erland, dated 12 Oct. 1891, published in *Elec. World* (*N.Y.*) 1891, 346 (7 Nov. 1891).
8. Arago had merely arranged a disk of copper below a compass needle with a sheet of paper or glass between them to shield the needle from air currents. When the disk was turned, the needle would tend to revolve in the same direction, pulled by the interaction of its own magnetism and that set up in the rotating disk. Arago could not correctly explain the working of his device and did nothing further with it.
9. Diagram from a paper, "The installation of the Niagara Falls Power Company," given by C. F. Scott before the Engineers' Club of Philadelphia, 17 Apr. 1897; the diagram was reprinted in E. D. Adams, *Niagara Power* (Niagara Falls Power Co., 1927). Scott later became professor of electrical engineering of the Sheffield Scientific School of Yale University.
10. From minutes of the meeting of the American Institute of Electrical Enigneers of 18 May 1917, at which Tesla was awarded the Edison Medal. Buck was then president of the institute.
11. These lectures, together with Tesla's lecture on polyphase motors, most of his patent specifications (complete with drawings), and 25 of his most important articles have been reprinted in a memorial volume, *Nikola Tesla—Lectures, Patents, Articles* (Nikola Tesla Museum, Belgrade, 1956).
12. A. Slaby, in a personal letter to Tesla, now in the Tesla Museum.
13. L. W. Austin, in a personal letter to me, dated 14 June 1927: "The 1891 lectures, published in 'Inventions, etc. of Nikola Tesla' in 1894, I am sure, furnished the material for at least some of the inventors who developed the coupled tuned circuits which came into use about 1900 and constitute Mr. Tesla's right to be called the 'father of radio.' "
14. *United States Reports: Marconi Wireless Co. vs. U.S.*, vol. 320, pp. 1–80.

A Theory of Ice Ages II

The theory that certain local terrestrial conditions caused Pleistocene glaciation is discussed further.

Maurice Ewing and William L. Donn

In a recently proposed theory of ice ages (*1*) we formulated the thesis that (i) the Pleistocene Ice Age was initiated when the North and South poles migrated into the thermally isolated locations of the Arctic Ocean and Antarctica, respectively, and that (ii) fluctuations of glacial with interglacial climate during the Pleistocene epoch were controlled primarily by alternations from an ice-free to an ice-covered state of the surface waters of the Arctic Ocean. According to this theory, the local terrestrial conditions of thermal isolation and adequate precipitation, rather than broad, world-wide changes of terrestrial or extraterrestrial origin, should be emphasized as the causes of Pleistocene glaciation.

Further Notes on the Northern Hemisphere

Despite the feeling of some authorities that the effects of an open Arctic Ocean would be quantitively insufficient to cause the amount of glaciation that existed, the validity of the theory seems to be illustrated by present conditions in the Arctic and Antarctic regions.

Thus, the unexplained glacial conditions which have continued in Greenland since the Pleistocene contrast very sharply with the present ice-free condition of northern Canada at the same latitudes. The significant geographic difference between Greenland and northern Canada is their location with respect to the North Atlantic Ocean. As a result of the location of Greenland, there is enough moisture in its atmosphere to cause sufficiently heavy precipitation of snow for the maintenance of glacial conditions, whereas the very scanty precipitation at the same latitudes in Canada results in the present lack of glaciers there. Also, the precipitation in the southern part of Greenland is much heavier than that in the northern part. Hence, an open Arctic Ocean during the Pleistocene seems to be the only geographic condition which could have produced glacial conditions in northern Canada equivalent to those in Greenland today. Further, the effects of the combination of thermal isolation and adequate precipitation can be seen from a comparison of present conditions in the Arctic and Antarctic areas. The thick Antarctic icecap contrasts sharply with conditions in the Arctic Ocean area, with the exception of those in Greeland. This can be explained by (i) the more complete thermal isolation of Antarctica than of the Arctic (the condition in the Arctic is the result of the small interchange of water between the Arctic and Atlantic oceans, without which interchange the Arctic Ocean would have a permanently thick frozen cover); and (ii) the availability of moisture from the surrounding open oceans for snow precipitation on Antarctica. Such precipitation is very slight over the nearly completely landlocked Arctic.

Greenland is similar to Antarctica in being thermally isolated, in being bounded largely by open water, and in having an icecap equivalent in thickness to that of the icecap in Antarctica. Greenland is also similar to Antarctica in that its icecap was probably maintained with little change during the Pleistocene interglacial stages. The following observation recorded by Charlesworth (*2*, vol. 1, p. 94) certainly supports this: "The Pleistocene ice sheets had a maximum thickness . . . which significantly enough is roughly that of the modern ice sheets of Greenland and Antarctica." In view of these conditions, we may expect the Greenland and Antarctic icecaps to be preserved, with minor fluctuations, as long as the Poles are located in their present positions.

Thus, the present contrast between Greenland and northern Canada and that between the Arctic and Antarctic regions, which result from local conditions, are comparable to contrasts between glacial and interglacial stages and make it a plausible conclusion that the latter are also the results of restricted terrestrial changes rather than of global or extraterrestrial causes.

Further evidence that there was formerly a source of precipitation in the Arctic region lies in the position of the glacial divide, as determined from indicators of ice movement and glacial re-

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bound. On the basis of indicators, J. Tuzo Wilson (*3*) shows that the divide ran approximately east-west through central Canada, except where its course was controlled by topography. Earlier notions based on the highest elevations covered by ice, as summarized by Flint (*4*), and deductions based on the theory that the source of nourishment was to the south (*5*), have placed this ice divide much further to the south. Also, detailed studies of ice movement in Alberta (*6*) show that movement was from the north rather than from the northeast, as had previously been supposed.

Although Lee *et al.* have applied the above data on motion indicators to late glacial conditions (*7*), the data of glacial rebound suggest, also, that the North American Wisconsin ice divide lay in the vicinity of Hudson Bay, thus giving independent supporting evidence for the existence of a source of precipitation to the north of the terminal moraine line in the eastern half of North America. The evidence for uplift northward is best given by the elevated beaches of the present Great Lakes and the ancient Lake Agassiz (*2*, vol. 2, p. 132; *4*, pp. 250–251; *8*). An uplift of six to eight inches per 100 miles per century is given for these areas. Uplift determined from elevated areas around Hudson Bay reaches a maximum of 1000 feet (*2*, vol. 2, p. 1321) and is continuing at present (*9*) at an undetermined rate. If the data from the Great Lakes region is extrapolated through Hudson Bay, it seems clear that a continuous thickening of ice occurred from the present hinge line northward to the Hudson Bay region.

Blake's study (*13*) indicates that rebound in Labrador is less than that around Hudson Bay and supports the location of the divide shown by Wilson.

Glacial rebound on northern Ellesmere Island and Ward Hunt Island (about 83°N) varies from 100 to 200 feet along the shore to at least 600 to 700 feet further inland (*11*), thus approaching the magnitude of the uplift at Hudson Bay, far to the south. This suggests and supports still further the argument that there must have been a source of moisture in the Arctic region.

The Southern Hemisphere

We wish to elaborate here on the statement in part I of this discussion (*1*) to the effect that Pleistocene glaciation in the Southern Hemisphere regions other than Antarctica and the sub-Antarctic islands was mainly limited to high elevations and was consequent upon the general cooling produced by the much greater change in the Northern Hemisphere.

From the excellent summaries of Charlesworth (*2*, vol. 1, p. 44; vol. 2, p. 1322) and Flint (*4*), it is noted that in South America glaciers extended along the Andes, with a few gaps, from Cape Horn to Sierra Nevada de Santa Marta in Colombia. The glaciers broadened considerably on Tierra del Fuego and on the plains east of the mountains in Patagonia. Pleistocene glaciation in Africa was confined to the Atlas Mountains of French Morocco and the high mountains of Equatorial East Africa, both of which areas have perennial snow fields today. In Australia, barely 150 square miles in the Australian Alps were glaciated, and upland areas of South Island (New Zealand), and of Tasmania (both south of 40°S) were extensively glaciated. Thus, except for Tasmania and the smaller region in Australia, it is noted by Charlesworth (*2*, vol. 1, p. 44; vol. 2, p. 1322) that Pleistocene glaciers were merely extensions of the glaciers that remain today in New Zealand, the Andes, and Africa. Further, with the exception of Auckland and the Macquarie Islands, the sub-Antarctic islands also have existing glaciers which were more extensive in Pleistocene time.

A moderate lowering of the snow line in the Southern Hemisphere, which will confirm the foregoing reconstruction of glacial conditions, is expected to result from the global cooling produced through the effects of glacial and pluvial conditions in the Northern Hemisphere upon the radiation and heat budgets of the earth.

A planetary decrease in the amount of absorbed insolation would result from a rise in albedo of the Northern Hemisphere. This would follow from the greater reflectivity of the ice in glaciated regions and of the clouds in the pluviated regions (the latter to be described in detail below.)

The areas in the Northern Hemisphere which were ice-covered during the Pleistocene glacial stages and are ice-free today cover 10.7 million square miles and are distributed around a latitude of 60°N. If we assume a mean cloudiness of 60 percent for this region in both glacial and nonglacial stages, the albedo in the remaining 40 percent would be raised from 10 to 70 during a glacial interval. If 300 calories per square centimeter per day (*12*) is taken as the mean insolation received at the surface at a latitude of 60°N, then the resulting decrease in insolation available for absorption in the glaciated areas is 2.0×10^{19} calories per day.

Further, as will be described in detail below, about 12 million square miles of arid regions were well watered (pluviated) during glacial stages. The mean cloudiness of these regions, which are distributed around latitudes of 30°N and 30°S, is about 20 percent at present. If an increase in cloudiness to 60 percent (a figure based on present equivalent areas) during the glaciopluvial stages is assumed, the albedo of these desert regions would increase from 15 (for sand) to 80 (for clouds). If 470 calories per square centimeter per day (*15*) is taken as the mean surface insolation, the increased albedo would result in a decrease of absorbable insolation of 4×10^{19} calories per day for the pluviated zones. A total reduction of 6.0×10^{19} calories per day would thus occur for the combination of glaciated and pluviated regions. (The difference in albedo between sea ice and rough water in high altitudes is so small that no significant change in this estimate would occur if the Arctic Ocean were open during a glacial stage, as postulated by our theory.) This is a significant percentage of the direct insolation of 85×10^{19} calories per day for the entire earth. It is noteworthy that the terrestrial changes described seem capable of reducing the radiation budget of the earth without reliance upon extraterrestrial changes, and thus of producing a sufficient degree of cooling to bring about glaciation in the Southern Hemisphere. It is also noteworthy that the pluviated regions are at least as important as the glacial areas in promoting global cooling. In the foregoing calculations, no account has been taken of the small effect of absorption in the atmosphere.

Although it is generally admitted that uplift of land areas results in cooling of such regions, it should also be noted that a minor contribution to the general cooling of the lands would also result from the glacial lowering of sea level, since a change of 300 feet in sea level produces an average change in temperature of 1°F.

Antarctica

The field evidence available for an estimate of the effect of the continental ice budget on Antarctica during Wisconsin time is scanty and inconclusive at present. Similarly, the conclusions about the Antarctic ice budget that can be derived from existing theories of glaciation are quite ambiguous. Thus, the Antarctic icecap appears to be in approximate equilibrium at present with regard to height (*13*) and lateral extent. Yet evidence in the form of exposed glaciated mountain areas exists to indicate that there was a former higher equilibrium stand of the icecap. Most authorities place this higher stand in Wisconsin time. Theories of glaciation require the assumption that, for the most part, the ocean and air surrounding Antarctica were cooler during glacial stages. Such conditions would produce a decrease in snow precipitation over Antarctica which would more than offset the decrease in wastage which results from lowering of temperatures. It is difficult to conceive of there having been glacial growth on frigid Antarctica during times when the surrounding environment was cooler than it now is. It seems more reasonable to suppose that former higher levels of the icecap were a result of growth during interglacial stages or even during the more recent climatic optimum. Possibly the continuing study of Antarctica will provide information for the dating of this higher stand; this is at present an unsolved problem.

Pluvial Stages

The effect of the Pleistocene conditions of moisture in presently arid areas is second in importance only to the contemporaneous glaciation in higher latitudes. The major desert areas, which are today uninhabited barren wastes, although they occupy a very large part of the temperate zones, were formerly fertile, well-watered lands (*14*). These areas, which were often covered by very large lakes, include the Sahara and Arabian deserts, the desert of central Asia, and the Australian Kalahari, the North American, the Atacama, and the Patagonian deserts. No theory of glaciation and no investigation of Pleistocene glacial stages would be complete without an explanation of the pluvial stages and their relation to glaciation.

Although there is a considerable amount of evidence which suggests strongly that pluvial and glacial conditions occurred simultaneously, the most positive evidence for this comes from Lake Lahontan in western North America (*15*).

The Lahontan data refer only to the end of the last glacial stage, but very strong evidence for glacial-pluvial simultaneity comes from observations around the Caspian and Black seas. According to P. F. Fedorov, every transgression of the Caspian Sea which occurred during glacial advances of Pleistocene time coincides, without exception, with a regression of the Black Sea (*16*); hence, it seems that pluviation was contemporaneous with glacial lowering of sea level throughout the Pleistocene period.

The predominant cause of present-day deserts is their location in either the belt of subtropical calms (the horse latitudes) or in the trade wind zone marginal to this belt; in these zones the dry air moves equatorward, becoming warmer and thereby able to carry increased amounts of moisture. A secondary cause is the location of these deserts on the lee sides of mountains and along coasts bathed by cool ocean waters. Some desert areas are the result of a combination of all these causes.

The higher stands of many lakes and rivers during the glaciopluvial stages were the result of the snows and meltwater of adjacent glaciers. But the largest of these pluviated regions, including most of the present-day deserts, were so remote from glaciated areas that the cause of pluvial conditions must be other than simple proximity to glaciers. The fact that there has been widespread rainfall in the past over broad areas which are not only arid at present but which lie in climatic zones where conditions are basically unfavorable for the formation of rain in significant amounts indicates strongly that a fundamental modification of the atmospheric circulation must have occurred during the glaciopluvial stages.

In part I of this discussion (*1*), the theory was advanced that the present north-polar high-pressure area is a reversal from a polar low, which resulted from the contrast in temperature between the relatively warm, open Arctic Ocean and the surrounding cold, glaciated continents. Further, it was stated that the Iceland low-pressure area, which at present weakens in summer and intensifies in winter, probably migrated southward during glacial stages. By an extension of the reasoning involved, it is possible to construct a model of modified circulation which could account for the pluvial conditions that have been described for the present major desert areas. The critical changes in circulation, which have been described, in principle, by a number of investigators in the past, are outlined below.

1) During a glacial stage, the Iceland "low" of the North Atlantic would migrate southward and would maintain present winter intensity all year as a result of the perennial temperature contrast between the cold glaciated continents and the relatively warm ocean. Increased storm intensity and frequency would therefore persist throughout the year, the paths of the storms being deflected far to the south of the present paths.

2) At present, the belts of subtropical calms (the horse latitudes) are located at approximately 30°N and 30°S and show greater intensity over the oceans in summer than in winter. During a glacial stage, this zone would also migrate southward in the strongly glaciated Northern Hemisphere and would probably weaken over the oceans because of the persistence of cold conditions over the continents.

3) The combination of an icecap extending into the middle latitudes, or present Temperate Zone, plus the southward migration of both the Iceland low and the horse latitudes would result in the southward displacement of the entire zone of the prevailing westerlies wind belt and hence of the entire belt of migratory cyclonic storms which predominate in this belt. These storms would consequently travel well into the regions which, at present, are deserts because they lie in the dry horse latitudes and adjacent areas.

4) Owing to the changes described above, polar air masses originating over the icecaps in the middle latitudes would tend to meet the extremely moist equatorial air much more frequently than at present, thereby generating very intense storms which would yield the very high precipitation characteristic only of hurricanes today.

5) Although in general it would be cooler than at present as a result of widespread global cooling during a glacial stage, the low-pressure doldrum belt would become relatively stronger through contrast with the very cold belt of the middle latitudes. Further, this belt, now located north of the equator in the vicinity of continents, would probably be displaced somewhat to the south of the equator as a result of the pronounced cooling of the northern continents. This would tend to increase the amount of moisture over the present desert regions of the low southern latitudes of South America and Africa, thus increasing precipitation over the deserts of South

Africa and the west coast of South America.

6) As a result of the present monsoon pattern in southern Asia and the Indian Ocean, the doldrums are located over Australia during the northern winter. With glacial conditions existing over the northern continents, the present winter-type pattern would tend to become semipermanent, bringing considerably more moisture and precipitation to Australia. It is a well-known fact, established from the fossil record [see Benson (*17*)], that, during the Pleistocene, large fauna with tropical affinities inhabited Australia. This and the pluvial conditions of central Australia can be explained by the theory of the change in circulation; the small high-altitude glacier of southern Australia could have existed in much the same manner as do equatorial glaciers on the mountain areas of Africa and South America at present (*18*).

References and Notes

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K. P. Schmidt—Herpetologist, Ecologist, Zoogeographer

Karl Patterson Schmidt died on 26 September 1957, at the age of 68, as the result of a bite by a boomslang the previous day. The snake had been brought from the Lincoln Park Zoo to the Chicago Natural History Museum for identification. The boomslang is an African "back-fanged" snake, widely but erroneously considered to be less dangerous than the front-fanged cobras and vipers. Moreover, this one was a juvenile and was therefore not expected to carry much venom. Schmidt did not consider the bite serious and took no preventive measures to reduce the toxic effects. He kept an account of his reactions to the poison, including the nausea and hemorrhages, but showed no indication that he anticipated death up to the moment he lapsed into a coma from extensive brain hemorrhages. Exactly a month before his death, he said in his last sentence in a published note in *Copeia* (1957, page 233), "one scarcely needs to be warned that a pit-viper with inch-long fangs is dangerous, whether aggressive or not, quite as one needs to be cautioned against the apparent harmlessness of coral snakes." His friends fervently wish he could have exercised this caution against the back-fanged boomslang as well. Dramatic as was his death, which was given wide publicity in the newspapers of the country, of far greater import was his continuous contribution to scientific knowledge and to education throughout his long professional life.

Karl Schmidt was born at Lake Forest, Illinois, in 1890, where his father was a professor of German in Lake Forest College. He began his focal interest in science at the Lake Forest Academy, and he completed his freshman year at the college with much distinction. Before he went to Cornell University for further undergraduate training in biology and paleontology, he spent six years on the family farm at Stanley, Wisconsin, where he helped clear its timber and establish a dairy farm. Particularly during this period he developed an intense interest in natural history, and his enthusiasm for the observation of nature was the central theme of his subsequent life. He had a remarkable ability to transmit this interest to younger men (I was one of those who felt his influence), and many scientists in various fields owe much of their initial inspiration to Schmidt. He started on his long series of field explorations while still an undergraduate, first as a geologist and later as a biologist. His developing professional interest was greatly augmented by his teachers and friends, among whom were J. G. Needham, J. H. Comstock, Anna B. Comstock, G. D. Harris, and A. H. Wright.

He was married in 1919 to Margaret Wightman, and together they immediately sailed to Puerto Rico on an expedition for the New York Academy of Science. Throughout their married life, Margaret Schmidt added a balance and an integration to their lives which unquestionably were major factors in her husband's productivity. She and their two sons, John and Robert, survive him.

Schmidt became assistant curator of reptiles and amphibians at the American Museum of Natural History in 1918. He joined the staff of the Chicago Natural History Museum in 1922, where he rose from assistant curator of reptiles and amphibians to curator, and then to chief curator of zoology in 1941. At the time of his retirement from administrative duties, in 1955, a volume with contributions by many of his associates was published in his honor (*Fieldiana: Zoology*, vol. 37, 1955).

He was a steady contributor to scientific journals and wrote nearly 150 articles and books on his researches in herpetology. He was former herpetological editor of *Copeia,* section editor of *Biological Abstracts,* and editor of the zoological journals of the Chicago Natural History Museum. He was author or joint author of several books on zoological subjects, among them *Ecological Animal*