

## HOW TO PRODUCE SODIUM-ALKALINE MAGMA IN THE CRUST? EXPERIMENTAL RECIPE

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Carbonates as carbonatites are often associated with alkaline magmas implying their mutual origin usually attributed to the mantle depths. We explore another possibility of the sodic alkaline rocks formation at the crustal depths due to interaction of a magma, carbonates and sodium chloride.

Key factor in this system is production of sodium carbonate in the exchange reaction



Sodium carbonate in contrast to NaCl has high solubility in the silicate melt and is a good solvent for many HFSE and LREE elements. To explore triple magma- $\text{CaCO}_3$ -NaCl ( $\text{H}_2\text{O}$ ) interaction we experimentally study this system at  $P=2-3$  Kbar.

We use andesite and spilitized andesite as the source rocks in experiments. To avoid direct interaction of  $\text{CaCO}_3$  and NaCl with melt we put these components in a small open capsule pended inside large welded one. Experiments were performed at  $T=950-1000^\circ\text{C}$  slightly below liquidus temperature. About 4 wt.% of water presents in the runs. Sphene as a source of the additional REE and HRSF elements was placed into large or small capsules. We vary ratio of  $\text{CaCO}_3/\text{NaCl}$  from 3 to 0. After experiment we study partially crystallized glass, fluid precipitates in the large and small capsules and  $\text{CaCO}_3$  partially transformed into calcium silicates.

Interaction between large and small capsules occurred via  $\text{H}_2\text{O}-\text{CO}_2$  fluid. Some silica with fluid was transferred into small capsule. We find  $\text{CaCl}_2$  and KCl as the well formed crystals on the surface of the glass and in the micro-spheres of the fluid precipitates at quenching.  $\text{CaCl}_2$  was formed in the reaction (1) and KCl in the exchange with melt (Ca on K).  $\text{NaHCO}_3$  was mainly dissolved in the melt and is very rare in the fluid precipitates as well as NaCl spent in reaction (1).

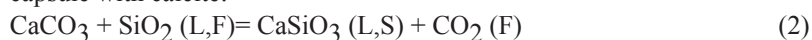
Table 1: Composition of experimental glasses

Run #	$\text{Na}_2\text{O}$	$\text{MgO}$	$\text{Al}_2\text{O}_3$	$\text{SiO}_2$	$\text{K}_2\text{O}$	$\text{CaO}$	$\text{TiO}_2$	$\text{MnO}$	$\text{FeO}$	$\text{BaO}$	Fluid*
35	8.4	2.11	17.7	56.54	1.19	4.91	2.03	0.16	4.80	0	1:1
36	7.81	1.48	18.05	58.09	0.56	6.10	2.30	0.15	3.11	0.06	0:1
37	6.22	1.86	19.41	61.90	1.68	3.46	1.36	0	3.01	0.04	1:0
39	9.60	0.82	18.93	55.55	1.59	4.78	1.77	0.30	4.28	0.13	3:1
42	5.17	0.29	15.64	61.08	1.37	9.69	0.61	0.08	3.13	0.47	3:1
42-2	5.81	1.06	16.54	62.97	1.91	4.83	0.69	0.08	4.53	0.14	3:1
rock1	6.16	4.61	17.50	49.79	1.24	3.14	1.30	0.19	11.84	0.043	-
rock2	2.82	6.73	14.88	57.83	1.80	6.50	0.81	0.13	8.48	0.048	-

\*Fluid - ratio of  $\text{CaCO}_3$  to NaCl in the small capsule. Rock 2 is used in the run42 and rock1 in all other ones. In the run 42 glass gains 3 wt.%  $\text{Na}_2\text{O}$ , and 3.4 wt.% in run39. All runs were performed at P=2 Kbar and T=1000°C.

Due to the fluid-magma interaction the upper part of the glassy sample from the main capsule is enriched with Ca, middle part with alkalis and the near bottom part remains unchanged. In the table 1 we put compositions of the experimental glasses. Maximum alkalis ( $\text{Na}_2\text{O}+\text{K}_2\text{O}$ ) content approaches 11-12 wt.% and can be classified as trachi-phonolites. This maximum is attained for the always alkalis enriched spilite while andesitic composition shifts to the trachi-andesitic one (see table 1). Modification of basalt into spilite (rock1 in table 1) can be attributed to the metasomatic alternation by the similar  $\text{Na}_2\text{CO}_3$  ( $\text{NaHCO}_3$ ) bearing fluid.

In our experiments initially essentially water fluid gains some  $\text{CO}_2$  due to the reaction of the  $\text{CaCO}_3$  transferred by fluid into the contact with melt and  $\text{SiO}_2$  moved by fluid into small capsule with calcite:



Production of pure  $\text{CO}_2$  in the reaction (2) leads to the increase of  $f_{\text{O}_2}$  in the same way as in the direct  $\text{CaCO}_3$ -Melt interaction [1, 2].

Amphibole and clinopyroxene are prevailing solid phases in the reported experiments. Highly alkaline nature of the melts is reflected in the specific composition of amphiboles enriched in alkalis, LREE and HFSE (Zr, Nb, Ti).

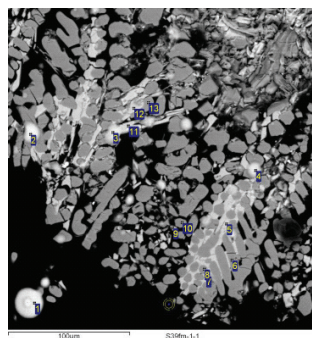
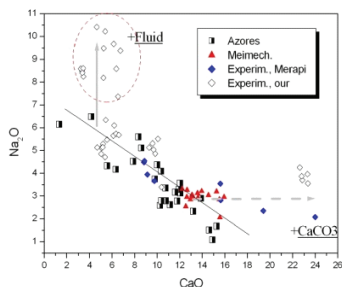


Figure 1: a) Sodium and calcium contents in the magmas and experimental glasses: Meimech.-[3], Azores – [4], Merapi –[2] b) experimental products from the small capsule run 39. Spheres are composed of  $\text{CaCl}_2$  (contain up to 0.2 wt.% BaO), dark grey – unreacted  $\text{CaCO}_3$ , light grey  $\text{Ca}_3\text{SiO}_5$

Content of Al in octahedral coordination in amphibole is reducing with rise of alkalinity due to formation of aluminates (such as  $\text{NaAlO}_2$ ) where Al is tetrahedral. Similarly  $\text{Fe}^{3+}$  in alkaline melts shifts to the tetrahedral coordination thus decreasing octahedral  $\text{Fe}^{3+}$  content in amphiboles. Clinopyroxenes in our runs demonstrates almost totally oxidized iron corresponding to the rather high  $f_{\text{O}_2}$  (NNO+3-4) [1].

**Geologic examples.** Process of the carbonate- salt – fluid - magma interaction modeled in our experiments can be anticipated in some geologic environments. First of all we expect that evolution of the magmas in the chambers located near the basement of the oceanic islands can occur at such conditions [5]. For example near Tenerife ocean depth is around 3500 m that with 2-3 volcanic load a.s.l. gives around 1.5-2 Kbar at the depth close to the bottom. At such

conditions hydrothermal circulation can get fluid entering into chamber through its bottom. As shown in our experiments such fluid formed at the interaction of NaCl and CaCO<sub>3</sub> will carry NaHCO<sub>3</sub>, Ba, LREE, HFSE into magma. Sea water involvement in the formation of the phonolites on Ua Pou Island is suggested, e.g. in [6].

Similar to the reported interaction between carbonates and sodium chloride may have place deeper in the crust (or upper mantle). Such conditions can arise in the zones of accretion, continental subduction etc. For example currently evaporates (halides and carbonates) had subducted in Mediterranean to the depths of about 40 km [7] probably contributing to the alkaline rocks formation in Italy.

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