Kutolin V.A., Shirokikh V.A. Kinetics of olivine and pyroxene dissolution in basalts: experimental basis for the upper mantle websterite model.

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Kinetics of olivine and pyroxene dissolution in basalt melt was studied at atmospheric pressure [1] and also at pressures from 5 to 30 kbar [2,3]. These experiments showed that olivine is dissolved in basalt melts 1.5-72 slower than orthopyroxene and 1.3-53 slower than clinopyroxene at pressure up to 20 kbar and faster than both pyroxenes at pressure of 30 kbar (Table 1). Based on the experimental data Kutolin and Agafonov [1] came to a conclusion that high contents of peridotites among the mantle nodules in basalts are due to higher stability of dunites and lherzolites compared to vebsterites and pyroxenites during the xenolith transportation to the surface by basalt magma, but not due to the abundance of these rocks in the mantle. Taking into account this fact the upper mantle composition calculated by corrected relative content of the various mantle nodules will correspond to olivine websterite (Table 2) but not to pyrolite [4]. This conclusion is supported by up-to-date geophysical data according to which the olivine content in mantle must be 30-40 % but not 50-60 % as in pyrolite model [5,6,7].

Table 1. Relative stability of olivine and pyroxenes during the dissolution in basalts.

P	1 bar				5 kbar		12 kbar		12.5 kbar	14 kbar	20 kbar	30 kbar	
$T^{o}C$	1150	1200	1250	1300	1250	1300	1300	1350	1350	1325	1400	1450	1500
Ol/Opx	10.9	5.4	3.7	1.5	72.2	2.6	0.9	1.9	1.7	4.0	5.7	0.8	0.4
Ol/Cpx	20.9	12.3	7.4	4.7	53.1	5.7	0.3	1.3	3.1	5.6	7.7	0.2	0.8
Source		[1]			[3]				[2]			[3]	

Table 2. Analyses of the websterite mantle xenoliths and estimate of the upper mantle composition.

NN sa.	KA	NK-66	5736-2	4/92	SP 1068	4/56	66SAL-1	BG-03
SiO_2	47.6	48.02	46.92	44.21	44.23	52.98	44.82	47.12
TiO_2	0.25	0.22	0.52	0.33	0.08	0.14	0.52	0.26
Al_2O_3	5.35	4.88	5.7	4.93	3.04	3.55	8.21	9.13
Fe_2O_3	2.20	9.9	4.82	2.03	2.56	3.42	2.07	6.67
FeO	5.80		5.39	8.87	5.86	5.39	7.91	
MnO	0.15	0.14	0.15	0.18	0.09	0.17	0.19	0.19
MgO	31.70	32.35	30.90	31.31	34.51	29.70	26.53	28.39
CaO	6.4	2.97	3.4	6.62	4.73	2.22	8.12	7.06
Na_2O	0.40	0.66	0.71	0.44	0.27	0.05	0.89	0.35
K_2O	0.15	0.07	0.91	0.02	0.07	0.06	0.03	0.04

KA – estimate of the upper mantle by Kutolin and Agafonov [1]. NK-66 – spinel-olivine websterite, Salt Lake, Hawaii. 5736-2 – websterite, Shiveluch volcano, Kamchatka. 4/92 – websterite, Itinome-gata, Japan. SP 1068 – spinel websterite, China. 4/56 – websterite, Kenia. 66SAL-1 – garnet websterite, Hawaii. BG – websterite, Romania.

As seen from Table 1 the data of [1,2,3] are consistent. Despite this fact, the authors of [2,3] rejected the idea of re-estimating the upper mantle composition [1] and advanced the two objections. The first one is that the influence of the basaltic melt is limited by the deep xenoliths' envelope preventing penetration to the central parts [2]. This objection is easy to decline since the xenoliths' dissolution and disintegration in melts occurs through destruction of the thin concentric incrustations at the xenolith's surface and their further desquamation, whereas the xenolith's central part remains almost unmodified [8,9,10].

The second objection belongs to Brearly and Skarfe [3] who calculated the rates of peridotite and pyroxenite dissolution in basalt melt. These calculations showed that the predominant disintegration of the pyroxenite xenoliths would occur at pressure of 10 kbar, unlike the peridotite nodules due to high dissolution rate of pyroxenes compared to olivine. Changing relative content of xenoliths of various compositions is not confirmed by calculations for magmas being under pressure of 20 and

30 kbar. This was the reason to reject the idea of re-estimating the upper mantle composition [1]. However, the basalt magma uplift rate was taken extremely high (5 and 10 km/h) in these calculations, whereas 0.4 km/h estimate is more reliable [11]. If we take this value the predominant disintegration of pyroxenites compared to peridotites occurs at pressure of 20 kbar as well. Moreover, the convection of magmatic melt is not considered though it strongly accelerates xenolith's dissolution [12], which is also acknowledged by the authors [3].

Thus, papers [2,3] do not give reasons to reject the conclusion [1] on predominant disintegration of pyroxenites compared to peridotites during the xenoliths' transportation by basalt magma, though it should be acknowledged that this process occurs only at pressures below 20 kbars. It is known that both petrographic observations and laboratory experiments on heating peridotite xenoliths [14] give evidence on more rapid dissolution of pyroxenes compared to olivine. Arzi [15] showed that stability of partially molten rock dramatically decreases when the melt portion exceeds 26 %. Thus, the websterite and lherzolite xenoliths containing more than 26 % of pyroxenes are less likely to survive than dunites and peridotites during their transportation to the surface. The upper mantle probing by basalts occurs with decreasing fraction of fertile xenoliths and increasing fraction of restites. Most of those peridotites nodules, the analyses of which were used for estimating the upper mantle composition [16] and exhibited a good convergence with the pyrolite model [4], are those restites.

As follows from [5,6] the analyses of the deep xenoliths with olivine content of about 30-40 % give a real estimate of the upper mantle composition. The analyses of such xenoliths are presented in Table 2. They all are represented by websterites by classification [17], thus, the websterite model [1] is preferred to the pyrolite one for the upper mantle [4]. The latter model confirms the geophysical data [5,6,7] and, besides, considers those changes occurred during the upper mantle probing by the basalt magma. Basalts and komatiites can be melted from the websterite upper mantle [18]. By composition olivine websterites are similar to a silicate part of chondrites [1], that's why the websterite model is in accordance with cosmogonic data. Moreover, analogy between the Earth and the Moon's upper mantles appears as the pyroxenite composition is predicted for the Moon's mantle [19].

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