Benchmark Papers
in Geology / 33

A BENCHMARK Books Series

WEST INDIES ISLAND ARCS

Edited by

PETER H. MATTSON

Benchmark Papers in Geology / 33

A BENCHMARK ® Books Series

WEST INDIES ISLAND ARCS

Edited by

PETER H. MATTSON

Queens College

Dowden, Hutchinson & Ross, Inc.

STROUDSBURG, PENNSYLVANIA

Benchmark Papers in Geology, Volume 33
Library of Congress Catalog Card Number: 76-28214
ISBN: 0-87933-196-8

79 78 77 1 2 3 4 5
Manufactured in the United States of America.

LIBRARY OF CONGRESS CATALOGING IN PUBLICATION DATA
Main entry under title:
West Indies island arcs.
(Benchmark papers in geology ; 33)
Bibliography: p. 361
Includes index.
1. Geology—West Indies—Addresses, essays, lectures. 2. Island arcs—West Indies—Addresses, essays, lectures. I. Mattson, Peter H.
QE220.W36 557.29'08 76-28214
ISBN 0-87933-196-8

Exclusive Distributor: **Halsted Press**
A Division of John Wiley and Sons, Inc.
ISBN: 0-470-98964-5

SERIES EDITOR'S FOREWORD

The philosophy behind the "Benchmark Papers in Geology" is one of collection, sifting, and rediffusion. Scientific literature today is so vast, so dispersed, and, in the case of old papers, so inaccessible for readers not in the immediate neighborhood of major libraries that much valuable information has been ignored by default. It has become just so difficult, or so time consuming, to search out the key papers in any basic area of research that one can hardly blame a busy man for skimping on some of his "homework."

This series of volumes has been devised, therefore, to make a practical contribution to this critical problem. The geologist, perhaps even more than any other scientist, often suffers from twin difficulties—isolation from central library resources and immensely diffused sources of material. New colleges and industrial libraries simply cannot afford to purchase complete runs of all the world's earth science literature. Specialists simply cannot locate reprints or copies of all their principal reference materials. So it is that we are now making a concerted effort to gather into single volumes the critical material needed to reconstruct the background of any and every major topic of our discipline.

We are interpreting "geology" in its broadest sense: the fundamental science of the planet Earth, its materials, its history, and its dynamics. Because of training and experience in "earthy" materials, we also take in astrogeology, the corresponding aspect of the planetary sciences. Besides the classical core disciplines such as mineralogy, petrology, structure, geomorphology, paleontology, and stratigraphy, we embrace the newer fields of geophysics and geochemistry as applied also to oceanography, geochronology, and paleoecology. We recognize the work of the mining geologists, the petroleum geologists, the hydrologists, the engineering and environmental geologists. Each specialist needs his working library. We are endeavoring to make his task a little easier.

Each volume in the series contains an Introduction prepared by a specialist (the volume editor)—a "state of the art" opening or a summary of the object and content of the volume. The articles, usually some twenty to fifty reproduced either in their entirety or in significant extracts, are selected in an attempt to cover the field, from the key papers of the last century to fairly recent work. Where the original works are in foreign

languages, we have endeavored to locate or commission translations. Geologists, because of their global subject, are often acutely aware of the oneness of our world. The selections cannot, therefore, be restricted to any one country, and whenever possible an attempt is made to scan the world literature.

To each article, or group of kindred articles, some sort of "highlight commentary" is usually supplied by the volume editor. This commentary should serve to bring that article into historical perspective and to emphasize its particular role in the growth of the field. References, or citations, wherever possible, will be reproduced in their entirety—for by this means the observant reader can assess the background material available to that particular author, or, if he wishes, he, too, can double check the earlier sources.

A "benchmark," in surveyor's terminology, is an established point on the ground, recorded on our maps. It is usually anything that is a vantage point, from a modest hill to a mountain peak. From the historical viewpoint, these benchmarks are the bricks of our scientific edifice.

RHODES W. FAIRBRIDGE

PREFACE

An introduction to the geology of the West Indies is, on the one hand, an easily limited subject because the islands have definite borders and are relatively small. The most superficial study reveals, however, that many interesting aspects lead outside the islands to the continents on the north, south, and west, and to the Atlantic Ocean on the east. This volume attempts to cover the main aspects of Caribbean geology, and several of the introductions and papers give references to broader areas and topics than can be contained here.

The volume includes 20 complete papers and segments of 16 other papers. The training and interests of the editor have of course slanted the coverage, toward geologic history, tectonics, and petrogenesis of the geological elements of the Caribbean islands and basins. Perhaps the most cursorily covered subjects are paleontology and geomorphology, but these would require a much larger volume and so are only included as references. Several classic papers are too long to be included, the prime example being the 1940 paper by Alfred Senn on Barbados. The editor attempted to enlarge the volume's coverage by including the 16 excerpts or abstracts of some significant longer papers which would otherwise have been omitted.

Helpful discussions and correspondence with Alice Boiteau, Marshall Kay, H. J. MacGillavry, John C. Maxwell, and A. A. Meyerhoff are gratefully acknowledged. Ms. Boiteau kindly checked translations of her two papers included here. Research Librarians Clare Mayers and Priscilla Heinz of Lamont-Doherty Geological Observatory, Columbia University, and O. Harry Mosely, Jr., of Queens College have aided in locating references and other bibliographic problems. Professor Rhodes Fairbridge, the Series Editor, has given invaluable advice and helped to improve the manuscript, and Mrs. Bernice Wisniewski of DH&R has guided the editor and his manuscript through the publication labyrinth. Finally, the volume could never have been written without the tolerance and patient encouragement of Leila Ott Mattson.

PETER H. MATTSON

CONTENTS

Series Editor's Foreword v
Preface vii
Contents by Author xiii

Introduction 1

PART I: GENERAL

Editor's Comments on Papers 1 and 2 6

1 **HESS, H. H.:** Gravity Anomalies and Island Arc Structure with Particular Reference to the West Indies 8
Am. Philos. Soc. Proc., **79**(1), 71–96 (1938)

2 **MOLNAR, P., and L. R. SYKES:** Tectonics of the Caribbean and Middle America Regions from Focal Mechanisms and Seismicity 36
Geol. Soc. America Bull., **80**, 1639–1670 (Sept. 1969)

PART II: CUBA

Editor's Comments on Papers 3 Through 10 70

3 **KHUDOLEY, K. M.:** Principal Features of Cuban Geology 77
Am. Assoc. Petroleum Geologists Bull., **51**(5), 668–677 (1967)

4 **MEYERHOFF, A. A., K. M. KHUDOLEY, and C. W. HATTEN:** Geologic Significance of Radiometric Dates from Cuba 88
Am. Assoc. Petroleum Geologists Bull., **53**(12), 2494–2500 (1969)

5 **THAYER, T. P., and P. W. GUILD:** Thrust Faults and Related Structures in Eastern Cuba 95
Am. Geophys. Union, Trans., **28**(6), 919–930 (1947)

6 **WASSALL, H.:** The Relationship of Oil and Serpentine in Cuba 106
Internat. Geol. Congr., 20th, Mexico, 1957, **Proc. Sec. 3**, pp. 65–77

7 **RIGASSI, D.:** The Geology of the Sierra de Los Organos, Cuba 120
Translated from *Archives Sci. [Geneve], Soc. Phys. Hist. Nat.*, **16**(2), 339–350 (1963)

8 **RIGASSI, D.:** Some New Views on Cuban Geology 134
Translated from *Chron. mines et Recherche Min.*, **29**(302), 3–7 (1961)

9 **BOITEAU, A., A. MICHARD, and P. SALIOT:** High Pressure Metamorphism Within the Purial Ophiolite Complex (Orinete, Cuba) 141
Translated from *Comptes rendus Acad. sci.* [*Paris*], Ser. D., **274**, 2137–2140 (April 1972)

10 **BOITEAU, A., J. BUTTERLIN, A. MICHARD, and P. SALIOT:** The Purial Ophiolitic Complex (Oriente, Cuba) and Its High-Pressure Metamorphism: Problems of Dating and Correlation 145
Translated from *Comptes rendus Acad. sci.* [*Paris*], Ser. D., **275**, 895–898 (Aug. 1972)

PART III: HISPANIOLA

Editor's Comments on Papers 11, 12, and 13 152

11 **BOWIN, C. O.:** Geology of Central Dominican Republic: A Case History of Part of an Island Arc 155
Caribbean Geological Investigations, Geol. Soc. American Mem. 98, H. H. Hess et al., 1966, pp. 11, 12, 13

12 **BUTTERLIN, J.:** L'ile d'Haiti: Summary of Geological and Tectonic History 157
La Constitution Géologique et la Structure des Antilles, Centre National de la Recherche Scientifique, Paris, 1956, pp. 89–90

13 **NAGLE, F.:** Geology of the Puerto Plata Area, Dominican Republic, Relative to the Puerto Rico Trench 160
Carib. Geol. Conf., 5th, Virgin Is., Trans., Geol. Bull. No. 5, New York: Queens College Press, 1971, pp. 79–84

PART IV: PUERTO RICO

Editor's Comments on Papers 14 Through 19 168

14 **KAYE, C. A.:** Notes on the Structural Geology of Puerto Rico 174
Geol. Soc. America Bull., **68**, 103 (Jan. 1957)

15 **MATTSON, P. H.:** Geology of the Mayagüez Area, Puerto Rico 175
Geol. Soc. America Bull., **71**, 319 (Mar. 1960)

16 **BERRYHILL, H. L., Jr., R. P. BRIGGS, and L. GLOVER, III:** Stratigraphy, Sedimentation, and Structure of Late Cretaceous Rocks in Eastern Puerto Rico—Preliminary Report 176
Am. Assoc. Petroleum Geologists Bull., **44**(2), 137 (1960)

17 **GLOVER, L., III, and P. H. MATTSON:** Successive Thrust and Transcurrent Faulting During the Early Tertiary in South-Central Puerto Rico 177
U. S. Geol. Survey Prof. Paper 400-B, 363–365 (1960)

18 **MATTSON, P. H.:** Geological Characteristics of Puerto Rico 179
Continental Margins and Island Arcs, Geol. Survey Canada Paper 66-15, W. H. Poole, ed., 1966, pp. 124–132, 134–138

19 **GLOVER, L., III:** Geology of the Coamo Area, Puerto Rico, and Its Relation to the Volcanic Arc-Trench Association 193
U. S. Geol. Survey Prof. Paper 636, 1–3 (1971)

PART V: VIRGIN ISLANDS

Editor's Comments on Papers 20 and 21 198

20 **DONNELLY, T. W.:** Geology of St. Thomas and St. John, U. S. Virgin Islands 200
Caribbean Geological Investigations, Geol. Soc. America Mem. 98, H. H. Hess et al., 1966, pp. 88–89

21 **DONNELLY, T. W.:** Tectonic Significance of the Spilite-Keratophyre Association 202
Carib. Geol. Conf., 3rd, Jamaica, 1966, Trans., pp. 14–15

PART VI: JAMAICA AND THE SOUTHERN ANTILLES

Editor's Comments on Papers 22, 23, and 24 206

22 **ROBINSON, E., J. F. LEWIS, and R. V. CANT:** Field Guide to Aspects of the Geology of Jamaica 210
International Field Institute Guidebook to the Caribbean Island-Arc System. American Geological Institute/National Science Foundation, 1970, pp. 3–9

23 **BEETS, D. J.:** Lithology and Stratigraphy of the Cretaceous and Danian Succession of Curaçao 222
Natuurwetenschap. Studiekring Suriname Nederlandse Antillen, no. 70, 1–2 (1972)

24 **MAXWELL, J. C.:** Geology of Tobago, British West Indies 224
Geol. Soc. America Bull., **59**, 852 (1948)

PART VII: TRINIDAD AND LESSER ANTILLES

Editor's Comments on Papers 25, 26, and 27 226

25 **KUGLER, H. G.:** Jurassic to Recent Sedimentary Environments in Trinidad 229
Vereinigung Schweiz. Petroleum-Geol. u. Ing. Bull., **20**(59), 27–60 (1953)

26 **MARTIN-KAYE, P. H. A.:** A Summary of the Geology of the Lesser Antilles 263
Overseas Geology and Mineral Resources, **10**(2), 172–189, 203–206 (1969)

27 **FINK, L. K., Jr.:** Field Guide to the Island of La Desirade with Notes on the Regional History and Development of the Lesser Antilles Island Arc 287
International Field Institute Guidebook to the Caribbean Island-Arc System. American Geological Institute/National Science Foundation, 1970, 18 pp.

PART VIII: CARIBBEAN BASINS AND TROUGHS

Editor's Comments on Papers 28 Through 31 304

28 **FOX, P. J., W. F. RUDDIMAN, W. B. F. RYAN, and B. C. HEEZEN:** The Geology of the Caribbean Crust, I: Beata Ridge 308
Tectonophysics, **10**, 495 (1970)

29 **FOX, P. J., E. SCHREIBER, and B. C. HEEZEN:** The Geology of the Caribbean Crust: Tertiary Sediments, Granitic and Basic Rocks from the Aves Ridge 309
Tectonophysics, **12**, 89 (1971)

30 **CHASE, R. L., and E. T. BUNCE:** Underthrusting of the Eastern Margin of the Antilles by the Floor of the Western North Atlantic Ocean, and Origin of the Barbados Ridge 310
Jour. Geophys. Research, **74**(6), 1413–1420 (1969)

31 **BOWIN, C. O.:** Geophysical Study of the Cayman Trough 318
Jour. Geophys. Research, **73**(16), 5159–5173 (1968)

PART IX: SYNTHESES

Editor's Comments on Papers 32 Through 35 334

32 **DONNELLY, T. W.:** Caribbean Island-Arcs in Light of the Sea-Floor Spreading Hypothesis 337
N. Y. Acad. Sci., Trans., Ser. 2, **30**(6), 745–750 (1968)

33 **MacGILLAVRY, H. J.:** Geological History of the Caribbean 343
Konikl. Nederlandse Akad. Wetensch. Proc., Ser. B, **73**(1), 64–65 (1970)

34 **FREELAND, G. L., and R. S. DIETZ:** Plate Tectonic Evolution of the Caribbean-Gulf of Mexico Region 345
Carib. Geol. Conf., 6th, Venezuela, 1972, Trans., pp. 259–264

35A **MATTSON, P. H.:** Plate Tectonics in the Caribbean 351
Nature, **235**(5334), 155–156 (1972)

35B **FREELAND, G. L., and R. S. DIETZ:** Plate Tectonics in the Caribbean: A Reply 352
Nature, **235**(5334), 156–157 (1972)

PART X: CARIBBEAN TECTONIC MODEL 353

Bibliography 361
Appendix A: Geological Mapping Projects 362
Appendix B: Geologic Maps and Bathymetric Charts 366
Appendix C: Caribbean Geological Conferences 368

Author Citation Index 369
Subject Index 375

About the Editor 381

CONTENTS BY AUTHOR

Beets, D. J., 222
Berryhill, H. L., Jr., 176
Boiteau, A., 141, 145
Bowin, C. O., 155, 318
Briggs, R. P., 176
Bunce, E. T., 310
Butterlin, J., 145, 157
Cant, R. V., 210
Chase, R. L., 310
Dietz, R. S., 345, 352
Donnelly, T. W., 200, 202, 337
Fink, L. K., Jr., 287
Fox, P. J., 308, 309
Freeland, G. L., 345, 352
Glover, L., III, 176, 177, 193
Guild, P. W., 95
Hatten, C. W., 88
Heezen, B. C., 308, 309
Hess, H. H., 8
Kaye, C. A., 174
Khudoley, K. M., 77, 88
Kugler, H. G., 229
Lewis, J. F., 210
MacGillavry, H. J., 343
Martin-Kaye, P. H. A., 263
Mattson, P. H., 175, 177, 179, 351
Maxwell, J. C., 224
Meyerhoff, A. A., 88
Michard, A., 141, 145
Molnar, P., 36
Nagle, F., 160
Rigassi, D., 120, 134
Robinson, E., 210
Ruddiman, W. F., 308
Ryan, W. B. F., 308
Saliot, P., 141, 145
Schreiber, E., 309
Sykes, L. R., 36
Thayer, T. P., 95
Wassall, H. W., 106

INTRODUCTION

Our knowledge of the geological framework of an area develops slowly. First, the explorers and naturalists describe their maps, collections, and observations, the products of long and often difficult and hazardous trips. Of necessity, they only skim the surface, traveling rapidly and taking relatively few scientific samples. They usually recognize only the most obvious features, although these may be most important and may still be puzzling modern scientists. Next, geologists begin reconnaissance studies, usually over large areas and often emphasizing economic aims. Paleontologists visit the most prolific and spectacular collecting sites, which results in maps and reports that are extremely valuable because they give the first details from the vast regions between the mines, volcanoes, and other obvious landmarks noticed by the first visitors. At this stage, local or colonial governments and scientists native to the area may become interested and involved; but the primary workers are usually from the world's great scientific centers. Finally, systematic detailed geologic mapping is organized by developing local governments and universities; native scientists grow in numbers and experience; and the quality and quantity of geological work approaches that in the better known parts of the world.

Charles Schuchert's 1935 book, *Historical Geology of the Antillean-Caribbean Region,* summarizes geological knowledge of the West Indies and surrounding regions up to its year of publication. At that time, the exploratory stage had ended and the reconnaissance stage had begun.

In the Caribbean, the exploratory stage began (from a geological point of view at least—political conquest and commercial exploration began with Columbus) with Alexander von Humboldt (1769-1859),

who became the first great explorer-naturalist to visit the West Indies when he spent a few months in Cuba in 1800–1801 and 1804. His work on Cuba was published as part of a three-volume set between 1814 and 1825. Other explorers were the paleontologists Fernandez de Castro in Cuba (1884) and W. M. Gabb in Hispaniola (1873); the Swedish chemist and geologist P. T. Cleve in the Virgin Islands (1871); De La Beche (1827) and J. G. Sawkins (1869) in Jamaica; and the most prolific of the early workers, Robert T. Hill (1859–1941), who visited and described Cuba, Puerto Rico, Jamaica, and Martinique from 1894 to 1905 in association with Professor Alexander Agassiz of Harvard.

These men described the West Indies as an orogenic system between North and South America. They saw, however, that mountain belts could not be traced across the Central American region from North to South America, as Humboldt had first thought. R. T. Hill suggested that an orogenic system existed between Tehuantepec in southern Mexico and the Andes of northern Colombia, and that it had a separate and distinct history from its larger neighbors. The Antillean orogenic system contains structural elements parallel to the American Cordillera but displaced eastward, such as the Lesser Antilles and the Beata and Aves Ridges; but it also contains elements oriented transversely to the Cordilleran grain, such as the Greater Antilles, the southern Antilles, and the Yucatan and Nicaragua Ridges. They recognized that some structural trends were younger and superimposed on older trends—the best example of this is the northwest-trending line of the younger volcanoes of Central America, superimposed on east-trending older structures.

Schuchert wrote after the first reconnaissance results appeared. Several mapping projects had begun in the Greater Antilles; the earliest, in Puerto Rico, was carried out by the New York Academy of Sciences and Columbia University. This and others are described later in this book.

Schuchert summarizes the deformation in the West Indies as occurring in at least four widespread episodes. The younger three are fairly well documented by the reconnaissance work: Antillean deformation in Late Miocene and Pliocene, Early Cenozoic deformation in the Late Eocene, and Laramide deformation in the Late Cretaceous. The oldest deformation was not well known at that time and is still poorly understood: late Middle Jurassic and Late Jurassic in Cuba, and at least as old as Late Cretaceous elsewhere in the West Indies. There may have been more than one pre-Cretaceous deformation in some areas, as will become apparent from the Cuban studies.

Schuchert described older deformations and strata in Central America and the Cordilleras, and suggests that any of these older elements could correlate with the undated metamorphic basement

rocks in the West Indies. He thought that the ultimate cause of the Caribbean deformation was subcrustal heating and lateral flow of heat from the ocean areas landward, as "subcrustal flowage and pressure" (1935, p. 46), an interesting comment for the 1930s. He postulated that during the Jurassic and Cretaceous subsidence behind regions of such subcrustal flow created basins which filled with sediments in the positions of the Greater Antilles. Epiorogenic uplift occurred sporadically. Late Mesozoic subcrustal flow from the Caribbean northward developed the Greater Antilles, Lesser Antilles, and Bahamas volcanic arcs. Thus, Schuchert uses subcrustal flow to create compressional pressure, directed from ocean basins toward land areas, in appropriate places and times to develop the known geologic features. Cooling of these regions after cessation of the Laramide and Late Eocene orogenies caused the Miocene-Pliocene block-faulting of the Antillean deformation.

Between 1914 and 1935, systematic reconnaissance began in the West Indies. T. W. Vaughan (1921) and W. P. Woodring (1924) and their coworkers studied Haiti and the Dominican Republic. Professor Charles P. Berkey (1915) and his students spent several summers in Puerto Rico and the Virgin Islands; and Professor L. M. R. Rutten and his students investigated Cuba and the southern Antilles in 1930, 1933, and 1939. This work, except for most of the Cuban reports, was published in time to be included in Schuchert's book. All of this work was hampered by a lack of good topographic base mapping, inadequate transportation networks, and generally rugged field conditions; but a great amount of good geology was done. They made their own base maps, often with poor control, and produced essentially strip geologic maps along streams and the roadways, trails, and railroads that then existed. Attempts to infer geologic relations between these lines were successful in areas of simple structural relations, but were not as successful in the more complex structures, such as southern Puerto Rico and parts of Cuba. The principal parts of the geologic framework were outlined: an older volcanic, plutonic, and metamorphic core flanked by younger and nonvolcanic, carbonate, and clastic deposits. More fossil and stratigraphic data were added to the record, but many incorrectly dated rocks, undated rocks, and essentially blank map areas remained.

The papers presented in this volume were originally published between 1938 and 1972: one in 1938, two in 1947–1948, four in the 1950s, and the rest in the last fifteen years. The 1950s begin the period of detailed geologic mapping and the beginning of systematic geophysical and oceanographic studies, although a small amount of geophysical work was done before World War II (see Paper 1). Syntheses attempting to fit all the details into a small number of models

and evolutionary sequences were of course being published very early, but those that could consider most of the modern data begin about 1968. Following the papers, a model (Part X) will be suggested that incorporates most of this data.

REFERENCES

Berkey, C. P. 1915. Geological Reconnaissance of Porto-Rico. *N.Y. Acad. Sci. Annals*, **26**:1-70.

Cleve, P. T. 1871. On the Geology of the Northeastern West India Islands. *Kungliga Sven. Vet. Akad., Hdl.*, **9**(12):48 pp.

De La Beche, H. T. 1827. Remarks on the Geology of Jamaica. *Geol. Soc. London Trans.*, ser. 2, **2**:143-194.

Fernandez de Castro, Manuel. 1884. Pruebas paleontologicas de que la Isla de Cuba ha estado unida al continente americano y breve idea de su constitucion geologica. *Acad. Ciencias Habana Anales*, **21**:146-165.

Gabb, W. M. 1873. Topography and Geology of Santo Domingo. *Amer. Philos. Soc. Trans.*, n.s., **15**:49-259.

Sawkins, J. G. 1869. Reports on the Geology of Jamaica; or Part II of the West Indian Survey. *Geol. Survey [London] Mem.*

Schuchert, Charles. 1935. *Historical Geology of the Antillean-Caribbean Region.* New York: Wiley.

Vaughan, T. W., W. Cooke, D. D. Condit, C. P. Ross, W. P. Woodring, and F. C. Calkins. 1921. A Geological Reconnaissance of the Dominican Republic. *Dom. Rep. Geol. Survey Mem., vol. 1.*

Woodring, W. P., J. S. Brown, and W. S. Burbank. 1924. *Geology of the Republic of Haiti.* Port-au-Prince: Department of Public Works, Geological Survey of Haiti.

Part I

GENERAL

Editor's Comments on Papers 1 and 2

1 HESS
Gravity Anomalies and Island Arc Structure with Particular Reference to the West Indies

2 MOLNAR and SYKES
Excerpt from *Tectonics of the Caribbean and Middle America Regions from Focal Mechanisms and Seismicity*

The 1938 paper of Harry H. Hess, "Gravity Anomalies and Island Arc Structure with Particular Reference to the West Indies," begins this volume. It inspired much later work, and it is also an example of the strong influence of geophysical studies on geological research. A great Dutch geophysicist, F. A. Vening Meinesz, developed the technique of measuring the force of gravity at sea, using a submarine beneath the turbulent waves as a stable platform for a delicate recording pendulum. Vening Meinesz passed through the Caribbean on his way to the East Indies, and while above the Puerto Rico Trench he recorded unusually low gravity values (about 0.03 percent below normal). Hess, using the same technique, measured gravity throughout the Caribbean. He confirmed Vening Meinesz's work and showed that a simple tectonic model, developed by Vening Meinesz and Philip Kuenen in the Netherlands and David Griggs and Hess in the United States, fit the data. This model, called the *tectogene*, postulated a symmetrical downbuckling of the earth's less dense crust into the more dense mantle. The model worked moderately well in island arcs, and could be visualized in experiments with clay layers and rotating drums, but the asymmetric pattern of island arcs and many mountain belts was difficult to explain. After World War II, Hess began to make basic geologic maps of critical areas in the West Indies and Venezuela, hoping to be able to develop a more adequate hypothesis of mountain making.

The war's end gave great impetus to scientific research. One of the branches of science most affected was the geophysical investigation of the ocean basins. War-surplus equipment became available, new ideas were born, and an enormous amount of basic data were produced by great oceanographic laboratories such as the Lamont-Doherty Geological Observatory of Columbia University, the Scripps Institution of