

Danmarks Geologiske Undersøgelse.

II. Række. Nr. 67.

On the Salt-Solutions
in Microscopic Cavities in Granites

By

Harald Faber

Med dansk Resumé.

I Kommission hos

C. A. Reitzels Forlag

Axel Sandal

København 1941.

Pris 2 Kr.

Danmarks Geologiske Undersøgelse.

II. Række. Nr. 67.

On the Salt-Solutions in Microscopic Cavities in Granites

By

Harald Faber

Med dansk Resumé.

I Kommission hos

C. A. Reitzels Forlag

Axel Sandal

København 1941.

FR. BAGGES KGL. HOFBOGTRYKKERI
KØBENHAVN

Contents.

	Page
Chap. 1. Introduction	5
Microphotos	9
Chap. 2. Method of Procedure.....	13
The Water	14
The Salts	20
Chap. 3. Pre-Cambrian Granites.....	26
Chap. 4. Pegmatites from pre-Cambrian Rocks.....	32
Chap. 5. Younger Granites	35
Chap. 6. Basalt.....	40
Postscript	41
Dansk Resumé	43
Literature	45

Introduction.

Microscopic cavities were observed by DAVY in 1822 and by BREWSTER in 1826 in various crystals of minerals and were more thoroughly studied by H. C. SORBY (*1*) who in 1858 from his observations drew certain conclusions as to the origin of minerals and rocks. SORBY examined first the microscopic structure of crystals which he had made under different conditions from solutions of various salts. The crystals contained microscopic cavities which were sometimes filled with a liquid, viz. that from which the crystals had been formed, the mother-liquor. If the crystals were formed at an elevated temperature the liquid enclosed in the cavities would contract when cooled and formed what looked like air bubbles. If the crystals were heated, the liquid would expand and would again fill the cavities. Some crystals would contain real air-bubbles or crystals of other salts; and all this as natural consequences of the varying conditions under which the crystals had been formed. SORBY then examined the crystals of minerals and found in them, and particularly in quartz in rocks, similar phenomena as those observed in the artificial crystals and therefrom drew his conclusions as to the origin of the minerals. In the sixth chapter he deals with minerals and rocks formed by combined action of heat and water, and he speaks particularly about the formation of granite.

In the quartz of granite he frequently found numerous microscopic cavities with fluids, often so many together that they were no more than one thousandth part of an inch from one another. Although their numbers varied in the different granites they were found in all the specimen examined. Also in feldspar and in mica he observed and even illustrated them. By an experiment it was proved that the liquid was water. When heating small pieces of the mineral the liquid expands and bursts the mineral and escapes. SORBY took a piece of glass tube, eight inches long, $\frac{1}{4}$ inch diameter, melted together at one end. Pieces of the mineral, dried at 100° C were placed in the glass tube, which was filled with dry air. The open end was closed by a dry cork and the tube was placed through two holes in opposite sides of a box filled with a mixture of ice and salt. The

closed end of the tube, containing the pieces of mineral, extended a few inches outside the box, and was heated so as to drive the liquid out of the cavities. It was then observed that small crystals were formed in the cooled part of the glass tube, and these melted at a temperature of 0°C and were consequently water (ice).

The salts dissolved in the liquid SORBY found to be chlorides and sulphates of alkalies and calcium.

In the cavities with liquids there were what looked like air bubbles, but, on being heated, the liquid expanded, and the air bubbles disappeared and this generally occurred at a temperature of about 200°C . The liquid had therefore been enclosed during the crystallization at a temperature of at least 200°C . When the liquid contracted by cooling below this temperature, these vacuoles reappeared. The liquid had probably been dissolved in the granitic magma like air in water¹⁾ and, when crystallization took place, it was set free like the air in water which is set free and forms bubbles in the ice when the water freezes. But if the magma had been under a considerable pressure before or during crystallization, this might have taken place at a considerably higher temperature than the 200°C . SORBY has carried on some ingenious calculations and has arrived at the result, that the granites he has examined and the metamorphic crystalline rocks surrounding them, have crystallized at a temperature of a dull red heat such as can just be seen in the dark, a temperature much below their melting point, and he thinks this crystallization has taken place under the combined action of heat and water (or rather salt-solutions).

The year before the publication of SORBY's paper A. DAUBRÉE (3), had described certain very important experiments. He heated various substances enclosed in a sealed glass tube with some water; the glass tube was placed in a very strong iron tube, hermetically closed, and this was heated, sometimes for two months, to a dull red heat, whereby a tremendous pressure was produced. There was therefore the combined action of water, a dull red heat and a high pressure, or just the conditions under which SORBY thought that granite had been formed. Only two of the experiments need be mentioned. In the one he heated pure caolin and an aqueous solution of potassium and sodium silicates and thereby obtained quartz and feldspar with small prismatic crystals. In the other experiment he changed obsidian into a trachytic substance.

Ten years later DAUBRÉE (3) wrote about SORBY's work: "Les ingénieu-

¹⁾ In this connection R. W. GORANSON's paper on "The solubility of water in granite magmas" (2) is of great interest. He melted a granite to a uniform glass, pulverized this very finely and then melted it with some water at 900°C under a pressure of several thousands atmospheres. Thereby he obtained a granite magma or glass in which were dissolved 4-9% of water. When the water was driven off by ignition the glass was reduced to a powder.

ses observations de M. Sorby, sur les liquides renfermés dans les vacuoles microscopiques des roches, ont confirmé l'intervention de l'eau et de la chaleur dans la formation du granite". And he returns to the question in 1879, when he writes: "Quand il s'agit d'expliquer l'origine et la formation des silicates dans beaucoup des roches, ce n'est pas à la voie sèche, mais bien à la voie hydrothermale, qu'il faut recourir le plus souvent". Already in 1867 he had used the term "hydrothermique". In 1879 he wrote (Pag 217) as a result of his investigations that: "l'eau permet la cristallization des silicates à une temperature bien inférieure à leurs points de fusion".

In the year 1870 appeared a paper by F. ZIRKEL (4) who had made certain observations which confirm those made by SORBY. ZIRKEL found numerous fluid enclosures with air bubbles in feldspar from Mull, Hebrides, and in other feldspars, and he thinks that such enclosures may be found in all minerals. He has, like SORBY, observed cubic crystals in the liquid-filled cavities; he has proved that the liquid contains chlorides, by precipitation with silver nitrate, and sodium, by yellow coloration of a blue flame, that the liquid consequently contains chloride of sodium, all of which SORBY had already done.

Another paper was published the following year by FR. PFAFF, who evidently did not know SORBY's work, although he quotes ZIRKEL who had mentioned SORBY. PFAFF (5) determined the amount of water in the microscopic cavities in minerals by pulverizing these in a hermetically closed small chamber through which a current of dry air is passed to a weighed glass containing a water absorbing liquid. He thinks all granites contain watery enclosures, both in the quartz and in the feldspars, and he proves the presence of chlorine and of sodium. PFAFF writes that it was very desirable if the amount of water and of natrium chloride in the rocks could be determined.

A criticism of SORBY's work by J. A. PHILLIPPS (6) appeared in 1875. He found that the quartz in all granites in Cornwall contain numerous microscopic cavities, partly filled with a liquid, but he observed that some of the cavities were completely filled, that is without the air bubbles, while others were quite empty. The quartz from Redruth contained "many fluid-cavities enclosing bubbles which, in some of the smaller ones, are observed to be in continued motion", while the quartz from Morvale "contains numerous gas and fluid-cavities". He also found that the bubbles in the cavities did not all disappear at the same temperature when heated. That some cavities are quite empty can be explained thereby that they are filled with air (gas) as he himself has observed. He lays particular stress on the fact, that some cavities, according to his observations, are completely filled with liquid. This, he thinks, is enough to disprove SORBY's conclusions. "If the presence of full fluid-cavities be

admitted—all such calculations (as Sorby's) must necessarily be fallacious". But how does he think of proving that these cavities are filled with liquid and not with glass or mineral? SORBY has expressly mentioned cavities filled with glass or stone. Without such proof it appears to me that PHILLIPPS is quite unjustified in rejecting the work of SORBY and others.

If the air bubbles, or what looks like such, are the result of the contraction of the liquid by cooling below the temperature at which it was enclosed, it follows that the air bubbles in all the cavities in a mineral or crystal should disappear at the same time and temperature when the mineral is heated.

PHILLIPPS' remark that this was not the case caused KÖNIGSBERGER and WOLF MÜLLER (7) in 1906 to examine very minutely the minerals in the biotitprotogine at Aar. They found that the bubbles in the cavities in the quartz disappeared almost simultaneously and with a difference of temperature of only from 3° to 12° C. Quartz from three different localities were examined and it was found that the bubbles disappeared respectively at temperatures of 199° to 210°, or 215° to 222°, or 223° to 229° C. They also found that the water in the liquid, the amount of which was determined as the loss of weight by heating to red heat, contained 7% of solids, but they give no analysis of the quantity or quality of the different salts.

It might be argued that the liquid is enclosed in the crystal as this grows and that, therefore, the liquid in the outer parts of the crystal were enclosed later than that in the centre part, and that, during the time of the growth of the crystal, the pressure might have decreased and that, therefore, the liquid last enclosed was enclosed under a lower pressure, and that therefore the relative size of the vapour-bubbles in the outer parts might be different from those in the centre part of the crystal.

Microphotos

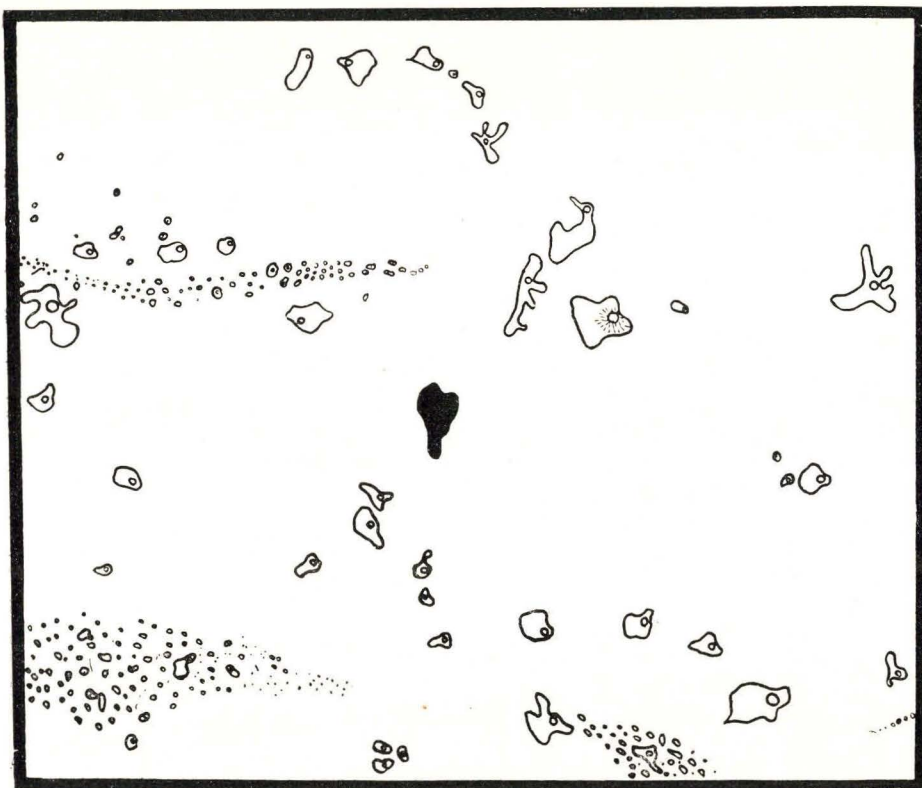
of cavities in quartz with fluid contents
and slow-moving libellæ

By

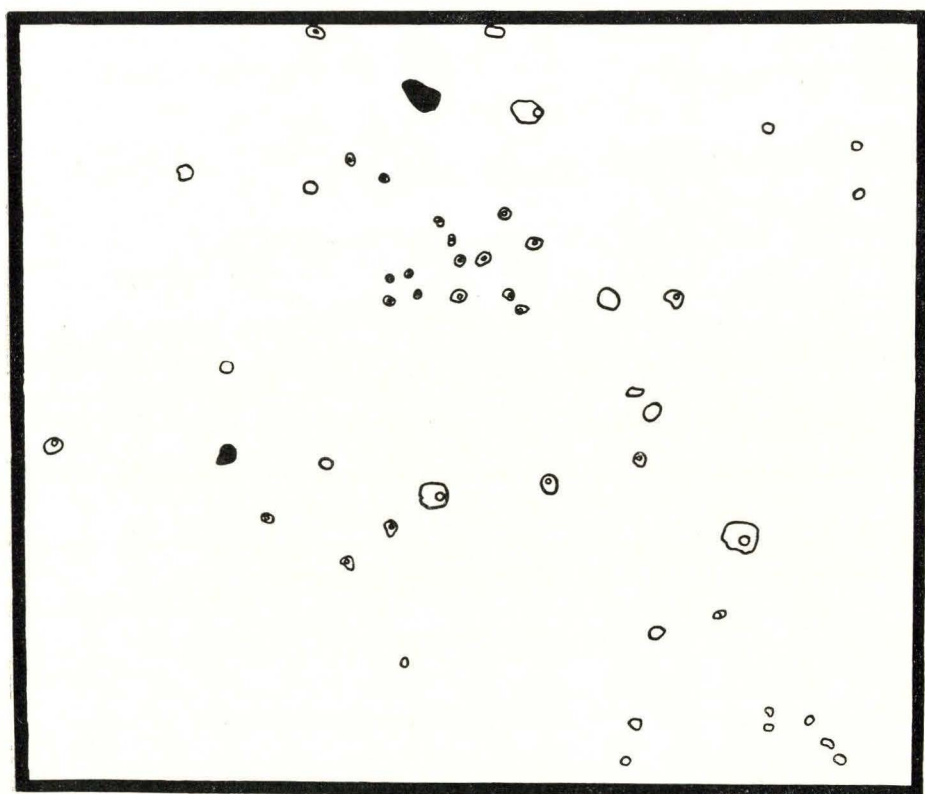
Messrs. Brock & Michelsen.

1. Cavities in quartz from pegmatite, from Barhult, Sweden.
2. Cavities in quartz from Hammer granite, Bornholm, Denmark.

The magnification of the original drawings is 1100 linear.
The reproductions are reduced to $\frac{2}{3}$ size (B & M).



No. 1.



No. 2.

Method of Procedure.

It is beyond question, according to the investigations mentioned in the Introduction, that granites contain a salt-solution in microscopic cavities, that this watery solution must have had some influence on the crystallization of the minerals, that these have crystallized at a temperature well below their melting points, and that a full understanding of the formation of granites and metamorphic rocks is impossible without a fuller knowledge of these salt-solutions. It therefore seems somewhat remarkable that a closer investigation of these solutions has never been undertaken. We know next to nothing of the amount of water present, we have absolutely no quantitative analysis of the salts present. Are the salts the same in all granites or are they different in granites from different geological periods? And are they found also in other eruptive rocks? Does the concentration of the salts vary in the different rocks? What are the quantities of sulphates and of chlorides? Do the amount of water and the quantity and quality of the salts vary according to the different modes of origin of the different granites and metamorphic rocks, whether they are ascended as a magma from below or resulted from fusion by heat and water or magmatic emanations acting on pre-existing rocks? etc. etc.

It seems the more peculiar that so little work has been done about the saline fluid in the cavities, when so much has been done to determine the quality and quantity of the gaseous matter in rocks, particularly by R. T. CHAMBERLIN (8) who in his paper on "The Gases in Rocks" has given 112 analyses of these and discusses their relation to various problems of cosmogony.

It has occurred to me that a certain amount of spade work on these saline solutions might be of interest and I have been encouraged to undertake this by various geologists; among these I wish especially to express my gratitude to Dr. KAREN CALLISEN of the Mineralogical Museum, Copenhagen, who has helped me in many ways. I have particularly to thank also Professor Dr. A. H. M. ANDREASEN, of Danmarks Technical Highschool, for the opportunity afforded me of working for four years in his laboratory as well as for much valuable advice.

The investigation is a twofold one in as much as it is desired to estimate both the quantity of water in the cavities and the quantity of the different salts in the solution.

The Water.

In the usual analyses of granites are given two figures for the amounts of water, at temperatures below and above 100° or 110° C, the first supposed to be the hygroscopic water, the other—if sufficiently heated—might include some of the chemically bound water in biotite, hornblende and such like minerals but might also include some of the fluid water from the cavities. But as the estimations are made on the finely powdered mineral or rock it is more than likely that some of the fluid water from the cavities has been set free and has been evaporated during the grinding process. The amount of water found at a temperature below 100° or 110° C may, therefore, be partly hygroscopic and partly derived from the cavities, but impossible to know how much of each. With special regard to the hygroscopic water I find that in freshly ground granite powder there is hardly any hygroscopic water while if the powder is kept for some time it may absorb as much as half a percent or more of hygroscopic water. This again makes the figure for the amount of water found by heating below 100° of doubtful value.

The amount of water found at higher temperature would include some of the water from the cavities, but it is impossible to know what proportion thereof it includes. It would probably also include some chemically bound water, but also here it is impossible to know what proportion thereof it includes. The two figures for water given in the usual analyses of granites and other rocks and minerals containing fluid water in cavities, do therefore seem to be of very little real value.

In his book on the chemical analysis of rocks HENRY S. WASHINGTON (9) writes: "By the term hygroscopic water is meant the water which is absorbed by the rock powder from the atmosphere and the water might be present in microscopic cavities". He does not even suggest that the two kinds of water should be estimated separately. It is evident, therefore, that the amount of water in the cavities cannot be found by the usual methods. Both SORBY and KÖNIGSBERGER & MÜLLER have made use of the fact that the water in the cavities, when heated, will burst the mineral and escape, and the last named used this method to find the amount of water in the quartz from Aar. In the same way I have estimated the amount of water in the quartz and feldspar from the pegmatite from Barhult in Sweden and from the pegmatite from Gloserhei, Arendal, in Norway, minerals which contain none or hardly any chemically bound water and where the estimation of the total quantity of water—all derived

from the cavities— is therefore a fairly simple matter. Analyses of these minerals are given in a later chapter. I have proceeded as follows: ten grammes of the mineral were prepared in grains of abt. 2mm—between sieves with mesh 2 and 3 mm—dried at 100° to get rid of the hygroscopic water, then heated for $\frac{1}{2}$ hour to a red heat and the loss of weight noted. This loss of weight I take to be equal to the amount of water in the cavities. In this way I found:

Amount of water in pegmatites

from Norway:		from Sweden:	
Feldspar	Quartz	Feldspar	Quartz
0,14%	0,15%	0,16%	0,15%;

with the following percentages of salts in the solutions:

18,8%	14,9%	18,2%	18,8%.
-------	-------	-------	--------

But when the question is of estimating the amount of water in cavities in rocks containing minerals with chemically bound water, the matter is considerably more complicated.

I have worked on the assumption that when the rock was prepared in grains of abt. 2 to 3 mm, and, after drying at 100 or 110°, heated for $\frac{1}{2}$ hour at a red heat, then the water in the cavities would escape and evaporate but that there would be no loss of chemically bound water¹). Several observations seemed to justify this assumption. It was found in several cases, but not in all, that when the water in the cavities had been evaporated, the grains of granite could be heated for another half hour to a bright red heat without suffering any appreciable further loss. This seems to show that the chemically bound water is not easily driven out by heating the granite, when in grains, while it can be fairly easily evaporated by heating to a bright red heat the granite in the form of a very fine powder.

I was anxious, however, to find, if possible, a better proof of the correctness of estimating in this way the amount of water in the cavities. After several vain attempts I was led to the following consideration: When the hygroscopic water has been removed, then the amount of water in the cavities is the difference between the total amount of water and the amount of chemically bound water, and these amounts can be estimated with considerable accuracy. There is in this an assumption which sometimes fails, as fully explained below.

The total amount of water can be found by first heating grains of granite, dried at 110°, to red heat, in order to drive out all or most of the water in the cavities and note the loss of weight, and then pulverizing the grains and ignite the fine powder sufficiently to drive out the remaining

¹) About a possible other loss see below.

water, viz. the remaining water from the cavities if any and the chemically bound water, and note the loss of weight. This loss of weight added to that found by heating the grains would be the total amount of water.

When the question is, not of pure feldspar or quartz, but of a granite with other minerals some of which may contain chemically bound water, then the loss of weight by this second heating may be complicated by other reactions. There may be f. inst. loss of weight by any carbonates present losing CO_2 , and loss by evaporation of other chemical compounds, depending on the minerals present, while on the other hand an oxidation, which is in fact sometimes observed by the gray powder turning reddish, will add to the weight of the powder. It will therefore be more correct to speak, not of an amount of chemically bound water, but simply of the loss of weight. This loss of weight added to the loss of weight found by heating the grains, gives us what I, with a less accurate but convenient expression, have called "the total amount of water".

Next comes the estimation of the chemically bound water by itself.

In order to find this it is necessary to get rid of all other kinds of water. By heating 10 gr. of the finely ground granite to 400° the hygroscopic water will, of course, be evaporated. (If the granite is freshly ground there would be hardly any hygroscopic water, while if the powder be kept for some time it may absorb as much as $\frac{1}{2}$ pCt or more of hygroscopic water). The fluid water from the cavities, when these are opened up by the grinding, would have been partly evaporated during the grinding. The remaining fluid water would be evaporated by the heating to 400° and be measured by the loss of weight. After this heating the powder should contain of water only the chemically bound water, and the quantity thereof should be found as the loss of weight by heating the powder to a bright red heat. It is a question, however, whether some of it has been lost by the heating to 400° . I find that, dealing with freshly ground granite powder free from hygroscopic water, the loss of weight by the heating to 400° is always less, sometimes even considerably less, than the total amount of fluid water, as found by the analyses given on a later page. This will be seen from the following table:

Sample of granite from:	Total amount of water in cavities	Loss of weight by heating the powder to 400°
Bjergbakke	0.13%	0.08%
Rønne	0.20%	0.14% ¹⁾
Svaneke	0.37%	0.29% ¹⁾
Cornwall	0.23%	0.15%
Devon	0.40%	0.16%

¹⁾ In a sample of finely ground Rønne granite which had been kept for some time I found the loss of weight by heating to 400° to be 0.75 pCt and in a sample of Svaneke granite, similarly kept, I found it 0.71 pCt., showing respectively abt. 0.60 and 0.40 pCt. of hygroscopic water, absorbed during the keeping of the powder.

The difference between the figures in the two columns is due to some of the fluid water having been evaporated during the grinding. If any appreciable quantity of chemically bound water was also lost by the heating, then one would expect a greater loss of weight by the heating. This makes it reasonable to assume that all the chemically bound water remains in the powder after heating to 400° and that the quantity thereof can be measured by the loss of weight found when heating the powder to a bright red heat. It will be seen by the analyses below that the estimation in this way of the chemically bound water gives very satisfactory results.

When speaking of measuring the quantity of chemically bound water by the loss of weight at red heat it is understood, as explained above, that there might be some complications such as loss of CO_2 by carbonates or of other volatile chemical compounds and increase in weight by oxidation of iron compounds. But these complications must be the same whether the heating is done in order to find the "total amount of water", or to find, what I, for brevity's sake, have called "chemically bound water". And if that be so then the difference between these two amounts would be the amount of fluid water in the cavities, independent of the complications.

In what is written on the foregoing pages there is a presumption, viz. that when grains of granite are heated to red heat the loss of weight is due solely to the evaporation of fluid water set free by the bursting of the cavities. If that were so there should be no loss of weight when the grains are gradually heated until such heat is reached which causes the cavities to burst. In a similar way, when the quantity of fluid water is measured as the difference between the total quantity of water and the chemically bound water, it is presumed that there is no other kind of water than the fluid water and the chemically bound water.

To find out how far these presumptions are tenable I have proceeded as follows: 10 gr. of grains of granite (2×3 mm), dried at 110° , were heated, for half an hour at the time, to gradually increased temperatures and the loss of weight after each heating was noted. In this way I found the losses of weight as shown in the table.

Temperature	Vang	Ronne Pegma- tite	Bjerg- bakke	Svaneke	Peter- head	Inveraray	Devon	Bergel- ler
180°	0.00	0.00	0.00	0.00	0.02	0.12	0.13	0.00
250°	0.02	0.00	0.00	0.01	0.03	0.33	0.33	0.01
300°	0.01	0.02	0.01	0.04	0.02	0.07	0.07	0.09
350°	0.01	0.03	0.02	0.07	0.03	0.07	0.06	0.01

From this it will be seen that almost all the granites examined, when heated, suffer no loss of weight to speak of until such a temperature is

reached when it is likely that some of the cavities will burst and some fluid water escape and cause a loss of weight. This means that in all these cases the loss of weight by heating the grains to red heat is due solely to the evaporation of the fluid water.

But it will be noticed that there is a conspicuous exception viz. the granite from Inveraray which shows a considerable loss of weight by being heated to 180° and a much larger further loss of weight by being heated to 250° . Further losses occur at still higher temperatures. In the case of this granite the loss of weight incurred by heating grains to red heat is therefore due only partly to the fluid water and partly to a loss of weight at lower temperatures as shown in the table. In this case it is, therefore, not correct to take the loss of weight at red heat as a measure of the fluid water. A deduction will have to be made of the loss of weight shown in the table. It is not possible to be quite sure whether some or all of the loss of weight incurred by the heating to 350° may be due to the beginning of the bursting of the cavities. A study of the table shows that in six cases the loss of weight by heating to 350° was 0,03 or less. If we assume, in the case of the granite from Inveraray, that 0,03% lost at 350° was due to a loss of fluid water, then the total loss independent of loss of fluid water would be 0,56%.

An estimation of the quantity of fluid water in the granite from Inveraray would then be as follows:

loss of weight by heating grains to red heat ..	0.83%
less loss of weight not due to fluid water.	0.56%
Amount of fluid water...	0.27%

The 0.56% is probably water due to beginning decomposition of some of the minerals whereby these have become hydrated.

The only other sample of granite in the table, which shows an appreciable loss of weight at 180° and 250° is the granite from Peterhead. It might therefore be advisable to apply a similar correction in the case of the Peterhead granite:

loss of weight by heating grains to red heat ..	0.25%
less loss of weight not due to fluid water.	0.07%
Amount of fluid water...	0.18%

It is difficult to know whether the loss of weight of 0,09% suffered by the Devon granite at 300° should be deducted from the loss of weight by ignition, seeing that there is only a loss of 0,01 at 180° and 250° . The loss of weight by ignition has been found to be 0,40%. If the 0,09% is deducted, that would make the percentage of fluid water in the Devon granite 0,31,

which would make the analysis of the Devon granite more uniform with the others.

It is then necessary to modify what is said previously about estimating the quantity of fluid water by heating grains (2×3 mm) to red heat. From the loss of weight suffered by this ignition should be deducted what loss of weight may be incurred by heating the grains to 300° . If the loss of weight found by ignition is below 0,20% it is unlikely that there should be any loss by 300° ; the higher the loss of weight by ignition the more it is necessary to ascertain if there is a loss by 300° .

With this modification the amount of fluid water can be found by ignition of grains (2×3 mm) of granite for half an hour.

The same modification applies when the quantity of fluid water is measured as the difference between the total water and the chemically bound water, as this also presumes that there is no other water than the fluid water and the chemically bound water.

(a). To find the total water 10 gr. of grains, dried at 110° , are heated to red heat. From the loss of weight suffered by this heating must be deducted the loss of weight, if any, suffered by heating 10 gr. to 300° , that is the water due to the beginning decomposition of the granite.

(b). The 10 gr. of grains heated to red heat are pulverized finely and heated to a bright red heat and the loss of weight noted.

(a)+(b). The losses of weight under (a) and (b) are together a measure of the total water, which I call (c).

(d). To find the chemically bound water 10 gr. of freshly ground granite are heated repeatedly for half an hour or more at the time, first to 300° then to 400° , to drive out all other kinds of water. I find that it takes generally several hours before constant weight is obtained. Then the powder is heated to a bright red heat and the loss of weight is considered to be the measure of the chemically bound water.

(c)-(d), called (e), should be the quantity of water in the cavities.

(f). For comparison I state (f) what is the percentage of fluid water found by the original quick method of estimation, viz. taking the loss of weight by heating 10 gr. of grains to a red heat for half an hour, less the loss of weight, if any, by heating 10 gr. of grains to 300° .

By this method I have found as follows in six samples of granite and one of feldspar from a pegmatite quarry in Norway: (see table p. 20).

The minute quantity of (d) in the feldspar which probably does not contain any "chemically bound water", may possibly be due to the above mentioned "complications".

It appears, therefore, that the quantity of fluid water in the cavities can be measured either by ignition of grains as above explained, or by the more elaborate proceeding just shown, and that the two methods give fairly well agreeing results.

	Feldspar Gloserhei	Ronne granite	Bjergbakke granite	Svaneke granite	Inveraray granite	Cornish granite	Devon granite
(a).....	0.10	0.17	0.10	0.43	0.21	0.31	0.34
(b)	0.10	0.28	0.14	0.20	0.34	0.24	0.20
(c).....	0.20	0.45	0.24	0.63	0.55	0.55	0.54
(d)	0.06	0.25	0.13	0.26	0.32	0.30	0.16
(e).....	0.14	0.20	0.11	0.37	0.23	0.25	0.38
(f)	0.14	0.20	0.13	0.38	0.27	0.23	0.40

I consider, after this investigation, that an analysis of a sample of granite, or other rock or mineral containing fluid water in microscopic cavities, is not complete without estimating the quantity of such fluid water, and this can be done easily and fairly reliably by noting the loss of weight by heating to red heat grains of the rock or mineral of size 2×3 mm, previously dried at 110° , and deducting a possible loss of weight by heating the grains to 300° .

The usual estimation of water in the finely powdered rock or mineral at temperatures below and above 100° or 110° gives results of little or no real value, as more fully explained at the beginning of this chapter.

The Salts.

In order to estimate the quantities of the various salts which are present, dissolved in the water in the microscopic cavities, it is necessary to operate with fairly large quantities of rock as the percentages of salts are very small. I have therefore secured of the different rocks to be examined abt. 10 kg in smaller or larger pieces. These were thoroughly washed in water and rinsed in lukewarm distilled water and dried. The pieces of rock were then crushed in a Gates Rock Breaker which reduced them to a fairly fine gravel. In case there might have been some dust left in the rock breaker the first handfuls passing through were thrown away. The gravel was then finely pulverized in a Rotary Mill, inside clothed with flint, and with about 25 kg flintballs. The grinding was done in this way that first some 4 kg of gravel were treated in the mill which was kept revolving for 3 to 4 hours. The rock powder was then emptied out and thrown away. By this means the previously cleaned and dried mill was so to speak thoroughly wiped with rock powder. After that the remaining 6 kg gravel were filled in the mill and this was kept running for 20 to 24 hours, whereby the rock was reduced to a very fine powder. This was taken out of the mill and passed through a sieve No 60, with a mesh of 0,25 mm in order to remove any grains of rock not sufficiently pulverized. The great bulk of the rock powder would pass through a sieve with a far finer mesh,

indeed nearly all of it is finer than what could be retained by the finest sieve made. 2 or 3 kg of the fine rock powder were then treated with water in order to dissolve the salts, and the resulting liquid analysed. The figures of the analyses are in all cases calculated to correspond to 2 kg of rock.

I consider it most likely that practically all the cavities are opened up by this thorough grinding, the more particularly so as the minerals are more likely to split where the cavities are. Should some cavities remain unbroken, so that the salts within these were not among the salts dissolved when the rock powder was treated with water, that would simply mean that a very small fraction of the salts would not be included in the figures given in the analyses.

The salts are leached out of the finely pulverized rock by means of lukewarm distilled water and then subjected to analysis. The analyses have all been done in V. Stein's analytical-chemical laboratory, Copenhagen.

This leaching can be done in different ways. In some cases 2 kg of the fine powder were treated by $2\frac{1}{2}$ or 3 liter warm distilled water in a large glazed earthenware jar and thoroughly stirred for some time, left till next day and then stirred again, after which the liquid was left for 4 to 6 weeks to let the powder settle. The clear liquid was then removed by a siphon and kept. The remaining settlement, the tails, were treated in the same way by stirring it in 2 liter warm distilled water and left standing for 4 to 6 weeks when the clear, or generally fairly clear, liquid could be drawn off by a siphon. The two liquids were mixed and the bulk, abt. 4 l, was reduced by evaporation to a smaller volume and then analysed.

The liquid would contain the salts that had been in the microscopic cavities. The salts are generally in solution but, as referred in Chap. I, cubic crystals, (? of NaCl) have been seen in the microscope by SORBY and others. These salts would be chlorides and sulphates. The analysis will show the quantity of Cl and SO_4 , and that is the essential point, as these acids could only derive their origin from the salts in the cavities. The analysis will show also the bases, Na, K, and Ca combined with these acids, but as the water dissolves something of the granite, partly silicates and partly hydrates of sodium and particularly of potassium, it is impossible to state definitely which quantities of these different bases are combined with the Cl and SO_4 found, and what is dissolved from the minerals of the rock. At most an approximate guess can be made as to the different salts which were present in the cavities. The liquid is distinctly alkaline owing to the hydrate of potassium and other hydrates derived from the feldspars. That is the reason why the liquid has to be kept, for the powder to settle, in glazed earthenware jars, as the alkaline liquid would attack the glass in ordinary jars.

Two kg finely ground granite from Rønne, Bornholm, were treated in the way explained, with two leachings. The analysis of the resulting liquid showed it to contain in mgr:

Cl	145	mgr.
SO ₄	364	-
K	433	-
Na	353	-
Ca	trace	-
Al ₂ O ₃	trace	-
SiO ₂	40	-
	1335	mgr.

It seems natural to assume that all the Cl is combined with Na, which would give 239 mgr. NaCl. The SO₄ would form salts with the alkalis but it is impossible to know in which proportion. One combination could be: Na₂SO₄ 370 mgr and K₂SO₄ 204 mgr; another might be Na₂SO₄ 222 mgr, K₂SO₄ 383 mgr and so on. Besides these salts there would be a rest consisting of matter dissolved from the granite.

Salts:	"Rest":
NaCl..... 239 mgr.	K..... 343 mgr.
Na ₂ SO ₄ 370 -	Na..... 139 -
K ₂ SO ₄ 204 -	SiO ₂ 40 -
total..... 813 mgr.	522 mgr.

giving the total of 1335 mgr.

It makes but little difference to the total quantity of salts whether there is more or less of the two alkalis in the sulphates. In the example chosen we find:

Chlorids	239 mgr	or 0.120 ⁰ / ₁₀₀
Sulphates...	574 -	or 0.287 ⁰ / ₁₀₀

or a total of salts equal to 0,407⁰/₁₀₀ of the granite.

As the Rønne granite was found to contain 0,20% of water in the cavities, in which the 0,407⁰/₁₀₀ of salts were dissolved, it follows that the liquid in the cavities contained 17% of salts.

Two kg of a sample of granite from Cornwall were treated in the same way, with two leachings, leaving the powder to settle in respectively seven and five weeks.

The resulting liquid was found to contain:

Cl	120 mgr.	
SO ₄	292	-
<hr/>		
K	254	-
Na	300	-
Ca	18	-
Al ₂ O ₃ . . .	tr.	
SiO ₂ . . .	50	-
<hr/>		
	1034 mgr.	

Assuming again that the chlorine was all present in combination with sodium we find NaCl 198 mgr. The calcium, in a solution containing sulphuric acid, would be present as CaSO₄. The 18 mgr Ca would correspond to 61 mgr CaSO₄. The remaining SO₄ would be combined with Na and K but it is impossible to know in which proportion. We can f. inst. assume Na₂SO₄ 192 mgr and K₂SO₄ 213, but it is of course a mere guess. However, it will not alter the total quantity of salts very much if a different apportionment be chosen.

We may, therefore, have the following salts in the solution with a "rest"

Salts		"Rest"	
NaCl	198 mgr.	K	160 mgr.
Na ₂ SO ₄	192 -	Na	160 -
K ₂ SO ₄	213 -	SiO ₂ . . .	50 -
CaSO ₄	61 -	<hr/>	
	664 mgr.		370 mgr.

The K and Na in the rest being probably mostly present as hydrates, dissolved from the feldspars, make the liquid very distinctly alkaline.

Under the stated assumption we have then

Chlorides	198 mgr	or	0.099 ⁰ / ₁₀₀
Sulphates	466 -	or	0.233 ⁰ / ₁₀₀

As the Cornwall granite was found to contain 0.23% of water, in the cavities, in which the 0.332⁰/₁₀₀ of salts were dissolved, it follows that the liquid in the cavities contained 12.7% of salts.

When it is a question of examining a larger number of samples it is a drawback that the leaching alone of each sample occupies three months. I tried therefore to find a quicker method and proceeded as follows: to 3 kg of the fine rock powder were added 2½ l warm distilled water; it was thoroughly stirred and after a little while brought on a filter in a large funnel and left to drain for two days. Somewhat between half or a third of the liquid would pass through the filter. On the assumption that

the liquid left with the powder on the filter has the same analysis as the filtrate it would suffice to analyse the filtrate and from that analysis calculate what would be the contents of the whole liquid.

Rønne granite treated in that way, by what might be called fractional filtration, gave the following result, calculated on 2000 gr. For comparison I put next the figures from the analysis of the leaching of Rønne granite as given on a previous page.

Rønne granite					
Analyses			Suggested salts		
	fract. filtr.	leaching		fract. filtr.	leaching
Cl	133 mgr.	145 mgr.	NaCl	0.110 ⁰ / ₀₀	0.120 ⁰ / ₀₀
SO ₄	395 -	364 -	Na ₂ SO ₄	0.185 ⁰ / ₀₀	0.185 ⁰ / ₀₀
Na	231 -	353 -	K ₂ SO ₄	0.130 ⁰ / ₀₀	0.102 ⁰ / ₀₀
K	338 -	433 -			
SiO ₂	40 -	40 -			
	1137 mgr.	1335 mgr.			

The agreement between the results obtained by the two methods is fairly satisfactory and seems to indicate that the quicker method, the fractional filtration, is about as reliable as the lengthy method with two leachings.

It has been suggested to me that the fine granite powder was apt to retain some of the salts and that this tendency could be counteracted by adding some ammonium acetate or ammonium formiate to the water used for the second leaching, having first leached with pure water. I tried this method on 2 kg Rønne granite, using first 3 l warm distilled water; after the powder had settled the clear liquid was drawn off and two l warm distilled water in which were dissolved 25 gr ammonium acetate were added and the liquid well stirred. After settling the liquid was drawn off, mixed with the first leaching, evaporated down to a smaller volume, and analysed.

The analysis showed that the ammonium acetate had had the effect of dissolving from the granite powder several times as much Na and K as that obtained by the fractional filtration or the leaching without acetate; besides this the acetate had dissolved a good deal of Ca and of Al₂O₄, neither of which were found in the liquid from the other methods¹⁾.

¹⁾ The analyses of the liquids from the fractional filtration and from leaching with ammonium acetate showed the following quantities of alkalies and other basis, in mgr pr. 2000 gr.

	fract. filtr.	leaching with acetate
Na	231	687
K	338	1552
Ca	—	1578
Al ₂ O ₃	—	287

But the essential question is whether this method with acetate had released some salts which had been retained by the granite powder when operating by the other methods. That would be seen from the quantities of Cl and SO_4 . Calculated on 2 kg the following quantities of Cl and SO_4 have been found by the three methods:

	by fract. filtr.	plain leaching	leaching with acetate
Cl	133 mgr.	145 mgr.	111 mgr.
SO_4	395 -	364 -	226 -

It seems, therefore, that the acetate method has not set more salts free but on the contrary yielded less of them, which was certainly unexpected.

Three kg of the Cornwall granite powder were treated, like the Rønne granite, by fractional filtration, stirred up in $2\frac{1}{2}$ l warm distilled water and brought on a filter. One l filtrate was obtained. This was analysed. By multiplying the figures of the analysis by $2\frac{1}{2}$ and by $\frac{2}{3}$ we get the figures of the total quantities present in 2000 gr granite. For comparison I put next the figures from the analysis of the leaching of Cornwall granite as given on a previous page.

Cornwall granite					
Analyses, mgr			Suggested salts, promille:		
	fract. filtr.	leaching		fract. filtr.	leaching
Cl	133	120	NaCl . . .	0.110	0.099
SO_4	205	292	Na_2SO_4 .	0.058	0.096
Na	302	300	K_2SO_4 . .	0.061	0.106
K	300	254	CaSO_4 . .	0.043	0.031
Ca	25	18		0.272	0.332
Al_2O_3 . .	27	5			
SiO_2 . . .	17	50			

Although the analyses of the liquids resulting from the two different treatments do not, in this case, agree as well as the correspondent analyses from the Rønne granite, still I consider the agreement sufficient to warrant the conclusion that the quicker method of investigation by fractional filtration gives sufficiently correct results. It has therefore been adopted for practical reasons.

Pre-cambrian Granites.

In order to examine the saline solutions in microscopic cavities in pre-cambrian granites I have chosen to take samples from the granites of Bornholm, which have been fully described by KAREN CALLISEN (10). Bornholm, a Danish island in the Baltic, consists chiefly of granite, overlaid in the South & West by younger, sedimentary rocks.

The granite consists of different varieties, supposed by K. C. to have originated from the same magma by magmatic differentiation. Within the greater part of the area the granite varieties, which are chiefly striated, pass gradually into one another, but two of the differentiation products, the Hammer- and the Svaneke granite, must have solidified somewhat later than the main mass of the granite. They show a marked eruptive contact, reduced size of grains, an aplitic zone, at the junction with the bordering, already consolidated granite, and enclose fragments of this.

From K. Callisen's descriptions of the different varieties I have made the following extracts:

The *Vang* granite in the North, contiguous to and South of the Hammer granite, is of a medium sized grain, darkish gray with a touch of red due to the microcline, the plagioclase being gray. The quartz has a faint undulatory extinction. Somewhat more than half of the feldspar is microcline-perthite. The largest grains of this have generally a core of plagioclase. The plagioclase grains are chiefly relatively large, generally with fine twin-lamellation on the albite-law. Hornblende is green; biotite pleochroitic, light yellow, dark olive-brown nearly black. Titanite, apatite and ore in fair quantities, the titanite forming girdles round the grains of ore.

The *Ronne* granite forms a narrow belt along the S. W. edge of the granite field. It is of medium to fine grain, dark gray, almost black. The chief minerals are quartz, microcline, plagioclase, green hornblende & brown biotite. Subordinate are ore, apatite, titanite, zircon & minutely, alteration products as muscovite, calcite, epidote & chlorite. There is less quartz than in the other varieties of Bornholm. A smaller

part of the quartz is enclosed in hornblende & biotite. Some cavities with fluid & libellæ in motion are observed. The quartz has but locally undulatory extinction. Plagioclase is more prominent than potassium feldspar and generally in fairly large crystals, mostly surrounded by microcline. The potassium feldspar is very fresh, and is generally microcline-perthite. It encloses often small roundish quartz grains. The plagioclase has a fine twin-lamellation on the albite-law.

Rønne pegmatite. In the Rønne granite are numerous pegmatite veins, generally with sharp boundaries towards the surrounding rock. A red microcline is the chief mineral. Larger crystals of quartz are rare, they are often smoke-coloured, even quite dark. Light gray plagioclase is present in fair amount, it consists of albite-oligoclase. As subordinate constituents are biotite and, in small quantities, ore, titanite & fluor-spar.

At *Bjergbakke*, near the centre of the island, is a light reddish-gray rock resembling the Hammer granite. The quartz is present in pretty large quantities, in irregular shaped grains with faint undulatory extinction. Microcline is often grown on to the plagioclase without quite covering it. Of dark minerals, biotite is present in only small quantities, hornblende in even smaller ones. Titanite, ore and fluor-spar are present.

Hammer granite. The northernmost part of the island is known as Hammer. The granite is light, reddish-gray, of a medium grain, and has a definite boundary line towards the Vang granite and sends apophyses into that rock from which it is separated by an aplitic zone, is in fact a somewhat younger eruptive. The chief constituents, in order of their relative quantities, are: microcline-perthite, quartz and acid oligoclase. The quartz grains, of irregular form, with numerous fissures, have a faint undulatory extinction. There are enclosures of small grains of microcline, biotite & titanite. The microcline is exceedingly fresh. Hornblende is very sparse. The dark minerals are chiefly a brown or olive biotite. Ore, with or without a belt of titanite, and orthite.

The *Svaneke* granite forms a 3-4 km broad zone along the Eastern shore with a sharp boundary to the main body to the west. That it is younger than the main, somewhat striated, granite, is proved partly by the aplitic boundary zone where it touches the striated granite, partly by the many fragments of this granite embodied in the Svaneke granite, proving that the older granite was already solidified when the Svaneke granite was pressed up. It is of a coarser grain than the other granites of Bornholm. The chief minerals are quartz, a reddish microcline-perthite & plagioclase. There is more biotite than hornblende. The microcline-perthite is the chief constituent of the granite. It is always quite fresh, while the perthite-plagioclase generally is somewhat altered. The plagioclase, of which there is a considerable quantity, is partly

in grains of a centimeter or more. It consists chiefly of oligoclase. There is more titanite in Svaneke granite than in any other granite of Bornholm. Apatite is present in fair quantities, epidote is generally found together with ore and the dark minerals. Fluor-spar and a small quantity of chalcopyrite is found.

A full description of all these varieties of pre-cambrian granites, with analyses, is given in K. Callisen's book (10). She thinks they are most likely simultaneous with the older primitive rocks in Southern Sweden.

I have examined samples of these six varieties of granite from Bornholm by the methods described in the previous chapter. The results are given in Table I.

This shows first the percentage of water. Then is given the full analysis of the liquid resulting from the treatment of the granite powder with distilled water, stating numbers of mgr in 2000 gr of rock, giving first the Cl and SO_4 , which are forming the salts in the cavities, and then the

Table I.
Analyses of the saline fluid in microscopic cavities in
Pre-cambrian Rocks.

		Vang granite	Rønne granite	Rønne Peg- matite	Bjerg- bakke granite	Hammer granite	Svaneke granite
1. Contents of water, per Cent		0.22	0.20	0.20	0.13	0.22	0.38
2. Analyses of the solu- tions, mgr in 2000 gr.	Cl	612	145	284	392	325	613
	SO_4	77	364	261	60	70	227
	Na	369	353	373	300	246	248
	K	501	433	376	295	242	561
	Ca	33	tr.	35	21	10	50
	Al_2O_3	tr.	tr.	tr.	tr.	tr.	tr.
	SiO_2	13	40	251	52	25	68
3. Suggested salts of Cl and SO_4 in Promille.	NaCl	0.470	0.120	0.234	0.323	0.268	0.315
	KCl	0.045	—	—	—	—	0.240
	Na_2SO_4	—	0.185	0.131	—	—	—
	K_2SO_4	—	0.102	—	0.009	0.042	0.097
	CaSO_4	0.054	—	0.060	0.035	0.017	0.085
	Total salts	0.569	0.407	0.425	0.367	0.327	0.737
4. Per Cent of salts in the liquid in the cavities		21	17	17	22	13	16

various other elements of which some form part of the salts and some are dissolved from the granite.

The next section of the table gives the results of my speculations as to the salts in the cavities, expressed as promille of the rocks; and then the total of the salts. From the percentage of water and the promille of salts is in part 4 of the table calculated the percent of salts in the solution in the cavities.

The amount of water is fairly equal in the different samples. That seems natural as the different parts of the large granite field are formed from the same magma. An exception forms the Bjergbakke granite with only 0.13% of water. As mentioned above the Hammer and the Svaneke granites are somewhat younger than the main field, are in fact pressed up after the main field was already solidified. The Hammer granite shows the same percentage of water as the main field but the Svaneke granite has nearly 50% more water.

Quite opposite to this agreement between most of the samples as far as the amount of water is concerned, there is the greatest possible difference between the analyses in part 2 of the table. With regard to the Cl and SO₄, there are distinctly two groups. In Rønne granite there is 2½ time as much SO₄ as Cl, and in the pegmatite within the Rønne granite the two acids are of about equal quantity, while in the other four samples the Cl is far in excess of the SO₄, being from 3 to 5 times greater, in the Vang granite even 8 times greater. Rønne granite has less quartz than any other of the Bornholm granites. From some investigations of pegmatites from Norway & Sweden, as explained in the next chapter, it seems as if there be a certain affinity between quartz and the chlorides. Might that be one of the reasons why the Rønne granite, with less quartz than the other granites, has less chlorides?

It does seem very remarkable that the salts (or the Cl & SO₄) in the cavities in these six samples of granite,—on four samples, if we leave out Hammer & Svaneke—being formed from the same magma, should show such great differences. There can be no question but that they do, and these investigations are the first to show that such differences can exist. Quite another question is how to explain this remarkable fact.

About the other contents of the liquid, the "rests" (Pag. 22–23), resulting from the treatment of the granite powder with water, see below. Rønne granite differs from the others by leaving only a trace of Ca in the liquid, although the analyses of the granite, given by Dr. Callisen, show 3 to 3½% of CaO₂. Rather surprising is the large quantity of SiO₂ in the liquid from Rønne pegmatite.

In trying to find a likely combination for the salts in the cavities I have proceeded as follows. There are reasons for assuming that the Cl is chiefly combined with Na. Both SORBY and ZIRKEL have seen cubic

crystals in some of the cavities and considered them to be cubes of NaCl. Also PFAFF assumes the presence of NaCl and writes that it was very desirable that the amount of water and of sodium chloride in the rocks should be determined. Besides this there is the consideration that NaCl is the chief salt in the oceans and is likely to have been so from very early times. I have therefore assumed that the Cl was combined with Na. Only in two cases, Vang and Svaneke, was the Na present insufficient to form NaCl with all the Cl present; the remainder of the Cl would then naturally be combined with K. The Ca would undoubtedly, in a liquid containing SO_4 , be present as CaSO_4 , forming CaSO_4 with some of the SO_4 . The remainder of the SO_4 must then be combined with Na, if any remains from the NaCl, and with K of which there is plenty in the liquid. By such consideration I have arrived at the figures given in part 3 of the table. Rönne granite is the only one with more sulphates than chlorides, and the only one to contain no CaSO_4 . As these figures for the various salts are, of course, only suggestions, their total quantities, as given in table, is also only a guess. But it may be argued, that a different grouping of the elements, giving different quantities of the different salts, would make but a small difference to the total quantity of salts in each rock. And that again would make but little difference to the calculated percentages of salts in the liquid in the cavities. These show, in part 4, that the saline solution contained in the cavities is fairly strong, containing from 13 to 22% of salts; the solution in Vang granite contains of NaCl alone 17%.

Deducting the quantities of the bases, which have been allotted to form the salts in the cavities, from the quantities of the bases given in the analyses in part 2 of the table, there remains a rest, as explained in the previous chapter. This "rest" consists of what the water has dissolved from the granite powder, chiefly K, with some smaller quantities of Na in case of some of the rocks, and then SiO_2 . It is probable that the SiO_2 is combined with some K to K_2SiO_3 but that would only account for a smaller quantity of the K. The remainder thereof is most likely present as hydrate, and this accounts for the alkaline reaction of the leachings. Expressed as promille of the rock I have calculated the "rests" to contain:

	Vang	Rönne	Bjergbakke	Hammer	Svaneke
K_2SiO_3	0,017	0,051	0,067	0,032	0,087
KOH.....	0,315	0,150	0,157	0,124	0,094

Besides this there is in some cases in the "rest" a small quantity of Na, most likely also present as a hydrate. It is freely acknowledged that the apportioning of the alkalis between the hydrochloric and sulphuric acid in the solution from the cavities is somewhat arbitrary.

But it does not make any great difference to the quantity of chlorides and sulphates, nor to the total quantity of salts whether a little more or less of Na and of K is assumed to be combined with the acids. But it follows that the same uncertainty also applies to the quantities of K and of Na calculated to be present in the "rest". If f. inst. in the case of Rönne granite, in part 3 of the Table I, a little more K was allotted to SO_4 , and consequently a little less Na, then the quantity of KOH in the "rest" from the Rönne granite would be somewhat less than the 0,150, and a little NaOH would make up the difference. But this would make but a slight difference to our conception of the salts in the cavities and of the "rest" as dissolved from the granite.

Taking it all together I think the suggestion of the salts as given in part 3 of the table is fairly reasonable and that most probably the various salts are present in about the quantities there stated. The question then at once crops up: What is the reason that the different varieties of the Bornholm granite on the one hand have mostly the same quantity of water in the cavities but on the other hand vary considerably as to the quantities of salts. Might it be that there is an affinity between the different minerals in the granite and the different salts? A very interesting experiment might give the answer to that question, but unfortunately it is not practicable. If we could separate the different minerals in a granite, and procure enough of each mineral to enable us to get 2000 gr in a finely pulverized state, and we then treated each mineral in the same way as we have treated the granites, then we should find, whether the different minerals had attracted different salts, whether, that is to say, there is such affinity between minerals and salts which would explain why the different varieties of granite, all having their origin from the same magma and having about the same quantity of water, still contain salts in different mixtures and quantities. Unfortunately such an experiment is not possible.

But in the next chapter I have, in a different way, tried to approach this question and apparently not quite without success.

Pegmatites from pre-Cambrian Rocks.

When examining the contents of the cavities in granites it is of course impossible to know what proportions of the Cl and SO_4 , or of the salts, are derived from the feldspars and what from the quartz. Information on that point could be obtained by examining separately the feldspar and the quartz from such pegmatites where these minerals are in sufficiently large crystals for such examination. In the Scandinavian pre-cambrian granites are several large pegmatite quarries where the two minerals are produced pure and in large quantities and sold for use in porcelain factories. The Royal Porcelain factory in Copenhagen have kindly supplied me with quartz and feldspar from a quarry at Gloserhei by Arendal in Norway, and the porcelain factory "Norden" have given me samples from a quarry Barhult pr. Lysekil in the western part of Sweden. The factories have also given me the following analyses of the minerals:

Gloserhei		Barhult	
Feldspar	Quartz	Feldspar	Quartz
SiO_2 64.67%	SiO_2 99.68%	SiO_2 64.38%	SiO_2 99.10%
Al_2O_3 19.37%	Fe_2O_3 0.14%	TiO_2 0.05%	Fe_2O_3 0.05%
Fe_2O_3 0.24%	Loss by	Al_2O_3 19.05%	Al_2O_3 0.32%
CaO 0.15%	heating .. 0.07%	Fe_2O_3 0.16%	CaO 0.03%
MgO 0.12%		CaO 0.36%	MgO 0.02%
Na_2O 1.98%		MgO 0.12%	K_2O 0.02%
K_2O 13.37%		K_2O 14.52%	Na_2O 0.05%
		Na_2O 1.49%	Loss by
		H_2O 0.20%	heating.... 0.18%
99.90%	99.89%	100.33%	99.77%

The feldspar in both cases is a beautiful red orthoclase and the quartz is pure white.

The minerals were treated in the usual way, washed, dried, crushed, ground during 20 hours in the rotary mill, leached in warm distilled

water, and the filtrate analysed. The amount of water was determined by heating grains (2×3 mm) to red heat and noting the loss of weight.

The results are stated in the adjoined table:

Table II.
Pegmatites.

		Gloserhei Norway		Barhult Sweden	
		Feldspar	Quartz	Feldspar	Quartz
1. Contents of water, in per Cent ...		0.14	0.15	0.16	0.15
2. Analyses of the solutions, mgr in 2000 gr	Cl	161	241	123	301
	SO ₄	231	82	324	144
	Na	247	118	155	510
	K	615	40	723	37
	Ca	12	200	29	209
	Al ₂ O ₃	10	8	—	6
	SiO ₂	727	399	280	161
3. Suggested salts formed by Cl and SO ₄ , in promille	NaCl	0.132	0.150	0.101	0.248
	KCl	—	0.039	—	—
	CaCl ₂	—	0.017	—	—
	Na ₂ SO ₄	0.062	—	0.116	—
	K ₂ SO ₄	0.109	—	0.088	—
	CaSO ₄	0.019	0.058	0.050	0.099
	Total salts	0.322	0.264	0.355	0.347
4. Per Cent of salts in the solution in the cavities		18.8	14.9	18.2	18.8

The amount of water is about the same in all four minerals. But there is a considerable difference as to contents of Cl and SO₄ between the feldspars and the quartz. For each 100 mgr SO₄ the feldspars contain 70 and 38 mgr Cl respectively, and the quartz contain 294 and 209 mgr Cl. That is to say that the chlorides are the chief salts in the quartz while the sulphates are predominant in the feldspars. Is a similar distribution general for all pegmatites? And what might be the cause of it?

There seems hardly any other explanation but that there is a certain affinity between the minerals and the salts, which causes the quartz to absorb more of the chlorides and the feldspar more of the sulphates. Or might there be another explanation?

From the considerations fully explained in previous chapters I have calculated the quantities of salts as given in part 3 of the table.

The total weight of salts, together with the amount of water in the cavities, give the proportions, in perCent, of salts in the saline solutions in the cavities, as stated in the table. They are very similar in the four minerals.

It will be noticed that the solution from 2000 gr of the quartz from Norway contains 200 mgr of Ca and that the analysis of the quartz given me shows no contents of calcium. Of course the quantity is so small that it might easily be overlooked, and also, the analysis given me did refer to another sample than the material which I examined. As explained in Chap. 2 (method of procedure) the solution from the leaching of the finely ground granites contain both the salts from the saline solution in the microscopic cavities and something which the water has dissolved from the granites, being mostly potassium hydrate and therefore more or less alkaline.

The leachings from the quartz differs naturally from the leachings from granites. In the case of the quartz from Norway the Cl disposed of all the very small quantities of Na and K and there was some Cl left over, and also some Ca. Hence the presence of CaCl, which is not suggested in any other of the rocks or minerals examined. In the "rest" (see Chap. 2) there is consequently no K or Na but a notable quantity of Ca.

Younger Granites.

Of younger granites I have examined: two samples of Caledonian Newer Granites from the Lower Red Sandstone or late Silurian, viz. one from Admiralty No. 1 Quarry, Peterhead, Aberdeenshire, and one from Furnace Granite Quarry, Inveraray, Argyll; two samples of granites from South West England, from the Permo-Carboniferous period, viz. one from Merrivale Quarry, Princetown, Devon, and one from Cornish (De Lank) Granite Quarry, Cornwall. I wish to thank the respective four firms for their kindness in supplying the necessary material. Further I have examined the tertiary granite at Bergeller, Engadine, Switzerland, one sample of fine-grained and one of porphyritic; these two samples were kindly procured for me by Prof. Dr. PAUL NIGGLI of the Mineralogical Institute, Zürich, to whom my thanks are due.

I have also examined a sample of granite from Kowloon peninsula, Hongkong, sent me by my son S. E. FABER. Unfortunately it has not been possible to ascertain the age of this granite.

The following remarks upon these samples have been kindly given me by KAREN CALLISEN, of the Mineralogical Museum of Copenhagen.

The granite from *Peterhead* is fairly coarse-grained, reddish. It contains a considerable quantity of quartz with some undulatory extinction. In several of the crystals are seen minute fluid-cavities with slowly moving gas-bubbles. The chief constituent is an orthoclase-perthite which is tinted by a reddish pigment. No fluid-cavities have been observed in that. There is considerably less plagioclase (oligoclase) than orthoclase and it is, like that, generally somewhat turbid. Brown biotite, some of the grains of which are wholly or partly chloritized. Inclusions of zircon are surrounded by dark haloes. Some apatite and ore.

Inveraray, A light grey, fine-grained and decidedly porphyritic granite. The ground-mass is a very fine-grained mixture of quartz, orthoclase and plagioclase with the usual accessories apatite, zircon & ore. The phenocrysts are of plagioclase, biotite and some rather small crystals of hornblende. The plagioclase contains a considerable amount of anti-

perthitic intergrowths of orthoclase; both feldspars are somewhat altered to sericite. Crystals of biotite & hornblende are sometimes inclosed in the plagioclase. The biotite is rather light yellowish brown. In some lamellæ is incipient chloritisation. The lamellæ are frequently somewhat bent and some crystals are broken. The hornblende seems to be of the green variety usual in granites, the crystals being as a rule fairly corroded. Some apatite & ore.

Princetown, Devon. A light grey granite of medium grain in which some feldspar crystals reach a considerable size (more than two cm in length). It is a rock rather rich in quartz and with both light and dark mica. The quartz shows some undulatory extinction. Smaller idiomorphic quartz-crystals are sometimes inclosed in the orthoclase and crystal-faces can sometimes be seen on the larger grains. The chief constituent is a somewhat turbid potassium orthoclase-perthite. The plagioclase (oligoclase) seems to be present in smaller quantities than the quartz. It is somewhat turbid and sericitized. The biotite has pleochroism: reddish brown—light yellow. It is often more or less discoloured until quite colourless. The brown biotite contains a considerable quantity of zircon crystals surrounded by strongly pleochroic rings. There is decidedly less muscovite than biotite. Only small grains of apatite and ore.

Cornish (De Lank). I am indebted to Mr. J. W. P. COGGIN for the following description of the "Silvery Grey" granite, of which the Cornish (De Lank) Granite Co. of St. Breward has kindly sent me samples. "It is principally made up of quartz, mica and feldspar. There are two species of feldspar, one orthoclase, the other triclinic, while the two species of mica are biotite (black) and muscovite (silvery white). A large proportion of quartz is present with little or no hornblende or pyrites. A petrological examination by FRANK RUTLEY some years ago gave the following:

Orthoclase feldspar.....	30 %
Plagioclase feldspar.....	6 %
Black Mica (Biotite).....	7 %
White Mica (Muscovite).....	11 %
Quartz.....	46 %

"The preponderance of the harder minerals makes our polishing surface brilliant".

Dr. KAREN CALLISEN found perthitic enclosures of albite in the orthoclase and microcline structure in most of the crystals.

Bergeller, somewhat porphyritic. Fairly light grey granite (two-mica-granite). Feldspar crystals sometimes 1 to 2 cm, one crystal observed ca. 4 cm long. The granite is in the microscope seen to be somewhat

crushed and shows effects of pressure. The quartz has strong undulatory extinction, there is fracturing of quartz crystals and plagioclase crystals. The potassium feldspar is perthitic and certain parts of the crystals show microcline twinning. Plagioclase (oligoclase) is present in fair quantities but not so much as the potassium feldspar and it occurs in smaller crystals. The lamellæ of biotite & muscovite are bent and the biotite is frequently altered to chlorite. Apatite and ore as usually in granite.

Bergeller, fine grained. A light grey, fine-grained granite (two-mica-granite). The quartz shows undulatory extinction. The potassium feldspar is somewhat perthitic, some of the crystals show traces of microcline twinning. The plagioclase (oligoclase) forms the largest grains in the granite and seems to be in quantity like the potassium orthoclase. The brown biotite is partly chloritized; muscovite, in small quantities epidote and calcite.

Granite from *Kowloon* peninsula, Hongkong.

A light gray, slightly reddish, medium grained rock, with a fair quantity of plagioclase. Most of the feldspar, however, is microperthite, the plagioclase component being albite with a fine twin-lamellation on the albite-law. Along the border of the perthitic albite-intergrowths some of the feldspar crystals show a somewhat dull microcline cross-hatching, in other parts the cross-hatching is submicroscopic. In the microperthite are frequently small grains of plagioclase and numerous grains of quartz, sometimes rounded, sometimes showing crystal planes, less frequently having a hexagonal cross section. In these grains of quartz, inclosed in the feldspar, are sometimes inclosed minute grains of feldspar.

The central parts of the plagioclase consists of oligoclase with 20-25% An. The marginal zone is pure albite. In the plagioclase are frequent grains of quartz, particularly in the outer parts. The central parts of the plagioclase are frequently altered by the development of small flakes of muscovite, epidote and calcite.

A fair quantity of quartz, with faint undulatory extinction. In some of the grains are numerous cavities with fluid, several of these have libellæ in motion.

The dark minerals are chiefly brown biotite, some of the grains of which are partly chloritized.

Small amounts of apatite, orthite, zircon & ore.

In Table III are given the analysis of the salt solutions in microscopic cavities in younger granites in the same manner as in the previous tables.

Dealing first with the percentages of water the figures for the two Scottish granites, from Peterhead and Inveraray, have been corrected

as fully explained on page 17 et 18, the greatest change being in the case of the Inveraray granite.

The granite from Devon shows an unusual large percentage of water. On page 18 it is shown that possibly a correction of the figure 0.40 is called for, as it might include 0.09% of water other than fluid water. If 0.09% were deducted, that would make the percentage of water in the Devon granite 0.31 and the corresponding percentage of salts in the solution in the cavities 12.5. That would make the Devon granite more conformable with the other silur-carboniferous granites. It does not seem possible to be quite sure which figures are the most correct.

In most of the younger granites examined Cl is in excess of SO_4 , the exceptions being the samples from Cornwall and Kowloon. Sodium is in four cases—in the two oldest groups of granites—in considerable excess of potassium, while in the Bornholm granites potassium is strongly predominant in three cases.

Table III.
Analyses of the saline fluid in microscopic cavities in
Younger Granites.

		Late Silur		Permo-carbonif.		Tertiary bergeller		Kowloon
		Peter-head	Inver-aray	Devon	Corn-wall	porphyr.	fine grain	
1. Contents of water %		0.18	0.27	0.40	0.23	0.15	0.19	0.16
2. Analyses of the solutions, mgr in 2000 gr.	Cl	249	267	451	120	140	101	111
	SO_4	137	165	98	292	99	69	226
	Na	303	362	516	300	279	229	448
	K	195	59	341	254	280	254	442
	Ca	15	31	22	18	19	20	10
	Al_2O_3	4	8	14	5	16	11	4
	SiO_2	103	67	31	50	80	50	78
3. Suggested salts formed by Cl and SO_4 in promille	NaCl	0.206	0.220	0.371	0.099	0.115	0.083	0.091
	Na_2SO_4	0.074	0.068	0.034	0.096	0.040	0.016	0.074
	K_2SO_4	—	—	—	0.106	—	—	0.083
	CaSO_4	0.026	0.052	0.037	0.031	0.032	0.034	0.017
	Total salts	0.306	0.340	0.442	0.332	0.187	0.133	0.265
4. Percent of salts in the solution in the cavities		14.5	11	10	12.6	11	6.6	14

The suggested salts, in part 3, have been calculated according to previously explained considerations. The quantities of the total salts in the first four samples, 0.3 to 0.4 ‰, are somewhat below the corresponding quantities in the pre-cambrian granites from Bornholm, and the tertiary granites contain even less. The percentages of salts in the solution in the cavities are generally smaller than those found in the pre-cambrian rocks.

CHAP. 6.

Basalt.

In order to find whether more modern and basic volcanic rocks differ materially from the granites, I examined the olivin basalt from Trangisvaag, Suderö, Faeroe Islands,—of which samples were kindly supplied me by Dr. NOE-NYGAARD of Danmark's Geological Survey. The basalt consists chiefly of olivin, pyroxen, labrador and ore. It forms "the base of the volcanic pile" which at that place consists of three layers, according to FRED. WALKER & C. F. DAVIDSON (11).

Amount of fluid water found as follows:

loss of weight by heating grains to red heat..	0.78%
less loss of weight by heating to 300°.....	0.55%
Amount of fluid water:...	0.23%

In order to find the quantity of the salts I extracted 2000 gr finely powdered rock by 3 l warm distilled water and left it to settle, drew the clear liquid off, stirred the settlement with 2 l warm distilled water, left to settle and drew the clear liquid off. The liquids were then evaporated to a smaller volume and analysed.

Another extraction was made when 2120 gr powdered rock were treated with 2 l warm distilled water and, after standing for a short time, brought on a filter. The clear filtrate. 1100 ccm, was analysed. For each 100 mgr SO_4 there were in the first extraction 75 mgr Cl, and in the second extraction 69 mgr Cl, showing a reasonable agreement.

The analysis of the first extraction was as follows:

Cl.....	131 mgr	} in 2000 gr
SO_4	186 -	
Na.....	263 -	
K.....	14 -	
Ca.....	8 -	
SiO_2	44 -	

from which I calculate the probable presence of

NaCl.....	216 mgr
Na ₂ SO ₄	275 -

total salts..... 491 mgr or 0.0245 pCt of

salts which, with the 0.23 pCt of fluid water, gives the salt-solution in the cavities to contain 10 pCt of salts.

Postscript.

I hope by the investigations mentioned in the previous pages to have thrown some little more light on the very interesting question of the saline solutions in granites. But it is of course only a very fragmentary investigation which for special reasons I am unable to carry further. It is my hope that others will take the matter up as I think it deserves.

From the examination of such few, spread samples it is not possible to draw any general conclusions. When the pre-cambrian granites averagely show a contents of salts of 0.47 ‰, the silur-permean of 0.34 ‰, and the tertiary of only 0.16 ‰, it was tempting to conclude that the proportion of salts was greater in the older rocks and gradually diminished in time. But I mention this, not because I think the conclusion is at all justified on the basis of the few samples examined, but rather to show that further, very much more widespread, investigations might lead to conclusions of interest. It is generally accepted that the water played an important part in the crystallization of granites, that by the action of water the silicates could crystallize from a fluid magma at temperatures much below their melting points. But what was the influence of the salts? And whence came they? The only way to approach the solution of the many questions in connection with the formation of granites and related rocks and the part played by the water and the salts, still found in the microscopic cavities, is to accumulate information by still further spade-work.

A fairly simple investigation which, however, I shall not myself be able to carry out, seems to me likely to throw some further light on the part played by the water and salts in the action of the granitic magma.

Water and salts, with heat and pressure, have been active during the eruption of a granitic magma. When the granitic mass is seen to have metamorphosed the sedimentary rocks, through which the granite has been thrust, and changed these into gneis, then it seems likely—almost certain—that it is the action of water, salts, heat and pressure which have caused the transformation of the sedimentary rocks into gneis. An examination of the water and salts in the gneis seems therefore indicated.

The investigation I have in mind would be as follows: first to find a locality where a granitic mass has changed the surrounding sedimentary rock into gneis; then to take samples of abt. 10 kg of rock: a) from well within the granite; b) from the granite near the zone of contact with the gneis; c) from the gneis near the zone of contact; d) from the gneis at various distances from the granite.

If these samples were examined as described in chap. 2 they seem bound to reveal how the water & salts, as magmatic emanations, have penetrated from the granitic magma into the sedimentary rock and thereby changed it into gneis.

Dansk Resumé.

I mange Aar har man vidst, at der i Granit og beslægtede Bjergarter, i Krystallernes Masse, findes mikroskopiske Hulheder, som oftest fyldte med en Vædske, der har vist sig at være Vand, og hvori der er opløst Salte, Klorider og Sulfater af Alkalier og Kalk. Man har ogsaa været paa det rene med, at dette Vand kan eller maa have spillet en Rolle ved Bjergartens Udkrystallisering. DAUBRÉE taler om en Udkrystallisering under »hydrothermal« Virken, samtidig Virken af Vand og Varme, og peger paa den Kendsgerning, at Silikater under Vandets Virkning kan krystallisere ved Temperaturer, der ligger langt under deres Smeltepunkt.

Det har forekommet mig mærkeligt, at man ikke har underkastet Indholdet af disse mikroskopiske Vædske-Hulheder en nærmere Undersøgelse, i Betragtning af deres utvivlsomme Sammenhæng med Spørgsmaalet om Granitens Dannelse. Man ved lidet om, hvormeget Vand det drejer sig om, og der foreligger slet ingen kvantativ Analyse af de tilstedeværende Salte. Jeg har søgt at foretage en saadan Undersøgelse. En foreløbig Redegørelse fremkom i »Meddelelser fra Dansk Geologisk Forening« Bd. 9. H. 3. S. 274.

Opgaven falder i to Afdelinger: at bestemme Vandmængden, og at analysere de opløste Salte. Det er almindeligt ved en Analyse af Granit og lignende Bjergarter at opgive: Vand over 110° , og Vand under 110° . Disse Værdier findes ved Undersøgelse af det fint pulveriserede Materiale. Men disse Værdier giver, som nærmere forklaret Side 14, hverken Oplysning om det hygroskopiske Vand, om Vandet i Hulhederne, om Vand der skyldes mulig Forvitring, eller om det i nogle af Mineralerne muligvis forekommende kemisk bundne Vand. De synes derfor af meget ringe Værdi. Jeg har fundet at, med visse Forbehold, Mængden af Vandet i de mikroskopiske Hulheder lader sig bestemme som Vægttabet ved Glødning i $\frac{1}{2}$ Time af Graniten, naar denne fremstilles i Gryn paa 2 à 3 mm, naar disse Gryn forud er tørrede for at fjerne det hygroskopiske Vand — i Tilfældet af delvis Forvitring maa dog Grynene opvarmes til 300° og vejes før Glødningen (se Side 17).

Jeg har fundet Mængden af Vand i de mikroskopiske Hulheder at variere mellem 0,14 og 0,38%. En kemisk Analyse af saadanne Bjergarter eller Mineraler, som indeholder flydende Vand, forekommer mig ufuldstændig, naar ikke Mængden af det flydende Vand bestemmes.

De i Vædsken opløste Salte har jeg søgt bestemt ved at male 5 kg af den groft knuste vadskede og tørrede Bjergart til et meget fint Pulver og derefter udlude to à tre kg deraf i lunket Vand og analysere det klare Filtrat. Jeg har fundet den samlede Mængde af Salte at variere: hos pre-kambriske Graniter mellem 0,327 og 0,737 ‰ og hos yngre Graniter mellem 0,133 og 0,442 ‰ . I nogle enkelte Graniter er Sulfaterne fundne at være i Majoritet, men det almindelige synes at være, at Kloriderne er overvejende. Der er noget der

tyder paa, at Kloriderne har en særlig Affinitet for Kvartsen og Sulfaterne for Feldspaten; dette synes at fremgaa af Undersøgelsen af norsk og svensk Pegmatit, men en nærmere Undersøgelse af dette ejendommelige Forhold vilde være ønskelig.

Det er almindelig antaget, at Vandet har spillet en Rolle ved Bjergarternes Udkrystallisering, men hvad Rolle har Saltene spillet, og hvor kommer de fra? Mængden af Salte opløste i Vædsken i Hulrummene har jeg fundet at svinge mellem ti og godt tyve Procent.

Literature.

1. SORBY, H. C.: On the Microscopic Structure of Crystals, indicating the Origin of Minerals & Rocks, in Quarterly Journal of the Geological Society of London, Vol. 14, 1858, Pag. 453.
 2. GORANSON, R. W.: The solubility of water in Granite Magmas. in American Journal of Science. Vol. XXII. 1931.
 3. DAUBRÉE, A.: Comp. red. 45. 1857 and Ann. des mines (5) 12. 1857.
— Géologie expérimentale. Paris 1867. Pag. 64 & 88.
— Etudes synthétiques de Géologie. Paris 1879. Pag. 232.
 4. ZIRKEL, F.: Mikromineralogische Mitteilungen, in Neues Jahrbuch für Mineralogie, 1870. Pag. 804.
 5. PFAFF, FR.: Pogg. Ann. 143, 1871. Pag. 610—620.
 6. PHILLIPPS, J. A.: in Quart. Journal of the Geological Society, London, 1875. Vol. 31. Pag. 332.
 7. KÖNIGSBERGER, J., and MÜLLER, W. J.: In Centralblatt für Mineralogie, 1906, Pag. 72.
 8. CHAMBERLIN, R. T.: The Gases in Rocks, Carnegie Institution of Washington, Pub. No. 106, 1908.
 9. WASHINGTON, HENRY S.: The Chemical Analysis of Rocks, New York, 1930, Pag. 238.
 10. CALLISEN, KAREN: Das Grundgebirge von Bornholm. Danmarks Geologiske Undersøgelse. II. Række. No. 50, Kjøbenhavn 1934.
 11. WALKER, FREDERICK, & CHARLES F. DAVIDSON: Geology of the Faeroes in Transact. of the Roy. Soc. of Edinburgh. Vol. LVIII, Part III, No. 30, 1935—36.
-

FR. BAGGES KGL. HOFBOGTRYKKERI
KØBENHAVN