Yet even then will our successors, I trust, as we now do, stand reverently before the memory of our Founders. In their very lineaments, of which, as portrayed by the master hand of Raeburn, we saw many not far from this spot a few years ago, the vigour and originality of the men are written in characters not to be mistaken. Happy is the institution which can show such a muster-roll, and happy the country which can boast such sons. I take leave of my theme with the fervent hope and firm conviction that, in the century which we now inaugurate, the Royal Society will continue with like success the noble task to which by its Charter it is devoted, of investigating the hidden treasures of nature, and appropriating them to the benefit and happiness of mankind.

On the motion of the Hon. Lord M'Laren, a vote of thanks was accorded to the President for his address.

The following Communications were read:—

2. On the Microscopic Characters of Volcanic Ashes and Cosmic Dust, and their Distribution in the Deep Sea Deposits. By Mr John Murray and Mons. A. Renard. Communicated by Mr John Murray.

In the Session of 1876, Mr John Murray communicated to this Society a paper on the distribution of volcanic débris over the floor of the ocean,* and in it announced the discovery of cosmic dust in deep sea deposits. It was shown that at points, where neither the action of waves, rivers, or currents can transport the débris of continents, volcanic materials play the most important rôle in the formation of the mineral constituents of the deep sea deposits. It was pointed out that pumice, on account of its structure, was able to float to great distances, but in time became waterlogged and sank to the bottom, there to decompose. On the other hand, incoherent volcanic matters, ejected in the form of lapilli, sand, and ashes, into the higher regions of the atmosphere, may, *ceteris paribus*, be conveyed, in consequence of their small dimensions and structure, to greater distances than other mineral particles derived from the continents. The possibility was also admitted that submarine volcanic eruptions might also contribute to the accumulation of

* *Proc. Roy. Soc. Edin.*, 1876–77.

those silicates and pyrogenous minerals and rocks, whose microscopic characters and distribution at the bottom of the sea we shall presently point out.

During the past few years we have added greatly to the observations which were the subject of Mr Murray's communication. The present paper has been suggested by the striking analogy which exists between the volcanic products we have found in all deep sea sediments and the ashes and incoherent products of a recent celebrated eruption,—that of Krakatoa. The remarkable meteorological phenomena we have recently witnessed have been attributed by some to the presence in the atmosphere of mineral particles derived from this volcanic eruption, and by others to that of cosmic dust. It is said that in several places in America, and even in Europe, matters have been collected which must be regarded as the ashes from Krakatoa, which have been suspended for several months in the upper currents of the atmosphere. The importance of this matter has been recognised by the Royal Society of London, which has appointed a committee of its members to collect all the documents and observations relative to the distribution of these ashes. The present state of the question induces us to make known some results of the detailed researches which we have undertaken upon similar subjects. We desire to make known to those who wish to study atmospheric dust, the distinctive microscopic characters by the aid of which we have been able to establish the volcanic or cosmic nature of certain particles found in deep sea deposits, and to show at the same time the enormous area of the ocean over which we have been able to detect their distribution.

We believe that no better example could be found in support of our interpretations than the microscopic study of the ashes from Krakatoa, whose mineralogical and chemical composition M. Renard * was the first to make known, and whose observations on this subject have been amply confirmed by the later researches of other mineralogists. On the other hand, the conditions under which floating pumice was found after that eruption agree perfectly with the interpretation given eight years ago by Mr Murray, relative to the mode of transport of these vitreous matters, and of the accumulation of their triturated débris on the bottom of the ocean. We shall also

* "Les cendres volcaniques de l'éruption du Krakatau" (*Bull. Acad. Roy. de Belgique*, sér. 3, t. vi. No. 11 Séance du 3 Nov. 1883).

see how the sorting which takes place in the transport of the ashes of a volcano has its analogy in what we find in the deep sea deposits.

In the First Part of this communication we shall give the mineralogical description of the fragmentary products of Krakatoa, and consider generally the observations relative to these ashes. We shall also give the diagnostic characters of this volcanic dust, and of all similar particles which we find in deep sea deposits. In the Second Part, we will treat of the cosmic matters found in the abysmal regions of the ocean, to which Mr Murray was the first to draw attention, and discuss their origin and distribution.

First Part.

It is unnecessary to refer to the abundance of floating pumice, to its various degrees of alteration, to its conveyance by means of rivers, waves, and currents, and to its universal presence in deep sea deposits, which have been pointed out in some detail in Mr Murray's paper above referred to; but we will briefly recapitulate the characters of these volcanic matters, in accordance with the examination we have made of a large number of soundings and dredgings. We need not describe in detail the special characters of the lapilli which have been brought up in the dredge and sounding-rod from great depths. These fragments of more or less scoriaceous rocks belong to the same lithological varieties as those derived from terrestrial volcanoes. They consist of fragments of trachyte of various dimensions, of basalt, and, above all, of augite-andesite; the most remarkable, beyond all question, being lapilli of sideromelan, which are often entirely transformed into palagonite, and pass into the clay which is found so widely distributed, especially in the Pacific.

We do not propose here to take up in detail the wide distribution of the materials ejected from Krakatoa; we are engaged in collecting these, and will place the observations on maps along with those of Mr Buchan on the upper currents of the atmosphere, which will be published in the "Challenger" Reports.

Before, however, passing to the description of the ashes themselves we will briefly refer to some points touched upon by Mr Murray in his paper. It is there pointed out that, in regions far removed from coasts, rounded fragments of pumice were collected on the surface of the sea by means of the tow-net, and that, at certain points on the bottom of the ocean, the greater part of the deposit is composed of vitreous splinters derived from the trituration of pumice stones. The description of the phenomena connected with the Krakatoa eruption gives us a complete explanation of these observations. The specimens of pumice from Krakatoa, which have been collected floating on the sea and which we have examined, are in like manner rounded. The angular surfaces are all worn away just as in pebbles; the only asperities to be observed consist of crystals and fragments of crystals, which project beyond the general surface of the vitreous matter, which last, on account of its structure, presents less resistance to wear and tear than the minerals which are embedded in it.

We may recall the fact that the Bay of Lampoung, in the Straits of Sunda, was blocked by the vast accumulation of pumice, formed in a few hours by the eruption of Krakatoa, which completely filled the bay. This floating bar of pumice stones was about 30 kilometres long, 1 kilometre broad, and 3 to 4 metres in depth, 2 or 3 metres of which were below the surface of the water, and 1 metre above. These numbers give about 150 millions of cubic metres of ejected matter. This moving elastic wall rose and fell with the waves and tide,* and was carried by currents thousands of miles from the point of eruption over the surface of the ocean. The rounded form of blocks of pumice met with everywhere floating on the surface of the sea, as well as of those samples which, after having floated some time, became waterlogged and sank to the bottom, may be perfectly explained if we remember the friability of this rock, and, at the same time, the agitation to which it is submitted by the waves, through which the pieces are continually being knocked against each other. We understand also how this wear and tear gives rise to an immense quantity of pulverulent pumice fragments, which contribute in a great measure to the formation of oceanic deposits. As a matter of fact, rounded fragments of pumice have been met with floating on the surface of every ocean, and during the last few years many samples have been sent to us by captains of ships and missionaries. As has been already pointed out, they are universally distributed in oceanic deposits, although frequently highly altered.

If it be easy to pronounce upon the volcanic nature of these larger fragments, it becomes, on the other hand, exceedingly difficult when we have to deal with particles reduced to powder, and when

* *Comptes rendus de l'Académie des Sciences*, 19 Nov. 1883, p. 1101.

recourse must be had to the microscope. Let us see what are the microscopic characters by which we recognise the particles of this dust.

We may here point out that it is not so much the presence of volcanic minerals which enables us in a marine sediment, as well as in an atmospheric dust like the ashes of Krakatoa, to recognise that the small fragments have an eruptive origin, as the microscopic structure of the small vitreous particles. It is well known that minerals reduced to small dimensions and irregularly fractured, as in the case of volcanic ashes, often lose their distinctive characters. Their size does not allow us to judge of their optical properties; their form, irregular and fragmentary, renders it difficult to determine the characteristic extinction of the species; the phenomena of coloration, of pleochroism, and the tint peculiar to the mineral, all lose so much of their intensity, that they no longer serve for the identification of isolated minerals like those of the volcanic ashes which we have to study. As a result of our observations, we believe that in most cases where a mineral, under the conditions we have just described, reaches dimensions less than 0·05 mm., its determination with certainty is no longer possible, and consequently its origin can no longer be established; whilst a vitreous fragment, like those of volcanic ashes or triturated pumice, continues to be discernible when its dimensions are less than 0·005 mm. A reason for showing that the absence or rarity of crystals, or of fragments of volcanic crystals, ought not to be taken as a proof that a sedimentary matter, either from the atmosphere or from the deep sea, is not of volcanic origin, is the sorting process to which these matters are subjected in the air and in the water, a phenomenon to which we shall presently recur.

The most reliable distinctive character is always found in the structure of the small vitreous particles which are derived from the trituration of pumice or have an analogous origin, inasmuch as they have been ejected from the volcano in the state of ash. The structure peculiar to these materials is seen in their fracture, which leaves its impress upon the smallest fragments of débris, in which the microscope can decipher no characteristic properties except such as have relation to form. In order to assure ourselves that these characters of pumice remain constant to the extreme limits of pulverisation, such as are employed in the preparation of silicates for chemical analysis, we pounded in an agate mortar several varieties of pumice, and the powder thus produced clearly showed itself to be composed of particles in which were recognisable, with little trouble, the characters of the pumice-like material which is constantly met with in the sediments, and of which the ashes of Krakatoa give us beautiful examples. The diagnostic character to which we here make allusion rests on the distinctive peculiarities of incoherent volcanic products. What distinguishes them from lavas is not merely the extraordinary abundance of vitreous matters, but also the prodigious number of gas-bubbles which are enclosed by the pumice and vitreous volcanic sands and ashes. These bubbles are due to the expansion of the gases dissolved in the magma, which also determine the eruption. If we admit, as everything seems to show, that these incoherent volcanic matters are the products of the pulverisation of a fluid magma, we can understand that these particles, on cooling rapidly, will remain in the vitreous state, and, on the other hand, that the dissolved gases, yielding to the expansion, will form numerous pores which will become elongated owing to the mode of projection. It is the existence of these bubbles, or of such a filamentous structure, which points out to us the vitreous volcanic materials in spite of the great fineness of subdivision. It is also this structure which allows these bodies to be carried to such great distances from the scene of eruption.

The examination of the Krakatoa ashes, and of the dust resulting from the pulverisation of the pumice of that volcano, shows markedly the peculiarity due to the bullous structure. If this grey-green pulverulent matter be placed under the microscope it is seen to be composed of almost impalpable grains, with a mean diameter of 0·1 mm., which are almost exclusively colourless or brownish vitreous particles permeated by bubbles. The bubbles are rarely globular, but often elongated, as we have just pointed out, and they give a drawn-out appearance to the fragments. As often happens, several bubbles are elongated parallel to each other, and in this case, the pore becomes a simple streak; the fragment then assumes a fibrous texture, which may cause it to resemble at first sight a striated felspar or an organic remnant; but an examination of the outline will never allow of this confusion. If we examine the terminal contours and lines of these bubble-containing fragments, we never find that they are straight lines, but that they show a ragged appearance, all the sinuosities being curvilinear. This mode of fracture is in correspondence with the vacuolated structure, and, just as in the porous pumice, the vitreous volcanic ashes are permeated by vacuoles; besides, everything goes to show that the fragmentary condition and the fresh fractures are due to a tension phenomenon which affects these vitreous matters in a manner analogous to what is observed in the "Rupert's drops."

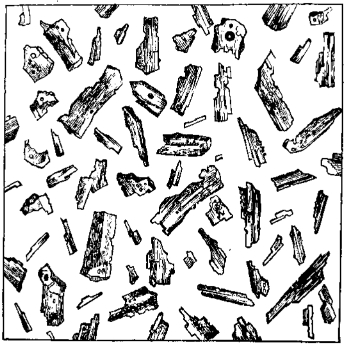

FIG. 1.—Vitreous particles of the Ashes of Krakatoa, which fell at Batavia, 27th August 1883 ($\frac{1}{250}$).

We have pointed out that brown vitreous fragments are rare in the ashes of Krakatoa. These, however, contain skeletons of magnetic iron, and are devitrified by microliths.* It is scarcely necessary to add that the particles, whose form we have indicated, are isotropic. If under crossed nicols we sometimes see the field illuminated, this is due to crystals in the vitreous matter, or to phenomena of tension, which are sometimes observed in the neighbourhood of the bubbles.

These details on the microstructure of the vitreous particles from Krakatoa can be applied with most perfect exactitude to the volcanic dusts, which we have determined as such, in the deep sea deposits. In virtue of their bulbous structure, their dimensions, and their mode of projection, they are capable of being widely transported from the point of eruption by aerial currents. It must be admitted,

* Just as we can divide pumice microscopically according as it is acid or basic, so the products of its trituration may be recognised under the microscope, inasmuch as the former often give colourless and more elongated particles, while the fragments of basic pumice have a more pronounced tint and more rounded pores.

however, that in the deep sea sediments a very large part of these vitreous splinters has not been derived from the pulverised ejections from a volcano, but from the trituration of floating pumice, of which we have given above a striking example. It will be understood that it is scarcely possible to trace the difference between volcanic ashes, properly so called, and the products resulting from the pulverisation of floating pumice which we have just indicated. As in the incoherent products of Krakatoa, so we find spread out on the bottom of the sea many more vitreous particles, similar to those we have just described, than of true volcanic minerals. This is easily explained, however, when we remember how the distribution of volcanic dust takes place.

Let us now point out the minerals which can be determined with certainty in the ashes of this great eruption; and we may at once remark that they are the same which we have almost always found associated in the deposits with the splinters of glass. In general all the crystals are fractured, except those which are still embedded in a vitreous layer; this vitreous coating is often crackled and bullous. In the ashes of Krakatoa, however, we have not remarked the globules of glass which are often described as glued to the minerals of volcanic ashes, nor have we seen the drawn-out vitreous filaments resembling Peles hair. The minerals of the Krakatoa ashes which are susceptible of a rigorous determination belong to plagioclase, augite, rhombic pyroxene, and magnetite.* We shall presently see the peculiarity which distinguishes each of these species in the ashes.

Among the most frequent minerals, but poorly represented in comparison with the vitreous matter, plagioclase felspar comes first. This mineral has about the same dimensions as the vitreous fragments, and, with the exception of the crystals entirely enclosed in the pumice matter, is in the form of débris. Sometimes twins on the albite plan can be distinguished, and the results of analysis clearly indicate that it is triclinic felspar which should almost exclusively be found in this ash. But the most interesting crystals of plagio-

* Lately the works on these same ashes have made known as accidental elements pyrites, apatite, and perhaps biotite (?). It is to be remarked, however, that these minerals must be extremely rare in comparison with the vitreous matters and mineral species above-mentioned.

clase, and the most characteristic of this ash, although represented very rarely, are in the form of rhombic tables, extremely thin, and covered with a fine lacework of vitreous matter. We know that the crystals described by Penck * in a great number of lapilli and of volcanic ashes, upon the nature of which doubts have been expressed, belong incontestibly to the plagioclases, and represent an isomorphic mixture analagous to that of bytownite. It is to Mr Max Schuster † that we owe this specific determination. Having found in numerous sediments of the Pacific these same crystals in the form of rhombic tables, and possessing preparations which would be of great interest to him in his remarkable optical studies on the felspars, we submitted them to this ingenious mineralogist in order to confirm our determination. We believe it will be interesting to give a resumé here of the results of the observations of Mr Schuster, which are perfectly applicable to the characteristic crystals of felspar from Krakatoa, as well as to those which we have discovered in a great number of deep sea soundings.

This plagioclase occurs for the most part in flat tabular crystals with the clinopinakoid especially developed. Individuals of the columnar type, elongated in the direction of the edge P/M, are rare. These tabular crystals consist essentially of a combination of the clinopinakoid with P and x, more rarely with P, u, and y, and occasionally x and y appear together. In the first case the crystals have the form of a rhomb, in the second case they are elongated through the predominance of either x or P. The dimensions of those crystals which were examined and measured, lie between the line 0·61 mm. broad and 1 mm. long as maximum, and 0·015 mm. broad and 0·042 mm. long as minimum. The extinction of the plagioclase is negative. Its value was found to vary between 22° and 32° on the clinopinakoid, and between 8° and 16° on the basal plane. The average values of many measurements made on good crystals are as follows:—24° 12′, 25° 6′, and 29° 6′ on the clinopinakoid, 10° 42′ on the one side, and 10° 18′ on the other side of the twinning line, as this is shown on the basal plane.

* Penck, "Studien über lockere vulkanische Auswürflinge," *Zeitschr. d. deutsch. geol. Gesellsch.*, 1878.

† Schuster, "Bemerkungen zu E. Mallard's Abhandlung sur l'isomorphisme des feldspaths tricliniques, &c.," *Min. petr. Mitth.*, v. 1882, p. 194.

Polysynthetic individuals, made up of repeated twins on the albite plan, were very rarely observed. The felspar in its optical properties is thus seen to lie between labradorite and bytownite. The twin growths are particularly frequent and interesting on account of the structure of the individuals. In addition to those of the albite type, others were observed in which the edges P/M and P/K could be definitely determined as the axes of twinning, whilst P and K formed the twinning planes. The plane of composition was principally either P or M when penetration twins were not observed.

These fragments and crystals of plagioclase contain inclusions of vitreous matter, and sometimes grains of magnetite. Perhaps a small number of felspathic grains may belong to sanidine, the presence of which is insinuated by the percentage of potass indicated by the analysis which follow ($K_2O = 0{\cdot}97$ per cent.).

We have said that the pyroxenic minerals of the ash are augite and a rhombic pyroxene; we distinguish them by the microscope sometimes in the form of fragments—and this is usually the case—sometimes in the form of crystals, which we can isolate from the volcanic glass covering them by treating them with hydrofluoric acid. In the crystals of augite we distinguish the faces of a prism, of the brachypinakoid, and indications of the faces of a pyramid. This augite is pleochroic and has a greenish tint, and extinguishes in certain cases obliquely to the prismatic edges. It is this character which often permits it to be distinguished from rhombic pyroxene with which the augite is associated. The crystals of hypersthene are transparent, of a deep brown colour, strongly dichroic, with green and brown tints. They are in rectangular prisms terminated by a pyramid, and extinguish between crossed nicols parallel to their longitudinal edges. Magnetic iron, which is rather abundant in the ashes, is recognised in the form of grains and octahedrons. We have not been able to detect with certainty either hornblende or olivine. The largest grains of this ash are true microscopic lapilli, where we distinguish in a vitreous mass microlithic crystals of felspar, of magnetite, and more rarely of pyroxene. Finally, we observe with the microscope particles of an organic origin, which are easily recognisable by their fibrous and reticulated structure. These impurities may have been transported by winds, or may have come from the ground where the ashes were collected.

In spite of all the uncertainties which the exact diagnoses of volcanic dust present, we can consider them often, from the point of view of their mineralogical composition, as analogous with the augite-andesites. We know, besides, that it is to these rocks that the lavas of the volcano of Krakatoa should be referred.

The ashes which fell at Batavia on the 27th August 1883, and samples of which were sent to Holland by M. Wolf, resident on that island, have been analysed with the following results:—

I. 1·119 grm. of substance dried at 110° C., and fused with carbonate of soda and potash, gave 0·7799 grm. of silica, 0·1754 grm. of alumina, 0·0911 grm. of peroxide of iron, 0·0401 grm. of lime, 0·398 grm. of pyrophosphate of magnesia, answering to 0·01434 grm. of magnesia.*

II. 1·222 grm. of substance dried at 110° C. gave 0·0335 grm. of loss on ignition (water, organic substances, chloride of sodium); the same substance treated with hydrofluoric and sulphuric acids gave 0·1161 grm. of chloride of sodium and potassium, and 0·0118 grm. of chloroplatinate of potassium, answering to 0·0118 grm. of potash and to 0·0188 grm. of chloride of potassium; by difference = 0·0973 grm. of chloride of sodium, answering to 0·05163 of soda.

III. 1·7287 grm. of substance dried at 110° C. was treated in a closed tube with hydrofluoric and sulphuric acid. The oxidation required 2·3 c.c. of permanganate of potash (1 c.c. = 0·0212 grm. FeO), answering to 0·047876 grm. of peroxide of iron.

	I.	II.	III.	
SiO_2	65·04	...	...	65·04
Al_2O_3	14·63	...	...	14·63
Fe_2O_3	4·47	...	...	4·47
FeO	...	...	2·82	2·82
MnO	traces	...	...	traces
MgO	1·20	...	...	1·20
CaO	3·34	...	...	3·34
K_2O	...	0·97	...	0·97
Na_2O	...	4·23	...	4·23
Loss	...	2·74	...	2·74
				99·44

It will be understood that it is barely possible to submit this analysis to discussion. The abundance of vitreous particles in the ashes renders illusory the calculation of the values obtained, and

* A recent determination of titanic acid has given 0·62 per cent. TiO_2.

the distribution of the substances among the different species of constituent minerals. This vitreous matter can indeed contain an indeterminate quantity of the different bases. On the other hand, the difficulties of the calculation are all the greater, as the constituent minerals of the ashes may contain, as isomorphs, the bases which the analysis suggests. It is none the less true, however, that the percentage composition expressed by the analysis supports the preceding mineralogical determinations, without permitting the species to be precisely determined. It agrees with the interpretation that the magma from which the ashes were formed belongs to the augite-andesites.

The vitreous and mineral fragments we have just described from the Krakatoa eruption being identical with those which we encounter in deep sea sediments, we may conclude that both have a similar origin. In certain cases, however, we have in place of augite a predominance of hornblende, and sometimes black mica is abundant. Again, we find more or less fragmentary crystals of peridote, of magnetite, of sanidine, and, more rarely, of leucite and of hauÿne. We can easily understand this variation in composition, following the nature of the magma from which the ashes collected in different regions of the sea were derived. But in all cases it is the predominance of vitreous particles, with their special structure, which indicates most clearly the volcanic nature of the inorganic constituents of a sediment.

If now we consider the conditions which govern the distribution of ashes in the atmosphere or at the bottom of the sea, we shall be able to show how it is that there is generally a predominance of vitreous particles in these ashes. In the first place, these are vitreous matters rather than minerals, properly so called, from the moment of ejection from the crater. Moreover, we should, in a general way, not expect to find that incoherent eruptive matters, which are spread out at a distance from the volcano, present a perfectly identical composition with those other loose products such as lapilli, volcanic bombs, and scoriæ, which are projected only a short distance from the focus of eruption. Even where there exists a perfect chemical and mineralogical identity, in the crater itself, between the lavas and the pulverulent materials of the same eruption (the supposition being that the ashes arise simply from the trituration of the lavas), we can easily understand that these latter, being carried far and wide by the winds, must undergo a true sorting in their passage through the atmosphere, according to the specific gravity of the amorphous elements or crystalline constituents. It results from this, that according to the points where they are collected, volcanic ashes may, although belonging to the same eruption, present differences not only with respect to the size of the grains, but also with respect to the minerals.

In this method of transport it is evident that the vitreous particles, other things being equal, will be transported farthest from the centre. In the first place they are more abundant than the other particles, and again they possess in their chemical nature and in their structure, conditions which permit the aerial currents to take them up and carry them to great distances; they consist of a silicate in which the heavy bases are poorly represented as compared with the other constituent elements; they are filled with gaseous bubbles which lower their specific gravity, and at the same time are capable of being broken up into the minutest particles. The minerals with which they are associated at the moment of ejection from the crater are not, like them, filled with gaseous bubbles; they do not break up so easily into impalpable powder, for they are not porous, and are not in the same state of tension as the rapidly-cooled vitreous dust. Finally, many of these species are precisely those whose specific gravity is very high, on account of the bases entering into their composition. These minerals will not then be carried so far from the centre of eruption, and in all cases the vitreous particles are the essential ones in the atmospheric dusts derived from volcanic ashes.

We have a beautiful illustration of this in the ashes of Krakatoa. In proportion as the ashes are collected at a greater distance from a volcano, so are they less rich in minerals, and the quantity of vitreous matter predominates. According to a verbal communication from Professor Judd, the ashes collected at Japan contain only a relatively small proportion of pyroxene and magnetite.

If we wish to assure ourselves of the nature of an atmospheric dust, and, as has lately been frequently attempted in Europe, to show that the dust is really from the Krakatoa eruption, it is important above all to seek for the presence of vitreous fragments. The characters which we have indicated permit any one to recognise them easily under the microscope. We would remark, however, that the presence of crystals, either of hypersthene, of augite, or of particles of magnetite in an atmospheric dust collected in Europe, does not prove in a certain manner that the dust belongs to the ashes from Krakatoa; for besides the difficulties of an exact mineralogical determination of the fragmentary elements, it is difficult to understand how these heavy minerals should have been carried by the aerial currents, while the vitreous dust is absent. As we have just shown, it is the contrary which should have taken place.

It results as a corollary from these considerations that the chemical composition of an ash may vary according to the point at which it has been collected, and it tends also, other things being equal, to become more acid the further it is removed from the centre of eruption. If we admit, for example, that the magma which gave birth to the ashes of Krakatoa is an augite-andesite, as everything seems to indicate, the percentage of silica (65 per cent.) which our analysis shows appears too high, but if we remember, what we have just said, that the ashes become deprived, during their passage through the atmosphere, of the heavier and more basic elements, it will be understood that the vitreous and felspathic materials, which have a lower specific gravity, and are, at the same time, more acid, will accumulate at points farthest from the volcano. It will be sufficient to have directed the attention to this fact to show how the percentage of silica in the ashes from the same eruption may vary according as they are collected at a variable distance from the crater.

The predominance of vitreous splinters in deep sea sediments far removed from coasts is even more pronounced than in volcanic ashes collected on land. This arises, as we indicated at the commencement, from the large quantity of pumice carried or projected into the ocean, whose trituration, which takes place so easily, gives origin to vitreous fragments difficult to distinguish from those projected from a volcano in the form of impalpable dust. In addition, we may state that in the distribution of volcanic materials on the bottom of the sea, the ashes are subjected to a mode of sorting having some analogy to that which takes place during transport through the atmosphere. When these ashes fall into the sea a separation takes place in the water; the heaviest particles reach the bottom first, and then the lighter and smaller ones, descending more slowly, are deposited upon the larger and heavier fragments and crystals from the same eruption. We have a fine example of this stratification of submarine tufa in the centre of the South Pacific, lat. 22° 21′ S., long. 150° 17′ W. This specimen is entirely covered with peroxide of manganese, and at the base of the fragment we see the large crystals of hornblende and particles of magnetite. This lower layer is covered by a deposit in which these minerals and coarser grains are observed to pass gradually into a layer composed of small crystals of felspar, débris of pumice, and more or less fine material.

We do not propose to occupy ourselves here with the mode of formation of volcanic ashes, and with those of Krakatoa in particular. It will suffice to indicate that in the dust of a volcano we find all the characters supporting the interpretation which regards volcanic ashes as formed by the pulverisation of an igneous fluid mass in which float crystals already formed, and from which, when projected by gases, the pulverised vitreous particles undergo a rapid cooling and decrepitation during their passage through the atmosphere. It is not only the microscopic examination of these volcanic matters that leads us to this conclusion, but the prodigious quantity of ashes formed during the eruption of this volcano, which do not agree with the interpretation that regards these ashes as the result of a pulverisation of a rock already solidified in the crater. Indeed one cannot understand how, in two or three days, the immense quantity of ashes ejected from Krakatoa could be formed by this process, as, for instance, on the 26th August 1883 and in the May eruption, which was the prelude to that catastrophe.

Second Part.

The recent brilliant sunsets have been attributed to the presence in the atmosphere of minute particles of an extra-terrestrial origin, as well as to volcanic dust. This induces us to conclude this brief abstract of our observations by a description of the cosmic particles which we have found, along with volcanic ashes and pumice, in those regions of the deep sea far from land, where the sediment accumulates with extreme slowness.

In another memoir * we have pointed out the distribution of these particles on the floor of the ocean, and indicated the conclusions which we believe are justified by their relative abundance in the red clay areas of the Central Pacific.

It is known that the atmosphere holds in suspension an immense number of microscopic particles which are of organic and inorganic origin, and are either dust taken up by aerial currents from the ground or are extra-terrestrial bodies. A large number of scientific men, headed by Ehrenberg, Daubrée, Reichenbach, Nordenskiold, and Tissandier, have studied this interesting problem, and have brought forward many facts in support of the cosmic origin of some of the metallic particles found in atmospheric precipitations. It is certain that serious objections may be raised against the origin of a large number of so-called cosmic dusts.

In a great many cases it can be shown that these dusts are composed of the same minerals as the terrestrial rocks which are to be met with at short distances from the spot where the dust has been collected, and we can attribute a cosmic origin only to the metallic iron in these dusts. It is somewhat astonishing, however, that no trace is ever found in these dusts of meteoric silicates, although in a great many meteorites it might be said that the iron is only accidentally present, while the silicates predominate. On the other hand, having regard to the mineralogical composition of meteorites, it appears strange that the so-called cosmic dusts should present characters so variable, from the point of view of their mineralogical composition, in the different regions where they have been collected. It might also be objected that even the iron, nickel, and cobalt could come from volcanic rocks in decomposition in which these bodies are sometimes present, and this objection would seem quite natural, especially in our particular case, when we remember the numerous volcanic fragments in decomposition on the bottom of the sea. Again, according to numerous researches, native iron is found, although rarely, in various rocks and sedimentary layers of the globe. A reduction of the oxide of iron into metal might also be admitted under the influence of organic substances. It might still further be objected in opposition to the cosmic origin of the fine particles of native iron that they might be carried by aerial currents

* *Proc. Roy. Soc. Edin.*

from our furnaces, locomotives, the ashes of our grates, and in the case of the ocean, from steamers. All our materials of combustion furnish considerable quantities of iron dust, and it would not be astonishing to find that this, after having been transported by the winds, should again fall on the surface of the earth at great distances from its source.

Such are the objections which present themselves when it is proposed to pronounce upon the origin of particles which we are inclined to regard as cosmic, and of which we propose here to give a short description. We shall see that many of these doubts are at once removed by a statement of the circumstances under which cosmic spherules are found in deep sea deposits, and it will be found also that all the objections are disposed of when we show the association of metallic spherules with the most characteristic bodies of undoubted meteorites.

In the first place, the considerable distance from land at which we find cosmic particles in greatest abundance in deep sea deposits, eliminates at once objections which might be raised with respect to metallic particles found in the neighbourhood of inhabited countries. On the other hand, the form and character of the spherules of extra-terrestrial origin are essentially different from those collected near manufacturing centres. These magnetic spherules have never elongated necks or a cracked surface like those derived from furnaces with which we have carefully compared them. Neither are the magnetic spherules with a metallic centre comparable either in their form or structure to those particles of native iron which have been described in the eruptive rocks, especially in the basaltic rocks of the north of Ireland, of Iceland, &c.

Having referred to the objections, let us now see on what we must rely, in support of the hypothesis that many of the magnetic particles from the bottom of the sea which are specially abundant in those regions where the rate of accumulation of the deposit is exceedingly slow, are of cosmic origin. If we plunge a magnet into an oceanic deposit, specially a red clay from the central parts of the Pacific, we extract particles, some of which are magnetite from volcanic rocks, and to which vitreous matters are often attached; others again are quite isolated, and differ in most of their properties from the former. The latter are generally round, measuring hardly 0·2 mm., generally they are smaller, their surface is quite covered with a brilliant black coating having all the properties of magnetic oxide of iron, often there may be noticed upon them cup-like depressions clearly marked. If we break down these spherules in an agate mortar, the brilliant black coating easily falls away and reveals white or grey metallic malleable nuclei, which may be beaten out by the pestle into thin lamellæ. This metallic centre, when treated with an acidulated solution of sulphate of copper, immediately assumes a coppery coat, thus showing that it consists of native iron. But there are some malleable metallic nuclei extracted from the spherules which do not give this reaction; they do not take the copper coating. Chemical reaction shows that they contain cobalt and nickel; very probably they constitute an alloy of iron and these two metals, such as is often found in meteorites, and whose presence

Fig. 2.—Black Spherule with Metallic Nucleus $\left(\frac{60}{1}\right)$. This spherule covered with a coating of black shining magnetite represents the most frequent shape. The depression here shown is often found at the surface of these spherules. From 2375 fms. South Pacific.

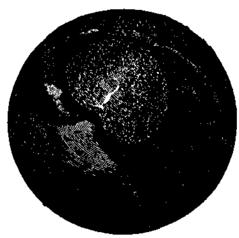

Fig. 3.—Black Spherule with Metallic Nucleus $\left(\frac{60}{1}\right)$. The black external coating o magnetic oxide has been broken away to show the metallic centre, represented by the clear part at the centre. From 3150 fms. Atlantic.

in large quantities hinders the production of the coppery coating on the iron. G. Rose has shown that this coating of black oxide of iron is found on the periphery of meteorites of native iron, and its presence is readily understood when we admit their cosmic origin. Indeed, these meteoric particles of native iron in their transit through the air must undergo combustion, and, like small portions of iron from a smith's anvil, be transformed either entirely or at the surface only into magnetic oxide, and in this latter case the nucleus is protected from further oxidation by the coating which thus covers it.

One may suppose that meteorites in their passage through the atmosphere break into numerous fragments, that incandescent particles of iron are thrown off all round them, and that these eventually fall to the surface of the globe as almost impalpable dust, in the form of magnetic oxide of iron more or less completely fused. The luminous trains of falling stars are probably due to the combustion of these innumerable particles resembling the sparks which fly from a ribbon of iron burnt in oxygen, or the particles of the same metal thrown off when striking a flint. It is easy to show that these particles in burning take a spherical form, and are surrounded by a layer of black magnetic oxide.

Among the magnetic grains found in the same conditions as these we have just described are other spherules, which we refer to the *chondres*, so that if the interpretation of a cosmic origin for the magnetic spherules with a metallic centre were not established in a manner absolutely beyond question, it almost becomes so when we take into account their association with the silicate spherules, of which we have now to speak. It will be seen by the microscopic details that these spherules have quite the constitution and structure of *chondres* so frequent in meteorites of the most ordinary type, and on the other hand they have never been found, as far as we know, in rocks of a terrestrial origin; in short, the presence of these spherules in the deep sea deposits, and their association with the metallic spherules, is a matter of prime importance. Let us see how we distinguish these silicate spherules, and the points upon which we rely in attributing to them a cosmic origin.

Among the fragments attracted by the magnet in deep sea deposits we distinguish granules slightly larger than the spherules with the shining black coating above described. These are yellowish-brown, with a bronze-like lustre, and under the microscope, it is noticed that the surface, instead of being quite smooth, is grooved by thin lamellæ. In size they never exceed a millimetre, generally they are about 0·5 mm. in diameter; they are never perfect spheres, as in the case of the black spherules with a metallic centre; and sometimes a depression more or less marked is to be observed in the periphery. When examined by the microscope we observe that the lamellæ which compose them are applied the one against the other, and have a radial eccentric disposition. It is the leafy radial structure (*radialblättrig*), like that of the *chondres* of bronzite, which predominates in our preparations. We have observed much less rarely the serial structure of the chondres with olivine, and indeed there is some doubt about the indications of this last type of structure. Fig. 4 shows the characters and texture of one of these spherules magnified 25 diameters. On account of their small dimensions, as well as of their friability due to their lamellar structure, it is difficult to polish one of these spherules, and we have been obliged to study them with reflected light, or to limit our observations to the study of the broken fragments.

These spherules break up following the lamellæ, which latter are seen to be extremely fine and perfectly transparent. In rotating

Fig. 4.—Spherule of bronzite ($\frac{25}{1}$) from 3500 fathoms in the Central South Pacific, showing many of the peculiarities belonging to chondres of bronzite or enstatite.

between crossed nicols they have the extinctions of the rhombic system, and in making use of the condenser it is seen that they have one optic axis. It is observed also that when several of these lamellæ are attached, they extinguish exactly at the same time, so that everything induces us to believe that they form a single individual.

In studying these transparent and very thin fragments with the aid of a high magnifying power, it is observed that they are dotted with brown-black inclusions, disposed with a certain symmetry, and showing somewhat regular contours; we refer these inclusions to magnetic iron, and their presence explains how these spherules of bronzite are extracted by the magnet. We would observe, however, that they are not so strongly magnetic as those with a metallic nucleus.

We designate them under the name of bronzite rather than of enstatite, because of the somewhat deep tint which they present; they are insoluble in hydrochloric acid. Owing to the small quantity of substance at our disposal, we were obliged to limit ourselves to a qualitative analysis. We have found in them silica, magnesia, and iron.

We have limited our remarks at this time to these succinct details, but we believe that we have said enough to show that these spherules in their essential characters are related to the chondres of meteorites, and have the same mode of formation. In conclusion, we may state that when the coating of manganese depositions, which surround sharks' teeth, ear-bones of cetaceans and other nuclei, is broken off and pounded in a mortar to fine dust, and the magnetic particles then extracted by means of a magnet, we find these latter to be composed of silicate spherules, spherules with a metallic centre, and magnetic iron, in all respects similar to those found in the deposits in which the nodules were embedded.

We have recently examined the dust collected by melting the snow at the Observatory on Ben Nevis, in order to see whether, in that elevated and isolated region, we should be able to find volcanic ashes or cosmic spherules analogous to those we have described. This atmospheric dust, which we have examined microscopically, has not shown any particles which could with certainty be regarded as identical with those substances which are the subject of this paper. Particles of coal, fragments of ashes, and grains of quartz predominated. Besides these, there were fragments of calcite, augite, mica, and grains of rock of all forms and of variable dimensions. These were associated with fibres of cotton, of vegetables, splinters of limonite and of tin—in short, everything indicating a terrestrial origin.

In order to give an idea of the facility with which the winds may carry these matters even to the summit of the mountain, we may add that Mr Omond has sent to us fragments of crystalline rocks, some having a diameter of two centimetres, which, he states, were collected on the surface of the snow at the summit after the storm of 26th January 1884.

Arrangements are being made to collect the dust at the top of Ben Nevis during calms with great care.

3. On the Nomenclature, Origin, and Distribution of Deep-Sea Deposits. By John Murray and A. Renard. Communicated by John Murray.

Introduction.—The sea is unquestionably the most powerful dynamic agent on the surface of the globe, and its effects are deeply imprinted on the external crust of our planet; but among the sedimentary deposits which are attributed to its action, and among the effects which it has wrought on the surface features of the earth, the attention of geologists has, till within quite recent times, been principally directed to the phenomena which take place in the immediate vicinity of the land. It is incontestable that the action of the sea along coasts and in shallow water has played the largest part in the formation and accumulation of those marine sediments which, so far as we can observe, form the principal strata of the solid crust of the globe; and it has been from an attentive study of the phenomena which take place along the shores of modern seas that we have been able to reconstruct in some degree the conditions under which the marine deposits of ancient times were laid down.

Attention has been paid only in a very limited degree to deposits of the same order and, for the greater part, of the same origin, which differ from the sands and gravels of the shores and shallow waters only by a lesser size of the grains, and by the fact that they are laid down at a greater distance from the land and in deeper water. And still less attention has been paid to those true deep-sea deposits which are only known through systematic submarine investigations. One might well ask what deposits are now taking place, or have in past ages taken place, at the