

## Karzhavin V.K. Features of heat release during crystallization of magmatic melt

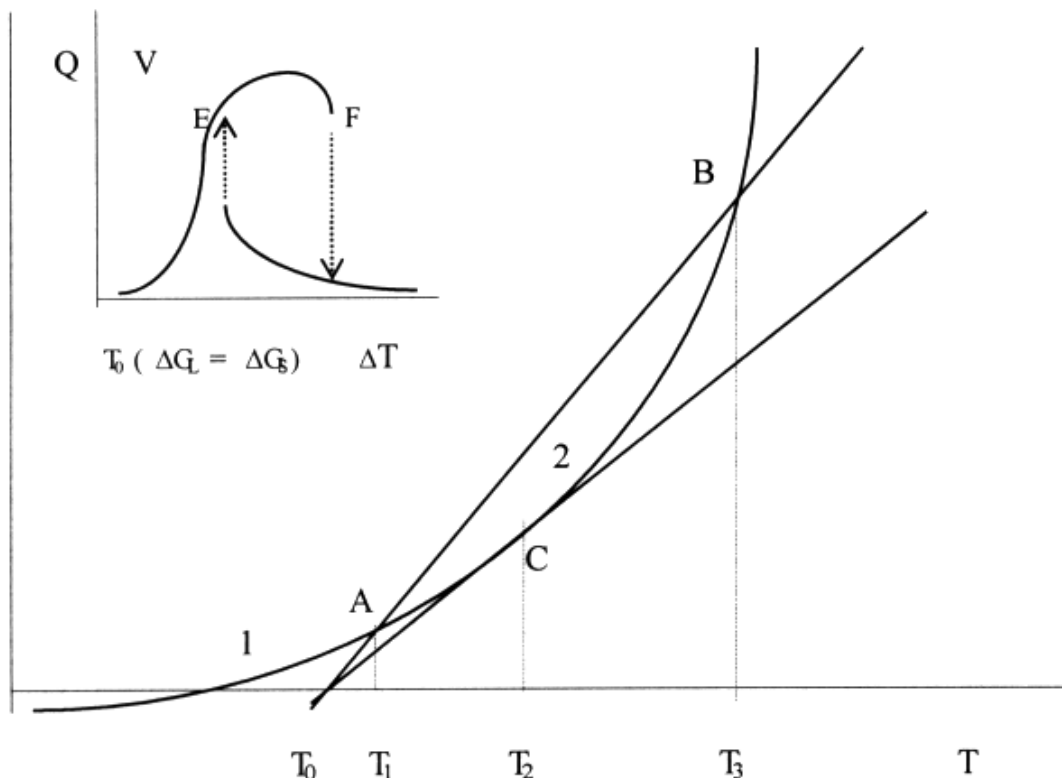
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Change of state of aggregation in the phase boundary is accompanied by intensive potential heat release of crystallization. The crystallization rate can increase abruptly (depending on the undercooling degree) with simultaneous temperature increase in the two-phase field and gradual temperature gradient changing. The value of the temperature gradient in a crystallizing system depends on the rate of heat release, which determines the character of the crystallization process. Depending on the conditions of heat release or heat outflow to the environment the crystallization front can advance forward, stay immovable, or even move backward [1].

Our calculations indicated that the value of the potential heat of crystallization for pyroxenes and olivines ranges from 25.6 to 29.6 % of the value of their total heat capacity within the interval from the melting temperature (molten state) to the standard conditions (25°C). This value is lower for plagioclases (from 15.8 to 21.4 %). Most of the melts are able to solidify forming various structures and minerals that differ in composition depending on the degree of deviation from the equilibrium state during crystallization [2]. The crystallization front position with the phase transition in space and time depends on temperature changes in system. A non-linear character of crystallization is determined by connection of the rate of the solid phase formation with the rate of heat release from the system to the environment. The crystallization heat released to the system and the heat removed to the environment have a certain relationship. Their relationship makes up the level of the positive feedback determined by the released heat accelerating the crystallization process. The negative feedback leads to decrease of the crystalliza-

tion rate through the environment temperature. Therefore, the heat effects in the crystallizing system are associated with variations in the rate of heat release to the environment through the potential crystallization heat. In turn, "...the wave-like heat release makes a harmony in temperature oscillations" [3], i.e. at certain conditions in the phase boundary shows up the cause and effect connection: heat – temperature of the environment:

Crystallization of magmatic melt and formation of intrusive bodies in the Earth's crust are necessary to consider as a process taking place in the open system where the liquid phase is transformed into the solid one, the heat release to the environment being not obvious. The released heat is known to change quantitatively with temperature increase by an exponential law during the isothermic process, and the heat exchange curve is of smaller bending and frequently described by a linear law [4]. The diagram presents the heat exchange curves for the melt crystallization and for the heat exchange with the environment. The A and B intersection points correspond to the stable and the metastable states of the system. The metastable point (point B) position depends on properties and volume of the melt, its initial temperature, the environment temperature, and the heat outflow rate. The heat outflow rate exceeds the rate of its inflow to the system at the beginning stage of crystallization with the initial environment temperature  $T_0$  (the melt hosting rock). The temperature increases approaching the stability point (point A) where the system possesses stationary conditions. In case of intensive heat inflow and not sufficient rate of the heat outflow the system can possess the metastable conditions (point B). exceeding of the heat outflow rate over the rate of the heat inflow will prevent further temperature increase in the system. The crystallization process ceases at this stage. The outflow heat curve becomes tangent to the curve of the heat inflow (point C) during further melt cooling up to the temperature of the environment. Such a position when the heat release and outflow become commensurable is practically unrealistic for natural systems.



In the insert graph the  $T_0$  point corresponds to equality of chemical potentials of the phases, which explains the abrupt change of the liquid phase crystallization rate. At undercooling in the system starts crystallization, the rate of which gradually increases (the upper branch, diffusion regime). The heat resistance of the environment will increase when the system approaches the temperature corresponding to F point. The crystallization rate gradually decreases, the liquid – solid transition process stops. Temperature increases in the two-phase field due to the released potential crystallization heat. The consequent heat outflow from the system and temperature decrease (lower branch, kinetic regime) initiates repeated necessary undercooling resulting in renewal of crystallization at a certain moment in time and space. Periodicity of the above-mentioned mechanisms causes oscillations in crystallization rate and temperature of the system. The inflowing heat plays a role of oscillation amplifier. The higher the rate of the heat outflow the more frequent will be the repetition of these oscillations, as the crystallization rate is controlled by the heat outflow rate.

The space-time factor affecting the conditions of the solid phase formation can be estimated [5]. Mathematic processing of the behavior of the magmatic melt crystallization curves allowed their description as the following indicative function:  $Y=A \cdot X^B \cdot e^{-CX}$ . The given function can be presented as  $Q=v \tau^B \cdot e^{-C\tau}$  in the application to the discussed problem. It is important to note that the integral of such type equations is a square of the intergrand curve, and in given case it corresponds to the quantity of the released heat during crystallization. Estimation of the heat quantity released at crystallization and cooling was carried out on the example of Imandrovskii lopolith (Cola peninsula) of about  $4500 \text{ km}^3$  in volume. The calculations indicated that the released heat as only potential crystallization heat was a huge value of the order of  $10^{21}$  joules. This is only a part of total heat capacity of the intruded magmatic melt to the earth's crust. A certain (multi-million) period is required to dissipate such a big quantity of heat released at melt crystallization and further cooling of the intrusive,

and this process depends on many thermal and thermodynamic properties.

We can outline that any heat changes through the host rock during the magmatic melt solidification in large volumes on a certain depth can result in the change of its cooling rate affecting the undercooling degree and forming a chemical heterogeneity at the crystallization front. The given phenomenon in natural conditions is expressed in rhythmically layered heterogeneity (hidden and real) of mineral composition in rocks within layered intrusions.

#### References:

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