Oppenheim, M. J. (1962), The spindle stage: a modification using a hypodermic syringe. *Am. Mineral.* **47,** 903–906.
Tocher, F. E. (1962) Extinction curves and 2V: a stereographic solution. *Mineral. Mag.* **33,** 52–58.
——— (1964) Direct stereographic determination of the optic axes from a few extinction measurements: a progressive elimination technique. *Mineral. Mag.* **33,** 780–789.
Vincent, H. C. G. (1954) An accessory to the polarizing microscope for the optical examination of crystals. *Mineral. Mag.* **30,** 513–517.
——— (1958) An improved orientation stage for microscopic optical crystallography. *Nature,* **181,** 693.
Wilcox, R. E. (1959) Use of the spindle stage for determining refractive indices of crystal fragments. *Am. Mineral.* **44,** 1272–1293.
——— (1960) Optic angle determination on the spindle stage. *Bull. Geol. Soc. Am.* **71,** 2003.
Wright, H. G. (1965) The petrographic use of the spindle stage and focal plane screening in the determination of the optical variation of some zoned minerals. *Mineral. Mag.* **35,** 656–660.

THE AMERICAN MINERALOGIST, VOL. 51, MAY-JUNE, 1966

UPPER STABILITY OF MUSCOVITE

B. Velde,[1] *Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C.*

Introduction

Muscovite is an important constituent of metamorphic rocks and is common in acidic igneous rocks. It is one of the first minerals to form in the metamorphism of pelitic sediments, and its disappearance marks higher grade metamorphic assemblages. A knowledge of its upper thermal stability, therefore, is useful to the petrologist.

Determinations of the stability of muscovite have been made previously by Yoder and Eugster (1955) and Crowley and Roy (1964) and of muscovite+quartz by Segnit and Kennedy (1961). All three studies reported the observed breakdown of muscovite but not the formation of muscovite from its anhydrous breakdown products, sanidine and corundum, near the breakdown temperature. Thus the establishment of equilibrium was not demonstrated. The recent work of Evans (1965) gives a determination of the upper stability of muscovite at 2 and 3 kb. These results (Evans, 1965) agree closely with those of the present study. It is interesting to note that Evans' experimental method was based upon reaction reversal.

---

[1] Present address: Laboratoire de Petrographie, Sorbonne, 1 rue Victor Cousin, Paris 5, France.

In the present study reversals of the reaction

$$\underset{\text{Muscovite}}{KAl_3Si_3O_{10}(OH)_2} \rightleftarrows \underset{\text{sanidine}}{KAlSi_3O_8} + \underset{\text{corundum}}{Al_2O_3} + \underset{\text{vapor}}{H_2O}$$

were accomplished within a range of 20° C. or less at five different total water pressures, thus demonstrating equilibrium for the reaction. Synthetic and natural micas were used, giving close agreement between the results.

EXPERIMENTAL METHOD

Various techniques were used at different pressures to obtain the desired hydrothermal conditions. At pressures of 160, 1000, 2000, and 8000 bars the starting materials, liquid and solid, were sealed in platinum tubes by arc-welding the ends. The sealed tubes were weighed before and after the experiments as a check on the possibility of compositional change during the experiment. The experiments at a water pressure of 1 bar were carried out in unsealed crimped tubes.

The starting materials used were of four types—synthetic muscovite, kaolinite+KOH, natural muscovite, and synthetic sanidine+corundum. Muscovite was synthesized from a mixture of pure kaolin (<0.42 weight per cent impurities)+KOH (<0.04 weight per cent impurities). Its diffraction pattern showed the presence of a $1M+2M_1$ polymorph mixture (for a discussion of these polymorphs see Yoder and Eugster, 1955). A natural muscovite from a pegmatite mine, Harney Peak, Black Hills, South Dakota, having a $2M_1$ polymorph, cell dimensions and optical properties of muscovite (Velde, 1965) was used as the natural mica. This mica was also used to produce the anhydrous phases sanidine+corundum. A partial chemical analysis (analyst, N. D. Berlin of Andrew S. McCreath and Sons, Inc.) indicated considerable sodium in the mica.[1] However, cell dimensions and $c \sin \beta$ $(00l)$ x-ray reflections of both the natural mica and all phases synthesized indicated the presence of muscovite and not paragonite or a sodium-bearing mica. The analysis is therefore believed to be in error for at least a part of the indicated sodium content.

Sanidine+corundum was synthesized from the natural muscovite by heating to 1000° C. in air for 12 hours or more. X-ray diffraction patterns did not detect mica, but optical studies revealed that about 10 per cent 5 μ diameter flakes of muscovite remained. For each experiment 10 to 15 mg of distilled water was added to about 70 mg of solids.

In the experiments at 1, 160, 1000 and 2000 bars temperatures were

---

[1] Muscovite analysis (weight per cent): SiO_2, 45.10; Al_2O_3, 36.46; MgO, trace; Fe_2O_3, 0.77; TiO_2, 0.05; K_2O, 9.64; Na_2O, 1.01.

maintained by furnaces that heated cold-seal bombs externally (Tuttle, 1949). The furnaces were controlled during the experiments by on-off type regulators which were sensitized by thermocouples of the chromel-alumel type or by motor-driven variable transformers which were sensitized by furnace resistances. The temperatures were measured with calibrated chromel-alumel thermocouples. An internally heated bomb was used in the 8000-bar experiments (Yoder, 1950). Errors through measurement or control inaccuracies were on the order of ±6° C. for the duration of each experiment.

Pressures were maintained by various methods depending upon the range of pressure needed. The experiments at 1 bar were conducted with the system open to a reservoir of water which was at atmospheric pressure and about 25° C. External static pressure was maintained by tank nitrogen for the experiments at 160 bars. Pressures of 1000 and 2000 bars were maintained by pumped water, and 8000-bar pressures by pumped argon. Errors in stated pressures are 6 per cent or less.

Identification of new phases was rather difficult because slow reaction rates produced small amounts of material during 3-week experiments. The breakdown of synthetic and natural muscovite starting material was considered to be demonstrated when 15 to 20 per cent of the run was sanidine+corundum as determined by optical examination. New grains of sanidine were on the order of 10 μ in diameter, and corundum grains were smaller, rarely giving unique *x*-ray diffraction reflections. The production of muscovite was determined by *x*-ray diffraction means and was based upon the presence of a 10 Å reflection. Small amounts ($\sim$10 per cent) of muscovite as determined optically in synthetic sanidine+corundum starting material probably provided seed crystals for muscovite growth under hydrothermal conditions. The results of both reactions agree well and are therefore considered valid.

DATA

The temperatures at which the reaction occurred are given in Table 1. These are the temperatures where the reaction sanidine+corundum $+H_2O \rightarrow$ muscovite and its reversal were observed to take place, giving a bracket or temperature interval in which the reaction can be said to occur. Figure 1 is a plot of these temperature ranges *vs.* total water pressure ($\cong P$ total). The dashes on either side of the temperature interval represent estimated errors of ±6° C.

This note on the stability of muscovite proposes only a revision of the maximum stability curve of muscovite in the presence of H_2O under physical conditions of $P_{H_2O} \cong P_{total}$ in the range 1 to 8000 bars. It is expected that muscovite+quartz would react to form a potassium feldspar,

TABLE 1

P_{total}, bars	Time, days	T, ° C.	Starting material	Product
1	21	550	musc	mica
1	21	560	musc	mica
1	21	570	musc	mica+S+C
1	21	560	S+C	S+C
1	21	550	S+C	S+C+mica
			reaction interval (550–570) ± 6° C.	
160	21	611	kaol+KOH	mica
160	21	620	kaol+KOH	mica
160	21	630	kaol+KOH	mica+S+C
160	21	610	S+C	S+C+mica
			reaction interval (610–630) ± 6° C.	
1000	12	650	kaol+KOH	mica
1000	7	660	kaol+KOH	mica+S?+C?
1000	12	610	kaol+KOH	mica+S+C
1000	12	645	S+C	S+C+mica
1000	8	655	S+C	S+C
1000	15	650	musc	mica
1000	20	660	musc	mica+S+C
			reaction interval (650–670) ± 6° C.	
2000	10	670	kaol+KOH	mica
2000	15	685	Synthetic musc	S+C+mica
2000	10	700	Synthetic musc	S+C+mica
2000	90	675	musc	mica
2000	15	685	musc	mica
2000	15	700	S+C	S+C
2000	10	715	Synthetic musc	mica+S+C
			reaction interval (675–700) ± 6° C.	
8000	.1	720	S+C	mica
8000	.1	720	kaol+KOH	mica
8000	.1	720	musc	mica
8000	.1	735	S+C	S+C+mica
8000	.1	735	kaol+KOH	mica+S+C
8000	.1	735	musc	mica+S+C
			reaction interval (720–740) ± 6° C.	

Pressures ± 6% or less.
Symbols

kaol = kaolinite
musc = $2M_1$ natural muscovite
Synthetic musc = Synthetic muscovite
S+C = Sanidine plus corundum synthetically produced
mica = identified by a 10 Å diffraction peak.

an aluminosilicate, and vapor at a lower temperature for a given pressure. The reaction corundum+quartz→aluminosilicate has a negative ΔG. This increases the relative stability of the breakdown products which include an aluminosilicate phase. Data given by Segnit and Kennedy (1961), Yoder and Eugster (1955) and Evans (1965) indicate that in fact the stability of muscovite is lowered by the presence of quartz. The reaction muscovite+quartz$\rightleftarrows$feldspar+aluminosilicate+vapor is undoubt-

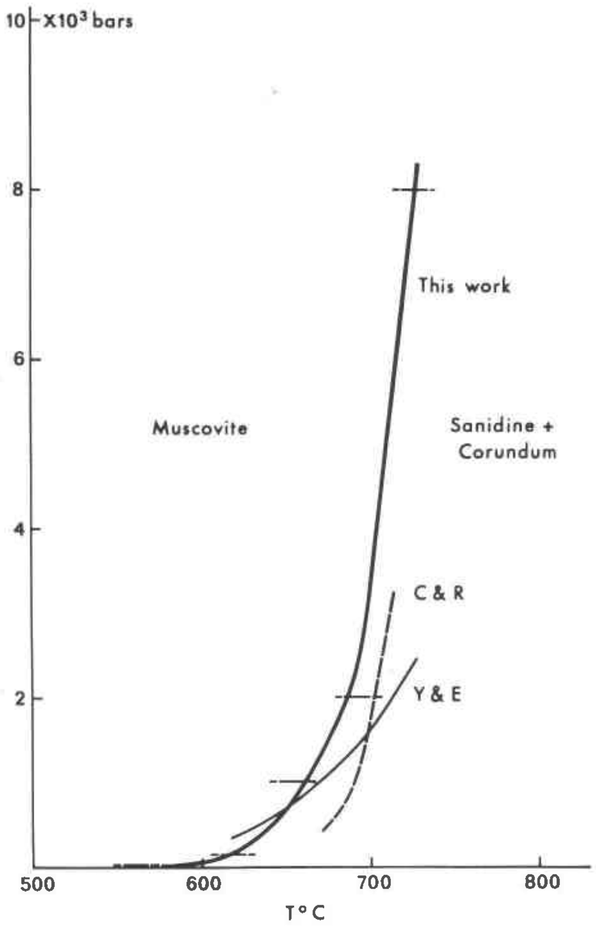

FIG. 1. Upper stability of muscovite as a function of total external pressure on the solids in an aqueous atmosphere. $P_{\text{total}} \cong P_{H_2O}$ temperature intervals are bracketed by estimated experimental error of ±6° C. Y&E, data from Yoder and Eugster (1955). C&R, data from Crowley and Roy (1964).

edly more useful as a limit of muscovite stability since geological environments containing muscovite most often contain quartz as well. The data given here indicate a maximum stability of muscovite.

ACKNOWLEDGMENTS

I would like to thank Dr. D. H. Lindsley of the Geophysical Laboratory for his advice and comments at all stages of the project and Dr. H. S.

Yoder, Jr., also of the Geophysical Laboratory, for the use of his internally heated gas apparatus for the 8-kb experiments.

REFERENCES

Crowley, M. S. and R. Roy (1964) Crystalline solubility in the muscovite and phlogopite groups. *Am. Mineral.* **49,** 348–362.

Evans, B. W. (1965) Application of a reaction-rate method to the breakdown equilibria of muscovite and muscovite plus quartz. *Am. J. Sci.* **263,** 647–667.

Segnit, R. E. and G. C. Kennedy (1961) Reactions and melting relations in the system muscovite-quartz at high pressures. *Am. J. Sci.* **259,** 280–287.

Tuttle, O. F. (1949) Two pressure vessels for silicate-water studies. *Bull. Geol. Soc. Am.* **60,** 1727–1729.

Velde, B. (1965) Experimental determination of muscovite polymorph stabilities. *Am. Mineral.* **50,** 436–449.

Yoder, H. S., Jr. (1950) High-low quartz inversion up to 10,000 bars. *Trans. Am. Geophys. Union* **31,** 827–835.

——— and H. P. Eugster (1955) Synthetic and natural muscovites. *Geochim. Cosmochim. Acta* **8,** 225–280.

THE AMERICAN MINERALOGIST, VOL. 51, MAY-JUNE, 1966

SCHROECKINGERITE FROM AMBROSIA LAKE URANIUM DISTRICT

V. J. Barczak, *Kerr-McGee Oil Industries, Inc., Oklahoma City, Oklahoma.*

Schroeckingerite $NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$, is a secondary uranium mineral named in honor of J. von Schroeckinger, who found (Schrauf, 1873) and later described (Schroeckinger, 1875) the occurrence at Joachimsthal, Bohemia. It since has been reported from a number of localities, including several in the United States. In the Western United States it is found in Sweetwater and Carbon Counties, Wyoming (Larsen and Gonyer, 1937; Vine and Prichard, 1954); in Yavapai County, Arizona (Axelrod *et al.*, 1951); in Grand, San Juan, Emery and Piute Counties, Utah (Weeks and Thompson, 1954; Gruner *et al.*, 1954). It has been reported as occurring in the Ambrosia Lake, New Mexico uranium district by Towle and Rapaport (1952) and Rapaport (1952). This occurrence later was disputed by Gruner *et al.* (1954), who stated the mineral identified as schroeckingerite actually was meta-autunite. The most recent papers on uranium mineralogy in the Ambrosia Lake area (Corbett, 1963) (Granger, 1963) do not mention schroeckingerite as one of the secondary minerals present in that area.

During a recent visit to Kerr-McGee section 22 mine, McKinley