carefully considered for each individual case. In addition the descriptors must be independent of any biased relationship between size and morphology. As a result, the numerical differences acquired from the representation must be related to real morphological changes.

6. The descriptors must, whenever possible, convey physical information.
7. The acquisition of descriptors must be automatized as much as possible, thereby minimizing all human error or subjectivity. This automatization can intervene (1) during the numerical acquisition, (2) while the data are processed, (3) during the measurement of degree of relevance, or (4) all of the above concurrently.

Once the image of the shape (projection of the form) is acquired, several morphometric approaches can be combined according to the problems that arise. This Mathematical Geology special issue offers a wide variety of approaches, applicable to organic as well as inorganic (mineral) objects. I hope that the reader finds these varied approaches helpful.

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