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DEGASSING OF THE OCEANIC FLOOR BASALTS AS A REFLECTION OF THE REGIME OF VOLATILE COMPONENTS IN THE UPPER MANTLE

(Figs. 6, Tab. 1)

Abstract: Experimental and theoretical data on the saturation conditions of H_2O and CO_2 in silicate melts under the pressure up to 20 kbar is presented. The initial concentrations of H_2O and $CO_2/(CO_2+H_2O)$ ratios in magmas from various tectonic-structural zones of the ocean were estimated based on these data as well as data on contents of volatile components in the volcanic glasses of oceanic floor rocks. Conception on relative depletion in volatiles (first of all in H_2O) of the upper mantle rocks beneath the oceans was confirmed. It was shown that the lower H_2O concentrations and the higher $CO_2/(CO_2+H_2O)$ ratios in the melt are typical of the basalts of the mid-oceanic ridges comparing to magmas of the island areas. A conclusion about possible heterogeneity in relation to distribution of volatile components with depth in the upper mantle beneath the oceans was made.

Резюме: Приводятся экспериментальные и теоретические данные по условиям насыщения водой и двуокисью углерода силикатных расплавов в области давления до 20 кбар. На основании этих данных, а также данных по содержанию летучих компонентов в стеклах пород океанического дна оценены первоначальные содержания H_2O и CO_2, соотношения $CO_2/(CO_2+H_2O)$ в магмах из различных тектоно-структурных зон океана. Подтверждено представление об относительной бедности летучими компонентами, в первую очередь H_2O, пород верхней мантии под океанами. Показано, что для базальтов срединно-океанических хребтов характерны более низкие концентрации H_2O и более высокие соотношения $CO_2/(CO_2+H_2O)$ в расплаве по сравнению с магмами островов и островных дуг. Сделан вывод о возможной гетерогенности верхней мантии под океанами в отношении распределения летучих компонентов по глубине.

Quantity and composition of the volatile components in basaltic magmas are the most important source of information concerning fluid and redox regimes in the upper mantle rocks, their peculiarities in the different tectonic-structural zones of the Earth. In this connection the basaltic magmatism oceanic floor represents a special interest. Volcanic glasses that are products of basaltic magmatism appear to be a unique phenomenon of the rapid magmas quenching under the water pressure in the most favourable conditions of the volatile components conservence of the depths origin. The data on water contents in the rock glasses from the different tectonic zones of the World ocean, that were obtained in the works of Delaney et al. (1978), Muenow et al. (1979; 1980), Garcia et al. (1979) are presented on Fig. 1. Nevertheless the contents of H_2O and CO_2 in volcanic glasses or melt inclusions of magmatic rock minerals give us the information about the concentration only in the magmatic melt quenching. But the alteration in the volatile components composition during the magma rise to the Earth surface are not clear.

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The depth's degassing can obviously lead to the H_2O, as well as CO_2, losses, but the decrease in concentration of low solubility gases, such as CO_2, CO, Ar, N etc., that can transfer from melt to the equilibrium fluid phase will be significant.

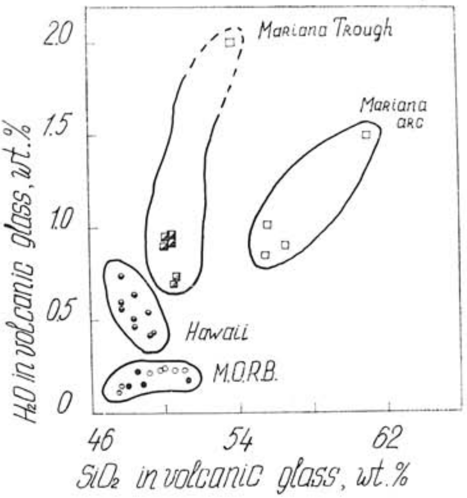

Fig. 1. The H_2O content in the volcanic rock glasses (1—4).

Thus we have a necessity in the ways of extrapolation of data on water and carbon dioxide contents in volcanic glasses and melt inclusions to high pressure range, such methods that could permit us to estimate the initial concentrations of H_2O and CO_2 in the regions of magma formation. The model of H_2O and CO_2 saturation of magmatic melts in the pressure range up to 20—30 kbar substantially contributes to the solution of this problem. The model was developed on the basis of experimental data on H_2O and CO_2 solubility in silicate melts at high pressures. These experimental data were obtained by the authors of this article (Kadik et al., 1972) as well as Eggler — Kadik (1979) and Mysen (1976).

Using this model one can regard the following questions: 1. The principle relationships between H_2O and CO_2 variations in basic magmatic melts and equilibrium fluid phase at the decrease of pressure as an important factor of magma degassing. 2. The conformity of H_2O and CO_2 content in volcanic glasses with some trends of their variations in melt under the decrease in pressure as a possible indication of H_2O and CO_2 content in the regions of magma formation. 3. Difference in the H_2O and CO_2 content in different tectonic zones of magma formation regions (mid-oceanic ridges, Island arcs, oceanic isles, continental margins) as reflection of the upper mantle heterogeneity related to the volatile components regime.

Now let us consider the main regularities of basaltic magma degassing concerning H_2O and CO_2. They are as follow:

1. The negligible variations in H_2O concentration in a wide pressure range is a distinctive feature of the degassing of melts containing H_2O and CO_2

(Fig. 2). The water content remains practically constant to rather low pressure (P ~ 1 kbar) values. Only in the pressure range less than 1 kbar, this process leads to a rapid decrease in the water concentration in the melt. This fact means that it is difficult to find out the initial H_2O concentration in magmas with the help of the quenching products, formed near the Earth's surface. The content of water in these products can differ from the initial in deep, magma fractions. Thus the difficulties in extrapolation of the data on volatile contents in volcanic glasses is confirmed so far as the great depths are concerned.

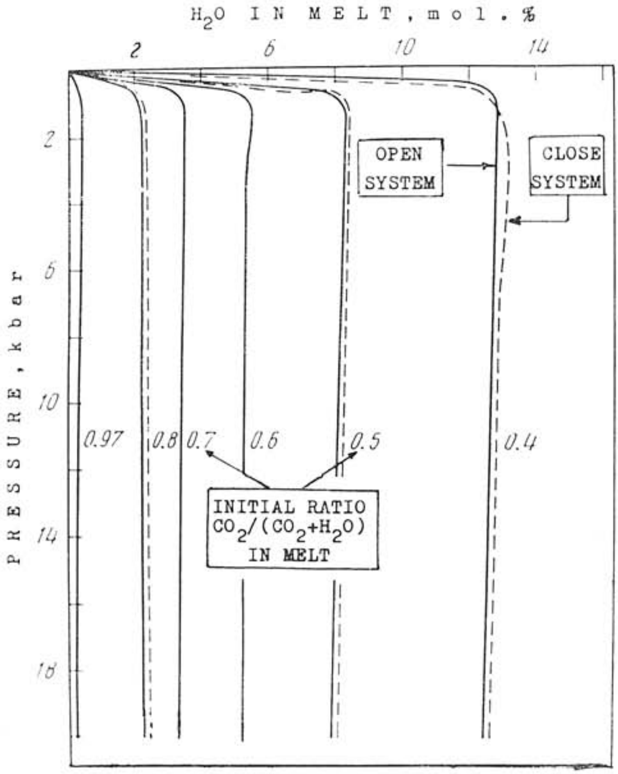

Fig. 2. Variation of concentration of H_2O in melt during the degassing.

2. Unlike water, melt degassing in the pressure range from 20 kbar up to the lowest level leads to-uniform decrease in CO_2 concentration, the initial ratio $CO_2/(CO_2+H_2O)$ in system negligibly affecting the CO_2 concentration under the given pressure (Fig. 3).

3. The abrupt prevalence of CO_2 in the fluid phase (Fig. 4) is a remarkable feature of fluid phase composition of basaltic magmas in a wide pressure range. The CO_2 concentration is equal to 95—98 mol. %. The degassing of the basic magmas can lead to formation of fluids with high water concentration only in the pressure range lower than 500 bar.

Therefore CO_2 is the main component of basalt degassing in depth. This fact well corresponds to the data on the concentration of fluid inclusions in magmatic rock minerals. The high concentration of water that is observed in volcanic emanations directly on the Earth's surface (90—50 mol. %) reflects the features of the vapour phase composition in basalts at low pressures. One can suppose that the lithosphere and the oceanic crust in the areas of the basaltic magma rise are under the principle influence of magmatic fluids saturated by CO_2.

Let us consider the estimations of H_2O and CO_2 possible concentrations in the regions of basaltic rock formation. We shall have compare the trends of alterations in the H_2O and CO_2 concentrations in magmatic melts during the degassing process with the content of these components volatile in volcanic glasses (Fig. 5). Each curve corresponds to a definite ratio $CO_2/(CO_2+H_2O)$, and thus this comparison permits to determine the initial value mentioned above. On the whole these results have permitted to reproduce the initial concentrations of H_2O and CO_2, as well as $CO_2/(CO_2+H_2O)$ in magmas from the various tectonic structural zones of the oceanic floor. These data are represented in Tab. 1. On the basis of these estimations the following conclusions can be drawn about the fluid regime of the upper mantle rocks beneath the oceans:

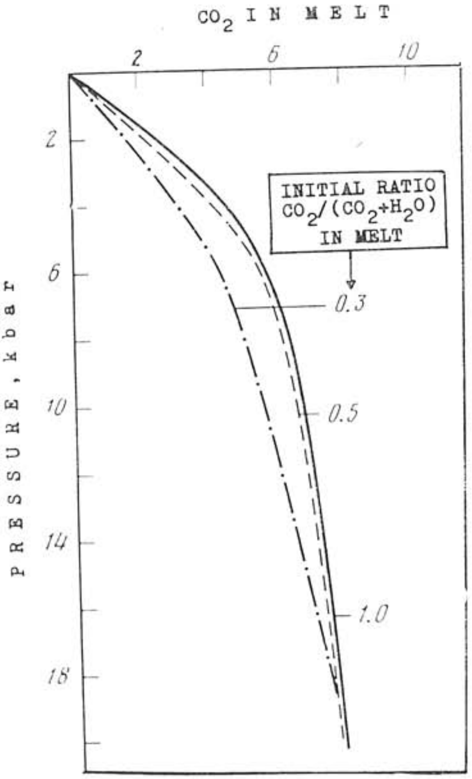

Fig. 3. Variation of concentration of CO_2 in melt during the gas release.

1. The relatively low concentration of water and carbon dioxide in magmas on depth should be mentioned first of all. Therefore the fact of negligible volatile concentrations in upper mantle of oceanic rocks is confirmed, proving the ideas of many scientists. However, there is a very important limitation to this conclusion, because it is based on the assumption that there are no reactions between the volatiles and the graphite phase on depth. We shall come back to this problem a little later.

2. The difference in the initial concentration of H_2O and CO_2 as well as in

the $CO_2/(CO_2+H_2O)$ ratio in magmas from various tectonic-structural oceanic zones can be regarded as a proof for the heterogeneous character of the upper mantle fluid regime. The lowest concentration of water and the highest ratio $CO_2/(CO_2+H_2O)$ are characteristic of the basaltic magmas from the mid-oceanic ridges, but the highest concentrations of H_2O and the lowest ratio $CO_2/(CO_2+H_2O)$ are characteristic of basalts and andesites of the Mariana arc and trough. On the whole the latter coincides with the estimations of the volatile regime in the magmas of oceanic rock for the other regions of the World Ocean. (Kadik — Maximov, 1982; Barsukov et al., 1981).

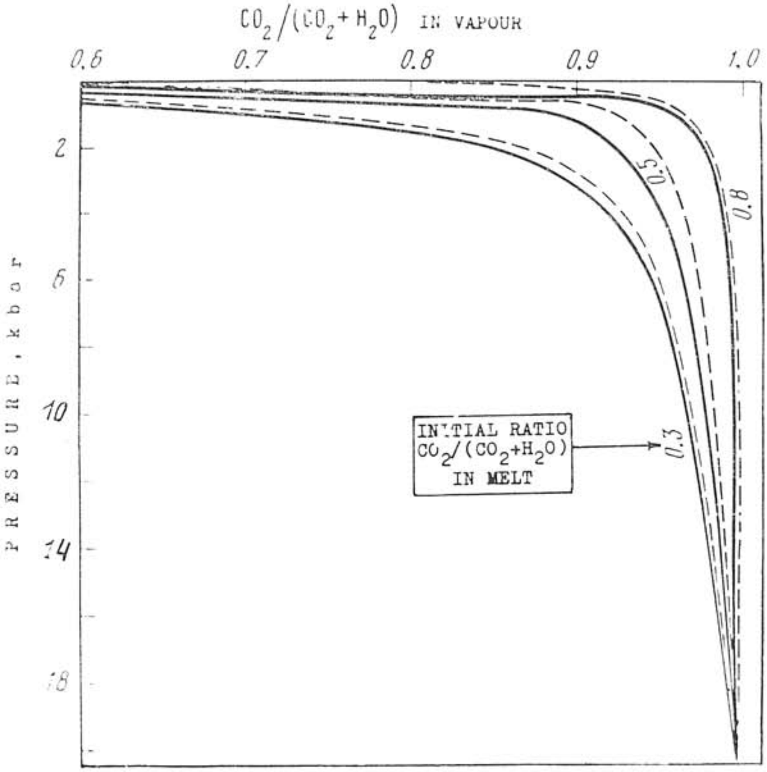

Fig. 4. Composition of vapour during the gas release.

The concentration of H_2O, CO_2 and the $CO_2/(CO_2+H_2O)$ ratio for the basalts of Hawaii take an intermediate place between the mid-oceanic ridge basalts and the Mariana arc and trough ones.

3. Concentration of H_2O and CO_2 in deep fractions of magmas permit to put forward some considerations about the fluid composition and the redox regime of the upper mantle rocks. If the partial melting have led to the complete dissolution of volatiles, the ratio $CO_2/(CO_2+H_2O)$ in deep fractions of

magmas should correspond to the initial concentrations of H_2O and CO_2 in the upper mantle before melting. On this basis the fluid composition in the regions of the oceanic basalt formation is characterized by the high CO_2 fraction which equals to 30—50 mol. %, the CO_2 fraction in the deep fluids decreases with the transition from the mid-oceanic ridges to the oceanic Islands (Hawaii) and oceanic arcs (Mariana).

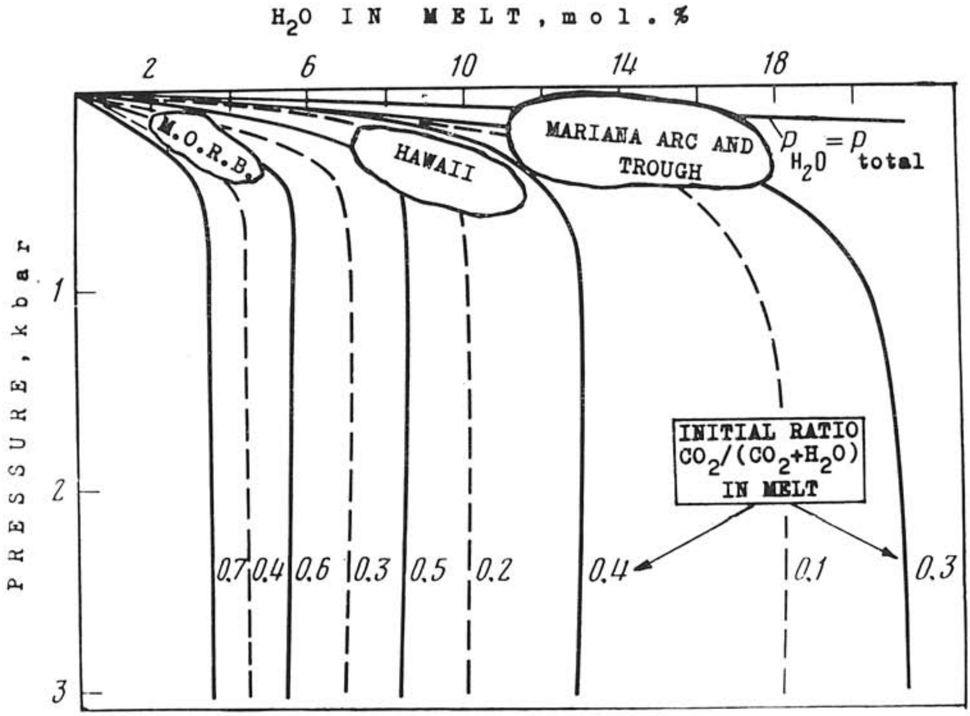

Fig. 5. Comparison of H_2O content in oceanic volcanic glasses with path of degassing of melt during the decompression.

We can make the next step and evaluate the composition of the fluids which should be characteristic of the regions of partial melting of the upper mantle rocks. The concentration of H_2O and CO_2 in this rocks should reflect the process of fractionation of the volatiles between melt and fluid. The composition of the remaining fluid should differ from the initial fluid composition that was characteristic of the upper mantle rocks before their melting.

On the basis of our estimations of H_2O and CO_2 concentration in depths basaltic magmas we can conclude that such a remaining fluid should represent practically pure carbon dioxide (CO_2 = 98—99 mol. %) in all the regions of basaltic magmas formation under discussion.

As a result of our analysis we can draw the following conclusions:

1. The evaluation of the possible H_2O and CO_2 content in the depth's fractions of mid-oceanic basalts proves the depletion in volatile component of upper

mantle rocks of these regions. This evaluation apparently reflects the peculiarity of evolution of mantle beneath the oceans, which are possibly connected with melting processes at the early stages of Earth's development. Another explanation can be based on the presence of the graphite phase in the regions of mid-oceanic basalts generation. According to some estimations (Kadik — Lukanin, 1984; Sato, 1978), the low H_2O concentration in the depth's fluids may be caused by the expenditure of H_2O in the process of interaction with graphite. This interaction is especially significant when the pressure is decrease of during the uprising movement of the mantle material (Fig. 6).

Table 1

Estimation of initial concentrations of H_2O and CO_2 in magmas from oceanic tectonic-structural zones

Region	H_2O		CO_2	
	wt. %	mol. %	wt. %	mol. %
Mid-oceanic ridges	0.5—0.6	7.0— 8.0	0.5—1.6	3.0—8.0
Hawaii	0.9—1.3	13.0—18.0	0.4—1.6	2.0—8.0
Mariana arc and trough	1.6—5.7	21.0—48.0	0.4—1.6	2.0—8.0

Since the formation of the ocean floor basalts takes place in relatively shallow depths (30—40 km) and in geodynamic conditions, that are connected with the mantle material uprising, the initial fluids should be characterized by a high $CO_2/(CO_2+H_2O)$ ratio.

2. A higher concentration of H_2O and a lower $CO_2/(CO_2+H_2O)$ ratio of the products of basalt eruptions (Hawaii) can reflect the peculiarities of magma

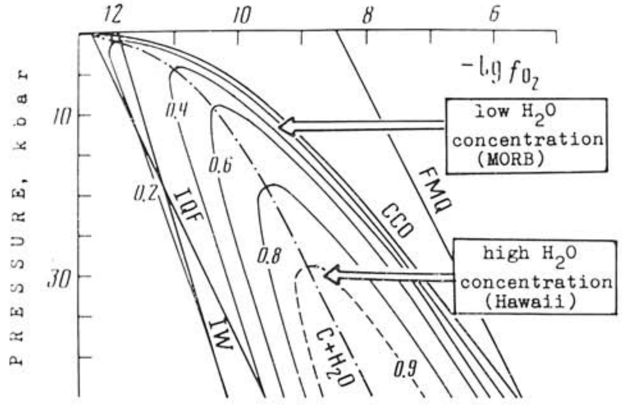

Fig. 6. Mole fraction of H_2O in the fluid in the presence of graphite.

generation in these regions, that are determined by the upper mantle melting during the uprising of hot Earth's depth's material (as plumes).

If we look at the fluid regime of those magmas from the point of view of the graphite phase participation in the endogenic reactions, it would be evident that the higher H_2O concentration and the lower $CO_2/(CO_2+H_2O)$ ratio of the basalts of oceanic islands, compared with the similar values for the mid-oceanic ridge basalts, can be explained a greater generation depth for the former (50—80 km) in comparison with the latter (20—30 km). This situation is presented in Fig. 6.

3. The highest concentration of H_2O and the lowest $CO_2/(CO_2+H_2O)$ ratio discovered in basalts and andesites of Mariana arc and trough are most probably connected with the processes of capture of the volatiles in the mantle during the oceanic crust subduction.

However, these ideas, though adopted by many scientists, demand further studies.

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