of the sun and the creation of the earth remains, however, hidden from us. Astronomers estimate the sun's age as about 8 million million years.

The study of radioactivity has led us to the above conclusions. Scientific research attempts to discover and to explain the connections of the natural phenomena. The most fascinating feature of such research is that the experimenter never knows whither the developments may lead. When Bequerel discovered radioactive rays, he had no idea that his discovery would lead to an efficient method for determining the age of the earth. The action of X-rays caused a green fluorescence of the glass walls of his tubes and Bequerel wished to determine whether all fluorescing substances sent out X-rays. Thus he discovered the action of uranium on a photographic plate and hence the radioactive rays. Continuing Becquerel's work, Pierre and Marie Curie were led to study the activity of uranium-containing minerals and discovered in pitchblende the presence of an element radiating much more strongly than uranium, namely, radium. The radioactive rays and radium were indeed epoch-making discoveries; but the most important contribution to the science of radioactivity was made by Rutherford and Soddy when they recognized that radioactive radiation was merely a subsidiary phenomenon accompanying the transformation of uranium and the other radioactive elements, and that it indicated a *disintegration of the atom.* They pointed out that the disintegration products must be present in uranium minerals and accumulate in the mineral in the course of time. Boltwood, who did so much for the early development of radiochemistry, studied a series of uranium minerals, and the constant ratio of uranium to lead struck him as remarkable. He concluded that lead was the end-product of the uranium disintegration and was the first to suggest that the uranium-lead ratio could be employed for the determination of the age of the earth. Simultaneously, the present Lord Rayleigh showed how the accumulation of helium in the uranium minerals furnished a method of determining their age. Experimental and theoretical researches by many workers were necessary in order to extend especially the lead method and to lead to the well-established numerical values here given.

The age of the earth according to ordinary time standards is enormous, but when compared with the age of some stars our earth is extraordinarily young. Three different astronomical methods can be applied to the calculation of the age of the stars, and all three astronomical clocks show the same time, 5 to 10 million million years. If the age of a human being is 1 second, of the human race 6 hours, then the lower limit of the age of the earth is one year, and the age of the stars is 5,000 years.

THE ORIGIN OF SOUTH AFRICAN ALLUVIAL DIAMONDS[1]

By Dr. GEORGE FREDERICK KUNZ

NEW YORK

ONE of the most important contributions of recent years to the technical literature on the diamond was the comprehensive and masterly treatise on "Diamond-Bearing Alluvial Gravels of the Union of South Africa," presented before the Empire Mining and Metallurgical Congress in Johannesburg in March, 1930. The author, Alpheus F. Williams, a graduate of the University of California and Lehigh University and general manager of the De Beers Consolidated Mines, is the son of the late Gardner F. Williams, the great organizing engineer who, after Cecil Rhodes had unified the mines, did much to bring about the establishment of the methods of control of the native labor that prevented the great amount of pilfering that had previously not only absorbed much of the profits of the mines, but had also damaged the market for the legitimate stones by the sale of the illicit stones. Mr. Williams's paper includes in its 169 pages some 52,000 words of text, 6 maps of the districts under discussion, 38 illustrations and an appendix listing the weight, name of finder and the location and date of discovery of 66 diamonds of 100 carats or more that have been found in the South African alluvial gravels. These 66 stones range in weight from 100 carats to 416 carats, and total 11,324 carats.

Ever since their discovery, the origin of the alluvial diamonds and the methods by which they were transported from their source to their final location have been subjects for speculation and debate. The first alluvial diamond in South Africa was found in the early spring of 1867 near the junction of the Orange and the Vaal Rivers among the bright pebbles picked up by a farmer's children. How many others had been picked up in this way and then lost or discarded no one will ever know, but fortunately this particular pebble caught the mother's eye, because of its bright-

[1] A review and discussion of the paper of Alpheus F. Williams on "Diamond-bearing Alluvial Gravels of South Africa."

ness, and she brought it to the attention of a neighbor, who became interested, and out of curiosity and in the face of considerable difficulty tried to find out what it was and its value. Naturally, gem experts were not plentiful in this remote district, and though no definite information was at first obtained, the prevailing opinion was that the stone was a topaz. However, when one of these amateur mineralogists discovered that the crystal would scratch glass, he expressed the opinion that it might be a diamond. The leading topaz advocate took exception to this, and the ensuing argument resulted in a wager of a new hat. This brought things to a point where the uncertainty must be settled, and the stone was submitted to a mineralogist resident at Grahamstown, who pronounced it a diamond of 21¼ carats, and valued it at £500. And thus, through a series of fortuitous circumstances, the diamond industry of South Africa was brought into existence.

Some ten months later a second stone turned up, more than thirty miles lower down the Orange River. During 1868 several more were picked up by natives along the Vaal River. After this beginning, for four years the alluvial diamond industry of the world centered around the gravels of the Vaal River basin, rapidly supplanting India and Brazil and the other less important producing districts. Up to this time, alluvial deposits of this kind were the sole source of supply, and the only diamonds known were "river" stones.

Late in 1870 and early in 1871 diamonds were discovered in "dry" diggings in several localities in the neighborhood of what is now Kimberley. In each case these deposits proved to be very restricted in area, of rounded or elliptical shape, not more than a few hundred feet in dimensions and of considerable depth, instead of broad and shallow as were the river diggings. Furthermore, these dry diggings, after working to a considerable depth, changed in character, and the friable "yellow ground" of the top layers gradually gave way to a soft blue green called "blue ground," and for the first time in history diamonds were found in their original matrix, of yellow, soft blue, and then hard blue.

The question immediately arose as to the relation between the river stones and the dry stones. Were they of the same or similar origin, or were the sources entirely different and independent?

The fact that the pipes of blue ground were some twenty miles from the nearest river deposits, with no diamonds in the gravels in the intervening areas, seemed to indicate a separate origin, but this was not necessarily conclusive. Another argument that carried even more weight was the fact that the characteristics of the river stones were entirely different from those of the mine stones, but later other pipes were discovered, the diamonds from which showed the same characteristics as certain of the river stones, indicating that while the river stones had not originated in the first known pipes, some of them may have come from others, and some from pipes never discovered, or from the top levels of pipes which have been discovered but are not now diamond-bearing. It is well established that the pipes are richer in diamonds in their upper levels than in the lower ones, and even though some lower levels now known are not diamondiferous, the upper levels that have been eroded away during past ages might still have supplied enormous quantities of diamonds to the gravels formed and washed away during the process of erosion. It is not even necessary to assume any great amount of erosion and lowering of the general level of the country surrounding the pipes. Kimberlite is generally accepted as being of volcanic origin. If considerable amounts of kimberlite emerged from the pipes and covered the surrounding territory, as is not infrequent in volcanic outpourings, even more kimberlite might have been raised to the surface than was left in the pipe, and it might also have been richer in diamonds than that remaining in the pipe, or less so.

The quantities of material available in the diamond pipes centered the main working of the industry on the mine product, and the output of the alluvial deposits soon took a secondary place. Although the extent of the alluvials was widened from time to time by new discoveries, no important developments were made until 1908, when diamonds were found in the sands along the coast of South West Africa, then a German colony. In 1911 rich discoveries were made in western Transvaal, and the territory worked gradually increased, but without further outstanding developments until the discovery of the Lichtenburg fields early in 1926. Late in the same year the coastal territory again came into prominence with the discovery of the phenomenal deposits in Namaqualand, at the mouth of the Orange River. As a result of these last two discoveries the alluvial output of South Africa in 1927 was over 49 per cent. of the total output by weight, and over 50 per cent. of the total value, while in 1928 it was over 48 per cent. by weight and over 66 per cent. by value; previous to this, these proportions had for many years averaged about 10 per cent. by weight and 22 per cent. by value. These enormous increases in the alluvial output naturally created a proportionate increase in interest in the character and origin of the alluvial stones, particularly those of these two exceptional districts.

After an exhaustive review of the contributing agencies, such as weathering and erosion, and of normal drainage and flood drainage in the transportation of weathered material, Mr. Williams expresses the opinion that "most of the diamonds found in the gravels of South Africa originally came from the disintegration of kimberlite deposits, but that this origin may not apply to all the diamond-bearing gravels in other parts of Africa, or in other parts of the world."

Taking into consideration the number of known diamond-bearing pipes and the possibility of others as yet unknown, the diamond content of the kimberlite of the various mines and particularly the fact that the diamond content of the pipes invariably decreases with depth, the amounts of kimberlite eroded in past ages from above the present ground level must have liberated enormous quantities of diamonds. In the Premier mine alone, operations to date have produced more than a *ton* of diamonds from each hundred feet of depth of the pipe; and there is geological and paleontological evidence indicating that the original pipes penetrated several thousand feet of strata that have since been eroded away.

Weathering and erosion over long periods of time liberated the diamonds from their matrix in these pipes, and the products of erosion were carried off by the streams draining the area, slowly during periods of ordinary rainfall and more rapidly in flood periods. As erosion proceeded more rapidly in some sections than others, the topography of the country was changed, and partly due to this and partly due to the deposition of erosion products in those portions of the streams where the current was less swift, the beds of many streams were gradually shifted, and the boundaries of the various drainage areas were changed. These changes were also affected by any changes of level due to earth-lift or depression that took place during this time. Particularly in those portions of the drainage area where active silt deposition was taking place, heavy floods were liable to make considerable changes in the stream path. In this way gravels and silt that had originally been deposited in one place were transported to other areas. Thus the eroded material was gradually shifted from place to place; some portions were left at the original location, while other portions were flushed to new locations at various periods; the remainder finally reached the sea, to be distributed up and down the coast by ocean currents and washed up on the shore by wave action.

The normal rate of transportation of solid material in moving water is dependent on the velocity of the water, the size of the particle and its specific gravity. The rate of progress of finely divided, suspended silt is equal to the speed of the water carrying it, but when the size of the particles of solid is such that it can no longer remain in suspension, movement progresses only by washing and rolling along the bed of the stream. Under such conditions the rate of progress depends on a number of conditions. Fine material moves faster than coarse; smooth, rounded stones move faster than rough or flat ones; material of high specific gravity, like the diamond, would tend to sink below ordinary gravel and sand, and would move slower, unless the current were sufficiently turbulent to wash everything along together. In addition to these variables there are others that are imposed by the character of the country through which the diamonds are being transported. Clefts and fissures in the rock along the stream bed catch stones and hold them, unless the increased turbulence of high water or the gradual disintegration and erosion of the rock sets them free again. In limestone and dolomitic areas, pot-holes of all sizes form temporary or permanent traps. These and many other hazards make the diamond's journey to the sea a long and tedious one, and only a fraction of them eventually reach the final destination. Many remain along the way, trapped in a rock crevice, a gravel bar or a pot-hole, or washed out on a flood plain. Others, particularly the small and faulty stones, perish on the way, unable to stand the cruel grinding and battering that serves only to put a nice polish on a larger and more perfect stone, or possibly slightly round its sharp edges and corners.

Although the edges and faces of many alluvial stones are as sharp and smooth as of those recovered directly from kimberlite, in general the alluvial stone shows the effects of abrasion in chipped and rounded edges and corners, and in faces pitted and marred by percussion marks. The degree to which the stone shows these effects is usually considered a measure of the distance through which it has been transported, but this is not always true. The wear on a diamond is not necessarily a measure of the distance it has traveled, but rather of the time occupied by the journey and of the amount of punishment to which it has been subjected (in pot-holes, etc.) during the transportation. In a pot-hole where the percentage of diamonds in the gravel was high, abrasion of diamond on diamond might give considerable wear, where with only a small percentage of diamonds the wear from the gravel alone would be small and might not even be apparent.

THE LICHTENBURG DIAMONDS

Although the main production of alluvial diamonds in South Africa continued for many years to come from the immediate vicinity of the original discovery, near Hopetown on the Orange River, other producing districts of less importance were gradually added, some at considerable distances. Shortly after the discovery of the kimberlite pipes, the mining industry was consolidated into a few large companies, but in contrast with this, the alluvial industry remained unorganized and in the hands of thousands of individual diggers. Production increased slowly, and it was not until 1913 that it passed 200,000 carats. During the war years production declined and did not again equal the prewar output until 1919. From 1919 to 1925 production fluctuated between 200,000 and 300,000 carats annually. Early in 1926 the Lichtenburg discoveries increased the output rapidly to 800,000 carats for the year, and to the high-water mark of 2,300,000 carats in 1927, after which there was a decrease.

In general, alluvial stones grade better than the average run of mine stones, both in size and quality. This is due to the rough treatment to which they have been subjected during their transportation, which broke up the faulty stones and washed away the smaller sizes. In this respect the Lichtenburg diamonds differ from those of other fields, for they include many small, broken and faulty stones. This is well shown by the average value of the stones recovered from various areas. While the average value per carat of stones from the Cape Province and Orange Free State runs from 100*s*. to 250*s*., the average for the Lichtenburg stones is about 50*s*. per carat. This may be accounted for by the peculiar conditions under which the gravels were deposited. The Lichtenburg area is dolomitic in character, and the gravels were deposited in a network of gullies and pot-holes in the dolomite in such a way that they were largely protected from further transportation. Because of the number and size of the gullies and pot-holes, their contents were not subjected to the same amount of churning and washing as would be the case in the ordinary small pot-hole, and as a result most of the contents remained intact, while in a small pot-hole subjected to violent churning by the river current, the smaller stones and the broken fragments of faulty stones would be washed away.

From the various facts that have been established concerning the alluvial gravel deposits in the western Transvaal, Mr. Williams has constructed a theory as to what occurred before and during the transportation of the diamonds and their associated gravels into the areas in which they are now found.

The head waters of the Orange and Vaal Rivers apparently extended well into the territory that is now drained northward into the Limpopo River. After erosion had proceeded for a sufficient time to produce an extended peneplain, earth movements tilted the strata, and erosion again moved large quantities of the material southward. It was at this time that the diamond-bearing gravels were first transported into the areas in which they are now found. By the time the rivers reached the dolomitic area they must have been of considerable size, and in the early stages must have passed through this country as torrents, carrying all their eroded material with them and depositing it in lower areas where the velocity of the stream was less. The gravels as they are now found rest on a bed originally cut by a river running under quite different conditions from those existing at the time of the deposition of the gravels. The change from a torrent to a moderately slow river must have occurred gradually, because the change depended on the general erosion of the country at the same time. It was at the end of this latter period that the bedrock of the river was so altered as to be able to trap a large amount of diamond-bearing gravel in its gullies and pot-holes.

Whether the gravels transported through the dolomitic area during the earlier period carried diamonds can not be definitely established, but there seems no reason to the contrary, and the assumption that they did would explain many of the problems involving the variation in type, size, quality and quantity of the stones found further down the river system, as well as at the mouth of the river.

The transportation of material by this river system toward the south and southwest continued until some change, either in earth-movement or the encroachment of the erosion of the rivers to the north, altered the direction of the flow and turned the drainage northward.

From many pages of evidence collected by himself and quoted from other authorities at too great length to include here, Mr. Williams has evolved the above explanation and reached the conclusion that the diamonds found in the Lichtenburg area came originally from gravel deposits or igneous formations located somewhere in northern Transvaal, or even to the north of this country. This, however, does not necessarily mean that there exist to-day in that section any diamond-bearing formations of commercial importance. The gravels as they are found to-day are the concentration product of erosion acting over many geological ages, and the original source may have been of very low grade.

The Namaqualand Diamonds

In 1908 diamonds were discovered along the coast of German Southwest Africa, north of the mouth of the Orange River, in such quantities that a year later production was at the rate of half a million carats a year, and five years later was three times that amount. This was the first important discovery of alluvial diamonds at any appreciable distance from the original discovery near Hopetown. Late in 1926 Merensky and his coworkers discovered the phenomenal coastal deposits of Namaqualand, just south of the mouth of the Orange River—the most outstanding discovery in diamond history, and, following the Lichtenburg discovery made a few months earlier, completing the most dramatic year the industry had ever experienced. Although several thousand carats were recovered in prospecting operations in 1926 and 1927, no active production from this new field was undertaken until 1928, when the output for the year exceeded 900,000 carats, valued at over £7,600,000.

The problem of the origin of the Namaqualand diamonds to a considerable extent begins where that of the Lichtenburg area ends.

Shortly after the discovery of the coastal diamonds of Southwest Africa, a theory was proposed that they had been washed up on the shore from a disintegrating submarine pipe somewhere off the coast. In the light of later information, particularly after the Namaqualand discoveries, this theory was abandoned in favor of one to the effect that these diamonds had a source the same as or similar to the inland alluvial deposits, differing only in that while the inland deposits had been dropped at various points along their courses, the coastal deposits were formed by the material that the rivers had succeeded in carrying clear to the mouth, later to be distributed up and down the coast by ocean currents and washed up on the shore by wave action. The remaining difficulty was to determine whether this transportation had been effected by the Orange River system alone or its ancient equivalent, or whether its work had been supplemented by the Kamma, Buffels and Groen Rivers, thus forming several sources of distribution instead of a single one. As has already been pointed out, there is evidence that in past geological times the drainage basin of the Orange River system extended well beyond its present limits, and while there is less actual evidence to support it, it is not unreasonable to assume that the mouth of the river has not always been where it is at present. This too might furnish more than one source of distribution. The diamond content of the marine terraces adjacent to the present mouth, however, seems to indicate that for a very long period the mouth could not have been many miles distant from its present position.

After careful consideration of all available evidence, Mr. Williams arrived at the conclusion that the coastal diamonds of both Namaqualand and Southwest Africa originated in the igneous rocks of the drainage basin of the Orange River, or its ancient equivalent; that after liberation by erosion they were transported by the river to the sea, and that after being deposited in the sea they were distributed up and down the coast by ocean currents and washed up on the shore line by wave action. During and subsequent to the time of the deposition of the diamonds along the shore there was a general coastal uplift, which resulted in the formation of a marine terrace. Apparently the Merensky deposit was the oldest of the marine terraces, only a portion of which remains. A very rich terrace of considerable extent was formed by the original deposition, but much of this was later washed away by successive floods, leaving only the fragments, of which the Merensky deposit was the chief one. The diamonds and gravel washed away from the original terrace were deposited in new areas along the coastal belt, or were again washed out to sea, where some may have been lost, and the remainder was again washed up along the shore line, and by subsequent earth-lift became a terrace of later age, although much of the material in it was derived from the original terrace. Mingled with the older material was the newer material brought down by the flood that washed out the original terrace. Mr. Williams thinks that there have been at least three and possibly four such periods, during which diamonds were concentrated along the shore line and later elevated into marine terraces. Although the various uplifts were apparently quite uniform in their extent, the erosion which partially destroyed the terraces was decidedly erratic in its action, leaving the terrace almost unaffected at one point but completely destroyed at another.

This is the story, as traced by Mr. Williams, that accounts for the formation of the Merensky terrace, which with its adjacent gravels had yielded, up to the beginning of 1930, more than a million and a quarter carats of as fine diamonds as the world has ever seen, valued at more than £10,000,000, as well as the other, though less richly seeded terraces up and down the coast of Southwest Africa and Namaqualand for a distance of several hundred miles.

The reviewer states that in the transportation of the diamonds from the interior to the sea, the conditions at the mouth of the river form one of the most important features, and in this connection he desires to emphasize certain factors that have an important bearing on the question. When the fresh water of a river meets the salt water of the sea, the salt causes the deposition of the silt suspended in the fresh water, and this gradually builds up a sand bar at the mouth of the river, which serves as a dam. This action is a familiar one in all large rivers carrying a large amount of suspended material, such as the Mississippi and the Hudson. During the seasons of ordinary flow in the Orange River the transportation of the gravel with its associated heavier minerals, such as diamond, garnet and ilmenite, was slow, and such as did reach the mouth from the upper river accumulated behind the bar. In seasons of moderately high water the transportation was more rapid, but the bar at the mouth of the river held back the transported material from the sea. In time of heavy flood, when the rush of water was sufficient to wash out the sand bar, the river flow carried down not only the additional amount of material for which the rapid current furnished the necessary carrying power, but also flushed out more or less gravel from the gravel bars that had formed along its course, as well as that which had accumulated behind the sand bar at the mouth, and carried it all out to sea. The sand bar was also subject to attack from the ocean side, by heavy storms at sea; these storms not only furnished the means of destroying the sand bar and for the time being opening the mouth of the river for the free transportation into the sea of the gravel and diamonds accumulated behind the bar, but also served to distribute the diamond-bearing gravel along the coast, to the northward in the case of a storm from the south or southwest, and to the southward in the case of a storm from the north or northwest. In this way the diamonds were carried many miles both to the north and the south of the mouth of the river. The carrying capacity of the storm water for the diamonds was increased by the fact that the turbulent water along the shore line was heavily charged with suspended sand, and the buoyancy of the diamonds in this sand-water was proportionately increased, because of its higher specific gravity.

Once deposited in the sea, the diamonds and gravel, under the influence of storms, ocean currents and wave action, were not only distributed up and down the coast and washed up on the shore line, but the constant riffling action of the waves supplied a concentrating action, with the result that the larger stones were deposited close to the river mouth, while the smaller ones were carried farther up and down the coast.

SCIENTIFIC EVENTS

ANTHROPOLOGISTS AT THE WELLCOME MUSEUM

The British Medical Journal reports that a reception for the members of the Royal Anthropological Institute and other bodies interested particularly in African races and culture was held at the Wellcome Historical Medical Museum on October 10, Dr. Henry S. Wellcome, the museum's founder and director, acting as host. After making a tour of the museum, which includes an exposition of the healing arts as practised among primitive peoples, the visitors were addressed by Lord Lugard, formerly Governor-General of Nigeria, and now British member of the Permanent Mandates Commission of the League of Nations. The interest which had been shown in the welfare of subject races during the past few years, said Lord Lugard, was one of the most remarkable phenomena of the twentieth century, but in reality it had been growing ever since the abolition of the oversea slave trade. In his own acquaintance with the lawless savage Lord Lugard had found that in fact tribal organization exercised an effective discipline, and created a strong patriotism for the local community and an unswerving loyalty to the chief. Tribalism had its own code of civil and criminal law, and had evolved among other things a system of land tenure. He emphasized the need for that first task of the anthropologist, the study of existing institutions among primitive peoples. To that end Dr. Wellcome's extremely interesting museum, illustrating the practice of medicine throughout the world from the earliest ages, makes a great contribution. Lord Lugard linked it with the ethnological museum in the Lateran Palace at Rome, which showed in contrast the earlier conditions of primitive savagery and the achievements of to-day, thanks to missionary effort on various lines, including educational and medical. Such collections conferred great benefits on both the white man and the black, and would assist in solving the problem of race relations in the future. Professor J. L. Myres, president of the Royal Anthropological Institute, also expressed to Dr. Wellcome the feelings of gratitude with which anthropologists regarded one of the most stimulating museums in the country. It was a museum where the objects themselves were of extraordinary interest; but what gave them their peculiar value was that they were all eloquent in their selection, arrangement and description of the continuity and development of one of the noblest of applied sciences that mankind had at its disposal. Other speeches were made by Dr. C. S. Myers, director of the National Institute of Industrial Psychology; Dr. H. J. E. Peake, vice-president of the Royal Anthropological Institute, and Mr. T. A. Joyce, deputy keeper of the department of ethnography in the British Museum. Dr. Wellcome, in a few sentences in reply, explained how, soon after he began collecting, the idea of assisting research workers and students took possession of his mind, and he gradually formed a museum which visualized, as a museum should do, within its particular sphere, the failures and mistakes as well as the successes of the past.

WILD LIFE IN CALIFORNIA

In an effort to preserve accurate records of the distribution of wild life in the Lassen Park area of California before further changes incident to its conversion into a public domain take place, the University of California Museum of Vertebrate Zoology has published a report extending to 595 pages.