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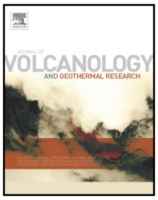

Review

Knowledge engineering in volcanology: Practical claims and general approach

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ABSTRACT

Knowledge engineering, being a branch of artificial intelligence, offers a variety of methods for elicitation and structuring of knowledge in a given domain. Only a few of them (ontologies and semantic nets, event/probability trees, Bayesian belief networks and event bushes) are known to volcanologists. Meanwhile, the tasks faced by volcanology and the solutions found so far favor a much wider application of knowledge engineering, especially tools for handling dynamic knowledge. This raises some fundamental logical and mathematical problems and requires an organizational effort, but may strongly improve panel discussions, enhance decision support, optimize physical modeling and support scientific collaboration.

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1. Introduction

The task of volcanic hazard and risk assessment, being the main practical purpose of volcanology, simultaneously poses a theoretical claim to rethink the whole body of volcanological knowledge, i.e., untangle the threads of inference, accurately select arguments to support or refute hypotheses, compare models, evaluate expert judgments and comprehend the field of knowledge in its entirety (e.g., reconstruct a full group of scenarios of unrest for a specific volcano). For a descriptive and language-dependent field like volcanology, this is a real challenge that suggests the need, first of all, to structure the knowledge and, wherever possible, semantically constrain it. This is why volcanologists make wide use of various graphic conceptualizations, along with verbal descriptions and quantitative data.

In the early days of volcanology, this was also strongly stimulated by the limited development of photographic techniques. Now, however, even the photographs in research papers are commonly supplied with notes, pointers, inscriptions and comments. In fact, every scientific drawing, including those based on a photograph, of a volcano or volcanic rock communicates a researcher's vision of its formation and

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dynamics and is an attempt to visualize (and sometimes also organize) scientific knowledge. At the same time, drawings in modern research papers (see, e.g., Fisher and Heiken, 1982; Branney and Kokelaar, 2002, and many others), supplied with terms and pointers, often resemble formalized graphic notations known from graph theory (Tutte, 1998), such as labeled graphs or hypergraphs (Gallo et al., 1993). Therefore, by representing and organizing the volcanological knowledge, the drawings become more and more formal and at some point can be readily substituted by simple boxes and arrows (nodes and arcs, in terms of graph theory) convertible into formalisms tractable by computer (Figs. 1a, b, c, 2a, b).

Looking at the above examples, some important observations can be made on how the knowledge is being represented and structured by conventional volcanological drawing. Indeed, these examples usually refer either (i) to a case when researchers aim to represent one scenario in one plot as shown in Fig. 1 (or even one scenario in several plots stage by stage), or (ii) show no scenario at all but merely the structure of a volcanic object (volcano, eruptive sequence and so forth) — this is exemplified by Fig. 2. Nevertheless, in historical reconstruction and especially in forecasting, it may be necessary to put several scenarios in one plot, methodologically speaking, to bring several alternative scenarios into one mental and intellectual framework.

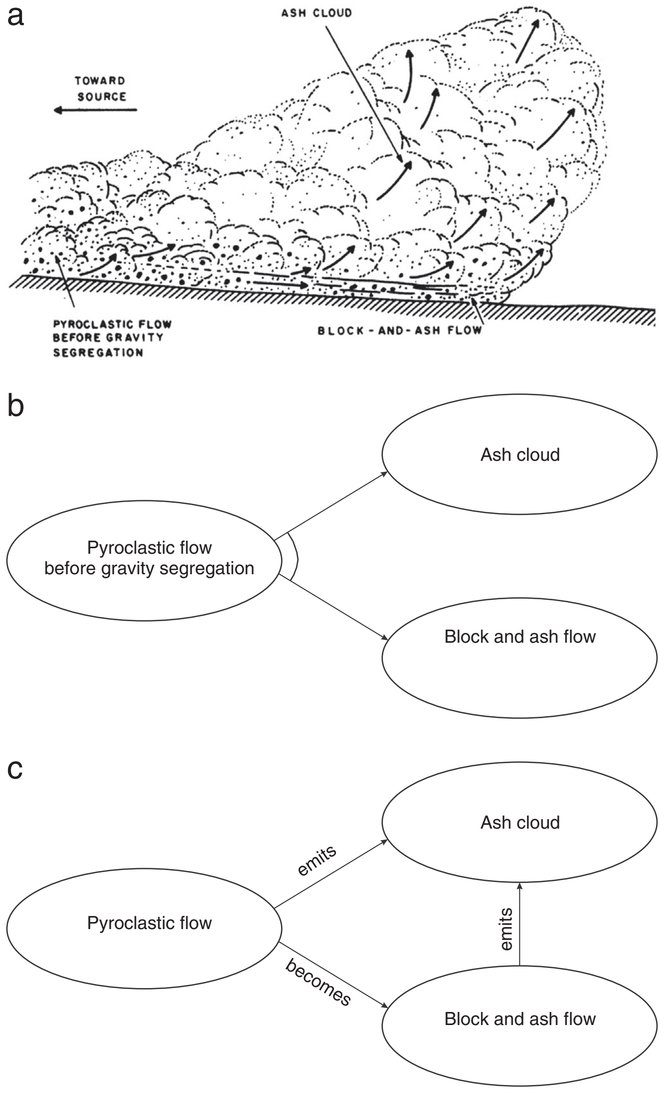

Fig. 1. Conceptual drawing of a pyroclastic flow behavior by Fisher and Heiken, 1982 (a) and formalized graphic notations showing the same (b). The notation at (b) can be represented as an AND–OR tree with the only "AND" node, by Giarratano and Riley (1998), and at (c), as a semantic network sensu Sowa (2006). This dual formalization illustrates that notation may better (c) or worse (b) match the modeled environment.

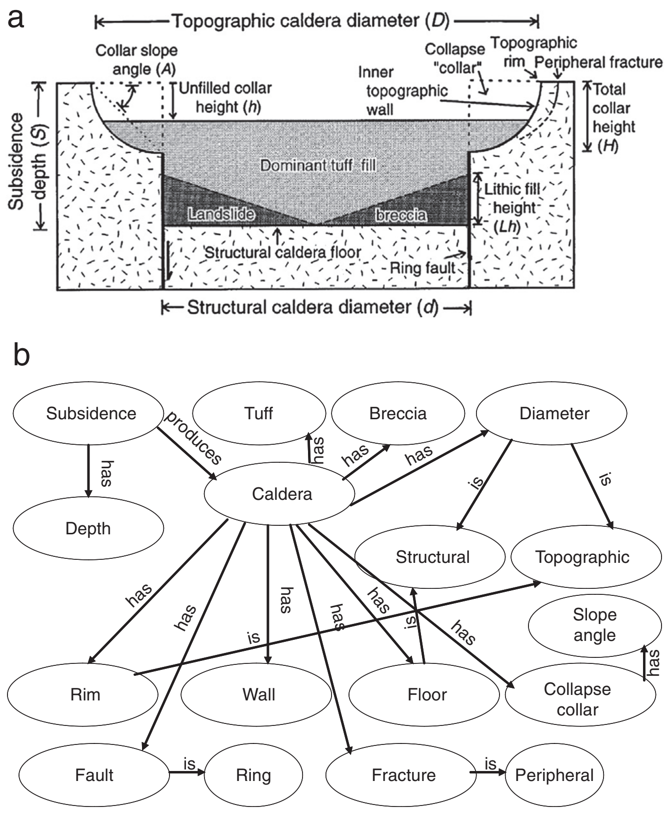

Fig. 2. Conceptual drawing of a caldera structure, after Lipman, 1997 (a) and formalized graphic notation showing the same (b). This notation can be converted into semantic network (Sowa, 2006).

To achieve this, volcanologists depart from conventional drawing and apply purely formal graphic conceptualizations, such as event trees (Newhall and Hoblitt, 2002; Fig. 3), Bayesian belief networks (Aspinall et al., 2003; Fig. 4) and trees (Marzocchi et al., 2008; Fig. 5), UML class diagrams (Gehl et al., 2013; Fig. 6), flowcharts (Gehl et al., 2013; Fig. 7) and others. Definitions of these and other methods mentioned in the text are given in Appendix A.

As is seen from the above, the study of volcanology for decades has been inclined to use what is now called *artificial intelligence* (Giarratano and Riley, 1998). In fact, it appears to have extensively intruded itself into such fields of artificial intelligence as knowledge representation, knowledge management and knowledge engineering, which are tightly interrelated. 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), and thus try to minimize the human subjectivity in information modeling (Pshenichny and Kanzheleva, 2011).

This raises a few questions, only some of which seem to have a straightforward answer. One issue that can be resolved relatively easily is the distinction between the volcanological knowledge per se and the knowledge of related human activities (from investigation to evacuation). Indeed, the examples presented in Figs. 6 and 7 clearly represent a