

MELTING OF ALBITE AT HIGH PRESSURES IN THE PRESENCE OF WATER

Mitsuhiko SHIMADA

*Abuyama Seismological Observatory, Kyoto University,
Takatsuki, Osaka, Japan*

Received 18 July 1969

The melting of albite has been investigated in the presence of water in the pressure range up to 30 kb, from the point of view that the effect of water on the melting of silicates is important for the investigation of the state of the earth's interior and the earth's thermal history. The melting relations have been determined under the following conditions: (a) that the water pressure is equal to the total pressure or the albite melt is saturated with water, and (b) that albite melt contains a fixed amount of water (10 wt% and 14 wt%) and is saturated with water up to a certain value of pressure but undersaturated in the higher pressures.

As pressure increases, the melting point of albite, in the presence of a fixed amount of water, decreases from 1118°C along the water-saturated melting curve up to a certain value of pressure. In the higher pressure region albite begins to melt incongruently, and the temperatures of the beginning of melting decrease with increase of pressure along the water-saturated melting curve and the temperatures of the end of melting increase approaching asymptotically the curve for the dry condition. In the region between the solidus and the liquidus, crystal and liquid coexist. The value of pressure, where the incongruent melting begins, is in good agreement with the results of the solubility of water in albite melt.

1. Introduction

There have been many discussions related to the importance of water in the earth's crust and mantle, especially of the effect of water on the melting points of silicates (e.g. [1]). The melting points of most solids increase with pressure, but it is well known from the hydrothermal experiments that in the presence of water the melting points of silicates decrease with increase of pressure [1]. Recently this effect has been discussed in relation to the cause of the low velocity layer [2,3] and to the earth's thermal history [4].

The presence of water in the lower crust or the upper mantle is considered likely from the geological evidence that hydrous minerals like amphibole or mica are included in the rocks which are believed to have originated in the upper mantle [3]. The amount of water is considered not so large that the condition of $P_{H_2O} < P_{total}$ is more probable than $P_{H_2O} = P_{total}$, though in the thermal history it is possible that the early earth retained larger amounts of water than the present earth [4].

The melting relations of silicates under the condi-

tion of $P_{H_2O} < P_{total}$ were illustrated schematically by Yoder and Tilley [5] and Kushiro [3]. A few direct experiments were done on basalt by Shimada [2] and on peridotite by Kushiro et al. [6]. In the melting relation of a rock, there is the melting interval in which liquid and solid coexist, even in the absence of water, because most rocks are regarded as the multicomponent systems of minerals. It would be desirable to determine the effect of water under the condition of $P_{H_2O} < P_{total}$ on the melting of a single silicate mineral. In this study the melting relation of albite was investigated. It was desired that the water in the silicate is at a fixed water pressure less than the total pressure. Unfortunately, in the present experiments the desired condition, i.e. a fixed water pressure, was not achieved, but runs were carried out with a fixed amount of water.

2. Experimental procedures

The high pressure equipment used for this study was a single-stage piston cylinder type of 12 mm diam-

eter chamber, described previously [2,7]. Melting relations were determined by the quenching method. Charges after the runs were examined both by the X-ray diffractometer and by the petrographic microscope. In almost all runs the expected pressure and temperature were attained through the liquidus field (cf. [8]).

Glasses were used as starting materials for all runs. $\text{NaAlSi}_3\text{O}_8$ glasses were synthetically prepared from Na_2CO_3 , Al_2O_3 and SiO_2 . Glasses were additionally prepared from natural albite from Ontario, Canada. Finely ground glasses were moistened with plenty of distilled water and dried until the expected amount of water remained. These moistened glasses of 1–2 mg were put into several platinum capsules and welded. To determine the final amount of water, some of them were opened and heated, and weighed before and after the heating. Each capsule was considered to contain the same amount of water but the uncertainty of the determination of the amount of water was $\pm 2\%$. In the runs for the condition of $P_{\text{H}_2\text{O}} = P_{\text{total}}$, finely ground glasses and excess water were sealed within platinum capsules.

3. Results and discussions

Experimental results are shown in figs. 1–3 and summarized in fig. 4. In these figures the melting point of 1118°C was adopted at atmospheric pressure [9].

Fig. 1 shows the melting relation in the condition of $P_{\text{H}_2\text{O}} = P_{\text{total}}$ or that albite melt is saturated or oversaturated with water. The curves from Goranson [10] and Burnham and Jahns [11] are also shown. Synthetic albite glasses were used for most runs. For comparison, natural albite glasses were also used and the results of the former are plotted by circles and the ones of the latter by squares.

Two sets of samples were prepared for the runs using a fixed amount of water. One contained 10 ± 2 wt% of water and the other 14 ± 2 wt%. The results of these runs are shown in fig. 2 and fig. 3, respectively. In these runs synthetic glasses were used as the starting materials.

The melting point of albite with 10% of water decreases with increase of pressure up to 4 kb along the water-saturated melting curve. In the higher pressure

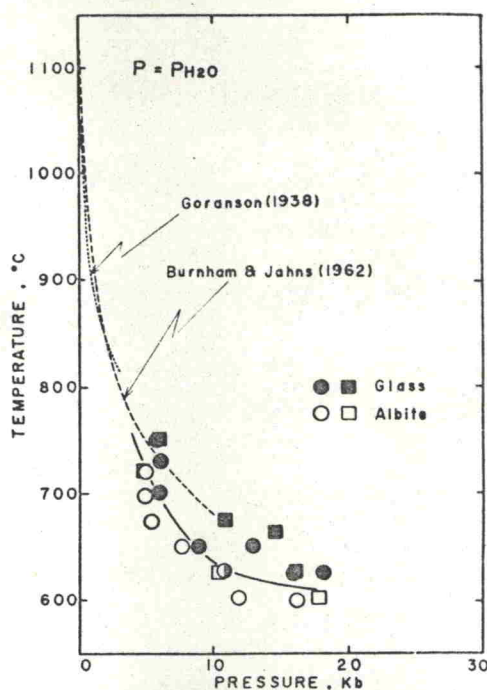


Fig. 1. Melting relation of albite under the condition of $P_{\text{H}_2\text{O}} = P_{\text{total}}$ or water-saturation. Circle symbols denote the results of synthetic albite and square symbols natural albite.

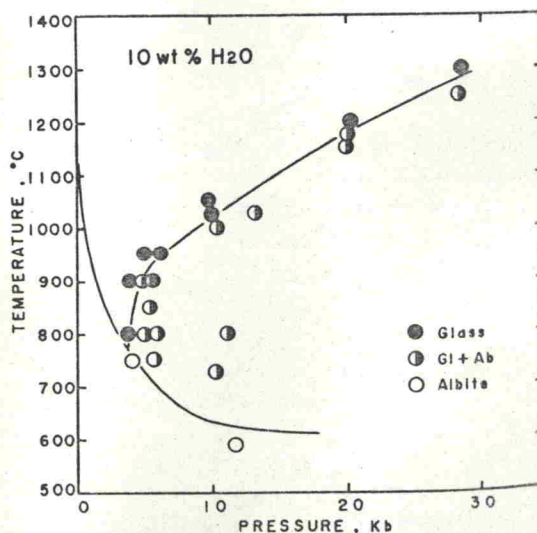


Fig. 2. Melting relation of albite with 10 ± 2 wt% of water.

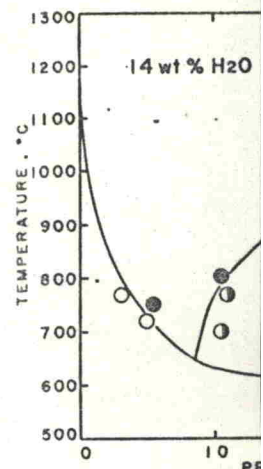


Fig. 3. Melting relation of albite with 14 wt% H_2O .

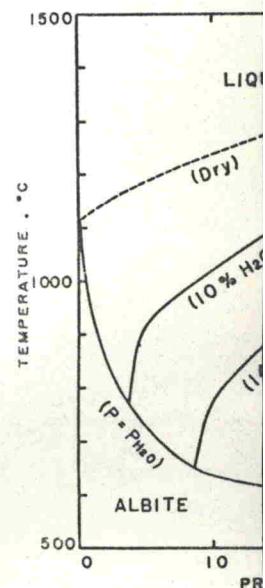


Fig. 4. Melting relations of albite + jadeite + quartz. The curves are after Boyd and England [12] and Birch and

region albite melts incongruently at the beginning of melting. The pressure along the water-saturated melting curve approaches asymptotically the curve

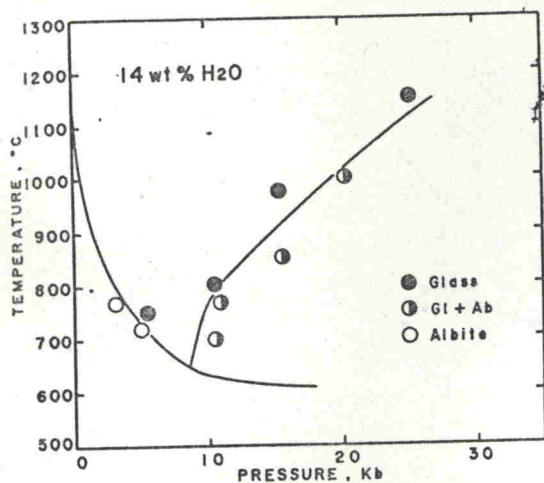


Fig. 3. Melting relation of albite with 14 ± 2 wt% of water.

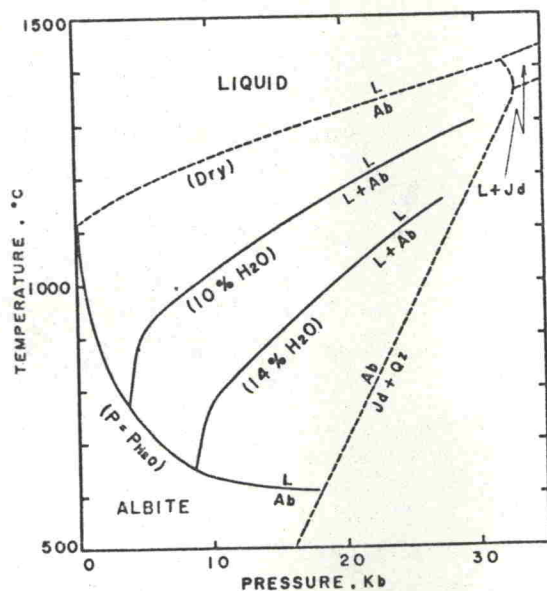


Fig. 4. Melting relations of albite-H₂O system. Melting curve and albite = jadeite + quartz equilibrium curve in dry condition after Boyd and England [8], Bell and Roseboom [12] and Birch and LeComte [13].

region albite melts incongruently, and the temperatures of the beginning of melting decrease with increase of pressure along the water-saturated curve and the temperatures of the end of melting increase approaching asymptotically the curve for the dry condition (fig. 4).

In the region between the solidus and the liquidus, crystal and liquid coexist. The pressure of 4 kb where the incongruent melting begins is in good agreement with the results of the solubility of water in albite melt described by Burnham and Jahns [11]. According to their results, it is at 4, 5 and 6 kb that the solubility of water in albite melt is 9, 10 and 11 wt%, respectively, at temperatures of the water-saturated liquidus. Thus, at this pressure and temperature albite melt is just saturated by 10 wt% of water and this is the maximum pressure satisfying the condition of $P_{H_2O} = P_{total}$ in the presence of 10 wt% of water.

The liquidus of albite with 14 wt% of water was drawn consistently with the results of the solubility (fig. 3).

It is suggested from fig. 4 that when water is present, albite melts incongruently and the solidus coincides with the water-saturated melting curve. Accordingly the presence of just a small amount of water would remarkably affect the state of the earth's interior.

It should be noticed that the solidi of rocks in the presence of water under the condition of $P_{H_2O} < P_{total}$, or undersaturation, do not coincide with the water-saturated solidus, and have been drawn in the higher temperature range [2,6]. In the present experiments, few data were presented near the solidi in the pressure range where albite melt was not saturated with water. It would be difficult from only the present data to conclude that the solidus for undersaturation coincides with the water-saturated melting curve, but justified from the isobaric phase diagram for the system albite-H₂O described by Burnham and Jahns [11]. These problems will be discussed in detail in the near future after sufficient data are obtained.

Acknowledgements

The author is indebted to Professor Haruo Miki and Dr. Shogo Matsushima of Kyoto University for their helpful advice and critical reading of the manuscript.

References

- [1] P.J. Wyllie, in: High pressure physics and chemistry, vol. 2, ed. R.S. Bradley (Academic Press, 1963) chapter 6.

- [2] M.Shimada, Melting of basalt at high pressures, *Zisin* 19 (1966) 167; Effects of pressure and water on the melting of basalt, *Spec. Contr. Geophys. Inst. Kyoto Univ.* 6 (1966) 303.
- [3] I.Kushiro, State of H_2O in the mantle, *Bull. Volc. Soc. Japan* 11 (1966) 116.
- [4] K.C.Condie, Possible role of water in the earth's thermal history, *J. Geophys. Res.* 73 (1968) 5466.
- [5] H.S.Yoder Jr. and C.E.Tilley, Origin of basalt magma: An experimental study of natural and synthetic rock system, *J. Geol.* 3 (1962) 342.
- [6] I.Kushiro, Y.Syono and S.Akimoto, Melting of a peridotite nodule at high pressures and high water pressures, *J. Geophys. Res.* 73 (1968) 6023.
- [7] M.Shimada, An experimental study of the basalt-eclogite transition, *Spec. Contr. Geophys. Inst. Kyoto Univ.* 7 (1967) 211.
- [8] F.R.Boyd and J.L.England, Effect of pressure on the melting of diopside, $CaMgSi_2O_6$, and albite, $NaAlSi_3O_8$ in the range up to 50 kilobars, *J. Geophys. Res.* 68 (1963) 311.
- [9] J.W.Greig and T.F.W.Barth, The system, $Na_2O \cdot Al_2O_3 \cdot 2SiO_2$ (nephelite, carnegieite)- $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$ (albite), *Amer. J. Sci.* 35A (1938) 93.
- [10] R.W.Goranson, Silicate-water systems: Phase equilibria in the $NaAlSi_3O_8-H_2O$ and $KAlSi_3O_8-H_2O$ systems at high temperatures and pressures, *Amer. J. Sci.* 35A (1938) 71.
- [11] C.W.Burnham and R.H.Jahns, A method for determining the solubility of water in silicate melts, *Amer. J. Sci.* 260 (1962) 721.
- [12] P.M.Bell and E.H.Roseboom Jr., Phase diagram for the system nepheline-quartz, *Carnegie Inst. Wash. Yearbook* 64 (1965) 139.
- [13] F.Birch and P.LeComte, Temperature-pressure plane for albite composition, *Amer. J. Sci.* 258 (1960) 209.

Data are given for cal water masses in the tectable, being up to wet phytoplankton. The utility of thorium-22 the sensitivity level of $\times 10^{-15}$ g thorium-2 to the fact that this are concerned.

1. Introduction *

Recent studies of the water have raised intriguing can be summarized as follows

- 1) Thorium-232 in sea water is quoted at levels ranging from 2×10^{-10} g/l for mid-ocean to 2×10^{-7} g/l for samples from coastal waters [2-5]. Since sea water is known to be [6,7]), a thorium-uranium the typical terrestrial value
- 2) Moore and Sackett and Goldberg [2] have reported

* Since submitting this manuscript papers have come to our attention. Moore, "Measurement of Thorium-232 concentrations in sea water," *J. Geophys. Res.* 74 (1969) 5700. Thorium-232 concentrations in sea water, *chim. et Cosmochim. Acta* 34 (1969) 1000. Interesting data on thorium-232 concentrations in sea water are referred to in our introduction.