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SEISMIC CONTROL OF LAYERING IN INTRUSIONS

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The influence of the tectonic framework on the history of lithification of magma has been persistently ignored in the literature. The possible effects of the tectonic environment with reference to the development of small scale structures have so far not been seriously considered. The emplacement of a pluton represents a climax to tectonic activity and is therefore likely to be not only preceded but also followed by prolonged periods of intermittent seismic events of varying degrees of violence. The temporary and differential effects of the primary waves of intermittent earth tremors on the nucleation, growth and settling rates of crystalline particles of varying density and habit nucleating near the upper contact of the pluton may be profound enough to provide an efficient mechanism for the development of mineralogical as well as of textural layering.

The quantitative evaluation of the net effect would involve a large number of assumptions such as the instantaneous boundary values and the gradients of the viscosity and of the temperature of the magma, the rates of nucleation and of crystal growth as well as the respective habits of the coprecipitating solids, and the intensities of earthquakes and their frequency above the level of seismic noise. However, it is a trivial matter to demonstrate in the laboratory that a supersaturated liquid will precipitate spontaneously if mildly disturbed, and that the higher the viscosity of the liquid—that is, the lower its temperature—the higher is the degree of departure from equilibrium saturation that it is capable of accommodating in the absence of nuclei. Whether or not the continued growth of a nucleus takes place at instantaneous equilibrium, the formation of a nucleus—as distinct from its subsequent growth—requires a finite amount of supersaturation unless the liquid is mechanically agitated. In fact, a nucleus forming at equilibrium saturation near the upper contact of an intrusion would have little chance for survival and would probably re-dissolve on its downward passage into regions of higher temperature. The greater the amount of supersaturation at which the nucleus has formed, the higher is its rate of growth at the instant immediately following nucleation, and the greater are its chances for survival. If one regards the habit of a growing crystal as a measure of the departure from equilibrium, the approach to equilibrium that has been accomplished in the time required for the settling of the precipitate could be estimated from the departure from equidimensionality of the euhedral crystal fraction in each layer. The retarding effect on the settling rates of micelles due to a slight mechanical agitation of a suspension is also well documented by experiments (Reich and Vold, 1959; Smellie and La Mer, 1958).

If cooling is to be considered a continuous process rather than an intermittent one, the prevailing notion that convection currents may be responsible for the development of layering (Wager and Deer, 1939) becomes difficult to support. As a rule (to which there are exceptions such as the Skaergaard intrusion) undeformed layered intrusions are sheet-like structures of low dip in which the layering is near horizontal, such as the Bushveld, the Stillwater, the Palisade and many another sill. The typical shape and attitude of layered plutons would impose severe limitations on the dimensions of individual convection cells. Theoretical work (Schwarzchild, 1961; Danielson, 1961) concerned with the dimensions of granules in the surface of the sun lead to the conclusion that in a fluid sheet of infinite extent the lateral dimensions of adjacent convection cells are likely to equal the depth of the sheet. It is hence to be expected that the lateral dimensions of adjacent convection cells in a sheet of magma be comparable to the depths of the convection cells, or at least be of the same order of magnitude as their depths. With the deposition of each layer the effective depths of the hypothetical convection cells would be reduced by an amount equal to the thickness of the deposited layer, and the lateral dimensions of the convection cells would, therefore, have to decrease also. This implies that ever increasing numbers of convection cells of continuously diminishing size would have to be redistributed with every cycle, and would lead to absurdly small dimensions of those convection cells which supposedly produce the final layers near the upper contact of the sill.

To operate efficiently adjacent convection cells must be able to maintain their dimensions over a significant time interval. The shrinkage of the lateral dimensions of each convection cell with the thinning of the liquid sheet would tend to create convection-free interstices between neighboring convection cells. These convection-free regions would grow at the expense of the surrounding convection cells until their dimensions become comparable to those of the shrunken cells themselves. Momentarily, then, heat transfer by convection would once more extend throughout the sheet of magma, the whole process being repeated on a diminished scale. It is inconceivable that such a mechanism could lead to the high degree of continuity in the layering that is observed in the larger sills.

The presence of convection currents would be likely to lead to the alignment of solid particles parallel to the local flow direction at the base of the current and thus give rise to the development of a lineation expressed as a preferred orientation of minerals in the plane of the layering. No such lineation has yet been discovered. Furthermore, textural features which may be associated with turbulence and convection, such as oscillatorily zoned plagioclase, are rarely found in layered intrusions in significant amounts.

It is realized that seismic activity is not the only possible explanation for the development of layering in intrusions. The suggestion is offered for consideration merely as a plausible alternative to other mechanisms which have been proposed in the past. One may legitimately ask what the implications of the postulated mechanism are, and whether there are criteria for evaluating the likelihood that the process has indeed been operating. If it is true that the layering in a given intrusion was formed by earthquakes intermittently triggering precipitation of a supersaturated magma, it should, in principle at least, be possible to reconstruct the seismic history of the region from the pattern of vertical variation in the layering of the intrusion. It should be possible to estimate the number of earthquakes that occurred during lithification of the intrusion by counting the number of layers. On the assumption that the amount of solids precipitated by each earthquake is related to the attained degree of supersaturation and hence, to the temperature drop of the magma, it should be possible to estimate the relative time intervals between successive earthquakes from the relative thickness of adjacent layers, interpreting sharp contacts to represent discontinuities in precipitation, while mineralogical and textural grading (as distinct from sharp contacts) merely to reflect differences in settling velocities of coprecipitating particles.

If one is willing to interpret the principle that the present is the key to the past in a very literal sense, one could perhaps estimate the time elapsed between the instant of emplacement and complete lithification by comparing the pattern of relative time intervals between successive earthquakes (estimated from the relative widths of adjacent bands) with the pattern of the longest available continuous seismograph record. It is assumed here that only those shocks whose intensity exceeds some critical value would trigger the formation of a layer, the depth of the layer depending on the time interval between successive critical shocks, rather than on the absolute intensity of the triggering shock. While, with the almost total lack of quantitative information, it would be futile to attempt the correlation of an individual band with any one time interval between successive shocks on the seismograph record, the comparison of the respective patterns may still be useful in revealing corresponding regularities, thereby suggesting, on the one hand, the minimum intensity a shock must have in order to give rise to the formation of a layer and, on the other hand, the minimum time that must elapse between successive shocks to produce a measurable record in the pattern of layering. Alternatively, such a comparison may offer a means of evaluating the amount of seismic control in the development of the layering by statistically analyzing the amount of agreement between the details of a seismograph record and the pattern of vertical variation in the layering of the intrusion.

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A SIMPLE APPARATUS FOR TRIMMING THIN SECTIONS

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A rock chip mounted on a glass slide can be quickly and evenly trimmed to a thickness of 60 microns or less, using the apparatus described here. It consists of a slide holder (Fig. 1), vacuum source and a vacuum line with a liquid trap (for cutting fluid). It is used in our laboratory with a Felker model 41-A cut-off machine, with rimlock diamond blade $7\frac{3}{4}$ inches in diameter.

In operation, a glass slide with rock chip mounted is pressed into the slide recess so that it bears firmly in the lower and back walls of the re-