XVI. *An Analysis of the Waters of the Dead Sea and the River Jordan. By* Alexander Marcet, *M.D. one of the Physicians to Guy's Hospital. Communicated by* Smithson Tennant, *Esq. F.R.S.*

Read June 18, 1807.

The Dead Sea, or Lake Asphaltite, is situated in the southern part of Syria, near Jerusalem, and occupies an extent of about 60 or 70 miles in length, and from 10 to 20 in breadth. This lake has been from time immemorial celebrated on account of the intense saltness of its waters, which is such as to prevent either animals or vegetables from living in it, a peculiarity from which it has derived its name. It appears that this saline quality has existed in the earliest ages; for independently of the frequent allusions made to it in the Scriptures, we find it described by several ancient authors, amongst others by Strabo,* who wrote during the reign of Augustus, by Tacitus,† and by Pliny.‡ Amongst modern travellers, Pococke,§ Volney,|| and others, have noticed and described this singular spot.

But although the most obvious peculiarities have for a long time been in some degree known, the only chemical analysis I have been able to find on record is that which was published

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* Strabonis *Geogr.* vol. ii. p. 1107.

† Tacitus, lib. v. *Hist.* cap. vi.

‡ Plinii lib. v. cap. xv. and xvi.

§ Pococke's *Travels* in 1743, ii. p. 34.

|| Volney, i. 281.

in the "*Memoires de l'Academie des Sciences*" for the year 1778, by Messrs. MACQUER, LAVOISIER, and SAGE. The names of LAVOISIER, and of his two distinguished associates, might appear to render any further investigation of the nature of this water superfluous; but whoever has perused the paper in question, must be convinced, that these gentlemen, however correct in their general statements, neither attained that degree of accuracy of which modern analysis is susceptible, nor did they bestow on the subject that share of attention which is indispensable in minute analytical experiments.

The gentleman to whom I am indebted for the specimen of the water of the Dead Sea which is the subject of this Paper, is Mr. GORDON of Clunie, who recently travelled in that country and undertook, not without some difficulty and danger, an excursion from Jerusalem to this remarkable lake. There he himself filled and brought to Sir JOSEPH BANKS a phial containing about one ounce and a half of this water, carefully corked, and in a state of perfect preservation. The same gentleman brought also in another phial, somewhat larger, a specimen of the River Jordan, which runs into the Dead Sea, without having any outlet, so that the river might be expected to hold in solution ingredients analogous to those of the Lake itself. These specimens Sir JOSEPH put into the hands of Mr. TENNANT, for examination. But knowing that I was engaged in similar researches, Mr. TENNANT was so obliging as to entrust me with this analysis, and to afford me frequent opportunities of availing myself of his assistance in the course of the enquiry.

Being possessed but of a small quantity of this water, a further supply of which could not easily be procured, I was anxious not to waste any considerable portion of the specimen by preliminary trials. With this view, I began by making a variety of comparative experiments on artificial solutions, in order to ascertain the accuracy of different modes of operating; and knowing by Lavoisier's analysis, and also by the general effects of reagents applied to minute quantities of the water, what were the principal ingredients which I might expect to find in it, I made solutions, the contents of which I had previously ascertained with precision, so that by analysing these solutions in different ways, I had an opportunity of judging of the degree of accuracy that could be expected from a variety of methods. Some of these trials I shall briefly relate; for although not strictly belonging to the particular analysis in question, yet I conceive that they may be of some general use, in pointing out the most eligible method to be pursued in inquiries of this kind. Indeed it must be confessed that the minute chemical examination of any individual substance, requires so much time and patience, that to obtain a knowledge of that substance only, would seldom appear a sufficient inducement to such a laborious undertaking, was it not always more or less connected with other useful collateral objects.

§ I.

General Properties of the Dead Sea.

1. One of the most obvious peculiarities of the Dead Sea-water, is its specific gravity, which I found to be 1,211, a degree of density scarcely to be met with, I believe, in any other natural water. The circumstance of this lake allowing bodies of considerable weight to float upon its surface, was

noticed by some of the most ancient writers. STRABO, amongst others, states that men could not dive in this water, and in going into it, would not sink lower than the navel; and POCOCKE, who bathed in it, relates that he could lie on its surface, motionless, and in any attitude, without danger of sinking. These peculiarities, which I, at first, suspected of being exaggerated, are fully confirmed by Mr. GORDON, who also bathed in the lake, and experienced all the effects just related.

2. The water of the Dead Sea is perfectly transparent, and does not deposite any crystals on standing in close vessels.

3. Its taste is peculiarly bitter, saline, and pungent.

4. Solutions of silver produce from it a very copious precipitate, showing the presence of marine acid.

5. Oxalic acid instantly discovers lime in the water.

6. The lime being separated, both caustic and carbonated alkalies readily throw down a magnesian precipitate.

7. Solutions of barytes produce a cloud, showing the existence of sulphuric acid.

8. No alumine can be discovered in the water by the delicate test of succinic acid combined with ammonia.

9. A small quantity of pulverised sea salt being added to a few drops of the water, cold and undiluted, the salt was readily dissolved with the assistance of gentle trituration, showing that the Dead Sea is not saturated with common salt.

10. None of the coloured infusions commonly used to ascertain the prevalence of an acid or an alkali, such as litmus, violet, and turmeric, were in the least altered by the water.

§. II

Preliminary Experiments to ascertain the Composition of the Salts concerned in this Analysis.

Having satisfied myself by these preliminary experiments that the Dead Sea contained muriat of lime, muriat of magnesia, and selenite, and having no doubt both from the taste of the water, and from LAVOISIER's statement,* that it contained also common salt, I proceeded to the comparative experiments above mentioned.

The first indispensable step was to ascertain with accuracy the proportions of acid, and base, in the three muriats just named. This I had already done in the course of a more general inquiry which I began some time ago in conjunction with Mr. TENNANT, and which has been of great use to me on the present occasion. But as the particulars of that series of experiments may probably be published at some future period, I shall now confine myself to such general statements as immediately belong to my subject.

1. The composition of muriat of lime was ascertained by pouring a known measure of muriatic acid on a piece of pure marble of known weight, and more than sufficient to saturate the acid. The remaining portion of marble being then weighed, and the solution evaporated and heated to redness, the proportions of acid and earth were easily deduced. But in order to draw such an inference, it was necessary to ascertain with precision the quantity of pure lime in a given weight of marble,

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* MACQUER, LAVOISIER, and SAGE, discovered the three muriats, but overlooked the small quantity of selenite.

which, from a number of experiments performed with great care by Mr. TENNANT and myself, appeared to be 56,1 parts of lime in 100 of marble. From a great variety of trials, made with considerable attention, and with due allowance for any accidental circumstances, muriat of lime appeared to consist of 50,77 parts of lime, to 49,23 of muriatic acid.

2. To ascertain the proportions of earth and acid in muriat of magnesia, required a synthetic process somewhat different. To a known weight of pure magnesia perfectly calcined, a known quantity of acid* was added, and after the whole of the magnesia was dissolved, the remaining portion of acid was saturated by marble. From the loss sustained by the marble, and the known proportions of acid and magnesia used, the composition of muriat of magnesia (supposed perfectly free from water) was deduced, and the proportions resulting from several careful trials, were 43,99 parts of magnesia, to 56,01 of muriatic acid.

3. Muriat of soda was analysed by various methods. But the only one which I shall now relate consisted in precipitating the acid by a solution of silver from a known weight of muriat of soda, and inferring the proportion of acid and alkali from the quantity of luna cornea obtained. This however required a previous exact knowledge of the proportions of acid and silver in luna cornea. In order to ascertain this point, a known quantity of acid was precipitated by nitrat of silver, and the weight

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[*] By a *known quantity* of acid, is meant as much acid as will dissolve a known weight of marble. In all these experiments the quantities of acid were not weighed, but measured by means of a peculiar apparatus, and the real weights or intrinsic quantities of acid, corresponding to the measures in question, were easily deduced from the results above mentioned.

of the luna cornea, after being melted and heated to redness, indicated 19,05 parts of acid to 80,95 of oxyd of silver. The composition of common salt, calculated from these data, proved to be 46 parts of acid to 54 of soda.

§ III.

Comparative Analyses of artificial Solutions.

I shall not enter into all the particulars of the various analyses of artificial solutions, resembling the water of the Dead Sea, which directed me in the choice of the method which I ultimately adopted. But it may be proper to state, in a summary manner, the principal means which were tried, and their respective defects and advantages.

These artificial mixtures all contained the three muriats above mentioned, but in each of them the small quantity of selenite was altogether disregarded.

1. The first of these solutions was evaporated to dryness, and the residue exposed for near an hour to a red heat in a platina crucible pretty closely covered. The object of this was to drive off the acid from the magnesia (muriat of magnesia being decomposable by heat), and after separating this earth from the other salts by means of distilled water, to precipitate the lime by carbonat of ammonia, and to obtain the muriat of soda by evaporation to dryness. But I soon found that the complete decomposition of muriat of magnesia by heat, under these circumstances, was extremely difficult, if not impossible, and accordingly the results obtained from this method indicated considerably less magnesia and proportionally more lime,

than the solution really contained. The quantity of common salt was tolerably accurate.

2. From another similar solution the lime was precipitated by oxalat of ammonia; the magnesia was separated by heat in an *open* crucible, and the common salt was obtained, as before, by evaporation and exposure to a low red heat. The result was satisfactory both as to the lime and magnesia; but as the separation of the latter could only be completed by long continued heat, in an open vessel, I found the muriat of soda materially reduced by sublimation, and was therefore obliged to abandon this mode of proceeding.

3. From a third artificial solution, the lime was precipitated by oxalat of ammonia, the magnesia by carbonat of ammonia recently prepared, and the sea salt was obtained as usual by evaporation and desiccation in a low red heat. The object of this mode of operating was to supersede the necessity of applying a red heat in the first instance. But I was again disappointed; for the magnesia was but imperfectly precipitated; and in order to separate the last portions of this earth, it was necessary to calcine the last residue containing the muriat of soda, which gave rise to the same objections as in the former experiments.

4. The last and most successful method consisted in dividing the artificial solution into two portions. From one of these the muriatic acid was precipitated by nitrat of silver, and its quantity ascertained. From the other the lime was separated by oxalat of ammonia, and the magnesia by caustic potash;*

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* Or by carbonat of ammonia. In this case the precipitation of magnesia is not so perfect; but the precipitate falls down more quickly, and the separation of any remaining portion of this earth may be ultimately completed by heat.

and the respective portions of acid belonging to each of these earths being calculated, the quantity of muriat of soda was inferred from the remaining quantity of acid.

This method afforded remarkably accurate results. The only objection to it seems to be that the muriat of soda being only estimated, and not actually obtained, if any error be made either in the estimation of the acid or in the separation of the lime and magnesia, these errors must also ultimately affect the computation of the muriat of soda, without allowing any immediate means of detecting them. This objection, however, is in a great degree removed, by a comparison of the two portions of the solution, from one of which the common salt can be obtained undecomposed; and the present method has this additional advantage, that the quantity of acid is a sort of check, which, when connected with some other point of comparison, prevents any gross error in the computation of the earths, from escaping notice.

This plan being very similar to that which I actually followed in the analysis of the water of the Dead Sea, it may be worth while to mention the summary results of the comparative experiments which decided me in its favour.

The artificial solution contained:

	Salts.		Acid.
Muriat of lime -	8,17 grains		4,02 grains.
Muriat of magnesia	26,10	=	14,62
Muriat of soda -	25,00	=	11,50
	59,27*	=	30,14

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* These happened to be very nearly the real proportions of salts in the Dead Sea; yet this coincidence was a matter of mere accident; for when I mixed up the ingredients, I was led to suppose from LAVOISIER's paper, that their proportion in the Dead Sea was very different from that which I afterwards ascertained.

And the contents inferred by the foregoing method were:

	Salts.		Acid.	
Muriat of lime	8,14	=	4,01	grains.
Muriat of magnesia	25,62	=	14,35	
Muriat of soda -	25,47	=	11,72	
	59,23	=	30,08	

§ IV.

Analysis of the Dead-Sea Water.

I now come to the actual examination of the water of the Dead Sea, the particulars of which will be found much shortened by the preceding observations.

1. 20 grains of this water (the whole supply of which amounted only to 540 grains) were put in a glass capsule, and slowly evaporated in a water bath, by means of an appropriate apparatus, the temperature of the capsule being constantly kept within 5 degrees of 180°. The object of this experiment was simply to know the weight of the solid contents of the water, dried under various degrees of heat, and to observe the appearances produced by evaporation. After a few hours, and when the residue had ceased to lose weight, the saline mass, whilst still warm, appeared in the form of a white semitransparent incrustation, which yielded to the touch, being soft, and of a pulpy consistence. In cooling it became hard, and of a much more opaque white colour. When examined with attention, the borders of this mass were found covered with small cubic crystals, and the same appearance was observed, though less conspicuously, in the centre under the saline incrustation, when in the state of semifusion just described. On standing in the

air for some time, the white opaque mass gradually absorbed water from the atmosphere, and returned to a liquid state. The 20 grains of the water, thus evaporated and dried at 180°, weighed, whilst still warm, 8,2 grains.

2. The same saline mass being afterwards exposed in a sand bath to the temperature of 212° FAHRENHEIT, was reduced to 7,7 grains. Hitherto not the least smell of muriatic acid was perceived, nor did any decomposition appear to take place.

3. But having raised the heat about 15° higher, the residue, after a few minutes, was found reduced to 7,4 grains; and on redissolving it, a few insoluble white particles appeared floating in the solution, showing an incipient decomposition in the muriat of magnesia.

It appears from these experiments that 100 parts of the Dead Sea water yield 41 of salts dried at 180°, and 38,5 dried at 212°.* What proportion these quantities bear to the same salts, when perfectly deprived of water, will be seen from the subsequent results. I now pass on to the chemical examination of the water.

4. To 100 grains of the Dead Sea water a few drops of muriat of barytes being added, a precipitate was obtained, which, after being well washed and exposed to a low red heat on a piece of laminated platina, weighed 0,09 grain, which, allowing for the unavoidable loss attending the manipulation of such very minute quantities, may safely be called 0,1 grain.

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* If the quantity of materials upon which these results are founded, should appear too small, I would observe that if the bulk of salt be considerable, it is impossible to dry it accurately, owing to the crust which forms on the surface, and prevents the escape of moisture. But at any rate no perfect accuracy can be relied on respecting this kind of limited desiccation, as its completion depends in a great degree on the shape of the vessel, the thickness of the stratum of salt, &c.

This residue, on being heated with fluat of lime, instantly ran into a globule, and was evidently sulphat of barytes.

5. To another portion of the Dead Sea water, weighing 250 grains, a solution of nitrat of silver being added till it ceased to produce any precipitate, a quantity of luna cornea was obtained, which after careful edulcoration and exposure to a red heat, weighed 163,2 grains, a quantity equivalent, according to the proportions above stated (§ II. 3), to 31,09 grains of real acid.

6. To the remaining solution a little muriat of ammonia was added, in order to remove the unavoidable small excess of silver, and this new precipitate was separated and well edulcorated.

7. The clear fluid, which had been much increased in bulk by these edulcorations, being concentrated to about 3 ounces, a strong solution of oxalat of ammonia, warm, but not nearly boiling,* was added to it, by which a precipitate was obtained, which collected and washed with the usual precautions, and after deducing 0,076 grains of lime † for the 0,136 grains of selenite belonging to 250 grains of the water, yielded 4,814 grains of pure lime = 4,66 grains acid = 9,48 grains muriat of lime.

I should not omit mentioning that the method which I used in all my experiments to ascertain the quantity of pure lime in

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* The precipitates of lime by oxalat of ammonia subside more readily if the solutions be used warm; but when concentrated and heated to the boiling point, this test acts also in some degree on magnesia, a circumstance which in the present instance, was to be particularly avoided.

† The proportion of lime in selenite, and of acid in sulphat of barytes, are taken from a paper of Mr. CHENEVIX, in NICHOLSON's Journal, Vol. II. in which they are stated to be 56,4 of lime in 100 parts of selenite, and 24 parts of acid in 100 parts of sulphat of barytes.

oxalat of lime, consisted in driving off the oxalic acid by a low-red heat, and adding to the calcareous residue, then converted into a subcarbonat, a known quantity of muriatic acid more than sufficient to dissolve the whole lime. A piece of marble of known weight was afterwards added to take up the excess of acid, and from these data the quantity of lime was calculated with great precision.

8. The clear solution containing nitrat of magnesia, nitrat of soda, and a small excess both of oxalat and muriat of ammonia, and amounting in bulk to about 4 ounces, was exposed to the heat of a lamp for concentration; but in a few minutes the mixture became turbid and began to deposite a white powder, which, from former observations, I supposed to be oxalat of magnesia. To this solution concentrated to between 2 and 3 ounces, and still warm, I added carbonat of ammonia with excess of pure ammonia. A considerable precipitation immediately appeared, and the mixture became opaque and milky. The next morning, however, the fluid had become quite transparent, and instead of a white impalpable precipitate, I found clusters of perfectly pellucid crystals spread over the bottom of the vessel, with distinct interstices between them.

This salt was no doubt an ammoniaco-magnesian carbonate; and the remaining solution, although still containing, as will presently appear, a vestige of magnesia, was so far free from it, as not to have its transparency disturbed by caustic potash. These crystals, after being well washed in distilled water, were exposed to a gentle heat to drive off the ammonia, in consequence of which they crumbled down into a white impalpable powder, exactly resembling common carbonat of magnesia. This powder being then treated, and its quantity estimated, in a way similar to that which had been employed with the lime; and being increased by the addition of about 0,5 grains of a similar precipitate (which had escaped the action of the carbonat of ammonia and was obtained from the last remaining solution by evaporation and calcination), amounted to 11,10 grains of pure magnesia = 14,15 grains of muriaic acid = 25,25 grains of muriat of magnesia.

9. The muriat of soda was next estimated from the 12,28 grains of muriatic acid found to remain after subtracting the sum of the two portions (4,66 grains and 14,15 grains) belonging to the lime and magnesia, from the 31,09 grains, or sum total of acid. These 12,28 grains gave according to the proportions before mentioned (§ II. 3), 26, 69 grains of muriat of soda

10. From these several results brought into one view, and the salts being supposed heated to redness, 250 grains of the Dead-Sea water appear to contain,

	Salts.		Acid.	
Muriat of lime -	9,480	grains	4,66	grains.
Muriat of magnesia	25,25	=	14,15	
Muriat of soda -	26,695	=	12,28	
Sulphat of lime -	0,136	-	-	
	61,561		31,09	

And therefore 100 grains of the same water would contain,

	Grains.
Muriat of lime - -	3,792
Muriat of magnesia -	10,100
Muriat of soda - -	10,676
Sulphat of lime - -	0,054
	24,622

§ V.

Second Analysis of the Dead Sea Water by a Method somewhat different from the former.

In the mode of proceeding just related, some small loss in the earths might naturally be suspected to have taken place in consequence of the previous separation of the acid and indispensable edulcorations. Besides, the muriat of soda being necessarily decomposed by the first part of the process, the analysis could not have been considered as quite satisfactory, had not the common salt been procured unaltered by some other process.

1. In order to obtain these points, 150 grains of the water were treated, with regard to the lime and magnesia, exactly as in the former analysis; but in this case, the acid, instead of being actually separated by silver, was only calculated from the former estimation (§ IV. 5).

2. The result proved perfectly agreeable to my expectation. It yielded a little more lime and magnesia than the former analysis, but this excess was scarcely perceptible. With regard to the muriat of soda, I was able actually to procure by evaporation, as much as 13,1 grains of this salt, the actual quantity of which, inferred as in the preceding analysis, was 15,54 grains, a difference easily accounted for by the necessity of heating the salt to redness for its ultimate separation.

3. On summing up the contents of these 150 grains of the water, they appeared to be as follow:

	Salts.		Acid.
Muriat of lime -	5,88 grains		2,89 grains.
Muriat of magnesia	15,37	=	8,61
Muriat of soda -	15,54	=	7,15
Selenite - -	0,08	-	- -
	36,87		18,65

And consequently the proportions of these salts in 100 grains of the water would be:

	Grains.
Muriat of lime - - -	3,920
Muriat of magnesia - -	10,246
Muriat of soda - - -	10,360
Sulphat of lime - - -	0,054
	24,580

The coincidence of these results with those of the former analysis was such as I could scarcely have expected to increase by further trials. The last statement, however, I consider as the most accurate of the two.

It may therefore be stated in general terms, that the Dead-Sea water contains about one fourth of its weight of salts supposed in a state of perfect desiccation; whilst, as I observed before, if these salts be only desiccated at the temperature of 180°, they will amount to 41 per cent. of the water. This great difference between the two states of desiccation depends on the great affinity which muriats, particularly that of magnesia, have for water. Muriat of soda is scarcely at all concerned in this difference: for I found, not without surprize, that 100 grains of artifical cubic crystals of muriat of soda, being fused and heated to redness in a platina crucible, lost at most half a grain.

In the analysis of MACQUER and LAVOISIER, the solid contents of the Dead Sea are estimated at about 45 per cent. of the water, and in the proportions of nearly 1 part of common salt to 4 of muriat of magnesia, and 3 of muriat of lime; proportions widely different from those which I had obtained. But their mode of operating, which they candidly relate, was so evidently inaccurate with regard to the separation and desiccation of the salts, and in general so deficient in the estimation of quantities and proportions, that these eminent chemists cannot be considered as having aimed, in this instance, at any thing like an exact analysis.

It may be observed also, that these gentlemen found the specific gravity of the water 1,240 instead of 1,211, as I have stated it to be; but it appears that their specimen had suffered some evaporation previous to their experiments, since they found crystals of common salt in one of their bottles, which could not have happened without evaporation. Besides, the specimen which I examined was, I understand, brought from a part of the lake not more than two miles distant from the mouth of the Jordan, a circumstance which may perhaps account for its being somewhat more diluted, than it might be found in other parts.

§ VI.

Analysis of the Water of the River Jordan.

As I had scarcely two ounces of this water, and as it contained but a very small proportion of saline ingredients, it would have been in vain to aim at analyzing it with strict accuracy. Yet I thought it worth while to endeavour to form as exact an estimation of its contents as I could, on account of its connection with the Dead Sea, into which, as was observed before, it pours its waters, and appears to remain in a stagnating state. This specimen was brought from a spot about three miles distant from that where the river enters the Dead Sea.

From the perfect pellucidity of this water, its softness, and the absence of any obvious saline taste, I was led to suppose that it was uncommonly pure, and could in no degree partake of the peculiar saline qualities of the Dead Sea. But I was soon induced to alter my opinion by the following results.

1. The same chemical reagents, as were used to ascertain the general properties of the Dead Sea water, being applied to this, produced analogous effects. The same three muriats and even the vestige of selenite, were distinctly discovered; and this resemblance became more striking in proportion as the water was concentrated by evaporation.

2. 500 grains of this water being evaporated at about 200°, the dry residue weighed exactly 0,8 grains. This makes the solid ingredients amount only to 1,6 grains in 1000 grains of the water, a singular contrast with the Dead Sea, which contains nearly 300 times that proportion of saline matter. As the water was concentrating, a few white particles were perceived on its surface, and a few others gradually subsided. When dried, the residue appeared in the form of a white incrustation, the upper edge of which exhibited great numbers of very minute crystals, which from their saline taste, and their cubic shape discoverable by the aid of a microscope, were evidently common salt.

3. Distilled water being thrown on this residue, a minute portion of it remained undissolved, and on pouring an acid on this substance, a distinct effervescence was produced, showing the presence of carbonat of lime.

4. From the clear fluid a precipitate was obtained by oxalat of ammonia, which, dried but not calcined, weighed 0,12 grains.

5. From the remaining clear solution a magnesian precipitate was produced by ammonia and phosphoric acid, which, after driving off the ammonia by heat, weighed 0,18 grains.

6. The solution had suffered too many alterations to allow me to separate, with any degree of accuracy, the muriat of soda; but from a variety of circumstances, I thought it not unlikely that it would have been found pretty nearly in the same proportions, with respect to the other salts, as it exists in the Dead Sea.

The inference I drew from this was, that the River Jordan might possibly be the source of the saline ingredients of the Dead Sea, or at least that the same source of impregnation might be common to both. This inquiry, however, would require a much more correct knowledge both of the proportions of the salts, and of local circumstances, than I have ben able to obtain.