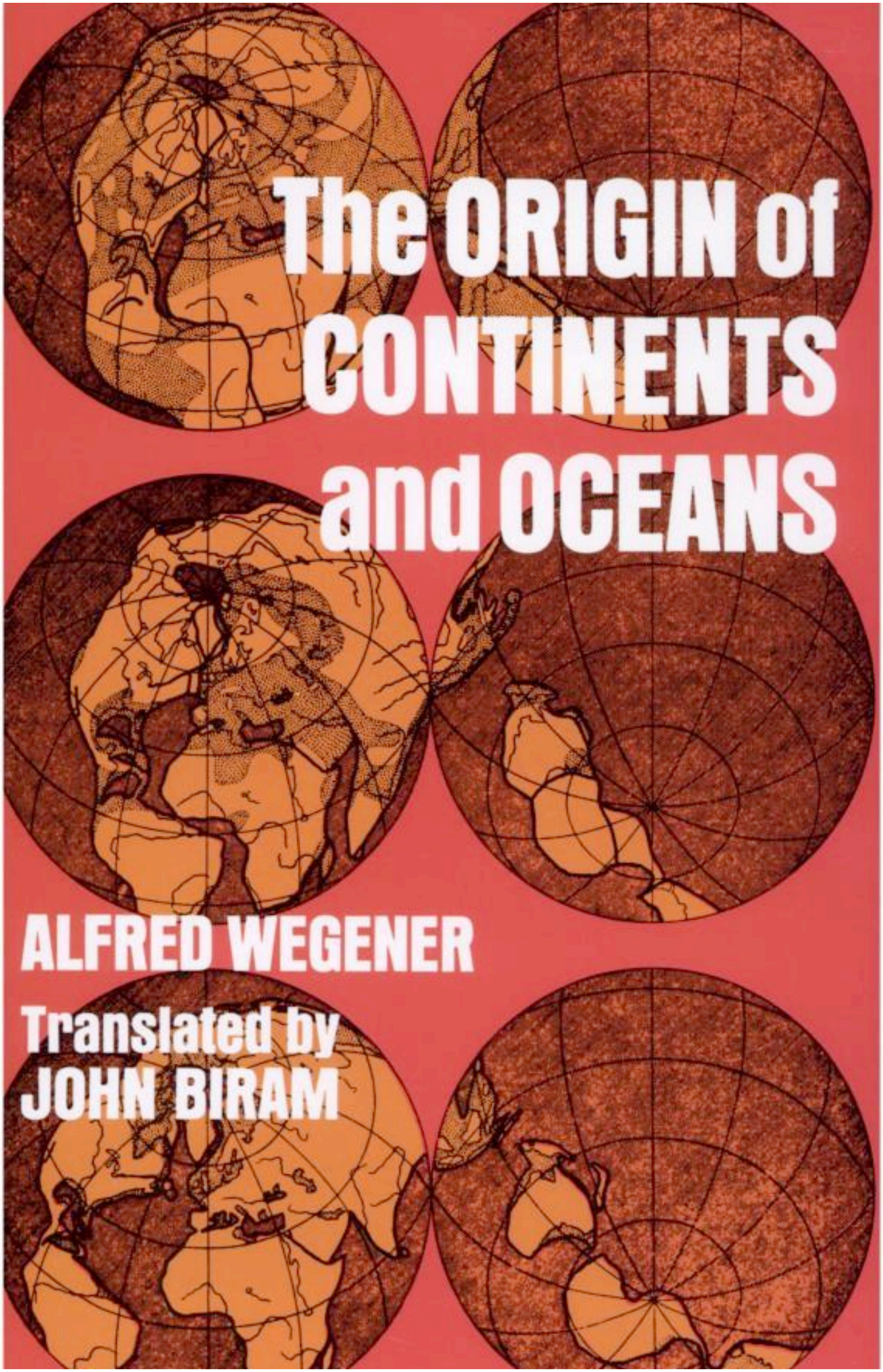
The ORIGIN of
CONTINENTS
and OCEANS
ALFRED WEGENER
Translated by
JOHN BIRAM

Alfred Wegener

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ALFRED WEGENER

Since its inception modern geology has been faced with an important group of problems: explaining parallel formations that are separated by great distances of sea; accounting for isolated life forms in widely separated areas (such as lemurs in Madagascar and India); explaining prepleistocene glaciations, and similar problems. The usual explanation has been to assume the one-time existence of land bridges (such as the hypothetical Lemuria) or parallelisms or diffusion with lost intermediary steps.

In 1915, however, one of the most influential and most controversial books in the history of science provided a new solution. This was Alfred Wegener's *Entstehung der Kontinente,* which dispensed with land bridges and parallel evolutions and offered a more economical concept. Wegener proposed that in the remote past the earth's continents were not separate (as now), but formed one supercontinent which later split apart, the fragments gradually drifting away from one another. Wegener created his supercontinent with attractive simplicity by tucking the point of South America into the Gulf of Guinea, coalescing North America, Greenland and Europe, rotating Australia and Antarctica up through the Indian Ocean, and closing the remaining gaps. Wegener then explained various phenomena in historical geology, geomorphy, paleontology, paleoclimatology and similar areas of science in terms of this continental drift. To back up his revolutionary theory he drew upon a seemingly inexhaustible fund of data. Later editions of his book added new data to refute his opponents or to strengthen his own views in the violent scientific quarrel that arose.

Even today this important question remains undecided, and geologists are divided into strongly opposed groups about the Wegener hypothesis. At the moment it seems to be gaining steadily in acceptance. It is one of the two basic theories of earth history, and since it has often been misrepresented in summary, every earth scientist owes it to himself to examine its theories and data.

Newly translated for Dover (1966) by John Biram, from the fourth (1929) German edition. 63 figures and portrait of Wegener. Index. x + 246pp. 5⅝ x 8½. Paperbound.

THE ORIGIN OF CONTINENTS AND OCEANS

BY

ALFRED WEGENER

Translated from the Fourth
Revised German Edition by
JOHN BIRAM

DOVER PUBLICATIONS, INC.
NEW YORK

Alfred Wegener

ALFRED WEGENER was born in Berlin on the 1st of November 1880, the youngest child of the evangelical preacher Dr. Richard Wegener and his wife Anna, née Schwarz. He attended the Köllnisches Gymnasium in Berlin and later studied at the Universities of Heidelberg, Innsbruck and Berlin. At the completion of his studies he entered the "Urania" at Berlin as an astronomer. However, he soon became a second technical assistant to his brother Kurt at the Prussian Aeronautical Observatory in Tegel. The two brothers carried out a joint balloon flight of 52½ hours, a record for that time; the flight began in Berlin and continued over Jutland and the Kattegat and then towards the Spessart area of Germany. The journey provided a test of the accuracy of the spirit-level clinometer as an instrument for flight navigation.

In 1906, Alfred Wegener went with a Danish national expedition to the northeast coast of Greenland for two years; on this expedition he learned the technique of polar travel. His published observations related essentially to meteorological questions. After returning from Greenland he became a lecturer in astronomy and meteorology at the University of Marburg. His lectures were the foundations of his textbook *Thermodynamik der Atmosphäre*, which went to three editions but is now out of print. In accordance with Alfred Wegener's plans, it was replaced by the book *Vorlesungen über Physik der Atmosphäre*, by Alfred and Kurt Wegener, published in 1935.

In 1912, together with J. P. Koch, Wegener undertook his second expedition to Greenland, with the purpose of spending a winter at the eastern edge of the inland ice, and then crossing Greenland at its widest part. The expedition was almost completely wrecked during the ascent of the inland glacier by intensive calving of the ice, which extended up to the encampment area. The crossing took place in 1913, after wintering, and lasted two months. The expedition was only just able to reach the west coast.

In 1914 Wegener was drafted as a reserve lieutenant of the Queen Elisabeth Grenadier Guards' Third Regiment and assigned to the field regiment. During the advance into Belgium he was shot through the arm. About fourteen days after his return to duty, a bullet lodged in his neck. As a result of this he was never fit for active duty again and was only employed in the field meteorological service. In 1915 the first edition of his book *Die Entstehung der Kontinente und Ozeane* appeared. This book was concerned with re-establishing the connection between geophysics on the one hand and geography and geology on the other, a connection which had been completely broken by specialist development of these branches of science. The second edition appeared in 1920, the third in 1922 and the fourth in 1929. Each edition was a complete revision, involving material compiled as a result of criticism, initially adverse, but subsequently interested. The third edition was translated into French in 1924 by M. Reichel under the title *La genèse des continents et des océans* and was published as a volume in the Librarie Scientifique Albert Blanchard, Paris. This edition was also translated into English by J. G. A. Skerl in the same year (*The Origin of Continents and Oceans*) with a foreword by the President of the English Geological Society, John W. Evans, C.B.E., F.R.S. This translation was published by Methuen & Co. Ltd., London. A Spanish translation of the third edition also came out in the same year, entitled *La génesis de los continentes y océanos*. The translator was Vicente Inglada Ors; the publisher, Biblioteca de la Revista de Occidente, Madrid. In 1925 G. F. Mirtzinka (Moscow and Leningrad) published a translation by Marii Mirtzink. In 1924 the work was supplemented by *Die Klimate der geologischen Vorzeit* by W. Köppen and A. Wegener (Verlag Gebrüder Bornträger).

After the war, Alfred, like his brother Kurt, became a departmental head at the German Marine Observatory in Hamburg, and he was also a lecturer in meteorology at the newly founded University of Hamburg. In 1924 he accepted an appointment as Professor of Meteorology and Geophysics at Graz University (Austria).

Wegener had planned a new Greenland expedition in collaboration with J. P. Koch, for 1928. The latter died in 1928 and this meant that the expedition had to be planned as a purely German affair. Wegener received the strong support of the German Research Association (Notgemeinschaft der Deutschen Wissenschaft; His Excellency Herr Schmidt-Ott, President). In 1929 he first of all clarified the question of the most favourable route up the inland icecap from the west coast. The main expedition began in 1930. Perhaps the most important result of the expedition was the discovery that the thickness of inland ice is more than 1800 metres.

In November 1930, Alfred Wegener met his death on the inland icecap.

Wegener had already decided by 1928 that a new revision of his book would be beyond him because the literature relevant to the problem had become too extensive and specialised for a single worker to survey. It was therefore his wish that any further edition that might prove necessary should appear without alteration.

KURT WEGENER

Foreword

SCIENTISTS still do not appear to understand sufficiently that all earth sciences must contribute evidence towards unveiling the state of our planet in earlier times, and that the truth of the matter can only be reached by combining all this evidence.

The well-known South African geologist du Toit wrote quite recently [78]: "As already stated, we must turn almost exclusively to the *geological* evidence to decide the probability of this hypothesis (continental drift), because arguments based on such matters as the distribution of fauna are not competent here; they can generally be explained equally well, even if less neatly, by the orthodox view that assumes the existence of extended land bridges, later sunk below sea level."

On the other hand, the palæontologist von Ihering [122] is short and to the point: "It is not my job to worry about geophysical processes." He holds to the "conviction that only the *history of life* on the earth enables one to grasp the geographical transformations of the past."

I myself in a weak moment once wrote of the drift theory [121]: "For all that, I believe that the final resolution of the problem can only come from *geophysics*, since only that branch of science provides sufficiently precise methods. Were geophysics to come to the conclusion that the drift theory is wrong, the theory would have to be abandoned by the systematic earth science as well, in spite of all corroboration, and another explanation for the facts would have to be sought."

It would be easy to add to the list of such opinions, each scientist deeming his own field to be the one most competent, or indeed the only one competent, to judge the issue.

Publisher's Note to the Last German Edition

In accordance with the author's express wish, and in appreciation of the great historical significance of this scientific document, we present the unrevised text of the fourth edition, as we did in the case of the fifth and sixth. We have avoided supplementation of the reference list, as was undertaken for the last editions, especially since the literature has increased meanwhile to an enormous extent. However, we did not want to omit the account of the life and work of Alfred Wegener prepared by his brother Kurt for the fifth edition. In all other respects this book is offered once again exactly as it came from the author's own hand.

Winter 1961 Editor and Publisher

In fact, however, the situation is obviously quite otherwise. At a specified time the earth can have had just one configuration. But the earth supplies no direct information about this. We are like a judge confronted by a defendant who declines to answer, and we must determine the truth from the circumstantial evidence. All the proofs we can muster have the deceptive character of this type of evidence. How would we assess a judge who based his decision on part of the available data only?

It is only by combining the information furnished by all the earth sciences that we can hope to determine "truth" here, that is to say, to find the picture that sets out all the known facts in the best arrangement and that therefore has the highest degree of probability. Further, we have to be prepared always for the possibility that each new discovery, no matter which science furnishes it, may modify the conclusions we draw.

This conviction gave me the stimulus to continue at times when my spirits failed me during the revision of this book. For it is beyond one man's power to follow up completely the details of the snowballing literature on drift theory in the various sciences. In spite of all my efforts, many gaps, even important ones, will be found in this book. That I was able to achieve the degree of comprehensiveness I did is due solely to the very large number of communications received from scientists in all the relevant fields, and I am most grateful for them.

The book is addressed equally to geodesists, geophysicists, geologists, palæontologists, zoogeographers, phytogeographers and palæoclimatologists. Its purpose is not only to provide research workers in these fields with an outline of the significance and usefulness of the drift theory as it applies to their own areas, but also mainly to orient them with regard to the applications and corroborations which the theory has found in areas other than their own.

Everything of interest concerning the history of this book, which is also the history of the drift theory, will be found in the first chapter.

The reader is referred to the Appendix for evidence of a shift of North America brought out by the new determinations of longitude in 1927; this result first appeared during the time the book was in proof.

Graz, November 1928 ALFRED WEGENER

Contents

CHAPTER 1

Historical Introduction

THE BACKGROUND to this book may not be wholly without interest. The first concept of continental drift first came to me as far back as 1910, when considering the map of the world, under the direct impression produced by the congruence of the coastlines on either side of the Atlantic. At first I did not pay attention to the idea because I regarded it as improbable. In the fall of 1911, I came quite accidentally upon a synoptic report in which I learned for the first time of palæontological evidence for a former land bridge between Brazil and Africa. As a result I undertook a cursory examination of relevant research in the fields of geology and palæontology, and this provided immediately such weighty corroboration that a conviction of the fundamental soundness of the idea took root in my mind. On the 6th of January 1912 I put forward the idea for the first time in an address to the Geological Association in Frankfurt am Main, entitled "The Geophysical Basis of the Evolution of the Large-scale Features of the Earth's Crust (Continents and Oceans)" ("Die Herausbildung der Grossformen der Erdrinde (Kontinente und Ozeane) auf geophysikalischer Grundlage"). A second address followed, this one on the 10th of January, delivered before the Society for the Advancement of Natural Science in Marburg under the title "Horizontal Displacements of the Continents" ("Horizontalverschiebungen der Kontinente"). In the same year, the two first publications also appeared [1, 2]. Further work on the theory was prevented by my participation in the crossing of Greenland led by J. P. Koch in 1912/1913, and later by war service. However, in 1915 I was able to make use of a prolonged sick-leave to furnish a rather more detailed account, with the same title as this volume and published by Vieweg [3]. When, after the end of the war, a second edition (1920) became necessary, the publisher was kind enough to transfer the book from the Sammlung Vieweg to the Sammlung Wissenschaft (Science Series); this made a more thoroughgoing revision possible. In 1922 appeared the third edition, again fundamentally improved, and in an unusually large printing so that I could work on other problems for a few years. It has been completely out of print for some time. A series of translations of this edition appeared, two Russian, one English, one French, one Spanish and one Swedish. I undertook to make a few changes in the German text for the Swedish translation, which appeared in 1926.

This fourth edition of the German original has once again been thoroughly revised; in fact, it has taken on an almost totally different character from its predecessors. When the previous edition was being written, there was already a comprehensive literature on continental drift which had to be taken into account. However, this literature was confined in the main to expressions of agreement or disagreement and to the citing of individual observations which spoke out or appeared to speak out either for or against the correctness of the theory; whereas since 1922, not only has the discussion of this question within the different earth sciences grown out of all proportion, but the very character of the discussion has altered to some extent. The theory is being used more and more as a basis for more extensive investigations. In addition, there is the recent precise evidence for the present-day shift of Greenland, which for many people has probably placed the discussion on a completely new footing. Therefore, while the earlier editions contained in essence merely a presentation of the theory itself and a collection of the individual facts in support of it, the present edition represents a transitional stage between the mere presentation of the theory and a synoptic exposition of these new branches of research.

Even when I was first occupied with this question, and also from time to time during the later development of the work, I encountered many points of agreement between my own views and those of earlier authors. As far back as 1857 Green spoke of "segments of the earth's crust which float on the liquid core" [63]. Rotation of the whole crust—whose components were supposed not to alter their relative positions—has already been assumed by several writers, such as Löffelholz von Colberg [4], Kreichgauer [5], Evans and others.

H. Wettstein wrote a book [6] in which (besides many inanities) the idea of large horizontal relative displacements of the continents is to be found. In his view, the continents—whose shelves he did not take into account—undergo not only displacement, but also deformation; they all drift westwards under tidal forces of the sun acting on the viscous material of the earth (an idea also held by E. H. L. Schwarz [7]). However, Wettstein, too, regarded the oceans as sunken continents, and he expressed fantastic views, which we pass over here, on the so-called geographical homologies and other problems of the earth's surface. Like myself, Pickering started out from the congruence of the southern Atlantic coastlines in a work [8] in which he expressed the supposition that America had broken away from Europe-Africa and was dragged the breadth of the Atlantic. However, he did not observe that one must in fact assume that an earlier connection between the two continents existed during their geological history up to the Cretaceous period, and he therefore assigned this connection to a dim and distant past, believing the breakaway to be bound up with G. H. Darwin's assumption that the moon was flung from the earth, and that traces of this can still be seen in the Pacific basin.

In a short article in 1909 Mantovani [86] expressed some ideas on continental displacement and explained them by means of maps which differ in part from mine but at some points agree astonishingly closely: for example, in regard to the earlier grouping of the southern continents around southern Africa. It was pointed out to me in correspondence that Coxworthy, in a book which appeared after 1890, put forward the hypothesis that today's continents are the disrupted parts of a once-coherent mass [9]. I have had no opportunity to examine the book.

I also discovered ideas very similar to my own in a work of F. B. Taylor's [10] which appeared in 1910. Here, he assumed by no means inconsiderable horizontal shifts of the individual continents in Tertiary times, and connected these with the large Tertiary systems of folding. He came to virtually the same conclusions as my own, for example, about the separation of Greenland from North America. In the case of the Atlantic, he assumed that only part of its width is due to drag displacement of the American land mass and that the rest is due to submergence and constitutes the mid-Atlantic ridge. This viewpoint, too, differs only quantitatively from my own, but not in crucial or novel ways. For this reason, Americans have sometimes called the drift theory the Taylor-Wegener theory. However, I have received the impression when reading Taylor that his main object was to find a formative principle for the arrangement of the large mountain chains and believed this to be found in the drift of land from polar regions; my impression is therefore that in Taylor's train of thought continental drift in our sense played only a subsidiary role and was given only a very cursory explanation.

I myself only became acquainted with these works—including Taylor's—at a time when I had already worked out the main framework of drift theory, and some of them I encountered much later on. It is of course not beyond the bounds of possibility that further works will be discovered in the course of time which will prove to contain elements of agreement with drift theory or to have anticipated a point here or there. Historical investigations have not been undertaken as yet and are not intended in the present book.

CHAPTER 2

The Nature of the Drift Theory and Its Relationship to Hitherto Prevalent Accounts of Changes in the Earth's Surface Configuration in Geological Times

It is a strange fact, characteristic of the incomplete state of our present knowledge, that totally opposing conclusions are drawn about prehistoric conditions on our planet, depending on whether the problem is approached from the biological or the geophysical viewpoint.

Palæontologists as well as zoo- and phytogeographers have come again and again to the conclusion that the majority of those continents which are now separated by broad stretches of ocean must have had land bridges in prehistoric times and that across these bridges undisturbed interchange of terrestrial fauna and flora took place. The palæontologist deduces this from the occurrence of numerous identical species that are known to have lived in many different places, while it appears inconceivable that they should have originated simultaneously but independently in these areas. Furthermore, in cases where only a limited percentage of identities is found in contemporary fossil fauna or flora, this is readily explained, of course, by the fact that only a fraction of the organisms living at that period is preserved in fossil form and has been discovered so far. For even if the whole groups of organisms on two such continents had once been absolutely identical, the incomplete state of our knowledge would necessarily mean that only part of the finds in both areas would be identical and the other, generally larger, part would seem to display differences. In addition, it is obviously the case that even where the possibility of interchange was unrestricted, the organisms would not have been quite identical in both continents; even today Europe and Asia, for example, do not have identical flora and fauna by any means.

Comparative study of *present-day* animal and plant kingdoms lead to the same result. The species found today on two such continents are indeed different, but the genera and families are still the same; and what is today a genus or family was once a species in prehistoric times. In this way the relationships between present-day terrestrial faunas and floras lead to the conclusion that they were once identical and that therefore there must have been exchanges, which could only have taken place over a wide land bridge. Only after the land bridge had been broken were the floras and faunas subdivided into today's various species. It is probably not an exaggeration to say that if we do not accept the idea of such former land connections, the whole evolution of life on earth and the affinities of present-day organisms occurring even on widely separated continents must remain an insoluble riddle.

Here is just one testimony amongst many: de Beaufort wrote [123]: "Many other examples could be given to show that it is impossible in zoogeography to arrive at an acceptable explanation of the distribution of animals if no connections between today's separate continents are assumed to have existed, and not only land bridges from which, as Matthew put it, only a few planks have been removed, but also such that joined land masses now separated by deep oceans."[1]

Obviously, there are many individual questions which are insufficiently explained by this theory. In many cases former land bridges have been assumed on the basis of very meagre evidence and have not been confirmed by the advance of research. In other cases there is still no complete agreement on the point in time when the connection was broken and the present-day separation began. However, in the case of the most important of these ancient land bridges, there does

[1] Arldt [135] states: "Of course, there are today still some opponents of the land-bridge theory. Among them, G. Pfeffer is worth special mention. He starts from the point that various forms now restricted to the southern hemisphere are manifest as fossils in the northern hemisphere. This precludes any doubt, he says, that these forms were once more or less universally distributed. If this conclusion is not completely compelling, still less is the further conclusion that we should assume a universal distribution even in all cases where there is a discontinuous distribution in the south but no fossil evidence as yet in the north. If he wants to explain distribution anomalies solely by migrations between the northern continents and their mediterranean bridges, the assumption rests on a very uncertain footing." That the affinities found on the southern continents can be explained more *simply* and *completely* by direct land bridges than by parallel migrations from the common northern region will require no further comment, even though in individual cases the processs could have been the one that Pfeffer assumed.

already exist today a gratifying unanimity among specialists, whether they base their conclusions on geographical distribution of the mammals or earthworms, on plants or on some other portion of the world of organisms. Arldt [11], using the statements or maps of twenty scientists,[2] has drawn up a sort of table of votes for or against the existence of the different land bridges in the various geological periods. For the four chief bridges, I have presented the results graphically in Figure 1. Three curves are shown for each

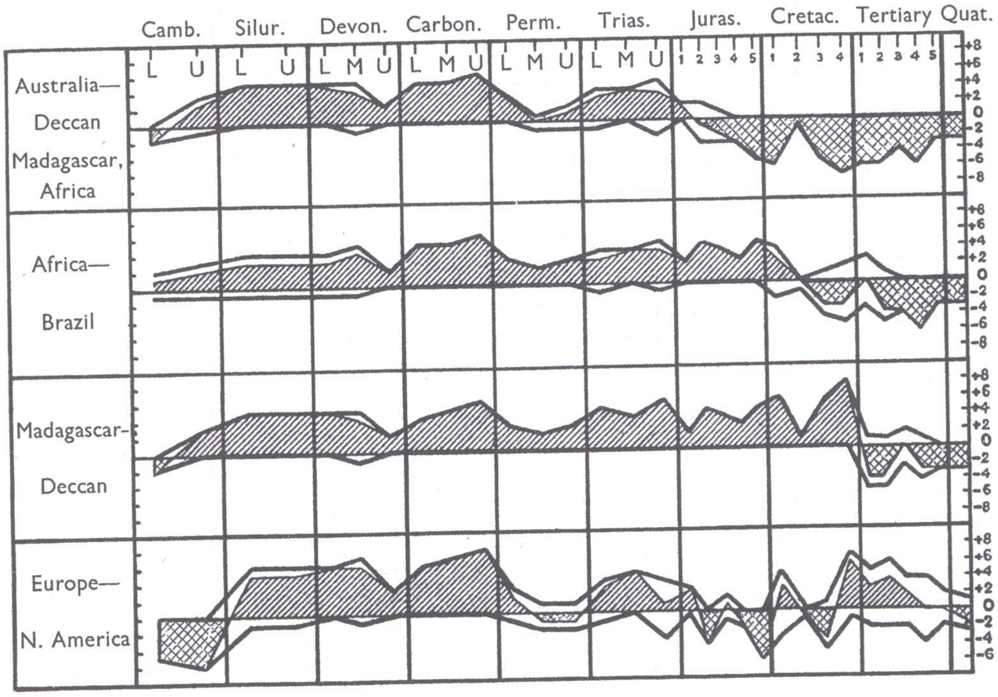

FIG. 1. The number of proponents (upper curves) and opponents (lower curves) of the existence of four land bridges since Cambrian times.

The difference (majority) is hatched, and crosshatched when the majority opposes.

bridge—the number of yeas, the number of nays and the difference between them, i.e., the strength of the majority vote, which is emphasised by hatching the appropriate area. Thus, the top section indicates that according to the majority of researchers the bridge between Australia on the one side and India, Madagascar and Africa

[2] Arldt, Burckhardt, Diener, Frech, Fritz, Handlirsch, Haug, von Ihering, Karpinsky, Koken, Kossmat, Katzer, Lapparent, Matthew, Neumayr, Ortmann, Osborn, Schuchert, Uhlig and Willis.

(ancient "Gondwanaland") on the other lasted from Cambrian times to the beginning of the Jurassic, but was then disrupted. The second section shows that the old bridge between South America and Africa ("Arch-helenis") is considered by most to have broken in the Lower to Middle Cretaceous. Still later, at the transition between Cretaceous and Tertiary, the old bridge between Madagascar and the Deccan ("Lemuria") is assumed by the majority to have broken (see section 3 of Fig. 1). The land bridge between North America and Europe was very much more irregular, as shown by section 4. But even here there is a substantial measure of agreement in spite of the frequent change in the behaviour of the curves. In earlier times the connection was repeatedly disturbed, i.e., in the Cambrian, Permian and also Jurassic and Cretaceous periods, but apparently only by shallow "transgressions," which permitted subsequent re-formation. However, the final breach, corresponding now to a broad stretch of ocean, can only have occurred in the Quaternary, at least in the north near Greenland.

Many of the details of this will be treated later in the book. Only one point is stressed here, so far not considered by the exponents of the land-bridge theory, but of great importance: These former land bridges are postulated not only for such regions as the Bering Strait, where today a shallow continental-shelf sea, or floodwater fills the gap, but also for regions now under ocean waters. All four examples in Figure 1 involve cases of this latter type. They have been chosen deliberately because it is precisely here that the new concept of drift theory begins, as we have yet to show.

Since it was previously taken for granted that the continental blocks—whether above sea level or inundated—have retained their mutual positions unchanged throughout the history of the planet, one could only have assumed that the postulated land bridges existed in the form of intermediate continents, that they sank below sea level at the time when interchange of terrestrial flora and fauna ceased and that they form the present-day ocean floors between the continents. The well-known palæontological reconstructions arose on the basis of such assumptions, one example of them, for the Carboniferous, is given in Figure 2.

This assumption of sunken intermediate continents was in fact the most obvious so long as one based one's stand on the theory of the contraction or shrinkage of the earth, a viewpoint we shall have to examine more closely in what follows. The theory first appeared in

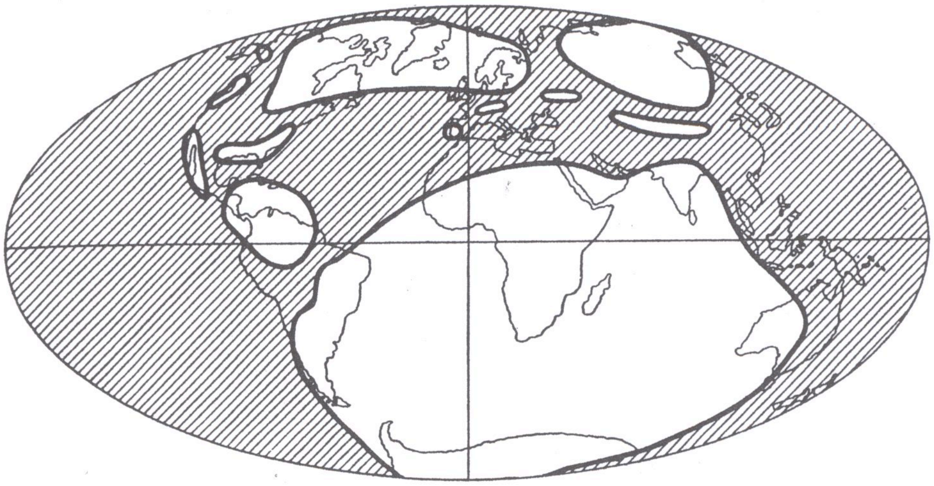

FIG. 2. Distribution of water (hatched) and land in the Carboniferous, according to the usual conception.

Europe. It was initiated and developed by Dana, Albert Heim and Eduard Suess in particular, and even today dominates the fundamental ideas presented in most European textbooks of geology. The essence of the theory was expressed most succinctly by Suess: "The collapse of the world is what we are witnessing" [12, Vol. 1, p. 778]. Just as a drying apple acquires surface wrinkles by loss of internal water, the earth is supposed to form mountains by surface folding as it cools and therefore shrinks internally. Because of this crustal contraction, an overall "arching pressure" is presumed to act over the crust so that individual portions remain uplifted as horsts. These horsts are, so to speak, supported by the arching pressure. In the further course of time, these portions that have remained behind may sink faster than the others and what was dry land can become sea floor and vice-versa, the cycle being repeated as often as required. This idea, put forth by Lyell, is based on the fact that one finds deposits from former seas almost everywhere on the continents. There is no denying that this theory provided historic service in furnishing an adequate synthesis of our geological knowledge over a long period of time. Furthermore, because the period was so long, contraction theory was applied to a large number of individual research results with such consistency that even today it possesses a degree of attractiveness, with its bold simplicity of concept and wide diversity of application.

Ever since our geological knowledge was made the subject of that impressive synthesis, the four volumes by Eduard Suess entitled *Das Antlitz der Erde*, written from the standpoint of contraction theory, there has been increasing doubt as to the correctness of the basic idea. The conception that all uplifts are only apparent and consist merely of remnants left from the general tendency of the crust to move towards the centre of the earth, was refuted by the detection of absolute uplifts [71]. The concept of a continuous and ubiquitous arching pressure, already disputed on theoretical grounds for the uppermost crust by Hergesell [124] has proved to be untenable because the structure of eastern Asia and the eastern African rift valleys have, on the contrary, enabled one to deduce the existence of tensile forces over large portions of the earth's crust. The concept of mountain folding as crustal wrinkling due to internal shrinkage of the earth led to the unacceptable result that pressure would have to be transmitted inside the earth's crust over a span of 180 great-circle degrees. Many authors, such as Ampferer [13], Reyer [14], Rudzki [15] and Andrée [16], among others, have opposed this quite rightly, claiming that the surface of the earth would have to undergo regular overall wrinkling, just as the drying apple does. However, it was particularly the discovery of the scale-like "sheet-fault structure" or overthrusts in the Alps which made the shrinkage theory of mountain formation, which presented enough difficulties in any case, seem more and more inadequate. This new concept of the structure of the Alps and that of many other ranges, which was introduced by the works of Bertrand, Schardt, Lugeon and others, leads to the idea of far larger compressions than did the earlier theory. Following previous ideas, Heim calculated in the case of the Alps a 50% contraction, but on the basis of the sheet-faulting theory, now generally accepted, contraction of $\frac{1}{4}$ to $\frac{1}{8}$ of the initial span [17]. Since the present-day width of the chain is about 150 km, a stretch of crust from 600 to 1200 km wide (5–10 degrees of latitude) must have been compressed in this case. Yet in the most recent large-scale synthesis on Alpine sheet-faults, R. Staub [18] agrees with Argand that the compression must have been even greater. On page 257 he concludes:

"The Alpine orogenesis is the result of the northward drift of the African land mass. If we smooth out only the Alpine folds and sheets over the transverse section between the Black Forest and Africa, then in relation to the present-day distances of about 1800 km, the original distance separating the two must have been about 3000 to 3500 km, which means an alpine compression (in the wider sense of the word Alpine) of around 1500 km. Africa must have been displaced relative to Europe by this amount. What is involved here is a true continental drift of the African land mass and an extensive one at that."[3]

Other geologists have put forward similar views, as for example F. Hermann [106], E. Hennig [19] or Kossmat [21], who states "that the formation of mountains must be explained by large-scale tangential movements of the crust, which cannot be incorporated in the scope of the simple contraction theory." In the case of Asia, Argand [20], especially, has developed an analogous theory in the course of a comprehensive investigation to which we shall return later. He and Staub have done the same for the case of the Alps. No attempt to relate these enormous compressions of the crust to a drop in temperature of the earth's core can be anything but a failure.

Moreover, even the apparently obvious basic assumption of contraction theory, namely that the earth is continuously cooling, is in full retreat before the discovery of radium. This element, whose decay produces heat continuously, is contained in measurable amounts everywhere in the earth's rock crust accessible to us. Many measurements lead to the conclusion that even if the inner portion had the same radium content, the production of heat would have to be incomparably greater than its conduction outwards from the centre, which we can measure by means of the rise of temperature with depth in mines, taking into account the thermal conductivity of rock. This would mean, however, that the temperature of the earth must rise continuously. Of course, the very low radioactivity of iron meteorites suggests that the iron core of the earth presumably contains much less radium than the crust, so that this paradoxical conclusion can

[3] It seems that estimations of the size of the Alpine compression are always on the increase. Staub wrote recently [214, similarly in 215]: "If we now, however, imagine these Alpine sheets, which are probably stacked twelvefold, to be smoothed out again . . ., the solid Alpine hinterland would necessarily lie much further south, and the original distance between foreland and hinterland would probably have been ten to twelve times greater than it is today." He adds: "Formation of a mountain range therefore originates quite clearly and certainly from independent drifting of larger blocks, surely continental blocks by their structure and composition; and thus, starting from Alpine geology and Hans Schardt's sheet theory, we arrive quite obviously and naturally at the acknowledgment of the basic principle of the great Wegener theory of continental drift."

perhaps be avoided. In any case, it is no longer possible, as it once was, to consider the thermal state of the earth as a temporary phase in the cooling process of a ball that was formerly at a higher temperature. It should be regarded as a state of equilibrium between radioactive heat production in the core and thermal loss into space. In fact, the most recent investigations into this question, which will be discussed in more detail later on, imply that actually, at least under the continental blocks, more heat is generated than is conducted away, so that here the temperature must be rising, though in the ocean basins conduction exceeds production. These two processes lead to equilibrium between production and loss rate, taking the earth as a whole. In any case, one can see that through these new views the foundation of the contraction theory has been completely removed.

There are still many other difficulties which tell against the contraction theory and its mode of thinking. The concept of an unlimited periodic interchange between continent and sea floor, which was suggested by marine sediments on present-day continents, had to be strictly curtailed. This is because more precise investigation of these sediments showed with increasing clarity that what was involved was coastal-water sediments, almost without exception. Many sedimentary deposits formerly claimed as oceanic proved to be coastal; one example is chalk, as proved by Cayaux. Dacqué [22] has given a good review of the problem. Only in the case of a very few types of sediment, such as the low-lime Alpine radiolarites and certain red clays reminiscent of the red deep-sea clay, is formation in deep waters (4–5 km) still assumed today, particularly since sea water dissolves out lime only at great depths. However, the area of these true deep-sea deposits on present-day continents is so tiny compared with the areas of the continents and the areas of coastal water sediments on them that the theory of the basically shallow-water nature of marine fossil deposits on present-day continents is unaffected. For the contraction theory, however, a considerable difficulty arises. Since coastal shallows must be counted, geophysically, as part of the continental blocks, the nature of these marine fossils implies that these blocks have been "permanent" throughout the history of the earth and have never formed ocean floors. Are we then still to assume that today's sea floors were ever continents? The justification for this conclusion is obviously removed by establishing that the marine sediments found on continents were formed in shallows. But more than this, the conclusion now leads to an open contradiction. If we reconstruct intercontinental bridges of the type shown in Figure 2, thus filling up a large part of today's ocean basins without having the possibility of compensating for this by submergence of present-day continental regions to the sea-floor level, there would be no room for the volume of the world's oceans in the now much reduced deep-sea basins. The water displacement of the intercontinental bridges would be so enormous that the level of the world's oceans would rise above that of the whole continental area of the earth and all would be flooded, today's continents and the bridges alike. The reconstruction would not therefore achieve the desired end, i.e., dry land bridges between continents. Figure 2 therefore represents an impossible reconstruction unless we introduce further hypotheses which are "ad hoc" improbabilities; for example, that the mass of ocean water was exactly the required amount less at the former period than it is today, or that the deep-sea basins remaining at that time were precisely the required amount deeper than today. Willis and A. Penck, among others, have brought up this peculiar difficulty.

Of the many objections to contraction theory, one more only will be emphasised; it has very special importance. Geophysicists have decided, mainly on the basis of gravity determinations, that the earth's crust floats in hydrostatic equilibrium on a rather denser, viscous substrate. This state is known as *isostasy*, which is nothing more than hydrostatic equilibrium according to Archimedes' principle, whereby the weight of the immersed body is equal to that of the fluid displaced. The introduction of a special word for this state of the earth's crust has some point because the liquid in which the crust is immersed apparently has a very high viscosity, one which is hard to imagine, so that oscillations in the state of equilibrium are excluded and the tendency to restore equilibrium after a perturbation is one which can only proceed with extreme slowness, requiring many millennia to reach completion. Under laboratory conditions, this "liquid" would perhaps scarcely be distinguishable from a "solid." However, it should be remembered here that even with steel, which we certainly consider a solid, typical flow phenomena occur, just before rupture, for example.

An example of perturbation of isostasy of the crust is shown by the load to which an inland icecap subjects it. The result is that the crust slowly sinks under this load and tends towards a new equilibrium position to correspond with the loading. When the icecap has melted, the original position of equilibrium is gradually resumed, and the shore lines formed during the process of depression are elevated along with the crust. The "isobase charts" of de Geer [23], drawn up from the shore lines, show for the last glaciation of Scandinavia a central depression of at least 250 m, gradually decreasing towards the perimeter; for the most extensive of the Quaternary glaciations still higher values must be assumed. In Figure 3 we reproduce a chart

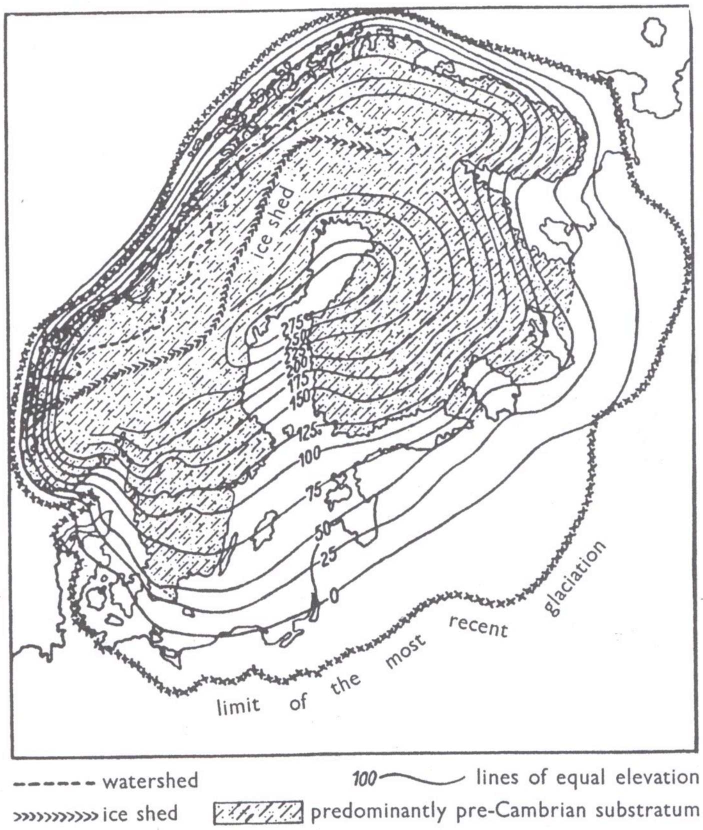

FIG. 3. Post-glacial elevation contours (in metres) for Fennoscandia (according to Högbom).

of this post-glacial elevation of "Fennoscandia" (Finland, Sweden and Norway) according to Högbom (taken from Born [43]). The same phenomenon has been proved by de Geer to have occurred for the glaciated region of North America. Rudzki [15] has shown that, assuming isostasy, plausible values for the thickness of inland ice layers can be calculated, i.e., 930 m for Scandinavia and 1670 m for North America, where the depression amounted to 500 m. Because of the viscosity of the substrate the equilibration movements naturally lag far behind: the shore lines generally formed only after the melting of the ice, but before the elevation of the land, and even today Scandinavia is still rising by about 1 m in 100 years, as shown by tide-gauge readings.

Even sedimentary deposits result in a subsidence of the blocks, as Osmond Fisher was probably the first to recognise: every deposition from above leads to a subsidence of the block, somewhat delayed of course, so that the new surface occupies almost the same level as the old. In this way many kilometres' thickness of deposit can arise and yet all the layers are formed in shallow water.

Later on we shall examine the theory of isostasy more closely. Here we shall simply say that it has been established by geophysical observations over so wide a range that it is now part of the solid foundation of geophysics and its basic truth can no longer be doubted.[4]

One can see immediately that this result runs quite counter to the ideas of contraction theory and that it is very hard to combine one with the other. In particular, it seems impossible, in view of the isostatic principle, that a continental block the size of a land bridge of required size could sink to the ocean bottom without a load or that the reverse should happen. Isostasy is therefore in contradiction not only to contraction theory, but in particular also to the theory of sunken land bridges as derived from the distribution of organisms.[5]

[4] Americans, e.g., Taylor [101], sometimes mean by "isostasy" Bowie's theory of the origin of geosynclines and mountain ranges. According to Bowie [224], the initial elevation of sediment-filled basins, the geosynclines, comes from a rise in their isotherms, and hence a volumetric expansion. Once this has led to a land elevation, erosion sets in and a jagged mountain range is formed, whose substrate continually rises due to reduction in loading. Finally, the isotherms are raised to an abnormal height by this elevation, and begin to move slowly downwards; the block cools and contracts and the surface sinks; a depression is formed from the mountain region and renewed sedimentation occurs. This produces further depression or subsidence until the isotherms are abnormally low in level, then rise again, and so on over many cycles. This concept, which cannot be applied to the great folded ranges with their overthrusts, as Taylor and others have emphasised, does indeed make use of the principle of isostasy but should not be given the simple title of "the theory of isostasy."

[5] The objections to the contraction theory enumerated here are mainly directed against its typical earlier form. Very recently, attempts have been made to modernise the theory and to answer the objections, partly by restricting it and partly by adding hypotheses; various authors have been involved, such as Kober [24], Stille [25], Nölcke [26], and Jeffreys [102], among others. This is also true of the theory publicised by R. T. Chamberlin [160] which supposes contraction to be caused by "rearrangement" of material in the earth resulting from the planetesimal origin of the earth accepted by this author. Although one cannot deny

In the foregoing, we deliberately reviewed the objections to contraction theory in some detail. This is because in one part of the train of thought discussed here another theory is rooted; this is known as the "theory of permanence" and is especially widespread among American geologists. Willis [27] formulated it as follows: "The great ocean basins constitute permanent features of the earth's surface, and have with little change in shape occupied the same positions as now since the ocean waters were first gathered." In fact, we have already referred above to the fact that the marine sediments on present-day continents were formed in shallow waters, and we deduced that the continental blocks as such have been permanent throughout the earth's history. Isostasy theory proves the impossibility of regarding present-day ocean floors as sunken continents, and this extends the scope of the result based on marine sediments to comprise a general permanence of deep-sea floors and continental blocks. Further, since here, too, the apparently obvious assumption was made that the continents have not changed their relative positions, Willis's formulation of the "permanence theory" appears to be a logical conclusion from our geophysical knowledge, disregarding, of course, the postulate of former land bridges, derived from the distribution of organisms. So we have the strange spectacle of two quite contradictory theories of the prehistoric configuration of the earth being held simultaneously—in Europe an almost universal adherence to the idea of former land bridges, in America to the theory of the permanence of ocean basins and continental blocks.

It is probably no accident that the permanence theory has its most numerous adherents in America: geology developed late there—thus simultaneously with geophysics—and this necessarily led to more rapid and complete adoption by geology of the results advanced by its sister science than in Europe. There was absolutely no temptation to make the contraction theory, which contradicts geophysics, one of the basic assumptions. It was quite otherwise in Europe, where geology already had a long period of development behind it before geophysics had produced its first results, and had, without benefit of geophysics, already arrived at an overall view of

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that these attempts show a certain adroitness in pursuit of their aim, one cannot say that they really refute the objections, nor that they have brought the contraction theory into satisfactory agreement with new research, especially in the field of geophysics. A thorough discussion of this neo-contraction theory must, however, be dispensed with here.

the earth's evolution in the form of the contraction theory. It is quite understandable that it is difficult for many European scientists to free themselves completely from this tradition and that they view the results of geophysics with a mistrust that never completely fades.

However, where does the truth lie? The earth at any one time can only have had one configuration. Were there land bridges then, or were the continents separated by broad stretches of ocean, as today? It is impossible to deny the postulate of former land bridges if we do not want to abandon wholly the attempt to understand the evolution of life on earth. But it is also impossible to overlook the grounds on which the exponents of permanence deny the existence of sunken intermediate continents. There clearly remains but one possibility: there must be a hidden error in the assumptions alleged to be obvious.

This is the starting point of displacement or drift theory. The basic "obvious" supposition common to both land-bridge and permanence theory—that the relative position of the continents, disregarding their variable shallow-water cover, has never altered—must be wrong. The continents must have shifted. South America must have lain alongside Africa and formed a unified block which was split in two in the Cretaceous; the two parts must then have become increasingly separated over a period of millions of years like pieces of a cracked ice floe in water. The edges of these two blocks are even today strikingly congruent. Not only does the large rectangular bend formed by the Brazilian coast at Cape São Roque mate exactly with the bend in the African coast at the Cameroons, but also south of these two corresponding points every projection on the Brazilian side matches a congruent bay on the African, and conversely. A pair of compasses and a globe will show that the sizes are precisely commensurate.

In the same way, North America at one time lay alongside Europe and formed a coherent block with it and Greenland, at least from Newfoundland and Ireland northwards. This block was first broken up in the later Tertiary, and in the north as late as the Quaternary, by a forked rift at Greenland, the sub-blocks then drifting away from each other. Antarctica, Australia and India up to the beginning of the Jurassic lay alongside southern Africa and formed together with it and South America a single large continent, partly covered by shallow water. This block split off into separate blocks in the course of the Jurassic, Cretaceous and Tertiary, and the sub-blocks drifted

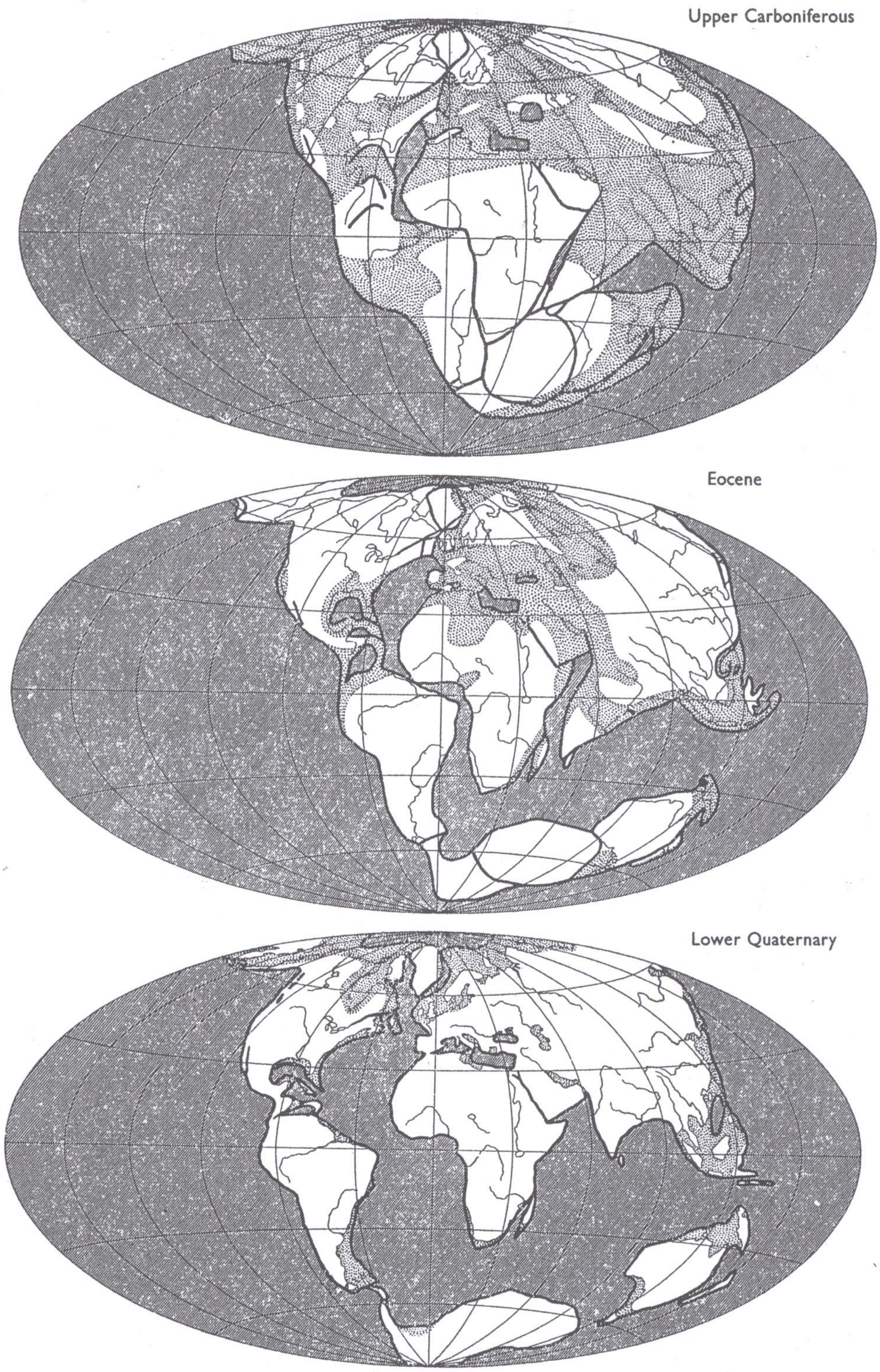

FIG. 4. Reconstruction of the map of the world according to drift theory for three epochs.

Hatching denotes oceans, dotted areas are shallow seas; present-day outlines and rivers are given simply to aid identification. The map grid is arbitrary (present-day Africa as reference area; see Chapter 8).

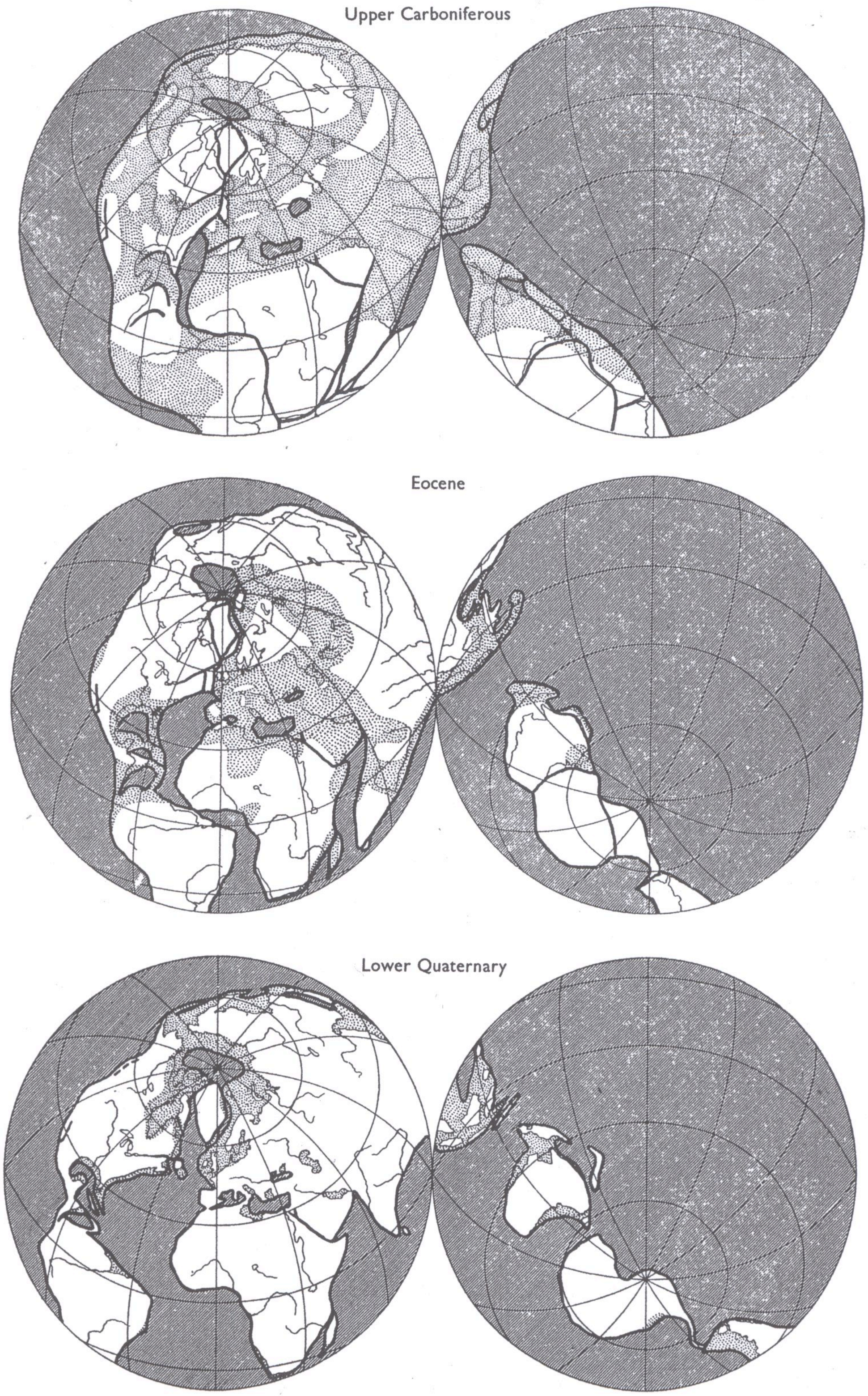

FIG. 5. Same as Fig. 4, in different projection.

away in all directions. Our three world maps (Figs. 4 and 5) for the Upper Carboniferous, Eocene and Lower Quaternary show this evolutionary process. In the case of India the process was somewhat different: originally it was joined to Asia by a long stretch of land, mostly under shallow water. After the separation of India from Australia on the one hand (in the early Jurassic) and from Madagascar on the other (at the transition from Tertiary to Cretaceous), this long junction zone became increasingly folded by the continuing approach of present-day India to Asia; it is now the largest folded range on earth, i.e., the Himalaya and the many other folded chains of upland Asia.

There are also other areas where the continental drift is linked causally with orogenesis. In the westward drift of both Americas, their leading edges were compressed and folded by the frontal resistance of the ancient Pacific floor, which was deeply chilled and hence a source of viscous drag. The result was the vast Andean range which extends from Alaska to Antarctica. Consider also the case of the Australian block, including New Guinea, which is separated only by a shelf sea: on the leading side, relative to the direction of displacement, one finds the high-altitude New Guinea range, a recent formation. Before this block split away from Antarctica, its direction was a different one, as our maps show. The present-day east coastline was then the leading side. At that time New Zealand, which was directly in front of this coast, had its mountains formed by folding. Later as a result of the change in direction of displacement, the mountains were cut off and left behind as island chains. The present-day cordilleran system of eastern Australia was formed in still earlier times; it arose at the same time as the earlier folds in South and North America, which formed the basis of the Andes (pre-cordilleras), at the leading edge of the continental blocks, then drifting as a whole before dividing.

We have just mentioned the separation of the former marginal chain, later the island chain of New Zealand, from the Australian block. This leads us to another point: smaller portions of blocks are left behind during continental drift, particularly when it is in a westerly direction. For instance, the marginal chains of East Asia split off as island arcs, the Lesser and Greater Antilles were left behind by the drift of the Central American block, and so was the so-called Southern Antilles arc (South Shetlands) between Tierra del Fuego and western Antarctica. In fact, all blocks which taper off towards the south exhibit a bend in the taper in an easterly direction because the tip has trailed behind: examples are the southern tip of Greenland, the Florida shelf, Tierra del Fuego, the Graham Coast and the continental fragment Ceylon.

It is easy to see that the whole idea of drift theory starts out from the supposition that deep-sea floors and continents consist of different materials and are, as it were, different layers of the earth's structure. The outermost layer, represented by the continental blocks, does not cover the whole earth's surface, or it may be truer to say that it no longer does so. The ocean floors represent the free surface of the next layer inwards, which is also assumed to run under the blocks. This is the geophysical aspect of drift theory.

If drift theory is taken as the basis, we can satisfy all the legitimate requirements of the land-bridge theory and of permanence theory. This now amounts to saying that there were land connections, but formed by contact between blocks now separated, not by intermediate continents which later sank; there is permanence, but of the area of ocean and area of continent as a whole, but not of individual oceans or continents.

Detailed substantiation of this new concept will form the chief part of the book.