ՀԱՅԱՍՏԱՆԻ ՀԱՆՐԱՊԵՏՈՒԹՅԱՆ ԳԻՏՈՒԹՅՈՒՆՆԵՐԻ
ԱԶԳԱՅԻՆ ԱԿԱԴԵՄԻԱ
НАЦИОНАЛЬНАЯ АКАДЕМИЯ НАУК РЕСПУБЛИКИ АРМЕНИЯ
NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF ARMENIA

Հայաստանի քիմիական հանդես
Химический журнал Армении **75, №1, 2022** Chemical Journal of Armenia

UDK 551.22 : 551.26+549.01
DOI:10.54503/0515-9628-2022.75.1-48

POSSIBLE PHYSICAL DESCRIPTION OF FORMATION OF RHYTHMIC LAYERING IN LAYERED MAGMATIC INTRUSIONS BASED ON ANALOGY TO CHEMICAL OSCILLATING PROCESSES

A.KH. ZILBERSHTEIN, D.S. DAVTYAN and A.O. TONOYAN

National Polytechnic University of Armenia
105 Teryan Str., Yerevan, Armenia
E-mail: atonoyan@mail.ru

Received 03.01.2022

For the first time the theoretical thermodynamical model of the process of formation of rhythmic layering observed in natural geological bodies – layered magmatic intrusions was proposed. The model is based on analogy to the well-known description of the process of frontal polymerization in a tubular reactor. The system of equations was presented, including the equation of thermal conductivity, balance and kinetic equations. The solutions of the system were obtained for various parameters of the process. The obtained oscillating solutions can be used for the description of the formation of rhythmic layering. The proposed system of the equations represents the possible physical model describing the process of formation of the rhythmic layering.

Pic. 1, ref. 4.

Introduction

The review article [1] presented the results of experimental and theoretical studies of various non-linear chemical and biological processes: frontal polymerization, tumor growth, nerve impulse propogation. For the first time the possibility of the oscillatory modes for the frontal polymerization process and for the nerve impulse propagation was shown. The wave nature of the propagation of tumors was first established experimentally and theoretically.

In paper [1] the original thermodynamical theory for description of the various chemical and biological oscillating processes was also proposed.

However this theory can be used for describing some natural rhythmic geological processes too.

In the present paper we propose the application of the theory to the physical description of formation of the rhythmic layering observed in natural geological bodies-layered magmatic intrusions.

Results and Discussion

Layered magmatic intrusions are well-known solid geological bodies, mostly precambrian. Such intrusions were formed due to crystallization of "liquid" magma, which was introduced into hosting rocks and filled the chamber in these rocks.

Different layers have the different chemical and mineral compositions.

Layered intrusions can be the deposits of various chemical elements. In part, the large layered intrusion of Bushveld (South Africa) is the largest Cu-Ni-PGE deposit.

There are some parts of the intrusion body where one can observe the so called "rhythmic layering" (see [2] for example). Rhythmic layering is defined as regularly recurring layers of different rocks (or different sequences of rocks), which have different chemical and mineral compositions. The thickness of the layers can be equal to tens of meters ("macrorythms") and/or some centimeters ("microrhythms"). If macrorhythms and microthythms coexist, the structure looks like a cluster structure.

It is important to note that"the exact nature of the rhythmic layering is still unsettled" (see [3]).

In this paper we propose the thermodynamical description of the process of formation of the rhythmic layering.

The rhythmic layering was studied in paper [4], using the layered intrusion Lukkulaisvaara (North Karelia), as an example.

According to data [4], the main difference between different neighboring layers is the difference between the ratio of the concentration of a plagioclase molecule to the concentration of a pyroxene molecule. That is the layers of mainly plagioclase neighbor on the layers of mainly pyroxene.

However the heat and temperature of crystallization of plagioclase differ from such parameters of pyroxene. So it is obvious that during the crystallization of rhythmic layering there was the periodical (normal to layers) spatial distribution of temperature in the chamber (see [4]). The period of this distribution has to be equal to thickness of two different neighboring layers.

We suppose that the process of formation of rhythmic layering can be described as the the process of filling accompanied by crystallization of hot liquid (magma) into the tubular reactor (chamber) with cold walls (hosting rocks).

In paper [1] such description was proposed for the chemical process of frontal polymerization.

The case was considered when frontal curing of epoxydian oligomers under the action of aromatic amines was carried out in the tubular reactor.

Frontal modes of exothermic curing reaction that are formed in the tubular reactor with adiabatic walls were described by equation of thermal conductivity:

$$c\rho(dT/dt) + u(dT/dx) = \lambda(d^2T/dx^2) + \lambda/2(d/dr(r(dT/dr)) + \\ +\lambda(d^2T/dy^2)+QV_{eq},\ V_{eq} = dS/dt \quad (1)$$

and the system of kinetic and balance equations:

$$dA_1/dt - u(dA_1/dx) = K_1A_1E - K_2A_1(EC) \quad (2)$$

$$dS/dt + u(dS/dx) = K_1A_1E - K_2A_2(EC) - K_3A_2(EC)$$

$$C + (EC) = E_0 - S;\ S = E + (EC)$$

$$(EC) = K_{eq}EC \quad (3)$$

$$2A_1 + A_2 + (E_0 - C) = 2A_0$$

with the following initial boundary conditions of equations (1), (2):

$$T = T_0,\ A_1 = A_0,\ E = E_0,\ A_2 = A_3 = C = 0, \text{ for } t = 0,\ x < L$$

$$T = T_0 \text{ for } x = L,\ 0 < r < r_1 \text{ for any } t$$

$$dT/dx(x = 0) = 0, \text{ at any } t \quad (4)$$

$$dT/dr(r = r_1) = \alpha(T - T_{en}) \quad (5)$$

$$u = 0 \text{ at } x > L/2,\ u = V \text{ at } x = L/2 \quad (6),$$

where: λ is the thermal conductivity coefficient; u is the flow rate; Q is the thermal effect of interaction between epoxydiane oligomers and m-PDA; T is the temperature; t is the time; x is the coordinate in the direction of the reactor axis; y is the angular coordinate; E, A_1, A_2 are concentrations of epoxy, primary and secondary amino groups; E_0, A_0 are their initial concentrations; C is the conversion product; (EC) is the E-C complex; L is the reactor length; T_z is the temperature exerted to the end of the reactor (x = L), which is equal to adiabatic heating of the reaction medium ($T_z > T_0$); r_1 is the reactor radius; α is the heat transfer coefficient from the reactor walls to the environment (T_{en}); V is the front velocity; K_1 is the constant of interaction between epoxy resin and the primary amino groups; K_2 and K_3 are the constants of interaction of the primary and secondary amines with

complexes (EC); K_{eq} is the equilibrium constant of formation of complexes (EC); T_0 is the flow tempereture.

The system of equations (1), (2) was solved numerically (see [1]). The function u(t) was obtained for various values of the α.

It was shown that for sufficiently large values of the α the function u(t) is oscillating one.

Moreover, it was observed that in the last case the form of the function T(t) is equivalent to the form of the function u(t), i.e the function T(t) is oscillating too (see [1]).

However from the definition of the u one can obtain the well-known expression dx = u dt, and consequently:

the oscillations of the function T(t) lead to the oscillations of the function T(x), i.e. to periodical spatial distribution of the temperature in the reactor.

Exactly this distribution describes the rhythmic layering in layered intrusions (see above).

Thus rhythmic layering that is formed (crystallized) in the tubular reactor with adiabatic walls can be described by the equation of thermal conductivity (Eq.(1)), and the system of kinetic and balance equations, which in this case is present in the form (see Eq.(2)):

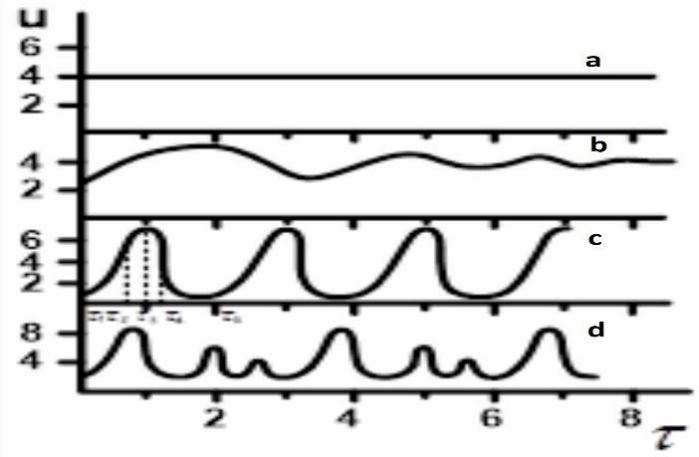
$$dA_1/dt - u\,(dA_1/dx) = dS/dt + u\,(dS/dx) = K_1A_1E - K_2A_1(EC) = K_1C_l^2 - K_2C_lC_{cr} \qquad (2')$$

$$A_1 = E = C_l,\ A_2 = 0,\ (CE) = C_{cr} \qquad (3').$$

The initial boundary conditions of equations (1) and (2′) see above (Eqs. (4), (5), (6)).

Where: u is the filling rate of magma into the reactor (chamber); Q is the heat of crystallization of magma; x is the coordinate in the direction normal to layers and parallel to the L; Cl and Ccr are concentrations of liquid (magma) and solid (crystals) phases; L is the chamber langth; α is the heat transfer coefficient of hosting rocks; V is the velocity of front of crystallization; Ten is the temperature of hosting rocks; T0 is the temperature of magma; K_1, K_2 are the constants; the other designations one can find above.

Thus the system of equations (1), (2′), (3′) can be used for physical (thermodynamical) description of the process of formation of rhythmic layering observed in layered intrusions.



Pic. 1. Time dependence of the front speed at different values of the α:
a - 2.8, b - 3.43, c - 4.2, d - 5.1

Conclusion

Thus the possible theoretical thermodynamical model (Eqs. (1), (2′), (3′)) was proposed for description of the process of formation of rhythmic layering observed in some natural geological bodies (layered magmatic intrusions, for example).

This description has been proposed for the first time.

It is very important to note that for large values of the α there are some regularly located extrema between main maxima (see Fig. 7d in [1]). This case can correspond to the above coexistence of macrorhythms and microrhythms.

ՇԵՐՏԱՎՈՐՎԱԾ ՄԱԳՄԱՏԻԿ ԻՆՏՐՈՒԶԻԱՆԵՐՈՒՄ ՌԻԹՄԻԿ ՇԵՐՏԱՎՈՐՄԱՆ ՁԵՎԱՎՈՐՄԱՆ ՀՆԱՐԱՎՈՐ ՖԻԶԻԿԱԿԱՆ ՆԿԱՐԱԳՐՈՒԹՅՈՒՆԸ ՔԻՄԻԱԿԱՆ ՏԱՏԱՆՈՂԱԿԱՆ ԳՈՐԾԸՆԹԱՑՆԵՐԻ ՆՄԱՆՈՒԹՅԱՆ ՀԻՄԱՆ ՎՐԱ

Ա.Խ. ՋԻԼԲԵՐՇՏԵՅՆ, Դ.Ս. ԴԱՎԹՅԱՆ, Ա. Հ. ՏՈՆՈՅԱՆ

Առաջին անգամ առաջարկվել է ռիթմիկ շերտավորման գործընթացի ձևավորման, տեսական թերմոդինամիկական մոդելը. գործընթացը դիտվում է բնական երկրաբանական մարմիններում շերտավորված մագմատիկ ինտրուզիաներում: Մոդելը հիմնված է ֆրոնտալ պոլիմերացման գործընթացի խողովակային ռեակտորի հայտնի նկարագրության զուգադրության վրա: Ներկայացված է հավասարումների համակարգ, որը ներառում է ջերմահաղորդականության, հավասարակշռության և կինետիկական հավասարումները: Համակարգի լուծումները ստացվել են գործընթացի տարբեր պարամետրերի համար: Ստացված տատանողական լուծումները կարող են օգտագործվել ռիթմիկ շերտավորման ձևավորման նկարագրության համար: Առաջարկվող հավասարումների համակարգը ներկայացնում է ռիթմիկ շերտավորման ձևավորման գործընթացը նկարագրող հնարավոր ֆիզիկական մոդելը:

ВОЗМОЖНОЕ ФИЗИЧЕСКОЕ ОПИСАНИЕ ФОРМИРОВАНИЯ РИТМИЧЕСКОЙ РАССЛОЕННОСТИ В РАССЛОЕННЫХ МАГМАТИЧЕСКИХ ИНТРУЗИЯХ НА ОСНОВЕ АНАЛОГИИ С ХИМИЧЕСКИМИ КОЛЕБАТЕЛЬНЫМИ ПРОЦЕССАМИ

А.Х. ЗИЛЬБЕРШТЕЙН, Д.С. ДАВТЯН, А.О.ТОНОЯН

Национальный Политехнический Университет Армении
Армения, Ереван, ул. Теряна 105
E-mail:atonoyan@mail.ru

Впервые предложена теоретическая термодинамическая модель процесса формирования ритмической расслоенности, наблюдаемой в природных геологических телах - расслоенных магматических интрузиях. Модель основана на аналогии с известным описанием процесса фронтальной полимеризации в трубчатом реакторе. Представлена система уравнений, включающая уравнение теплопроводности, уравнения баланса и кинетические уравнения. Решения системы получены для различных параметров процесса. Полученные колебательные решения могут быть использованы для описания формирования ритмической расслоенности. Предлагаемая система уравнений представляет собой возможную физическую модель, описывающую процесс формирования ритмической расслоенности.

REFERENCES

[1] Tonoyan A.O. Kotikyan S.Yu. Davtyan S.P. // Rev. J. Chem., 2016, 6, p. 218.
[2] Hess H.H. (1960). Stillwater igneous complex, Montana. Geol Soc. Amer. Memoir., 80, p. 230.
[3] Large layered intrusions. (2021). http://www.planetology.ru, 20.pdf, p.52.
[4] Zilbershtein A.Kh., Semenov V.S., Glebovitsky V.A., Dech V.N., Semenov S.V. // Bulletin of the University of St. Petersburg, 2010, 7, p. 3.