MATHEMATICAL GEOLOGY AND KNOWLEDGE ENGINEERING:

VIEW FROM ST. PETERSBURG

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The science of mathematical geology, finally shaped up in 1968 (Vistelius, 1980), was born under the circumstance that had, and still has, taken place nevermore in the human history, and hopefully – and likely! – will never do. This was the siege of Leningrad of 1941-1944 during the World War Two, in which the city lost dead and wounded more than one half of its two-million population. In addition to severe famine and bombing, collapse of city transport, power and heat supply, the winter of 1941-1942 was incredibly cold, with temperatures well below minus 40 centigrade.

In those tragic winter months Andrei Vistelius, 27-year-old geologist, was dying in the city but continued to work. He was not drafted into the military even as a volunteer because of severe health problems and also due to the fact that he was nobly born. By God's grace, he survived, and the results of his contemplations were published in 1944 – and very soon, yet in 1948, were rapidly translated into English and republished by Nature. This was the rise of the new science, the mathematical geology. Decades later Andrei Borisovich Vistelius, a worldwide-recognized geologist, became the first president of the International Association of Mathematical Geology and the founder of the International Journal of Mathematical Geology (now Mathematical Geosciences). He was contributing abundantly to the science he had founded and named until his death in 1995. All his life he worked in Leningrad (renamed back to St. Petersburg in 1991). He was remembered by his colleagues and friends all over the world, who became the first generation of mathematical geologists – William Christian Krumbein, Frits Agterberg, Michael Dacey, Eric Harold Timothy Whitten and others.

Now, looking back and ahead, we query ourselves, whether the mathematical geology has become, or still is, what Vistelius meant it to be? Whether we still share his vision of geology, geosciences, natural science and the science in general? And are we satisfied with what we have come to?

To our mind, the honest answer would be: NOT EXACTLY. Omitting the points of probable personal disagreement with some fragments of the Vistelius' theory, as no one ever agrees with anyone utterly and entirely, we would like to focus on the destiny of the mathematical geology in general.

Defining this science, Vistelius emphasized that

- The key concept in mathematical modeling of the Earth’s evolution is probability;
- Any process and its result on and in the Earth can be comprehended either as deterministic, or as stochastic and independent of its own history, or stochastic and partly predetermined by its history;
- Of several models pretending to explain the phenomenon in question, only one should be finally selected, and others, rejected;
- Forward problems should be the basis for mathematical modeling in geology, and inverse problems should be addressed by the models developed for solution of forward problems.

The latter issue requires special consideration. Vistelius (1980) stated that, focusing on forward tasks, the mathematical geology should first formulate a conceptual model that would give a comprehensive vision of the modeled phenomenon based not only on the experience of particular researcher but, necessarily, on all relevant geological information available. Then, by Vistelius, based on this model, a mathematical construction should be built. In this construction, the typical features of the modeled natural phenomena should be identified – this process is understood as formulation of statistical hypothesis. Then these features, suggested theoretically, are compared with new observations. If the latter confirm them, the model is accepted, otherwise, rejected. Therefore, concludes Vistelius, the success of mathematical modeling in geology entirely depends on the art of building the conceptual model. Development of these models must eventually lead to the axiomatic of the domains of knowledge in geology.

Exactly this issue, in our mind, appeared to be the hardest challenge for the mathematical geology. Thus, most of the works published in the field of mathematical geology so far are still “observation-driven”, i.e., represent reverse problems, and even if not, the conceptual models proposed are commonly quite simple and ad hoc. No qualitative axiomatics has been proposed so far, to our knowledge, for any domain of the geoscience.

The reason for this, in our opinion, dates back to the program of Vistelius quoted above. His ideas, running well ahead of time, unavoidably remained rather declarative. Indeed, claiming to construct conceptual models of studied phenomena prior to mathematical formalization, he did not suggest any method to build such models from the verbal and graphic geological information coming from various sources, researchers and schools, while the latter brings extremely high conceptual, or epistemic, uncertainty (Woo, 1999; Fitelson, 2003; Pshenichny, 2004) and greatly impedes building an integer model (Diviacco, 2012).

Furthermore, Vistelius did not provide any guidelines to proceed from conceptual to mathematical model, perhaps leaving this entirely on the discretion of the researcher’s intuition. Then, Vistelius rigorously insisted on the singularity of final mathematical model, while this may indicate not only the power but also weakness of the modeling. Finally, he complained that methods to develop axiomatics from conceptual models are inexistent in the natural science.

These shortcomings of his theory unlikely could be fixed by Vistelius himself or anyone else in his times because mathematics offers little to no tools for handling them. Much later, in the 1980-1990s, there appeared a branch of artificial intelligence represented by three interrelated disciplines, knowledge representation, knowledge management and knowledge engineering. Knowledge engineering, extending from acquisition of knowledge from experts to its representation in an expert system (Giarratano and Riley, 1998) – or, broadly speaking, in any kind of information system – is understood as a selection of methods of various origins (from statistics to psychology, from linguistics to physiology) to look at how qualitative (commonly, though not necessarily, verbal) expressions are treated by humans (Feigenbaum, 1984).

These features of knowledge engineering and related fields obviously may provide methodology to formulate conceptual models and even build axiomatics in geology. Perhaps the experience of knowledge engineering in building axiomatics for ontologies of various domains of knowledge (Mouromtsev et al., 2013) may be helpful. Moreover, a concept of information modeling was introduced recently by Pshenichny and Kanzheleva (2011) as a research of natural objects (e.g., geoentities) and enquiry of their typical and charasteristic features through the analysis of verbal, graphic and other information about them. Knowledge engineering is meant as a tool to minimize the human subjectivity in information modeling by interviewing experts and other means of knowledge acquisition from texts, datasets, maps and other sources, and information model itself shows no principal difference from the conceptual model sensu Vistelius (1980). Thus it may serve as a bridge between the traditional formats (and intuitive spirit) of geological information and a mathematical model – exactly what is needed to make the theory of Vistelius work. Also, it can bridge up such general theories as synergetics, systems theory and others with geology. Published examples of information modeling (see, e.g., the research of Aspinall et al. (2003) on the Soufriere Hills volcano by Bayesian belief networks or Behncke and Pshenichny (2009) on Etna by the method of event bush) demonstrate that this modeling initially considers forward problems, and reverse problems can be approached only based on the solutions obtained from the forward ones.

The principal issue is how to proceed from the conceptual model to the mathematical one. The mathematical geology does not suggest universal guidelines, nor does the information modeling in general. Still, Aspinall et al. (2003) and many other researchers describe the procedure of assigning probabilistic values to the nodes or states of Bayesian networks or event trees. Moreover, the method of event bush, being the key tool of information modeling for the acyclic multiple-path environments, has evolved enough to offer an algorithm of passage from strict qualitative model to variables and equations (Carniel et al., 2011).

Nevertheless, one point in knowledge engineering/information modeling approach seems to be in definite contradiction with the mathematical geology as narrated by Vistelius. As was shown before (Pshenichny, 2004; Pshenichny and Diviacco, 2011), it is natural that organization of geological information leads not to one but to a number of conceptual models and each model may readily lead to a number of mathematical formalizations and a number of quantitative models within the same formalization (e.g., assigning different prior probability values to the same belief network). New observations may fit not one but several models and therefore give no ground for choosing one. Furthermore, the historical record is full of examples when rejected model was revived with new data coming, and this itself does not favor “rejection” of any model. Rather, a family of models of similar semantics should be kept in mind, and this point is strongly supported by the modern studies of sociology of science and scientific collaboration (Diviacco, 2012). Perhaps not a single model in the natural science can “win forever”, like not a single team may ensure eternal championship. However, to our mind, an assumption of the multiplicity of rival models may only enrich the theory of mathematical geology.

In conclusion, the mathematical geology, being introduced by Andrei Vistelius in the 1940-1960s, encountered serious problems of implementation, which can be solved only now, with development of knowledge engineering. However, the latter not only provides practical tools to fill the gap between the traditional geological knowledge and mathematical modeling but also brings valuable improvement of the theoretical foundations of the mathematical geology.

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