ISSN 0016-7029, Geochemistry International, 2007, Vol. 45, No. 2, pp. 193–197. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © A.A. Yaroshevskii, 2007, published in Geokhimiya, 2007, No. 2, pp. 224–228.

SHORT COMMUNICATIONS

"Pseudocyclicity" as a Result of Random Events with Reference to the Rhythmic Layering of Magmatic Complexes

A. A. Yaroshevskii
Division of Geology, Moscow State University, Vorob'evy gory, Moscow, 119899 Russia
Received April 20, 2006

DOI: 10.1134/S0016702907020085

The possible causes of and mechanisms forming rhythmic layering in magmatic complexes remain largely obscure [1, 2]. It is hardly reasonable to search for the reasons of rhythmic rock alternations among variations in external factors relative to the magmatic chamber, including additional magma injections, which should have always occurred at the right place at the right time in the course of systematic melt fractionation in magmatic chambers: rhythmic layering is too typical of differentiated complexes, and its tendencies and relations (such as the compositional variations of the rocks and minerals) are too strongly correlated with the laws of crystallization fractionation, to have always and everywhere external driving forces, which are independent of processes in the magmatic chamber itself. The problem is thus formulated as finding such characteristics of the magmatic system itself and such a character of processes in the chamber that should inevitably result in periodical oscillating character of the solidification process. It is also senseless to call upon self-organization or similar structure-forming processes (even with reference to the fundamentals of the thermodynamics of irreversible processes developed by I. Prigogine), because nobody has ever outlined any specific interactions between the structural elements of the systems that would have brought about such spatial structuring.

In this publication I would like to attract attention to certain features of the distributions of chemical elements in the rock succession of layered magmatic complexes that could result from the assumption of random variations in the quantitative proportions of solid phases in the volume of a crystallizing magmatic mass. In order to explain these features, we conducted the following simple mathematical simulation.

We assumed that the concentration of one of the components in 286 "samples" (which were numbered from 1 through 286) varies according to the normal law around an average value of 40% (Fig. 1), and the samples are evenly "mixed" in the volume of a model magmatic chamber. Using, then, a generator of random numbers (as follows from our experience, the best "generating device" is the classical method of successively taking out 286 slips of paper, with written numerals from 1 to 286, from a hat), we successively picked up the samples from the "chamber". The succession thus obtained formed the "vertical section" of the model intrusion and was utilized to examine the tendencies in the distribution of the component in the vertical section. The results are shown in Fig. 2. In this plot, points corresponding to the concentrations of the component in the successively extracted sample are connected with a line, whose overall configuration illustrates the general tendencies of the model distribution, which turned out to be closely similar to some features observed in the distributions of rock-forming minerals in a natural magmatic body. As an example of such a body, we employed the layered series of the Kivakka intrusions, which was thoroughly examined by Bychkova and Koptev-Dvornikov [3, 4] and for which very detailed quantitative data are available on the variations in the mineralogy of the rocks composing the series (Fig. 3). For comparison, we selected an interval of the vertical section (from 630 to 900 m, Fig. 4) for which plagioclase contents were determined in 286 samples. The comparison of Figs. 2 and 4 allowed us to identify some features of the natural rock succession that are unexpectedly well approximated by the modeled "section."

First, the model of the two-component system reproduces a principally important feature of the natural rock succession: the broad and contrasting variations in the contents of mineral phases in rocks adjacent in the vertical section.

Second, both the model and the naturally occurring rock succession show unsystematic (random) variations in the concentrations of mineral phases in both the rocks with the lowest plagioclase contents ("bronzitites"—"melanocratic norites") and those with its highest concentrations ("norites"—"leucocratic norites"), with none of these rocks showing a tendency toward unchanging compositions.

Third, both in nature and in our model, the heights of the maxima and the depths of the minima for the adjacent samples alternating in the vertical section randomly vary, also exhibiting no tendency toward any unchanging relations.

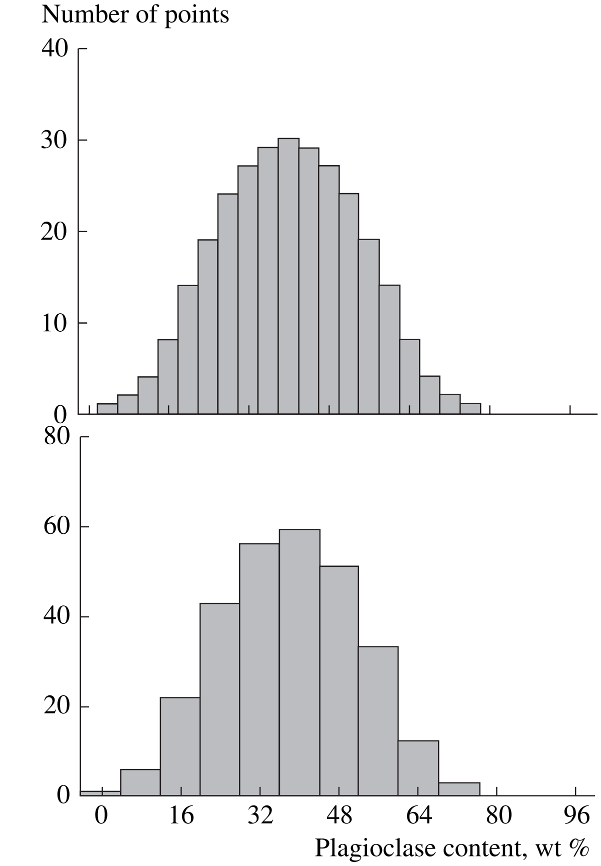

Fig. 1. Assumed model distribution of the solid phase (plagioclase) in the cumulus rocks. The upper and lower plots show the grouping of contents with steps of 4 and 8 wt %, respectively.

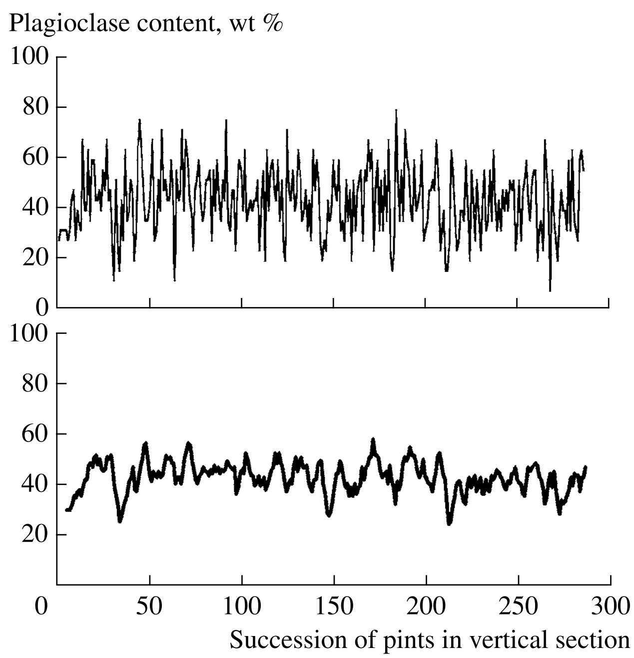

Fig. 2. Distribution of plagioclase contents in a succession of points. The upper and lower plots show the modeled distribution and the distribution quintuple smoothed by the sliding window method.

Hence, we had fairly good reasons to conclude that such an important parameter of the vertical section of a layered series as quantitative mineral compositions of the rocks alternating in the vertical section of a rhythmically layered series definitely reflects the "overprinting" of a certain factor (or more than one factor) on the systematic course of the formation of cumulus rocks. This factor (or factors) predetermined the random variations in the quantitative proportions of the solid phases received by the cumulus from the convecting volume of the magmatic mass.

In the second variant of our model, we took into account the fact that the plagioclase distribution in the rocks of the layered series has an unclearly pronounced bimodal character, with maxima at approximately 16 and 40% (Fig. 5), which implies an unclear tendency toward stable compositions, which correspond to bronzitites and norites. The tendencies in the modal plagioclase distribution are, in this case (Fig. 6), the same as in the first model (we utilized the same succession of random numbers): an increase in the occurrence frequency of samples with lower plagioclase contents only insignificantly increased the number of corresponding points in the model succession.

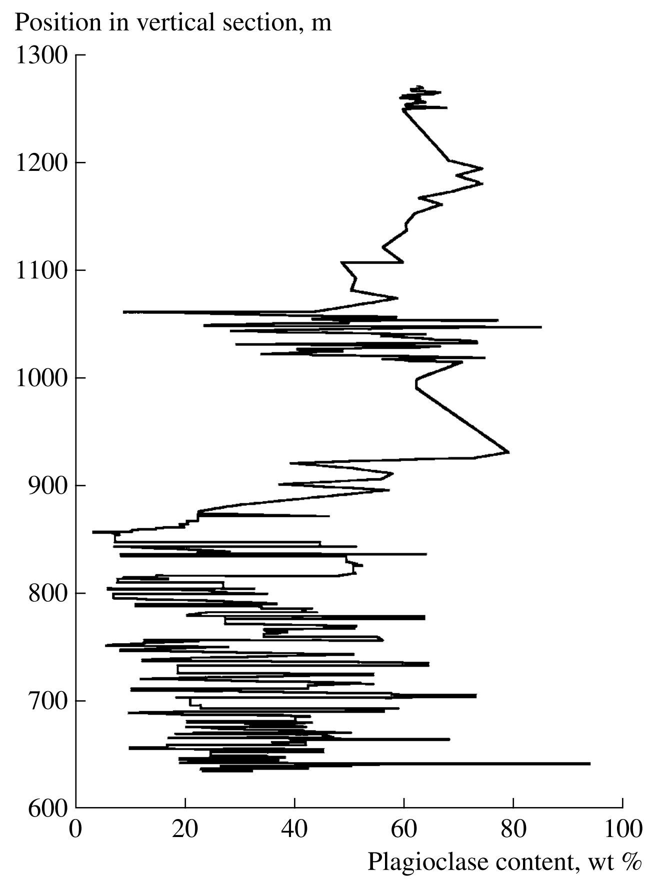

Fig. 3. Distribution of plagioclase contents in the vertical section of the layered series of the Kivakka intrusion (based on the data of Bychkova and Koptev-Dvornikov [4]).

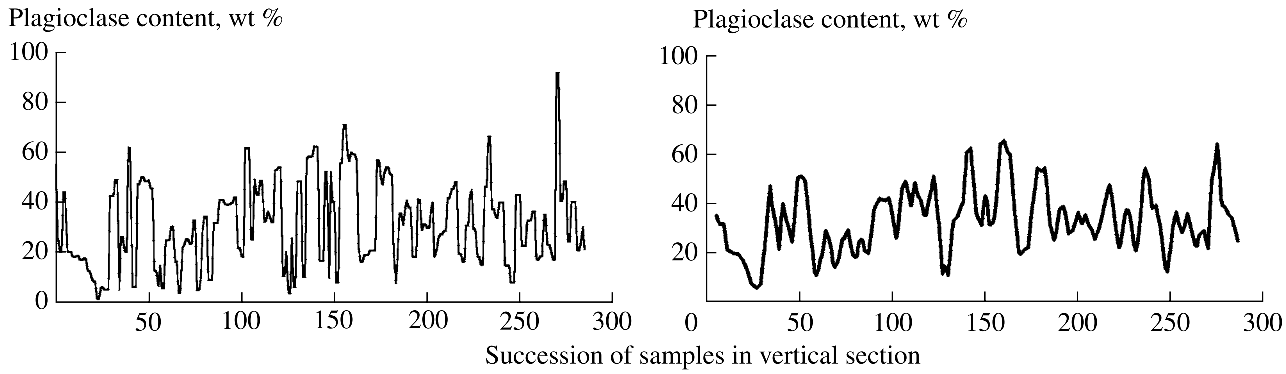

Fig. 4. Distribution of plagioclase contents in a succession of samples from the Kivakka intrusion in the range between 630 and 900 m in its vertical section. The left-hand and right-hand plots show the "raw" data and the distribution quintuple smoothed by the sliding window method, respectively.

However, the comparison of Figs. 2 (or 6) and 4 also highlights the features of the natural rock succession that could not be reproduced within the framework of the model of random events.

One of these features is the finite thickness of the alternating rocks in the natural rock succession; in terms of a succession of points, this means that the points with close concentrations of components are grouped (clustered). In other words, such parameter of the layered series as the thicknesses of alternating layers of compositionally contrasting rocks could not result from purely random variations in the proportions

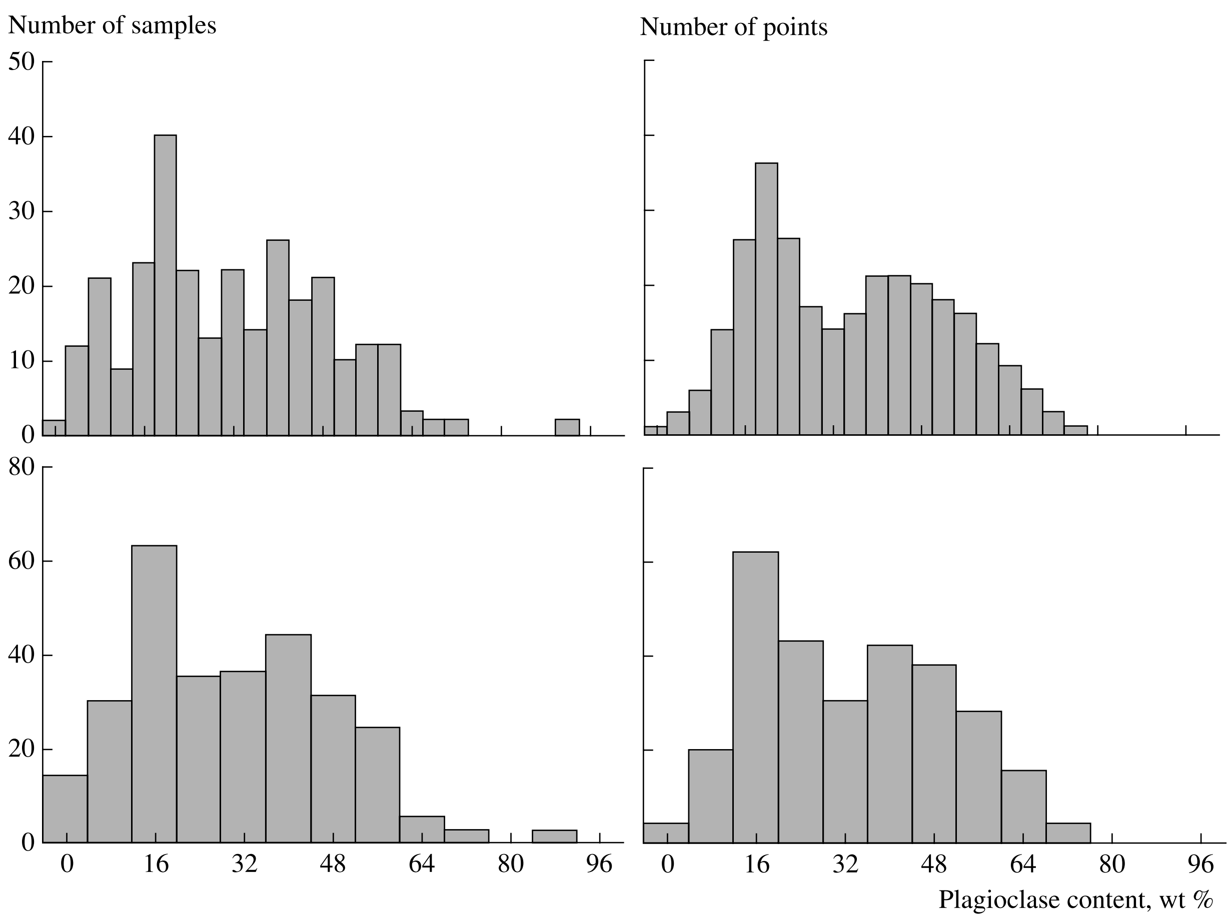

Fig. 5. Distribution of plagioclase contents in the rocks of the layered series of the Kivakka intrusion (left-hand plots) and in the second variant of the model (right-hand plots). The upper and lower plots show the grouping of contents with steps of 4 and 8 wt %, respectively.

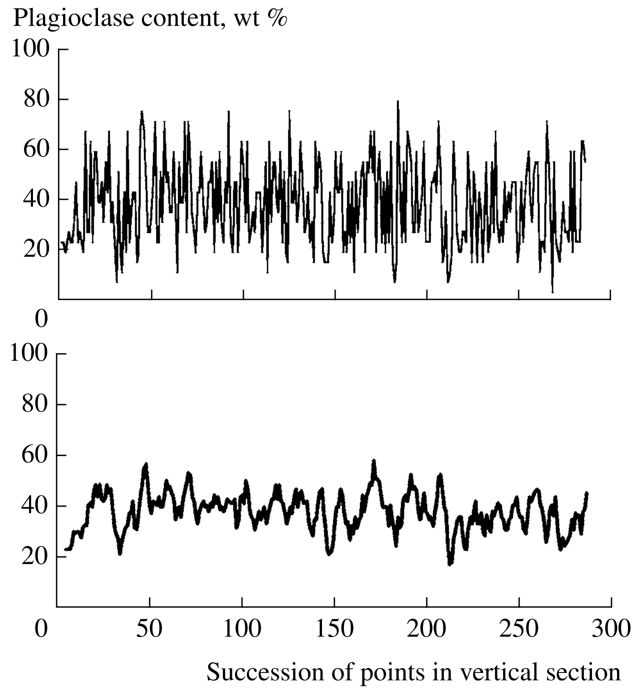

Fig. 6. Distribution of plagioclase contents in a succession of points. The upper and lower plots show the distribution obtained in the second variant of the model and the distribution quintuple smoothed by the sliding window method.

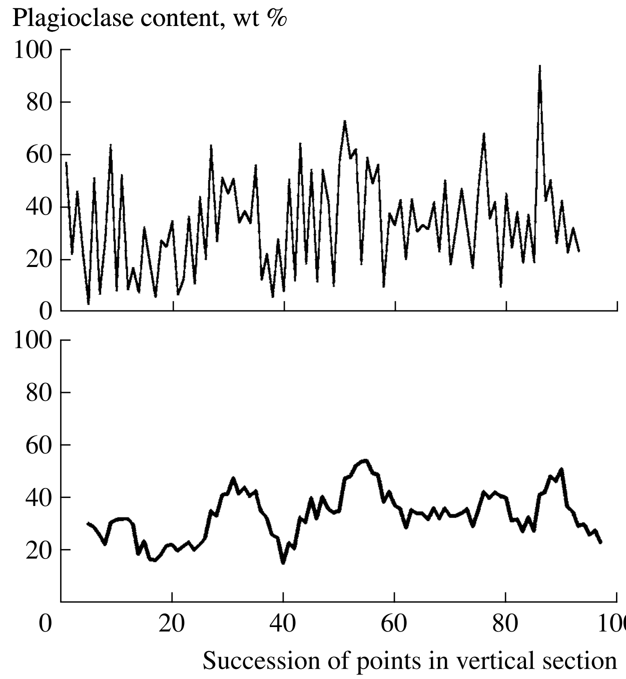

Fig. 7. Distribution of plagioclase contents in the succession of rock layers composing the layered series of the Kivakka intrusion (each point corresponds to one layer). The upper and lower plots show the observed distribution and the distribution quintuple smoothed by the sliding window method.

of solid phases in the flows forming the cumulus. In his elegant publication devoted to the analysis of tendencies in the ratios of the thicknesses of layers composing the rhythmically layered series of the Kivakka intrusion, Kotov [5] demonstrated that the observed succession of the thicknesses displays no indications of autocorrelation and does not comply with the implications of the purely stochastic model. The possible mechanism (or mechanisms) that controlled the variations of the layer thicknesses in the rhythmically layered series remain obscure.

Another feature of the distribution of the parameters of the rhythmically layered rock series is the readily observable periodicity in the distribution of rock compositions. This feature can be seen in the plots showing the distribution of plagioclase contents in Figs. 3 and 4 and is even better pronounced, and is rigorously validated, by statistically significant variations of the autocorrelation coefficients, if the vertical section is represented in the form of a succession of random numbers with one point corresponding to each layer (in contrast to "raw" data, in which a unit layer is commonly characterized by a few neighboring samples with close plagioclase contents) (Fig. 7). The autocorrelation coefficient, with a step of 18–20 points, is higher than 0.2, and this tendency is graphically clearly pronounced in the smoothed curve of plagioclase contents in the rock succession (Fig. 7).

Thus, we distinguished three groups of parameters characterizing rhythmic layering. First, these were the broad variations in the quantitative mineral composition of the rocks, which could well result from random variations in the proportions of solid phases in the magmatic chamber. The sense of our model in application to the naturally occurring process that can explain these relations is the assumption that the proportions of plagioclase and bronzite suspended in the convecting melt (this is an inevitable state of any solidifying intrusion, according to our models [2]) vary (because of the locally uneven sinking velocities of the crystals due to the dispersion of, for example, crystal sizes, the chaotic structure of the magmatic mass, and other "random" phenomena and processes) and bring about a normal distribution of the contents of solid phases suspended in the melt. This, in turn, predetermines random variations in the proportions of crystalline phases supplied for the cumulus in the bottom part of the chamber.

Second, it is clear that such parameters as the tendency to a bimodal distribution of mineral phases in the alternating rock layers in rhythmically layered series and, first of all, the pronounced cyclic character of this distribution, as well as the finite (and varying) thicknesses of the rock layers in these series, cannot be reproduced within the framework of the model of random events. The identification of a mechanism (or mechanisms) that could result in these structural tendencies of layered series is, in fact, the main problem in deciphering the genesis of rhythmic layering in intrusive magmatic complexes. Although the structure of the rock succession that results from purely random events closely resembles naturally occurring sequences (Figs. 4, 6), it is not adequate to them and, thus, can be referred to only as "pseudocyclicity."

ACKNOWLEDGMENTS

This study was financially supported by the Russian Foundation for Basic Research, project no. 06-05-64649.

REFERENCES

1. A. A. Yaroshevskii, "Origin of Cyclic Structures of Igneous Rocks,"Geokhimiya, No. 5, 562–574 (1970).
2. A. A. Yaroshevskii, "Boundary Conditions of the Possible Formation Mechanism of Cyclic Layering of Differentiated Mafic–Ultramafic Igneous Complexes," Izv. Sekts. Nauk Zemle RAEN, No. 14 (2006).
3. Ya. V. Bychkova, Extended Abstract of Candidate's Dissertation in Geology and Mineralogy (Moscow, 2003).
4. Ya. V. Bychkova and E. V. Koptev-Dvornikov, "Rhythmic Layering of the Kivakka Type: Geology, Petrography, Petrochemistry, and a Hypothesis for Its Formation," Petrologiya **12**, 281–302 (2004) [Petrology **12**, 244–264 (2004)].
5. S. R. Kotov, Extended Abstract of Candidate's Dissertation in Geology and Mineralogy (St. Petersburg, 1998).