lusions. This was verified by special trial, proving that such lines appear on perfectly blank areas. The rays so observed are sometimes double.

APPLICATION OF THESE PHENOMENA.

Against the obstacles of bad atmosphere, minuteness of detail and faintness, the observer has to wage a hard fight, and it is a matter of congratulation that he sees such faint canal-like marks on the very limit of vision. With full rays the public may then discuss the interpretation.

The ray illusion is to me a very satisfactory explanation of many faint canals radiating from those small spots on Mars, called "lakes" or "oases." The only objective reality in such cases is the spot from which they start. The reader will notice that rays on opposite sides of a star are usually in line. So when two lakes or oases lie along such a line they will appear connected by a canal. Nor do the oases need to be very close together. A ray 16 min. long to the naked eye appears 4 min. long on a planet magnified 240 diameters. With the planet Mars 16 sec. in diameter the ray then extends one-fourth across it. It appears like a canal over one thousand miles long.

I believe the industrious observer has found and will find it difficult to avoid instinctively placing his head in a position favorable to producing combinations of this kind. After he has laboriously memorized the leading details, so that he may recognize what he sees, when, for an instant, Heaven vouchsafes him a brief view, he naturally has a powerful inclination always to observe in the same posture, for he finds that with a slight movement of his head

his structure of fainter canals is liable to disorganization. This insistence upon the same attitude is at once understood when we consider a larger part of the faint canals to be due to rays in the eye.

We have here the medicine to prevent this disease in the future. Let the observer constantly vary the position of the head. As soon as the seeing becomes sufficiently good to reveal fine detail, let the movement of the head begin. A rotation through an arc of twenty or thirty degrees ought to be large enough to test thoroughly any fancied combination of canals. Drawings carefully made in this way will have one source of error eliminated.

The halo with its light area and secondary image accounts for details which have no objective reality, such as bright limbs of definite width, canals paralleling the limb or dark areas, numerous light margins along dark areas and light areas in the midst of dark—abundantly exemplified in Schiaparelli's map of 1881-2.

When a ribbon-like mark has sufficient width, it must appear double; for the positive secondary image of the adjacent light areas will appear within it. To this end its apparent width to the naked eye must be some 8 min. or 10 min. (if eyes are alike in this dimension). In a telescope magnifying, say, 400 diameters, this width need be only a little over 1 sec. If the planet is 16 sec. in diameter (a rough average of its favorable position in recent years) this will amount to closely 10 deg. on its surface. Now the double canals of Schiaparelli, in 1881-2, and of Perrotin and Thallon, in 1886, are frankly of this width and, I believe, are due to this cause. In any case

the test to be applied is evidently the relation between the apparent width of a double and the radius of the halo illusion. The prevention of error in the future will evidently be the application of different powers to each canal, particularly a low power which will make its width appear less than 6 min. This must be done with care, for low powers increase the number of rays.

The halo illusion is also responsible for marginal canals. When a dark area becomes 6 min. or 8 min. wide, it appears double, having a light interior and dark edges. With any increase of width the dark edges, giving the effect of the marginal canals, remain. Hence along the edge of any dark area there appears a fictitious canal. Prof. E. W. Maunder observed this in his excellent artificial planet study of a few years ago. I believe that high powers by reducing contrast will help to eliminate this error.

The mention of the chromatic rings draws attention to chromatic aberration in the eye and in the telescope. This effect in the telescope is so great that colors in a refracting telescope are not in the least trustworthy. The blue-green tint attributed to the dark areas on Mars is a product of the telescope. Its existence on our neighbor can only be verified by the use of a reflector.

Thus in conclusion we see that there are fundamental defects in the human eye producing faint canal illusions, that these have worked serious injury to our observations in the past and that in the future they may be avoided chiefly by the simple expedients of varying the position of the head and using a wide range of magnifying power.

GLACIAL GEOLOGY.*

MODERN THEORIES OF GLACIAL CLIMATE.

BY WILLIAM NORTH RICE.

SURELY no part of the world affords better opportunity for the study of glacial geology than America. Its ice sheet, four million square miles in area, far exceeds any of the ice sheets of the Old World. The imbricated sheets of till in the Mississippi Valley afford clear evidence of the complex series of glacial and interglacial epochs. The driftless islands in the vast area of till, and the interlobate moraines, show the division of the marginal portion of the ice sheet into lobes determined by the topography. The old beaches along the shores of the Great Lakes, the living Niagara, and the various extinct Niagaras, record the stages of the melting of the ice. The Malaspina Glacier affords illustrations of the formation of eskers and of other phenomena which must have marked the stagnant margin of the waning ice sheet. Surely our country affords most favorable conditions for the study of the history of the Glacial period.

It is a curious fact that the first published suggestion of the agency of ice in connection with the drift came from a cotton manufacturer in Connecticut, Peter Dobson by name. In the American Journal of Science, in 1826, he gives a very clear and satisfactory description of the glaciated boulders observed in the drift, and gives as his conclusion: "I think we can not account for their appearances unless we call in the aid of ice along with water, and that they (the boulders) have been worn by being suspended and carried in ice, over rocks and earth, under water." It was his idea that these boulders were lifted from the bottom of the sea by sheets of anchor ice. This theory was certainly more satisfactory than most of the theories in vogue before that time, and more satisfactory than many of the opinions held at a later date.

The credit of the introduction and championship of the glacier theory of the drift belongs, not to a native, but to an adopted citizen of this country. Louis Agassiz came to this country in 1846. In his early home in Switzerland, he had already adopted the belief of Venetz and Charpentier in the former great extension of the Alpine glaciers, and their agency in the transportation of blocks from the Alps across the Swiss lowland to the Jura. It is, indeed, a curious fact that these Swiss geologists were anticipated, in the conception of the transportation of these blocks through the agency of glaciers, by Playfair, who suggested the idea in 1802. In the early papers of Agassiz the conception of the Glacial period took a form which he himself later recognized as an exaggeration. He conceived at first of a fall of temperature so widespread and so extreme that a polar ice cap extended southward over the whole breadth of Europe and across the Mediterranean, reaching the Atlas Mountains. Later he recognized the ice sheet that covered the Alps as entirely separate from the ice sheet of northern Europe. The tendency to an exaggerated view of the Glacial period overcame him again in later years, when

he maintained that, at the climax of the Glacial period, there was "floating ice under the equator, such as now exists on the coasts of Greenland." Incidentally, he based upon this extravagant conception of the Glacial period an argument against Darwin's views of the origin of species, maintaining that the widespread cold of the Glacial period produced a general extermination of life, necessitating a new creation. But the extravagance of some of his conceptions, and his vain attempt to stop the resistless progress of the doctrine of evolution, may well be forgiven, in memory of the great service which he rendered in bringing into general acceptance the glacier theory of the drift.

As Agassiz traveled in various parts of his adopted country, he recognized everywhere in the northern states the traces of glaciation, already familiar to him in Switzerland and in Scotland; and his views found more ready acceptance in this country than in some of the countries of Europe. Guyot, who had been associated with Agassiz in the study of the glaciers of Switzerland, came to this country in 1848; and he was, of course, a strong ally in the defense of the glacier theory. As early as 1841 Edward Hitchcock had been so strongly impressed by the writings of Agassiz that he recognized clearly the traces of glaciers in Massachusetts; and, in his presidential address before the Association of American Geologists, and in the postscript to his "Final Report on the Geology of Massachusetts," he shows himself almost persuaded to adopt the glacier theory for the explanation of the drift in general. He could not, however, quite bring himself to the acceptance of the conception of a glacier capable of moving with so little slope as to be able to transport material southward over the whole of northeastern America; and he accordingly limited the action of glaciers to those cases in which the drift appeared to be dispersed somewhat radially from local centers in mountainous or hilly regions. The general southward movement of the drift seemed to him to require the conception of submergence of the land, and transportation by icebergs floating southward from the Arctic regions. As early as 1852, one of the best and most popular text-books of the time, that of Gray and Adams, gave the preference to the glacier theory of the drift. Dana, in his presidential address before the American Association for the Advancement of Science, in 1855, manifestly inclined to the glacier theory; and, in the first edition of his "Manual of Geology," in 1862, he gave his adhesion more decidedly to that view. The next generation of American students of geology were brought up on the various editions of Dana's "Manual" and "Text-Book," so that thenceforward the glacier theory was recognized in this country as orthodox. In some of the countries of Europe the theory of submergence and transportation of boulders by icebergs held the ground longer. In 1864 Lyell still maintained the submergence of the plain of northern Europe, and of the glaciated region of North America; and it was not until 1875 that Torell, in a memorable meeting of

the German Geological Society, convinced the German geologists that the drift of northern Germany was transported by an ice sheet whose center was in the mountains of Scandinavia, and the name Diluvium, though still used in German geological writings, was completely emptied of its original connotation.

Within the last few decades the labors of a large number of earnest and able investigators have developed the glacier theory more in detail, and have added vastly to our knowledge of Quaternary history. The imaginary polar ice cap has given place to ice sheets of more limited dimensions, though still vast, developed respectively about the Laurentide, Keewatin and Cordilleran centers. The series of terminal moraines, marking stages of readvance or halts in the retreat of the ice sheet, have been carefully mapped. From the experience gained in the study of terminal moraines in this country, Lewis was enabled, in 1886, to recognize and interpret the terminal moraines of the ice sheet in England; and Salisbury, in the following year, those of north Germany. The recognition of interlobate moraines and of driftless areas led to a clearer understanding of the nature of the movement of the great ice sheet. The driftless area of Wisconsin was noticed by J. D. Whitney as early as 1862, and has been more carefully studied by Chamberlin and Salisbury; and the latter investigator has called attention to a smaller driftless area in Illinois. The Quaternary period, instead of being brief and comparatively simple, has been shown to be of long duration and great complexity. It has been analyzed into a succession of glacial and interglacial epochs; and, from the vast amount of erosion in some of the interglacial epochs, it has been inferred that post-Glacial time is very short in comparison with inter-Glacial time. The history of the series of lakes held between the front of the receding ice sheet and the southern watershed of the Saint Lawrence basin, has been studied by Gilbert, Taylor, Fairchild, and others. In Chamberlin's theory that the cause of the Glacial climate is primarily the diminution of the amount of carbon dioxide in the atmosphere, and that the location of the main centers of glaciation is due to the path of cyclonic storms, we have a theory which, if it can not be accepted with full confidence as the true one, is at least the only theory of the Glacial climate which has not yet been weighed in the balance and found wanting. There seems still to be some disagreement among physicists on the critical question, what effect small changes in the amount of carbon dioxide in the atmosphere would produce upon the climate. The views of Arrhenius, upon which the theory of Chamberlin is based, have been contested by Angström and Very, and are not accepted by Hann. If the physicists can be brought to an agreement on this fundamental point, we may feel that we have, at last, a theory of the Glacial climate. The alternative at present seems to be the acceptance of Chamberlin's theory, or the confession that we have as yet no explanation of the Glacial climate.

* Abstract of a paper read before the American Association for the Advancement of Science.