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We and the World Outside.

Geological Aspects of the Problem of Meteorites.[1]

By

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There is something exciting and tempting in things that we see or otherwise sense without totally comprehending them, in realities that we prove or believe we prove without being able to grasp them. However, phenomena that were formerly completely incomprehensible to us may suddenly seem absolutely clear after being interpreted in a natural way. But how often do we not find that the light thrown upon hidden matters, the answers given to the questions we ask, merely lay bare the gaps in our knowledge and make us realize our limits. Our ability of observation is considerable, and by means of the instruments we have constructed it has increased still more. Our imagination seems to us to be unlimited; and if our power of construction builds on a firm ground and is stimulated by imagination, it will be able to create the most perfect edifices of thought. But often these architectonic masterpieces of our thinking stand just as empty and hollow as the iron frame of a sky-scraper under building. The firm ground and the firm frame may make us believe that the building is complete. But the most important thing is still missing. It remains to us to fill in the frame and make the house inhabitable. Maybe we feel the existence of hidden things in the building constructed by our thought, maybe we look för the secrets — and stare into empty space. Then we have to go on working.

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We have to collect more knowledge and sift more material before even being able to see where the secret lies hid. This is often a tiresome task, and in many cases it is never fulfilled.

When on a starlit night we stand looking up at the sparkling points in the dark sky, our thoughts are apt to wander. Suddenly we see a bright line flash across a part of the sky, and we think, A falling star. Somebody says, What a shame, I forgot to wish; and the matter is forgotten. Somebody else might think of the little cosmic orb whose long course was interrupted when it happened to get too near our earth.

It rarely happens that anybody is lucky enough to see the shining path of a big stone through our atmosphere. If we do, we do not merely obtain more stuff for our imagination, but also have good reason to gather our whole knowledge about meteors; perhaps we shall then find an imposing construction of thought before us. Should we find the meteorite, the stone that fell, then we have everything that is needed for the unveiling. This is how we might reason; but when we have got further, when we have examined and studied the stone that fell from the sky, we shall certainly know more about it than when we just saw it falling, though the great secrets will still remain unsolved. The frame of our edifice of thought will have acquired more firmness, but we little know what is hidden inside this frame. My object here is to try to get to close quarters with some of these mysteries, some of the profound questions in connexion with these projectiles fired against our earth.

Long before the beginning of our era, meteors had been observed, and we can be sure that fallen stones had also been collected. As far as we know, none of these have been preserved till our own times, with the possible exception of the black stone in Kaba, still worshipped by the Mohammedans. Meteors were long considered to be omens, and they themselves were not pondered upon, but so much the more the misfortunes and inflictions they presaged. When later on people were beginning to doubt omens, and the learned attacked belief in them, it was also denied that stones could possibly fall down on the earth. During the Age of Enlightenment everyone was derided and abused who insisted he had seen stones fall, and it was no good showing them either. Their strange character, entirely different from the rocks of this earth, was explained in different ways, mostly as being the result of lighting. But gradually a rich material was collected, and such reliable observations of fallen stones were made that in 1794 the German physicist CHLADNI dared to maintain their cosmic origin. Some new falls attracted great attention, and this caused CHLADNI's opinion to be soon recognized. Ever since the beginning of the nineteenth century it has been generally known that foreign bodies can fall down on our earth, and most interest has been directed to the nature of these bodies. Thorough investigations and systematization of the material began, but it is not until a hundred years after the publication of CHLADNI's famous work, i. e. about 1900, that we find a scientifically satisfactory survey of the chemical composition, the mineral content, the structure, and the characteristic qualities of meteorites. Certainly a whole series of new finds has been made since that time, but they have given rise to no essential or well-founded views on the problem of meteorites. The investigation of details in connexion with the composition and structure of meteorites, however, has promoted many attempts to decide their age and find out the formation of their strange characteristics.

I shall not stop here to consider these works, but immediately tackle one of the fundamental problems of meteorite study: the problem of the origin of meteorites.

The popular idea of meteorites is that they are fragments of a broken-up celestial body. We like to think of the different types of meteorites as representing the different shells of the earth, the iron meteorites naturally representing the nucleus, whereas the stone meteorites represent an outer shell. I could have been content to refer to this idea of the origin of meteorites, quite especially as it is also my own, had it not been subjected to criticism from different quarters, in the first place from certain astronomers and astrophysicists. They maintain the idea that the meteorites have been formed by means of accumulation of cosmic dust. I cannot help admitting that this theory may seem reasonable enough, and although to me it seems petrologically impossible, it has counted a mineralogist and petrologist among its foremost defenders, namely A. E. NORDENSKIÖLD.

Although, like other scientists, he was unable to advance other than entirely hypothetical points of view in support of the theory of accumulation, NORDENSKIÖLD was led to embrace it as a result of his study of meteorites and similar phenomena. In his arctic voyages he found not only the big iron blocks near Ovifak in West Greenland, which he interpreted as meteorites, but also examined the »cosmic» dust he found in the snow fields. He studied the meteorites that fell in Sweden in 1869 and 1876 at Hessle and Ställdalen and also investigated a good many falls where no stones were found. In 1883 NORDENSKIÖLD published his general views on the problem of meteorites in his well-known work, »On the Geological Significance of Cosmic Matter Falling on the Earth». The increase in bulk that is no doubt the result of the falling of cosmic matter on to the earth led him to the conclusion that the whole earth had been formed by means of such accumulation. This thought was further developed to apply also to meteorites. These, he said, iron meteorites and stone meteorites alike, are »dust conglomerates from the universe and not fragments from a former planet».

Since the accumulation theory, in somewhat varying forms, has also been maintained by other scientists, I shall here give a short account of the facts that, according to my opinion, give sufficient reason for a complete denial of it. All these reasons are to be found in the petrological character of the meteorites — in the varying mineral content, the type of the minerals, and the structure.

Meteorites contain a great number of different minerals, but only a few of these occur in such great amounts that they form an essential part of the mass. These minerals are, beside native iron, iron-nickel alloys and iron sulphide (troilite), in the first place silicates, like olivine, orthorhombic pyroxene and felspar. Among the rarer minerals should be mentioned chromite, moissanite SiC, cohenite Fe_3C, graphite and diamond.

Several of the minerals occur in well-developed crystals. Thus stone meteorites are rich in crystals and crystal aggregates of olivine and pyroxene, mostly embedded in glassy matrix along with other minerals. The general petrological picture of these meteorites is mostly in accordance with the one we find in the magma rocks, more particularly the porphyries. The various components have been crystallized out of a melt, and during growth, the crystals have been kept suspended in the remaining part of the melt. Crystallization has gone on until, on account of a sudden freezing, the melt solidified into a glassy mass.

So far the similarity between the stone meteorites and the tellurian igneous rocks is complete. It also appears in the forms of the minerals. The incomplete, skeleton-like crystals that so often occur in meteorites, in the octahedral kamacite of the iron meteorites as well as in the olivine crystals of stone meteorites, are also to be found in our rocks, though to a lesser extent. They occur where a swift and irregular crystallization has been interrupted by the freezing of the melt. The mineral content of meteorites and the forming of minerals can thus be given a natural explanation of the same kind as that of tellurian igneous rocks, and synthetic meteorite-like forms can be produced from melts. The question then arises, whether the mineral content etc. of the meteorites can be just as naturally explained according to the accumulation theory. Is it possible that a successive accumulation of grains of dust, however small, could have given rise to rocks of as complex a nature as the meteorites? Is it possible that crystals of olivine, pyroxene and felspar should have chosen and collected, during their course through the universe, exactly the atoms and molecules that they need for growing? Is it possible that the various crystals should have been kept suspended at a suitable distance from one another while they were choosing amorphous particles to join them together as a glassy cement? This process is not merely improbable; it is impossible.

And still more impossible does this imagined process appear if we take into consideration the varying mineralogical contents of the different meteorites. Nobody, least of all a scientist, can consider it possible for one meteorite in growing to collect from the universe olivine, pyroxene, felspar, iron sulphide, and iron, whereas another simply collects olivine and iron, a third merely silicates, and a fourth nothing but iron. Nobody can explain by means of the accumulation theory the reason why one meteorite contains olivine crystals with a certain magnesia content, whereas in another meteorite olivine has a different composition. Not even the theory that their courses have passed through different parts of the universe provides a sufficient explanation for the varying petrological characteristics of the meteorites.

All the petrological traits that we can study in meteorites are only to be explained as being the results of a differentiation out of a melt, or rather out of magmas of sufficient sizes. In these they are normal phenomena. How a differentiation can take place in a melt according to the specific gravity of the components may be observed in an ordinary blast-furnace, where the light silicates, forming the slag, swim on top of the heavier iron. And in our earth we find the differentiation carried through in the main as well as in every detail. The iron that forms the nucleus is covered by lighter shells of ferriferous silicates and sulphides, whereas the outer crust consists of light silicates. Within a large body of this kind a locally determined differentiation round different centres is also to be found. The somewhat varying outward conditions give rise to variations in the course of crystallization, and thus also in the differentiation products. The natural consequence of this is that crystals of e. g. olivine and pyroxene obtain not exactly the same composition if formed from magmas in different places or at different times. The differentiation shown by meteorites with regard to their mineral content and the varying chemical composition of the minerals is a sure enough sign of origin from a body of sufficient size for such a differentiation to take place, i. e. a body of planetary dimensions.

I could have illuminated these facts by means of further details, but I desist. I consider myself justified in drawing the following conclusion from what has already been said: for petrological reasons we have a right to reject absolutely the theory of cosmic accumulation, in as far as it applies to the individual meteorites. Instead we have to consider them as being fragments of one or more large celestial bodies in which a magmatic differentiation of the material has taken place.

Before I continue my attempts to find out further facts about the planet broken up into meteorites I shall mention some traits in the meteorites that distinguish them from all known tellurian rocks.

First of all, most meteorites, unlike tellurian rocks, are rich in native iron. Further it should be observed that the more particular structure of the iron meteorites, with the above-mentioned kamacite, has never been observed in tellurian iron, nor been otherwise than hinted at in synthetic iron. For this reason there is hardly ever any difficulty in identifying an iron meteorite of this type, even if its fall has not been observed.

In ordinary stone meteorites, too, there are special characteristics distinguishing them from the rocks of this earth. Thus a few of their common minerals have never been found or only very rarely in our rocks; this is true in particular of native iron and iron sulphide (troilite). The structure also shows a strange development, above all in the liability of the crystals to gather in spherical aggregates. The occurrence of such »chondres» in a stone is a rarely failing sign that the stone is of cosmic origin. The typical chondritic structure has never been observed in our igneous rocks, but occasional chondres or other spherical aggregates of a similar type may be found on a microscopical analysis of slaggy lava rocks. The best example of this known to me is given by a sample of Kilauea lava, recently acquired by the Geological Institute in Lund. Glass-filled spheres of small olivine crystals along with larger free crystals lie enclosed in the glassy matrix. The lava is full of vesicles and gives the impression of originating from the topmost froth of a magma mass poured or thrown out, possibly a part of the sections of the melt that were blown up by an explosion and spread all over. It should be especially observed that it is in basic heavy lavas that the chondritic structure has been found, that is to say in rocks that are most closely related to the stone meteorites with regard to chemical and mineralogical composition.

The experiments that have been made in order to obtain synthetically a chondritic crystallization in melts of olivine and pyroxene, have so far given no very brilliant results, but under certain conditions a spherical arrangement of the crystals has been achieved, if the melt has been put into swift motion with a spray of drops on the surface.

From what we know so far about meteorites we can thus conclude that with regard to their composition they seem to correspond to the parts of our earth that are to be found under the firm crust, that they consist of minerals which would develop in these magmas too, and that they possess a structure that would also arise in these melts, were they brought to sudden freezing by means of a quick removal to the surface of the earth. A close investigation of meteorites has thus given support to the popular idea of their formation as a result of a blowing-up of one or more planets. Personally I consider this way of formation the only possibility of creating a series of bodies with such differentiation and such petrological development as is shown by meteorites.

Once we have got so far in our thoughts, finding the edifice well founded and firmly joined together, we can go on.

If we try to form a detailed idea of a body from which the meteorites may derive their origin, it is clear enough to us, as I have just mentioned that its material has been differentiated in very much the same way as that of our own earth. Taking one step further, we realize that the meteorites merely correspond to those parts of the earth that are to be found deep down. Hence we ask: were there no lighter differentiation products that formed an outer layer, corresponding to the firm crust of the earth? The average composition of meteorites is so like that of our earth that we have every reason to assume an origin from a body of the same composition as the earth. The meteorites known to us show an average surplus of iron and magnesia, i. e. of heavy rocks, nucleus rocks, as compared to the earth, but a lack of silica, alumina, lime and alkalies, i. e. of light rocks, the rocks of the crust of the earth. The difference we have found through the analyses may, of course, be due to the fact that there was an original difference between the earth and the exploded body. But if there was no such difference, and it seems to me that there is no reason for supposing it without any kind of evidence, the difference must originate in the fact that we have found no meteorites originating from the outer layer of the planet, fragments like the rocks of the earth's crust.

There arise new problems and questions, and the next point will be: why have we found no meteorites like the ordinary eruptives, like granites and gabbros, porphyries and basalts? They ought to be normal differentiation products of the magma body that gave rise to the heavy meteorites.

There are two reasons why we may have overlooked this group. For one thing the light outer crust of the planet has merely a small volume as compared to the heavier underlying parts, and hence the light fragments must be comparatively few. The other reason, which is still more important, is that we would consider a stone which looked like a granite or some other known rock not as one of cosmic but as one of tellurian origin. Any attempt to pass it off as a meteorite would be in vain.

Then is there no possibility of identifying meteorites of this type? For the present I can think of only one way, and that is reliable observations of the actual fall. However, such falls are seldom so clear that we can found our whole argument on them. I shall give some examples, and I shall choose three chondrites that have fallen within a limited area with comparatively uniform conditions of terrain: the Lundsgård meteorite that fell on April 3rd, 1889, the Hedeskoga meteorite that fell on April 20th, 1922, and the Ekeby meteorite that fell on April 5th, 1939.

The Lundsgård meteorite. The stone fell on a cloudy night, and thus no light observations could be made. The sound was very strongly perceptible. The stone was found some days later outside a farm. It had penetrated 30 cm. down into the earth, but bounced up again. — If the stone had shown the type of an ordinary tellurian rock, it would not have been recognized as a meteorite.

The Hedeskoga meteorite. The bright meteor was observed within an area of about 15,000 $km.^2$. The sound was heard at a great distance from the place of the fall. The stone fell in the closed yard of a farm. A number of people in the house heard the fall and immediately started looking for the body. But the black stone could not be found in the dark, since it had sunk down to the level of the ground. It was not found until the next morning. — If the stone had had the appearance of granite or some other tellurian rock, it is hardly probable that it would have been noticed by the inhabitants of the farm, and it would not have been identified as a meteorite.

The Ekeby meteorite. The sky was clouded when the meteorite fell, and no light observations have been reported except from one place about 60 km. from the place of fall. There it had been observed through a rent in the clouds. From many points of view the observations of the loud sound were of interest. Particularly detailed information has been given concerning the length of time the sound was heard at the place of fall. The actual fall was observed quite accidentally. Six navvies were working with their foreman on a railway. They were waiting for a train to pass. One of them looked at his watch and read the time. Then they suddenly perceived the sound of something that they first took to be an aeroplane. They got off the bank of the railway. The sound became stronger and stronger. Once more they looked at the watch. Then the train came, passed by and disappeared in a curve. The sound could be heard again, now stronger and with explosions. They looked into the direction from which the noise was heard. A flock of wild pigeons flew past, but were suddenly seized by a current of air, whirled round helplessly and were thrown against the ground as a body thumped into the wet soil, flinging round a cascade of earth. The workmen were standing at a distance of 100 m. from the place where it fell. Immediately they went there, found the hole in the ground and dug out the stone. — In this case those who found the stone would certainly have dared to maintain that it was the one that fell, of whatever kind it had been. But if their information had not been immediately controlled on the spot, no meteorite scientist would have dared to believe in the cosmic origin of the stone, had it had the appearance of a tellurian rock.

The three examples mentioned here may be considered typical. In all the cases the stones could be set down as meteorites on account of their petrological character. I shall mention a fourth fall after which no meteorite could be found, in spite of good observations of the fall itself.

On February 12th, 1922, a meteorite fell at Skåne-Tranås, within the same region of South Sweden as the three others mentioned above. Both light and sound phenomena were observed by a great number of people. The stone fell on an ice-covered mill-pond. Two persons were standing by the pond and observed the fall and still more saw the water bubbling up through the hole that was cut in the ice. The spot was marked, and after the water had been let out of the pond, the bottom was carefully examined. A lot of stones were found, all of tellurian character: granites, diabases, gneisses, sandstones, etc. All search for an iron or stone meteorite was in vain. It is possible that the stone that fell was broken up in the water, but it is also possible that it ought to have been looked for among the stones that were collected. But at the time this possibility did not occur to me. Of course it is by no means certain that the stone could have been identified.

The meteorite literature mentions many other cases of vain search for the stones. Sometimes vague or entirely unreliable information may have been obtained about the place of the fall. In other cases the stone may have been broken up. But according to my opinion, it is especially important that in the following we should direct our attention towards the possibility that the stones could be similar to our common rocks.

In one of his works A. E. Nordenskiöld describes the hail-storm over the middle part of Sweden on July 4th, 1883. Over a strictly limited area fell hard hailstones, as big as potatoes or ducks' eggs, some round and others angular. The lumps of ice contained white stones, the size of beans or hazel nuts. Were they of cosmic origin? Nordenskiöld merely states that »they had such a striking resemblance to common terrestrial quartz that it would be extremely daring to suppose a cosmic origin». At one time I shared the same opinion as Nordenskiöld, but I am now convinced of the possibility that cosmic bodies of this kind can fall on our earth.

I shall finish my lecture by showing what will be the logical consequence of a supposition or determination of an outer light stone crust in the exploded planet. The general magmatic differentiation has been parallel to the solidification, and it has developed along the same lines and according to the same laws as in our earth. There may thus have existed on the planet beside the lithosphere also a hydrosphere and an atmosphere. If this has been the case, we should find among the meteorites not merely fragments of magmatic rocks but also of sedimentary rocks.

Several years ago I was sent from a farm in South-Sweden a small sample of a stone that was said to be a meteorite. A farmer had been walking with his wife and daughter in the garden one morning, when suddenly a stone came spinning through the air. Nobody had thrown it. It was crumbled against the garden path, but the fragments were collected and sent to me. It was loose sandstone. In spite of the assurance of the absolutely trustworthy finders that the stone was a meteorite, I presumed some kind of mistake, and the fragments were not preserved for further investigation — alas. Others may have acted like me.

I have already advanced so far from the ground that is generally recognized as safe that I ought to stop. But I have special reasons for going one step further.

If sediments could be formed on the exploded planet it would also have been able to hold organic life. If this was the case, the sediment fragments might contain fossil remains, and meteorites with fossils ought to occur. The idea appears phantastic to me. And yet it will soon be 15 years since I received a stone of this kind. My scepticism about its cosmic origin is clear enough from my silence, and even now I have to break this silence almost against my own will. I shall mention at once that we are concerned with a limestone, and that the fossils in it are merely insignificant shell fragments. But probably the whole stone has been formed by the activity of organisms, just as the tellurian limestones it reminds us of. The most important problem is of course to settle whether the stone is a meteorite or not. I shall relate all that I know about the observations when it fell.

On Easter Eve, April 11th, 1925, a beautiful meteor was observed moving towards the west across Östergötland and the Baltic outside. Like every other meteor it was extinguished at a great height, leaving a narrow streak of light with a cloudy tail.

The following day the papers contained notices on these observations, and the same day I was informed that the stone had fallen near the farm of Bleckenstad, just south of Mjölby. Unluckily I was not able to go there myself, but immediately sent one of the assistants of the Institute, Dr. Sven Holgersson. On his return two days later he handed over to me the meteorite with a description of his investigation on the spot. It appeared from this that the fall had been observed by several people. One of these, farmer Oskar Gustafsson, had at once collected bits of the crumbled stone and given them to Holgersson. Everyone who had witnessed the fall had been questioned. The ground round the place where the stone had fallen was carefully examined in search of other stones that had more similarity to known meteorites. No such were found, but only a small heap of fragments from a stone of exactly the same kind as the one found by Gustafsson. The fields round the place were also searched, and more fragments were found. They all lay in a narrow belt along the course the stone was said to have taken.

Then what were the impressions of the observers?

Oskar Gustafsson, a respected and reliable man, whose words could not be doubted, had related that he had seen the bright body in the sky and that it was seen to fall. He was standing on the road leading up to his farm, and in the field in front of him, some 50 m. from the road, two children were playing, his niece and nephew. Suddenly he saw the falling body sweeping over the heads of the children like a white ball and breaking against the ground. »It looked like a newspaper that has been crumpled up in a ball. Somehow it fluttered open.» The children were scared out of their wits, the boy fell on the ground, and then rushed to his uncle crying: »The moon is falling down. We must go home.» Gustafsson had taken the children up to the house and had then gone back in order to find out what it was that had fallen down. He found the split-up white stone and knew at once that it was limestone. He collected some of the splinters, finding the whole thing rather curious. One thing he was convinced of. Nobody could have thrown the stone there, and for the 25 years he had owned the farm he had not limed the land a single time. He was absolutely certain that the stone must have fallen from the sky.

Similar observations had been made by others who were in the neighbourhood. Someone even believed he saw several stones fall, some of which had flown a bit further.

After Holgersson's return I asked for some complementary information, and I was also told about the results that the representative sent by the Swedish Riksmuseum, Dr. ZENZÉN, had come to. But there were no essential new points. Recently I have again been in contact with some of those present at the time of the fall and heard them anew on their observations. Their accounts now agree with my old notes in every point.

From HOLGERSSON's own observations I shall only mention that all the splinters he found were lying loosely on top of the crop and the grass in the field. They must have only just got there.

There is not much to be said about the fall observations. Under the conditions they could hardly have been better. The stone, or rather the splinters, that were preserved were according to GUSTAFSSON's account and HOLGERSSON's investigations the very stone that fell. It remains for us to examine them.

The splinters all consist of the same material. It is a white, or slightly greyish-yellow fine-grained mass, somewhat porous. Analysis shows that it is almost pure calcium carbonate. Not even 1 % of the weight is made up of impurities. These consist of silicon, aluminium, magnesium, and iron. The thorough spectral-analytic examinations that have been undertaken have given no elements above those already mentioned.

Under the microscope the stone appears to be even-grained and consist of grains of calcite with a diameter of about 0.003 mm. Slight shadings in the colouring, depending on the somewhat uneven distribution of the impurities, are noticeable. Here and there a small fragment of a calcareous shell is found. They are indefinable, simple, flat as well as tubular.

Among Swedish rocks I can find none that show any striking resemblance to these splinters. We possess few of such purity, and all of these have an absolutely different structure. It is impossible to mistake the splinters for any of them. Nor can they be mistaken for burned or slaked lime, lime from a sugar-refinery or any other product to be found in the country.

Naturally it would be extremely valuable to point out some trait in the splinters which would have to be considered as having arisen during a course through the atmosphere. Stone meteorites show a characteristic crust and a characteristic corrosion on the surface. Is there nothing of this kind to be seen in the limestone?

As I have already pointed out, the limestone has been completely split up into small fragments, and hence the possible excavations of the surface cannot be studied any longer. However, certain surfaces of the splinters show a peculiar gloss. I have tried in vain to find something corresponding in natural limestones or in burnt or otherwise prepared stones. This shiny surface may be the result of a corrosion during the course through the atmosphere. The sharp edges of the splinters testify that the stone was split up only just before the fall, and they also show that the stone cannot have been long on the ground.

The Bleckenstad meteorite (this is my name for it) was observed as it fell. The stone was collected in a satisfactory way. It is a sedimentary, fossiliferous limestone. This was my view on the matter 15 years ago, and it is still, though in the meantime I have been doing my best to find a different explanation.

However, I want to leave further examination and testing of the material to others. Yet there is one thing that I want to stress — we have no right to reject supposed meteorites because of their dissimilarity to our present idea of meteorites. It is our duty to pay quite special attention to them and carefully try out their genuineness. When over and over again I have put aside the Bleckenstad meteorite, I may have acted as unwisely as those who got rid of the Skåne-Tranås stone because it was not of iron, and as the eighteenth-century people who declared that they would not believe in meteorites even if they saw one falling before their feet.

The Bleckenstad stone does not solve the problem, even if it is accepted as a meteorite. It opens new spaces to our eyes. The cosmic projectiles cutting through our atmosphere will create still more questions in our mind. Will new finds provide answers to some of these questions, or will they only give rise to more? Our thoughts begin to wander. Before us we have a construction of imagination and reality, but we see right through it, into a far distance, awaiting new messages from the world outside.

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