minerals, more or less altered. The Foraminifera and fragments of Echinoderms and other organisms in these muds are frequently filled with glauconitic substance, and beautiful casts of these organisms remain after treatment with weak acid. At times there are few calcareous organisms in these deposits, and at other times the remains of Diatoms and Radiolarians are abundant. When these muds are dried they become earthy and of a gray-green colour. They frequently give out a sulphuretted hydrogen odour. The green colour appears sometimes to be due to the presence of organic matter, probably of vegetable origin, and to the reduction of peroxide of iron to protoxide under its influence. The *green sands* differ from the muds only in the comparative absence of the argillaceous and other amorphous matter, and by the more important part played by the grains of glauconite, which chiefly give the green colour to these sands.

Red Muds.—In some localities, as for instance off the Brazilian coast of America, the deposits differ from blue muds by the large quantity of ochreous matter brought down by the rivers and deposited along the coast. The ferruginous particles when mixed up with the argillaceous matter give the whole deposit a reddish colour. These deposits, rich in iron in the state of limonite, do not appear to contain any traces of glauconite, and have relatively few remains of siliceous organisms.

Volcanic Muds and Sands.—The muds and sands around volcanic islands are black or gray; when dried they are rarely coherent. The mineral particles are generally fragmentary, and consist of lapilli of the basic and acid series of modern volcanic rocks, which are scoriaceous or compact, vitreous or crystalline, and usually present traces of alteration. The minerals are sometimes isolated, sometimes surrounded by their matrix, and consist principally of plagioclases, sanadin, amphibole, pyroxene, biotite, olivine, and magnetic iron; the size of the particles diminishes with distance from the shore, but the mean diameter is generally 0·5 mm. Glauconite does not appear to be present in these deposits, and quartz is also very rare or absent. The fragments of shells and rocks are frequently covered with a coating of peroxide of manganese. Shells of calcareous organisms are often present in great abundance, and render the deposit of a lighter colour. The remains of Diatoms and Radiolarians are usually present.

Coral Muds.—These muds frequently contain as much as 95 per cent. of carbonate of lime, which consists of fragments of Corals, calcareous Algæ, Foraminifera, Serpulæ, Mollusks, and remains of other lime-secreting organisms. There is a large amount of amorphous calcareous matter, which gives the deposit a sticky and chalky character. The particles may be of all sizes according to the distance from the reefs, the mean diameter being 1 to 2 mm., but occasionally there are large blocks of coral and large calcareous concretions; the particles are white and red. Remains of siliceous organisms seldom make up over 2 or 3 per cent. of a typical coral mud. The *residue* consists usually of a small amount of argillaceous matter, with a few fragments of feldspar and other volcanic minerals; but off barrier and fringing reefs facing continents we may have a great variety of rocks and minerals. Beyond a depth of 1000 fathoms off coral islands the debris of the reefs begins to diminish, and the remains of pelagic organisms to increase; the deposit becomes more argillaceous, of a reddish or rose colour, and gradually passes into a Globigerina ooze or red clay. *Coral Sands* contain much less amorphous matter than coral muds, but in other respects they are similar, the sands being usually found nearer the reefs and in shallower water than the muds, except inside lagoons. In some regions the remains of calcareous algæ predominate, and in these cases the name *coralline mud or sand* is employed to point out the distinction.

Such is a rapid view of the deposits found in the deeper waters of the littoral zones, where the debris from the neighbouring land plays the most important part in the formation of muds and sands.

When, however, we pass beyond a distance of about 200 miles from land, we find that the deposits are characterised by the great abundance of fragmentary volcanic materials which have usually undergone great alteration, and by the enormous abundance of the shells and skeletons of minute pelagic organisms which have fallen to the bottom from the surface waters. These true deep-sea deposits may be divided into those in which the organic elements predominate, and those in which the mineral constituents play the chief part. We shall commence with the former.

(*To be continued.*)

THE TWO MANNERS OF MOTION OF WATER[1]

IT has long been a matter of very general regret with those who are interested in natural philosophy that in spite of the most strenuous efforts of the ablest mathematicians the theory of fluid motion fits very ill with the actual behaviour of fluids, and this for unexplained reasons. The theory itself appears to be very tolerably complete, and affords the means of calculating the results to be expected in almost every case of fluid motion, but while in many cases the theoretical results agree with those actually obtained, in other cases they are altogether different.

If we take a small body, such as a raindrop, moving through the air, the theory gives us the true law of resistance; but if we take a large body, such as a ship moving through the water, the theoretical law of resistance is altogether out; and what is the most unsatisfactory part of the matter is that the theory affords no clue to the reason why it should apply to the one class more than to the other.

When seven years ago I had the honour of lecturing in this room on the then novel subject of vortex motion, I ventured to insist that the reason why such ill success had attended our theoretical efforts was because, owing to the uniform clearness or opacity of water and air, we can see nothing of the internal motion, and while exhibiting the phenomena of vortex rings in water, rendered strikingly apparent by partially colouring the water, but otherwise as strikingly invisible, I ventured to predict that the more general application of this method, which I may call the method of colour-bands, would reveal clues to those mysteries of fluid motion which had baffled philosophy.

To-night I venture to claim what is at all events a partial verification of that prediction. The fact that we can see as far into fluids as into solids naturally raises the question why the same success should not have been obtained in the case of the theory of fluids as in that of solids. The answer is plain enough. As a rule there is no internal motion in solid bodies, and hence our theory, based on the assumption of relative internal rest, applies to all cases. It is not, however, impossible that an at all events seemingly solid body should have internal motion, and a simple experiment will show that if a class of such bodies existed they would apparently have disobeyed the laws of motion.

These two wooden cubes are apparently just alike, each has a string tied to it. Now if a ball is suspended by a string you all know that it hangs vertically below the point of suspension, or swings like a pendulum; you see this one does so, the other you see behaves quite differently, turning up sideways. The effect is very striking so long as you do not know the cause. There is a heavy revolving wheel inside which makes it behave like a top.

Now what I wish you to see is that had such bodies been a work of Nature so that we could not see what was going on—if, for instance, apples were of this nature while pears were what they are, the laws of motion would not have been discovered, or if discovered for pears would not have applied to apples, and so would hardly have been thought satisfactory.

Such is the case with fluids. Here are two vessels of water which appear exactly similar, even more so than the solids, because you can see right through them, and there is nothing unreasonable in supposing that the same laws of motion would apply to both vessels. The application of the method of colour-bands, however, reveals a secret—the water of the one is at rest while that in the other is in a high state of agitation.

I am speaking of the two manners of motion of water—not because there are only two motions possible: looked at by their general appearance the motions of water are infinite in number; but what it is my object to make clear to-night is that all the various phenomena of moving water may be divided into two broadly distinct classes, not according to what with uniform fluids are their apparent motions, but according to what are the internal motions of the fluids which are invisible with clear fluids but which become visible with colour-bands.

The phenomena to be shown will, I hope, have some interest in themselves, but their intrinsic interest is as nothing compared to their philosophical interest. On this, however, I can but slightly touch. I have already pointed out that the problems of fluid motion may be divided into two classes, those in which the theoretical results agree with the experimental and those in which they are altogether different. Now what makes the recognition

[1] Lecture at the Royal Institution on Friday, March 28, by Prof. Osborne Reynolds, F.R.S.

of the two manners of internal motion of fluids so important is that all those problems to which the theory fits belong to the one class of internal motions. The point before us to-night is simple enough, and may be well expressed by analogy. Most of us have more or less familiarity with the motion of troops, and we can well understand that there exists a science of military tactics which treats of the best manœuvres to meet particular circumstances. Suppose this science proceeds on the assumption that the discipline of the troops is perfect, and hence takes no account of such moral effects as may be produced by the presence of an enemy. Such a theory would stand in the same relation to the movements of troops as that of hydrodynamics does to the movements of water. For although only disciplined motion may be recognised in military tactics, troops have another manner of motion when anything disturbs their order. And this is precisely how it is with water: it will move in a perfectly direct, disciplined manner under some circumstances, while under others it becomes a mass of eddies and cross streams, which may be well likened to a whirling struggling mob, where each individual element is obstructing the others. Nor does the analogy end here. The circumstances which determine whether the motion of troops shall be a march or a scramble are closely analogous to those which determine whether the motion of water shall be direct or sinuous. In both cases there is a certain influence necessary for order: with troops, it is discipline; with water, it is viscosity or treaclyness. The better the discipline of the troops, or the more treacly the fluid, the less likely is steady motion to be disturbed under any circumstances. On the other hand, speed and size are in both cases influences conducive to unsteadiness. The larger the army and the more rapid the evolutions the greater the chance of disorder; so with fluid, the larger the channel and the greater the velocity the more chance of eddies. With troops some evolutions are much more difficult to effect with steadiness than others, and some evolutions which would be perfectly safe on parade would be sheer madness in the presence of an enemy. It is much the same with water.

One of my chief objects in introducing this analogy is to illustrate the fact that even while executing manœuvres in a steady manner there may be a fundamental difference in the condition of the fluid. This is easily realised in the case of troops, difficult and easy manœuvres may be executed in equally steady manners if all goes well, but the conditions of the moving troops are essentially different, for while in the one case any slight disarrangement would be easily rectified, in the other it would inevitably lead to a scramble. The source of such a change in the manner of motion may be ascribed either to the delicacy of the manœuvre or to the upsetting disarrangement, but as a matter of fact both these causes are necessary. In the case of extreme delicacy an indefinitely small disturbance, such as is always to be counted upon, will effect the change. Under these circumstances we may well describe the condition of the troops in the simple manœuvre as stable, while that in the difficult manœuvre is unstable, *i.e.* will break down on the smallest disarrangement. The small disarrangement is the immediate cause of the breakdown in the same sense as the sound of a voice is sometimes the cause of an avalanche, but since such disarrangement is certain to occur a condition of instability is the real cause of the change.

All this is exactly true for the motion of water. Supposing no disarrangement, the water would move in the manner indicated in the theory, just as if there were no disturbance an egg would stand on its end, but as there is always some slight disturbance it is only when the condition of steady motion is more or less stable that it can exist. In addition then to the theories either of military tactics or of hydrodynamics, it is necessary to know under what circumstances the manœuvres of which they treat are stable or unstable. It is in definitely separating these that the method of colour-bands has done good service, which will remove the discredit in which the theory of hydrodynamics has been held.

In the first place it has shown that the property of viscosity or treaclyness possessed more or less by all fluids is the general influence conducive to steadiness, while, on the other hand, space and velocity have the counter influence. Also that the effect of these influences is subject to a perfectly definite law, which is that a particular evolution becomes unstable for a definite value of the viscosity divided by the product of the velocity and space. This law explains a vast number of phenomena which have hitherto appeared paradoxical. One general conclusion is that with sufficiently slow motion all manners of motion are stable.

The effect of viscosity is well shown by introducing a band of coloured water across a beaker filled with clear water at rest. Then, when all is quite still, turn the beaker about its axis. The glass turns, but not the water, except that which is quite close to the glass. The coloured water which is close to the glass is drawn out into what looks like a long smear, but it is not a smear. It is simply a colour-band extending from the point in which the colour touched the glass in a spiral manner inwards; showing that the viscosity is slowly communicating the motion of the glass to the water within. To show this it is only necessary to turn the beaker back, and the smear closes up until the colour-band assumes its radial position. Throughout this evolution the motion has been quite steady—quite according to the theory.

When water flows steadily, it flows in streams. Water flowing along a pipe is such a stream. This is bounded by the solid surface of the pipe, but if the water is flowing steadily we can imagine the water to be divided by ideal tubes into a faggot of indefinitely small streams, any one of which may be coloured without altering its motion, just as one column of infantry may be distinguished from another by colour.

If there is internal motion, it is clear that we cannot consider the whole stream bounded by the pipe as a faggot of elementary streams, as the water is continually crossing the pipe from one side to another, any more than we can distinguish the streaks of colour in a human stream in the corridor of a theatre.

Solid walls are not necessary to form a stream. The jets from a fountain or the cascade in Niagara are streams bounded by free surfaces. A river is a stream half bounded by a solid surface. Streams may be parallel, as in a pipe; converging or diverging, as in conical pipes; or they may be straight and curved. All these circumstances have their influence on stability in the manner indicated in the accompanying diagram.

Circumstances conducive to

Direct or Steady Motion	*Sinuous or Unsteady Motion*
(1) Viscosity or fluid friction which continually destroys disturbance. Thus treacle is steadier than water.	(5) Particular variation of velocity across the stream, as when a stream flows through still water.
(2) A free bounding surface.	(6) Solid bounding walls.
(3) Converging solid boundaries.	(7) Diverging solid bounding walls.
(4) Curvature of the streams with the velocity greatest on the outside.	(8) Curvature with the velocity greatest on the inside.

It has for a long time been noticed that a stream of fluid through fluid otherwise at rest is in an unstable condition. It is this instability which renders flames and jets sensitive to the slight disarrangement caused by sound.

I have here a glass vessel of clean water in front of the lantern, so that any colour-bands will be projected on to the screen. You see the ends of two vertical tubes facing each other: nothing is flowing through these tubes, and the water in the vessel is at rest. I now open two taps, so as to allow a steady stream of coloured water to enter at the lower pipe, water flowing out at the upper. The water enters quite steadily, forms a sort of vortex ring at the end, which proceeds across the vessel, and passes out at the lower pipe. The coloured stream then extends straight across the vessel, and fills both pipes: you see no motion; it looks like a red glass rod. The red water is, however, flowing slowly, so slowly that viscosity is paramount, and hence the stream is steady. As the speed is increased, a certain wriggling, sinuous motion appears in the column; a little faster and the column breaks up into beautiful and well-defined eddies, and spreads into the surrounding water, which, becoming opaque with colour, gradually draws a veil over the experiment. The final breaking up of the column was doubtless determined by some slight vibration in the apparatus, but such vibration, which is always going on, will not affect the stream until it is in a sufficiently unstable condition. The same is true of all streams bounded by standing water.

If the motion is sufficiently slow, according to the size of the stream and the viscosity, the stream is steady and stable. Then at a certain critical velocity, determined by the ratio of the viscosity of the water to the diameter of the stream, the stream becomes unstable. So that under any conditions which involve a stream through surrounding water, the motion becomes unstable at sufficiently great velocities.

Now one of the most noticeable facts in experimental hydrodynamics is the difference in the way in which water flows along contracting and expanding channels. Such channels are now projected on the screen, surrounded and filled with clean, still water. The mouth of the tube at which the water enters is wide; the tube then contracts for some way, then expands again gradually until it is as wide as at the mouth. At present nothing is to be seen of what is going on. On colouring one of the elementary streams, however, outside the mouth, a colour-band is formed. This colour-band is drawn in with the surrounding water, and shows what is going on. It enters quite steadily, preserving its clear streak-like character until it has reached the neck, where convergence ceases; then on entering the expanding channel it is altogether broken up into eddies. Thus the motion is direct and steady in the contracting tube, sinuous in the expanding.

The theory of hydrodynamics affords no clue to the cause of this difference, and even as seen by the method of colour-bands the reason for the sinuous motion is not obvious. If the current be started suddenly at the first instant, the motion is the same in both parts of the channel. Its changing in the expanding pipe seemed to imply that there the motion is unstable. If this were so, it ought to appear from the theory. I am ashamed to think of the time spent in trying to make this out from the theory without any result. I then had recourse to the method of colour again, and found that there is an intermediate stage.

When the tap is first opened, the immediately ensuing motion is nearly the same in both parts; but, while that in the contracting tube maintains its character, that in the expanding changes its character: a vortex ring is formed which, moving forwards, leaves the motion behind that of a parallel stream through the surrounding water. When the motion is sufficiently slow, the stream is stable, as already explained; there is then direct motion in both the contracting and expanding portions of the tube, but these are not similar, the first being a faggot of similar elementary contracting streams, the latter being that of one parallel stream through surrounding fluid. The first is a stable form, the second an unstable, and on increasing the velocity the first remains, while the second breaks down, and, as before, the expanding tube is filled with eddies. This experiment is typical of a large class of motions. Whenever fluid flows through a narrow neck, as it approaches the neck it is steady, after passing the neck it is sinuous. The same is produced by an obstacle in the middle of a stream, and virtually the same by the motion of a solid through the water.

The object projected on the screen is not unlike a ship. Here the ship is fixed and the water flowing past it, but the effect would be the same were the ship moving through the water. In the front of the ship the stream is steady, so long as it contracts, until it has passed the middle; you then see the eddies formed as the streams expand again round the stern. It is these eddies which account for the difference between the actual and theoretical resistance of ships.

It appears then that the motion in the expanding channel is sinuous, because the only steady motion is that of a stream through still water. Numerous cases in which the motion is sinuous may be explained in the same way, but not all. If we have a parallel channel, neither contracting or expanding, the steady moving streams will be a faggot of steady parallel elementary streams all in motion but having different velocities, those in the middle moving the fastest. Here we have a stream but not through standing water. When this investigation began, it was not known whether such a stream was ever steady; but there was a well-known anomaly in the resistance encountered in parallel channels. In rivers and all pipes of sensible size experience had shown that the resistance increased as the square of the velocity, whereas in very small pipes, such as represent the smaller veins in animals, Poiseuille had proved that the resistance increased as the velocity. Thus since the resistance would be as the square of the velocity with sinuous motion, and as the velocity in the case of direct motion, it appeared that the discrepancy would be accounted for if it could be shown that the motion becomes unstable at sufficiently large velocities according to the size of the pipe. This has been done. You see on the screen a pipe with its end open. It is surrounded by water, and by opening a tap I can draw the water through it. This makes no difference to the appearance until I colour one of the elementary streams, when you see a beautiful streak of colour extend all along the pipe. So far the stream has been running steadily, and it appears quite stable. As the speed increases the colour-band naturally becomes finer, but on reaching a certain speed the colour-band becomes unsteady and mixes with the surrounding fluid filling the pipe. This sinuous motion comes on at a definite velocity; diminish the velocity ever so little, the band becomes straight and clear, increase it again and it breaks up. This critical speed depends on the size of the tube in the exact inverse ratio, the smaller the tube the greater the velocity. Also the more viscous the fluid the greater the velocity.

We have here then not only a complete explanation of the difference in the laws of resistance generally experienced and that found by Poiseuille, but also we have complete evidence of the instability of steady streams flowing between solid surfaces. The cause of this instability is not yet completely ascertained, but this much is certain, that while lateral stiffness in the walls of the tube is unimportant, inextensibility or tangential rigidity is essential to the creation of eddies. I cannot show you this, because the only way in which we can produce the necessary condition is by wind blowing over the surface of water. When the wind blows over water it imparts motion to the surface of the water just as a moving solid surface. Moving in this way the water is not susceptible of eddies, it is unstable, but the result is waves. This is proved by a very old experiment, which has recently attracted considerable notice. If oil be put on the surface it spreads out into an indefinitely thin sheet with only one of the characteristics of a solid surface, it offers resistance, very slight, but still resistance to extension or contraction. This resistance, slight as it is, is sufficient to entirely alter the character of the motion. It renders the motion of the water unstable internally, and instead of waves what the wind does is to produce eddies beneath the surface. To those who have observed the phenomenon of oil preventing waves there is probably nothing more striking throughout the region of mechanics. A film of oil so thin that we have no means of illustrating its thickness, and which cannot be perceived except by its effects—which possesses no mechanical properties that can be made apparent to our senses—is yet able to prevent an action involving forces the strongest that we can conceive, able to upset our ships and destroy our coasts. This, however, becomes intelligible when we perceive that the action of the oil is not to calm the sea by sheer force, but merely, as by its moral force, to alter the manner of motion produced by the action of the wind from that of the terrible waves on the surface into the harmless eddies below. The wind brings the water into a highly unstable condition, into what morally we should call a condition of great excitement; the oil by an influence we cannot perceive directs this excitement. This influence, although insensibly small, is however now proved to be of a mechanical kind, and to me it seems that this instance of one of the most powerful mechanical actions of which the forces of Nature are capable being entirely controlled by a mechanical force so slight as to be imperceptible does away with every argument against strictly mechanical sources for what we may call mental and moral forces.

But to return to the instability in parallel channels. This has been the most complete as well as the most definite result of the method of colour-bands. The circumstances are such as render definite experiments possible; these have been made and reveal a definite law of instability, which law has been tested by reference to all the numerous and important experiments that have been recorded with reference to the law of resistance in pipes, whence it appears that the change in the variation of the resistance from the velocity to the square of the velocity agrees as regards the velocity at which it occurs with the change from stability to instability. It is thus shown that water behaves in exactly the same manner, whether the channel is, as in Poiseuille's experiments, of the size of a hair, or whether it be the size of a water main or of the Mississippi. The only difference being that in order that the motions may be compared the velocities must be inversely as the size of the channels. This is not the only point explained.

If we consider other fluids than water, some fluids like oil or treacle apparently flow more slowly and steadily than water; this however is only in smaller channels. The velocity at which sinuous motion commences increases with the viscosity. Thus while water in ordinary streams is always above its critical velocity and the motion sinuous, the motion of treacle in such streams as we see is below its critical velocity and the motion is steady. But if Nature had produced rivers of treacle the size of the Thames the treacle would have flowed as easily as water. Thus in the lava streams from a volcano, although looked at closely the lava has the consistency of a pudding, in the large and rapid streams down the mountain side the lava flows with eddies like water.

There is now only one experiment left. This relates to the effect of curvature in the streams on the stability of the motion. Here again we see the whole effect altered by apparently a very slight cause. If the water be flowing in a bent channel in steady streams, the question as to whether the motion will be stable or not turns on the variation of the velocity across the channel. In front of the lantern is a cylinder with glass ends, so that the light passes through in the direction of the axis. The cylinder is full of water, the disk of light on the screen being the light which passes through this water, and is bounded by the circular walls of the cylinder. By means of two tubes temporarily attached, a stream of colour is introduced so as to form a colour-band right across the cylinder, extending from wall to wall; the motion is very slow, and, the taps being closed and the tubes removed, the colour-band is practically stationary. The vessel is now caused to revolve about its axis. At first only the walls of the cylinder move, but the colour-band shows that the water gradually takes up the motion, the streak being wound off at the ends into two spiral lines, but otherwise remaining still and vertical; when the streak is all wound off and the spirals meet in the middle, the whole water is in motion. But as the vessel is revolving, the motion is greatest at the outside, and is thus stable. There are no eddies, although the spiral rings are so close as nearly to touch each other. The vessel stops, and gradually stops the water, beginning at the outside. If this went on steadily, the spirals would be unwound and the streak restored; but as the velocity is now greater towards the centre, the motion is unstable for some distance from the outside, and eddies form, breaking up the spirals for a certain distance towards the middle, but leaving the middle revolving steadily. Besides indicating the effect of curvature, this experiment neatly illustrates the action of the earth's surface on the air moving over it, the variation of temperature having much the same effect on the stability of the moving fluid as the curvature of the vessel. The moving air is unstable for a few thousand feet above the earth's surface, and the motion consequently sinuous to this height. The mixing of the lower and upper strata produces the heavy cumulus clouds, but above this the influence of the temperature predominates; the motion is stable, and clouds, if they form, are stratus, like the inner spirals of the colour-bands.

REPORT ON ATMOSPHERIC SAND-DUST FROM UNALASKA [1]

THE specimen of sand which fell during a rain-storm, October 20, 1883, at Unalaska, Alaska, has been submitted to microscopical analysis, and found to be undoubtedly of volcanic origin. It is gray, and the grains are rather uniform in size, rarely attaining a diameter of 0·35 mm. Under a hand lens can be distinguished light-coloured crystals and fragments which are occasionally glassy in lustre, mixed with others of darker colours; both are more or less dusty in appearance from the presence of finer particles. For convenience of manipulation and preservation, as well as to render the optical tests more definite and decisive, the sand was mounted in Canada balsam upon glass slides, after the manner of thin sections of rocks for microscopical investigations. It is composed chiefly of either broken or complete crystals of feldspar, augite, hornblende, and magnetite, with numerous fragments of ground-mass and a few small particles of glass freighted with grains of iron oxide or other heavy minerals. The feldspar frequently occurs in well-preserved crystals. Cleavage plates are common, but irregular fragments predominate. A few thin cleavage lamellæ parallel to the base between crossed nicols show no bending due to polysynthetical twinning, and extinction takes place when the lines which indicate the clinopinacoidal cleavage are parallel to the principal section of either nicol. While it is evident that such thin plates are orthoclase, the prevailing feldspar is undoubtedly basic plagioclase, for chemical analysis shows the sand to contain only 52·48 per cent. SiO_2. The perfect crystals are usually about 0·15 × 0·13 mm. in size, and slightly tabular, parallel to the clinopinacoid. At times they present an almost hexagonal aspect, and generally contain inclusions so abundantly as to render the middle portion feebly translucent. Among the imprisoned particles may be recognised hornblende microlites, grains of iron oxide with crystallites of an indeterminable nature, and their arrangement frequently imparts a distinct zonal structure to the feldspar. The hornblende, which is not nearly as prominent a constituent of the sand as the feldspar, occurs chiefly in cleavage plates and irregular angular fragments. It has a brown to dark brown colour, with deep absorption and strong pleochroism, as in the andesite which it characterises. The size of the hornblende fragments varies within small limits, averaging 0·10 × 0·05 mm., and the extinction angle is about 9°. It occasionally contains numerous crystallites arranged parallel to the vertical (c'') axis. In the number of slides examined several brownish foliæ, apparently of biotite, were observed under such circumstances that their characterising optical properties could not be satisfactorily determined. Of the FeMg silicates augite is the most abundant. It is of a pale green colour, non-pleochroitic, and its angle of extinction as seen in the cleavage plates is about 46°. Like hornblende, it is found generally in irregular fragments. The prismatic fragments vary from 0·10 to 0·35 mm. in greatest length. The grains of magnetite, which may, in considerable quantities, be readily picked out of the sand with a magnet, are for the most part of irregular outline and small size. Instead of forming independent grains of themselves, they are generally found cleaving to fragments of the ground-mass, or included in the other minerals.

Besides the mineral ingredients already mentioned, the sand contains numerous irregular grains swarming with clear crystallites and microlites embedded in a grayish translucent to transparent, often amorphous, base. These composite fragments correspond to the ground-mass of the eruptive rocks to which the volcanic sand is allied. They vary in size up to a diameter of 0·26 mm., and are generally rendered heavier than they would otherwise be by small particles of magnetite or augite. The crystal fragments frequently have portions of the ground-mass attached to them, and present that ragged appearance which distinguishes volcanic sand from that which has been produced by other methods. Feldspar, augite, hornblende, magnetite, with fragments of the ground-mass, make up the bulk of the sand. Its composition is that of a hornblende-andesite very like those which occur at many points along the western coast. One is surprised to find a conspicuous deficiency in the most common and generally prevailing element of volcanic ashes. It is true that clear or sparingly microlitic glass particles are found in the sand from Unalaska, but they are rather exceptional and uncommon. This paucity in glass fragments may be readily comprehended by reflecting upon the origin and distribution of volcanic ashes.

The United States Geological Survey party sent out last summer in my charge under the direction of Capt. Dutton for the reconnaissance of the southern portions of the Cascade Range, collected a lot of volcanic sand about a dozen miles north-east of Mount Shasta. It does not form a thick deposit, but is widespread over the basaltic slopes south of Sheep Rock, and like that collected at Unalaska consists chiefly of crystal fragments, of which feldspar is the most abundant. Hornblende, hypersthene, augite, and magnetite are less prominent. In addition to these and numerous fragments of microlitic ground-mass, there are many clear or sparingly crystallitic glass particles of a pumiceous character. The composition of the sand is that of a hypersthene-bearing hornblende-andesite like that which forms the well-preserved and prominent crater springing up from the north-western slope of Mount Shasta, about two miles from that summit. This crater is the counterpart of Shasta cone, when we consider the whole volcanic pile, and has been christened Shastina by Capt. Dutton to indicate the relation it bears to its majestic neighbour. In the volcanic sand which travelled about a dozen miles north-east from Shastina, grains may be found having a diameter of 0·5 mm., so that it is, on the whole, considerably coarser and less uniform than that which fell at Unalaska, October 20, 1883, but like the latter it is made up chiefly of fragments of crystalline matter.

On the other hand, volcanic dust which has been carried long distances is composed principally of glass particles, and there is a conspicuous paucity of crystals and fragments of dense microlitic ground-mass. That which emanated from a crater in Iceland and fell over Norway and Sweden March 29 and 30, 1875, more than 750 miles from its source, is composed almost exclusively of sharp-edged angular glass fragments with curved sides. These splinters, chips, and shards of glass show by their more or less curved outlines, as well as by their tubular or vesicular structure, that they differ from pumice only in being fragmental. In the formation of pumice the inflation and distension by inclosed steam and gases is carried so far as to produce a froth, but if the same process be continued until explosion takes place,

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