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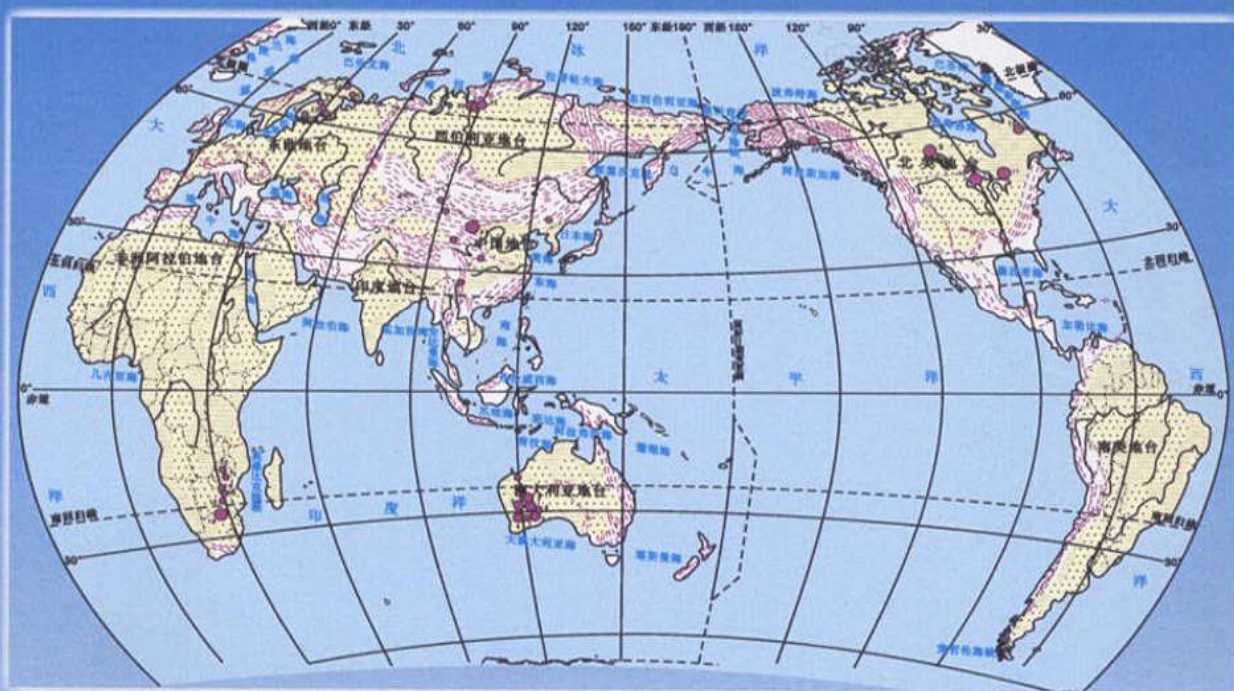
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镁铁质层状侵入体的母岩浆：应用优化 COMAGMTA 模型 计算岩浆结晶过程中硫化物-硅酸盐的共熔线

Parental magmas of mafic layered intrusions: Using an updated COMAGMAT model for calculations of sulfide-silicate cotectics during their crystallization

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1 Introduction

25 years ago we proposed a petrologic technique (called geochemical thermometry) designed to resolve inverse problems for mafic igneous rocks, including estimates of the initial temperature, trapped liquid and mineral compositions, as well as original modal proportions, as “recorded” by the whole-rock chemistry (Frenkel et al. 1988; Ariskin, 1999). This method is based on an assumption that any crystal-liquid mush that produces a completely crystalline rock should pass through a stage when relative movements of solids and interstitial liquid have ceased, so that the system may be considered as closed. In this case, it is theoretically feasible to calculate all thermodynamic parameters for the initial system, using phase equilibria models designed for the calculation of equilibrium melting/crystallization relations in igneous rocks. In this paper we present results of applications of this approach for modeling the composition of parental magmas of several mafic layered intrusions, followed by quantification of sulfide-silicate cotectics during crystallization of these parents.

2 Two main assumptions

underlie this approach. The most important is that the original liquid and crystals are assumed to be in chemical equilibrium. The second assumption is that samples have different bulk compositions due to variations of the modal proportions of cumulus minerals only, with the “trapped” liquid and temperature being the same. If both assumptions are true, one can state that during equilibrium melting of samples having the same “formation temperature”, the modeled compositions of residual melts will converge with increasing temperature and intersect at a point in the temperature-compositional space that represents the conditions under which the assemblage was formed (Frenkel et al. 1988; Ariskin, 1999). In practice, the method of geochemical thermometry is accomplished by means of the COMAGMAT magma crystallization model, because equilibrium crystallization is reversible with respect to equilibrium melting, so that the construction of “melting” lines can be replaced with the crystallization trajectories for starting compositions identical to those of the rocks under consideration (Ariskin, 1999; Ariskin and Barmina, 2004).

3 Estimates of parental melt compositions

Using the COMAGMAT model (Ariskin, 1999) a set of low pressure calculations have been conducted for the most primitive rocks representing the Marginal Series and Lower Zones from the differentiated sills (Eastern

Siberia and Kamchatka, Russia), more thick bodies (e.g. Partridge River intrusion, Minnesota, USA), and large layered complexes, such as Skaergaard, Kiglapait, and Dovyren (Northern Transbaikalia, Russia) (Ariskin and Barmina,2004; Ariskin et al. 2009). It allowed us to define the range of initial temperatures and parental melt compositions intrinsic to the original crystal mush from which the most primitive rocks have been crystallized (some of them are given in the first four columns in Table 1). In parallel, estimates of the original crystal-melt proportions for the intrusive parents were obtained. These modal proportions indicate that parental magmatic suspensions may contain from few percents (Siberian traps) to 15-25% (Talnakh and Kiglapait), and even 40-50% of crystals (Dovyren and Partridge River intrusion). This is in general agreement with results of dynamic calculations simulating emplacement of a non-isothermal magma which show the primary crystallinity of intrusive magmas is strongly depend upon the extent of cooling during the injection process (Sharapov et al.1997). Coupled with the results of geochemical thermometry these evidences argue that almost instantaneous injection of super-heated melts into magma chambers is unrealistic.

Table 1 Parental melts proposed for mafic layered intrusions(Ariskin and Barmina, 2004; Ariskin et al. 2009) and a komatiite-hosted Ni deposit (Barnes, 2007)

| Melt | PRI, 1167 °C | TALN, 1200 °C | KIGL, 1230 °C | DOV, 1252 °C | KOM, 1612 °C |
|--------------------------------|--------------|---------------|---------------|--------------|--------------|
| SiO ₂ | 47.28 | 48.75 | 47.17 | 52.75 | 46.90 |
| TiO ₂ | 2.69 | 1.30 | 1.08 | 0.61 | 0.27 |
| Al ₂ O ₃ | 15.80 | 15.42 | 17.70 | 15.33 | 6.50 |
| FeO | 16.24 | 12.00 | 13.51 | 8.91 | 9.89 |
| MnO | 0.20 | 0.22 | 0.19 | — | 0.20 |
| MgO | 5.67 | 7.94 | 8.03 | 9.54 | 30.00 |
| CaO | 8.02 | 11.43 | 8.73 | 10.15 | 5.00 |
| Na ₂ O | 2.86 | 2.16 | 3.19 | 1.58 | 0.43 |
| K ₂ O | 0.97 | 0.65 | 0.28 | 0.91 | — |
| P ₂ O ₅ | 0.28 | 0.14 | 0.12 | 0.07 | — |

Fertile layered intrusions: PRI . Partridge River Intrusion (Minnesota, USA, h=500 m); TALN . Talnakh (NW Siberian Platform, Russia, h~150 m); DOV . Ioko-Dovyren (Northern TransBaikalia, Russia, h=3.2 km); KOM . assumed parent for komatiite-hosted nickel sulfide deposits. Barred complexes: KIGL, Kiglapait (Labrador, Canada, h=9 km). Data for PRI, TALN, and KIGL are from (Ariskin and Barmina,2004). Information on the Dovyren parental magma is from(Ariskin et al. 2009). The KOM composition is from (Barnes,2007).

4 Modeling sulfide-silicate ratios

A unique ability of a new version of COMAGMAT to model precipitation of various sulfide-silicate assemblages (Bychkov et al. 2009) allows one to estimate bulk silicate-sulfide ratio in crystallized materials, both during equilibrium and fractional crystallization. To approach the goal we performed a representative set of calculations simulating equilibrium crystallization of five types of proposed parental magmas, ranging from komatiite to ferro-troctolite and tholeiitic compositions (Table 1). The main aim of this modeling was to quantify a combined effect of the temperature decrease and FeO-enrichment in the melt on the sulfide proportion during equilibrium crystallization of same cotectics, such as Ol+Pl, Ol+Pl+Aug, or Pig+Pl+Aug. All of the calculations were carried out at 1 atm with crystal increment of 0.5% and QFM conditions. Sulfur contents in the initial melts were given to provide sulfide saturation from the beginning of the crystallization process, with 0.19 wt% S in

TALN, 0.22 wt% in PRI, 0.18 wt% in KIGL, 0.15 wt% in DOV, and 0.40 wt% in the proposed KOM magmas. The most important results are summarized in Table. 2.

Table 2 Silicate-sulfide ratios and sulfide proportions for different mineral assemblages, as a function of temperature and FeO variations in the melt

| Mineral assemblage | Parental magma | Silicate/ Sulfide ratio | T, °C | FeO*, wt% | Average sulfide proportion |
|----------------------|----------------|-------------------------|-----------|-------------|----------------------------|
| Ol+Sulf | DOV | 90-60 | 1240-1195 | 9.05-8.75 | ~1.5 wt.% |
| | KOM | 40-50 | 1600-1225 | 10.00-7.75 | |
| | KIGL | 60-50 | 1235-1215 | 13.50-13.55 | |
| Ol+Pl+Sulf | DOV | 275-350 | 1195-1175 | 9.35-8.80 | ~0.4 wt.% |
| | KIGL | 350-175 | 1210-1100 | 13.50-18.50 | |
| | PRI | 325-185 | 1170-1070 | 16.50-19.00 | |
| | TALN | 375-300 | 1200-1150 | 12.00-13.75 | |
| Ol+Pl+Cpx+Sulf | KIGL | 130-125 | 1100-1090 | 18.75-18.50 | ~0.8 wt.% |
| | PRI | 110-140 | 1060-1000 | 19.00-16.50 | |
| | TALN | 200-125 | 1150-1075 | 13.75-16.25 | |
| Ol+Opx+Sulf | KOM | 225-185 | 1225-1195 | 7.75-7.45 | ~0.5 wt.% |
| Ol+Pl+Cpx+Opx+Sulf | DOV | 190-300 | 1175-1130 | 9.50-12.50 | ~0.4 wt.% |
| | KOM | 230-250 | 1195-1185 | 7.65-7.45 | |
| Pl+Cpx+Pig+Opx +Sulf | DOV | 160-145 | 1128-1123 | 12.50-12.00 | ~0.7 wt.% |
| Pl+Cpx+Pig+Sulf | DOV | 160-150 | 1120-1100 | 12.00-11.00 | ~0.7 wt.% |

In total, three of the sulfide-saturated melts (KIGL, DOV, KOM) are characterized by low silicate-sulfide ratios of 50-90 for the Ol-Sulf cotectics, corresponding to 1-2 wt% of sulfides in the crystallizing material (Table 2). Ol+Pl-Sulf cotectics demonstrate much more variable values in the range of 175-377, corresponding to a lower sulfide proportion of 0.25-0.60 wt%. Crystallization of a gabbroic and gabbro-noritic assemblages (Pl+Aug±Pig±Opx) provides intermediate values of silicate-sulfide ratios of about 150-160 (Table 2).

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References

- Frenkel et al. (1988) *Geochem. Intern.* 25 (6): 35-50.
 Ariskin, A. A. (1999) *J. Volcanol. Geotherm. Res.* 90: 115-162.
 Ariskin, A. A. and Barmina, G. S. (2004) *Geochem. Intern.* 42 (Suppl. 1): S1-157.
 Ariskin et al. (2009) *Geochem. Intern.* (in press)
 Barnes, S.J. (2007) *Economic Geology* 102(2): 299-304.
 Sharapov, A. N. et al. (1997) *Petrology* 5 (1): 8-19.
 Bychkov et al. (2009, this volume)

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