SHORT COMMUNICATIONS

MINERALOGICAL MAGAZINE, SEPTEMBER 1985, VOL. 49, PP. 601-603

Interaction of jadeite with water at 20–30 kbar and 650 °C

CLINOPYROXENE-FLUID equilibria are important for the understanding of metasomatic processes operating in the upper mantle. To extend our knowledge on the behaviour of sodium in such processes we studied jadeite solubility in aqueous fluids at subsolidus temperatures. Experiments were conducted in a simplified piston-cylinder apparatus with $\frac{1}{2}$ in. internal diameter (Holloway, 1978). The starting materials (gel of $NaAlSi_2O_6$ composition and water) were sealed in platinum tubes (2 mm OD, 0.1 mm wall thickness) which were inserted in graphite furnaces in NaCl cells (Mirwald *et al.*, 1975). The temperature was measured by $Pt+Pt_{0.87}Rh_{0.13}$ thermocouples but no correction was made for the pressure effect on the emf.

Jadeite and diaspore were the only solid phases found in the run products. They were identified optically and by electron microprobe analyses (Table I). Material precipitated from the fluid during quenching of the runs was represented by an amorphous substance and spherulitic aggregates made of thin needles of jadeite. The difference between equilibrium crystals of jadeite and quench material in the products of the runs is such that they can be readily distinguished (see fig. 1). The conditions of the experiments and interpretation of their products are given in Table II.

At 20 kbar and 650 °C, jadeite was found to be the only primary crystalline phase in run products. A run with 33 wt. % $NaAlSi_2O_6$ bulk composition yielded under these conditions only quench material (tiny amorphous spheres), while in run products of the experiment with 39 wt. % $NaAlSi_2O_6$ small amounts of equilibrium jadeite crystals were present (Table II, nos. 2 and 3). From these results jadeite solubility at 650 °C and 20 kbar was inferred to be about 35 wt. % which corresponds to Na_2O/H_2O weight ratio of 0.08. It was also concluded that jadeite dissolves congruently in water under these conditions.

Table I.

Compositions of clinopyroxene and diaspore from the run products in the join $NaAlSi_2O_6$-H_2O at 650°C and 30 kbar (run 8, Table II) obtained by electron microprobe analyses.

	Clinopyroxene	Diaspore
SiO_2	59.36 (1.992)*	0
Al_2O_3	25.76 (1.019)	82.52
Na_2O	15.03 (0.978)	0
Total	100.16 (3.988)	82.52

* Numbers of cations per 6 oxygens are shown in brackets.

Table II.

Experimental data for the join $NaAlSi_2O_6$-H_2O at 650°C

Run No.	Pressure	Duration (hours)	$NaAlSi_2O_6$ wt % in the charge	Phase assemblage, interpreted from run products
1	20	7	30	Fl
2	20	30	33	Fl
3	20	9	39	Jd(s.a.) + Fl
4	20	4	47.5	Jd + Fl
5	30	9.5	20	Dp + Fl
6	30	24	25	Jd(s.a.) + Dp + Fl
7	30	11	30	Jd + Dp + Fl
8	30	15	30.5	Jd + Dp + Fl

Abbreviations : Jd = jadeite; Dp = diaspore; Fl = fluid; s.a. = small amount.

At 650 °C and 30 kbar primary diaspore ($HAlO_2$) appears together with jadeite in run products (fig. 1); this indicates that jadeite dissolves in water incongruently giving, upon interaction with H_2O, diaspore and fluid with Na/Al and Si/Al atomic ratios of more than 1 and 2 respectively. The total amount of non-volatile oxides dissolved in fluid equilibrated with jadeite and diaspore at 30 kbar and 650 °C was estimated to be close to or slightly less than 25 wt. % (Table II, runs 5 and 6). From visual estimates of the diaspore content in run products with a small amount of jadeite, at 5–10 % this gives an approximate composition of the fluid as 4 wt. % Na_2O, 4–5 wt. % Al_2O_3 and 15 % SiO_2 ($Na_2O/H_2O = 0.05$ by weight). Comparison of our results for 20 and 30 kbars shows that jadeite solubility drops with increasing pressure. Furthermore, our data show that the Al contents in fluids co-existing with jadeite decrease faster than those of Na and Si.

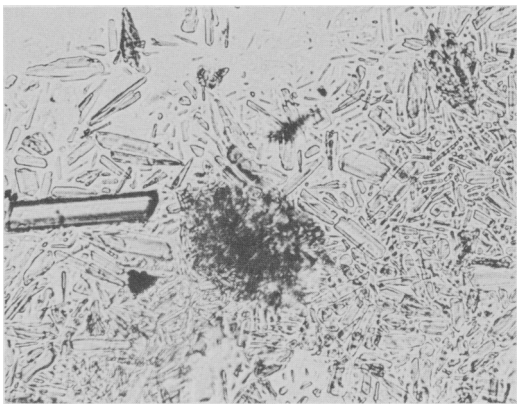

FIG. 1. Photomicrograph of products of run 8. In the centre of the field is an aggregate of very small needles of quench jadeite crystals: one large crystal of diaspore is present and the remaining crystals are equilibrium jadeite. Magnification × 64.

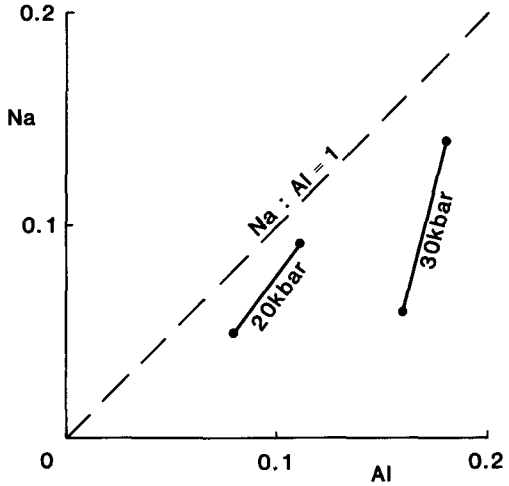

FIG. 2. Numbers of Na and Al atoms per 6 oxygens in clinopyroxene, synthesized at 20 and 30 kbar (900 °C) in the join jadeite–diopside–H_2O (Ryabchikov *et al.*, 1982).

These findings are consistent with the results previously reported for the join jadeite–diopside–H_2O (Ryabchikov *et al.*, 1982). Sodium contents in fluids equilibrated with omphacitic pyroxenes also decrease with rising pressure at constant concentration of Na in crystals, and the Na/Al ratios are higher in the fluids than in the co-existing clinopyroxenes. Moreover omphacitic pyroxenes synthesized at 30 kbar and 900 °C are characterized by consistently lower Na/Al ratios than clinopyroxenes produced at 20 kbar and at the same temperature (fig. 2). This fact may be compared with the congruent character of the solubility of jadeite at 20 kbar due to the reaction of jadeite with water observed in the present work.

Comparison of the results for the joins jadeite–H_2O and jadeite–diopside–H_2O (Ryabchikov *et al.*, 1982) also shows that Na_2O/H_2O ratios measured in fluids co-existing with pure jadeite at 650 °C are lower than Na_2O/H_2O ratios in aqueous solutions equilibrated at 900 °C and the same pressure with pyroxenes containing 1.5–2 wt. % Na_2O. This implies that with rising temperature the solubility of alkaline clinopyroxene in water increases drastically. Very rough estimates show that in this temperature range the sodium content in fluid interacting with clinopyroxene of constant composition should increase by a factor of 20.

As has been shown above, aqueous fluids equilibrated with crystalline minerals at higher pressures are characterized by larger alkali/Al ratios, other conditions being equal. This means that the fluids which may ascend from the deeper horizons in the mantle may produce, on interaction with the surrounding lherzolites, at higher levels, rocks of increased alkalinity. Magmas generated during the anatexis of this part of the mantle may inherit this feature of the source rocks. In this way metasomatic alteration of the mantle may result in the production of primary alkaline magmas.

It is also interesting to note that, according to the data for low-temperature hydrothermal solutions, polyvalent cations such as Nb^{5+} and Ta^{5+} are mobile in aqueous solutions containing substantial amounts of dissolved simple alkali silicates. Since fluids in the mantle at pressures above *c.*25 kbar should, according to our data, contain simple alkali silicates it may provide an explanation for the elevated concentrations of Nb and other polyvalent metals in alkaline magmas and kimberlites, whose

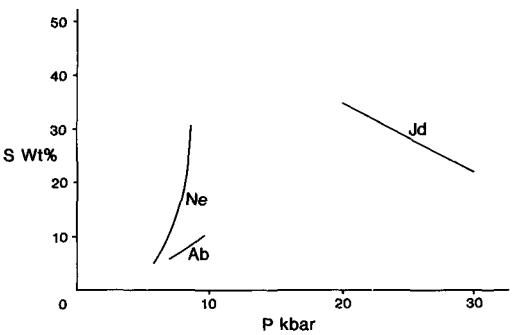

FIG. 3. Solubilities of albite (at 700–760 °C), nepheline (at 750–900 °C) and jadeite (at 650 °C) in aqueous fluids as the functions of pressure (Clark, 1966 and present work).

source is also believed to be a metasomatized mantle.

In contrast to jadeite and omphacitic pyroxenes, all the phases with low densities stable at lower pressures including quartz, albite, sanidine, and phlogopite exhibit solubilities increasing with rising pressure, fig. 3 (Kennedy, 1950; Clark, 1966; Ryabchikov and Boettcher, 1980). In comparison with the results of the present work for jadeite, it implies that for the isochemical phase assemblage a maximum should exist on the sodium concentration in the fluid-pressure curve in the pressure range where the plagioclase–clinopyroxene reaction takes place. For mantle lherzolites such boundary pressures lie between 10 and 15 kbar, and corresponding depth levels may be most favourable for the precipitation of sodium from ascending fluids.

It can also be hypothesized that a similar maximum solubility for potassium may exist but at much higher pressures (50–80 kbar) where the traces of potassium present in mantle lherzolite at shallower depths in the form of small amounts of phlogopite or sanidine are transferred into clinopyroxene solid solution.

If the appearance of the zones of anomalous mantle enriched in alkalis is due to metasomatism caused by ascending fluids, then Na-rich zones should be confined to shallower depths than K-rich zones. Subsequent involvement of such zones in the processes of partial melting may explain the appearance of alkali-rich primary magmas. The confinement of the sources of K-rich basic magmas (including kimberlites) to depths greater than that of Na-rich basalts is in accord with the model outlined which is partly based on the results of our experiments.

REFERENCES

Clark, S. P., ed. (1966) *Handbook of physical constants.* Geol. Soc. Am. Mem. 97, 587 pp.

Holloway, J. R. (1978) *A simplified piston cylinder design.* Dept. Chemistry, Arizona State University, Tempe, Arizona.

Kennedy, G. C. (1950) *Econ. Geol.* **45,** 629–53.

Mirwald, P. W., Getting, I. C., and Kennedy, G. C. (1975) *J. Geophys. Res.* **80,** 1519–25.

Ryabchikov, I. D., and Boettcher, A. L. (1980) *Am. Mineral.* **65,** 915–19.

—— Schreyer, W., and Abraham, K. (1982) *Contrib. Mineral. Petrol.* **79,** 80–4.

[*Manuscript received 2 July 1984*]

© *Copyright the Mineralogical Society*

IGEM Staromonetry 35, Moscow 109017, USSR I. D. RYABCHIKOV

Geology Department, Manchester University, Manchester M13 9PL, UK W. S. MACKENZIE

MINERALOGICAL MAGAZINE, SEPTEMBER 1985, VOL. 49, PP. 603–606

Priderite stability in the system $K_2MgTi_7O_{16}$–$BaMgTi_7O_{16}$

MAFIC and ultramafic magmas anomalously enriched in K, Ba, Ti, Zr, and other incompatible and LIL elements are probably direct partial melts of mantle sources which are also enriched in these elements. Potential mineral reservoirs for these elements obviously must be stable under the *P,T* conditions of the mantle source. The commoner reservoirs for K and, to a lesser extent, Ti are phlogopite and K-rich amphibole, both of which are stable up to 30 kbar and at temperatures in excess of continental mantle geotherms (Modreski and Boettcher, 1972; Kushiro and Erlank, 1970). Much less common minerals containing these elements are wadeite ($Zr_2K_4Si_6O_{18}$) and priderite, of approximate composition $(K,Ba)_{1.33}(Fe,Mg,Ti)_{8-x}O_{16}$, where x is very small and is dependent on the amounts of Ba and Fe^{+3} in the formula, as given by Norrish (1951). These minerals occur in the lamproites of the West Kimberley region, Western Australia (Prider, 1939; Jacques *et al.*, 1984) and in the high potash lavas of the Leucite Hills, Wyoming (Carmichael, 1967; Kuehner *et al.*, 1981). The occurrence of both of these minerals as microphenocrysts, associated with diopside, phlogopite, and K-richterite phenocrysts, suggests wadeite and priderite may be early formed phases in the evolution of these highly unusual magmas. Wadeite is stable up to 25 kbar and 1250 °C (Arima