

anticipated that the position of the vapor-saturated liquidus surface would be rather similar with CaCO₃ instead of Ca(OH)₂, and spurrite instead of calciochondrite. Liquidus temperatures would be somewhat higher throughout the system, because CO₂ is less soluble in these liquids than H₂O, and calcite in the presence of CO₂ melts at 1310°C instead of 785°C for portlandite in the presence of H₂O. The thermal divide corresponding to XYB should persist in the CO₂ system. It may therefore be concluded that liquids with compositions richer in SiO₂ than XYB in Fig. 7 with CO₂ as an additional component, are unable to yield low temperature residual liquids by fractional crystallization, and these liquids are therefore unable to precipitate carbonated and hydrated phases. Only liquids with compositions poorer in SiO₂ than XYB are capable of yielding through fractional crystallization residual liquids that precipitate carbonated and hydrated phases.

The high temperature silicate liquids that precipitate forsterite, pyroxenes, and monticellite may be compared with ultrabasic magmas, and the low temperature hydrated or carbonated liquids may be used as a model for carbonatite magmas. The results presented in this paper thus indicate that normal peridotite or kimberlite magmas (if these exist in nature) are incapable of producing a carbonatite magma as a residue from fractional crystallization.

When CO₂ replaces H₂O as a component, complexities arise involving the decarbonation reactions. Intersection of the decarbonation reactions involving silicate minerals such as forsterite and monticellite with the melting reactions will permit these minerals to crystallize in two different environments: on the SiO₂ side of the thermal divide XYB, as shown in Fig. 7, and also on the low temperature side of this thermal barrier, alongside calcite. This introduces all kinds of additional possibilities (FRANZ, 1965). Finally, it must be mentioned that the presence of alkalis in the system may modify the paths of crystallization considerably (WYLLIE, 1965), and a liquid corresponding to an alkali peridotite magma may be able to bypass the thermal divide XYB and yield a carbonated residual liquid by fractional crystallization.

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REFERENCES

- DAVIDSON C. F. (1964) On diamantiferous diatremes. *Econ. Geol.* **59**, 1368–1380.
 DAWSON J. B. (1964) Carbonate tuff cones in northern Tanganyika. *Geol. Mag.* **101**, 129–137.
 ECKERMANN H. VON (1948) The alkaline district of Alno Island. *Sverig. geol. Unders. Ser. Ca*, No. 36.
 ECKERMANN H. VON (1958) The alkaline and carbonatitic dykes of the Alno formation on the mainland northwest of Alno island. *Kungl. Svensk. Vetensk. Handl., Fj. ser., Bd. 7*, 61 p.
 FRANZ G. W. (1965) Melting relationships in the system CaO-MgO-SiO₂-CO₂-H₂O: a study of synthetic kimberlites. Ph. D. thesis, The Pennsylvania State University.
 GARSON M. S. (1962) The Tundulu carbonatite ring-complex in southern Nyasaland. *Geol. Survey Nyasaland, Mem.* **2**, 248 p.
 HAAS J. L. and WYLLIE P. J. (1963) The system CaO-SiO₂-CO₂-H₂O. 1. Melting relationships in the presence of excess vapor (abstract). *Trans. Amer. Geophys. Un.* **44**, 117.
 HARKER R. I. (1964) Differential thermal analysis in closed systems at high hydrostatic pressures. *Amer. Min.* **49**, 1741–1747.

- KENNEDY G. C., WASSERBURG G. J., HEARD H. C. and NEWTON R. C. (1962) The upper three-phase region in the system $\text{SiO}_2\text{-H}_2\text{O}$. *Amer. J. Sci.* **260**, 501-521.
- MUAN A. and OSBORN E. F. (1965) *Phase Equilibria among Oxides in Steelmaking*. Addison-Wesley, Reading, Mass.
- SAETHER E. (1957) The alkaline district of the Fen area in southern Norway. *Norsk. Vidensk. Selsk. Skrift* **1**.
- TUTTLE O. F. (1949) Two pressure vessels for silicate-water studies. *Bull. Geol. Soc. Amer.* **60**, 1727-1729.
- WYLLIE P. J. (1965a) Melting relationships in the system $\text{CaO-MgO-CO}_2\text{-H}_2\text{O}$, with petrological applications. *J. Petrol.* **6**, 101-123.
- WYLLIE P. J. (1965b) Experimental data bearing on the petrogenetic links between kimberlites and carbonatites. Proc. Int. Miner. Assoc., New Delhi, 1964. *Indian Min.*, in press.
- WYLLIE P. J. and HAAS J. L. (1965) The system $\text{CaO-SiO}_2\text{-CO}_2\text{-H}_2\text{O}$: 1. Melting relationships with excess vapor at 1 kilobar pressure. *Geochim. et Cosmochim. Acta* **29**, 871-892.
- WYLLIE P. J. and RAYNOR E. J. (1965) D.T.A. and quenching methods in the system $\text{CaO-CO}_2\text{-H}_2\text{O}$. *Amer. Min.*, in press.
- WYLLIE P. J. and TUTTLE O. F. (1960) The system $\text{CaO-CO}_2\text{-H}_2\text{O}$ and the origin of carbonatites. *J. Petrol.* **1**, 1-46.
- YODER H. S. (1958) Effect of water on the melting of silicates. *Carnegie Inst. Wash. Y. B.* **57**, 189-191.