Experiment in a solution of the geological problems

Ariskin A.A. Geochemical thermometry of the Skaergaard rocks

V.I. Vernadsky Institute of Geochemistry and Analytical Chemistry (GEOKHI RAN)

key words: [magma differentiation, computer modeling, residual melt]

In late 80s the mass-balance calculations results (Hunter, Sparks, 1987) and the computer modeling data (Ariskin et al., 1987) were presented and made doubtful the traditional theories of the Skaergaard magma fractionation (Wager, 1960). These calculations based on experimental data on basalt phase equilibrium showed that according to composition of the marginal facies quenched rocks a normal evolution of the toleite series type characterized by SiO_2 concentration in melt with formation of ferroandesites (icelandites) should be expected for the Skaergaard magma. As a result, the canonical Wager's trend in the area of the extreme iron enrichment was stated to be incorrect due to underestimation of middle and acid differentiates in the total intrusion volume. This initiates a discussion (Contrib. Mineral. Petrol., 1990, v. 104) that has not so far solved the contradictions between the specialists in the field of phase equilibria and petrologists basing on geological observations.

As a rule, the Fenner tendency supporters appeal to the Osborn experiments showing that Mt formation during crystallization in the regime of oxygen closed system can delay but does not stop FeO accumulation, whereas the iron oxide contents sharply decrease in open systems (fO_2=constant, Osborn, 1959). However, these runs conducted in simple synthetic systems can point to qualitative features, but the attempts of the Scaergaard fractionation modeling in closed systems do not result in extreme iron enrichment and silica depletion (Ariskin et al., 1987; Toplis, Carroll, 1996). It is possible to reach certainty in these questions if the way to estimate composition of intercumulative material of real rocks (assuming its identity with the major magma chamber differentiates) will be found. The geochemical thermometry method resulting in temperature values and the intercumulus melt composition for each certain sample (Frenkel et al., 1987; 1988) was proposed for solving the tasks of that type.

The proposed method is realized by constructing and analyzing the trajectories of the equilibrium crystallization of cumulative rocks at given pressure and oxygen fugacity (Ariskin, Barmina, 2000). We made calculations for more than 70 samples from the Marginal group and Layered series of the Skaergard massive by KOMAGMAT-3.65 software. As a result it was found that the initial material was a typical ferrobasalt undersaturated in SiO_2 but not a high aluminous toleite (Wager and Brown, 1967). The intercumulative melt compositions calculated for the five lower horizons of the Layered series (Table) exhibited high degree of iron (up to 18 wt.%) and titanium accumulation at SiO_2 variations of about 49 wt.%. Such trends are well known on the example of Fe-Ti basalts from the Galapagosskii islands. However, they are remarkably different from the Wager trend that includes monotonous silica depletion (up to 47 wt.%) even after magnetite and ilmenite formation.

Zones	Lower (LZa – LZb – LZc)			Middle (MZ)	Upper (UZa)
T,°C	1145	1125	1100	1090	1085
$\log f_{O2}$	-7.5	-7.4	-8.9	-9.8	-10.3
	Compositions of the inercumulative liquids, wt.%				
SiO_2	49.26	50.06	48.04	49.05	50.31
TiO_2	2.50	2.83	5.50	5.25	4.68
Al_2O_3	12.74	11.97	10.26	10.35	11.05
FeO	14.84	15.73	17.05	17.50	17.31
MnO	0.20	0.21	0.22	0.23	0.24
MgO	6.29 3	5.56	4.82	4.00	3.35
CaO	11.02	10.27	11.00	10.20	9.01
Na_2O	2.59	2.73	2.57	2.80	3.40
K_2O	0.39	0.42	0.38	0.39	0.49
P_2O_5	0.17	0.22	0.15	0.21	0.17
	Mineral composition, mol. %				
Ol	*Fo* (74.9)	*Fo* (72.1)	*Fo* (64.0)	сл.	*Fo* (52.5)
Pl	*An* (66.3)	*An* (61.9)	*An* (57.4)	*An* (54.2)	*An* (48.0)
Aug		*En* (47.0) *Fs* (13.6) *Wo* (39.4)	*En* (42.2) *Fs* (16.8) *Wo* (41.0)	*En* (39.5) *Fs* (20.2) *Wo* (40.5)	*En* (38.0) *Fs* (22.6) *Wo* (39.4)
Pig			Traces	*En* (54.3) *Fs* (34.1) *Wo* (11.6)	*En* (51.4) *Fs* (37.7) *Wo* (10.9)
Ilm			*Il* (91.4)	*Il* (93.8)	*Il* (93.7)
Mt			*Ulv* (54.0)	*Ulv* (72.3)	*Ulv* (81.4)

The below presented figure demonstrates principal character of that difference. In this figure the Wager trend (*stars*) and thermometry data (*circles*) are projected into OLIV-CPX-SiO_2 diagram plotted by Gurov for plagioclase saturated toleite basalts. In fact this is the projection from the PLAG apex of the basalt tetrahedron, thus, the olivine field corresponds to Ol-Pl cotectic and the OLIV-CPX curve exhibits melt evolution for the Ol-Cpx-Pl association. The noncorrespondence of classical trend to the basalt crystallization lows is noticed. Based on petrographical observations the series of the Scaergaard liquids form in conditions of Cpx saturation, however the Wager composition data plot too far from the experimentally established Ol-Cpx-Ol curve. Obviously, this sequence is the artifact of the mass balance calculations that have not considered the phase equilibrium data including the overestimated magnetite cumulate proportion.

The compositions of liquids by thermometry data are divided into two groups. The three most primitive compositions plot to the cotectic control curve, whereas the liquids in equilibrium with Mt-Ilm paragenesis give a subparallel curve in the field of CPX-normative compositions. This gap can be due to imperfection of the used projection method or due to calculation uncertainties at temperatures below 1100^{o}C. On the other hand this can be considered as a geochemical signal of infiltration processes at the middle and late stages of the intrusive solidification.

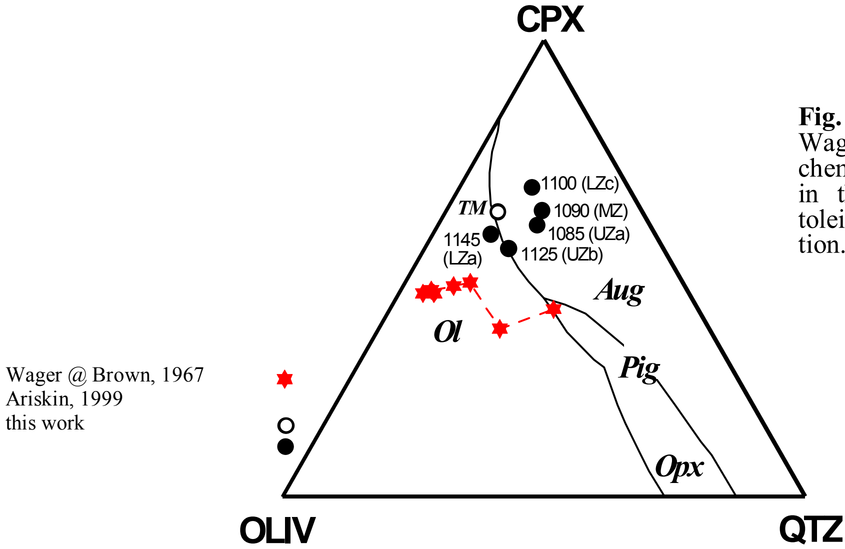

Fig. Comparison of the Wager trend and the geochemical thermometry data in the phase diagram of toleite magma crystallization.