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“Experimental Investigations on the Action of Sea Water in accelerating the Deposit of River Silt and the Formation of Deltas.”

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THE formation of deltas by sediment-bearing rivers, especially when discharging into tideless seas, has been attributed to two causes, namely: (1) the checking and eventual stoppage of the issuing current on encountering the vast inert mass of sea water in front of the mouth of the river, causing the rapid arrest of the heavier materials rolled along the river-bed, and the gradual settlement of the silt carried in suspension by the river; and (2) the acceleration of the deposit of the suspended silt by the action of the sea water upon it. The first cause is a well-understood physical action, which increases with the amount of retardation of the river-current on emerging into the open sea, and with the density of the matter in suspension. The second cause partakes somewhat of the nature of a chemical action, depending upon whatever greater influence may be possessed by sea water in promoting the settlement of the suspended silt, than the river water in which the silt has been brought down in suspension, resulting from differences in chemical composition.

This acceleration of deposit by sea water appears to have been accepted by geologists as the main cause of the formation of deltas, though the subject has been very little investigated, being based upon some experiments made on the rates of deposit of Mississippi silt in river water, sea water, and some saline solutions, by Mr. Sidell, one of the engineers engaged in the early surveys of the mouths of the Mississippi river, and recorded by him in a report dated 25 January, 1839, published in Humphreys and Abbot's book on the Mississippi.¹ No details are given of these experiments; but the solutions employed were made with common salt, Epsom salt, alum, sea water, brine from salt springs, and sulphuric acid; and it is stated that “the river water alone took from

¹ “Report upon the Physics and Hydraulics of the Mississippi River,” Capt. A. A. Humphreys and Lieut. H. L. Abbot. Enlarged Edition, 1876, Appendix A, No. 2, p. 500.

10 days to 14 days to settle, while the solutions became perfectly limpid in from 14 hours to 18 hours, or from one-fifteenth to one-eighteenth part of the time." From these results, Mr. Sidell concludes "that the earthy matter is deposited more suddenly than would be the case if it depended on the check of velocity alone; that the bars will be formed just at the débouchés, or where the salt water is first met; and that the greater the quantity of water brought down, the sooner, on account of the sudden precipitation, will the bars be formed at the débouchés."

Experiments on Rates of Deposit of River Silt.—The results of Mr. Sidell's experiments were brought to the Author's notice in 1894, by some correspondence on his Paper on "The Training of Rivers," contributed by Mr. J. V. Wilfrid Amor;¹ and the results appeared sufficiently remarkable, and the subject of the influence of sea water on the deposit of silt of adequate interest, in regard to the formation of deltas, to merit further investigation. Accordingly, samples were obtained by the Author, in 1894–95, of the silty sediments of the Rhone, the Danube, the Dnieper, the Nile, the Hugli, and the Mississippi.² The silt from the Dnieper was sent in place of silt from the Volga which had been asked for by the Author; but though the Dnieper is not a deltaic river, the sample of its silt possesses the interest of differing materially in composition and rate of deposit from the samples of silt from the other rivers.

Cylindrical glass tubes, 4 feet long, and between $\frac{1}{2}$ inch and 1 inch in diameter, were employed for the experiments. In order to render the conditions of the experiments as uniform as practicable, the silt from each river was passed through a fine sieve having about 7,400 meshes to the square inch, and an ounce of this sifted silt was used in each experiment. After closing the bottom of the tube with a cork, the ounce of silt was put in; and the tube was then filled with the liquid to be experimented with, to a height of 3 feet. The tube was next closed by a cork at the top, and after thoroughly shaking up the silt in the liquid the tube was set in a vertical position and the settlement of the silt was observed.

The first experiments showed that there was little difference between the rate of deposit of the silt in sea water and in the fresh water supplied by the waterworks from the Thames, but that the settlement took place much more slowly in distilled water; and consequently distilled water was adopted as the standard

¹ Minutes of Proceedings Inst. C.E., vol. cxviii. p. 107.

² These samples were kindly supplied to the Author by Mr. A. Guérard, Mr. C. H. L. Kühl, Mr. V. de Timonoff, Mr. W. Willecocks, Mr. P. W. Soutter, and Mr. C. Donovan.

fresh water. This result seemed to indicate that some river waters might, on account of the salts contained in solution in them, be as efficient in promoting the deposit of silt as sea water is. With the exception of the Nile silt, there was no sign of that great difference in the rate of settlement of the samples of silt as a whole in sea water and in fresh water, recorded by Mr. Sidell, unless mere turbidity is taken into account.

A saturated solution of Tidman's sea salt, having a specific gravity of 1.200, produced a notable acceleration in the deposit of all the samples of silt, as compared with their rate of settlement in sea water with a specific gravity of 1.024. This acceleration, however, in the saturated solution, in comparison with sea water, was not at all commensurate with the increased strength of the solution, and must be affected by the considerable augmentation in the specific gravity of the liquid. The degree of saltiness, therefore, of the sea into which a river flows must affect the influence of its waters on the silt discharged into it, though not in proportion to the amount of salts in solution; and the waters of the Dead Sea should therefore prove more effective in promoting the deposit of silt than ordinary sea water, in spite of their greater specific gravity.

In carrying out, with the help of his assistant, Mr. Edward Blundell, experiments on the deposit of silt, as opportunity permitted between 1896 and 1899, the Author, besides observing the relative rates of settlement of the samples of river silt in sea water, Thames water, and distilled water, has endeavoured to gain an insight into some of the other problems relating to the subject. Thus it appeared of interest to try to ascertain whether differences in the composition of the silt could explain to some extent the differences in rate of deposit exhibited by the different samples of silt in the same solution; also which salts, constituting the main ingredients in solution in sea and river water, have the chief influence in accelerating the deposit of silt; and, lastly, how far samples of the chief substances shown by analysis to enter into the composition of the samples of river silt, taken separately manifest differences in their rates of deposit in the various solutions experimented upon, which might possibly indicate their relative influence on the deposit of the samples of silt.

Composition of Samples of River Silt.—Analyses of the six samples of river silt were made by Dr. A. Voelcker for the Author, the results of which are given in Table I. These analyses show that more than eleven-twelfths of the Dnieper silt consists of sand, and that there is a large proportion of sand in the silt of the Mississippi, the Danube, and the Hugli, whilst the smaller proportion of sand in the Rhone silt is compensated for by

TABLE I.—ANALYSES OF RIVER SILT.

Substances.	Hugli.	Rhone.	Danube.	Dnieper.	Nile.	Mississippi.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Organic matter and combined water . . .	3·21	1·73	3·58	1·24	5·91	4·16
Oxide of iron and alumina	13·78	6·92	10·08	3·02	21·25	9·55
Lime	3·64	19·24	4·56	1·41	2·40	1·16
Carbonic acid	4·41	14·91	5·66	1·90	7·78	2·69
Magnesia and alkalies	0·28	4·80	0·21	0·21		0·66
Silica and insoluble silicates	74·68	52·40	75·91	92·22	62·66	81·78
Totals	100·00	100·00	100·00	100·00	100·00	100·00

a large quantity of carbonate of lime and magnesia, constituting with the sand nearly four-fifths of the whole. Irrespective of the sand, which in every instance amounts to more than half of the total materials, clay predominates considerably over the rest of the ingredients in the Nile silt, and to a minor extent in the Hugli silt; whilst in the silts from the Danube and the Mississippi, the clay amounts to about half the remaining constituents after eliminating the sand. The Nile and Mississippi samples contain the largest quantity of organic matter, and the Danube and Hugli samples come next in this respect; but the proportion of this constituent is small, not reaching even in the Nile silt quite one-seventeenth of the whole, and only amounting to about one-thirtieth in the Danube and Hugli silts.

The analyses merely represent the composition of the special samples of silt sent to the Author, collected in each case at some particular time and place; whilst the silt in each river must vary in constitution according to the locality, the time of year, the stage of the river and the relative discharge of its tributaries. It is, however, important to note, in relation to the experiments, that the sample of Nile silt was obtained by collecting the mud deposited from bottles filled daily with Nile water, at a distance from the shore, during a period of 41 days in September and October, 1894; whereas the Author understands that the other samples of silt were taken from the deposit which had taken place in the bed of the respective rivers. From the slow rate of settlement of Mississippi silt, even in sea water and other saline solutions, recorded by Mr. Sidell, it is evident that his experiments dealt with the very finest silt in suspension in the Mississippi, and that the period of settlement given was continued till the solution became perfectly clear. Accordingly, the Nile mud, col-

lected from the top layer of the river, doubtless corresponds in fineness and lightness to the silt experimented upon by Mr. Sidell far more closely than the other samples of silt; and it is the only sample of silt the settlement of which in distilled water at all approximately accorded with the slow rate in river water given by Mr. Sidell. The silt, however, carried down by a river, and eventually discharged into the sea, is not fairly represented by merely the fine light matter carried in suspension in the upper layers of the river water, for it has been ascertained that the silt brought down by a river in flood increases in volume and density with the depth below the surface; and the heaviest particles are carried along in successive stages, being rolled along the bed or scoured from sandbanks by a rising flood, and brought to rest or dropped as the flood subsides, remaining undisturbed till the next flood puts them in motion again and carries them down another stage.

Principal Substances in Solution in Sea Water and River Water.—Sodium chloride, known as common salt, constitutes about 78 per cent. by weight of the salts in solution in sea water; and the only other salts entering appreciably into its composition are magnesium chloride constituting about $9\frac{1}{2}$ per cent. of the soluble salts, magnesium sulphate 6 per cent., calcium sulphate nearly 4 per cent., and potassium chloride, or in some analyses potassium sulphate, to the extent of only $2\frac{1}{2}$ per cent. of the soluble salts.¹ The whole of the soluble salts of sea water constitute about one-thirtieth part of its weight.

Taking the weights of the salts in solution in sea water in grains per gallon, in order to compare them readily with the analyses of substances in solution in river water, which are generally given in this form, they are, for the analysis selected, sodium chloride 1,851 grains, magnesium chloride 221 grains, magnesium sulphate 145 grains, calcium sulphate 93 grains, potassium chloride 52 grains, and calcium carbonate only $3\frac{1}{2}$ grains.

River water contains a much smaller quantity of salts in solution than sea water, even without taking the sodium chloride in the latter into account; and its composition varies with every stage of the river, and depends upon the strata through which the river flows, and the extent to which it is fed by underground springs which have collected salts in their course. From some analyses of the waters of rivers which serve to supply large towns in England and Scotland, a gallon of Thames water was found to contain $10\frac{1}{2}$ grains of calcium carbonate, $1\frac{1}{4}$ grain of magnesium

¹ "Treatise on Chemistry," Professors Roscoe and Schorlemmer, vol. i. p. 257.

carbonate, and 3 grains of calcium sulphate. In the Trent, the amounts of these salts were $\frac{1}{3}$ grain, $5\frac{2}{3}$ grains, and $21\frac{1}{2}$ grains per gallon respectively; in the Don, $2\frac{1}{4}$ grains, 1 grain, and $\frac{1}{3}$ grain, whilst in the Dee, the total amount of these three salts was only $1\frac{1}{3}$ grain per gallon.¹ From an analysis of the waters of the Rhone at the confluence of the River Cèze, the calcium salts in solution were found to amount to about $8\frac{1}{2}$ grains per gallon; and an analysis of the waters of the Danube at Daggendorf gave a very similar quantity of calcium salts. The results of several analyses show that the waters of the Hugli, at various points above Calcutta, contain 7 grains to 11 grains of calcium carbonate per gallon, and about 4 grains of magnesium carbonate on the average, but no calcium sulphate; whilst small variable quantities of sodium carbonate have been found, not exceeding $1\frac{1}{2}$ grain per gallon.² In the Nile also, there are about 7 grains to 9 grains of calcium carbonate per gallon, and small quantities of salts of magnesium, sodium, and potassium, varying in amount with the stage of the river.³ A sample of water taken from the Mississippi at New Orleans at the end of 1898, when the river had begun to rise, was found to contain 4 grains of calcium carbonate per gallon, 1 grain of magnesium carbonate, $1\frac{1}{2}$ grain of sodium carbonate, and $8\frac{1}{2}$ grains of sodium chloride per gallon, being about half the amount given in an analysis of water from the Trent. The amount of sodium chloride in a tidal river necessarily varies according to the locality, the stage of the river, and the state of the tide, even at a considerable distance from the mouth of the river, as is well illustrated by analyses of the water of the Hugli at high water during the dry season, which give the amount of sodium chloride in a gallon of water in March as 6 grains at Cossipur, about 100 miles up the river, 0·6 grain at Pultah, about 11 miles higher up, and 0·7 grain at Chinsurah, about 8 miles further up; whilst in May, when the flood-tide is strongest, the amounts were $32\frac{1}{2}$ grains at Cossipur, 3·6 grains at Pultah, and 1·6 grain at Chinsurah. The organic matter in solution in the rivers mentioned, according to the analyses referred to, ranges from a maximum of 7 grains per gallon in the Hugli just above Calcutta, $3\frac{2}{3}$ grains in the Trent, and about 3 grains in the Don, Danube, and Nile, down to $1\frac{2}{3}$ grain in the Dee, and a very small amount in the Mississippi at New Orleans.

The principal substances, accordingly, which are found in solution in river waters are calcium carbonate, calcium sulphate, magnesium

¹ "Treatise on Chemistry," Professors Roscoe and Schorlemmer, vol. i. p. 255.

² "Report on the Water of the Hooghly," F. M. Macnamara. Calcutta, 1863.

³ Minutes of Proceedings Inst. C.E., vol. ix. p. 376.

carbonate, a small amount occasionally of sodium carbonate, a very variable quantity of sodium chloride, and organic matter.

Results of Experiments on Rates of Deposit.—The samples of silt from the Hugli, the Rhone, and the Danube, were alone sufficient

TABLE II.—TIME OF SETTLEMENT OF DELTAIC SILTS AND COMPONENT SUBSTANCES IN VARIOUS SOLUTIONS, IN MINUTES PER FOOT.

Solution.	Strength of Solution.	Deltaic Silts.			Component Substances.		
		Hugli.	Rhone.	Danube.	Calcium Carbonate.	Peat.	China Clay.
		Minutes.	Minutes.	Minutes.	Minutes.	Minutes.	Minutes.
Sea salt, saturated (Specific gravity, 1.200)	..	7½	7	6½	13	..	24
Sea water (Specific gravity, 1.024 and 1.018)	$\frac{1}{30}$	23	24	26	12	35	93
Thames water . . .	$\frac{1}{3,500}$	27	25	34	18	25	71
Pond water . . .	..	22	14	30	11	20	21
Distilled water . .	..	56	32	65	14	54	65
Sodium chloride (Specific gravity, 1.058)	$\frac{1}{10}$	23	29	28	17	21	151
Magnesium chloride (Specific gravity, 1.030)	$\frac{1}{10}$	28	34	31	30	22	135
Magnesium sulphate (Specific gravity, 1.040)	$\frac{1}{10}$	37	40	38	14	34	165
Calcium sulphate . .	$\frac{1}{420}$	23	22	26	9	24	125
Potassium chloride (Specific gravity, 1.052)	$\frac{1}{10}$	16	17	20	15	28	156
Potassium sulphate (Specific gravity, 1.050)	$\frac{1}{11.8}$	17	21	25	11	24	152
Calcium bicarbonate .	$\frac{1}{2,700}$	26	27	31	12	35	84
Magnesium carbonate (Specific gravity, 1.018) . .	$\frac{1}{48}$	30	38	40	9	35	67
Sodium carbonate (Specific gravity, 1.032)	$\frac{1}{10}$	30	45	51	10	..	180

in quantity to be subjected to experiments on deposit in solutions of the chief substances contained in sea water and river water, as well as in sea water and distilled water. Experiments were also made in the same solutions with china clay, as representing pure

clay of uniform composition, calcium carbonate, as being the salt of lime found in river silt, and peat, which was used as the most uniform substance available constituting vegetable organic matter. The solutions were made by dissolving each very soluble salt in ten times its weight of distilled water; and in the case of the sparingly soluble salts, concentrated solutions were used. For a solution of organic matter, water from a pond was employed, to which only rain-water, vegetable matter, and aquatic insect life have access. The results obtained are given in Table II.

Since the rate of settlement became slower as the material got more concentrated in the lower part of the tube, especially with such bulky substances as china clay and peat, the rate has been given for the first foot from the top, except in the case of the peat, where, owing to the floating of a small quantity in every instance, it became necessary to measure the period of settlement for the foot between 6 inches and 18 inches from the top of the solution.

The few experiments possible on the rate of settlement of the limited quantities of silt received from the Dnieper, the Nile, and the Mississippi, gave the following results:—

TABLE III.—TIME OF SETTLEMENT OF RIVER SILTS IN VARIOUS SOLUTIONS, IN MINUTES PER FOOT.

Solution.	Dnieper.	Nile.	Mississippi.
	Minutes.	Minutes.	Minutes.
Sea Salt, saturated	4	10	9
Sea Water	12	13	30
Thames Water	13	20	36
Distilled Water	20	3 days. ¹	57

Experiments were also made with silver sand pounded very fine; but as this sand always settled down to the bottom of the solution in two or three minutes, it appeared unnecessary to continue these experiments.

The figures in Table II show that, whilst the deposit of silt is much more rapid in a saturated solution of sea-salt than in any other solution, the rate of settlement in sea water differs little from that in a stronger solution of its chief ingredient, sodium chloride, as well as in a solution of another constituent, namely, calcium sulphate. The rate of deposit of silt in Thames water also closely approximates to the rate in a solution of its principal

¹ The silt settled in this period to the bottom of the tube, but the water remained somewhat turbid above.

salt, calcium carbonate. The solutions in which the silts deposit most quickly, next to a saturated solution of sea salt, are the solutions of potassium chloride and potassium sulphate, and pond water, followed pretty closely in this respect by the solution of calcium sulphate, sea water, the sodium chloride and calcium bi-carbonate solutions, and Thames water. The deposit of silt was slowest in distilled water; and, unlike solutions of salts, the distilled water remained more or less cloudy above for a long time after the deposit of the silt had been practically completed. The Rhone silt settled in distilled water more quickly than the silts from the Hugli and the Danube, in spite of its smaller proportion of sand, evidently on account of the large quantity of calcium carbonate it contains, and the small amounts of clay and organic matter in its composition (Table I).

Out of the six samples of silt, the Dnieper silt naturally settled quickest in all the experiments, owing to the large amount of sand and the small quantities of clay and organic matter it contained; and, with the exception of the Hugli silt, the samples of silt settled in distilled water in the order in which they would stand in regard to the amount of sand and calcium carbonate in their composition. Though the Hugli silt settled rather more quickly in distilled water than the Danube silt, in spite of its containing more clay in its composition, its final clearing was slower. The very slow settlement of the finer particles of the Nile silt may be traced to the large proportion of clay and organic matter in its composition, and to the manner in which the sample was obtained from the silt carried in suspension in the upper layers of the river water.

With the exception of sand, which always settles rapidly, the substances selected as the best available representations in a pure state of the principal constituents of silt, fail to exhibit as a whole much accordance in settling with the rates of deposit of the river silts, except in a saturated solution of sea salt, pond water, Thames water, calcium bi-carbonate solution, and sea water; but this may be attributed to the rate of settlement of china clay being apparently much more retarded by an increase in the specific gravity of the solution than the samples of silt, except in a saturated solution of sea salt and a magnesium carbonate solution.

Influence of Strength of Solution on Rate of Settlement.—On comparing the strengths of the different solutions experimented upon, as given in Table II, with the rates of settlement of the silts in them, it became evident that the rate of settlement of silt cannot always increase with the strength of the solution, except apparently in the case of the solution of Tidman's sea salt. For

instance, the settlement of silt in sea water, containing salts in solution equivalent to one-thirtieth of its weight is slightly quicker than in a 10 per cent. solution of sodium chloride, and very nearly the same as in a 1 in 420 solution of calcium sulphate; whilst its rate of settlement in Thames water, containing in solution salts of only $\frac{1}{3500}$ part of its weight, approximates closely to its rate in a 1 in 2,700 solution of calcium bi-carbonate. To test definitely the correctness of the conclusion deduced from the various experiments, that an increase in the strength of a solution of the salts experimented on does not necessarily increase the rate of deposit of silt, observations were made of the rates of deposit of the Hugli, Rhone, and Danube silts, in a 1 in 60 solution of sodium chloride, which, compared with their settlement in a 10 per cent. solution, gave $20\frac{3}{4}$ minutes per foot in place of 23 minutes for the Hugli silt, $24\frac{1}{2}$ minutes instead of 29 minutes for the Rhone silt, and $23\frac{1}{4}$ minutes instead of 28 minutes for the Danube silt, showing that the samples of silt settle quicker in a 1 in 60 solution than in a 1 in 10 solution of sodium chloride, and proving that the maximum rate of deposit does not always correspond with the maximum strength of the solution. It is evident, however, that there must be some limiting diluteness of the solutions, beyond which the rate of settlement of the silt must decrease; and this limit must depend upon the nature of the solution, the constitution of the silt, and the relation of the volume of the solution to the volume of the silt.

The apparent conflict between the results of this last experiment and the acceleration of the settlement of silt by concentrating the solution of sea salt, seems capable of explanation by the following considerations. Two of the salts which in solution have been shown by experiment to have a greater influence on the rate of deposit than sodium chloride, namely, potassium chloride and calcium bi-carbonate, are present in such very small quantities in ordinary sea water, that they are too diluted to exert their greatest influence on the settlement of silt; and the concentration, accordingly, of the solution of sea salt increases their proportion in the solution, and consequently their influence on settlement, without materially modifying that of the salts present in larger quantities.

Experiments on Settlement of Silt in Weak Solutions.—In view of the quicker rate of deposit of silt in a 1 in 60 solution of sodium chloride than in a 1 in 10 solution, the Author has endeavoured to ascertain approximately the strengths of the solutions of some of the principal salts contained in sea and river waters, which cause the most rapid deposit of silt. With sodium chloride, a 1 in

125 solution gave the quickest rate of settlement, reaching 19 minutes per foot for the Hugli silt, $24\frac{1}{4}$ minutes per foot for the Rhone silt, and 23 minutes per foot for the Danube silt, only slightly quicker than with a 1 in 60 solution, but a little more so than with a 1 in 200 solution.

With magnesium chloride, the settlement of silt was on the whole quickest with a 1 in 200 solution, in which the rate was $19\frac{1}{2}$ minutes per foot for the Hugli silt, $20\frac{1}{2}$ minutes for the Rhone silt, and 19 minutes for the Danube silt, though there was little appreciable difference in the rate between that in a 1 in 300 solution and that in a 1 in 100 solution; but a 1 in 75 solution gave a distinct slackening in the rate of deposit, with $20\frac{1}{2}$ minutes, $23\frac{3}{4}$ minutes, and $21\frac{3}{4}$ minutes per foot respectively.

With magnesium sulphate, which with a 10 per cent. solution gave a slower rate of deposit than the other solutions of salts, with the sole exception of sodium carbonate, which is rarely found in river water, the rate of settlement of silt was quickest with a 1 in 500 solution, in which the rates were $16\frac{1}{2}$ minutes per foot for the Hugli silt, $19\frac{3}{4}$ minutes per foot for the Rhone silt, and $17\frac{1}{2}$ minutes per foot for the Danube silt.

Potassium chloride causes the quickest settlement of silt, with a 10 per cent. solution, of all the salts experimented with, as shown by Table II; but it furnishes still quicker results with weaker solutions, the quickest rate being attained with about a 1 in 60 solution, in which the Hugli silt settled 1 foot in $10\frac{1}{2}$ minutes, the Rhone silt in 15 minutes, and the Danube silt in 13 minutes.

Calcium sulphate, which, next to calcium bi-carbonate in the presence of free carbonic acid gas, is the most sparingly soluble of the salts used, might have been expected to give the quickest settlement of silt in a saturated solution of only 1 in 420, especially as the settlement of the silt in this solution was quite as quick as in sea water; but experiment proved that still weaker solutions caused a more rapid settlement of silt. Thus the settlement of silt was quicker in a 1 in 1,500 solution than in a 1 in 420 solution, but somewhat quicker still in a 1 in 1,000 solution, averaging $16\frac{1}{2}$ minutes per foot for the Hugli silt, 18 minutes for the Rhone silt, and 19 minutes for the Danube silt. These results furnish an explanation of the cause of silt settling in Thames water, with its small quantities of salts in solution, only a little more slowly than in sea water with its much larger proportion of salts in solution; for the chief salts in solution in Thames water are calcium bi-carbonate and calcium sulphate, very weak solutions of which have more influence in promoting the deposit of silt

than the stronger solutions of the other salts experimented with, except potassium chloride. Moreover, the considerably quicker rate of deposit of silt in a much stronger solution of potassium chloride than is contained in sea water accounts for the very rapid settlement of silt in a concentrated solution of sea salt, notwithstanding the high specific gravity of the liquid.

Experiments have also been made on the rate of settlement of calcium carbonate and china clay (which next to sand constitute the principal ingredients of river silt) in solutions of the salts of such strength, as mentioned above, which occasioned the quickest rates of settlement, to ascertain how far these substances, like silt, settle more quickly in these weak solutions than in the strong solutions originally employed. Comparing the results given in Table II with the following Table, in which the rates of settlement of the silts in the most efficient solutions are collected together, and also of calcium carbonate and china clay in similar solutions, the influence of the strength of the solutions on the rates of settlement is clearly indicated.

In Table IV, china clay again exhibits, as it did in Table II, a want of accordance in its settlement with the relative rates of deposit of the silts in the different solutions, indicating that china clay cannot be regarded as fairly representing in its behaviour the clay contained in river silts, either on account of the solutions of salts not acting in the same manner on china clay as on the clay of river silt, or owing to the fineness, lightness, or the cohesion of the particles of china clay when not separated by the intermixture of sand and carbonate of lime with them. The more rapid rate, however, of the settlement of carbonate of lime and china clay in these weaker solutions of salts than in the 10 per cent. solutions, as exhibited by a comparison of Table IV with Table II, conforms in a general way with the settlement of the silts in the respective solutions.

Conditions affecting the Settlement of River Silt.—Although sodium chloride has an accelerating influence on the deposit of river silt, the other principal salts in solution in sea water, namely magnesium chloride, magnesium sulphate, potassium chloride, and particularly calcium sulphate, have a considerably greater influence in promoting the deposit of silt in proportion to the amounts of these salts contained in sea water. Moreover, the proportions in which magnesium chloride, magnesium sulphate, and calcium sulphate are present in sea water, do not greatly differ from those for which the rate of settlement of silt has been found by experiment to be a maximum in simple solutions of these salts. Accord-

TABLE IV.—TIME OF SETTLEMENT OF DELTAIC SILTS, CALCIUM CARBONATE, AND CHINA CLAY, IN SOLUTIONS OF SALTS OF DEFINITE STRENGTHS, IN MINUTES PER FOOT.

Solution.	Strength of Solution.	Deltaic Silts.			Substances.	
		Hugli.	Rhone.	Danube.	Calcium Carbonate.	China Clay.
		Minutes.	Minutes.	Minutes.	Minutes.	Minutes.
Sodium chloride {	$\frac{1}{60}$	20 $\frac{3}{4}$	24 $\frac{1}{2}$	23 $\frac{1}{4}$	10	79
„ „ {	$\frac{1}{125}$	19	24 $\frac{1}{4}$	23	9 $\frac{1}{2}$	98
Magnesium chloride . . . {	$\frac{1}{200}$	19 $\frac{1}{2}$	20 $\frac{1}{2}$	19	13 $\frac{3}{4}$	90
„ sulphate {	$\frac{1}{500}$	16 $\frac{1}{2}$	19 $\frac{3}{4}$	17 $\frac{1}{2}$	7 $\frac{1}{2}$	69
Calcium sulphate {	$\frac{1}{1,000}$	16 $\frac{1}{2}$	18	19	7	71
Potassium chloride . . . {	$\frac{1}{60}$	10 $\frac{1}{2}$	15	13	8 $\frac{3}{4}$	111

ingly, though it might be difficult to determine the relative influences of the various salts in solution in sea water in accelerating the deposit of silt, it is evident that their several effects in promoting deposit are not cumulative, otherwise the settlement of silt in sea water would be much more rapid; and it appears probable from the experiments that the slower rate of settlement of silt in sea water than in solutions of magnesium chloride, magnesium sulphate, and calcium sulphate, of strengths corresponding to the proportions of these salts in sea water, must be attributed either to the large amount of sodium chloride in sea water giving it the preponderating influence and neutralizing the action of the other salts which are more efficient than sea water when alone in solution, or to the influence of one or more of the specially active salts being retarded by the increased specific gravity due mainly to the sodium chloride in solution, or by some interference with the normal action of the several salts in solution in consequence of the presence of other salts.

If river water were perfectly pure, sea water would have a marked effect in causing the deposit of the lighter portions of silt brought down in suspension by the river, as soon as the turbid waters discharged into the sea become intimately mixed with the sea water; but these conditions are in reality never fully realized. In the first place, river water invariably contains some calcium

bi-carbonate, calcium sulphate, or organic matter in solution, small quantities of which substances promote the deposit of silt as effectually as sea water does; and therefore river water approximates to sea water in its influence on the deposit of silt, according to the amount of these substances contained in solution in it. River water may, indeed, be as efficient in causing silt to settle as sea water is; and in such a case, the settlement of the silt carried in suspension by the river cannot be affected by admixture with sea water, but must be wholly due to the arrest of the current on entering the sea. Secondly, it must be borne in mind that river silt consists of a mixture of sand, calcium carbonate, clay, and organic matter. Sand is practically unaffected by the nature of the water in which it is suspended, and settles directly the river current is arrested; whilst the settlement of calcium carbonate is only slightly modified by the composition of the fluid in which it floats. Organic matter also appears to have its rate of deposit altered only within very moderate limits by variations in the constitution of the water in which it is immersed; and it is in fact almost wholly the finer particles of clay in suspension, mingled possibly with a little organic matter, which, as indicated by the experiments with Nile silt, if borne along by fairly pure river water, are deposited by admixture with sea water. Lastly, however, it must be noted that this very fine silt floating in the upper layers of the river water, does not really mix at once with the sea water on being discharged from the mouth of the river, but is at any rate partially borne along by the issuing fresh-water current, over the top of the denser sea water, to a considerable distance from the shore, varying according to the velocity and volume of the river water flowing into the sea. Thus the turbid water issuing from the Rhone was seen by the Author, in 1892, about 6 miles seawards from its mouth, and occasionally in flood time it extends to double that distance; the muddy outflow from the Nile is very distinctly visible crossing the outlet of Port Said Harbour, at a distance of about 35 miles from the nearest mouth of the river; and the silt-bearing current issuing from the Amazon is said to have been observed at sea 300 miles beyond its mouth. Moreover, the finest silt is very readily kept in suspension by the slightest motion of the water resulting from currents, winds, or waves; and if the action of sea water on river silt was as rapid as assumed by Mr. Sidell, a turbid river like the Hugli should become clear on entering the Bay of Bengal, whereas its waters are as densely charged with reddish-brown silt beyond its outlet, as at Calcutta, 100 miles up the river.

Conclusions as to the Influence of Sea Water on the Formation of Deltas.—The fine, light, clayey matter which renders the upper layers of river water turbid, and is therefore a very conspicuous feature to the casual observer, forms a very small part of the sediment brought down by the river; and the Mississippi has been observed to appear very turbid during a low stage, at New Orleans, when very little sedimentary matter could be found in the river. It is, indeed, this light matter, so effective in producing turbidity, and constituting the finest portion of the very fine sample of Nile silt, which occupied such a long time in depositing in distilled water. Clay, in reality, constitutes only a small proportion of the whole of the sediment brought down by rivers, amounting, even in the special sample of Nile silt, to little more than one-fifth of the whole, in the Hugli silt to rather over one-seventh, and only about one-tenth in the Danube and Mississippi samples of silt; whilst the finest matter, which is the portion chiefly affected by the action of sea water or solutions of other substances, forms only a small part again of the clay.

Considerably the largest portion of the silt brought down by rivers consists of sand and calcium carbonate, whose settlement is practically unaffected by sea water, and occurs earliest on the checking of the river current on entering the sea. Thus, according to Mr. Guérard, much the greater part of the alluvium brought down by the Rhone consists of fine sand rolled along the bed of the river¹; and the bar in front of its mouth is composed of sand. In the Hugli also, five of the seven bars stretching across the navigable channel between Calcutta and the mouth of the river are composed of pure sand, and the other two consist of sand with a small admixture of silt due to local erosion of the adjacent banks.² Sand, moreover, largely predominates in the Mississippi and Danube silts, and sand and calcium carbonate together constitute considerably the largest portion of the Hugli and Rhone silts; whilst even in the light suspended Nile silt, sand and calcium carbonate comprise nearly three-fourths of the whole.

The bars, accordingly, at the mouths of deltaic rivers are not due, as supposed by Mr. Sidell, to the action of sea water on the river silt, but are the result of the settlement of the sand and calcium carbonate, and occasionally some of the heavier portions

¹ Minutes of Proceedings Inst. C.E., vol. lxxxii. p. 309.

² "Report on the River Hugli," L. F. Vernon-Harcourt. Calcutta, 1897, pp. 9-11.

of the clay, owing to the stoppage of the lower portion of the river current on entering the sea. Moreover, the bars across the outlet channels of the passes traversing the Mississippi delta are at a greater distance from the mouth of the pass in proportion to the volume of water discharged by the pass, instead of being formed closer to the mouth in proportion to the greater discharge, as Mr. Sidell supposed would be the case.

The deltas also, though to some extent formed of deposited clay, are composed chiefly of sand and calcium carbonate; and whereas the lighter clayey matter in suspension, if brought down by very pure river water, would be more quickly deposited by admixture with sea water, a portion of it is carried out some distance to sea, over the top of the salt water, before being deposited or dispersed. Moreover, this very light material, on which sea water appears to have most effect, is also most readily carried about and dispersed by any motion of the water, and even stirred up from the bottom by currents and waves; and therefore the deposits produced by the action of sea water on the lightest particles of river silt are much smaller in amount and less permanent in character, except in still water in very sheltered places, than the settlement of the denser portions of silt resulting from the arrest of the river current on emerging into the open sea.

Consequently, though sea water promotes the deposit of the very light clayey matter contained in river silt, under favourable conditions, a property shown by the Author's experiments to be also possessed by certain substances found in solution in river water, there are no grounds for regarding it as exercising the very preponderating influence on the formation of deltas attributed to it by geologists, apparently merely on account of the conclusions Mr. Sidell deduced from his experiments. The chief factor, indeed, in producing bars and the advance of a delta in front of the mouths of sediment-bearing rivers, more particularly when the river discharges into a tideless sea, appears to be the deposit of the heavier silt brought down by the river, and especially the sand rolled along the bed of the river, when the issuing current is checked and eventually brought to rest on flowing into the sea.