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The New View of the Earth

Moving Continents and Moving Oceans

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W. H. Freeman and Company
San Francisco

新しい地球観・・動く大陸・動く大洋

Translator's Note: I acknowledge with gratitude the generous help of Dr. Hiroo Kanamori and Ms. Lilla Weinberger, without whom my translation could not have been completed. —*M. O.*

Library of Congress Cataloging in Publication Data

Uyeda, Seiya, 1929–
A new view of the Earth.

Translation of Atarashii Chikyukan.
Bibliography: p.
Includes index.
1. Continental drift. I. Title.
QE511.5.U93-1-3 551.1'3 77-9900
ISBN 0-7167-0283-5
ISBN 0-7167-0282-7 pbk.

ATARASHII CHIKYUKAN (The New View of the Earth)
by Seiya Uyeda

Originally published in Japanese by IWANAMI SHOTEN, Publishers, Tokyo.

Printed in the United States of America

1 2 3 4 5 6 7 8 9

Preface

This book is a translation of the original Japanese edition *Atarashii Chikyukan (The New View of the Earth)*, published in 1972. For the English version, I have made extensive additions, in both the text and the illustrations, to incorporate still more recent developments in our current understanding of the earth, and I have omitted some material that did not seem relevant to readers outside of Japan.

A number of my friends contributed to the initial writing of the book: in particular, Dr. Hiroo Kanamori, Dr. Kazuaki Nakamura, Dr. Masashi Yasui, and my wife Matsuko Uyeda all had valuable comments to make on the Japanese edition, and Sir Edward Bullard and Dr. Frank Press had additional suggestions for this one. Dr. Allan Cox has gone through the text with meticulous care, and greatly improved both its science and its language. Robert Geller and Seth Stein read the proofs and suggested a number of important changes that I have incorporated into the final book. I also thank my translator Mrs. Masako Ohnuki and my editor Michele Liapes for their painstaking efforts.

September, 1977 Seiya Uyeda

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Introduction

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Rapid Progress Versus Eternal Questions

In recent years truly dramatic discoveries in scientific research have unfolded, and progress has accelerated at a stunning pace. One reason is the advent of the electronic computer, which enables us to compile enormous amounts of data into meaningful categories, so that the multitudes of observations can be applied to the development of significant and universal concepts. The current abundance of new ideas is evident in the succession of papers now being written. Of the modern sciences, the field of earth science is beginning to be the most rapidly advancing. In particular, that area concerned with the solid part of the earth has recently undergone phenomenal changes of the sort that occur only rarely in any one field. They are remarkable changes—of interest to the layman as well as to the scientist—and I shall describe them in the chapters that follow.

The rapid progress does not mean, however, that all the questions have been completely resolved. In fact, recently, while still writing this book, I recalled an article of the late 1940s enumerating six important unresolved questions that were important at the time. It was not until I contacted my old friend Keiiti Aki of the Massachusetts Institute of Technology, with whom I had read and discussed the article so many years ago when both of us as undergraduates were looking for problems to tackle, that I was able to locate it. He promptly forwarded a copy to me, thanking me for reminding him of the memorable piece. It was a lecture entitled "Some Unsolved Problems of Geophysics" by L. H. Adams (1947) the president of the American Geophysical Union, and the six problems were the following:

(1) the origin of the mountain chains;
(2) the origin of geosynclines (deep basins filled with sediments);
(3) the cause of volcanoes and other igneous activity;
(4) the cause of deep earthquakes;
(5) the origin of the earth's magnetic field;
(6) the temperatures prevailing in the interior of the earth.

Although these problems were not the *only* existing questions of importance, all six were indeed significant. Furthermore, none of them have yet been completely solved; all of them remain as important as ever. To be sure, some people may argue, "Look at how many of these problems we *have* solved!" But have we really? This issue is going to be one of the main themes of this book. Indeed, as any earth scientist will agree, these problems have been considered crucial not only since the 1940s, but for hundreds of years. The progress of earth science may not be as rapid as it seems after all.

Some Peculiarities of Earth Science

How is it that, despite the rapid progress, we have not answered many fundamental questions about the earth? The fact is that many basic problems of earth science defy answer by means of direct experiments. This poses considerable difficulties for us. Consider, for instance, the sixth of Adams' problems—the temperature of the earth's interior. It is simply not possible—at least at the present time—to *measure* the temperature at the center of the earth. One can merely deduce it indirectly from other evidence.

Then, continental drift and movements within the earth—the central topics of this book—are beset by similar difficulties. The mere penetration of the deep interior of the earth would itself be a difficult task, but the measurement of movements at great depth is beyond the capability of any known instrument or method because of the vast scale of the deep movements and their extreme slowness. Consequently it is very difficult for us to prove by direct observation the actual existence of such phenomena. Even if we can eventually detect the present movements of the continents in relation to one another by precise geodetic measurements of distances, using such instruments as a laser reflector on the surface of the moon, this will in no way prove that similar continental movements occurred in the remote geological past. The continental shifts, splits, and collisions that have occurred throughout the earth's history are once-in-a-lifetime phenomena; and the components involved in these movements have been too massive, and the period of time too vast, for reproduction in the laboratory.

These, then, are the problems that make the basic issues of earth science so difficult to resolve despite the new discoveries that have been made and the storehouse of information that is now accumulating. Indeed, they might lead us to wonder if research in such a field has any validity at all. The potential solution to a problem sometimes seems to become more elusive as research advances, so that the gap between them remains virtually unchanged. However progress *is* being made because our understanding of the scope and significance of the basic problems in earth science is becoming more profound. Perhaps we are not learning to ask better questions, but at least we are beginning to understand more clearly the meanings of our questions.

The difficulty of direct verification is a serious one in earth science, and almost inherent in the field. Yet advances in observation and theory justify more and more the use of indirect verification and bring us increasingly nearer to the truth.

The Uniqueness of Earth Science

Paradoxically, the fact that solutions to these problems have been hard to come by may have helped earth scientists. We have been obliged to examine and observe patiently many seemingly unrelated phenomena. These observations have led us to propose daring new hypotheses. Then, to prove them, we have had to seek additional and unshakable observations to support them, no matter how indirect such observations might be. The successful combination of the basic field work of earth science with the more abstract concepts of physics and chemistry has been a triumph that geologists savor. The unknown mechanisms—such as those responsible for the origin of the earth, for convection within the mantle, for the origin of the earth's magnetic field, and for deep-focus earthquakes—seem to offer a special challenge and appeal to the earth scientist. The approaches to this challenge vary widely, as do the intellectual tastes and motivations of individuals: for there are many types of people, and human wisdom is advanced by the efforts of all of them.

Insight

Scientific research includes various types of work. At least two processes are necessary—(1) the accumulation of data by experiment and observation, and (2) the analysis and theorization of that data. Many individual researchers tend to focus on one or the other of these processes, depending on their own inclinations. The modern age demands highly refined skills in any one aspect of the work, thereby creating niches for people who specialize in one of the following categories: experimentation, observation, analysis, or theory. Such specialization is unavoidable to a certain extent. A true researcher, however, should not allow himself to become immersed in one to the exclusion of the others. For example, it is possible for one to get so absorbed in taking measurements day and night, that he forgets to think. But if his work is to be really valuable, he must back his efforts by sound reasoning.

Indeed, good research requires a deep understanding of the scope of basic problems and a high degree of trained perception. Only too often superficial ideas and notions are mistaken for genuine creative thought. Although such ideas in themselves should not be discouraged, what the theoretician really needs is the special ability called *insight*—that capacity to select the genuinely promising idea from the others and to develop it into a theory or a set of predictions that can be experimentally verified. It is the most important quality a scientist can have.

The concepts treated in this book are the results of true scientific insight. It was insight that produced an important shift in our perspective of the earth—from a *fixist* view of an unchanging and stable body to a *mobilist* view of drifting land masses and ocean basins.

Outline of the Book

Throughout the book, general background in earth science will be provided for lay readers. In the first chapter we will discuss the history of the theory of continental drift, first introduced by Alfred Wegener. It was a theory that enjoyed temporary popularity after its introduction, followed by denunciation and rejection as an almost heretical idea. It then experienced a dramatic revival after World War II, owing to the introduction of paleomagnetism, which is the study of the history of the earth's magnetic field by means of the natural magnetization of rocks.

In the second chapter we will outline the findings in ocean floor geology that helped to revive the theory of continental drift. In this field, too, fantastic progress has been made since World War II, yielding an enormous amount of information that we could not have obtained from research limited to the land.

The theories of sea-floor spreading and plate tectonics will be outlined in the third and fourth chapters. The theory of sea-floor spreading is based on the idea that the ocean floor is created at the mid-oceanic ridges, spreads out horizontally, and disappears in the deep trenches. This theory was a remarkable synthesis of numerous independent data, and its dramatic success resulted in the even more fascinating concept of plate tectonics. Basically, the earth's surface is thought to consist of about 10 plate-like solid blocks, approximately 70 kilometers thick, which interact with one another. A further application of this concept to the past suggests that such interactions have been the primary cause of mountain building and other large-scale movements of the earth's crust throughout the earth's geologic history.

In Chapter 5 we shall examine island arcs from the new perspective of plate tectonics, using Japan as an example. The Japanese island arcs form part of a circum-Pacific belt of volcanoes, large earthquakes, deep trenches, and faults that are assumed to have been caused by the underthrusting of the floor of the Pacific Ocean beneath the Asian continent.

In the last chapter, we will describe the transition from the so-called fixist to the mobilist view of the earth, along with the possible driving mechanisms of plate tectonics.

大陸移動説・その誕生・死・および復活

Chapter 1

The Theory of Continental Drift: Its Birth, Death, and Revival

Wegener's Idea

In 1912 the German scientist Alfred Wegener (1880–1930) proposed a new theory.* He maintained that the continents on either side of the Atlantic—the North American and South American continents and the European-African continent—were once joined and that they had split and drifted apart into their present positions. He insisted that all other continents, including India, Australia, Africa, and Antarctica, also belonged to the one gigantic protocontinent. He named this great hypothetical continent *Pangaea.* Figure 1-1 illustrates the process of continental breakup. Wegener believed that Pangaea was united until the late Carboniferous period, about 300 million years ago, and then began to split apart, ending up in the present distribution of continents. Since Pangaea was the only continent, it was surrounded by one enormous ocean. No individual oceans, such as the Atlantic, Indian, or Antarctic, existed at that time. This was the essential idea of continental drift. It was a spark that generated a new view of the earth.

The source of Wegener's idea was the realization that the outlines of the continents fit like the pieces of a jigsaw puzzle. This conformity can be seen by anyone who looks closely at the coastlines along

*It is true that the idea of continental drift dates back, long before Wegener, to A. Snider (in 1858) and even to F. Bacon (in 1620). But it was Wegener who first made the case an important scientific issue.

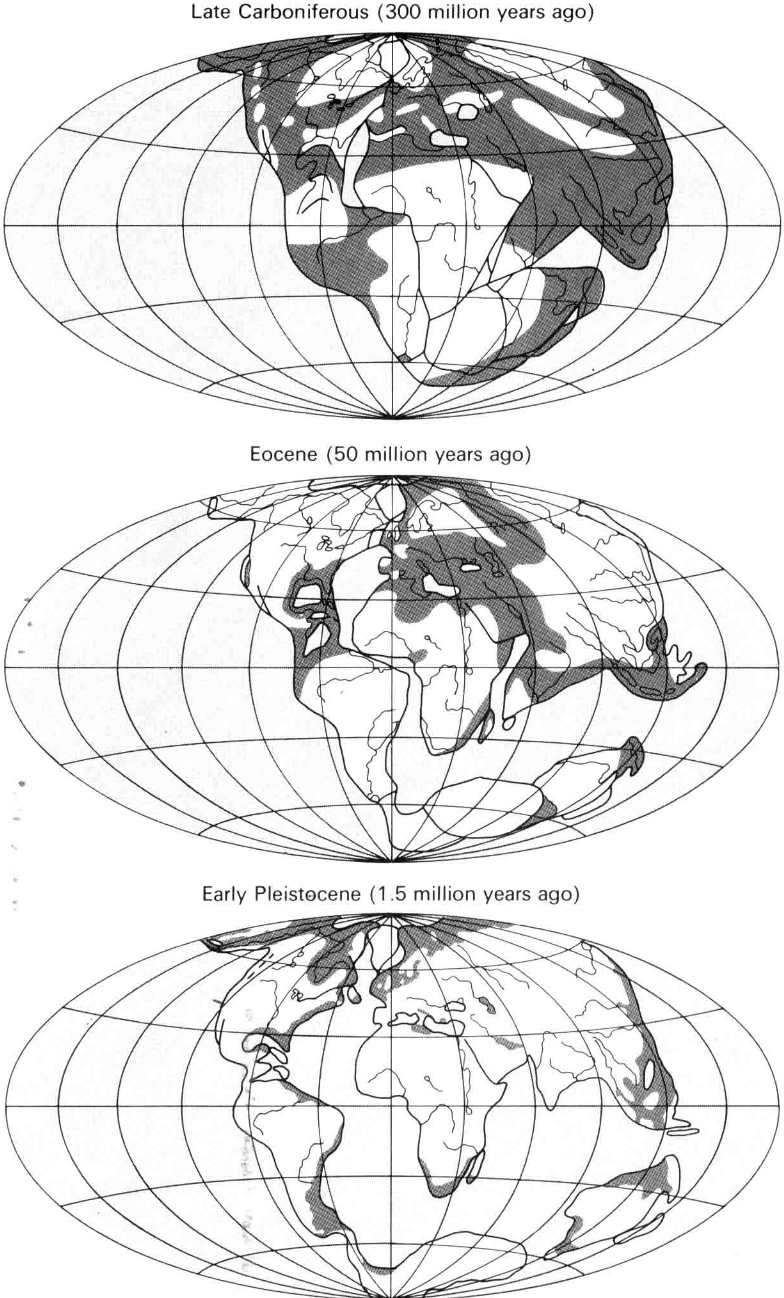

FIGURE 1-1
Reconstruction of the map of the world for three periods according to Wegener's theory of continental drift. Africa is placed in its present-day position as a standard of reference. The heavily shaded areas represent shallow seas. Ages in millions of years have been added. [After A. Wegener, *The Origin of Continents and Oceans*. Methuen, London, 1924.]

FIGURE 1-2
Alfred Wegener. [Photo from Historical Pictures Services, Inc., Chicago.]

the Atlantic Ocean. The idea, simple as it was, was considered preposterous at the time because it conflicted with the universal belief that the earth was immobile.

Wegener (Figure 1-2), a meteorologist by profession, was one of the pioneers in the field of high-altitude meteorological observation. Also his exploration of the previously unpenetrated continent of Greenland contributed to the research in this area. The culmination of these diverse activities was the conception and development of his theory of continental drift. It began as a simple idea, but Wegener did not allow it to remain as such: he pursued it resolutely and systematized the theory. It was because of this perseverance that he was a great scientist. Ideas occur to any scientist from time to time. But he fails to develop most of them, and then forgets them because they seem either too fantastic or impractical. The majority of them are indeed useless. Wegener confessed that he himself considered the possiblity of continental drift to be fantastic and impractical, and at first did nothing about it. However, unlike many scientists who abandon interesting ideas and regret it later, Wegener began to develop his seemingly simple theory. His search for new knowledge started with the study of geology and paleontology, fields remote from his speciality. This project, conceived in 1910, was interrupted by his expeditions to Greenland and his military service during World War I, in which he was injured. Yet such obstacles did not deter him. In 1915 he published his monumental work, *Die Entstehung der Kontinente und Ozeane (The Origin of Continents and Oceans)*, and by 1923 had revised it three times. In 1924, he published *Die Klimate der Geologischen Vorzeit (The Climate Through Geological Time)* with a meteorologist, W. Köppen. During this period he also published a great many other papers. These works were the fruit of his revolutionary view of the earth as developed from the concept of continental drift. It was as if modern solid earth science had evolved within the mind of this one man who was tens of years ahead of everyone else.

The Geologic Method

As a meteorologist, Wegener needed more than anything else a knowledge of geology for his pursuit of the history of continental drift. We, too, need an understanding of the basics of geology in order to grasp Wegener's ideas.

The two following fundamental principles that geologists apply when studying the history of the earth are particularly important:

(1) *The law of superposition.* If one stratum (or layer) overlies another, the top stratum is younger than the bottom one.

(2) *The law of faunal assemblage.* Strata that contain fossils of the same species of animals and plants were produced in the same period.

The first law is self-evident: without the existence of the prior stratum, the new stratum could not be deposited on top of it. This law enables us to detect the chronological relationships of the stratified rocks in one place.

The law of faunal assemblage gives us clues about the time relationships among strata scattered in different places. Everyone knows that all forms of life are constantly undergoing evolution. The process might seem slow to us, but considered on a geological time scale it is actually quite rapid. Primitive life forms first appeared on the earth about three billion years ago, and gradually evolved into more complex creatures. This one-way trend of evolution—from the simple to the complex—has enabled us to identify the chronological age of the strata by the fossils (such as trilobites and dinosaurs) preserved within them. Figure 1-3 gives the geological ages as determined by the fossils of animals and plants. The study of fossils is called paleontology and constitutes quite an elaborate system of science. These names of geological eras, periods, and epochs—each with its own legitimate and interesting origin—will be mentioned throughout this book.

Informative though it is, the paleontologic method has two intrinsic limitations. The first is the amount of time that we can go back. As shown in Figure 1-3, it is only in the strata of the past 600 million years or so that plant and animal fossils are complex enough that we can use them to compare the ages of the strata. There are not enough fossils in the older strata to date them. This early period with few or no fossils is in a way a prehistoric, or biological, "dark age," and is called the Precambrian era. The second limitation is that it cannot provide us with "absolute" chronology, since it uses the evolution of animals and plants as its clock. It can determine, for instance, that stratum A is older than B, but it cannot tell us how old either stratum is or how much older A is than B.

Such limitations have been overcome in recent years, thanks to the development of methods of absolute age determination. From the spontaneous disintegration of such radioactive elements as the uranium, thorium, strontium, and potassium that are contained in rocks in small amounts, we can determine the absolute age of the rocks. These radioactive elements constantly and regularly transform into other elements in accord with what is called the law of disintegration. This transformation can be considered a kind of evolution, too, but unlike that of plants and animals, the exact rate of transformation has been determined by physicists. The absolute ages given in Figure 1-3 have been obtained by this method.

Geological strata consist of either igneous rocks or sedimentary rocks. Igneous rocks are primary rocks formed by the cooling and

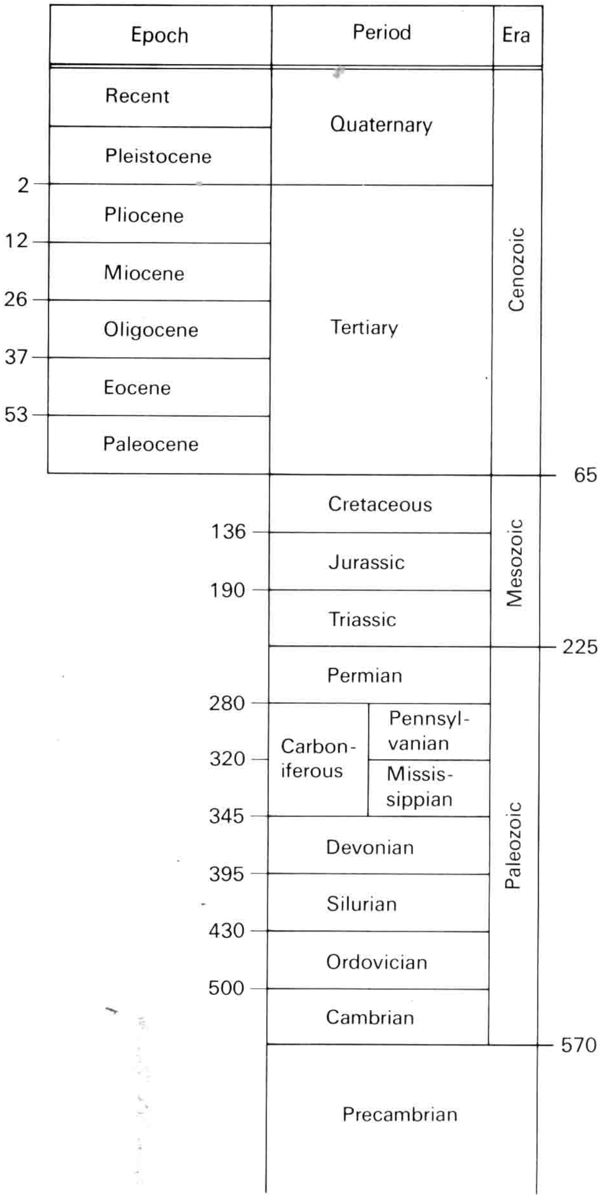

FIGURE 1-3
The geologic time scale. The numbers at the sides of the column are ages in millions o years. [After F. Press and R. Siever, *Earth*. W. H. Freeman and Company. Copyright © 1974.]

solidification of magma; sedimentary rocks are secondary rocks formed as a result of erosion and deposition. Sediments are called secondary because most of the particles transported by water and deposited were originally parts of other rocks on land. Most of the rocks we see in strata at the present time are sedimentary rocks. Thus the surface of the land is almost completely covered with sedimentary rocks—even mountain ranges as high as the Alps and the Himalayas, meaning that these great mountain tops were once under water!

Suppose some region is elevated high above sea level: at this point in time deposition ceases and erosion takes over. Even the highest mountains are gradually eroded into level land. The history of an elevated region that has undergone erosion is very difficult to trace because no sedimentary record exists and the history can be studied only indirectly through the record of erosion. If this region is submerged once again, the deposition process will resume and a more complete record of the geologic history will start to accumulate. Any geologist knows for a fact that the rocks forming many of the mountains were once deposited underwater, but the initial idea can be quite a shock. I remember well my own surprise when I first heard it.

The Land Bridge

If the continents now scattered in the world oceans once formed a single enormous continent, the strata that existed before the breakup would have to be related to one another. Moreover, the strata that formed after the split would be unrelated. To establish this hypothesis and thus confirm his theory of continental drift, Wegener set out to gather evidence. His skepticism about the concept, he explains, was overcome when he came across a paleontological paper discussing the possibility that Brazil had once been linked to Africa. It came as a surprise to Wegener to find that such an assertion had already been put forth, quite independently of his hypothesis of continental drift. But it is exactly this point that I find interesting, because it seems to demonstrate the importance of the *perspective* from which one interprets scientific data. As an amateur in paleontology, Wegener was unaware of any evidence suggesting the ancient connection among continents, and yet paleontologists had long been studying this very possibility. The established interpretation of this concept, however, was entirely different from Wegener's. It was the land-bridge theory.

Having surveyed the distribution of fossils of such animals as monkeys, earthworms, and snails, and of various kinds of plants, paleontologists observed that close affinities prevailed between Africa and South America, Europe and North America, Madagascar and India. For example, since such organisms as snails cannot swim