

## The zeolite facies, with comments on the interpretation of hydrothermal syntheses

D. S. COOMBS, A. J. ELLIS,\* W. S. FYFE and A. M. TAYLOR  
Departments of Geology and Chemistry, University of Otago, New Zealand

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**Abstract**—Field, petrographic and experimental evidence is presented on assemblages involving Ca–Al and Na–Al silicates, warranting recognition of a zeolite facies. This facies largely bridges the gap between diagenesis and conventional metamorphism. The metamorphic geology of the New Zealand Geosyncline is reviewed and zeolite facies rocks are shown to be of regional extent. They include lower grade heulandite–analcime–quartz assemblages and higher grade laumontite–albite–quartz in tuffs and volcanic greywackes. Thomsonite is found in basic igneous rocks of the Otama Complex. Separating the zeolitic rocks from typical greenschists is a broad belt with quartz–prehnite and quartz–pumpellyite assemblages.

The significance of zeolite sequences in amygdaloids is often a matter of doubt, but zeolite occurrences in sedimentary rocks, active thermal areas, alkaline igneous rocks and miscellaneous joints and cavities lend some support to two broad generalizations: firstly the water content relative to  $(\text{Ca}, \text{Na}_2)\text{O} \cdot \text{Al}_2\text{O}_3$  tends to increase for lower temperatures of formation in accordance with theoretical expectations based on entropy; secondly zeolites can be divided into three groups based on silica content: those whose occurrence is favoured by an environment supersaturated in silica, those that often coexist with quartz, and those favoured by silica-deficient environments.

The common species in the Wairakei thermal area are mordenite and wairakite, both of which are readily synthesized whereas laumontite and heulandite, typical of regional metamorphism, are not readily synthesized. This fact, together with the profound influence of starting materials on reaction products in hydrothermal syntheses, emphasizes the lack of equilibrium in our experiments, even in runs of 30 days. The field of high-silica phases such as mordenite is extended when the silica activity is higher than that of quartz. The effect of differing  $P_{\text{load}}$  and  $P_{\text{H}_2\text{O}}$  on important transitions such as analcime + quartz = albite + water is explored on theoretical grounds. Experiments place the reaction temperature at 280°C at 1000 bars water pressure, but the equilibrium temperature may be much lower. Preliminary solubility work indicates a reaction temperature near 200°C at saturated water vapour pressure. Under conditions where load pressure equals three times the water pressure the temperature may be lowered by about 200°C. The upper limit of the zeolite facies is believed to be about 300°C, when water and load pressures are approximately equal.

Fields of synthesis are given for the following: analcime–wairakite series, Na–Ca mordenite series, epistilbite, prehnite and an unidentified phase Z. Phillipsite was synthesized from chabazite. The upper limit of thomsonite is considered to be near 300°C where it breaks down to anorthite.

The range of composition and density of naturally-occurring zeolites is reviewed. New analyses and optical data are given for heulandite from Cape Blomidon, Nova Scotia, and for prehnite from Prospect Quarry, New South Wales.

### 1. INTRODUCTION

(W. S. F., D. S. C.)

THE writers consider that mineral assemblages in which zeolites are characteristic are of such widespread occurrence that a new mineral and metamorphic facies, the zeolite facies, should be recognized, as has recently been proposed by TURNER (in FYFE *et al.*, 1958). Field and laboratory studies indicate that the range of conditions under which the mineral assemblages of this facies form are at least as extensive as for other recognized major facies. The zeolite facies bridges a wide gap between sedimentary processes and the hitherto recognized metamorphic facies and it allows a more complete model of the evolution of metamorphic rocks in progressive regional metamorphism to be developed.

\* Now at Dominion Laboratory, D.S.I.R., Wellington.