Geophysical Research Abstracts
Vol. 13, EGU2011-9800, 2011
EGU General Assembly 2011

Power-law size distributions in volcanotectonics

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Many processes associated with volcanoes give rise to power-law size distributions (or other similar statistical distributions). These include (1) the lengths of tectonic fractures in volcanic systems, (2) the openings of tectonic fractures, (3) the lengths of volcanic fissures, (4) the diameters of crater cones on volcanic fissures, (5) the thicknesses of dykes, (6) the volumes of erupted materials (such as lava flows and pyroclastic layers), and presumably (7) the energy released during volcanic eruptions.

Power-law size distributions imply that there are a large number of small events, processes, or objects of a particular type and a small number of large events, processes, or objects of the same type. More specifically, power laws are scale free; in contrast to, say, normal (Gaussian) distributions, there are no objects (or events or processes) that are typical for the distribution as a whole.

While power-law distributions have received great attention in recent decades, the mechanisms that generate them are still poorly understood. Of the many mechanisms proposed to explain power-law distributions perhaps the best known are (a) the Yule (or Yule-Simon) process, (b) the self-organised criticality process, and (c) the preferential attachment process. The Yule process was initially used to explain the statistics of biological taxa (taxonomic groups), which have power-law distributions for lifetimes and sizes. The self-organising criticality process is based on the idea that a dynamical system such as a fault zone arranges itself so as to move rapidly to a critical point where it tends to sit - a state of affairs referred to as self-organised criticality. The term critical point (or phase transition) refers to the point at which an existing length scale of the dynamical system diverges and leaves the system with no length scale (or, depending on the type of system, no size-scale or time-scale), resulting in a scale-free system or network. Processes that happen in the vicinity of a critical point are referred to as critical phenomena - one instance of which is a power-law distribution. The preferential-attachment process is based on a model of a continuously growing network where the new links or edges are preferably attached to the nodes or vertices that are already well connected (have many links). The model, however, assumes but does not explain either continuous growth or preferential attachment. For a proper explanation of the growth and preferential attachment, some basic physical theories are needed.

Here we focus on power-law size distributions of fracture lengths and openings, and volcanic fissure lengths and sizes of crater cones. We show that the power-law length distributions are a natural consequence of the way that rock fractures grow. Since the openings are linearly related to fracture lengths, it follows that, when the lengths follow power laws, the openings (and dyke thicknesses) also follow power-law size distributions. The opening and lengths partly determine the volumetric flow rate (the cubic law) and the flow channelling during fissure eruptions which, in turn, contribute to the power-law size distribution of crater cones on individual fissures. We show that all these size distributions are eventually related to the energy input into the volcanic systems, in particular the strain energy, and relate the power-law distributions to entropy.