Climatic Changes

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canal given to the life of the new Pacific, it will receive a new inspiration in the awakening of its peoples, and the development of their resources.

We are at the beginning of a revolutionary epoch, and a new era of the world. With nine-tenths of the area of the British Empire lying within, or bordering upon, Pacific waters, and with these areas occupied by comparatively a handful of white people; and with congested Asia, peopled by two-thirds of the human race looking the world over for the first time to find outside their domains food and standing room, I am left with the solemn conviction that our first duty to ourselves and to posterity is to look to this Pacific situation at once, study all of its relations and bearing towards us, and adapt ourselves to the facts without delay.

Mr. FRESHFIELD (after the paper): If there is no one here who desires to continue this discussion, I am sure you will wish me to express the thanks of the meeting to Dr. Vaughan Cornish for the masterly description of the canal and its works which he has given us. We, his audience, feel as if we had been there, and that we could have learned very little more if we had been there. He has made the principal features of the great enterprise perfectly clear to us: the step up from the Atlantic, the deep cut which has given so much trouble to succeeding engineers, until American skill and mechanical invention at last got the better of the natural obstacles. It is one of the most dramatic things that have happened in the lives of this generation—the destruction of the great barrier thrown across the globe by the American continent. That barrier is at last by human agency to be broken down so that the Pacific and the Atlantic will no longer be separate oceans. All those nice maps Francis Galton used to make, showing the relative distances from London by the quickest route of various places on the Earth's surface are now upset from beginning to end by the Trans-Siberian railway and the Panama canal.

Dr. CORNISH: With reference to the interesting remarks of Dr. Vrooman, there is a sort of labour-vacuum in the white countries of the Pacific, and a great labour-pressure from Asia tending to fill the vacuum. The Panama canal will take to British Columbia many emigrants from Britain and the continent of Europe who would otherwise get no further than the eastern parts of the United States or of Canada. Thus it will help to fill the vacuum there and consequently diminish the pressure. Ultimately this will also strengthen the military position of the province.

CLIMATIC CHANGES.

By ELLSWORTH HUNTINGTON.

PROFESSOR GREGORY's recent article on climatic changes, and Prince Kropotkin's reply, illustrate a significant trend in this much-discussed question. They indicate that geographers are rapidly coming to an agreement. In spite of much divergence of opinion both authors lay stress upon two important points. In the first place, they emphasize the fact that during historic times there have been climatic pulsations larger than those visible during a single lifetime. This I need hardly say has been the keynote of my own writings since the publication of 'The Pulse

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of Asia' in 1907. In the second place, both authors assert that changes of climate are of different types in different regions. This also is a conclusion upon which I have recently laid much emphasis. In an article entitled "The Shifting of Climatic Zones in Mexico,"* which seems to have escaped Professor Gregory's notice, I have shown that the ruins of the Maya civilization in Yucatan appear to indicate that the climate of that region has changed in a direction inverse to the changes which have apparently taken place in New Mexico and Arizona. The hypothesis is there elaborated that the climatic pulsations indicated by changes in the growth of the big trees in California, and by many other indications, are due to an alternate equatorward and poleward shifting of the earth's climatic zones. A journey to Guatemala in the spring of 1913 showed that the evidence of relative aridity in the past in Guatemala is even stronger than I had supposed, as has been set forth in an article entitled "Guatemala and the Highest Native American Civilization,"† In addition to the evidence of the trees and of the Maya ruins, Kullmer's studies of storm tracks have led me to believe that climatic changes are even more complicated than would be the case if they were due simply to the shifting of zones from one latitude to another. In a paper presented before the Geological Society of America at its mid-winter meeting in December, 1913, I elaborated the idea that different parts of a continent, even in the same latitude, probably change in different directions. The basis of this was actual differences which any one can find by a proper sifting of meteorological records of the past three or four decades. A comparison of these conclusions with those expressed by Professor Gregory and Prince Kropotkin shows the direction in which studies of climate are now trending. It is certainly significant that Professor Gregory, who stands primarily for the hypothesis of uniformity, Prince Kropotkin, who represents the idea of progressive desiccation, and myself, who stand for climatic fluctuations which may or may not tend toward desiccation, should all independently have modified our original views so that we agree not only that during historic times there have been pulsations larger than those now evident, but that the effect of these pulsations has differed from place to place.

In spite of this agreement, however, there is still considerable diversity of opinion. This will be evident from a comparison of the hypotheses of Professor Gregory and Prince Kropotkin with my own pulsatory hypothesis. Several other hypotheses might be mentioned, such as Drayson and Marriott's modification of Croll's hypothesis of the precession of the equinoxes, and Thirlmere's hypothesis of long and regular climatic cycles.

* *Bulletin of the American Geographical Society*, vol. 45, 1913 (January-February), pp. 1-12 and 107-116.

† *Proceedings of the American Philosophical Society*, vol. 52, 1913 (September, October), pp. 467-487.

These, however, have never been elaborated with specific reference to the great body of facts now available. Moreover, they involve a degree of rigidity which seems to be out of harmony with such facts as the fluctuations of the Caspian sea and the variations of growth in California trees. Therefore they are not here considered, and we shall confine ourselves to the three chief hypotheses mentioned above.

First among these stands the old hypothesis of a progressive desiccation which is supposed to be specially noticeable in deserts, but which affects all parts of the world. This has had a great army of supporters, among whom I count it an honour to have been one at the beginning of my climatic studies. I also count it an honour to have been among the most active of those who have modified this hypothesis. It was, I believe, a necessary step toward a true solution of our problem. It involved the belief that for long periods at the time of Christ and earlier the climate of large areas in the desert portions of Asia was distinctly moister than at present. In this belief I stand squarely with Kropotkin, although I dissent from him in certain other respects. Curzon, Holdich, Stein, Rickmers, Carruthers, and many other prominent Asiatic travellers, among whom Hedin stands out as a notable exception, also accept this view. This does not mean that any of us necessarily believes that the whole world is drying up, or that central Asia is at the present moment growing drier, or that all sorts of pulsations may not have taken place. It merely means that the great majority of travellers who know inner Asia from long personal observation agree that the average conditions for the past few centuries have been drier than for a similar period during earlier times, let us say 2000 years ago. The idea of progressive world-wide desiccation is probably wrong, but it is founded on what seems to be a solid kernel of truth, and it has erred merely because it jumped to too broad a conclusion.

Side by side with the hypothesis of progressive desiccation stands the equally old and honourable hypothesis of climatic uniformity. It, too, has had a great army of supporters who deserve credit for having emphasized certain facts which the believers in desiccation have tended to overlook. The believers in uniformity point out that the Caspian sea has at certain times stood lower than at present, that terrible drought and famine have prevailed for long intervals at certain epochs, and that in the later days of the Roman Empire there was tremendous activity in the search for water and in the construction of irrigation systems. These facts and many others seem to lead irresistibly to the conclusion that long periods in the past were as dry as or drier than the present. With this conclusion I agree most heartily. It forms the solid kernel of truth which gives to the hypothesis of uniformity exactly the same claim to respect which belongs to the hypothesis of progressive change. Its supporters, like their opponents, have apparently made the mistake of generalizing too broadly. They have failed to notice that their evidence of dry

conditions in the past is strong in certain centuries and weak or wholly lacking in others.

The pulsatory hypothesis represents an attempt to harmonize the difference between its two predecessors. Without conscious prepossession either one way or the other, and with no purpose except to discover the truth, I have tried to arrive at this by means of numerical tests. The size of ruins has been estimated in respect to their water supply, the height of lakes has been investigated, the rate of growth of trees has been measured, and each fact has been carefully assigned to its specific century. The first result of this method was to show that dry times and moist times apparently occur alternately at irregular intervals and with varying degrees of intensity. This seemed to harmonize conflicting evidence advanced in support of each of the other hypotheses. Apparent success in this respect led to the same error which has marred the other two hypotheses. I generalized too broadly and assumed that pulsations similar to those of which evidence seems to be found in the deserts of central and western Asia have occurred all over the world. Further application of the same methods seemed at first to confirm this by showing that in regions such as the deserts of Asia and the mountains of California, lying far remote from one another, similar phenomena have apparently occurred at the same time. More minute investigation of trees in various parts of America, however, and especially the study of ruins in Central America speedily led to a modification of this idea, and to the definite conclusion that no generalizations are possible. Each region and each period must be investigated independently.

The same change which has come to the pulsatory hypothesis has also come to the hypotheses of progressive desiccation and of climatic uniformity, if Prince Kropotkin, Professor Gregory, and myself may be regarded as protagonists of the three. Prince Kropotkin's present idea seems to be that regions lying at high altitudes and in continental interiors change more slowly than do low regions on the borders of continents. Professor Gregory wisely makes no generalizations, but adopts the safe plan of attempting to determine what happened in each place on its own merits. I take pleasure in expressing my appreciation of the value of the map appended to his article. To be sure I question the accuracy of perhaps half of it, but the method is eminently sound. For example, as I shall show in another publication, the evidence upon the basis of which he marks Baluchistan, Syria, Greece, and North Africa, as having suffered no change of climate during historic times depends primarily upon the type of plants, such as the palm and the vine, which can grow in certain specific places. The value of these as evidence depends on the assumption that changes of climate involve pronounced changes of temperature. As a matter of fact the variations which we now experience from decade to decade show beyond question that large changes in rainfall can take place without appreciable changes of mean temperature. Yet

in spite of what seem to be errors, it is worth much to have such a map before us.

The method employed in this map needs to be supplemented by another which I have recently begun to employ. In every branch of science the present is regarded as the key to the past and to the future. Any other method involves us in mere speculation, which cannot possibly be tested. Therefore we ought to test past changes of climate by means of present changes. For example, the Indian Meteorological Survey has recently shown that the winter rainfall in north-western India is closely correlated with that of regions far to the west. An increase of rainfall in Malta during a given winter is quite sure to be accompanied by an increase eastward across the Mediterranean to Syria, and thus on to Mesopotamia. In the highlands of Persia it becomes less strong, but is still distinct, and in Northern India it again becomes strong. This would seem to suggest that if the variations which we now see from one short series of years to another should be magnified and should last for centuries, there would be a belt of increased rainfall and storminess extending from Sicily to India, but varying in intensity in its various portions. The thing for us to do would seem to be to make careful maps showing how such changes from rainy to dry years both here and in many other parts of the world are distributed, and also to make equally careful maps showing how past changes seem to have been distributed. If the present and the past changes show the same distribution we may safely accept the working hypothesis that they are due to the same cause.

Thus far we have dealt with the points upon which there is agreement among the three main hypotheses of climatic change. Let us now turn to the differences, which are by no means less important. The chief difference lies in the basal assumptions made by one or the other hypothesis. In the first place, any theory of progressive changes, whether it be the form advocated by Prince Kropotkin, the modification of Rickmers, or the sweeping form suggested by Lowell in his work on Mars, is based fundamentally on the assumption that unless some great cosmic change intervenes, the climate of the future is bound to be distinctly drier than that of the present or past. The change may be pronounced in one place and inappreciable in another, but in any case it tends toward a certain ultimate result which is an inevitable consequence of the constitution of the earth as it exists to-day. The cause may be some cosmic phenomenon, as is assumed by Lowell; it may be the continuous melting of glaciers as assumed by Kropotkin; or it may be the supposed inherent tendency of desert basins to become progressively more arid, as assumed by Rickmers. In either case the ultimate result is a definite and permanent change of climate which cannot be eradicated without the introduction of some new force. In other words, the force or cause which inaugurated the glacial period is assumed to have ceased to act. Therefore the Earth's climate is tending inevitably back toward a certain "normal" condition

in which it must remain until the intervention of some great change, such as the revival of the process which led to glaciation, or a renewed upheaval of the lands.

The hypothesis of uniformity, as advocated by Professor Gregory and others, makes essentially the same assumption, although its supporters rarely recognize this. They hold that during the glacial period great and pronounced climatic pulsations took place. These culminated at the end of the glacial period, the last being the so-called glacial stages which ended perhaps two or three thousand years before Christ. At that time there occurred a cosmic change of such a nature that the earth's climate settled into a "normal" condition. Thenceforth no changes took place except little ones of no great importance which vary back and forth about a certain definite mean. This mean cannot change unless some new force not now operative comes into play. In other words, the assumption of those who agree with Professor Gregory is almost identical with that of those who believe in a progressive change. The only difference is that one group believes that the effect of the glacial period came to a definite end prior to historic times, while the other group believes that although the impetus which caused the glacial period has ceased to act, the results have not yet wholly died away.

The pulsatory hypothesis holds that neither of these assumptions is justified. We do not yet know the cause of climatic changes. We do not know whether the great changes of the glacial period and the little changes which we see from year to year are due to the same cause or to different causes. We do not even know the cause of the little changes, much less of the great ones. How, then, can we know whether the causes which produced the glacial period ceased to act several thousand years ago? What right have we, on the other hand, to assume that the effect of such causes is still to be felt, but is dying out by gradual degrees? How can we know that the forces which caused the great pulsations of the glacial period are not still active and may not have had various degrees of activity at different epochs both before and after the beginning of historic times? We are far from being in a position to make any assumptions. The only safe course is to say that we do not know what the earth's "normal" climate is. Perhaps there is no such thing as a normal climate, for what we call normal to-day may not have been normal in the past for many thousand years, and may not be normal again for other thousands. We must simply go ahead without any assumption whatever, and find out whether the facts best agree with the idea of climatic uniformity, progressive climatic changes, or pulsatory changes. Each of the three possibilities is equally valid until it is disproved, and neither can be accepted without definite proof.

Before leaving the subject an important distinction should be made clear. In Professor Gregory's article he devotes a large portion of the space to an attempt to prove that my ideas of climatic changes

are wrong. Nevertheless he entitles his article "Is the Earth Drying Up?" He specifically notes the distinction between the theories of pulsatory changes and of progressive desiccation. Nevertheless, he commits the common error of confusing them after he gets into the middle of his subject. The belief in pulsatory changes by no means involves a belief in desiccation. To put the matter specifically, if the pulsatory hypothesis is correct, it seems as if the climatic conditions at the time of Christ, when large areas which are now inadequately supplied with water were filled with highly prosperous cities and a dense agricultural population, must prove that climatic conditions were then very different from what they were a few centuries later. At that later date those same areas had become depopulated after a desperate struggle to obtain sufficient water by means of the wholesale development of irrigation works. At that time, too, the Caspian sea stood much lower than it does to-day. Thus it appears that within the space of six or seven hundred years the climate was both distinctly moister and distinctly drier than now. Going back to earlier times it seems probable, although we cannot speak with certainty, that the supply of moisture during certain centuries was distinctly greater than at the time of Christ, but this does not prohibit the possibility that at certain other periods, such as the twelfth century before Christ, the climate may have been as dry as now. There seems to be good ground for the general statement that the climate for a thousand years before the time of Christ was on the whole moister than for the last thousand years. This does not mean, however, that the earth as a whole is drying up, or even that the particular regions under discussion are drying up. So far as the Earth is concerned, the present conditions of relative aridity in Asia are perhaps compensated by an increase of moisture elsewhere. So far as inner Asia is concerned the seventh century of our era, as I have repeatedly stated, seems to have been even drier than to-day, and the twelfth century may have been almost equally dry. Although in those regions the past was apparently drier than the present, we may now, nevertheless, be on the road back toward a glacial epoch. I do not assert that this is the case, for we know nothing certain about it as yet. It is merely a possibility which is quite in harmony with the pulsatory hypothesis. It is equally possible that a change in the other direction may be in progress.

To sum the whole matter up, the pulsatory hypothesis as it now stands makes no assumption whatever, and is not dependent upon any special explanation of the cause of climatic changes. It may lead to an understanding of such causes, but its truth or falsity is entirely independent of our ideas as to why climatic conditions change.

The reader who has persisted to this point may perhaps feel disappointed that he has been rewarded by nothing but generalities. I hope that such is the case. I have purposely avoided specific facts. They are too numerous to be presented at this time. Moreover, I have presented

them at length in three forthcoming publications. The first is a volume entitled "The Climatic Factor, as illustrated in Arid America," which is published by the Carnegie Institution of Washington. At the time of writing it is on the point of leaving the hands of the printer. It sums up the investigations of four years in the more arid parts of the United States, and in Mexico, Yucatan, and Guatemala. The second is a paper entitled "The Cyclonic Solar Hypothesis of Climatic Changes," which will probably appear in the Bulletin of the Geological Society of America. It is the logical continuation of "The Climatic Factor," for it begins where that stops, and takes up the problem of the possible cause of climatic changes. The third is a paper entitled "Pulsatory Climatic Changes" which is to appear in the Annals of the Association of American Geographers. It is a direct reply to the specific criticisms of the pulsatory hypothesis which have been advanced by Gregory, Hedin, Berg, Herbet, and various others. It also deals with the comparison of present climatic changes with those of the past. The present article is merely an attempt to point out certain broad lines along which the thoughts of students of the problem are moving. It is also, as it were, a request that geographers withhold judgment until the three papers here mentioned are before them.

The following note on Prof. Ellsworth Huntington's statement is sent by Prof. J. W. Gregory, F.R.S.:—

Professor Ellsworth Huntington's lucid statement of his views shows that the increasing desiccation of the world has lost one of its weightiest champions. As he remarks, I did not, all through my recent paper, discriminate his climatic pulsations from progressive desiccation; it seemed unnecessary, because he represented the pulsations as secondary oscillations on a general movement towards desiccation, and it was only with the resultant movement that I was concerned. With his present conclusions, that the pulsations are greater than any accompanying resultant movement, and that it is not possible to say whether the earth as a whole is becoming wetter or drier or is even advancing towards a new glacial period, I fully concur; because it was the object of my paper to show that there has been no general change of climate in historic times. Geographers will await with pleasure Professor Huntington's three forthcoming contributions to the subject.