A model and simulation of branching mineral growth from cooling contacts and glasses

ANTHONY D. FOWLER AND DANIEL E. ROACH

Ottawa Carleton Geoscience Centre, and Department of Geology, University of Ottawa, 770 King Edward Ave. Ottawa, ON, K1N 6N5, Canada

Abstract

Silicate minerals grown from glasses, and rapidly cooled melts, often have non-compact branching or 'spherulitic' morphology. The branching patterns are observed in volcanic rocks, glasses, meteorites, slags and sometimes in shallow level intrusive rocks. Experiments, observations, theory and simulations all support the concept that the crystal morphology is the result of growth under diffusion limited conditions. We show that in a silicate melt under appropriate conditions the equations for heat transfer and chemical-diffusion reduce to the Laplace equation. This means that the temperature or chemical gradient is a steady state field. Interaction between this field and a random variable (Brownian motion of growth species) is modelled and yields complex branching objects. The growing cluster affects the field such that an in-filled structure cannot be formed. The branching structures of the model crystal are remarkably similar to those formed in nature, and to those produced in laboratory experiments, implying that the model captures the essence of the branching-growth process.

KEYWORDS: branching mineral growth, glass, cooling, diffusion-limited aggregation.

Introduction

BRANCHING-TEXTURED silicate minerals (and more rarely carbonates and oxides) are formed in environments where the kinetics of crystallization are rapid with respect to rates of chemical diffusion (Keith and Padden, 1963). Usually the environments are characterized by sharp thermal gradients and, sluggish diffusion or both (i.e. glassy cooling contacts of silicate melts). Natural examples are the branching plagioclase and olivines of volcanic rocks (Bryan, 1972; Fowler *et al.*, 1987 and 1989). The textures are characterized by tip splitting wherein branches bifurcate during propagation. Figure 1 exhibits an example from the quenched rim of an Archaean pillow basalt. Similar textures have been synthesized in the laboratory under conditions of very high supercooling (e.g. Lofgren, 1974; Donaldson, 1974) and simulated using a variation of the simple growth algorithm, Diffusion Limited Aggregation (Fowler *et al.*, 1989). Although at first glance the textures apparently have a random branching structure, in general they possess a dilation symmetry, or scale invariance. That is, small segments when suitably expanded look like the whole. Fowler *et al.* (1989) show that these scale-invariant branching structures can be measured using fractal geometry which allows us to quantify irregular objects. The knowledge that these branching crystals have a fractal dimension of ~ 1.7 was the original motivation for this work, because other similar fractal objects have been modelled by related techniques (see discussion).

Theoretical work on crystal growth in silicate magmas and other systems, e.g. snowflakes (Nittman and Stanley, 1986) and plastics (Keith and Padden, 1963) demonstrates that the branching is the result of growth under chemical diffusion limited conditions. The unpredictable or random nature of the diffusion process, coupled with rapid crystal growth, leads to a texture that is not random but organized on many length scales (i.e. scale invariant).

Here we relate Fourier's heat equation and Fick's diffusion law to conditions present during non-equilibrium crystal growth, and demonstrate how they reduce to the Laplace equation (a steady state) under the imposed conditions. We then use the discrete form of the Laplace equation, suitable for

Mineralogical Magazine, August 1996, Vol. 60, pp. 595–601
© Copyright the Mineralogical Society