THE ALTERATION OF FELDSPAR AND ITS PRODUCTS AS STUDIED IN THE LABORATORY.

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ABSTRACT. A large amount of research has been done in the laboratory on the alteration of the feldspars and the production of the attendant secondary minerals. This experimental work, covering a period of about twenty years, has been compiled into several phase diagrams which show the influence that acidity, temperature, and the concentrations of aluminum and potassium have on the differential formation of sericite (muscovite), kaolin, and pyrophyllite. The mechanism of formation is also reviewed.

INTRODUCTION.

CONSIDERABLE research has recently been carried on by many workers with the various minerals that occur as alteration products of the feldspars, and it was felt that the results could be brought together graphically so as to present a unified picture. The data are assembled in the accompanying diagrams.

Some of the questions that are pertinent in a study of this kind are the following: What causes the formation of a given mineral, is it chemical-physical environment (modifying process), or parent mineral (provenance)? Are the minerals end members of a continuous series, or do they form directly and separately? And, is the formative process of the alteration products an ionic or a colloidal one?

The formulas and K:Al:Si ratios of the chief minerals dealt with are shown in the following table (5):

Mineral	Formula	K:Al:Si Ratio
Orthoclase	$KAlSi_3O_8$	2: 2: 6
Kaolin	$(OH)_8Al_4Si_4O_{10}$	0: 6: 6
Sericite	$(OH)_2KAl_3Si_3O_{10}$	2: 6: 6
Pyrophyllite	$(OH)_2Al_2Si_4O_{10}$	0: 3: 6

Leucite, $KAlSi_2O_6$; boehmite, $Al_2O_3 \cdot H_2O$; and corundum, Al_2O_3, are also discussed.

Because of the extremely short time available for the alteration products to crystallize under laboratory conditions, and their inherent fineness of grain, they are often somewhat difficult to identify. They do not agree perfectly with the natural minerals in X-Ray and thermal patterns because of their imperfect crystallization (9).

MECHANISM OF FORMATION.

Evidence is rather inconclusive as to whether the formation of these secondary minerals in nature is colloidal or ionic. It has been shown that both types of formation may occur.

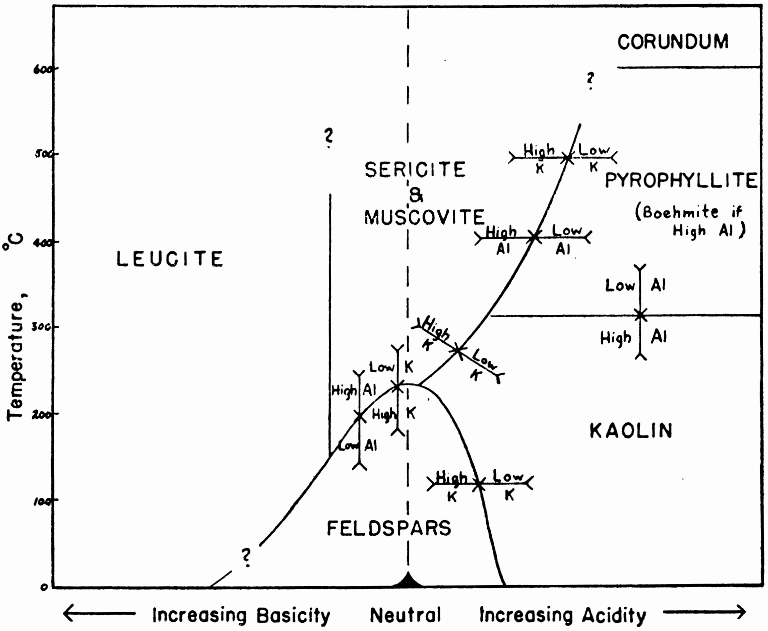

Fig. 1. Effect of temperature and acidity on the alteration of feldspars. Minerals form in the fields indicated. Within these major fields changes in K and Al concentration tend to drive the boundaries in the directions shown by the arrows.

Schwartz and Trageser (13) in 1935 stated that feldspar broke up into colloidal alumina and silica, and that these recombined to form the various hydrous aluminum silicates, depending upon temperature, pressure, and pH. Kaolin actually was formed by Ewell and Insley in 1935 from coprecipitated alumina and silica gels and admixtures of alumina and silica at 310° C. (3).

On the other hand, in 1940 Armstrong (1) ground feldspars very finely in water and electrodialyzed the suspension.

He found that all of the components went into a true ionic solution, and concluded that clays could form in this manner. He confirmed that the rate of solution in minerals is as follows: Ca>Na>K>Si>Al. Gruner (5) stated that the alteration of feldspar to sericite was in the nature of leaching of silica and simultaneous addition of Al and K.

Norton ((9) found that the end products were different depending on the parent minerals, if other conditions remained the same. He felt that the cation of the mineral seemed to govern the end product, and minerals with a lower total alkali content were more stable. In 1941 (10) he also found that break-up occurred to a greater extent in weak acids (CO_2) than in strong ones. The speed of reaction also decreased with greater CO_2 pressure, after a certain point.

Norton (9) also found no evidence of intermediate steps in the reaction that would result from orthoclase forming sericite, kaolin, and gibbsite in that order. The conversion apparently goes directly to a final stable end product. If the environment changes, however, the mineral may under some circumstances be converted to another one more stable.

EXPLANATION OF DIAGRAMS.

The diagrams are intended to show the varying conditions under which the different minerals will form. The problem is made more complex because of the necessity of representing four types of conditions on the same two-dimensional surface. The boundaries are difficult to fix because of the lack of complete data, and therefore must be taken as more or less approximate. Many parts of the fields are unknown. At best the diagrams are of a qualitative nature, but they may serve to unify somewhat the large amount of scattered information on the subject of laboratory feldspar alteration.

In each diagram, two controlling conditions are taken as the vertical and horizontal coördinate axes. The influence of the pair of conditions not shown by the horizontal and vertical coördinates is depicted by the arrows at the field boundaries. The existence of the condition written adjacent to the arrow tends to drive the phase boundary in the direction in which the arrow points. For example, at the kaolin-pyrophillite boundary, an excess of Al favors the formation of kaolin.

STABILITY RANGE OF FELDSPAR.

The stability range of the feldspars is rather uncertain. At many places on the diagrams not included in the feldspar field, feldspars may be metastable. These regions are placed in the fields of the alteration products, however, because it has been found that the specified secondary minerals may form under the given conditions.

Gruner (5) found that in HCl solutions at 300° to 400° C., feldspars did not form but might be metastable, providing K was high enough and no additional Al was available. If the K concentration were too low, it would be altered. However, Gruner also decomposed feldspars from 350° C. on up if K and Al were both great enough. Under neutral or somewhat basic conditions, feldspar may also be stable. Components of feldspars were differentially leached out by long grinding in cold water, but Armstrong (1) reports no new minerals formed. Norton (9), in experiments with high temperatures and pressures and CO_2 charged water, concluded that feldspars were stable below 250° and above 350° C. under those particular conditions.

KAOLIN FIELD.

Gruner (5) reports that kaolin forms below 350° C. in HCl solutions, and is stable below that temperature regardless of the K concentration, providing the Al:Si ratio is approximately 1:1. If there is less aluminum, kaolin will not form in the higher range. An excess of K prevents the change of muscovite to kaolin (4). Kaolin will not alter to muscovite at 300° C., however, even with a very large amount of KCl. Lindgren (6, 7) states that kaolin forms in hot or cold acid waters and is not stable in alkaline solutions. That kaolin may form in neutral solutions was shown by Ewell and Insley (3) when they produced it from alumina-silica gels at 310° C.

MUSCOVITE-SERICITE FIELD.

Gruner (4) found that muscovite formed from 350° C. and up to above 525° C. in HCl solutions if K and Al were in excess. If KCl dropped below a certain limit, muscovite altered to kaolin. The kaolin-muscovite boundary lies at about 350° C. to 360° C. for p.l N HCl, and as acidity decreases muscovite probably forms at lower and lower temperatures but does not reach 300° C. at 0.05 N. Muscovite forms in neutral solutions at a temperature as low as 200° C. and in somewhat basic solutions also at relatively low temperatures. Bateman (2) and Lindgren (6, 7) agree that heated alkaline solutions develop sericite.

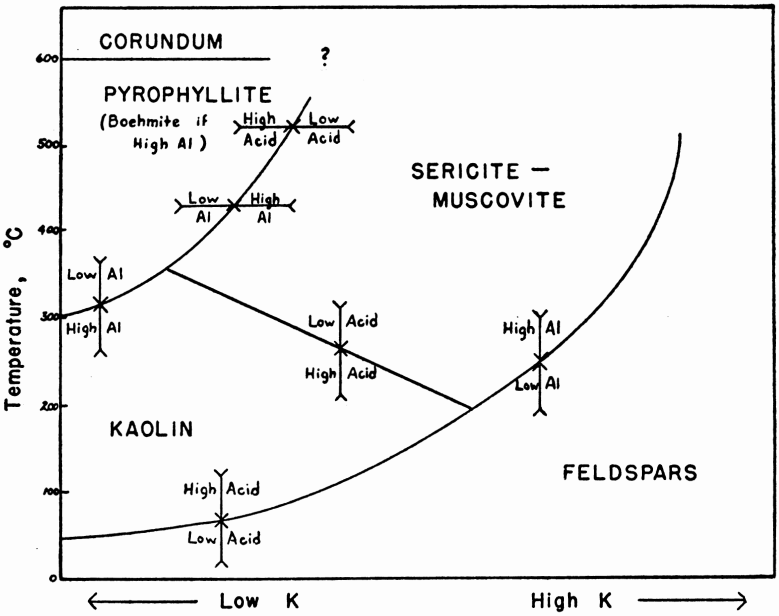

Fig. 2. Effect of temperature and potassium concentration on the alteration of feldspars. Minerals form in the fields indicated. Within these fields changes in Al concentration and in acidity tend to drive the boundaries in the directions shown by the arrows.

PYROPHYLLITE FIELD.

Gruner states (5) that pyrophyllite forms from about 300° C. on up to over 525° C. in acid solutions. From 300°-350° C., kaolin will form unless the Al:Si ratio is considerably less than 1:1. If K is rather low, pyrophyllite will form from feldspar at 400° C., but if K is increased no alteration takes place.

FIELDS OF BOEHMITE, CORUNDUM, AND LEUCITE.

Boehmite apparently forms over the same temperature range as pyrophyllite, i.e., from 300° C. to 550° C., in HCl solutions, the difference in the production of the two minerals depending on the Al concentration (5). If there is considerable Al at 300° C., kaolinite will form and the excess Al will go to form boehmite.

Corundum was found by Schwartz and Trageser (13) to form above 600° C. in acid solution, if the Al concentration was high.

In basic solutions, kaliophilite or leucite will form at 300 °C. to 400° C. (5).

CONCLUSIONS AND ACKNOWLEDGMENTS.

In conclusion, it will be seen that kaolin forms in acid solutions up to about 350° C. if Al is rather high and K is low; muscovite forms from as low a temperature as 200° C., through 525° C. in slightly basic and rather acid solutions if K and Al were high; and pyrophyllite forms from about 300° C. up to 550° C. if Al and K are both low. It appears thus that the Al:Si ratio and the K concentration are very important in determining which mineral will form, since, if the temperature and acidity are proper, that mineral will be stable whose formula most closely resembles the composition of the solution around it.

In most conditions of hydrothermal alteration around ore deposits, sericite is formed because most metallizing solutions are alkaline. Kaolin, however, is formed near the surface by acid waters (7), and may replace sericite through leaching with carbonate and sulphate waters. The formation of pyrophyllite in nature may be rare because there is probably much Al available in solution. However, it may in addition be easily mistaken for sericite under the microscope (5).

None of the workers attempted to differentiate between sericite and illite. Since illite can form under a variety of conditions, including possibly acid waters near the surface (P. D. Krynine, personal communication), this aspect of the problem of feldspar alteration deserves considerable additional study.

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