THE SECULAR VARIATIONS OF CLIMATE.

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SYNOPSIS.

After a brief discussion of the secular variations of the climate of the earth, the following theories, proposed for the explanation of these variations are described. None of these theories is sufficient to account for the known variations of climate, and some require dynamical conditions which are not in accord with celestial mechanics. These theories are:

1. The effect of the temperature of the interior of the earth.
2. Emanations of radioactive substances in the earth's crust.
3. Variations of solar energy according to Russell's theory of stellar evolution.
4. Variations of the inclination of the earth's axis (precessional motion and variations of latitude).
5. The "pendulation" theory.
6. Variations in the carbon dioxide content of the air.
7. Volcanic action; dislocation of parts of the earth's crust; distribution of sea and land.
8. Cosmic causes.

It is concluded that no single theory is likely to be the right one, but that the factors represented by several combine to give the known secular variations of climate.

Undoubtedly the question of the secular variations of the earth's climate is one of great importance and of intimate connection with the theory of the evolution of our planet. The investigation of this problem has been, for a long time, the subject of discussion among scientists; and lately, under the title "An Astronomical Explanation of the Glacial Periods," in the *Scientific American Monthly* for November, 1920, Mr. F. J. B. Cordeiro made an attempt at explaining the glacial periods by supposing a change of the inclination of the earth's axis with respect to the ecliptic and by assuming the possibility of demonstrating such a change.

The writer does not intend to give a new explanation of the problem, but simply to summarize as briefly as possible the outlines of this important question, and to point out the direction in which the real interpretation seems to lie.

Whatever the origin of our planet and the solar system itself may be, there is absolutely no doubt that every body in the universe is undergoing a slow, but steady and continuous, evolution. The powerful instruments which lately have been placed in the hands of scientists clearly show continuous changes of the celestial bodies even within a short interval of time: The famous Great Red-Spot of Jupiter, which appeared suddenly about 50 years ago and which has almost disappeared; the continuous fluctuations of solar energy; the phenomena of the variable stars, which can not be explained as eclipse phenomena; the novæ; Hubble's variable nebula; the variability of the Crab nebula in Taurus (Messier 1) recently detected by Lampland at Flagstaff, Ariz., and verified at Mount Wilson, Calif.; the earth's volcanic action and the continuous dislocation of its strata. These prove clearly that evolution is a natural law in the history of the universe.

The place of the earth amid the other members of the Sun's family makes the study of its evolution very complicated and uncertain. The earth is subjected (1) to its own forces, and (2) to the influence of the members of the solar system beginning with the sun. There is no doubt that the most important element controlling the earth's climate is temperature, and as far as we know the temperature changes do not seem regular or of the same sign since the earlier geological periods.

Temperature of the earth's interior.—Years ago, it was believed that the high temperature of the interior of the earth should have a certain influence on the outside, at least in the earlier periods as far as the Tertiary. However, according to the results of the investigation of the thermal conductivity of the different strata forming the earth's crust, and the study of the fossils of the earliest geologic periods, the earth's interior heat can by no means explain the temperature variations on its surface, such as the glacial periods.

Radium.—On the other hand, according to Strutt and Rutherford, a normal distribution of radium of only $\frac{1}{5700}$ to $\frac{1}{6600}$ milligrams per cubic meter of the earth is enough to counterbalance the loss of the earth's heat by radiation. No one knows, of course, the quantity of radium in the earth's mass, and consequently we have no means of checking that theory.

Solar influence.—The influence of the solar heat upon the earth's climate is unquestionable and its effects do not need to be described here. However, the very difficult point in that problem is to discover the laws of the variability of that action during the different geological periods and also to find if other factors have contributed to a certain extent.

The geological history of our planet shows that the variations of its surface temperature were not continuous and in one direction only—as has been said above—and this fact introduces more difficulties in the general problem. Prof. H. N. Russell's theory of the evolution of the stars, based on the frequency of their absolute magnitudes relative to their spectral types, regards the sun, as it is now, as a dwarf, late-type star. According to this theory, the sun started as a giant star of late spectral type and low temperature, reached its maximum temperature after passing through the successive spectral types from the latest to the earliest, and now, is cooling and following the descending branch of stellar evolution.

There are many strong evidences supporting Russell's theory, and if this is the case with our sun, undoubtedly the enormous range of its temperature during the process described above, should have had a great influence upon the earth. As is well known, we try to guess and to find the cause of the secular variation of climate by means of the marks of the various influences on the earth's surface; and these marks are so complicated that it is impossible to regard the variation of the sun's heat as the only cause of terrestrial atmospheric phenomena.

Changes of the pole.—The fact that the climatic zones are arranged perpendicularly to the axis of diurnal rotation, implies that any change of the pole must produce corresponding climatic changes on the earth. The change of the polar axis presents two aspects: (1) Precessional motion of the axis itself, that is to say a motion of the earth such as is illustrated by the gyroscope; and (2) change of the rotation axis relatively to the earth, that is to say, change of the location of the poles on the earth's surface. Both phenomena are very well known to astronomy, the first as precession and nutation, and the second as the secular variation of geographic latitudes. The amount of the precessional

motion of the axis is about 47° in 25,800 years. This period, in spite of its enormous length, can not explain the climatic variation of the past geologic periods, except a mutual change of climate between the northern and southern hemispheres. As regards the displacement of the poles on the earth's surface, the amount of the motion is, to-day, negligible.

Mr. Cordeiro tries to develop a theory of the displacement of the earth's axis in the earliest time on the basis of the moon's tidal effect, and thus to explain the cause of the glacial periods of the earth. A discussion of his theory is beyond the limits of the present article.

"Pendulation" theory.[1]—According to the "pendulation" theory, the earth, besides its rotation on its axis, is also swinging on an axis extending through the earth from Sumatra to Ecuador with an amplitude of from 30° to 40°. Each swing corresponds to a geological period. In the paleozoic period the motion brought Europe northward and reached in the Permean age the first glacial period. During the Mesozoic period, the swing changed southward and Europe reached the Cretaceous period with subtropical climate. In the Tertiary, the swing was again toward the north until the Diluvian, when the second glacial period occurred. Since then the swing changed toward the south, etc. It is not the aim of the present article to go into the details of the theory, but it is necessary to add that it does not explain fully the climatic changes during the different periods, and in the different parts of the earth's surface.

Other theories.—Besides the above-described theories, a number of different explanations also have been proposed. Arrhenius and others believe that the percentage of carbon dioxide of the earth's atmosphere has been different in the different periods. Others also tried to attribute the climatic changes to cosmic causes such as the change of the eccentricity of the earth's orbit, and others to volcanic action, to the dislocation of strata and to the distribution of the seas. In fact, no one of all these theories can offer a full explanation of the climatic changes.[2]

Conclusion.—It is believed to be beyond any doubt that the cause of the climatic changes in the different periods is not a single one and that these changes are a compound effect of a great many factors. The fact that no one of the above-mentioned theories can explain fully the climatic changes does not mean that all these theories are entirely wrong. It is very probable that several of the above reasons have contributed to a certain extent. It seems that, in trying to find the solution of this enigma, the best thing to do is to combine the possibilities instead of attributing the phenomenon to certain entirely isolated reasons.

[1] Cf. Simroth, Dr. Heinrich: Die pendulationstheorie, Leipzig, 1907; and Eckardt, Wilhelm R.: Paleoklimatologie, Leipzig, 1910.

[2] See W. J. Humphreys, Physics of the air, 1920, pp. 556–629; also Prof. Arldt, of Radelberg, in a publication under the title "Die Ursachen der Klimaschwankungen der Vorzeit, besonders der Eiszeiten," *Zeitschrift fur Gletscherkunde*, Band XI, p. i-27, 1918, has grouped and discussed the different theories on the subject. An abstract of his article appeared in *Science*, Jan. 7, 1921, pp. 22–23.

THE FREEZING OF PEACH BUDS.[1]

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[Author's abstract.]

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It is very desirable that some physical measurement of the hardiness of fruit buds be worked out before the relationship between various environmental conditions and the loss of fruit due to spring freezes can be determined definitely. Some experiments carried on at the University of Maryland Agricultural Experiment Station during the early part of the present year (January to March, 1921) indicate an increase in the tenderness of peach buds with the approach of spring. By means of a portable galvanometer and a needle-type thermocouple inserted in the bud which was then exposed to low temperature (about 7° F.) the freezing point of the sap within the bud could very easily be determined. Other data obtained indicate that wet buds freeze at higher temperature than dry buds. A period of cold weather immediately following a rain is thus apparently more dangerous to a peach orchard than cold weather alone. The accompanying table illustrates the change in resistance offered by peach buds of the Elberta variety to low temperatures.

Average determinations made from the lateral fruit buds of Elberta peach given in degrees Fahrenheit.

Date of experiment	Jan. 21.	Jan. 26.	Feb. 12.	Feb. 18.	Feb. 25.	Mar. 5.	Mar. 11.	Mar. 14.
Temperature at which ice crystals formed	17.8	19.2	17.8	18.1	18.5	19.0	19.4	22.3
Freezing point of sap	21.0	22.1	20.3	21.6	21.6	22.8	24.4	24.6

In the discussion of Dr. Johnston's paper, Dr. A. D. Hopkins mentioned an unusual feature in connection with the damage to foliage in the freeze of March 29, 1921. On some Ginkgo, mulberry, and even some apple trees there were whole branches on which the leaves and flowers suffered no damage whatever, while all the green parts on the other branches of the same trees were killed. Dr. Hopkins marked these with copper tags, in order to see if in future springs when freezes occurred the same branches showed corresponding hardiness. If they do, as seems likely, it would appear advisable to grow cuttings from these hardy branches and in that way develop a frost-resistant tree. This would be of great value in fruit raising.

[1] Presented before American Meteorological Society, Washington, D. C., Apr. 20, 1921.