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EQUILIBRIUM STUDIES WITH CERTAIN ACIDS
AND MINERALS AND THEIR PROBABLE
RELATION TO THE DECOMPOSITION
OF MINERALS BY BACTERIA

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INTRODUCTION

The importance of the bacterial population to the soil is well recognized. The rôle of micro-organisms in the processes of ammonification, of nitrification, and of nitrogen fixation has been the subject of so much investigation, and has been reviewed so often in the literature that it is generally accepted as fact. The influence of bacterial life, or of the end-products resulting therefrom, causing as it does the solution of necessary plant nutrients from the mineral particles within the soil, has been the object of much speculation, some of which has been substantiated by experiment. Aside from this effect of bacteria upon the mineral particles within the soil, there is some reason for believing that rocks may undergo disintegration and degradation into soil through the action of bacteria. This subject has been discussed and investigated at some length by various writers, whose work will be mentioned later.

The formation of the mineral portion of the soil is due to the operation upon the rock mass of three general factors, namely, changes in

physical environment, chemical action, and biological activity. The first of these exerts so apparent an influence upon rocks that it has long been recognized and subjected to careful investigation by geologists. As applied to soils, these effects belong in the realm of the soil physicist and therefore will not be considered in this paper.

The chemical agencies chiefly instrumental in breaking down and dissolving mineral material are water, solutions of varying amounts of NH_3 and CO_2 , various salts, organic acids, and organic compounds. The effect of solutions, especially of neutral salts, has been the subject of extensive investigation. This work will be reviewed later in the section of this paper dealing with method of attack and theory.

Certain biological activities are generally acknowledged to be operative in breaking down the rock mass and preparing it for use as a suitable medium for the growth of plants. Some of these are mechanical, such as the manifest action of roots in prying apart portions of rock. Other effects on rocks are far less easily discernible, due to the slight action of a vast population of microscopic flora found upon rock in all stages of its decomposition. The growth of algae, both alone and in their symbiotic relationships with the lichens, may aid, through the effect of respiration products, in the solution of minerals. It is likely, however, that the more important office of these simple green plants is to serve directly or indirectly as a source of energy for the growth of the still smaller organisms—the bacteria—in situations where the supply of organic materials is limited.

A statement concerning the effect of bacteria in rock decomposition was made by Müntz¹ as early as the year 1890. He found bacteria "in the denuded rocks of the Alps, the Pyrenees, the Auvergne, and the Vosges comprising the most varied mineralogical types: granites, porphyries, gneiss, mica schist, volcanic rocks, limestones, and sandstones, Often the action is not confined to the surface, but extends into the depth of the rock mass. This is the case with the so-called rotten rocks of which the particles become disengaged and separate as is often seen in limestones, schists, and granites. . . . In decomposed rocks I have always verified the presence of nitrifying organisms."

Branner² takes issue with Müntz's assumptions, citing the need of bacteria for a large supply of oxygen and nitrogen, and their saprophytic habit as prohibitive of their growth to any extent upon or in rocks. Had Branner's statements been made some years later, they undoubtedly would have been modified by recent information concerning the nitrogen compounds of the fundamental rocks. The investigations of Hall and Miller³ show that part of the nitrogen in certain

clay soils may have been derived from the nitrogen compounds in the rocks from which those soils were formed.

Merrill⁴ mentions bacteria as possible agencies in the decomposition of rocks.

Renault⁵ found bacteria present in coal, and postulates their action in coal beds as that of the transformation of carbonaceous material into methane and hydrogen.

Holland⁶ suggests that the phenomenon of laterization may be due to the action of bacteria, possibly to some specific organism allied to the sulfur and iron bacteria, and gives certain observations which lead to this belief.

Lacroix⁷ makes the following statement: "The bare rocky islet of Cabras, near San Thome in the Gulf of Guinea, is covered with a mantle of slightly ferruginous aluminum phosphate which is sometimes several centimeters thick. This has originated from the interaction of some of the products of bird guano and the underlying rock, aided, doubtless, by microbes."

All the conclusions in the literature mentioned thus far are of a conjectural character and are the result of observation only, no controlled or investigational work having been presented in support of the opinions offered. The most important systematic investigation of the action of bacteria on rocks was undertaken by K. Bassalik⁸, and is reported by him in two papers, *The Decomposition of Silicates by Soil Bacteria*, and *The Decomposition of Silicates by Soil Bacteria and Yeasts*.

The first of these papers is more or less preliminary, the author drawing the conclusion that bacteria are able to derive their necessary mineral nutrients from the feldspars, and that appreciable quantities of unweathered orthoclase are dissolved by bacteria, probably by means of CO₂ produced by the latter.

The second paper reports an elaborate study of the effect of the growth of several organisms upon various minerals. *B. extorquens*, several of the nitrifying organisms, butyric acid bacteria, and yeasts were tried upon twelve widely varying silicates and upon apatite. A partial summary of Bassalik's results is given here:

1. Bacteria are able by means of their products of respiration to cause a significant solubility of pulverized silicates.

2. Those which produce organic acids, as *Clostridium Pasteurianum*, influence more strongly the solubility of the silicates.

3. In the action of micro-organisms upon rocks, the intensity of contact of the organism and the mineral to be dissolved is of greater importance than the various agents of solubility.

4. Thus, *B. extorquens*, which produces only CO₂, has the strongest solvent effect through its close and firm envelope of the mineral particles.

5. Yeasts, which produce much more CO_2 in cultures than *B. extorquens*, cause a smaller solubility because of the absence of the close contact with the mineral particles.

6. The nitrite bacteria are also able to effect a significant solubility of silicates as the result of their physiological property of oxidizing NH_3 , but they affect those minerals rich in *alkaline earths* much more than those rich in *silicates*.

7. The significant solubility of apatite seems to be a property only of those bacteria which produce organic acids, for this mineral is dissolved only in moderate degree by those organisms which produce CO_2 .

8. In the filtrates of the bacterial cultures, especially with *B. extorquens*, can be recovered all the chemical constituents present in the minerals experimented with. Those most easily going into solution are the alkalis, then the alkaline earths and iron, silicic acid much less, and clay the least.

This summary presents some interesting conclusions, and a close review of the paper shows that they are the result of careful work. Bassalik, however, does not get at the fundamental causes of the differences in the effects of organisms. This investigator refers, in conclusions 3, 4, and 5, to the closeness of contact of organisms to the mineral as an important factor in determining the magnitude of the action of *B. extorquens*; but he does not offer plausible proof of this assumption, and it would seem that his conclusion concerning this point may be erroneous. If we have in solution H_2CO_3 from the production of CO_2 by *B. extorquens*, the concentration of the acid should depend upon the partial pressure of the CO_2 above the liquid and the rate of CO_2 production by the organism. The same should be true with the yeast, and as the yeast, according to Bassalik's own statement, produces CO_2 more rapidly than does *B. extorquens*, and if, as he also states, the solubility is effected by the concentration of CO_2 , the yeast should effect the greater solution of the mineral. This should be true, both in the solution culture and in the solution film surrounding the mineral particles, where the organisms are grown upon the moist mineral. Thus it would seem that any greater effect of *B. extorquens* should be attributed to some specific action on the mineral, such as oxidation, hydration, etc., rather than to CO_2 . Furthermore, the bacterial envelope, which is referred to as enclosing the mineral particles, may consist of a gelatinous coating produced from the mineral particle itself, rather than of an aggregate of bacteria (this coating being greater where the action upon the mineral is greater).

In 1915 T. Kawamura⁹ described an organism found in some volcanic material upon one of the mountains of Japan, at an altitude of 6,600 feet. This organism is of special interest as one which has a specific action upon a silicate material. It forms a zoogloeic mass, the ash of which contains an unusually large amount of silica, 8.873 per cent. Kawamura proposed the name *Volcanothrix silicophila* for the organism.

A comprehensive discussion of the action of bacteria upon minerals would not be complete without some reference to the action of certain organisms upon the iron, sulfur, and phosphorus compounds found in rocks and soils. However, since it is the purpose of this paper to deal with an entirely different phase of the subject, a brief reference to the bacterial processes affecting these compounds will suffice.

Lipman and McLean¹⁰ studied the effect of the oxidation of sulfur upon rock phosphate and found appreciable amounts of the phosphate dissolved through the action of the resulting acid.

Stoklasa¹¹ found marked solubility of bone meal through the action of soil bacteria and attributed it to the action of enzymes upon the bone meal.

Koch and Kroeber¹² and later Kroeber¹³ determined the solubility of different forms of phosphate in the acids produced by the growth of soil and sewage organisms upon dextrose. Kroeber concluded that the acids produced by bacteria and yeasts in the soil may be of great importance in rendering phosphate soluble. In cultures where CaCO_3 was present little or no phosphate was made soluble.

Sackett, Patten, and Brown¹⁴ in a somewhat similar work found that there was a decided solution of the insoluble phosphate when bacterial growth was accompanied by acid formation. They believed that acid is not the sole solvent.

Hopkins and Whiting¹⁵ discuss the effect upon rock phosphate of the nitrous acid produced through the oxidation of NH_3 by *Nitrosomonas*.

OBJECT OF INVESTIGATION

Bacteria may effect the solution and disintegration of minerals in at least two ways:

1. Through the oxidation or reduction of one or more of the constituents of the mineral by specific organisms.
2. By the action of some end-product of bacterial activity: i. e., H ion resulting from acid produced, or OH ion from the production of NH_3 .

In the present investigation some of the fundamental considerations in connection with the second phase of the subject were studied, the work being limited to the effect of acid end-products. In none of the work reviewed in the foregoing section have attempts been made to obtain results which may be used to determine whether the action of bacteria upon minerals may follow the usual chemical laws, or at least

present some constant relationship which may be expressed in an empirical formula. The work in hand has had for its object the procurement and interpretation of data suitable for the confirmation of some such relationship.

METHOD OF ATTACK AND THEORY

In order to obtain such data it was found necessary to use a different method of attack from that usually pursued in a bacteriological problem. The most common approach to such a problem is by the determination, either in solution culture, in sand culture, or in culture upon the moist pulverized mineral itself, of the amount of material made soluble by the growth of certain organisms. This method gives a series of isolated results, which, though no doubt interesting in themselves, are entirely unrelated either among themselves or to any factor which may control the magnitude of the bacterial effect. In dealing with the phase of the problem studied in this paper, a different method is employed, a method by which it is hoped to show a certain relationship between H ion produced by bacteria and the amounts of bases brought into solution.

The magnitude of the effect of bacterial end-products upon a mineral will depend upon the equilibrium involving that end-product and mineral. As stated before, in this study it is elected to deal with cases in which acids are the end-products in question. Therefore, it was deemed necessary first to study the equilibria of certain acids, used over a wide range of concentrations, with certain minerals. The object of these equilibrium studies was to compare the H ion concentrations of the acids, at the various molar concentrations, with the amounts of material which are brought into solution, so to speak, by these H ion concentrations. Later, studies were made of the H ion production by certain organisms, and of the equilibria involving these acids and the minerals, the H ion and the amounts of material in solution being determined.

There is an extensive literature dealing with the equilibria of various soils and minerals in contact with solutions of acids, of bases, and of salts. This literature deals largely with the absorption of bases by soils and minerals, and with the exchange of bases between solution and soil or solution and mineral. In nearly every instance, however, the data are insufficient to warrant their use for substitution in formulae.

The earlier work is so ably and completely reviewed by Sullivan,¹⁶ in his consideration of *The Interaction between Minerals and Water Solutions*, that it seems advisable to refer the reader to that excellent résumé rather than to attempt a repetition here. This review covers the work of Thompson,¹⁷ Way,¹⁸ Eichhorn,¹⁹ Henneberg and Stohmann,²⁰ Lemberg,²¹ Peters,²² Liebig,²³ Rautenberg,²⁴ Van Bemmelen,²⁵ Armsby,²⁶ and Boedeker,²⁷ and deals largely with the controversy of the physical process of adsorption versus chemical reaction as the cause of the absorption and exchange of bases in soils.

The work of Dittrick²⁸ is not included above. His work is reported in two papers, and covers experiments with a granite and an amphibole paridotite, and solutions of KCl, NaCl, NH₄Cl, CaCl₂, MgCl₂, KNO₃, K₂SO₄, and K₂CO₃, in the concentrations N/1, N/10, and N/100. He found Ca and Mg dissolved by the solutions, the least by N/1 solution, more by the N/10 solution, and most by the N/100 solution. The amount of exchange was greater with the more decomposed rock. Repeated extraction with solutions removed roughly twice as much material as a single extraction.

The action of an acid upon a silicate is really an exchange of H ion for any of the bases which come into solution through its action. This exchange is a reversible chemical reaction, and as such should conform with the chemical laws applicable to such reactions.

Let us consider a simple case of reversible reaction, or balanced action, that of the union of hydrogen and iodine to form hydriodic acid: $H_2 + I_2 \approx 2HI$.

In this reaction there is a point of equilibrium which is represented by the equation:

$$\frac{C_{H_2} \times C_{I_2}}{C_{HI}^2} = \frac{k_1}{k} = K.$$

This is an example of homogeneous equilibrium, involving the gaseous phase only.

A somewhat different case is encountered with the decomposition of calcium carbonate into carbon dioxide and calcium oxide:

Here we have both gaseous and solid phases. The amount of gas taking part in the reaction may be measured by its pressure, but the solid must be considered in a different light. This reaction may be considered as taking place in the gaseous phase, the solids present furnishing a constant supply of CaCO₃ and CaO vapor. Then if C is the

pressure of CaCO_3 , C_1 the pressure of CaO , and c the pressure of CO_2 at equilibrium, the equation at equilibrium is:

$$kC = k_1 C_1 c, \text{ or } c = \frac{kC}{k_1 C_1} = K$$

Going farther we have the following as a reaction in which we have a solid and a gas on both sides of the equation:

Let c be the concentration of H_2O , C that of Fe , C_1 of FeO , and c_1 of H_2 . At equilibrium we then have the equation:

$$k c C = k_1 c_1 C_1.$$

$$\text{and } \frac{c}{c_1} = \frac{k_1 C_1}{k C} = K$$

$$\text{or } \frac{c}{c_1} = K$$

Now applying this last equation to a case where we have a solution of a salt acting upon a solid to form another salt in solution and a solid we will take the following reaction:

Let C , c , c_1 and C_1 be the respective concentrations of the reacting substances. Then from the above equation

$$\frac{c}{c_1} = K,$$

$$\text{or } \frac{C_{\text{Na}_2\text{CO}_3}}{C_{\text{Na}_2\text{SO}_4}} = K.$$

This last equation shows that the equilibrium point is measured by the ratio of concentrations of the soluble reacting materials. As stated by Walker:²⁹ "The active masses of the barium salts may be accounted constant in the reaction, for although they are generally spoken of as 'insoluble', they are in reality measurably soluble in water. The aqueous liquid in contact with them will be and remain saturated with respect to them, i.e., their concentration and active mass in the solution will be constant. The equilibrium will thus be determined by a certain ratio of the concentrations of the soluble sodium salts, independent of what the actual values of the concentrations may be."

A mineral in contact with an acid solution is very similar to the last case cited above, and at any concentration of the acid the equilibrium should be measured by the ratio

$$\frac{\text{concentration of the acid}}{\text{concentration of the material in solution}} = K$$

when these are measured at equilibrium.

The H ion is usually assumed to be the measure of the active acid. In acid solution the H ion concentration is some function of the molar concentration of the acid. Since gas chain measurements yield values which approach the theoretical H ion concentration, determinations of the H ion concentrations, C_h , by this method may be substituted for "concentration of acid" in the above formula and the ratio

$$\frac{C_h}{C_{\text{material in solution}}}$$

will be constant.

When dealing with materials as complex in their chemical structure as are minerals, it is recognized that a rigid adherence to the theoretical laws can not be expected, and it becomes necessary, therefore, for a comprehensive knowledge of such reactions as are considered in this paper, to resort to certain empirical formulae. It is obviously impracticable to attempt to consider in the term "concentration of material in solution," as used in the formula above, all the bases which may be present in the solution in contact with the mineral at equilibrium. These considerations lead to the assumption that any one of the bases may be taken as measuring the magnitude of the action of the acid on the mineral. Consequently, it is suggested that the formula thus far developed theoretically, be changed to the empirical formula

$$\frac{C_h}{C_a} = K,$$

where C_h is the concentration of hydrogen ion, and C_a represents the molar concentration of Ca, Mg, Fe, or K in solution at equilibrium with the acid.

Since it is desired to study the initial H ion concentration with respect to Ca, Mg, Fe, or K in solution, it becomes necessary to add a still further modification to the empirical formula—namely, the expression of the initial H ion concentration in terms of, or as some function of, the H ion concentration at equilibrium. It is found that this is an exponential function of the H ion concentration at equilibrium. (See fig. 0.) In this figure, $\log. C_h$ of the acid alone is plotted against $\log. C_h$ of acid in contact with the mineral. The resulting graph is a straight line, indicating that the ratio is constant, at least over a certain range of concentrations. Thus C_h of the acid alone is a logarithmic or exponential function of C_h of the acid in contact with the mineral, or $C_h = C_h^x$. Then the equation $\frac{C_h}{C_a} = K$ becomes $\frac{C_h^x}{C_a} = K$, where C_h^x is the

initial H ion concentration of the acid, C_a the concentration of Ca, Mg, Fe, or K in solution at equilibrium, and K is a constant. This equation is the one used in the consideration of the data contained in this paper.

The formation of acid as the end-product of bacterial activity is a property common to many organisms including many which are commonly found in soils. Acid production by bacteria has been the subject of many investigations. It is used as a means for identifying the various members of the Colon group of bacteria, and consequently the fermentation of sugars by this group has been widely studied. A review of the entire field will not be attempted, but it is well to mention work having a more or less direct bearing upon the subject in hand.

Harden³⁰ studied the *Chemical Action of B. coli communis and Similar Organisms on Carbohydrates and Allied Compounds*. He found that the lactic acid produced never exceeds one-half of the sugar fermented. The amount of acid formed varies with the different sugars.

In a later study with Penfold³¹ he used *B. coli* on a medium composed of 2 per cent glucose and 1 per cent peptone. He gets of alcohol, acetic acid, formic acid, CO₂, lactic acid, and succinic acid, respectively 17.22 per cent, 20.60 per cent, 2.55 per cent, 17.30 per cent, 40.60 per cent, and 4.80 per cent of the sugar used. With a selected strain of *B. coli*, the lactic acid reaches 70 per cent of the amount of sugar used.

Michaelis and Marcora³² find that the highest degree of acidity produced by *B. coli* at 37° C. is 1×10^{-5} .

In the lactic acid fermentation of sugars, Clafflin³³ notes the formation also of formic, propionic, and acetic acids, the acetic acid formation depending upon the degree of aeration. Ninety-five to 97 per cent of the sugar may be converted into lactic acid, with a very low production of volatile acids, not over one-half per cent. He claims that the nature of the acid produced depends upon the organism and not upon the nature of the medium.

In the present work it must be shown what is the amount of acid, or rather the H ion concentration, produced by the organisms upon the carbohydrate media used, and what is the effect of this concentration upon the minerals. Is this effect similar to that of the acids alone?

EXPERIMENTAL METHODS

As suggested in the foregoing section, the experimental work is divided into two parts, the first consisting of the equilibrium studies with the minerals and acid solutions, the second of bacteriological studies.

Equilibrium studies.—The acids used were hydrochloric, sulfuric, oxalic, phosphoric, lactic, formic, and acetic. It will be observed that these acids vary in the degree of dissociation for any given concentration, hydrochloric acid being the most highly dissociated, and acetic acid being the least ionized. The minerals were calcium silicate, orthoclase feldspar, biotite, and granite. They were ground in a ball mill to pass a 200-mesh sieve. The acids were used in the concentrations: N/5, N/25, N/50, N/100, N/250, N/500, N/1,000, N/2,000, N/5,000, and N/10,000.

The work was carried on at room temperature. The equilibrium studies were arranged in four series, one for each mineral, and each series contained a sub-series for each acid. 200 cubic centimeters of solution were thoroughly shaken with 5 grams of mineral, Jena glassware being used. The solutions were allowed to remain in contact with the mineral for three days, which time is shown in the following table to be sufficient for equilibrium.

TABLE SHOWING THE EFFECT OF THE TIME OF CONTACT
UPON THE H ION CONCENTRATION.

Orthoclase + N 5 HCl Days	H ion concentration
1.....	.709 $\times 10^{-1}$
2.....	.636 $\times 10^{-1}$
3.....	.615 $\times 10^{-1}$
4.....	.656 $\times 10^{-1}$
5.....	.615 $\times 10^{-1}$

As much as possible of the supernatant solution was then pipetted off and filtered through a Whatman No. 42 filter paper, an unfiltered portion being taken, however, for the H ion determination. In an aliquot of the filtered solution, calcium, iron, magnesium, and potassium were determined, the calcium and iron by titration with potassium permanganate, the magnesium and potassium gravimetrically as the pyrophosphate and chloroplatinate respectively.

The H ion determinations were made by the use of the hydrogen electrode, with the same modifications as were used by Sharp and Hoagland³⁴ for soils. These determinations are made both on the acid solutions, and on the acids in contact with the minerals.

A question arose as to the possibility of the formation of a gelatinous coating upon the surface of the mineral, which would hinder the further action of the acid, and prevent attainment of equilibrium. In order to ascertain whether the amount of shaking had been sufficient to remove this film and allow the reaction to come to equilibrium, the following experiment was proposed. A 5-gram portion of mineral was shaken with 200 cc. of N/5 HCl, as in the experimental procedure. The mineral and solution were then poured upon a filter paper, and the mineral was dried and then ground in a mortar. H ion determinations were made upon the filtrate. The filtrate was poured upon the dried mineral and allowed to remain for three days with frequent shaking. H ion determinations were again made. The following data show that there is no significant change in H ion concentration in the second contact of the solution with the mineral:

	H ion Conc.
Calcium silicate +N 5 HCl....1st contact.....	0.607×10^{-1}
Calcium silicate +N 5 HCl....2d contact... .	0.607×10^{-1}
Labradorite +N 5 HCl....1st contact.....	0.797×10^{-1}
Labradorite +N 5 HCl....2d contact.....	0.828×10^{-1}

Bacteriological work.—Three organisms were used, *Azotobacter*, *Bacillus coli*, and *B. lactis acidi*. The first of these was chosen because of the very high H ion concentration which it produced upon dextrose solution, nearly $1. \times 10^{-1}$ as determined by Dr. Waynick in this laboratory. *B. coli* is referred to in the literature previously cited as producing large amounts of acid, and *B. lactis acidi* was taken as a typical acid producer. *Azotobacter* were grown upon 2 per cent dextrose solution, *B. coli* in a solution of 2 per cent dextrose and 1 per cent peptone as used by Penfold, and *B. lactis acidi* in 1 per cent dextrose. The work was arranged in three series, one for each organism. Each series contained five cultures, each culture containing 1,000 cc. of solution in 1,200 cc. Florence flasks. One culture contained no mineral. The other cultures contained 25 grams of mineral each, one with calcium silicate, one with orthoclase feldspar, another with biotite, and one with granite. These cultures were run for a total time of sixteen days, H ion determinations being made at 1, 2, 3, 5, 7, 9, 11, and 16 days, and on each of these days 100 cc. of solution was removed for the determination of calcium, iron, magnesium, and potassium. The cultures were grown at a temperature of 28° C. and the customary bacteriological precautions were observed throughout the work.

DATA

The data obtained by the methods given above are reported in tables 1 to 38 inclusive. The amounts of calcium, magnesium, iron, and potassium are calculated and expressed as moles per liter. Both the initial and final H ion concentrations are also reported as gram molecules per liter. For the convenience of the reader, the logarithms of these numerical values are given in adjacent columns.

Accompanying each table is a graphical representation of the relation between certain series of values given in that table. (Owing to a loss of material during the analysis, tables 3, 9, and 22 are incomplete; there are, therefore, no graphs for these tables.) The logarithms of the H ion concentrations, $\log. C_h$, are plotted along the ordinates, and the logarithms of the concentrations of Ca, Mg, Fe, or k, $\log. C_a$, along the abscissas, and the average curve is drawn through the points thus obtained.

In the section of this paper dealing with "Method of Attack and Theory," certain assumptions are made and ultimately expressed in the empirical formula, $\frac{C_h^x}{C_a} = K$. By substitution of the experimental data in this formula, the values of the constants x and K may be calculated. If these values of x and K are constant for a given series, then the ratio, $\frac{C_h^x}{C_a}$, is constant for that series, and the plotted graph representing that ratio will be a straight line, or conversely, a straight line curve indicates that x and K are constant. The straight line graph expresses a direct ratio between series of values, these values being, in this case, the logarithms of C_h and of C_a .

The exponential constant x and the reasons for its use have been discussed previously. It expresses the relation of H ion at equilibrium to the initial H ion concentration of the acid. That this relationship is of an exponential character may be due to chemical reaction, to adsorption, or to a combination of these phenomena. It is not proposed, however, to differentiate here between adsorption and chemical reaction, the purpose of this work being to provide a means, empirical if necessary, of accounting for the magnitude of the action of acids upon minerals.

The constant K is the numerical expression of the ratio of the logarithm of the initial H ion concentration to the logarithm of Ca, Mg,

Fe, of K brought into solution, so to speak, by that H ion concentration. The numerical magnitude of K for any table represents the slope or inclination of the graph plotted from that table. The range of values for K may be very large, varying from infinity, for a horizontal line, to zero, for a vertical line.

Since it is possible to draw a straight line averaging the points plotted from the experimental data, the graphical method is employed for obtaining values of $\log. C_h$ and $\log. C_a$ for substitution in the equation for the calculation of x and K. By this means average values of x and K may be computed without resorting to a calculation of all the possible combinations of equations for which data are available. The use of this procedure eliminates a large part of the tedious mathematical routine, and it is recognized as yielding averages sufficiently close to the statistical average to serve the purpose contemplated in this paper. If the above preliminary remarks are borne carefully in mind, the following consideration of the groups of tables and graphs will be clear.

Tables 1 to 7 contain the data for the equilibria between calcium silicate and the acids. The figures accompanying these tables are sufficient to show that the graph for any given series is a straight line. As stated before, this signifies that x and K are constant for each series, and that the reaction of the acid with the mineral takes place in accordance with the formula $\frac{C_h^x}{C_a} = K$. The slope of the graphs, however, seems

to become less for the equilibria involving the less dissociated acids, the slope for acetic acid being much less than that for hydrochloric acid. As explained before, this difference in slope is indicated by the following numerical values for the constant K calculated from the graphs, the slope becoming less as K increases:

HCl.....	K = 0.01391
Sulfuric acid.....	K = 0.2642
Phosphoric acid.....	K = 0.4448
Lactic acid.....	K = 14.86
Formic acid.....	K = 335.5
Acetic acid.....	K = 941.2

Since, as stated before, the graphs represent ratios of $\log. C_h$ to $\log. C_a$, and since this ratio varies with the slope of the graph, it would seem, from a comparison of the curves for HCl and acetic acid, that an acid such as HCl, which is highly ionized, brings smaller amounts of material into solution per unit increase of H ion than do those acids, acetic for instance, which have a lower ionization constant. This apparent difference in the action of various acids is due undoubtedly to

the fact that the commercial calcium silicate was used for this work, and that it contained considerable quantities of CaCO_3 , as shown by the marked effervescence which occurred when the acid was added to this material. The loss of CO_2 from the system undoubtedly affected the true equilibrium, and this apparently greater action of the less dissociated acids is the result. As will be seen in the considerations which follow, this difference in effect between various acids occurs only with calcium silicate.

In tables 1 to 7, as well as in those which follow, there are no data for calcium where oxalic acid is used, because of the insolubility of the resulting calcium oxalate. This fact is mentioned again, and its importance is emphasized further, in connection with a general statement concerning the action of the H ion concentration of acids upon minerals.

The data for the various acids and orthoclase are found in tables 8 to 12 inclusive. From a comparison of the corresponding graphs, it is seen that they are quite steep, and that all have approximately the same slope. This observation is verified by a consideration of the constant, K , as calculated for the various members of this group of tables. The fact that K is very small is evidence that the graphs approach the perpendicular, and when it is remembered that the values for K range from zero to infinity for a change of 90 degrees in slope, it is obvious that the very small range of values for K given here, 0.00002661 to 0.000001427, represents a very small difference in the slopes of the various curves. The fact that K is constant for each series, and that the corresponding graph is a straight line, goes to show that the calcium coming into solution is a logarithmic function of the initial H ion concentration of the acid, and that the assumptions expressed in the formula $\frac{C_h^x}{C_a} = K$ are verified by experimental evidence.

Further proof of these assumptions is offered in the next group of tables, numbers 13 to 19 inclusive, which give the data for the acids in equilibrium with biotite. Data for calcium, magnesium, and potassium in solution are reported. As in the previous series of tables, the graphs for calcium are straight lines and have about the same slope, the extreme range of values for K being from 0.00005790 to 0.000001071. The constant K for the magnesium determinations is more variable, but still no large discrepancy is apparent, the values ranging from 0.04373 to 0.000008395.

A deviation from the straight line graph is encountered in the figures and tables expressing the equilibria for granite and the acids,

tables 20 to 26 inclusive. When the logarithms of the data for iron are plotted against the logarithms for H ion concentrations and the lines are drawn through the points thus obtained, the resulting curves are not straight lines. (See figures 20 to 26.) The flatter portion of the curve occurs in every instance at approximately the value, $\bar{3}.0$, represented by that logarithm of the H ion concentration, and probably is due to the formation of another compound of iron at that concentration. Since these curves are not straight lines, it is obvious that no constant values for x and K may be calculated therefrom, and furthermore it may be inferred that any iron compounds in the mineral do not react with the acids in accordance with the proposed formula. The curves for calcium, however, are straight lines, thus affording still further proof that the assumptions regarding the nature of such reactions are correct as far as calcium is concerned. The graphs have nearly the same slope throughout the series of figures, the values for K ranging from 0.000001328 to 0.000007799.

In a general survey of the graphs thus far discussed, instances may be observed in which certain plotted points are far from coincident with the straight line graph. In certain cases, these discrepancies represent error in the determinations. Where they appear in the lower portion of the graph, however, the last two or three points dropping below the curve, they occur because the lower limit of the determination has been reached, and no smaller amounts can be determined with any degree of accuracy.

A consideration of the meaning and the possible relationships of the results thus far reviewed is not inappropriate at this point. It is the opinion of the writer that that type of investigation is the most valuable which has for its object the procurement of data which are related, either among themselves, or to certain controllable factors, and which may be taken as the basis for, or in verification of, some general law suitable either for the explanation of certain phenomena or for direct application in the prediction of future results. Thus a general consideration of the tables and figures leads to the following remarks.

All the straight line graphs for a given mineral, excepting calcium silicate, the deviation of which has been explained, have practically the same slope and give nearly the same values for x and K . It follows therefore, that if the curves for one mineral in contact with the various acids be superimposed one upon the other, they will all fall practically in the same straight line. This would seem to indicate, for a given mineral, and within the limits of the concentrations used, that the amount of calcium, magnesium, or potassium coming into solution is a function

of the H ion concentration of the acid, regardless of the nature of the acid used, except, and this exception is extremely important, in those cases where the acid forms compounds which are less soluble at any given H ion concentration than the compounds in the mineral itself. The importance of this exception must be emphasized, and it is illustrated in a very striking manner by the different series with oxalic acid where only traces of calcium are found in solution. It is recognized that this illustration represents an extreme case and that other so-called insoluble compounds may approach the mineral compounds in solubility.

The objection was raised to the foregoing generalization that a N/100 solution of acetic acid, for instance, contains the same total molar concentration of hydrogen as a N/100 hydrochloric acid solution, regardless of the relative H ion concentration of these acids. The hydrochloric acid is, of course, the more highly dissociated acid, but will not the slightly dissociated acetic acid continue to give off H ion as that already in solution combines with the mineral, and should not the ultimate result be the same with the acetic as with the hydrochloric acid for a given molar concentration? That this objection is not substantiated by fact is due doubtless to the following reason. In general the salts of acetic acid are much more highly dissociated than is the acid itself. Consequently, the acetates formed by the contact of acetic acid with the mineral will be fairly highly dissociated, thus supplying the solution at equilibrium with a certain concentration of acetic ion. The presence of this acetate ion will depress or prevent the further ionization of the acetic acid in solution, and thus practically limit the action of the acetic acid to its original H ion concentration. This same explanation will hold for other slightly dissociated acids.

The general relation existing between the H ion concentration of acids and the amounts of Ca, of Mg, or of K in solution, may have the following practical application. It is desired to determine the effect of certain acids upon a mineral. This mineral may be studied in equilibrium with different concentrations of HCl, and the logarithmic graph constructed as in the foregoing mineral series. Any point on this graph represents a ratio of $\log. H$ ion to $\log. C_a$, or whatever base it is desired to consider, in solution. Thus, by determining the H ion concentration of the acid whose action it is desired to predict, we may, by referring to the graph, estimate the magnitude of the effect of the acid upon the mineral, at least within certain limits already discussed. The application suggested above may be made to the effect of acids produced by bacterial growth, and in the prediction of their action upon a given mineral.

The above application is suggested merely as a possibility, and it is fully recognized that there is room for much further study and research before the existence of such a general relationship can be definitely established. It must be emphasized also that the constants for one mineral and one set of conditions can not be applied directly to another mineral and a different set of conditions. The constants must be determined, and the resulting graph constructed for every application of the relation suggested.

The data obtained from the bacterial series still await consideration. As expressed in tables 26 to 38, and in the corresponding figures, the action of the acids produced by bacteria seems to differ in magnitude from the action of the acids used in the foregoing series. In regard to this difference, it should be observed that C_h , the H ion concentration, was determined, for the bacterial series, in solution cultures with no mineral present. Had the bacterial growth been stopped immediately following the H ion determination, and had this solution then been brought into contact with the mineral, the magnitude of the effect should have been comparable with that of the acid series. Instead, the amounts of material coming into solution were determined in a series parallel with the above, wherein bacteria were grown in solution in contact with the minerals. It had been assumed that the rate of H ion production would be the same, both in solution culture and in solution in contact with the mineral. This assumption was found to be incorrect. In the mineral cultures the acid was partly neutralized as produced, and the growth of the organism was not inhibited by the increasing concentration of acid as it was in the dextrose solution with no mineral. Consequently, the total H ion as produced in the mineral cultures, and indicated by the large relative amounts of material coming into solution in these cultures, was much greater than that produced in the parallel series without mineral. Since the data for H ion, C_h , as expressed in the tables, were obtained from the latter series, it is obvious that the graphs plotted from a ratio of H ion, as determined in dextrose solution, to material in solution, as determined in the mineral cultures, are not directly comparable with the graphs for the equilibria between acids and minerals.

The lack of agreement between the acid series and the bacterial series is made evident by a review of the curves and the corresponding constants for the bacterial series. The graphs are straight lines, but they have less slope than do those graphs for the corresponding mineral in equilibrium with the acids. For instance, the constant, K , for orthoclase and *Azotobacter* is 19.77 against a value approaching 10^{-6} for

orthoclase and the acids, and the graph for the former has much less slope than the graph for the latter. The constant, K , for orthoclase and *B. coli* is 13,490, against 10^{-6} for orthoclase and the acids. *B. lactis acidi*, which produced acid very slowly, is represented by graphs which more nearly resemble those of the acid-mineral series, and the value for K for calcium from orthoclase, for instance, is 0.0006652. Since discrepancies of the same general nature and magnitude as those just pointed out, are apparent in the other graphs and constants for the bacterial-mineral series, the reader is referred to the graphs and tables for further comparisons.

The important point brought out by the bacterial series is that the graphs for calcium, for magnesium, and for potassium are straight lines, and that x and K are constant for a given series. Thus it is shown that the reactions between minerals and the acids produced by bacterial growth, conform with the given empirical formula. Since this same formula has been successfully applied to the chemical equilibria between various acid solutions and the same minerals, it may be concluded that the action of bacterial end-products upon minerals, at least when these end-products are acids, is explainable upon the basis that it is a chemical reaction.

SUMMARY

Equilibria of certain minerals and various concentrations of acids are studied.

Equilibria of the same minerals with solutions in which bacteria are producing acid are also studied.

The data obtained from the acid-mineral series are applied to the formula $\frac{C_h^x}{C_a} = K$.

It is found that the reactions occurring in the mineral-acid equilibria conform with the given formula.

It is suggested that a general relation exists between the initial H ion concentration of the acid and the amount of material which the acid brings into solution when in contact with a mineral.

A practical application of the relation just referred to, is suggested.

The data obtained from the bacterial studies are applied to the formula $\frac{C_h^x}{C_a} = K$.

The reactions occurring in the bacterial series also conform with the above formula.

It is concluded that the action of acid bacterial end-products upon minerals is explainable as a chemical reaction.

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NOTE

The following legend refers to all the figures:

+ = Curve for Calcium.

○ = Curve for Magnesium.

⊕ = Curve for Potassium or Iron.

The numbers along the ordinates represent the logarithms of the H ion concentrations, or $\log. C_h$. Those along the abscissas measure the logarithms of the concentrations, or $\log. C_a$, of calcium, magnesium, iron, or potassium.

Fig. 0.

(See Table 8)

Relation of $\log. H$ ion, HCl , to $\log. H$ ion,
 $HCl + Orthoclase$.

TABLE I
HYDROCHLORIC ACID AND CALCIUM SILICATE

Concentration HCl	C _H , H ion Hydrochloric Acid	Log. H ion Hydrochloric Acid	H ion Hydrochloric Acid + Calcium Silicate	C _a , Calcium, Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.0882	$\bar{2}.94547$	0.0313	0.00306	$\bar{3}.485721$
N 25	0.0218	$\bar{2}.33846$	0.00000534	0.00218	$\bar{3}.338456$
N 50	0.0135	$\bar{2}.13003$	0.00000175	0.00121	$\bar{3}.02785$
N 100	0.00685	$\bar{3}.83569$	0.000000671	0.000685	$\bar{4}.835691$
N 250	0.00321	$\bar{3}.50651$	0.000000131	0.000376	$\bar{4}.575188$
N 500	0.00114	$\bar{3}.05690$	0.0000000842	0.000240	$\bar{4}.380211$
N 1,000	0.000677	$\bar{4}.83059$	0.0000000587	0.000159	$\bar{4}.201397$
N 2,000	0.000281	$\bar{4}.44871$	0.0000000965	0.000122	$\bar{4}.086360$
N 5,000	0.0000326	$\bar{5}.51322$	0.0000000719	0.000120	$\bar{4}.079181$
N 10,000	0.0000192	$\bar{5}.28330$	0.000000620	0.000117	$\bar{4}.068168$

Constants for the equation $\frac{C_H^x}{C_a} = K$:

$$x = 0.636$$

$$K = .01391$$

Fig. 1.
Hydrochloric Acid and Calcium Silicate.
(See Table 1)

TABLE 2

SULFURIC ACID AND CALCIUM SILICATE

Concentration	C _H , H ion Sulfuric Acid	Log. H ion Sulfuric Acid	H ion Sulfuric Acid + Calcium Silicate	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.0567	2.75358	0.0300	0.00188	3.274158
N 25	0.0186	2.26951	0.00000579	0.00197	3.294466
N 50	0.0130	2.11394	0.000000450	0.00115	3.060698
N 100	0.00632	3.80072	0.000000203	0.000655	4.816241
N 250	0.00296	3.47129	0.0000000810	0.000356	4.551450
N 500	0.00162	3.20952	0.0000000719	0.000218	4.338456
N 1,000	0.000931	4.96895	0.000000180	0.000148	4.170262
N 2,000	0.000600	4.77815	0.0000000323	0.000099	5.995635
N 5,000	0.000259	4.41330	0.0000000235	0.000079	5.897627
N 10,000	0.000174	4.24055	0.0000000364	0.000089	5.949390

Constants for the equation $\frac{C_H^x}{C_a} = K$:

By graphical average:

$$x = 0.799$$

$$K = 0.2642$$

By calculation:

$$x = 0.858 \pm 0.0074 \quad \text{C. v.} = 5.99\%$$

$$K = 0.7332 \pm 0.0313 \quad \text{C. v.} = 29.05\%$$

Figure 2.
Sulfuric Acid and Calcium Silicate.
(See Table 2)

TABLE 3

OXALIC ACID AND CALCIUM SILICATE

Concentration	C _b , H ion Oxalic Acid	Log. H ion Oxalic Acid	H ion Oxalic Acid + Calcium Silicate	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.0218	2.33846	0.0347	.....	.....
N 25	0.0110	2.04139	0.0000192	.....	.....
N 50	0.00561	3.74896	0.00000175	.....	.....
N 100	0.00347	3.54033	0.000000433	.....	.....
N 250	0.00169	3.22789	0.0000000941	.....	.....
N 500	0.00105	3.02119	0.0000000778	.....	.....
N 1,000	0.000554	4.74351	0.0000000719	.....	.....
N 2,000	0.000317	4.50106	0.0000000637	.....	.....
N 5,000	0.000132	4.12057	0.0000000544	.....	.....
N 10,000	0.0000785	5.89487	0.000000469	.....	.....

TABLE 4

PHOSPHORIC ACID AND CALCIUM SILICATE

Concentration	C _b , H ion Phosphoric Acid	Log. H ion Phosphoric Acid	H ion Phosphoric Acid + Calcium Silicate	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.0125	2.09691	0.0498	0.00307	3.487138
N 25	0.00632	3.80072	0.00000707	0.000872	4.940516
N 50	0.00424	3.62737	0.00000294	0.000525	4.720159
N 100	0.00273	3.43616	0.00000054	0.000366	4.563418
N 250	0.00144	3.15836	0.000000268	0.000208	4.318063
N 500	0.000762	4.88195	0.0000000941	0.000149	4.173186
N 1,000	0.000372	4.57054	0.0000000482	0.000109	4.037426
N 2,000	0.000213	4.32838	0.0000000350	0.000089	5.949390
N 5,000	0.0000642	5.80754	0.0000000235	0.000074	5.869232
N 10,000	0.0000431	5.63448	0.0000000395	0.000074	5.869232

Constants for the equation $\frac{C_H^x}{C_a} = K$:

$$x = 0.835$$

$$K = 0.4448$$

Figure 4.
Phosphoric Acid and Calcium Silicate.
(See Table 4)

TABLE 5

LACTIC ACID AND CALCIUM SILICATE

Concentration	C _h , H ion Lactic Acid	Log. H ion Lactic Acid	H ion Lactic Acid + Calcium Silicate	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.00561	3.74896	0.00577	0.00308	3.488551
N 25	0.00252	3.40140	0.000130	0.00201	3.303196
N 50	0.00169	3.22789	0.00000108	0.00123	3.089905
N 100	0.00114	3.05690	0.000000572	0.000812	4.909556
N 250	0.000677	4.83059	0.000000141	0.000445	4.648360
N 500	0.000472	4.67394	0.0000000877	0.000208	4.318063
N 1,000	0.000270	4.43136	0.0000000719	0.000148	4.170262
N 2,000	0.000189	4.27646	0.0000000364	0.000099	5.995635
N 5,000	0.000112	4.04922	0.0000000395	0.000079	5.897627
N 10,000	0.0000547	5.73799	0.000000126	0.000074	5.869232

Constants for the equation $\frac{C_H^x}{C_a} = K$:

By graphical average:

$$x = 1.144$$

$$K = 14.86$$

Constants by calculation:

$$x = 1.118 \pm 0.0368 \quad \text{C. v.} = 25.9\%$$

$$K = 12.09 \pm 0.326 \quad \text{C. v.} = 12.01\%$$

Figure 5.
Lactic Acid and Calcium Silicate.
(See Table 5)

TABLE 6

FORMIC ACID AND CALCIUM SILICATE

Concentration	C _H , H ion Formic Acid	Log. H ion Formic Acid	H ion Formic Acid + Calcium Silicate	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.00518	$\bar{3}.71433$	0.00577	.....	.....
N 25	0.00233	$\bar{3}.36736$	0.0000635	.....	.....
N 50	0.00156	$\bar{3}.19312$	0.000000620	0.00119	$\bar{3}.075547$
N 100	0.0010	$\bar{3}.00000$	0.000000327	0.000694	$\bar{4}.841359$
N 250	0.000762	$\bar{4}.88195$	0.0000000719	0.000365	$\bar{4}.563481$
N 500	0.000472	$\bar{4}.67394$	0.0000000522	0.000208	$\bar{4}.318063$
N 1,000	0.000343	$\bar{4}.53529$	0.0000000350	0.000138	$\bar{4}.139879$
N 2,000	0.000181	$\bar{4}.25768$	0.0000000276	0.000119	$\bar{4}.075547$
N 5,000	0.0000753	$\bar{5}.87679$	0.0000000245	0.000099	$\bar{5}.995635$
N 10,000	0.0000398	$\bar{5}.59988$	0.0000000719	0.0000248	$\bar{5}.394452$

Constants for the equation $\frac{C_{\bar{H}}^x}{C_a} = K$:

$$x = 1.324$$

$$K = 335.5$$

Figure 6.
Formic Acid and Calcium Silicate.
(See Table 6)

TABLE 7
ACETIC ACID AND CALCIUM SILICATE

Concentration	C _H , H ion Acetic Acid	Log. H ion Acetic Acid	H ion Acetic Acid + Calcium Silicate	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.00224	$\bar{3}.35025$	0.000547	0.00285	$\bar{3}.454845$
N 25	0.000860	$\bar{4}.93450$	0.00000797	0.00250	$\bar{3}.397940$
N 50	0.000677	$\bar{4}.83059$	0.00000100	0.00126	$\bar{3}.100371$
N 100	0.000454	$\bar{4}.65706$	0.000000279	0.000742	$\bar{4}.870404$
N 250	0.000387	$\bar{4}.58771$	0.000000116	0.000347	$\bar{4}.540329$
N 500	0.000213	$\bar{4}.32838$	0.0000000350	0.000178	$\bar{4}.250420$
N 1,000	0.000189	$\bar{4}.27646$	0.0000000395	0.0000892	$\bar{5}.950365$
N 2,000	0.000104	$\bar{4}.01703$	0.0000000350	0.0000694	$\bar{5}.841359$
N 5,000	0.0000884	$\bar{5}.94645$	0.000000116	0.0000694	$\bar{5}.841359$
N 10,000	0.0000414	$\bar{5}.61700$	0.000000238	0.0000495	$\bar{5}.694605$

Constants for the equation $\frac{C_H^x}{C_a} = K$:

$$x = 1.465$$

$$K = 941.2$$

Figure 7.
Acetic Acid and Calcium Silicate.
(See Table 7)

TABLE 8
HYDROCHLORIC ACID AND ORTHOCLASE

Concentration	C _H , H ion Hydrochloric Acid	Log. H ion Hydrochloric Acid	H ion Hydrochloric Acid +Orthoclase	C _{Ca} , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.0882	$\bar{2}.94547$	0.0615	0.00159	$\bar{3}.201397$
N 25	0.0218	$\bar{2}.33846$	0.0218	0.001449	$\bar{3}.159567$
N 50	0.0135	$\bar{2}.13003$	0.00836	0.001045	$\bar{3}.019116$
N 100	0.00685	$\bar{3}.83569$	0.00296	0.00094	$\bar{4}.973128$
N 250	0.00321	$\bar{3}.50651$	0.000554	0.000685	$\bar{4}.835691$
N 500	0.00114	$\bar{3}.05690$	0.0000784	0.000565	$\bar{4}.752048$
N 1,000	0.000677	$\bar{4}.83059$	0.000000935	0.00056	$\bar{4}.748188$
N 2,000	0.000281	$\bar{4}.44871$	0.00000110	0.00040	$\bar{4}.602060$
N 5,000	0.0000326	$\bar{5}.51322$	0.000000261	0.00038	$\bar{4}.579784$
N 10,000	0.00000192	$\bar{6}.28330$	0.00000010	0.000336	$\bar{4}.526339$

Constants for Calcium:

$$x = 0.225$$

$$K = 0.000006310$$

Figure 8.
Hydrochloric Acid and Orthoclase.
(See Table 8)

TABLE 9

OXALIC ACID AND ORTHOCLASE

Concentration	C _b , H ion Oxalic Acid	Log. H ion Oxalic Acid	H ion Oxalic Acid +Orthoclase	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.0218	$\bar{2}.33846$	0.0245	.....	.....
N 25	0.0110	$\bar{2}.04139$	0.00905	.....	.....
N 50	0.00561	$\bar{3}.74896$	0.00376	.....	.....
N 100	0.00347	$\bar{3}.54033$	0.000650	.....	.....
N 250	0.00169	$\bar{3}.22789$	0.00000564	.....	.....
N 500	0.00105	$\bar{3}.02119$	0.000000735	.....	.....
N 1,000	0.000554	$\bar{4}.74351$	0.000000438	.....	.....
N 2,000	0.000317	$\bar{4}.56937$	0.000000294	.....	.....
N 5,000	0.000132	$\bar{4}.12057$	0.000000294	.....	.....
N 10,000	0.0000785	$\bar{5}.89487$	0.000000294	.....	.....

TABLE 10

LACTIC ACID AND ORTHOCLASE

Concentration	C _b , H ion Lactic Acid	Log. H ion Lactic Acid	H ion Lactic Acid +Orthoclase	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.00561	$\bar{3}.74896$	0.00441	0.001190	$\bar{3}.075547$
N 25	0.00252	$\bar{3}.40140$	0.00123	0.00094	$\bar{4}.973128$
N 50	0.00169	$\bar{3}.22789$	0.000650	0.00077	$\bar{4}.886491$
N 100	0.00114	$\bar{3}.05690$	0.000372	0.000495	$\bar{4}.694605$
N 250	0.000677	$\bar{4}.83059$	0.000181	0.00073	$\bar{4}.863323$
N 500	0.000472	$\bar{4}.67394$	0.0000414	0.000495	$\bar{4}.694605$
N 1,000	0.000270	$\bar{4}.43136$	0.00000322	0.000465	$\bar{4}.667453$
N 2,000	0.000189	$\bar{4}.27646$	0.00000217	0.000475	$\bar{4}.676694$
N 5,000	0.000110	$\bar{4}.04139$	0.000000282	0.000366	$\bar{4}.563481$
N 10,000	0.0000547	$\bar{5}.73799$	0.000000261	0.000238	$\bar{4}.376577$

Constants for Calcium:

$$x = 0.324$$

$$K = 0.00002661$$

Figure 10.
Lactic Acid and Orthoclase.
(See Table 10)

TABLE 11
FORMIC ACID AND ORTHOCLASE

Concentration	C _H , H ion Formic Acid	Log. H ion Formic Acid	H ion Formic Acid +Orthoclase	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.00518	3.71433	0.00296	0.000862	4.935507
N 25	0.00233	3.36736	0.000677	0.000812	4.909556
N 50	0.00156	3.19312	0.000270	0.000723	4.859138
N 100	0.0010	3.00000	0.0000957	0.000713	4.853090
N 250	0.000762	4.88195	0.0000153	0.000605	4.781755
N 500	0.000472	4.67394	0.00000579	0.000535	4.728354
N 1,000	0.000343	4.53529	0.000000197	0.000535	4.728354
N 2,000	0.000181	4.25768	0.000000197	0.000495	4.694605
N 5,000	0.0000753	5.87679	0.000000205	0.000475	4.676694
N 10,000	0.0000398	5.59988	0.0000000923	0.000426	4.629410

Constants for Calcium:

$$x = 0.142$$

$$K = 0.000001427$$

Figure 11.
Formic Acid and Orthoclase.
(See Table 11)

TABLE 12
ACETIC ACID AND ORTHOCLASE.

Concentration	C_h , H ion Acetic Acid	Log. H ion Acetic Acid	H ion Acetic Acid +Orthoclase	C_a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.00224	$\bar{3}.35025$	0.000472	0.000074	$\bar{4}.869232$
N 25	0.000860	$\bar{4}.93450$	0.000132	0.000058	$\bar{4}.763428$
N 50	0.000677	$\bar{4}.83059$	0.0000696	0.00062	$\bar{4}.792392$
N 100	0.000454	$\bar{4}.65706$	0.0000431	0.00065	$\bar{4}.812913$
N 250	0.000387	$\bar{4}.58771$	0.0000179	0.00051	$\bar{4}.707570$
N 500	0.000213	$\bar{4}.32838$	0.00000745	0.00048	$\bar{4}.681241$
N 1,000	0.000189	$\bar{4}.27646$	0.00000225	0.00043	$\bar{4}.633468$
N 2,000	0.000104	$\bar{4}.01703$	0.000000627	0.00039	$\bar{4}.591065$
N 5,000	0.0000884	$\bar{5}.94645$	0.000000438	0.00033	$\bar{4}.518514$
N 10,000	0.0000414	$\bar{5}.61700$	0.000000261	0.00029	$\bar{4}.462398$

Constants for Calcium:

$$x = 0.235$$

$$K = 0.000006966$$

Figure 12.
Acetic Acid and Orthoclase.
(See Table 12)

TABLE 13.

HYDROCHLORIC ACID AND BIOTITE.

Concentration HCl	C _H , H ion Hydrochloric Acid	Log. H ion Hydrochloric Acid	H ion Hydrochloric +Biotite	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _a , Mag- nesium Mols. per Liter	Log. Mag- nesium Mols. per Liter	C _a , Potassium Mols. per Liter	Log. Potassium Mols. per Liter
N 5	0.0882	2.94547	0.0615	0.00385	3.585461	0.00457	3.659916	0.00158	3.198657
N 25	0.0218	2.33846	0.0146	0.00354	3.549003	0.00282	3.450249	0.00104	3.017033
N 50	0.0135	2.13003	0.00498	0.00351	3.545307	0.00201	3.303196	0.000856	4.932474
N 100	0.00685	3.83569	0.000512	0.00306	3.485721	0.00150	3.176091	0.000731	4.863917
N 250	0.00321	3.50651	0.00000863	0.00247	3.392697	0.000996	4.998259	0.000658	4.818226
N 500	0.00114	3.05690	0.000000572	0.00191	3.281033	0.00066	4.819544	0.000597	4.775974
N 1,000	0.00677	4.83059	0.0000000912	0.00153	3.184691	0.00044	4.643453	0.000535	4.728354
N 2,000	0.000281	4.44871	0.0000000350	0.00117	3.068186	0.00031	4.491352	0.000383	4.583199
N 5,000	0.0000326	5.51322	0.0000000270	0.00111	3.045323	0.00026	4.414973	0.000366	4.563481
N 10,000	0.0000192	6.28330	0.0000000217	0.00081	4.908485	0.00028	4.447158	0.00035	4.544068

Constants for Calcium:

$$x = 0.288$$

$$K = 0.000006054$$

Constants for Magnesium:

$$x = 0.490$$

$$K = 0.0004667$$

Constants for Potassium:

$$x = 0.219$$

$$K = 0.000006746$$

Figure 13.
Hydrochloric Acid and Biotite.
(See Table 13)

TABLE 14.
SULFURIC ACID AND BIOTITE.

Concentration	C _h H ion Sulfuric Acid	Log. H ion Sulfuric Acid	H ion Sulfuric Acid +Biotite	C _s Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _s Mag- nesium Mols. per Liter	Log. Mag- nesium Mols. per Liter	C _k Potassium Mols. per Liter	Log. Potassium Mols. per Liter
N 5	0.0567	2.75358	0.0313	0.00393	3.594393	0.00629	3.798651	0.00212	3.326336
N 25	0.0186	2.26951	0.00836	0.00326	3.513218	0.002705	3.432167	0.00133	3.123852
N 50	0.0130	2.11394	0.000472	0.00308	3.488551	0.001835	3.263636	0.00162	3.209515
N 100	0.00632	3.80072	0.000343	0.00291	3.463893	0.00137	3.136721	0.00145	3.161368
N 250	0.00296	3.47129	0.00000967	0.00252	3.301401	0.000745	4.872156	0.00104	3.017033
N 500	0.00162	3.20952	0.00000004	0.00204	3.309630	0.000585	4.767156	0.00090	4.954243
N 1,000	0.000931	4.96895	0.00000000719	0.00182	3.260071	0.000378	4.577492	0.000694	4.841359
N 2,000	0.000600	4.77815	0.0000000302	0.00144	3.158362	0.000324	4.510545	0.000468	4.670246
N 5,000	0.000259	4.41330	0.00000000217	0.00106	3.025306	0.000252	4.401401	0.000432	4.635484
N 10,000	0.000174	4.24055	0.0000000002	0.00085	4.929419	0.000288	4.459392	0.000395	4.596597

Constants for Calcium:

$$x = 0.188$$

$$K = 0.000001071$$

Constants for Magnesium:

$$x = 0.611$$

$$K = 0.004571$$

Constants for Potassium:

$$x = 0.316$$

$$K = 0.00002379$$

Figure 14.
Sulfuric Acid and Biotite.
(See Table 14)

TABLE 15
OXALIC ACID AND BIOTITE

Concentration	C_{H^+} , H ion Oxalic Acid	Log, H ion Oxalic Acid	H ion Oxalic Acid +Biotite	C_{Ca} , Calcium Mols. per Liter	Log, Calcium Mols. per Liter	C_{Mg} , Mag- nesium Mols. per Liter	Log, Mag- nesium Mols. per Liter	C_{K} , Potassium Mols. per Liter	Log, Potassium Mols. per Liter
N 5	0.0218	2.33846	0.0277	.....	.....	0.00106	3.025306	.....	.....
N 25	0.0110	2.04139	0.00347	.....	.....	0.001375	3.138303	.....	.....
N 50	0.00561	3.74896	0.000600	.....	.....	0.001735	3.239299	.....	.....
N 100	0.00347	3.54033	0.000120	.....	.....	0.000995	4.995635	.....	.....
N 250	0.00169	3.22789	0.0000010	.....	.....	0.00072	4.857332	.....	.....
N 500	0.00105	3.02119	0.000000257	.....	.....	0.00052	4.792392	.....	.....
N 1,000	0.000554	4.74351	0.000000107	.....	.....	0.00064	4.806180	.....	.....
N 2,000	0.000317	4.50106	0.0000000428	.....	.....	0.00069	4.770852	.....	.....
N 5,000	0.000132	4.12057	0.0000000035	.....	.....	0.00038	4.579784	.....	.....
N 10,000	0.0000785	5.89487	0.00000000637	.....	.....	0.00033	4.518514	.....	.....

Constants for Magnesium:

$$x = 0.291$$

$$K = 0.00001579$$

Figure 15.
Oxalic Acid and Biotite.
(See Table 15)

TABLE 16
PHOSPHORIC ACID AND BIOTITE

Concentration	C _H , H ion Phosphoric Acid	Log. H ion Phosphoric Acid	H ion Phosphoric + Biotite	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _a , Mag- nesium Mols. per Liter	Log. Mag- nesium Mols. per Liter	C _a , Potassium Mols. per Liter	Log. Potassium Mols. per Liter
N 5	0.0125	2.09691	0.0115	0.00342	3.534026	0.00687	3.836957	0.00155	3.190332
N 25	0.00632	3.80072	0.00233	0.00324	3.510545	0.00368	3.565848	0.00134	3.127105
N 50	0.00424	3.62737	0.000230	0.00300	3.477121	0.00339	3.530200	0.00117	3.068186
N 100	0.00273	3.43616	0.00000208	0.00264	3.421604	0.00203	3.307496	0.000834	4.921166
N 250	0.00144	3.15836	0.000000144	0.00103	3.367356	0.00103	3.012837	0.000238	4.376577
N 500	0.000762	4.88195	0.0000000416	0.00168	3.225309	0.00063	4.799341	0.000255	4.406540
N 1,000	0.000372	4.57054	0.0000000147	0.00132	3.120574	0.000503	4.701568	0.000263	4.419956
N 2,000	0.000213	4.32838	0.00000000663	0.00105	3.021189	0.000332	4.521138	0.000255	4.406540
N 5,000	0.0000642	5.80754	0.00000000379	0.00090	4.556303	0.00036	4.556303	0.000246	4.390935
N 10,000	0.0000431	5.63448	0.00000000778	0.00072	4.863323	0.000512	4.709270	0.000304	4.482874

Constants for Calcium:

$x = 0.290$
 $K = 0.000005930$

Constants for Magnesium:

$x = 0.714$
 $K = 0.009398$

Constants for Potassium:

$x = 0.392$
 $K = 0.00008882$

TABLE 17
LACTIC ACID AND BIOTITE

Concentration	C _H , H ion Lactic Acid	Log. H ion Lactic Acid	H ion Lactic Acid + Biotite	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _a , Mag- nesium Mols. per Liter	Log. Mag- nesium Mols. per Liter	C _a , Potassium Mols. per Liter	Log. Potassium Mols. per Liter
N 5	0.00561	3.74896	0.00233	0.00332	3.521138	0.00254	3.404834	0.000349	4.542825
N 25	0.00252	3.40140	0.000472	0.00314	3.496930	0.00190	3.278754	0.000505	4.703291
N 50	0.00169	3.22789	0.000181	0.00293	3.468688	0.00153	3.184691	0.000427	4.630428
N 100	0.00114	3.05690	0.0000398	0.00260	3.414973	0.00133	3.123852	0.000370	4.568202
N 250	0.000677	4.83059	0.00000735	0.00230	3.361728	0.000845	4.926857	0.000218	4.338456
N 500	0.000472	4.67394	0.000000302	0.00172	3.235528	0.00053	4.724276	0.000185	4.267172
N 1,000	0.000270	4.43136	0.0000000778	0.00131	3.117271	0.00046	4.662758	0.000210	4.322219
N 2,000	0.000189	4.27646	0.0000000350	0.00098	4.991226	0.00033	4.518514	0.000156	4.193125
N 5,00	0.000112	4.04922	0.0000000217	0.00087	4.939519	0.00017	4.230449	0.000148	4.170262
N 10,000	0.0000547	5.73799	0.0000000384	0.00062	4.792392	0.000144	4.158362	0.000210	4.322219

Constants for Calcium:

x = 0.443
K = 0.00005566

Constants for Magnesium:

x = 0.743
K = 0.04373

Constants for Potassium:

x = 0.396
K = 0.000166

Figure 17.
Lactic Acid and Biotite.
(See Table 17)

TABLE 18
FORMIC ACID AND BIOTITE

Concentration	C _H , H ion Formic Acid	Log. H ion Formic Acid	H ion Formic Acid +Biotite	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _a , Mag- nesium Mols. per Liter	Log. Mag- nesium Mols. per Liter	C _a , Potassium Mols. per Liter	Log. Potassium Mols. per Liter
N 5	0.00518	3.71433	0.00252	0.00310	3.491362	0.00149	3.173186	0.000888	4.948413
N 25	0.00233	3.36736	0.000587	0.00306	3.485721	0.00127	3.103804	0.000847	4.927883
N 50	0.00156	3.19312	0.000249	0.00285	3.454845	.....	.....	0.000744	4.871573
N 100	0.0010	3.0000	0.0000753	0.00252	3.401401	0.000503	4.701568	0.000436	4.639486
N 250	0.000763	4.88195	0.000000935	0.00239	3.378398	0.000314	4.496930	0.000325	4.511883
N 500	0.000472	4.67394	0.0000000778	0.00171	3.232996	0.00027	4.431364	0.000308	4.488551
N 1,000	0.000343	4.53529	0.00000000411	0.00131	3.117271	0.00038	4.579784	0.000275	4.439333
N 2,000	0.000181	4.25768	0.00000000276	0.00097	4.986772	0.000234	4.369216	0.000279	4.445604
N 5,000	0.0000753	5.87679	0.00000000134	0.00089	4.949390	0.00017	4.230449	0.000271	4.432969
N 10,000	0.0000398	5.59988	0.00000000315	0.000585	4.767156	0.00016	4.204120	0.000226	4.354108

Constants for Calcium:

$$x = 0.447$$

$$K = 0.00005790$$

Constants for Magnesium:

$$x = 0.529$$

$$K = 0.0007431$$

Constants for Potassium:

$$x = 0.272$$

$$K = 0.00001808$$

Figure 18.
Formic Acid and Biotite.
(See Table 18)

TABLE 19
ACETIC ACID AND BIOTITE

Concentration	C _H , H ion Acetic Acid	Log. H ion Acetic Acid	H ion Acetic Acid +Biotite	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _a , Mag- nesium Mols. per Liter	Log. Mag- nesium Mols. per Liter	C _a , Potassium Mols. per Liter	Log. Potassium Mols. per Liter
N 5	0.00224	3.35025	0.000343	0.00295	3.469822	0.00196	3.292256	0.000687	4.836957
N 25	0.000860	4.93450	.....	.....	.....	.....	.....	.....	.....
N 50	0.000677	4.83059	0.0000313	0.00268	3.428135	0.00164	3.214844	0.000530	4.724276
N 100	0.000454	4.65706	.....	.....	.....	.....	.....	.....	.....
N 250	0.000387	4.58771	0.000000579	0.00235	3.371068	0.00128	3.107210	0.000271	4.432969
N 500	0.000313	4.32838	.....	.....	.....	.....	.....	.....	.....
N 1,000	0.000189	4.27646	0.00000000445	0.00145	3.161368	0.00150	3.176091	0.000263	4.419956
N 2,000	0.000104	4.01703	.....	.....	.....	.....	.....	.....	.....
N 5,000	0.0000884	5.94645	0.00000000245	0.00079	4.897627	0.000845	4.926857	0.000255	4.406540
N 10,000	0.0000414	5.61700	0.00000000663	0.00058	4.763428	0.000585	4.767156	0.000271	4.432969

Constants for Calcium:
x = 0.603
K = 0.0004426

Constants for Magnesium:
x = 0.308
K = 0.00008395

Constants for Potassium:
x = 0.310
K = 0.00002812

TABLE 20
HYDROCHLORIC ACID AND GRANITE

Concentration	C _H , H ion Hydrochloric Acid	Log. H ion Hydrochloric Acid	H ion Hydrochloric +Granite	C _{Ca} , Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _{Ca} , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.0882	2.94547	0.0567	0.00595	3.774517	0.00139	3.143015
N 25	0.0218	2.33846	0.0165	0.00536	3.729165	0.00135	3.130334
N 50	0.0135	2.13003	0.00607	0.00432	3.635484	0.00116	3.064458
N 100	0.0685	3.83569	0.00144	0.00333	3.522444	0.00103	3.012837
N 250	0.00321	3.50651	0.0000228	0.00167	3.222716	0.000832	4.920123
N 500	0.00114	3.05690	0.00000216	0.000782	4.693207	0.000654	4.815578
N 1,000	0.00677	4.83059	0.00000192	0.000287	4.457882	0.000605	4.781755
N 2,000	0.000281	4.44871	0.000000753	0.000129	4.110590	0.000535	4.728354
N 5,000	0.0000326	5.51322	0.0000000852	0.000119	4.075547	0.000356	4.551450
N 10,000	0.0000192	6.28330	0.0000000653	0.000119	4.075547	0.000158	4.191657

Constants for Calcium:

$$x = 0.204$$

$$K = 0.000004056$$

Figure 20.
Hydrochloric Acid and Granite.
(See Table 20)

TABLE 21
SULFURIC ACID AND GRANITE

Concentration	C _H H ion Sulfuric Acid	Log. H ion Sulfuric Acid	H ion Sulfuric Acid + Granite	C _H Iron Mols. per Liter	Log. Iron Mols. per Liter	C _H Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.0567	2.75358	0.0300	.....	.....	0.00135	3.130334.
N 25	0.0186	2.26951	0.0115	0.00385	3.585461	0.00127	3.103804
N 50	0.0130	3.11394	0.06539	0.00321	3.506505	0.00127	3.103804
N 100	0.00632	3.80072	0.00183	0.00204	3.309630	0.00101	3.004321
N 250	0.00296	3.47129	0.000117	0.00103	3.012837	0.000901	4.954725
N 500	0.00162	3.70952	0.00000349	0.000455	4.658011	0.000352	4.930440
N 1,000	0.000931	4.96895	0.00000119	0.000192	4.296665	0.000792	4.898725
N 2,000	0.000600	4.77815	0.000000197	0.000109	4.037426	0.000783	4.293762
N 5,000	0.000259	4.41330	0.0000000384	0.000109	4.037426	0.000576	4.759668
N 10,000	0.000174	4.24055	0.0000000421	0.000059	5.770852	0.000338	4.528917

Constants for Calcium:
x = 0.145
K = 0.000001328

Figure 21.
Sulfuric Acid and Granite.
(See Table 21)

TABLE 22
OXALIC ACID AND GRANITE

Concentration	C _H , H ion Oxalic Acid	Log. H ion Oxalic Acid	H ion Oxalic Acid +Granite	C _a , Iron Mols. per Liter	Log. Iron Mols. per Liter
N 5	0.0213	$\bar{2}.33846$	0.0255	.....	.....
N 25	0.0110	$\bar{2}.04139$	0.00772	.....	.....
N 50	0.00561	$\bar{3}.74896$	0.00226	.....	.....
N 100	0.00347	$\bar{3}.54033$	0.00000129	.....	.....
N 250	0.00169	$\bar{3}.22789$	0.0000141	.....	.....
N 500	0.00105	$\bar{3}.02119$	0.00000254	.....	.....
N 1,000	0.000554	$\bar{4}.74351$	0.000000863	.....	.....
N 2,000	0.000317	$\bar{4}.50106$	0.000000421	.....	.....
N 5,000	0.000132	$\bar{4}.12057$	0.000000241	.....	.....
N 10,000	0.0000785	$\bar{5}.89487$	0.000000261	.....	.....

TABLE 23
PHOSPHORIC ACID AND GRANITE

Concen- tration	C _H , H ion Phosphoric Acid	Log. H ion Phosphoric Acid	H ion Phosphoric Acid +Granite	C _a , Iron Mols. per Liter	Log. Iron Mols. per Liter	C _a , Calcium Mols. per Liter	Log. Calci- um Mols. per Liter
N 5	0.0125	$\bar{2}.09691$	0.001	0.00496	$\bar{3}.695482$	0.00174	$\bar{3}.232996$
N 25	0.00632	$\bar{3}.80072$	0.00296	0.00410	$\bar{3}.612784$	0.000119	$\bar{4}.075547$
N 50	0.00424	$\bar{3}.62737$	0.0001	0.00351	$\bar{3}.545307$	0.000178	$\bar{4}.250420$
N 100	0.00273	$\bar{3}.43616$	0.0000486	0.00716	$\bar{3}.334454$	0.000515	$\bar{4}.711807$
N 250	0.00144	$\bar{3}.15836$	0.00000461	0.000675	$\bar{4}.829304$	0.000505	$\bar{4}.703291$
N 500	0.000762	$\bar{4}.88195$	0.000000232	0.000308	$\bar{4}.488551$	0.000416	$\bar{4}.619093$
N 1,000	0.000372	$\bar{4}.57054$	0.000000117	0.000188	$\bar{4}.274158$	0.000436	$\bar{4}.639486$
N 2,000	0.000213	$\bar{4}.32838$	0.0000000787	0.000159	$\bar{4}.201397$	0.000386	$\bar{4}.586587$
N 5,000	0.0000642	$\bar{5}.80754$	0.0000000961	0.000148	$\bar{4}.170262$	0.000297	$\bar{4}.472756$
N 10,000	0.0000431	$\bar{5}.63448$	0.000000222	0.000119	$\bar{4}.075547$	0.000376	$\bar{4}.575188$

Constants for Calcium:

$$x = 0.136$$

$$K = 0.000001987$$

Figure 23.
Phosphoric Acid and Granite.
(See Table 23)

TABLE 24
LACTIC ACID AND GRANITE

Concentration	Ch, H ion Lactic Acid	Log, H ion Lactic Acid	H on Lactic Acid +Granite	Ca, Iron Mols. per Liter	Log, Iron Mols. per Liter	Ca, Calcium Mols. per Liter	Log, Calcium Mols. per Liter
N 5	0.00561	5.74896	0.00321	0.00492	5.691965	0.00144	5.158362
N 25	0.00252	5.40140	0.00677	0.00402	5.604226	0.00118	5.071882
N 50	0.00169	5.22789	0.00317	0.00302	5.480007	0.00100	5.000000
N 100	0.00114	5.05690	0.00167	0.00184	5.264818	0.00101	5.004321
N 250	0.000677	4.83059	0.000339	0.000555	4.744293	0.000783	4.893762
N 500	0.000472	4.67394	0.0000364	0.000238	4.376577	0.000783	4.893762
N 1,000	0.000270	4.43136	0.0000309	0.00009	5.954243	0.000634	4.802089
N 2,000	0.000189	4.27646	0.0000216	0.0000894	5.841359	0.000733	4.865104
N 5,000	0.000112	4.04922	0.00000335	0.000119	4.728354	0.000535	4.728354
N 10,000	0.0000547	5.73799	0.0000753	0.0000694	5.841359	0.000455	4.658011

Constants for Calcium:

$x = 0.246$
 $K = 0.000005781$

Figure 24.
Lactic Acid and Granite.
(See Table 24)

TABLE 25

FORMIC ACID AND GRANITE

Concentration	Ch. H ion Formic Acid	Log. H ion Formic Acid	H ion Formic Acid +Granite	Ca, Iron Mols. per Liter	Log. Iron Mols. per Liter	Ca, Calcium Mols. per Liter	Log. Calcium Mols. per Liter
N 5	0.00518	3.71433	0.00233	0.00474	3.675778	0.00135	3.130334
N 25	0.00233	3.36736	0.000554	0.00456	3.658965	0.00108	3.033424
N 50	0.00156	3.19312	0.000249	0.00387	3.587711	0.00101	3.004321
N 100	0.0010	3.00000	0.000137	0.00226	3.354108	0.00094	4.973128
N 250	0.000762	4.88195	0.0000228	0.000891	4.949390	0.00088	4.944483
N 500	0.000472	4.67394	0.00000129	0.000802	4.904174	0.000772	4.887617
N 1,000	0.000343	4.53529	0.000000967	0.000208	4.318063	0.000634	4.802089
N 2,000	0.000181	4.25768	0.000000513	0.00009	5.954243	0.000575	4.759668
N 5,000	0.0000753	5.87679	0.0000000787	0.000079	5.897627	0.000485	4.685742
N 10,000	0.0000398	5.59988	0.0000000117	0.00009	5.954243	0.000366	4.563481

Constants for Calcium:

$$x = 0.263$$

$$K = 0.000007799$$

Figure 25.
Formic Acid and Granite.
(See Table 25)

TABLE 26
ACETIC ACID AND GRANITE

Concentration	Ch, H ion Acetic Acid	Log, H ion Acetic Acid	H ion Acetic Acid +Granite	Ca, Iron Mols. per Liter	Log, Iron Mols. per Liter	Ca, Calcium Mols. per Liter	Log, Calcium Mols. per Liter
N 5	0.00224	3.35025	0.000343	0.00377	3.576341	0.00113	3.053078
N 25	0.000860	4.93450	0.0000596	0.00356	3.551450	0.00105	3.021189
N 50	0.000677	4.83059	0.0000415	0.00215	3.332438	0.00102	3.008600
N 100	0.000454	4.65706	0.0000228	0.00121	3.082785	0.000970	4.986772
N 250	0.000387	4.58771	0.00000687	0.000625	4.795880	0.000792	4.898725
N 500	0.000213	4.32838	0.00000110	0.000455	4.658011	0.000782	4.893207
N 1,000	0.000189	4.27646	0.000000863	0.000178	4.250420	0.000734	4.865696
N 2,000	0.000104	4.01703	0.000000653	0.000089	3.949390	0.000525	4.720159
N 5,000	0.0000884	5.94645	0.0000000302	0.00009	5.954243	0.000584	4.766413
N 10,000	0.0000414	5.61700	0.0000000646	0.000109	4.037426	0.000495	4.694605

Constants for Calcium:

$$x = 0.232$$

$$K = 0.000004113$$

Figure 26.
Acetic Acid and Granite.
(See Table 26)

TABLE 27.
ORTHOCLASE AND AZOTOBACTER.

Time Days	C _h , H ion Dextrose +Azotobacter	Log. H ion Dextrose +Azotobacter	H ion Orthoclase +Azotobacter	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
0	0.00000282	$\bar{6}.450249$	0.000000962	0.000238	$\bar{4}.376577$
1	0.00000261	$\bar{6}.416641$	0.000000787	0.000675	$\bar{4}.829304$
2	0.00000331	$\bar{6}.519828$	0.00000161	0.000455	$\bar{4}.658011$
3	0.00000359	$\bar{6}.555094$	0.000000887	0.000575	$\bar{4}.774517$
5	0.00000421	$\bar{6}.624282$	0.000000887	0.000852	$\bar{4}.930440$
7	0.00000534	$\bar{6}.727541$	0.00000197	0.00107	$\bar{3}.029384$
9	0.00000627	$\bar{6}.797268$	0.00000251	0.00404	$\bar{3}.606381$
11	0.00000935	$\bar{6}.970812$	0.00000331	0.00198	$\bar{3}.296665$
16	0.0000177	$\bar{5}.247973$	0.00000389	0.00119	$\bar{3}.075547$

Constants for Calcium:
x = 1.804
K = 19.77

Figure 27.
Orthoclase and Azotobacter.
(See Table 27)

TABLE 28

BIOTITE AND AZOTOBACTER

Time Days	C _b , H ion Dextrose+ Azotobacter	Log. H ion Dextrose+ Azotobacter	H ion Biotite+ Azotobacter	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _a , Mag- nesium Mols. per Liter	Log. Mag- nesium Mols. per Liter	C _a , Potassium Mols. per Liter	Log. Potassium Mols. per Liter
0	0.00000282	6.450249	0.00000040	0.001605	3.205475	0.000862	4.935507	0.00079	4.897627
1	0.00000261	6.416641	0.000000384	0.00200	3.301030	0.001005	3.002166	0.000435	4.638489
2	0.00000331	6.519828	0.0000004	0.00220	3.342423	0.000628	4.797960	0.00036	4.556303
3	0.00000359	5.555094	0.00000034	0.00242	3.383815	0.000503	4.701568	0.000445	4.648360
5	0.00000421	6.624282	0.000000596	0.00244	3.387390	0.000484	4.684854	0.00042	4.623249
7	0.00000534	6.727541	0.00000132	0.00293	3.466868	0.000556	4.745075	0.000715	4.854306
9	0.00000627	6.797268	0.00000197	0.00275	3.439333	0.000807	4.906874	0.00069	4.838849
11	0.00000935	6.970812	0.00000282	0.00258	3.411620	0.001401	3.146438	0.000585	4.767156
16	0.0000177	5.247973	0.00000205	0.00258	3.411620	0.000000	.....	0.000765	4.883661

Constants for Calcium:

$$x = 0.374$$

$$K = 0.000002198$$

Constants for Magnesium:

$$x = 1.312$$

$$K = 0.2388$$

Constants for Potassium:

$$x = 0.422$$

$$K = 0.00001963$$

Figure 28.
Biotite and Azotobacter.
(See Table 28)

TABLE 29
GRANITE AND AZOTOBACTER

Time Days	Ch, H ion Dextrose +Azotobacter	Log. H ion Dextrose +Azotobacter	H ion Granite +Azotobacter	Ca, Calcium Mols. per Liter	Log. Calcium Mols. per Liter	Ca, Iron Mols. per Liter	Log. Iron Mols. per Liter
0	0.00000282	6.450249	0.000000887	0.000495	4.694605	0.000099	5.995635
1	0.00000261	6.416641	0.000000727	0.000792	4.898725	0.000376	4.575188
2	0.00000331	6.519828	0.000000620	0.000693	4.840733	0.000357	4.552668
3	0.00000359	6.555094	0.000000384	0.000812	4.909556	0.000317	4.501059
5	0.0000044	6.624282	0.000000572	0.000852	4.930440	0.000317	4.501059
7	0.00000534	6.727541	0.00000149	0.00113	3.053078	0.000317	4.501059
9	0.00000627	6.797268	0.00000045	0.00137	3.136721	0.000357	4.552668
11	0.00000935	6.970812	0.00000175	0.00127	3.103804	0.000396	4.597695
16	0.0000177	5.247973	0.00000197	0.00121	3.082785	0.000456	4.658965

Constants for Calcium:

$$x = 1.252$$

$$K = 0.07178$$

Figure 29.
Granite and Azotobacter.
(See Table 29)

TABLE 30

CALCIUM SILICATE AND AZOTOBACTER

Time Days	C _b , H ion Dextrose +Azotobacter	Log. H ion Dextrose +Azotobacter	H ion Calcium Silicate +Azotobacter	C _b , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
0	0.00000282	$\bar{6}.450249$	0.0000000778	0.00142	$\bar{3}.152288$
1	0.00000261	$\bar{6}.416641$	0.0000000778	0.00201	$\bar{3}.303196$
2	0.00000331	$\bar{6}.519828$	0.0000000912	0.00186	$\bar{3}.269513$
3	0.00000359	$\bar{6}.555094$	0.0000000912	0.00196	$\bar{3}.292256$
5	0.00000421	$\bar{6}.624282$	0.0000000112	0.00279	$\bar{3}.445604$
7	0.00000534	$\bar{6}.727541$	0.0000000941	.....	.....
9	0.00000935	$\bar{6}.797268$	0.000000107	0.00396	$\bar{3}.597695$
11	0.00000935	$\bar{6}.960812$	0.0000000778	0.00396	$\bar{3}.597695$
16	0.0000177	$\bar{5}.247973$	0.000000731	0.00406	$\bar{3}.695482$

Constants for Calcium:

$$x = 1,280$$

$$K = 0.03381$$

Figure 30.
Calcium Silicate and Azotobacter.
(See Table 30)

TABLE 31
ORTHOCLEASE AND B. COLI

Time Days	Ch, H ion Dextrose +B. Coli	Log. H ion Dextrose +B. Coli	H ion Orthoclease +B. Coli	Ca, Calcium Mols. per Liter	Log. Calcium Mols. per Liter
0	0.00000261	$\bar{6}.416641$	0.000000962	0.000694	$\bar{4}.841359$
1	0.000301	$\bar{4}.478566$	0.000141	0.000753	$\bar{4}.876795$
2	0.000486	$\bar{4}.686636$	0.000267	0.00206	$\bar{3}.313867$
3	0.000505	$\bar{4}.703291$	0.000339	0.00230	$\bar{3}.361728$
5	0.000505	$\bar{4}.703291$	0.000289	0.00224	$\bar{3}.350248$
7	0.000467	$\bar{4}.669317$	0.000278	0.00270	$\bar{3}.431364$
9	0.000414	$\bar{4}.617000$	0.000237	.....	.....
11	0.000467	$\bar{4}.669317$	0.000313	0.00282	$\bar{3}.450249$
16	0.000431	$\bar{4}.634477$	0.000179	0.00271	$\bar{3}.432969$

Constants for Calcium:

$$x = 1.690$$

$$K = 13,490.0$$

Figure 31.
Orthoclase and B. Coli.
(See Table 31)

TABLE 32
BIOTITE AND B. COLI

Time Days	Ch, H ion Dextrose +B. coli	Log. H ion Dextrose +B. coli	H ion Biotite +B. coli	Ca, Calcium Mols. per Liter	Log. Calcium Mols. per Liter	Ca, Mag- nesium Mols. per Liter	Log. Mag- nesium Mols. per Liter	Ca, Potassium Mols. per Liter	Log. Potassium Mols. per Liter
0	0.00000261	6.416614	0.000000596	0.00176	3.245513	0.001096	3.039811	0.000525	4.720159
1	0.0000301	4.478566	0.000210	0.00106	3.025306	0.000358	4.553883	0.000332	4.521138
2	0.000486	4.686636	0.000367	0.00186	3.269513	0.000807	4.906874	0.000424	4.627366
3	0.000505	4.703291	0.000431	0.00205	3.311754	0.000807	4.906874	0.000458	4.660865
5	0.000535	4.728354	0.000398	0.00204	3.309630	0.000987	4.994317	0.000475	4.676694
7	0.000567	4.753583	0.000348	0.00225	3.352183	0.001006	3.002598	0.000486	4.686636
9	0.000584	4.766413	0.000348	0.00238	3.376577	0.001096	3.039811	0.000500	4.698970
11	0.000597	4.775974	0.000301	0.00240	3.380211	0.00115	3.060698	0.00050	4.698970
16	0.000579	4.762679	0.000382	0.00228	3.357935	0.001113	3.046495	0.00052	4.716003

Constants for Calcium:

x = 1.225

K = 8.299

Constants for Magnesium:

x = 1.870

K = 401,800

Constants for Potassium:

x = 0.808

K = 0.05784

TABLE 33
GRANITE AND B. COLI

Time Days	Ch, H ion Dextrose +B. coli	Log. H ion Dextrose +B. coli	H ion Granite +B. coli	C _{Ca} Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _{Fe} Iron Mols. per Liter	Log. Iron Mols. per Liter
0	0.0000261	6.416614	0.000000596	0.000654	4.815578	0.000792	4.898725
1	0.000301	4.478566	0.000153	0.000841	4.924796	0.00127	3.103804
2	0.000486	4.686636	0.000278	0.00120	3.079181	0.00161	3.26826
3	0.000505	4.703291	0.000376	0.00131	3.117271	0.00198	3.296665
5	0.000505	4.703291	0.000278	0.00137	3.136721	0.00335	3.525045
7	0.000467	4.669371	0.000289	0.00146	3.164353	0.00394	3.595496
9	0.000414	4.617000	0.000237	0.00150	3.116091	0.00410	3.612784
11	0.000467	4.669317	0.000339	0.00156	3.193125	0.00411	3.613842
16	0.000431	4.634477	0.000172	0.00153	3.184691	0.00408	3.610660

Constants for Calcium:

$$x = 0.875$$

$$K = 0.06502$$

Figure 33.
Granite and B. coli.
(See Table 33)

TABLE 34
CALCIUM SILICATE AND B. COLI

Time Days	Ch, H ion Dextrose +B. coli	Log. H ion Dextrose +B. coli	H ion Calcium Silicate +B. coli	Ca, Calcium Mols. per Liter	Log. Calcium Mols. per Liter
0	0.000000261	$\bar{6}.416614$	0.000000220	0.00337	$\bar{3}.527630$
1	0.000301	$\bar{4}.478566$	0.0000716	0.0108	$\bar{2}.033424$
2	0.000486	$\bar{4}.686636$	0.0000564	0.0397	$\bar{2}.598791$
3	0.000505	$\bar{4}.703291$	0.0000687	0.0526	$\bar{2}.720986$
5	0.000535	$\bar{4}.728354$	0.0000806	0.0723	$\bar{2}.859138$
7	0.000567	$\bar{4}.753583$	0.0000745	0.0848	$\bar{2}.928396$
9	0.000584	$\bar{4}.766413$	0.0000716	0.0972	$\bar{2}.987666$
11	0.000597	$\bar{4}.775974$	0.0000716	0.1018	$\bar{1}.007748$
16	0.000579	$\bar{4}.762679$	0.0000635	0.1238	$\bar{1}.092721$

Constants for Calcium:

$$x = 5.070$$

$$K = 1,667. \times 10^{11}$$

Figure 34.
Calcium Silicate and *B. coli*.
(See Table 34)

TABLE 35

ORTHOCLASE AND B. LACTIS ACIDI

Time Days	C _H , H ion Dextrose +B. lactis acidi	Log. H ion Dextrose +B. lactis acidi	H ion Orthoclase +B. lactis acidi	C _a , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
0	0.00000421	$\bar{6}.624282$	0.000000354	0.00147	$\bar{3}.167317$
1	0.0000157	$\bar{5}.195900$	0.00000935	0.000912	$\bar{4}.959995$
2	0.000228	$\bar{4}.357935$	0.00000967	0.000852	$\bar{4}.930440$
3	0.000398	$\bar{4}.599883$	0.00000967	0.00162	$\bar{3}.209515$
5	0.000642	$\bar{4}.807535$	0.0000217	0.00228	$\bar{3}.357935$
7	0.000696	$\bar{4}.842609$	0.0000170	0.00235	$\bar{3}.371068$
9	0.000696	$\bar{4}.842609$	0.0000192	0.00249	$\bar{3}.396199$
11	0.000789	$\bar{4}.897077$	0.0000244	0.00271	$\bar{3}.432969$
16	0.000642	$\bar{4}.807535$	0.0000286	0.00210	$\bar{3}.322219$

Constants for Calcium:

$$x = 0.867$$

$$K = 0.0006652$$

Figure 35.
Orthoclase and B. lactis acidi.
(See Table 35)

TABLE 36

BIOTITE AND B. LACTIS ACIDI

Time Days	Ch, H ion Dextrose+ B. lactis acidi	Log. H ion Dextrose+ B. lactis acidi	H ion Biotite+ B. lactis acidi	Ca, Calcium Mols. per Liter	Log. Calcium Mols. per Liter	Ca, Mag- nesium Mols. per Liter	Log. Mag- nesium Mols. per Liter	Ca, Potassium Mols. per Liter	Log. Potassium Mols. per Liter
0	0.00000421	6.624282	0.000000195	0.000872	4.940516	0.000144	4.158362	0.00040	4.602060
1	0.0000157	5.195900	0.000000787	0.00101	3.004321	0.000216	4.334454	0.00051	4.707570
2	0.000228	4.357935	0.00000149	0.000712	4.852480	0.000252	4.401401	0.00062	4.792392
3	0.000398	4.599883	0.000000727	0.00103	3.012837	0.000269	4.420752	0.00054	4.732314
5	0.000462	4.807535	0.00000241	0.00129	3.110590	0.000264	4.421604	0.00066	4.819544
7	0.000496	4.842609	0.00000306	0.00139	3.143015	0.000276	4.440909	0.00070	4.845098
9	0.000496	4.842609	0.00000345	0.00137	3.136721	0.000282	4.450249	0.00073	4.893323
11	0.000789	4.897077	0.00000653	0.00155	3.190332	0.000272	4.434569	0.00068	4.832509
16	0.000642	4.807535	0.00000967	0.00139	3.143015	0.000296	4.471292	0.00070	4.845098

Constants for Calcium:

$$x = 0.564$$

$$K = 0.00003190$$

Constants for Magnesium:

$$x = 0.096$$

$$K = 0.000001637$$

Constants for Potassium:

$$x = 0.106$$

$$K = 0.0000007569$$

Figure 36.
Biotite and B. lactis acidi.
(See Table 36)

TABLE 37

GRANITE AND B. LACTIS ACIDI

Time Days	C _H , H ion Dextrose+ B. lactis acidi	Log. H ion Dextrose+ B. lactis acidi	H ion Granite+ B. lactis acidi	C _{Ca} , Calcium Mols. per Liter	Log. Calcium Mols. per Liter	C _{Fe} , Iron Mols. per Liter	Log. Iron Mols. per Liter
0	0.00000421	6.624282	0.000000187	0.000317	4.501059	0.000218	4.338456
1	0.0000157	5.195900	0.00000627	0.000773	4.888179	0.000317	4.501059
2	0.000228	4.357935	0.00000735	0.000693	4.840733	0.000635	4.802774
3	0.000398	4.599883	0.00000653	0.000734	4.865696	0.000614	4.788168
5	0.000642	4.807535	0.0000192	0.000753	4.876795	0.000892	4.950365
7	0.000696	4.842609	0.0000177	0.000773	4.888179	0.00101	3.004321
9	0.000696	4.842609	0.0000192	0.000734	4.865696	0.000982	4.992111
11	0.000789	4.897077	0.0000192	0.000753	4.876795	0.00101	4.876795
16	0.000642	4.807535	0.0000192	0.000795	4.900367	0.00117	3.068186

Constants for Calcium:

$$x = 0.067$$

$$K = 0.0000003846$$

Constants for Iron:

$$x = 0.291$$

$$K = 0.00001002$$

Figure 37.
Granite and *B. lactis acid*i.
(See Table 37)

TABLE 38
CALCIUM SILICATE AND B. LACTIS ACIDI

Time Days	C ₁ , H ion Dextrose +B. lactis acidi	Log. H ion Dextrose +B. lactis acidi	H ion Calcium Silicate +B. lactis acidi	C ₂ , Calcium Mols. per Liter	Log. Calcium Mols. per Liter
0	0.00000421	$\bar{6}.624282$	0.0000000877	0.00229	$\bar{3}.359835$
1	0.0000157	$\bar{5}.195900$	0.000000136	0.00248	$\bar{3}.394452$
2	0.000228	$\bar{4}.357935$	0.000000142	0.00475	$\bar{3}.676694$
3	0.000398	$\bar{4}.599883$	0.0000000778	0.00416	$\bar{3}.619093$
5	0.000642	$\bar{4}.807535$	0.0000000778	0.00486	$\bar{3}.686636$
7	0.000696	$\bar{4}.842609$	0.0000000411	0.00554	$\bar{3}.743510$
9	0.000696	$\bar{4}.842609$	0.0000000544	0.00545	$\bar{3}.736397$
11	0.000789	$\bar{4}.897077$	0.0000000544	0.00525	$\bar{3}.720159$
16	0.000642	$\bar{4}.807535$	0.0000000544	0.00565	$\bar{3}.752048$

Constants for Calcium:
x = 0.170
K = 0.0000002710

Figure 38.
Calcium Silicate and *B. lactis acidii*.
(See Table 38)