THE MORPHOLOGY OF THE EARTH

A STUDY AND SYNTHESIS OF WORLD SCENERY

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INTRODUCTION

Our realm of study is the outer part of the earth, and our subject is its evolution, principally from the Mesozoic era to the present day. In a spirit of patient enquiry we seek to find order, system and if possible explanation amid the major topographic features of the globe.

The synthetic study of such a realm has required field work upon a scale that only modern transport could have provided, for very early in the research a principle emerged that is more important then the research itself; that while the geologist may often be in error the Earth is never wrong. It was necessary for the author to see as much of the earth's surface as possible, yet not to interpret it in terms of preconceived philosophies; often to sit passively upon hills just letting the scenery " soak in " and teach the beholder —when he was sufficiently humble.

But even in this age no man can cover the entire earth and recourse had to be made to libraries for further information. This has exposed fearful inadequacies in the coverage of certain regions, even admitting the insufficiency of sources available to the writer. For these and other reasons no attempt has been made to provide even coverage for the earth's surface. Much useful data has been assembled in F. Matchatschek's *Das Relief der Erde* (Borntraeger), and the reader may be well advised to proceed with the present volume in one hand and Matchatschek in the other. Students are further recommended A. K. Lobeck's *Physiographic Diagrams* (Columbia Geographical Press) of the several continents.

Very early, an optimum of about 500 pages of text was set for the book. To approach this the original manuscript has been cut time and again, and many topics have been omitted on the assumption that the reader was already sufficiently familiar with them. Always the attempt has been to provide data that are less familiar but withal to adduce a series of comparative examples illustrating principles that the reader could then apply to his own experience.

The research is set out in no spirit of idle iconoclasm but in a bright seeking of truth from the earth itself, and if at the end our path is strewn with broken, though cherished, hypotheses—a cooling, shrinking earth, growing continents, immobile continents, compressional mountain ranges, cyclic denudation by downwearing and others—why so much the better for Geology, so long as the new hypotheses explain the facts of earth structure more truly. Their turn to retire gracefully will come with equal certainty.

My gratitude is here expressed to the University of Natal which has granted special

study leave for field work on a number of occasions. Also, the University and the Council for Scientific and Industrial Research have contributed towards the cost of preparing the illustrations. Credits for figures have been scrupulously assigned, though I have not always been able to contact their authors for permission to publish. To them also my thanks are due. The courtesy of the following publishers is also acknowledged: Geological Society of America, *Geographical Review*, American Association Petroleum Geologists, Messrs. Harper and Brothers, Geological Society of London, Scottish Geographical Society, Messrs. Pergamon Press, *Revue Geographie Physique et Geologie Dynamique*, American Museum of Natural History, New Zealand Geological Survey, Illinois State Geological Survey, Columbia Geographical Press, (C. S. Hammond and Co.).

Lastly, this proface would be incomplete without acknowledgement of the deep enjoyment that I have derived from the research: not only from the lands and peoples that I have visited (and may hope to visit in the future), but also in my home. Into a tiny study roughly ten feet square have entered mighty vistas—sunrise upon great plains, tangled tropical jungles, towering snow-clad mountains and tempestuous seas. It has been fun to spend an occasional weekend in the Andes, or snatch a rare visit to Cambodia before dinner. And though I have not been exempt from " language difficulties " these foreign travels at home have usually been without " let or hindrance " which is much to be appreciated in these official-ridden days.

LESTER KING

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PART A

THE BASIS OF SCENERY: THE BEHAVIOUR OF THE EARTH'S CRUST

CHAPTER I

THE STRUCTURE OF THE EARTH'S CRUST

Genesis. Fundamental Rock Types. The Layered Crust. Properties of Sub-crustal Matter. Isostasy and Isobary. Crustal Temperatures. Igneous Action. Radiothermal Energy of the Rocks. Sub-crustal Convection Currents. Continental Drift. Some Dead Wood : a Digression. Palæogeography. Model of the Earth.

GENESIS

"In the beginning, the earth was without form and void." It was born of a heavenly body about 4,500 million years ago; and for a long period thereafter no record remains of earth's nature or of its behaviour. But more than 3,000 million years ago rocks existed, physically and chemically similar to sedimentary rocks that are forming today, which suggests that geological and meteorological conditions at the surface of the globe had then stabilised and were similar to those now prevailing.

If sedimentary rocks were forming, then scenery existed, with mountains and valleys and plains and deltas, and a primeval ocean beating upon a primeval shore. The aspect of those early lands was stark, for the terrains were devoid of life and the transition from one landform to another, from rocky hill to gravel plain or desert dunes, was abrupt without true soils or plant cover to smooth out the contours. Everywhere the aspect of the lands was such as we now find only in the great deserts—the Sahara, the Mohave or the Namib.

Of these early landscapes no vestige remains and we shall consider them no further, but ever since there has been scenery, and the earth's face has been remade from each geological age to the next as global forces have periodically elevated new regions into mountains which in turn have been torn down and levelled into plains by the forces of erosion. The rival tectonic and denudational powers, predominantly constructional and destructional respectively, share in fashioning the surface of the solid globe and their constant interplay forms the theme of this book.

Although most of our scenic study, as developed in the sequel, deals with landscapes which have existed only since the Jurassic period at earliest, we must never overlook the long processions of kaleidoscopic landscapes that have evolved throughout earlier geologic time; for the structural traits and limitations inherited from earlier periods frequently influence modern scenic evolution. Thus the Appalachian folds of Palæozoic time still control the ridge-and-valley topography of that province in North America; and in my own sub-tropical city of Durban visitors are frequently taken to see the glacial pavements polished by glaciers of Carboniferous age, now being exhumed from beneath thick Dwyka tillite by modern erosion or by human activities. Scenic studies must therefore often take cognizance of geologic events that long precede the development of modern landscapes.

We shall first consider in this chapter the nature and behaviour of the earth's crust, which constitutes the very basis of scenery.

Fundamental Rock Types

The materials of the earth-body are rocks. Of the three main categories of rocks—igneous, sedimentary and metamorphic—the second and third are patently remade from previous rocks, so that only igneous rocks can be regarded as primary or in a pristine state. Even so, researches upon "granitization" have shown that much supposedly primary igneous rock is earlier rock-material that has been plutonically metamorphosed even to the stage at which refusion has occurred (Sederholm 1923, 1926; Read 1955; Reynolds 1949, 1958). Whether any primary igneous rock (in the strict sense) is now visible at the earth's surface may be doubted. The most likely examples are among the plateau basalts and peridotite intrusions. But at greater depths within the crust the proportion of pristine igneous matter may increase.

Natural division of igneous rocks into three distinct chemical groups acid, basic and ultrabasic, represented respectively by granite or granodiorite, gabbro (basalt) and peridotite, is widespread. Each type has its own characteristic mode of occurrence and appears distinctively in association with certain tectonic conditions (Chapters I, II, IV). In a general way too, each type is associated with certain levels in the earth's crust; granodiorite in the high-standing continental masses, basalt at the level of the ocean floors and beneath the continents, while peridotite exists typically at still greater depths. All igneous rock types other than these three are developed only to a minor extent, and many are plainly derived by magmatic differentiation or assimilation from one or other of the three main types.

The distinctive importance of these three types has promoted enquiry whether they represent three primary magmatic types separated one from another very early in the earth's cooling history, or whether they may be derived from one another by processes of magmatic differentiation acting progressively throughout geological time to produce ever greater segregation. Abundant evidence (Tyrrell 1926) leads to the conception of acid and basic magma types as distinct throughout known geologic time. To this, Hess and his co-workers (1932) have added primary peridotite magmas which they regard, indeed, as the principal heat-bringers of all igneous activity.

The Layered Crust

The earth is a globe, and its radial structure is a product partly of its original composition and partly of processes active during geologic time. The bulk of the earth-body (the mantle) is believed to consist of olivine or peridotite, about which is a thin envelope of basic material like basalt. In the continents appears a light acid or granitic portion. Layering is concentric according to density. The outermost layers behave towards stresses of short period as though rigid, and are termed the earth's crust. Below this the earth-body is apparently weak for hundreds of kilometres, material even in the crystalline state being deformed plastically (p. 12). The crust is relatively thin, its base, known as the Mohorovičić discontinuity, being situated at an average depth of about 35 Km. beneath the continents and of 5 Km. beneath the oceans. Sharp downwarping of the "Moho" is thus characteristic of continental margins (Fig. 1).

Much information upon the structure of the outer earth has been derived by analysis of both natural and artificial earthquake waves transmitted through it. Earthquakes originate at any level from the surface down to depths of 700 Km. and this

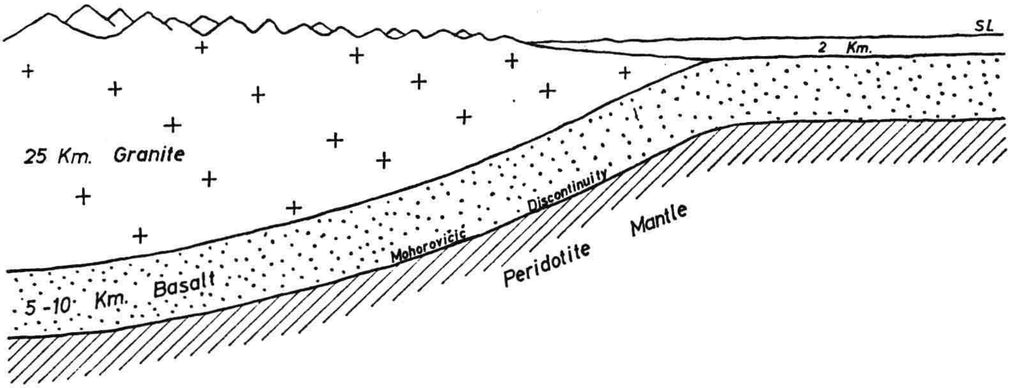

FIG. 1. Simple interpretation of a crustal section at the margin of a continent.

affords a classification of shocks into: *Normal* earthquakes originating above a depth of 100 Km., *Intermediate* shocks from that depth down to 300 Km., and *Deep-Focus* earthquakes known to originate from between 300 and 700 Km. The great majority of shocks belong to the shallow class, and are tectonic in origin, often being demonstrably connected with present faulting or volcanic activity. The intermediate shocks are generally associated with zones of Cainozoic folding and faulting. The deep-focus earthquakes, which may be connected with early-Cainozoic or late-Cretaceous events about the Pacific border are registered from three regions only, the Mediterranean, the island arcs of the western Pacific and from beneath Andean South America. In these regions they are associated with abundant normal and intermediate shocks in such a way that all could be thought of as originating on deep-reaching shear-zones extending from the Pacific side towards and beneath the landward areas. Benioff (1954), who points out that stress may accumulate even in the deep zones for more than a decade, has interpreted the shears as compressional but evidence cited later in connection with island arcs suggests rather a tensional origin (Fig. 2).

The structure of continents, as deduced from the passage of earthquake waves, has been expressed by Gutenberg and Richter (1951): " The typical continental structure consists of a series of layers, the uppermost of which is of the sedimentary rocks (including metamorphosed sediments). The elastic constants within this layer, as well as its thickness, are subject to much local variation. Over large areas the sediments are completely absent, whereas in deep basins of geosynclinal character they may extend to depths over 15 Km. Where the sediments are absent, the exposed rocks are usually granitic (basaltic in volcanic regions); moreover in many localities granitic rocks are known to underlie the existing sediment. Investigations still in progress indicate that the velocity of longitudinal waves in that upper part of the continental crust which is commonly called the ' granitic layer ' increases from about 6 Km./sec., near the surface to (locally) as much as $6\frac{3}{4}$ Km./sec., at a depth of roughly 10 Km. and possibly

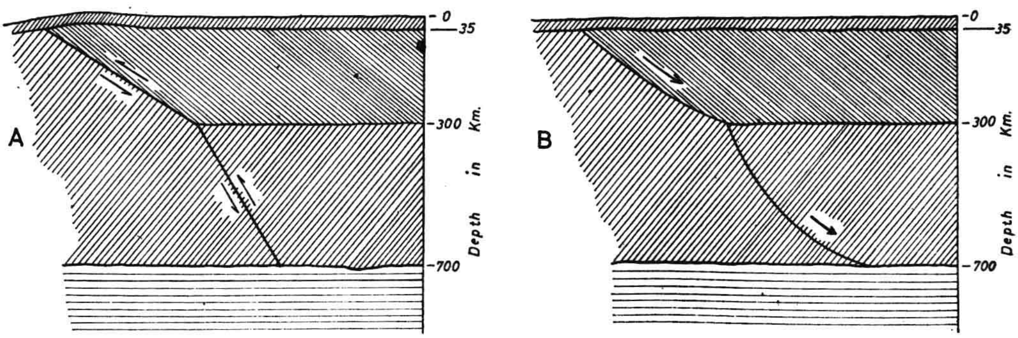

FIG. 2. Compressional (A) and Tensional (B) interpretations of earth structure from records of shallow, intermediate and deep earthquake foci. (A) *after H. Benioff.* (B) *Reinterpreted.*

decreases below this to about 6 Km./sec. This decrease may be attributed, at least partly, to an effect of increasing temperature on the moduli of elasticity. Most of the earthquake foci seem to be in this low-velocity layer ".

" Below the ' granitic layer ' one to three crustal layers have been identified. Their thicknesses and elastic properties differ notably in the various regions. It has been suggested that in this intermediate layer (or layers) the material is basaltic. The lower boundary of these layers is the Mohorovičić discontinuity."

Estimates, based on seismic analysis, of the thickness of the granitic crust, and of the whole continental thickness, have been given by Gutenberg (1936) (Table I).

Analysis of trans-oceanic earthquake waves (Angenheister 1920) reveals the floor of the deep Pacific Basin as devoid of granite—evidently from primordial time. Its floor is heavily basaltic, perhaps of an oceanite type, though Tilley (1951) has preferred tholeiite for the actual floor with more olivinic types below. An earthquake shock in the Aleutian Islands, recorded at Lwiro in the Belgian Congo was noted by Kovach (1959) to have complementary paths that were almost entirely continental and oceanic (Fig. 3).

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