currents are known. In the case of copper, if water is moving rapidly over the surface at one place and is comparatively stagnant elsewhere, the copper ions will be carried away more quickly from the point of rapid motion than from the rest of the surface, and therefore a concentration cell is set up; the point of rapid motion is anodic and suffers corrosion. Where a material consists of two phases, a current may flow between these two phases, even when the composition of the liquid is the same everywhere. This is possibly the reason why—as mentioned above—a steel disc suffers alteration even under conditions of uniform aeration; for though—by whirling—we may diminish or even eliminate differential aeration currents, we can still get currents set up between the iron and carbide particles of the steel. Owing to the fact that under conditions of whirling the individual anodic and cathodic areas are of microscopic, instead of macroscopic, size, the hydroxide is precipitated close to the surface, and tends to cling to it. Thus the rust produced under these conditions of uniform aeration is far more adherent than that produced by differential aeration.

Climatic Changes during Geological Times.[1]

By C. E. P. BROOKS.

II. CAUSES OF GEOLOGICAL CHANGES OF CLIMATE.

THE preceding article closed with a discussion of Wegener's theory of continental drift. That theory is still *sub judice*, but it was pointed out that even if it be ultimately accepted, it does not solve the problem of climatic changes. Köppen and Wegener themselves recognise this, for they adopt astronomical changes as an explanation of glacial and interglacial stages, and suggest also that astronomical changes may have been important in the Tertiary succession of Europe. Apart from this, however, any one looking at Wegener's reconstructions and remembering the way in which the land and sea distribution at the present day dominates the local distribution of climate, cannot but realise that these extensive rearrangements must have brought about corresponding changes of climate, quite apart from those due to the supposed changes of latitude. Köppen and Wegener implicitly assume that the distribution of climate depends only on the distribution of solar heat at the outer limit of the earth's atmosphere, but even if the radiation from the sun be supposed to have remained constant, there are many factors of climate other than the astronomical conditions. These factors have been discussed in a large number of books and papers which include some very brilliant work. This great mass of literature is surely worth a thought.

In the middle decades of the nineteenth century, when radio-activity had not been discovered and pre-Quaternary glaciations were a heresy, the earth was believed to be cooling from an original molten state and the uniform warmth of the earlier geological periods was attributed to this earth-heat. In this scheme of things the Quaternary glaciation—"The Great Ice-Age"—marked the gap between the waning of earth-heat and the assumption of full control by the sun. This primitive view is no longer tenable, but still it occasionally crops up, as in the ingenious speculations of Marsden Manson, who supposes that the internal heat maintained the oceans at a high temperature, thus giving rise to a dense mantle of cloud which shut out the heat of the sun. The earlier ice-ages were due to local cooling in the centres of the great continents, the Quaternary to the final cooling of the seas, while the introduction of the present zonal distribution occurred when the last remnants of the universal cloud layer broke down.

Another early theory of climatic changes, variations in the heat received from the sun, perished from lack of evidence. Dubois attempted to bolster up his hypothesis that during the Quaternary glaciation the sun was a red star by arguments from colour blindness regarded as an ancestral trait belonging to the time when the earth was bathed in a perpetual sunset glow. Other views attributed the Quaternary ice-age to the shutting out of the sun's heat by a cloud of cosmic dust, and one ingenious theory gives us an ice-age for the birth of each planet between the earth and the sun. Recently Huntington and Visher[2] have attempted to revive the theory of solar control. Starting from the accepted view that the earth is slightly warmer at minima of the eleven-year sunspot period than at maxima, and the controversial view that storminess increases from minima to maxima of sunspots, they suppose that the warm periods were times of few sunspots and the ice-ages times of many sunspots. Such an enormous extrapolation from a small and imperfectly understood basis would not be warranted unless supported by convincing evidence. At present we know nothing of the variations of solar activity during the geological past, and even if the variations which Huntington and Visher postulate have actually occurred, it is improbable that they would have the results which are attributed to them.

Whatever may be the case with the total radiation received by the earth in a year, there can be no doubt that its distribution in seasons and latitudes has varied greatly with changes in the obliquity of the ecliptic and in the eccentricity of the earth's orbit. The idea that these changes were responsible for geological changes of climate is very old, but it was not until the appearance of Croll's brilliant essay, "Climate and Time," that they won general respect. Croll supposed that the most favourable conditions for glaciation occurred during times of great eccentricity, and were located in the hemisphere with winter in aphelion, the short hot summer being insufficient to melt the accumulated snowfall of the long cold winter. Murphy first pointed out that the reverse was more likely to be true, and subsequent research has confirmed Murphy's view. Although the total quantity of heat received over a whole hemisphere in a year is not affected by astronomical changes, this is not true of individual belts of latitude, and in high latitudes more heat is received in the course of a year when summer falls in

[1] Continued from p. 17.

[2] Huntington, Ellsworth, and Visher, S. S., "Climatic Changes: their Nature and Cause." New Haven, 1922.

perihelion than when summer falls in aphelion. Moreover, the summer conditions are of greater importance for glaciation than are the winter conditions.

This astronomical theory of climatic changes has to face two great difficulties. First, it requires glaciation to alternate in the northern and southern hemispheres, while geologists believe that glacial stages have been synchronous over the whole world; and secondly, the astronomical time-scale is incompatible with the geological time-scale as set out in the absolute chronology of de Geer. Recently, means have been found to overcome the first of these difficulties; thus R. Spitaler,[3] after an elaborate computation of the temperature of land and sea in different latitudes under a great variety of astronomical conditions, considers that each stage of the Quaternary ice-age represents a time of maximum eccentricity covering several precession periods of 21,000 years each, the ice-sheets advancing when aphelion fell in spring or summer and retreating when aphelion fell in autumn or winter, but being able to persist through the whole stage owing to the general cooling of the oceans. Spitaler's scheme, however, requires much more time than the geologists will allow. W. Köppen[4] attributes a similar persistence to the cooling introduced by the ice-sheets themselves; on the basis of calculations by M. Milankovitch, in which the heat received in summer is regarded as the essential variable, he achieves a more moderate time-scale, which, however, still presents several difficulties. Thus Spitaler and Köppen make the main glacial stages synchronous in each hemisphere, but with secondary maxima at different times. The astronomical theory has this in its favour, that we can be reasonably certain that the postulated astronomical changes have occurred. But if they were of such dominant importance during the Quaternary, it is curious that they have not been recognised in the climatic alternations of earlier geological periods—for example, there should have been several ice-ages at intervals during the Tertiary. If until the Quaternary they were masked by much greater effects due to non-astronomical factors, why not attribute the Ice-Age itself to the latter also?

The interval between the founding of the astronomical theory by Croll and its recent revival has witnessed the birth and death of the carbon dioxide theory, introduced by Arrhenius[5] in 1896 and taken up by F. Frech, T. C. Chamberlin and others. The theory is that carbon dioxide acts like the glass of a greenhouse, allowing the sun's rays to reach the earth's surface almost unchanged, but absorbing the greater part of the return long-wave terrestrial radiation. Subsequent research has shown, however, that water-vapour has exactly the same properties, and that there is always sufficient water-vapour present to absorb practically all the radiation which would be taken up by carbon dioxide, so that the latter can play only a very minor rôle.

Chamberlin introduced another remarkable conception—the reversal of the oceanic circulation.[6] Ocean currents are due to three causes, differences of temperature in different parts of the surface, differences of salinity, and the action of the wind on the surface layers. At present the latter cause predominates, the warm surface waters of the tropical oceans being driven westwards and then polewards by the prevailing winds. Chamberlin supposed that at times the evaporation in the inter-tropical regions was so great that the surface layers, owing to their increased salinity, became heavy enough to sink to the bottom, where their heat was conserved as they spread polewards, until they emerged in high latitudes and brought about mild polar climates. The chief objection to this is that great evaporation implies also heavy rainfall, while the periods in which the mild polar climates prevailed are marked by aridity in middle latitudes.

Somewhat less sensational variations in the system of ocean currents have frequently been adduced as causes of climatic change. The remarkable difference of climate between the British Isles and Labrador is usually attributed to the fact that the former are washed by the warm Gulf Stream Drift, the latter by the cold Labrador Current, and it has been supposed that the opening of a gap between North and South America, by allowing the warm water of the Guiana Current to pass through into the Pacific, caused the Quaternary ice-age in Europe. This particular conclusion is not warranted by the premises, but from the great differences of climate which can exist between places along the same parallel of latitude, it is obvious that the redistribution of land and sea may account for considerable changes of climate. This was the view of Lyell, who attributed the Quaternary ice-age to an expansion of the tropical oceans, from which much water was evaporated, and in high latitudes an extension of the land areas, on which the water-vapour fell as snow. Similarly, W. Ramsay[7] has insisted on the importance of high ground in lowering the temperature, not only locally but also over the whole world. Such ideas must remain speculative, however, until they have been supported by an adequate numerical basis.

F. Kerner has done more than any one else to calculate what effect a given change of land and sea distribution would have on the local and general temperatures; his results show that geographical changes go a long way towards accounting for the climatic vicissitudes of Europe during the Tertiary,[8] but he failed to account for the mild Arctic climates of the Jurassic and Eocene, his calculated January temperatures for the 75th parallel being nowhere above the freezing-point.[9] One of Kerner's papers, however,[9] contains a suggestion of what may ultimately prove to be the most important factor in climatic changes, namely, the cooling power of an ice-covered polar ocean. Brooks had previously shown a similar cooling power of land ice; when an ice-sheet reaches certain dimensions, the cold ice-winds bring the neighbouring land below the snow line, and the process continually repeated enables the ice-sheet to grow to very large dimensions. Calculations show that the extension of

[3] Spitaler, Rudolf, "Das Klima des Eiszeitalters." Prag, 1921. (Lithographed.)
[4] Köppen, W., und Wegener, A., "Die Klimate der geologischen Vorzeit." Berlin, 1924.
[5] Arrhenius, Svante, "On the Influence of the Carbonic Acid in the Air upon the Temperature of the Ground," *Phil. Mag.*, **41**, 1896, p. 237.
[6] Chamberlin, T. C., "On a Possible Reversal of the Deep Sea Circulation and its Influence on Geologic Climates," *Jour. Geol.*, **14**, 1906, p. 363.
[7] Ramsay, W., "Orogenesis und Klima," *Öfvers. Finska Vetensk. Soc. Förh.*, **52**, 1910; "The Probable Solution of the Climate Problem in Geology," *Geol. Mag.*, **61**, 1924, p. 152.
[8] Kerner, F. "Synthese der morphogenen Winterklimate Europas zur Tertiärzeit." Wien, 1913.
[9] Kerner, F., "Das akryogene Seeklima und seine Bedeutung für geologischen Probleme der Arktis." Wien, *Sitzungsber. Ak. Wiss.*, **131**, 1922, p. 153.

the Scandinavian ice to England, and the rapid collapse of the ice-sheets at the close of the Quaternary glaciation, are accounted for by this effect. A floating polar ice-cap can be dealt with in the same way; at the close of a warm period the ocean will remain entirely free of ice until the temperature falls to freezing-point in winter. A small further fall, and a floating ice-cap will spread over the whole of the polar ocean. Kerner's and Brooks's calculations indicate that a general rise of temperature by 5° F. persisting over many years would suffice to render the whole Arctic Ocean non-glacial, a change which would reverberate over the whole globe.

This idea entirely alters the scale of the problem. Many factors which are inadequate to account for the temperature change of some 40° F. in the polar and cold temperate regions between an ice-age and a warm period may easily account for a change of 10° F., the remaining 30° being due to the cooling power of land ice and sea ice. Only two types of climate are possible, the 'non-glacial' or warm and the 'glacial' or cold. The transition from one to the other may be due to any of the climatic factors which have been so ardently advocated, but the close association between cold climates and mountain-building suggests the dominance of geographical causes. After a major orogenic period the continents are high and extensive, the ocean currents are restricted, and perhaps volcanoes send out large quantities of dust to interfere with the free passage of the sun's rays; all these causes, combined perhaps with unfavourable astronomical conditions, lower the amount of heat reaching high latitudes, so that the temperature of the polar oceans falls below the freezing-point in winter and a floating ice-cap is formed. After a long period of rest and erosion, the continents are low and small, there is a free oceanic circulation, and volcanoes are unknown; so much heat reaches high latitudes that the polar oceans are above the freezing-point even in winter, and there is no ice.

What of the Upper Carboniferous glaciation of the tropics? The geographical theory can be indicated only briefly; it postulates a high plateau, with a cold ocean to the south, a warm ocean to the north, and a permanent 'south-west monsoon' blowing from the former to the latter, covering the plateau with a dense layer of low cloud which with the assistance of a volcanic dust veil reflected a large proportion of the sun's rays back to space and kept the temperature low enough for snow to fall abundantly above a level of about 6000 feet, giving rise to ice-sheets which reached the sea. Whether the difficulties which confront this theory are greater than those confronting the theory of continental drift which is its only alternative, time will show.

Recent Developments in the University of Sheffield.

ON July 1 and 2 the University of Sheffield celebrated the twenty-first anniversary of the granting of its charter of incorporation. Congratulatory addresses were presented by sister universities throughout Great Britain and the Dominions, scientific and other institutions and societies, and public bodies. Among the recipients of honorary degrees may be mentioned H.R.H. Princess Mary, Lord Derby, Sir Austen Chamberlain, Sir Charles Eliot, Prof. P. F. Frankland, and Engineer Vice-Admiral Sir Robert B. Dixon. New engineering and metallurgical laboratories were formally opened by Sir Robert Hadfield, and the numerous delegates and other visitors were afforded an opportunity of acquainting themselves with the work of the various departments.

The University of Sheffield received its charter twenty-one years ago, but the history of the institutions out of which it grew goes back much further. The Technical School, the germ of the present Applied Science Department, was founded in 1886; Firth College, from which the faculties of arts and pure science took their origin, dates from 1879; while the Medical School will be able to celebrate its centenary in 1928. These three institutions united in 1897 to form the University College of Sheffield, which received full university status in 1905. The history of the University during the past twenty-one years has been one of almost unbroken progress in every direction. The numbers of its students and staff have greatly increased, especially since the War; the amount of research work carried on within its walls has grown steadily; new departments and courses have been established as the need for them arose and the resources of the University permitted; and generous financial support has been received from private and public sources. Though a complete survey of recent progress is not possible here, a few notes on the main lines of development may perhaps be not without interest.

The most rapid and extensive progress in recent years has taken place in the Department of Applied Science, which includes the faculties of engineering and metallurgy, and a number of associated departments. Expansion in these branches has been made possible largely by the growing recognition in industrial circles of the importance of technical training and scientific research. Thanks to the generous support of leading Sheffield industrialists, the departments of the faculty of engineering have been able to make several important additions to their resources. The Edgar Allen and Jonas Research Laboratories, opened in 1923, are designed respectively for research in magnetism, magnetic properties of materials, and allied subjects, and for investigations on the mechanical properties of materials. Further provision for research in this latter subject has been made in the new laboratory opened by Sir Robert Hadfield on July 2, which is being used at present for work on the effects of high temperatures, heat treatments and repetition stresses, but can be adapted, as the need arises, for the investigation of many other engineering problems. All these new laboratories are equipped with the most modern machines and apparatus, constructed in many cases in the engineering workshops.

One of the most important post-War developments is the establishment, in association with the faculty of engineering, of a Department of Fuel Technology. This