form of partially altered massive scapolite mixed with calcite. It seems probable that the petalite originally found here was from an erratic similar to the spodumene boulder found in Sterling, Massachusetts.

Graphite and magnetite both occur sparingly in thin veins in the gneiss, and in altered scapolite rock.

Spinel in small blue-gray octahedrons occurs in the limestone in the usual close association with chondrodite.

Rutile, doubtfully identified as rod-like inclusions in gray scapolite, and quartz, abundant in massive form in the pegmatite, complete the list of oxide minerals recognized.

Sulphides sparingly present in minute grains in the limestone include arsenopyrite, chalcopyrite, pyrite, and pyrrhotite. The first three were identified by crystal form under the binoculars as well as by other tests.

Apatite of a pale green color is common throughout the deposit in crystals ranging in size from microscopic needles to prisms three inches in length. It was seen in massive scapolite, in boltonite rock, and in druses with titanite and diopside. It appears always to have formed at an early stage of crystallization. Some gray crystals contain the rod-like inclusions thought to be rutile also seen in scapolite.

Fluorite, yttrocerite and cerium ochre are names of minerals reported from Bolton but not identified in the collection studied.

THE FORMATION OF KAOLIN AT MODERATE DEPTHS[1]

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In an intelligent discussion of the formation of kaolin it is necessary to consider the minerals from which kaolin may be formed, the reagents that will change these minerals to kaolin, the source of these reagents, and the minerals that will be formed simultaneously with the kaolin.

In the present paper the writer will attempt to indicate the type of minerals from which kaolin may be formed with an outline of the probable reactions and a summary of the results of some of the reactions. In addition attention will be drawn to two kaolin

[1] Read at the meeting of the Mineralogical Society of America, Ann Arbor, Michigan, Dec. 29, 1922.

deposits which in his opinion are due almost entirely to the action of carbon dioxide and surface water.

Inasmuch as kaolin is a hydrous silicate of alumina it is at once evident that the original material must contain aluminium and silica and observation has shown that the feldspars and feldspathoid minerals are the principal ones involved. Under some conditions the micas may be concerned though it is difficult to conceive of muscovite as a source of kaolin in view of its well known resistance to acids.

To account for the formation of kaolin it is necessary to provide an acid reagent which together with water will remove the alkaline element and hydrate the aluminium silicate. Simple hydrolysis has been suggested by some writers but the reactions given leave the feeling that granite ought not to outcrop on lakes and rivers if this is a serious factor. It may be argued that this reaction is effective only under pressure, but in that case it may be eliminated as an important factor in this discussion which deals only with deposits of moderate depth, that is not more than six hundred feet.

The possible acids that may be involved are sulphuric, nitric, hydrofluoric, hydrochloric, phosphoric, boracic, carbonic, and hydrogen sulphide. Certain humous acids are also suggested in the case of fire clays underlying coal deposits. Of these, nitric and boracic acids are probably best eliminated as serious factors in view of the low percentage of nitrates and borates commonly found in surface waters, either lake, river, or ocean. Such borates, or borosilicates as are found in kaolin deposits give no evidence of having been connected with the formation of kaolin (e.g. tourmaline).

Phosphoric acid is more abundant but is usually combined with lime, and is associated with the feldspars in the form of apatite which crystallized before the feldspar so that we must conceive of peculiar conditions that would permit of a reaction that would permit phosphoric acid to be active as a kaolinizing agent. Another discouraging factor in this connection is the remarkably small percentage of phosphoric acid present in the ordinary feldspathic rock. In case, however, there were a phosphate deposit in contact with an igneous rock a reaction that looks possible, in case nothing were present but the feldspar and phosphate, is as follows:

$$Ca_3P_2O_8 + 6KAlSi_3O_8 + 6H_2O = K_6P_2O_8 + 3H_4Al_2Si_2O_9$$
$$+ 3CaSiO_3 + 9SiO_2$$
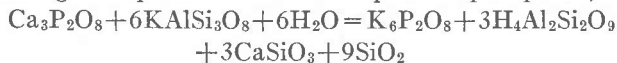
Kaolin is supposed by some writers to be due to sulphate solutions and an examination of the analyses of river and lake waters gives some ground for this supposition, but when the solubilities of sulphates, chlorides, and carbonates of lime, magnesia, soda and potash, are considered it is at once evident that except when the water drains an igneous region such data are of little value in determining the acid that is of most importance in the kaolinization of a feldspar.

Lindgren[2] in advocating the influence of sulphuric acid in the formation of kaolin indicates rather definitely that kaolin is not formed by metasomatic action as at depth sericite and carbonates are found, while nearer the surface sericite and adularia occur and only still nearer the surface is kaolin found. His mention of alunite as one of the minerals in this upper region, however, rather weakens his argument for sulphuric acid as a kaolinizing agent.

The fundamental fact in this connection appears to be that the common soluble sulphates that may be considered are ferrous and ferric sulphates which would necessitate either the precipitation of ferric oxide with the solution of the alkali or the substitution of the iron for the alkali. In the case of a pure white kaolin deposit neither of these conditions is permissible. Gypsum is out of the question as a reagent although it may form as a result of the action of sulphates on lime feldspar, possibly with the simultaneous formation of kaolin. The normal reaction when sulphate solutions attack orthoclase so far as observed by the writer result in the formation of alum or alunite and silica without kaolin. This is the reaction involved in the production of the "Iron Hat."

In the case of the chloride solutions it must be noted that free hydrochloric acid is extremely rare and there is a tendency for chloride solutions to become rich in soda at the expense of potash without marked kaolinization. This is well shown by the action of Sonstadt's solution on certain zeolites[3] and is probably the principal reason for the low potash content of sea water.

The action of hydrofluoric acid is suggested by some writers. This is possible but highly improbable as an important factor as it necessitates deposits of fluorides commensurate with the kaolin deposits. Collins[4] prepared kaolin artificially by means of hydro-

[2] Mineral Deposits, p. 457.

[3] Walker, T. L., *Am. Min.*, 7, 100-102, 1922.

[4] Collins, J. H., *Min. Mag.*, *VII*, p. 213.

fluoric acid with the simultaneous formation of potassium fluoride and silica. No suggestion is given as to later reactions of the potassium fluoride on the rocks if this reaction occurs in nature. Inasmuch as potassium fluoride is unknown and hieratite is one of the extremely rare minerals it seems better to look for a more satisfactory reaction. In case anorthite were the feldspar two parts of hydrofluoric acid and one part of water would suffice to form fluorite and kaolin. The presence of fluorite and topaz in kaolin cannot, however, be looked upon as proof that the hydrofluoric acid was involved in the formation of the kaolin. With our knowledge that fluorite granite is not uncommon it requires definite proof that the fluorite is secondary. It is also difficult to conceive what reactions would result in the simultaneous formation of topaz and kaolin. Certainly the fluorine that is involved in the formation of topaz is not to be considered as a kaolinizing reagent.

The one common acid that remains to be considered is carbonic, which in the writer's opinion is responsible for most of the kaolinization that is shown by surface deposits. The extension of this reaction to depth requires explanation, for the writer has observed the results of this reaction at a depth of 540 feet. It will extend just so far as there is free circulation of water and just so long as there is a supply of carbonic acid. It can hardly be expected that the small quantity of carbonic acid that would be carried into a fissure by rain water will have a very pronounced effect. The effect will be directly proportional to the quantity of water and carbonic acid. If there is a source of carbonic acid that can be drawn upon to supplement that brought in by rain the action will be more extensive.

In the case of the kaolinized diabase dyke at the Helen iron mine which has been described by the writer, the reaction resulted from the oxidation of a large body of siderite which set large quantities of carbonic acid free while the iron formed goethite.[5] This dyke is completely kaolinized at a depth of 300 feet and at the sixth level (about 450 feet) partial kaolinization was observed. On the surface at the edge of the iron ore body the diabase is perfectly fresh and no trace of decomposition was observed. At a depth of 540 feet another body of kaolin was found where the wall rock of feldspathic sericite schist had been kaolinized. In this

[5] *Ont. Bur. Mines, XXIV* Ann. Rep. 1915, Pt. 1, pp. 192-194, and 202-204.

case the recalculation of the analysis shows almost equal parts of kaolin, sericite, and quartz, with about seven percent of goethite, thus showing rather conclusively that the feldspars are more liable to kaolinizing agencies than sericite or muscovite. Chemical activity was rather marked as the ore was warm to the touch and steam was abundant in the lower levels. The mine waters carried certain iron sulphates as a result of the oxidation of pyrite, and this might give rise to the idea that sulphate solutions were the cause of the kaolinization, but as the siderite has been completely oxidized and only a small part of the pyrite has been oxidized and the percentage of pyrite is usually quite small it seems unreasonable to give undue prominence to the action of the sulphates.

The second of these deposits at the Helen mine verges on the deep seated type of some writers as it is more than one hundred feet deeper than the workings at the Cornwall kaolin mines.[6]

In the case of the kaolin deposits at Huberdeau, Quebec, the source of the carbonic acid would appear to the writer to be a crystalline limestone which is separated from the kaolinized granite and gneiss by a shattered quartzite. Even with the extent of the quartzite the amount of carbonic acid that would be normally introduced from the surface can hardly be looked upon as a sufficient explanation of the very complete kaolinization that is known to extend to a depth of one hundred feet as shown by the workings. In this case it would appear to the writer that in addition to the normal reaction resulting in the formation of potassium carbonate, kaolin and metasilicic acid there was a reaction between the metasilicic acid and the limestone with the formation of diopside or wollastonite and carbonic acid which supplemented the CO_2 in the rain water which gained access to both types of rock through the porous quartzite. In the quartzite there are frequent particles of kaolin which has given rise to the idea that the kaolin must have been brought in probably from below. In view of the frequent presence of feldspar in sandstones and sands this idea seems unnecessary to explain the presence of kaolin in quartzite.

In case it is granted that carbonic acid is ever active in the process of kaolinization it would seem to the writer that in these two cases the ideal conditions exist for it to be most effective, for there is a large potential supply of carbonic acid, there is plenty of water (both mines are wet). In the first case the acid is released by oxi-

[6] Ries, H., Clays, Their Occurrence, Properties and Uses, Second Ed., p. 6, 1908.

dation of iron carbonate. In the second case it is assumed that a reaction that is usually attributed to contact metamorphism can also take place in the wet way at a temperature low for metamorphism but yielding products that are warm to the touch.

STANNITE, ITS ASSOCIATED MINERALS AND THEIR PARAGENESIS

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INTRODUCTION

Recently in examining polished surfaces of stannite with a reflecting microscope the writer was impressed by the variety of included minerals, and by the uniform nature of the associations in specimens from the various districts. Further studies were made on all the available specimens with the results noted here. The writer is indebted to Dr. E. Steidtmann of the University of Wisconsin for the use of some of the material.

OCCURRENCE OF STANNITE

Stannite is listed in textbooks of mineralogy as a rare mineral due to its known occurrence in but few districts. However, it occurs in considerable amounts locally in these districts especially in Bolivia. Dana[1] lists stannite from several places in Cornwall, England, Zinnwald in the Erzgebirge, and the Cronebare Mine, County Wicklow, Ireland; also from Bolivia and the Black Hills, S. D. It has been described from Tasmania and Australia,[2] from the Bolivian[3] tin-silver deposits, and from one locality on the Seward Peninsula, Alaska.[4]

[1] Dana, E. S., System of Mineralogy. Sixth Edition, p. 83 and App. I.

[2] Andrews, E. C., The Geol. of the New England Plateau, New S. Wales. *Geol Sur. Rec.*, **8**, 146, 1905.

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[3] Stelzner, A. W., Die Silber-Zinnerzlagerstatten Bolivias. *Z. deut. Geol. Ges.*, **49**, pp. 53-142, 1899.

Singewald, J. F. and Miller, B. L. The Mineral Deposits of South America. McGraw-Hill Book Co., **1919.**

[4] Knopf, A., Geol. of the Seward Peninsula Tin Deposits. *U. S. Geol. Sur.*, Bull. **358,** 18, 1908.