SHEET EVOLUTION OF CONTINENTS

A MORPHO-STRUCTURAL APPROACH

THE EXPANDING CONTINENTS

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DR. K. P. RODE

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FOREWORD

Referring to the continental drift theories which were then being advanced, Arthur Beiser, the author of "The Earth, in Life Nature Library" says, "there are many more hypotheses than there are continents — nearly as many serious objections ..... Theories in science live and die by the sword of experiments, no matter how attractive they may seem to the layman".

Dr. K.P. Rode, in his "Sheet Evolution of Continents", offers a new concept of continental genesis. According to him, continents have expanded by repeated movements of rock sheets which originally lay closely packed like playing cards piled up together within the region of Central Asia as part and parcel of the Tibeto-Himalayan mountain system. The region had been a scene of almost continuous deposition from the pre-Cambrian to the end of lower Tertiary period with numerous episodes of volcanism.

Since the Tertiary period, these sheet complexes were overwhelmed by repeated volcanic flooding and were thus subjected to extensive migration and slicing, resulting in the formation of separate and widely-spaced continental masses. The trends of migration are indicated by the island arcs, submarine swells and platforms, oceanic deeps, etc. The identity of the structural lines and the complementary nature of the geological formations of the various belts when placed in superposition could best be explained by the theory of sheet movements.

Dr. Rode's theory is as revolutionary and provocative as was Darwin's theory "Origin of Species by Natural Selection" initially. He has treated the subject in a systematic and scholarly manner. His facts are well-marshalled and conclusions not unduly speculative. His original approach to the problem is bound to stimulate further work on the subject towards better understanding of the continental expansion and migration.

The book is a compilation of revised versions of various papers read by him at many conferences, including the International Geological Congress. Those who have strongly opposed the theory were doubtless too preoccupied with matters of their own to pay much heed to the subject or to have cared to investigate it.

It was perhaps, Francis Bacon, the English philosopher and essayist, who first conceived the idea that continents were once united and later drifted apart. The idea arose from the study of a world map where the outline of the eastern and western coasts of the Atlantic fit in a jigsaw manner like two torn pieces of a picture. Alfred Wegener, a German meteorologist, visualised that originally there were two continents, a Northern Eurasia and a Southern Gondwanaland. The two were joined together into a single great continental mass which Wegener named "Pangaea" meaning all land, surrounded by a vast single ocean called "Panthalessa". In course of time, the Pangaea broke apart into a number of continental blocks which drifted away to their present positions. In 1912, Wegener elaborated the theory of Continental Drift, providing evidence from geology, geophysics, biology and climatology. Wegener's thesis that the earth's rotation was responsible for the break-up and drifting of the Pangaea blocks has been found to be untenable to account for movements over vast areas.

Since the publication of Wegener's theory, several others have put forward their own views to explain the present distribution of land and sea,the formation of mountain systems, etc. During the past decade or so, increased knowledge of the ocean floor has led to the concept of Plate Tectonics. It is now a widely-accepted theory, according to which the present continents were once joined together into a supercontinent, Pangaea as conceived by Wegener. Pangaea began to break up into rigid plates which started drifting apart about 200 million years ago to form the present continents. Originally, there were some eight plates of continental dimensions and more than 12 smaller plates of various sizes floating in various directions on the surface of the earth's mantle resembling movements of materials on a conveyer belt, but at rates of 1 to 15 cm annually. The varying temperatures within the earth set up convection currents in the mantle in much the same manner as boiling water in a pot. The currents propel the plates, makes them collide, ride on, shear apart, plunge into the mantle and behave in many other ways to account for various phenomena and features existing on the earth and to provide clues in the fields of earthquake research, mineral exploration, etc.

In contradiction to the plate theory, Dr. Bruce Heezen has put forward the "Expansion Concept", according to which, the earth is expanding, the distance between the "Grand Triangle" (Carey, S.W.) of Canberra, Tokyo and New York can be measured and also the distance of the Moon from these places. These have been made possible presently by the use of the laser beams. The circumference of the earth has been found to be increasing at the rate of 10 cm a year.

The known theories do not give a satisfactory explanation relating to the behaviour of various rivers and drainage courses, syntaxial bends, appearance and disappearance of ranges, valleys, etc., and particularly to the presence of successive imbricated, and intimately related masses on land and across the sea over distances. Dr. Rode's hypothesis not only provides satisfactory explanations to all these but is also capable of predicting similar lithological and fossil assemblages when encountered.

Just as the conquering races in armed conflicts of the past had left behind traces of their culture not only in the form of architecture and art but also words and expressions in the vocabularies of local languages of the countries they occupied, similarly the migrating land masses, as postulated by Dr. Rode, have left behind their remnants bearing unmistakeable characteristics in the lands through which they have travelled. From an analysis of numerous stratigraphical and geostructural data collected from the various parts of the world, he has been able to identify the remnants of the migrating land masses in successive stages in widely-separated lands.

The critics of Dr. Rode's theory would be astounded to know that a large block of land, at least 103,600 sq. km. in area and named "Wrangellia", appears to have migrated thousands of kilometers northward from its original place near the equator. This is borne out by pieces of the block which now form parts of Alaska, Canada, and perhaps the Pacific Northwest, as recorded by the U.S. Geological Survey, Department of the Interior, news release dated March 6, 1978. The block has been named "Wrangellia, as much of the evidence of its existence and movement was discovered in the Wrangell Mountains in southwestern Alaska. The geologists are unable to fit Wrangellia into the framework of plate tectonics, the question being as to how Wrangellia broke up and got locked into the present configurations.

Dr. Rode's concept of sheet movements finds considerable support in the above subject, because "The Wrangellia rocks form a distinct sequence or layer cake of rocks that are quite different from the rocks they now butt against", said one geologist, adding that "the sequence consists of a thick stack of volcanic flows, some in 'pillows' or mounds that apparently were formed under water. This is further confirmed by the fact that they are capped by fossiliferous limestone and are resting on limestone, shales and other volcanic rocks. The fossils suggest deposition in warm tropical equatorial climate, and unusual patterns of Palaeomagnetism of rocks provide evidence of their original home and later migration of Wrangellia.

Wrangellia is one unchallenged example where rocks themselves seem to provide clues to their origin and displacements. Dr Rode has given such examples from the world over in his book which contains maps and illustrations showing the trends of continental expansion and migration, based on results of 30 years of his close observation and study. It is hoped that the above facts will serve to stimulate earnest study of the subject. Undoubtedly, many points will be called in question but these will contribute towards better understanding of the geological processes by which the present features on the earth's surface have been developed. To the most intriguing question as to what made the continents drift, Dr. Rode's answer is the existence of the extensive flood basalts in their extrusive and intrusive phases. Here again, the Wrangellia rocks also bear excellent testimony, with their "thick stack of volcanic flows, some in 'pillows' or 'mounds'."

With the progress of science, many concepts are changing. Fossils were originally considered as concretions of mineral matter. A.G. Werner, a founder of economic geology, believed that all rocks had been precipitated in the order of five "suite" or series all over the earth. In a book "World in Collision", Immanual Velikovsky propounded a theory that the planet Venus was actually expelled by Jupiter in a violent disruption; as a result, its temperature was very high and its atmosphere heavier than that of the earth. His theory was considered absurd. But the Venus Mariner probe of 1974 confirmed the presence of a comet-like tail on Venus. Earlier, the 1962 Mariner probe recorded a temperature of over 400°C and the Russian probe of 1966 showed that the atmosphere of Venus was 95 times heavier than that of the earth. We are, therefore, not justified in discarding any new concept without proper scrutiny. Many brilliant theories must have been submerged in this way.

17th August, 1985

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A. K. DEY

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PREFACE

The placid concepts of the nineteenth century geology which attempted to explain all the surface phenomena of the earth's surface on the simple notion of uniformitarianism where the ups and downs were attributed to the work of dynamic agencies of the earth's surface and interior. Mountains were usually remanent of elevated features worn out by rains, winds etc. and that they were formed *in situ* only affected by vertical movements of upheaval and subsidence. The earth's movements operated only in the vertical direction without any effects of horizontal movements. These were the principles of uniformitarianism as worked out by C. Lyell, Werner, Emil Haug etc. The middle of the last century witnessed the discovery of Glossopteris group of plants not only in India but in Africa and Australia as also in South America. The occurrence of identical plants over such vastly separated land terrains posed the problem before these pioneers as the plants could not migrate across the ocean. Some hints at lateral movements of land forms were suggested to explain such widely separated occurrences. But the publication of Wegener's "Origin of Continents and Oceans" gave a serious jolt to the orthodox concepts of the last century. The controversy generated heat and passion leading to serious discussions in the form of symposia. The geologists and particularly biogeologists offered full support to the drift theory whereas the orthodox authorities and geophysicists vehemently opposed the drift concept. As time passed on the advocates of drift theory outweighed those of the orthodox views. Discovery of rock-magnetism encouraged the geophysicists to accept the validity of the drift without yet knowing the mechanism of the drift and the adequacy of the forces involved. The geophysicists took recourse to convection currents whose existence is yet to be fully established enough to bring about such vast changes on the earth's surface.

It is at this juncture that the author has proposed a new concept of sheet movements. He first enunciated it in the Algiers session of the International Geological Congress in 1952 and the same was elaborated further in the subsequent sessions at the I.G.C. in Mexico (1956), Delhi (1964) etc. Since then, the theory was being discussed at several symposia and sessions of the Indian Science Congress. The present attempt is to bring out the salient features of the theory systematically with illustrations from all the continents. In the present publication, the theory has been elaborated with special reference to morphology and structure of the earth's surface. In the earlier chapters, the geographical aspects of the problem, their morphological features and stratigraphic-structural aspects have been illustrated which can be explained on the basis of this theory. Such geo-structural features like mountain ranges, river valleys, plateaux, rift valleys, embayments, gulfs, oceanic ridges, island arcs, oceanic trenches have all been described whose formation inevitably leads to the concept of sheet movement. The second half of the book deals with the phenomena of sheet movements, the process, mechanism, the forces involved, and the trends which have been elaborated. Almost every feature of the earth has a place in the scheme. Towards the end are given paleogeographical maps of the world which show different stages of the evolution of the continents and oceans in a sequence starting from a stage of no land surface on the earth passing through the island stage, mini continents, continents and supercontinents. The supercontinents give way to several subsidiary continents shifting to their present positions through the intervention of volcanism and gravity slopes until they reach the present stage occupying nearly one-third of the earth's surface. The theory finds its expression in the evolution of every geological feature without exception. Not a single feature appears on the earth's surface which has not followed the process as envisaged in this theory of sheet movement. This is the justification for the appearance of this book. It is hoped that the geoscientists will apply their minds to this process of evolution critically to bring about improvements in the theory and the processes invoked, so that the many problems that still embarrass the scientists may yet find the solution through the new approach.

1st September, 1985 **K. P. Rode**

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CONTENTS

I. THE EARTH AS A GEOID **1**

Structure of the Earth 1
Relief of the Earths Surface Land and Sea 3
Global Distribution of Land and Sea 3
Primordial Crust 3
The Oceans and Their Distribution 5
The Pacific Ocean 5
The Indian and the Atlantic Oceans 5
The Continents 6

II. THE CRUST OF THE EARTH **9**
(Oceanic and Continental)

The Oceanic Crust 9
The Continental Crust 10

III. GEOMORPHOLOGICAL FEATURES OF THE CONTINENTS **12**
Mountain Ranges as Vertebral Ribs of Continents 12

Mountain Ranges their Distribution in Space 12
Arctic Linkages in Laurasian Mountain Systems 18
Mountain Ranges of North America 18
Mountain Ranges of Central America 19
Mountain Ranges of South America 19
Mountain Ranges of Antarctica 20
Mountain Ranges of Australia 20
Mountain Building During Geological Times 21
Caledonian Orogeny 22
Variscan Orogeny 24
Alpine Orogeny 24
River Valley Systems 25
River Sytems as Arteries of Continents 28
River Systems of Asia 28
River Systems of Europe 29
River Systems of North America 33
River Systems of South America 36
River Systems of Africa 38
River Systems of Australia 40
Drainage System in Antarctica 42
Rift Valleys 42
The Red Sea Rift 43
The Persian Gulf 43

IV. GEOMORPHOLOGICAL FEATURES OF THE SEA AND OCEAN FLOOR **44**

Continental Shelves 44
Continental Slopes 45
The Ocean Floor 45
The Pacific Ocean Floor 45
The Indian Ocean Floor 46
The Atlantic Ocean Floor 47
Oceanic Deeps and Trenches 48

Oceanic Trenches in the Inner Pacific Ocean 48
Mid Oceanic Ridges 49
Ridges in Indian Ocean 51

V. GEOLOGICAL FORMATIONS OF THE EARTH **53**
(Some Bio-Stratigraphic Problems)
The Palaeozoic Era 54
The Cambrian Formations 54
The Ordovician Formations 57
The Silurian Formations 61
The Devonian Formations 63
The Carboniferous Formations 65
The Permian Formations 68
The Mesozoic Era 70
The Triassic Formations 70
The Jurassic Formations 72
The Cretaceous Formations 75
The Tertiary Era 79
Lower Tertiary Formations 79
Upper Tertiary Formations 81
The Tertiary Crustal Movements 81
Magmatic Activity During the Tertiary and Quaternary Eras 85
The Quaternary Glaciation 85

VI. THE PROBLEM OF THE GONDWANA LAND **89**
Diverse Concepts of Continental Drift 89
The Expanding Earth 91
Palaeomagnetism 91
Plate Tectonics 92

VII. THE THEORY OF SHEET MOVEMENT AND CONTINENTAL EXPANSION **96**
The Theory of Sheet Movements 96
Some Major Features of New Theory 97
(A) Indications of Sheet Movements 97
(B) Guides to Sheet Movements 99
(C) Agencies of Sheet Movements 100
(D) Mechanism of Sheet Movements 104
(E) Route of Sheet Movements 106
(F) Stages of Movements of Major Sheet Complexes 106

VIII. GUIDES TO THE COURSE OF SHEET MOVEMENTS **108**
River Systems as Guides
River Systems of the British Isles 108
Inter-relationships between these various River Systems 111
River Systems and Their Tectonic Significance 114
Syntaxial Bends in River Courses, Their Significance 117

IX. STRUCTURAL HOMOMORPHY **121**
The Nature of Crustal Processes 121
List of Patterns described 122
(1) The Satpura-Rewa Gondwana Basins of India 126
(2) The Jhelum Indus Syntaxis 127
(3) Himalaya-Burma-Baluchistan Relationships 132
(4) The New Guinea Pattern 134
(5) Borneo Structural Pattern 137
(6) Japanese Arc Pattern 139

(7) Kamchatka Structural Pattern 141
(8) The Verkhoyank-Kolyma Structural Pattern 143
(9) Ural Structural Pattern 144
(10) Great Britain Structural Pattern 145
(11) Scandinavian Structural Pattern 150
(12) Alaskan Structural Pattern 152
(13) The Alphine Arcs Structural Pattern 154
(14) Carpathian Structural Pattern 157
(15) The Apennine Structural Pattern 159
(16) The Antillean Structural Pattern 162
(17) Guiana Structural Pattern 165
(18) U-Shaped Alabama Arc Pattern 166
(19) Oval Shaped Michigan Pattern 168
(20) The Karroo (Gondwana) Pattern 168
(21) Madagascar Pattern 170
(22) Homomorphous Linear Patterns 174
(23) Dome Structures Radial Movement of Sheets 176
(24) Guiana Rotational Movements 178
(25) Brahmaputra Rotational Movements 178

X. STRUCTURAL EVOLUTION OF CONTINENTS AND OCEANS **180**

Individual Continents 180
Structural Evolution of Eurasia 181
The Structure and Evolution of Asia 182
Structure and Evolution of Europe 183
Structure and Evolution of North America 188
Structural Evolution of Africa 191
Structural Evolution of South American Continent 193
Structural Evolution of the Indian Subcontinent 195
Structural Evolution of Australasia 199
Structural Evolution of Antarctica 202
Origin and Evolution of the Oceans 210
The Pacific Ocean 210
The Evolution of the Indian Ocean 212
Evolution of the Mediterranean Sea 213
Evolution of the Atlantic Ocean 214
Evolution of the Arctic Ocean 214

XI. PALAEOGEOGRAPHICAL EVOLUTION OF THE EARTH'S CRUST **217**

Earliest Stages in Crustal Evolution 217
The Cambrian Palaeogeography 221
The Ordovician Palaeogeography 224
The Silurian Palaeogeography 225
The Devonian Palaeogeography 226
The Premo-Carboniferous Palaeogeography 228
Permo-Carboniferous glaciation 229
The Triassic Palaeogeography 230
The Jurassic Palaeogeography 231
The Cretaceous Palaeogeography 233
Appearance of Angiosperm 234
The Lower Tertiary Palaeogeography 235
The Upper Tertiary Palaeogeography 237
The Quaternary Palaeogeography 239
Pleistocene 'Glaciation' 241
Epilogue 242

Bibliography **243**
List of Coloured Plates **251**

LIST OF ILLUSTRATIONS

Chapter I

1. Structure of the Earth 2
2. The Continents: Their Distribution and Linkages 7

Chapter II

3. Structure of the Earth's Crust 10

Chapter III

4. Major Mountain Ranges of the World 13
5. Tibetan Plateau: A Unique Feature 14
6. Physical Features of the Indo-Australian Region 16
7. Major Orogenies of the World 23
8. Himalayan and Tibetan Systems of Rivers 26
9. River Systems of East and North-East Asia 30
10. River Systems of Europe 31
11. River Systems of North America 34
12. River Systems of South America 37
13. River Systems of Africa 39
14. River Systems of Australia 41

Chapter IV

15. Submarine Features of the Southern Oceans 50

Chapter V

16. Pre-Cambrian Continental Shields 55
17. Lower Cambrian World 56
18. Cambrian Life Provinces of the World 58
19. Ordovician World 60
20. Silurian World 62
21. Mid. Palaeozoic World 64
22. Permocarboniferous World 67
23. Upper Palaeozoic Coal Fields of the World 69
24. Triassic World 71
25. Jurassic World 73
26. Cretaceous World: Angiosperms 76
27. Cretaceous World: Marine and Continental 78
28. Lower Tertiary World 80
29. Upper Tertiary World 82
30. Faunal Trends: Stratigraphical Data 83
31. Quaternary World: Pleistocene "Volcanic activity" 86
32. Quaternary World: Pleistocene "Glaciation" 87

Chapter VI

33. Wegenet's Concept of the Drifting Continents 90
34. Lithospheric Plates of the World 94

Chapter VII

35. Igneous Activity: Network of Plateau Basalts and Serpentine Belts 102
36. Outcrop of Whin Sill 103
37. Whin Sill in Section 103

Chapter VIII

38. River Systems of the British Isles 109
39. Sheet Migration in British Isles 112
40. Drainage Basins of the Danube 116
41. Indus Syntaxis 118
42. Brahmaputra Syntaxis 119

Chapter IX

43. Structural Homomorphic Patterns 123
44. Relations Between the Gondwana Basins of Narbada and Son Belts 125
45. Gondwana Belts of India 127
46. The Jhelum Syntaxis 129
47. Aravalli-Baluchistan Relations 132
48. Structural Similarities in New Guinea Patterns 135
49. Migration of Berneo Structural 138
50. Evolution and Emplacement of Japan 140
51. (a) Kamachatka Pattern 142
(b) Kolyma Pattern
52. Tertiary Dyke Systems In British Isles 147
53. Appalachian British Isles Correspondence 149
54. Structural Relations of the Atlantic Coastal Belts of Europe and North America 150
55. Norwegian Pattern and its Migration from Pamirs 151
56. Mediterranean Orogen with Tertiary Igneous Activity 155
57. Mediterranean Orogenic Arcs 156
58. The Apennine Structures in the Mediterranean Region 161
59. Morpho-Structural Map of the Central American Region 163
60. Central American Region: Orogenic Trends 164
61. Migration of Michigan and Alabama Structures 167
62. Gondwana Basins 171
63. Homomorphy in Coastal Lines 172
64. Madagascar Pattern 174

Chapter X

65. Igneous Activity in East and S. East Asia 184
66. Migration of Sheets in Eastern Tibet 185
67. Current Concepts of Structural Evolution of Europe 186
68. Sheet Evolution of Europe 187
69. Structural Evolution of North America 190
70. Trends of Sheet Movements in Africa 193
71. Trends of Evolution in South America 194
72. Geological Sketch Map of Indian Sub-Continent 195
73. Primary Composite Sheet Structure of the Himalayas 196
74. Stages and Routes of Migration of the Aravalli-Baluchistan Sheets 197
75. Evolution of Peninsular India 198
76. Geotectonic Evolution of Australasia: Current Concept 199
77. Trends of Evolution in Australia 200
78. Evolution and Emplacement of Australia 201
79. Antarctica: Its Physical Features 203
80. Evolution and Emplacement of Gondwana Continents 205
81. Antarctica: Its Extra Continental Linkages' 206
82. Evolution of Australo-Antarctica 207
83. The Proto Gondwanaland 208
84. Relations of Gondwanaland 209
85. Central Pacific Volcanicity (Holocene) 211
86. Evolution of Arctic Ocean 215

Chapter XI

87. Submarine Stages in Continental Evolution 223

LIST OF COLOURED PLATES

Plates

1. Geological Sketch Map of the World
2. Exotic Blocks of Mallajohar
3. Sheet Movements Through Volcanism
4. Indian Gondwana Belts in Superposition:
   A. Dharwar Krishna Valley
5. Indian Gondwana Belts in Superposition:
   B. Damodar Basin
6. Indian Gondwana Belts in Superposition:
   C. Mahanadi Basin
7. Indian Gondwana Belts in Superposition:
   D. Godavari Basin
8. Indian Gondwana Belts in Superposition:
   E. Rewah (Sen) Basin
9. Indian Gondwana Belts in Superposition:
   F. Satpura (Narbaba) Basin
10. Indian Gondwana Belts in Superposition:
    1. *Cuddapahs and Vindhyas*
11. Indian Gondwana Belts in Superposition:
    2. *Lower Gondwanas*
12. Indian Gondwana Belts in Superposition:
    3. *Upper Gondwanas*
13. Indian Gondwana Belts in Superposition:
    4. *Deccan Trap*
14. Gondwana Coal Fields of India in Pre-Tertiary Period
15. Homomorphic Alpine Arcs in Mediterranean Region
16. Carpathian Patterns
17. Central American Region: Structural Correspondences
18. Evolution of Earth's Crust: *Archacan Panthelessa*
    Evolution of Earth's Crust: *Low Palaeozoic*
    Evolution of Earth's Crust: *Mid Palaeozoic*
    Evolution of Earth's Crust: *Upper Palaeozoic*
19. Evolution of Earth's Crust: *Low Mesozoic*
    Evolution of Earth's Crust: *Upper Mesozoic*
    Evolution of Earth's Crust: *Lower Tertiary*
20. Evolution of Earth's Crust: *Upper Tertiary*
21. Evolution of Earth's Crust: *Lower Quaternary*
22. Evolution of Earth's Crust: *Middle Quaternary*
23. Evolution of Earth's Crust: *Upper Quaternary*
24. Stages in Continental Expansion
25. Continental Expansion: Stages in the Expansion of the Earth's Crust.

CHAPTER I

The Earth as a Geoid

The science of geology seeks to understand and elucidate the origin, structure and evolution of the earth and particularly, of the accessible part of the crust. The earth as a planet of the solar system has its origin intimately involved in the evolution of the planets of the system. Several theories have been put forth by competent astronomers, geophysicists and geologists on the possible origin of the planetary system and to explain the various characteristics associated with this system.

Though vastly diverse in approach. all these various theories agree in one particular aspect. that the earth at some stage or the other has passed through a molten state which imparted to it a systematic spherical form with successive concentric shells of roughly homogeneous matter of decreasing density.

The earth as a planet rotates round its N-S axis once in 24 hours and revolves round the sun along an elliptical orbit once a year of almost 365 days. Under the influence of its own gravity, the earth assumes a spherical shape but owing to rotation round its own axis, this sphere gets slightly bulged along its equatorial belt and is flattened at its poles to assume the shape of an oblate spheroid or an ellipsoid of rotation. Its polar diameter is 7.900 miles (or 12713.8 km.) while its equatorial diameter is 7,927 miles (or 12756.8 km.)

Further, the composition of the earth's outer shells is not homogeneous and this introduces an unevenness to its surface, departing from the spheroid of rotation. This uneven spheroid of the earth is called the Geoid.

STRUCTURE OF THE EARTH

Studies of earthquake waves have clearly brought out a shell structure of the earth with a thick central core, surrounded by a mantle of almost comparable thickness and enveloped by a thin outermost shell of the crust. The central core has a radius of 3473 km. largely made up of metallic constituents, chiefly iron and nickel and, therefore, called the *Nife*, with an average density of 10.72. It is largely solid but a good thickness of it behaves as a liquid (Fig. 1)

From the depth of 2900 km. to roughly 33 km. from the surface, the shell constitutes the *Mantle*, the inner portion of which (the *Inner Mantle*) is largely of metallic oxide and sulphide ores with a density ranging from 4.6 to 5.6, while the *Outer Mantle* or *Upper Mantle*, from the depth of 1000 km. is largely peridotitic, low in silicates and is mixed with metallic ores and has a density ranging between 3.3 to 4.64. A part of this Upper Mantle is a low velocity zone called the Asthenosphere and behaves as a viscous belt. Separated from the Mantle by distinct discontinuity called the *Moho*, is the *crust* which envelopes the Upper Mantle and has an irregular thickness ranging from 33 km. below the continents to 8 km. below the Pacific Ocean floor. This crust is also divisible into a lower or the oceanic crust, largely made of mafic silicates and as such is called the *Sima* or Simatic crust, with an average density of 2.9, while the upper or the continental crust is largely made of alumino silicates and hence called the *Sial* or Sialic crust, with an average density of about 2.7.

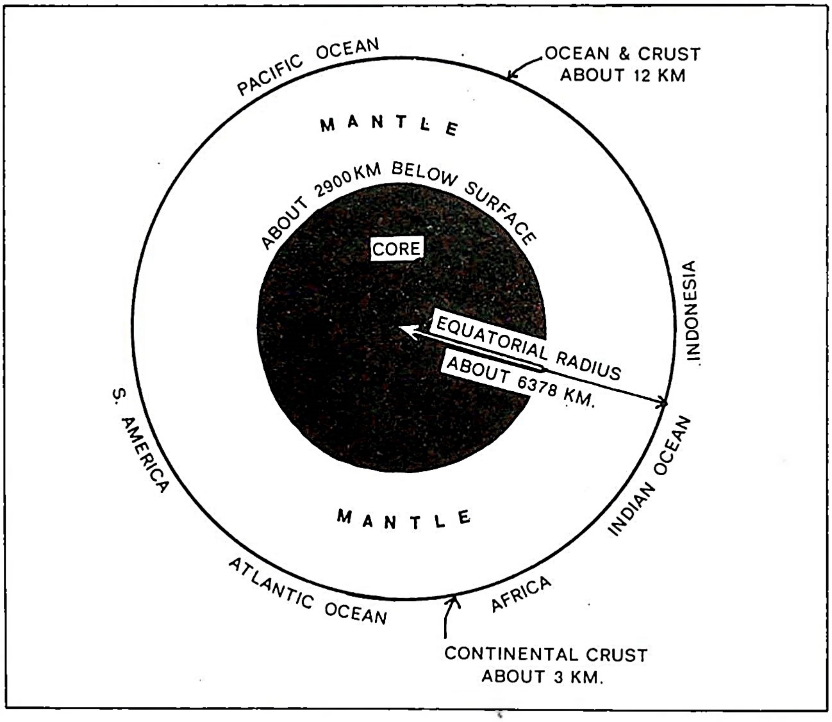


Fig. 1. Structure of the Earth
(From—Arthur Holmes)

The Crustal Sima probably forms a continuous envelope over the Mantle all over the earth whereas the Sial layer occurs over the Sima in discontinuous patches of continental size, and is completely absent in the region of the Pacific Ocean. It is of variable thickness in different oceanic and continental regions.

The crust as the outermost shell of the earth is highly heterogeneous in composition and as such is also the zone of highest irregularity in surface features. Some features are exposed above the sea level and constitute the land surface, while others are submerged to variable depths below the sea level and constitute the sea features. There are, however, still others which are partly submerged and these can be considered as transitional features.

RELIEF OF THE EARTH SURFACE—LAND AND SEA

The combined areas of land and sea surfaces at different levels have been estimated and plotted on a graph. This hypsograph brings out two levels very prominently, one at a height of 840 metres above the sea level and the other at a depth of 3,808 metres below the sea level. The average height of all the land surfaces taken together corresponds to the height of continental platform 840 metres above the sea level, while the average depth of all the oceanic features corresponds to that of a deep sea platform 3,808 metres below the sea level.

These two levels constitute significant features of the earth crust. Actually, the continental crust exhibits wide departure from this average level, a highly varied relief in the nature of extensive plains and depressions, some even below the sea level to plateaux and mountain ranges rising to over 8 km. above the sea level. The oceanic floor also exhibits considerable irregularity with its diverse submarine features, such as shallow plains, platforms, banks, plateaux, rises, sea mounts, guyots and ridges, often peeping out above the sea level as islands, island arcs and archipelagos. We also meet with ocean deeps and narrow trenches extending for thousands of kilometres and at places reaching depths of over 10 km.

It is thus seen that the surface of the crust exhibits relief features varying in altitude from over 11 km. below the sea level to almost 9 km. above the sea level, totalling an altitude difference of about 20 km.

When the earth is viewed as a whole, this variation of relief to the extent of 20 km. is insignificant but, for the thickness of the crustal layer itself, this variation is enormous and has to be accounted for.

It is observed that inspite of such marked differences in the altitude in different parts of the earth crust, the general gravitational equilibrium of the crust as a whole is not disturbed to any significant extent. This tendency of the earth to maintain gravitational equilibrium has been termed Isostasy. In this, the high elevation of the mountain belt is compensated by the lower density of constituent rocks over great depths while the low relief of the oceanic sector is compensated by the high density of the rocks below the oceanic waters.

Global Distribution of Land and Sea

The distribution of land and sea on the earth surface appears quite irregular. It is seen that less than 30 per cent (actually 29 per cent) of the earth surface is occupied by land and the rest, more than 70 per cent, is covered by sea. Geographically, the land is again not evenly distributed over the whole earth surface, 80 per cent of the whole land is seen concentrated in the Northern Hemisphere whereas the sea, besides monopolising 90 per cent of the Southern Hemisphere, also overspreads nearly half the Northern Hemisphere as well.

PRIMORDIAL CRUST

The marked disparity in the proportion of land and sea on the earth surface, coupled with the peculiar concentration of land in one hemisphere and its almost total absence in the other, must have some bearing on the mode of evolution of land and sea on the earth surface. The problem of the evolution of oceans and continents has been the core of geological studies ever since the early period of the geological sciences.

Are the continents primordial features of the earth surface which later yielded place to oceans or whether oceans are older than continents?

In the former case, the floor of the oceans should have preserved the characteristics of the sialic continents, which they do not. Sialic rocks are typically missing in the vast oceanic regions, giving no indication of the former existence of continental surface at the bed of the oceans. Continents could not, therefore, have yielded place to oceans through subsidence. On the other hand, simatic rocks which are pervasive under the oceans could have developed in the upper portion of the mantle as primary crust during the primordial viscous stages of the earth before the formation of the oceans. It is in the depressions of this simatic crust that the earliest oceans may have been formed mainly through condensation of the hot hydrous atmosphere which was enveloping the primordial earth as and when the temperatures fell sufficiently to permit the condensation of atmospheric vapours. It is possible that some of these vapcurs may have been contributed by submarine volcanoes as part of the process of degassing of the earth's interior.

This early stage of the earth is essentially pre-geological when the processes of normal sedimentation had not commenced and whose records are not preserved for our study. Waters of these early oceans must have been quite warm and the debris on the earth surface was all pyrogenetic and derived only from submarine volcanic eruptives.

The debris of these basic eruptives was subjected to rapid hydrothermal decomposition, dissolution, precipitation and deposition of individual products of decomposition released separately. These products were essentially sialic in their characteristics and they accumulated to give rise to continental masses.

This was the early state of the cratonisation or continentalisation of the simatic crust.

The assimilation of such secondary rocks by intruding basic magmas may also lead to the development of migmatite rocks like granites, gneisses, epidiorites, schists etc. which are important components of continental shields.

It is thus obvious that the development of sialic continental mass secondarily from the primary magmatic simatic rocks took place fairly late in the earth's history and as such continents cannot claim primordial status in their evolution.

The continents in their formation have utilised parts of simatic basement of the oceans and as such they do not constitute any extra load over the simatic crust to disturb the gravitational equilibrium as seen from the general maintenance of Isostasy over large parts of the crust.

Basic volcanism has been almost a continuous process throughout the earth's geological history and it is, therefore, plausible that the continental crust has been growing almost continuously during all the geological period and in this process, it has upto the Quaternary and Recent Period developed to the extent to occupy 30 per cent to 35 per cent of the earth surface. One can easily visualise that in the coming period of the earth's history, it would develop new continents in the domain of the Pacific Ocean, the prospective sites being the Darwin Rise and the associated Island Arcs of Melanesia, Micronesia, and Polynesia in the region of the Central Pacific Ocean.

The Oceans and Their Distribution

The continents and oceans exhibit a peculiar pattern of distribution on the earth surface in which large continental masses appear somewhat detached from one another with the occurrence of variously-sized marine basins, intervening between them.

The Pacific Ocean

The Pacific Ocean is the most prominent feature on the earth surface. This alone occupies almost a third of the earth surface with an area more than the total land surface and yet having no trace of sialic crust within most of its basin. It extends almost from Pole to Pole and encompasses nearly half of the earth's equatorial circumference. It is the deepest ocean with an average depth of over 4270 m. and reaches depths of over 10370 m. in several trench-like depressions. There is enormous manifestation of active volcanism commencing from the CircumPacific borders against the continents and extending far into the interior in the central parts of the Ocean in the nature of volcanic ridges and island arcs, often associated with oceanic deeps and trenches. This one ocean has vitally influenced the evolution of most of the continental masses through the repeated development of geosynclines along its periphery against the continents which served as the sites of continuous and profuse volcanism and also as basins of sedimentation of continental and pyroclastic materials. These geosynclinal basins were theatres of orogenic disturbances and upheavals from time to time and these orogenic belts later became fused with the adjoining continental masses, resulting in the repeated expansion of the continents and their encroachment over the Pacific basin.

The Indian and the Atlantic Oceans

The other oceans like the Indian and the Atlantic are vastly different in their behaviour towards the adjoining continents. They are smaller in expanse and their borders are controlled by the outline of the adjoining continents. They do not give rise to active geosynclines along the continental borders nor are these borders normally prone to volcanism. The mountain ranges in the bordering continents hardly bear any close relationship with the coastal borders, the mountain trends often cut these coasts transversely or obliquely. There is, on the other hand, a system of mid-oceanic ridges, often with centres of volcanic eruptions. These oceanic ridges often simulate one or the other border of the adjoining continents. The ridges or rises in the Indian Ocean between India and Africa constitute a system of several arcuate ridges, more or less parallel among themselves running north-south. Among these arcs the Laccadiv-Chagos Ridge closely parallels the western coast of peninsular India whereas the remaining ridges of the system closely simulate the Madagascar or Mozambique coast of peninsular Africa. The main Mid-Indian Ocean Ridge runs due south through Rodriguez St. Paul, Kerguelan and Gaussberg to East Antarctica. This ridge divides the Indian Ocean halfway between Africa and Australia. Has this ridge any relationship with the continental masses on either side?

The Mid-Atlantic Ridge between Eurafrica and Americas is the best studied and the most discussed among the submarine ridges of the world. Its peculiar S-shaped outline and its association with volcanic islands have aroused many ideas among geoscientists. It shows parallelism, in part, to continental outlines on either side. Near its southern end, it meets obliquely the Walvis Ridge linking it with Africa near the Angola coast. The parallelism of these mid-oceanic ridges in the Indian and Atlantic oceans with the flanking continental borders is suggestive of some deep-seated control exercised by the continents on the evolution of the mid-oceanic ridges and through them on the evolutionary history of these oceans. These may thus attest to the secondary origin of these oceanic basins as younger than the flanking continents themselves.

The volcanism observed associated with some of the islands along the mid-Atlantic ridge may point to the processes which have operated in the recent geological past (in the evolution of crustal features in this part of the world).

THE CONTINENTS

Continents are large crustal surface features which are standing above the sea level and are generally surrounded by oceanic waters. They constitute nearly 30 per cent of the earth's surface and are found distributed in a highly irregular manner. They appear crowded in the northern hemisphere to constitute the so-called Land Hemisphere whereas they are meagrely developed in the southern hemisphere which is almost wholely occupied by the oceans and which, as such, is often called the Water (Oceanic) Hemisphere. Among the continents, Eurasia constitutes by far the largest land mass on the earth's surface. This continent is further characterised by the highest mountain ranges rising to over 8,535 m. and plateaux rising to over 4,575 m. This supercontinental mass is broad and almost continuous along its northern border but is highly indented and embayed along its southern border. It is further linked up with another large land mass of Africa with only narrow shallow seas intervening between them. These somewhat closely-knit continental masses of Eurasia and Africa together comprise nearly 60 per cent of the total land mass on the earth's surface. Other continental masses though widely separated do exhibit linkages with these continents, even though they are tenuous in the nature of submarine ridges and island arcs. Thus, the North American continent is linked with Eurasia in the region of the Bering Straits shallow sea through Alaska and Aleutian arc and also in the west, in the region of the Norwegian Sea through Greenland and Spitsbergen as also through the Iceland-Farroe ridge across the North Atlantic Ocean.

This North American continent is also linked up with the South American continent through the Central American Isthmanian and Antillean ranges linking the North American Cordillera with the Andes of South America. The South American continent, in its turn, at the southern end is linked with the Antarctic continent through the acutely-bent South Scotia-South Sandwich arc. The Antarctic continent is linked up with Australia and New Zealand through the submarine ridges of Balleny and Macquarie and is also linked with India through the long-distended Mid-Indian Ocean Ridge passing through St. Paul-Amsterdam submarine plateau. Antarctica is again linked up with Africa through the Prince Edward Crozet and Kerguelen-Gaussberg ridges. Australia is similarly linked up with south and east Asia through the Island Arcs of Indonesia, Philippines and Taiwan.

Thus, all the continental land masses though separated by vast oceans do exhibit a crowding in one hemisphere and are variously interlinked among themselves through island arcs and submarine ridges of various dimensions (Fig. 2). This peculiar behaviour of continental masses as seen in their crowding in one hemisphere and in their extensive linkages among themselves must have a deep bearing on the mode of origin, evolution and emplacement of all these continental masses, of their intervening oceans and of their interlinking island arcs and submarine ridges.

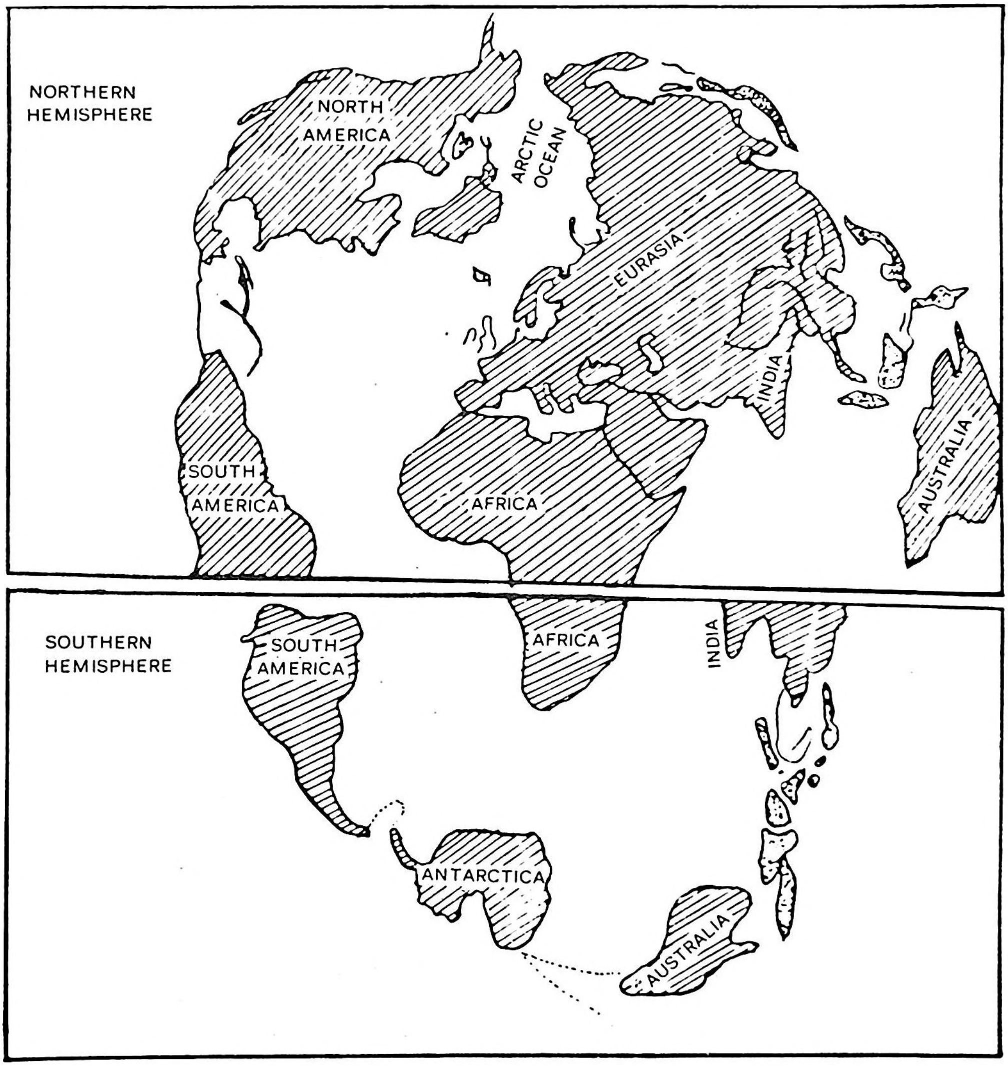


Fig. 2. The Continents, Their Distribution and Linkages

Besides these deep-seated features of the earth's crust, even some of the morphological features of the earth's surface exhibit certain peculiarities which call for explanation.

(1) The bulging coastline of South America along the Pacific Coast from Colombia to Peru has a certain curvature and size which is almost repeated in the Mid-Atlantic Ridge and again in the Morocco-Mauritania-Liberian Coast of North-West Africa. A similar curvature is repeated along the Persian Gulf in South-Western Iran and again in the Himalayan mountain arc against the Indo-Gangetic plains though in a more condensed form.

(2) The Chilean coast of the Andes and particularly the precordillera, is simulated by the Atlantic coast of peninsular Africa and also partly by the western coast of peninsular India.

(3) The Somalia-Kenya-Tanganyika coast of East Africa is very similar to the east coast of peninsular India. This coastline is complementary to the north-western coast of Australia.

(4) The Queensland coastal belt of Australia, east of the Great Dividing Range, has the same shape and size as that of New Guinea and partly simulates the shape and size of Philippines and also of Indo-China east of the lower Mekong.

(5) The eastern coast of China south of Shanghai has the same curvature and size as that of the Riukiu arc as also of the Japanese Island arc.

(6) The Pacific coastal belt of Canada and Alaska corresponds remarkably in form, size and broken coastline with that obtaining in the western coast of Greenland.

(7) The Adriatic coast of Yugoslavia and Albania is very similar to the Tyrrhenian or western coast of Italian Peninsula.

Many more examples can be added to this list in which configuration of land features, fairly widely separated, exhibit identity in form and size.

What is the significance of this homomorphy in physical features? How are they related? How are they produced? These are some of the questions which are not easy to answer on the basis of any of our present concepts.

It would be the attempt of the author to answer these and many other geomorphological, geological and geostructural questions of crustal evolution on the basis of the new concept of Sheet Movements under the impulse of volcanism, as developed by him and presented at the sessions of the International Geological Congress first at Algiers in 1952 and elaborated further at its later sessions at Mexico in 1956, Copenhagen in 1960 and New Delhi in 1964 and also in several other seminars and symposia during the last 30 years.

CHAPTER II

The Crust of the Earth
(Oceanic and Continental)

The top layer of the solid earth resting everywhere on the heavy mantle is the earth's crust. Part of this crust is exposed as a land mass and constitutes the continental crust, while a large part is submerged under the deep oceanic waters and this constitutes the oceanic crust.

The oceanic crust is gabbroidal or basaltic in composition, formed of silicates of mafic constituents (simatic) with a density about 2.9. The continental crust, on the other hand, for a large part exposed above the sea level, is mainly composed of granodiorites, granites, gneisses, schists and other metamorphic and sedimentary rocks all abounding in silicates of alumina alkalis, lime etc. As such they are lighter in density, ranging between 2.6 and 2.8. This continental crust of lighter rocks is designated jointly as Sial. This extends under the continents to various depths, ranging to as much as 35 km. or more.

THE OCEANIC CRUST

The heavier rocks constituting the oceanic crust are similarly designated Sima and lie directly under the deep oceanic waters. They are not confined to oceanic segments but continue variably under the continental crust also.

The crust under the deep oceans is more basic in character but differs from the underlying mantle sima which is formed of peridotitic rocks of distinctly higher density. The oceanic crust is separated from the underlying mantle sima by a sharp boundary known as Mohorovicic Discontinuity (Fig.3). This junction plane may be as shallow as 8 km. below the deep Pacific waters, while in continental regions, it may be as deep as 50 km. There is a sudden variation of density on the two sides of the discontinuity from the value of 2.8 to 2.9 above the discontinuity to 3.3 below the discontinuity. The elastic properties also exhibit an abrupt change in the velocities of the earthquake waves, particularly of longitudinal waves while passing from crustal sima above the discontinuity to mantle sima below the same plane. The crustal sima is also continuous both below the oceans as under the continent and as such constitutes a truly primordial feature of the earth formed during the pre-oceanic hot stages of the earth.

Being under the uneven load of crustal sial and being in a zone of high geothermal heat, coupled with the additional heat of radioactive origin conserved due to the sialic cover, the rocks of the crustal sima are more prone to melting as and when the overlying load pressures decrease or differential pressure increases in the region or when the accumulated radioactive heat raises the temperature above the melting point. The conditions for this are best along the borders of the continental masses against the Pacific sima

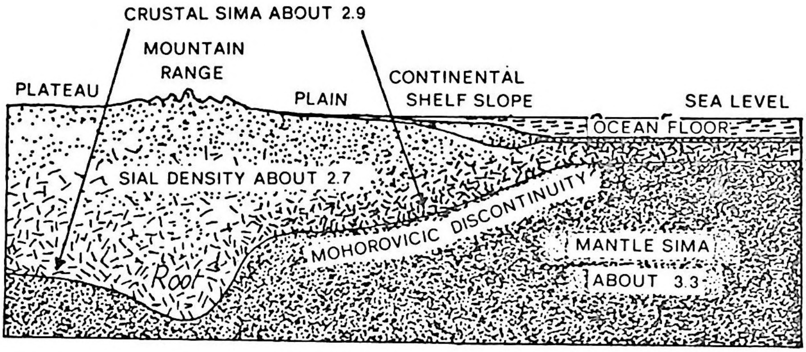


Fig. 3. Structure of the Earth's Crust
(From Arthur Holmes)

where the slightest crustal movements are enough to generate deep oblique fractures. thus permitting sudden relief of pressures. These fractures also permit percolation of oceanic waters to deeper levels within the fractured sima zone. These would induce melting of associated simatic rocks leading to volcanism along the continental borders as we find in the CircumPacific geosynclinal belts. From these oblique fracture zones called Benioff Zone, the basic magmas thus generated try to rise vertically up through the shatter zone into the continental cover along the border. They break through it and detach a portion of the sialic cover from the main continental mass to form an island arc.

THE CONTINENTAL CRUST

Shields and Platforms

Next to the oceanic crust, the most important feature of the earth's surface is the continental crust which covers about 30 per cent of the earth's surface. It is essentially composed of sialic rocks such as granites, gneisses, schists etc. The continental crust is not continuous but occurs in detached masses separated by uneven spread of oceanic crust in between. Even the individual continental masses are usually very heterogeneous in their structure, being composed partly of hard igneous and metamorphic rocks and partly of folded and unfolded belts of soft sedimentary rocks. The hard rock formations are grouped together to form a stable shield mass, frequently surviving as a core of the continent associated with bands and layers of soft sedimentary formations in the peripheral zones.

Most of the sialic rocks have, as their integral constituents, appreciable content of hydrous minerals. It is, therefore, possible that all the continental rock formations may have come into existence only after the formation of oceanic basins on the primary surface of the earth and we can hardly find traces of pre-oceanic primordial sialic formations anywhere on the earth surface. Granitic terrains are often found extending almost continuously for thousands of square kms. but we rarely find contact metamorphic effects on the associated sedimentary inclusions so as to indicate the zone of intrusion of granitic magma. It is, therefore, difficult to conceive the existence of granitic magmas of such continental dimensions which would yet preserve the tiny bands and shreds of pre-existing sediments undigested. On the other hand, there are all indications of granitisation of associated sediments to suggest metasomatic rather than magmatic origin of granites of these vast terrains. These granitic terrains carry abundant development of basic intrusives as dykes and sills often in highly metamorphosed condition as amphibolites, hornblende schists, chlorite-biotite schists, epidiorites etc. which are capable of inducing granitisation of associated sialic sediments by variable replacement of silica of sediments by al + alk derived from hornblendic constituents of crustal sima or eclogites of the upper mantle.

Vast outpourings of basaltic magma occur repeatedly in the earth's history. Intrusive phases of flood basalts in the nature of extensive sills are capable of granitising vast terrains of sedimetary and metamorphic rocks, particularly in deeper tectonic zones. Metamorphosed remnants of these invading basic magmas occur frequently associated within the granitoid rocks in the nature of amphibolites, hornblende-biotite-chlorite schists and as irregular bands and patches in gneisses often considered as "xenoliths". The deeper zones of continental masses abound in granites, gneisses and schists to constitute what is termed as "Basement Complex". Vast segments of such basement complexes when exposed without the cover of post-Cambrian marine sediments are often recognised as Continental Shields, suggesting therby that these stable blocks have withstood younger orogenic movements and have remained exposed as stable land masses ever since the Cambrian times. The basal formations in many sedimentary sequences have been subjected to repeated basic intrusions at different geological periods and as such have suffered quite high grades of metasomatic and contact metamorphic effect, resulting in the formation of complex shield mass whereas the higher formations in the same sequence have largely escaped metamorphism. These shield masses are thus complex mixtures of sedimentary metamorphic and eruptive materials of diverse ages. It is, however, difficult in many cases to ascertain geological ages of rock formations of such complex shield masses merely from the degree of metamorphism, since quite high grades of metamorphism are products of even as young orogenics as the Alpine.

This mode of development of shield masses brings out in perspective the role played by simatic volcanism in expanding continental shields both in thickness and in area. At some stage, the continental volcanism at the base of a vast continent leads to the stoping of basal part of the shield, often leading to the rupture in the middle part of the continent, dividing it into two parts along the medial rift. This is how the rift of Tethys sea brought about the disruption of the middle Palaeozoic Pangaea.

CHAPTER III

Geomorphological Features of the Continents

MOUNTAIN RANGES AS VERTEBRAL RIBS OF CONTINENTS

Mountain Ranges, Their Distribution in Space

The relief of the continental surfaces is vividly brought out by the folded mountain ranges in different parts of the world. They appear as ribs in the skeleton of earth's crust. They are distributed all over the continental surfaces, both longitudinally and latitudinally as also in criss-cross directions. Two or more ranges may coalesce into a knot or diverge from a common point. The geographical distribution of the ranges appears on the face as very irregular and haphazard. Most of these are significantly interlinked and as such are possibly genetically interrelated. Many of these ranges, particularly those of geologically older ages, Caledonian and Variscan, appear as disconnected horsts and ranges with a flat top and terraced sides while the younger ranges of the Alpine age exhibit sharp serrated tops and steeply eroded uneven sides. This differential behaviour of older and younger mountain ranges towards processes of erosion is rather significant. It is usually thought that the older ranges have suffered erosion for longer periods giving rise to mature (smooth) flat-topped topography while younger ranges are still immature, with sharp uneven surface features.

Mountain ranges extend for thousands of kilometers in length and may attain a breadth of scores or even hundreds of kilometres. Some of these like the CircumPacific ranges run almost continuously from near the North Pole to the South Pole along the Pacific coast of the continents. The Alpine group of mountain ranges, on the other hand, run east-west along the tropical belt extending from West Indies and the western end of the Mediterranean region interruptedly along southern Europe and northern African coast through Turkey and Iran to coalesce into the Tibeto-Himalayan ranges. These extend further south-east to New Guinea and New Zealand where they merge into the CircumPacific system of mountain ranges. Both these sytems of ranges, CircumPacific and the Alpine belong to the tertiary orogenesis and meet each other at the two ends of the Alpine system in the West Indies and the East Indies. Between these two ends, a number of ranges of different ages appear to diverge from the Alpine orogenic belt, making various angles with it. Thus, starting from the west end, we see the Appalachian ranges appear to approach the Mexican Gulf-Alpine arcs at a highly oblique angle. In the Mediterranean region, the belt of the Variscan horsts skirts the Alpine belt at a number of places in southern Europe. The Ural Variscan belt in the Eastern Europe appears to meet the Alpine belt in the Caspian-Aral region almost at right angles. The Tienshan (Variscan) range meets the Alphine belt in the Pamir region tangentially at very low angles. The Altait Caledonian range almost parallels the belt in the Tarim region. The Tienshan and Tsin-

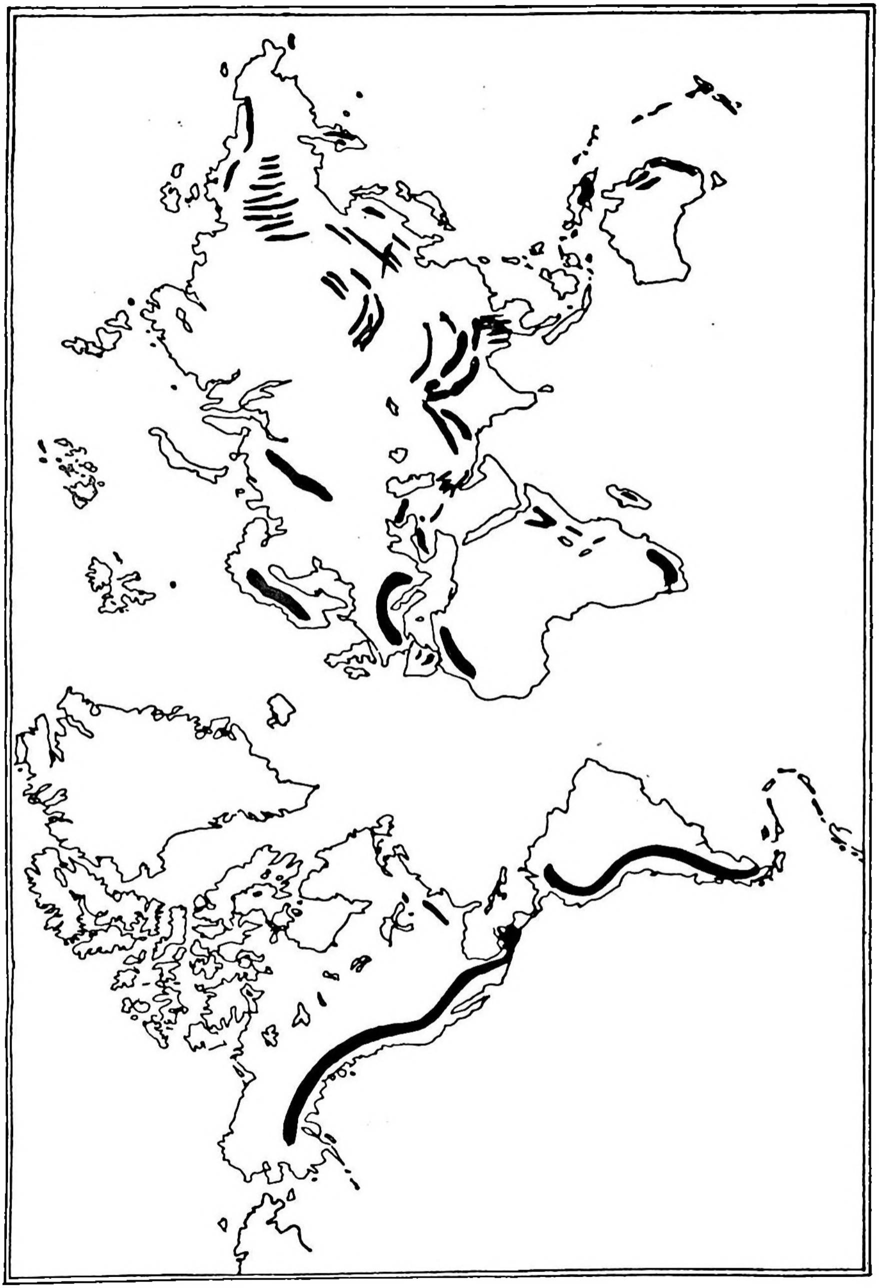


Fig. 4. Major Mountain Ranges of the World

ling ranges meet the same belt in the upper Hwang Ho region while the Sikiang range meets it in South China region. Most of these ranges meeting the Alpine ranges obliquely are pre-Alpine-Variscan or Caledonian in age. What is the nature of these relationships in time and space? (Fig.4)

The coalescence of a number of Alpine and pre-Alpine ranges has produced knot-like complex structures, the most spectacular among these being the Pamir knot. Here the Himalayan, the Karakoram, the Kunlun, the Tienshan, Alaishan, Tadjhic range, the Hindukush and to a certain extent, the Hazara range all meet and coalesce to produce a most complex structural plateau with a height exceeding at places 7200 m. above the sea level. What has brought about this peculiar and spectacular coalescence of diverse structural mountain ranges?

Almost a prototype of this knot, though not so complex or high, can be seen in the Armenian highland knot on the Perso-Russian-Turkish border between the Black Sea and the Caspian Sea and rising at places to a height of 5800 m. above sea level. There is yet another structural knot of Carpathian arcs, which simulates the above two structures, is much less complex and rises to a height of about 2600 m. These knot-like structures are not simple morphological features developed through the action of surface agencies but are brought about by the complex play of crustal processes which yet need to be fully comprehended.

Asia

The highest mountain ranges on the earth's surface, whose heights range above 7500 m., are confined to the Nepal Himalayas and the Karakoram ranges followed by those in the Pamir and Assam Himalayas (Fig. 5). Ranges next in elevation between 6000 m. and 7600 m. occur in the Tibetan and peri-Tibetan mountains of Tienshan, Hindukush, Kunlun, as also those in China and Pakistan. The other ranges reaching these heights are to be met with only in the CircumPacific ranges of Andes and in a solitary peak in Alaskan Rockies. Mountain ranges in all other regions of the earth are much lower in height, rarely exceeding 5400 m. and appear only as linkages between the high Tibeto-Himalayan ranges of Central Asia and those of CircumPacific ranges along the borders of the land hemisphere.

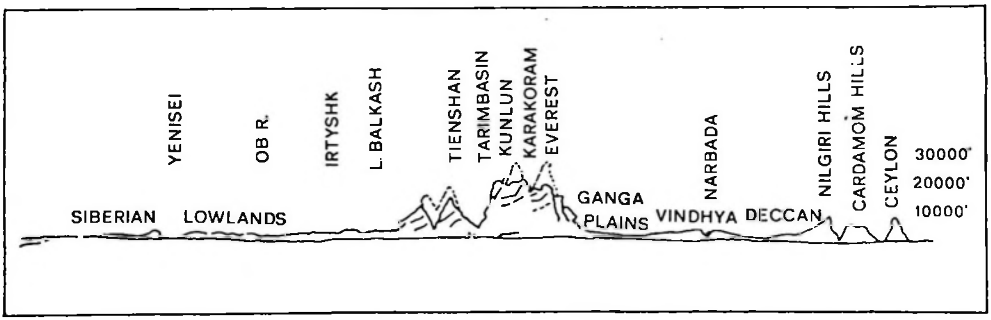


Fig. 5. Tibetan Plateau—A Unique Feature

The mighty mountain range of Himalayas rising like a wall along the southern border of Tibetan Plateau runs for a length of 2400 km. from the Naga Parvat (8126 m) in the north west to Namcha Barva (7756 m) in the east with a marked curvature convex to the south west. This great range curiously terminates almost abruptly both in the north-west and in the east forming acute syntaxial bends round the high pivots. The nature of this syntaxial bends is, however, variously interpreted. In the east in the Assam-Arunachal Pradesh, the Himalayan fold belt abuts against a series of tightly-packed concentrically arcuate ranges separated by the narrow longitudinal river courses of Salween, Mekong and partly Yangtsekiang. At about the latitude of Yunnan, the tightly-packed mountain ranges start splaying out in the region of Burma, Thailand, Indo-China and South China. In their southward trend, these ranges along with their intervening rivers apparently terminate against the gulfs of Martaban, Siam, Tongking and the South China sea. Only the Tennasserim-Malaya Range continues southward for a longer distance almost upto Singapore. Actually, the other arcs are seen to reappear southward as in the case of Arakan Yoma, Pegu Yoma trends continuing through Andaman-Nicobar Island arc and through Sumatra-Java. The Thai trend reappears in the Borneo ranges and further in Flinders and Gray ranges in the South Australia whereas the eastern strands of the Indo-China ranges reappear in the ranges of Phillippines and New Guinea and again in the Great Dividing Range of east Australia. (Fig. 6)

North of the Himalayas we have the tremendous plateau of Tibet which rises to an average height of over 4270 m. This plateau appears to have been brought about due to the fusion of several mighty mountain ranges which at one end have culminated into the Pamir Plateau.

This Tibetan Plateau has its surface studded with numerous lakes aligned roughly east-west. It has a gentle slope to the east where it is drained by the Tsang Po, Salween, Meking, Yangtsekiang and partly by the Hwang Ho rivers. The northern borders of this plateau are marked by the mighty Kunlun ranges rising at places of over 7600 m and which abut in the north against the Tarim Tsaidam depression. Along the eastern slope of the Tibetan Plateau in the region of upper reaches of the Yangtsekiang and the Hwang Ho, the eastward continuation of the Kunlun and the Tsinghai ranges appear to be displaced radially in a clockwise manner parallel to the northern tributaries of the Yangtzekiang via Yalung, Tatu, Kialing and Han Kiang. The same radial displacement is seen further NE in the region of the upper Hwang Ho, and in Tsaidam, Nanshan, Alashan, Yin shan and Hingan ranges in the region of the lower Hwang Ho and Amur basins, all having their linkages with the Kunlun, Tsinghai Ranges of northeast Tibet. In the northern parts of the Tibetan Plateau, the Kunlun mountain system appears to have been deeply breached by the Tarim and its tributaries thereby bringing about separation of Tienshan Range on the northwest and the Altai Range on the northeast.

The Altai Range, through its highly bent northern continuation of Yablonovyy and Stanovoy ranges, is linked with the Verkhoyansk, Cherskage, Kolyma and Chukotsky ranges of North East Siberia, ultimately joining with the CircumPacific ranges of Kamchatka. The E-W trending Tienshan Range is linked with the N-S trending Ural Range, through the interventing Dzungarai and Kazakh Plateaus in the source regions of the Irtysh, Ishim and Tobol tributaries of the Ob in the SW Siberia.

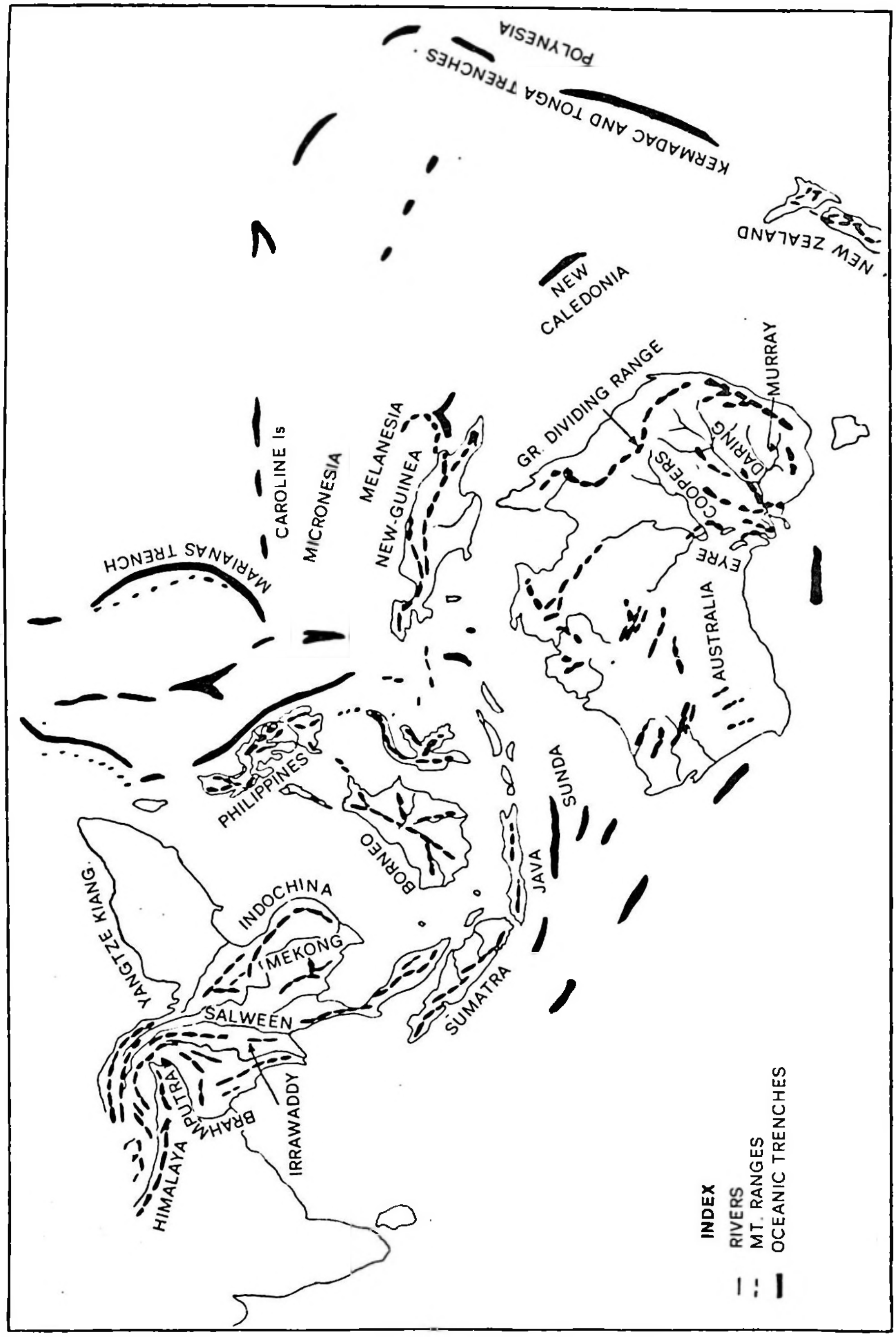


Fig. 6. Physical Features of the Indo-Australasian Region

In the north-western part of Tibet, the Pamir Plateau represents, as already mentioned, a scharung or fusion of a number of mighty ranges, including the Himalayas, Kailas, Karakoram, Kunlun, Tienshan, Alaishan, Hindukush and somewhat distantly, the Hazara-Swat-Sulaiman ranges of the Pakistan region as well. Of these the Hindukush ranges turn southwest and west into Parapomisus, Herat-Meshad, Kopet Dog ranges and join the Elburz mountains of northwest Iran while the Sulaíman-Baluchistan-Mekran ranges turn west in an irregular series of wide folds northwestward through Zagros ranges, linking with the Armenian Plateau and with the typical Alpine folds on the Turkish Peninsula.

After tremendous structural disturbances in the region of West Asia, the westward linkages of the Armenian-Turkish ranges appear submerged in the Aegean and Black Sea regions but undoubtedly continue into the Tertiary folds of southern Europe and north African coastal ranges. The westward linkages of the Tienshan-Alaishan ranges of southwestern Siberia appear interrupted and distended. They possibly run through Turkmenia, Usturt-S, Ural, Saretov, Podolian and Ukrainian Uplands into Central European region where disconnected Variscan Block mountains meet tangentially the Carpathian-Alpine fold belts of southern Europe.

Europe

The Urals in the Kama-Petchora source region send one branch as Timan Range towards the north-west, apparently linking with the Kola Peninsula of the Scandinavian shield and send another branch further north to connect the Novaya Zemlya Arc in the Arctic region. The Russian Platform bears numerous upland structures possibly linking the Urals with the Scandinavian ranges.

The Scandinavian structures are linked, on the one hand, with those of the British Isles, through the submarine ridge passing along the islands of Zetland, Orkney etc. and on the other, with the Greenland structure through Faeroe-Iceland submarine ridge.

The Alphine ranges of southern Europe which represent the westward continuation of Turko-Armenian folded ranges consist of: (1) The Grecian Alps, (2) The Balkan Alps, (3) The Dinaric Alps, (4) The Apennine Alps, (5) The Austrian Alps, (6) The Western Alps, (7) The Pyrenese ranges, (8) The Valencian Arcs, (9) The Balearic Arcs and (10) The Betic-Andalusian Alps. These mountain ranges all belong to the Alpine orogenic system. Though frequently interrupted, they are yet interlinked to constitute a broad belt of tertiary mountain system along the northern side of the Mediterranean Sea.

Africa

South of this sea, we get the development of similar mountain arcs passing through Cyprus, Crete, Libya, Sicily, coastal Atlas, Rif Arcs and the Anti-Atlas Arcs. Separated from the coastal folded ranges also occur other highland masses as inselberge along an east-west belt in the interior Sahara region of the African continent. They are: Darfur, Innedi, Tibesti, Ahaggar, Tademait, Anti-Atlas, Hamada du Dras and the Mauritanian uplands along the Atlantic coast.

The only other folded mountain range on the African continent occurs along the southern tip as the East-West trending Cape folds abruptly terminating at both ends against the ocean. Its continuation or relations with other orogenic arcs are not apparent.

The highlands of Ethiopia, Kenya, Tanganyika and South Africa are only residual trappean masses often rising to great heights (5200-5800 m) as in Mt. Kenya and Kilimanjoro. They much resemble the Deccan Traps of Western Ghat in Peninsular India.

ARCTIC LINKAGES IN LAURASIAN MOUNTAIN SYSTEMS

While considering the distribution of the mountain system of North America, it is noteworthy that its nearest approach to the mountain systems of the Old World occurs in the north-eastern Anadyr peninsular projection of Siberia. Here the Alaskan Rockies have a sharp bend in their trends towards NW and have a near headlong collision with Kolyma and Chukosky ranges of Siberia in the region of the Bering Straits, while the proboscis-like prolongation of the Aleutian island arc abuts at right angles against the Kamchatka Peninsula. Another linkage, tenuous though it is, occurs along the submarine Lomonosov Ridge across the North Pole while a more tangible linkage occurs between Taimyr Peninsula and Greenland through the island arc of Savernaya Zemlya, Franz Josephland and Spitzbergen. Yet another submarine linkage between Greenland and Norway, as already mentioned earlier, occurs through the Iceland-Faeroe-Zetland arc. These numerous linkages of Alaska and Greenland with various parts of Arctic Eurasia are very significant.

Mountain Ranges of North America

The most important mountain range of North America is unquestionably the NNW-SSE trending Rockyan Cordillaron system extending from Alaska in the north to Mexico in the south, covering a length of over 6000 km. This range rises in places as high as 6187 metres as in Mt. Kinlay in Alaska and 5450 metres in Mexico. In the region of the United States where it is broadest, the Rocky System has differentiated breadthwise into a number of N-S trending belts between the Pacific coast near San Francisco and Denver facing the Interior Plains. It encompasses a breadth of over 2000 km whereas the breadth in the Canadian Rockies in the north, as also in Mexico in the south, is less than 1000 kms. This doubling of the breadth of the Range in the middle region is significant.

The other prominent mountain ranges in North America are the flat-topped stumpy Appalachian and the Acadian Ranges near the Atlantic border of the continent running NE-SW extending from the Gulf of St. Lawrence in the north to the Gulf of Mexico in the south, often rising to about 2000 metres as in Mt. Mitchel and Mt. White.

These two mountain systems of North America, the Rockies along the Pacific coast and the Appalachian-Acadian along the Atlantic coast, appear diverging northward such that if the Appalachians are prolonged south-west, they would meet the Rockyan Cordillera near the Mexico City but for the intervention of the Mexican Gulf, as also for the covering of the Tertiary Gulf coastal formations. There are, however, indications of incipient linkages between these two major ranges across the Mississippi plains in the form of Nashvalley Dome, Ozark Plateau, Ouachita and Wichita Arcs, Black Hills, etc. in the intervening region, exhibiting characteristics of one or the other of the two mountain ranges.

The Cordilleran Range of the United States get condensed as it runs south through Mexico but further south gets still more narrowed within the Central American Isthmanian

Zone to its minimum width in the Panama link zone before it suffers a remarkable fanwise radial broadening eastward in the region of Colombian-Venezuelan Andes. This part of the North Andean mountain range again shows condensation as it runs south through the Ecuador.

Mountain Ranges of Central America

The Central America Isthmanian range, essentially volcanic in build, is highly zigzag in its southward trend and sends out Island Arcs transversely eastward in the nature of:

L. Orinoco-Guiana Amapoa.

Sierra de Meride-Caracas-Amapa

Costa Rica-Providence Bank-Petro Bank-Hispaniola

Honduras-Rosalind Bank-Jamaica-Hispaniola,

Br. Honduras-Misterous Bank-Grand Caymen Arc,

Yucatan-Cuba-Haiti-Puerto Rico.

Gulf Coast-Bahama Arc.

Mountain Ranges of South America

The continent of South America is dominated by the Andes Mountain ranges running continuously from the northern border in Venezuela-Colombia ranges and all along the Pacific board through Ecuador, Peru, Bolivia and Chile to the southern tip in Tierra del Fuego, and continues still further SE as a submarine ridge of Scotia. There are, however, certain features which serve to divide this vastly extended Andean Range longitudinally into a number of segments.

1. The Venezuelan Andes differentiated into (a) northern island arc from Guajira-Aruba-Curacao extended eastward to meet Lesser Antilles, and (b) Cordillera do Meride extending eastward through Caracas and Sucre to Trinidad. These Venezealand Andean Arcs trend SW to meet the Cordillera Oriental of Colombia.

2. The Colombian Andes divided northward into Cordillera Occidental, Cord. Central and Cord. Oriental become united in the south.

3. This Colombian Andes continues southwest as a unitary system into Ecuador Andes with a minor break.

4. The Ecuador Andes meets the Peruvian Andes obliquely near the political border but the relations of the two arcs are not clear.

5. The Peruvian Andean Ranges, often rising to 7000 m, are extensively breached by the tributaries of the Amazon, particularly the Ucayali and Maranon, whereby large segments of the Andean ranges are nearly obliterated.

6. The Andes of Bolivia are the broadest in the region of Cochabamba in the upper reaches of the Madeira tributary of the Amazon.

7. Near the trijunction of Peru, Bolivia and Chile, the Andean Range suffers a sudden change of strike from NW-SE in Peru to N-S in the Chile sector. The cause of this

violent change in the strike of the mighty Andes is not adequately understood nor can we explain cogently the sudden reduction of the width of this Peruvian range in the northwest.

8. The Chilean-Argentinian Andes are almost north-south in their trend and appear gradually reduced in width as we go south. Here they are extensively breached by the tributaries of the Paraguay-Parana system, the Colorado and other rivers of southern Argentina giving rise to a wide belt of Pre-Cordilleran ranges east of the Andes. The cause of this reduction in the width as also in the number of its longitudinal ranges is not properly understood.

9. Over the whole length of the Andes south of 40°S latitude the entire coastal belt of Andes is highly dissected through indentation by the Pacific waters through creeks and embayments giving a fjord topography. Even the high level plateaux rising to more than 4000 m have numerous lakes at the water divide. What is the cause of this dissection and peneplanation at such high level?

10. Near the southern extremity, the Chilean Andes take a definite bend to the east in Tierre del Fuego region, ending in the narrow Cape of San Diego.

The Andean structural belt appears to continue as a submarine ridge of Scotia up to the Volcanic arc of South Sandwich islands round an oceanic deep where it reverses its trend southwestward to meet the Grahamland Peninsular arc of West Antarctica and in this way, serves as a linkage between South America and West Antarctica. The nature of this acute reversal of the Scotia Arc is also not easily comprehended.

Mountain Ranges in Antarctica

The Grahamland arc of West Antarctica spreads out in the south in a series of radiating ranges in the Ellsworth Highland, the south-eastern branch of which turns round eastward round the Ellsworth trench to meet the most important mountain of East Antarctica; the Transantarctic Mountain Range, running from Coatsland along the Weddell Sea in NW, passes through the South Pole along the longitude N 20.0 W and N 160.0 E. It borders the zone of rifts which have given rise to Weddell and Ross sea depressions and which separate West Antarctica from East Antarctica. This Transantarctic Mountain Range bends round at both of its ends to join the border highlands of Coatsland, Queen Maudland, on the north, and Oatsland Adelieland, on the apparent south, serving like ramparts surrounding vast depressions in the central parts of this ice-covered continent. From these coastal highlands are seen submarine arcuate ridges radiating away and linking the continental mass of East Antarctica individually with New Zealand, Australia, India and South Africa.

Mountain Ranges of Australia

Australia is a platform type of continental mass with comparatively low elevations. The mountain ranges are few and are flat-topped plateau-like masses, the most conspicuous of which is the Great Dividing Range, running roughly parallel to the east coast of Australia right from Cape York peninsula in the north to Melbourne in the south. It rises at places to over 2230 m and constitutes the water divide between the coastal eastern and the central parts of the continent. The western Australian mass is again a plateau mass supporting the hill ranges of Musgrave, Macdonnell and Robinson, occasionally rising to almost 1525 m.

The New Zealand and New Guinea Ranges are typically Alpine in structure rising to 4000 m and more and have together the shape, size and curvature remarkably similar to the Great Dividing Range coastal belt of Eastern Australia to which they are linked by the submarine features of the Great Barrier Reef and the Lord Howe Rise in the Coral-Tasman Sea region. The New Zealand Island mass and the Australian Great Dividing Range are linked with the Antarctic Range through the Tasmania-Macquarie-Balleni submarine ridges while both these land masses are connected with New Guinea and through it with the Philippine-Taiwan and the East Asiatic mountain ranges.

In the above pages, we have studied the distribution of mountains, plateaux and hill ranges in different continents of the eastern and western hemispheres. From this it is obvious that the various mountain trends, developed in distant continental masses, all appear intimately interconnected through linkages either subareal or submarine and exhibit trend systems which can be followed not only in the same continents but even on other continents across the wide seas and oceans. It is again noteworthy that most of these regional trend systems converge towards the region of the Tibeto-Himalayan and Central Asian Highlands. These widespread structural linkages among the mountain systems of diverse continents of the land hemisphere bring in an element of close genetic relationship supported by geostructural and even faunistic similarities. These relations throw light on the course of structural evolution and emplacement of associated continental masses. We have yet to understand the nature of crustal processes which give meaning to these intra-and inter-continental linkages and their present distribution.

MOUNTAIN BUILDING DURING GEOLOGICAL TIME

Mountain ranges constitute the tangible framework of continents and yield the most reliable evidence of the structural movements which the continental crust has experienced since early geological periods. Such evidences are preserved fairly clearly for most of the phanerozoic (post-Cambrian) part of the geological history. The evidences of earlier Precambrian orogenies though recorded are only sporadic, of uncertain areal extent and are of equivocal geological dating. The well-authenticated orogenies which have moulded considerable areas on the earth's surface and whose phases have been worked out in detail on the basis of faunal stratigraphical and structural evidences are available only since the Cambrian Period. Any conclusions regarding Palaeogeographical changes in the earth's surface would be reliable only for the post-Cambrian period since earlier orogenies have been largely vitiated through ultra-metamorphism and complex structural inversions. The first comprehensive attempts at synthesizing the structural history of the earth's surface were made by E. Suess (*The Face of the Earth*, 1904-1909) on the basis of information available to him till the closing years of the last century. He recognised mainly three short periods of strong orogeny separated by long periods of geosynclinal sedimentation during the post-Cambrian period and determined their aereal distribution on the earth's surface. He also recognised that marine belts peripheral to the continents which had served as geosynclinal basins had been squeezed and folded up as mountains and were ultimately fused with the adjoining continental masses, thus increasing their areal dimensions. The orogenic mountain belts thus offered the best evidence regarding the changes suffered by the earth's surface during various geological periods.

The concept of compressional squeezing of geosynclinal belts by adjoining cratonic foreland masses as the principal mode of orogenic upheaval had since long been dominating the geological thought and had been utilised to ascertain the relative palaeogeographical positions of different continental masses during the various geological periods.

The major orogenies were supposed to be global in their field of action and as such vast continents were supposed to have converged simultaneously over varying distances to bring about squeezing of intervening geosynclinal sediments into folded ranges. Later, H. Stille in his *Grundfragen der vergleichenden Taktonik* (1924), slightly modified this concept and recognised as many as 24 orogenic phases of varying intensities which were grouped under three major orogenies during the post-Cambrian period. In their duration, these phases were merging one into the other and some phases even overlapped. Stille further visualised that some orogenic upheavals in certain parts were coeval with geosynclinal sedimentation in other parts.

J.H.F. Umbgrove in his "The Pulse of the Earth" (1942) has illustrated these major post-Cambrian orogenies and their phases very conveniently in map-plates (1-5). These maps give a fairly clear picture of their areal distribution in the world. His plate 5 is particularly very instructive (Fig 7). A study of these map plates brings out some very interesting facts regarding the regional distribution of individual orogenies as well as their joint development.

Caledonian Orogeny

The most typical development of the Caledonian (Silur-Devon) orogeny, which in general is very localised, occurs in NW Europe along the Norwegian belt, apparently continuing SW into the British Isles and possibly also into the Spitzbergen ranges in the north (NW). Other significant developments of this orogeny are seen along the eastern board of Greenland, New Foundland, New England states of eastern Canada continuing along the western face of the Appalachian ranges in the United States. Traces of the same orogenic movements are recorded in the Rockies also. However, the widest development of the Caledonian orogeny is met with in the Altai Ranges of Mongolian region, south of the Angara Shield. The same orogeny is further developed in the Taimyr Peninsula of Siberia north-west of the Angara Shield and again in the lower Lena basin thus almost encircling the Angara Shield.

Besides traces in the Himalayan and Chinese terrains, another significant development of the Caledonian structure is met with in the central and south eastern Australia and in Tasmania.

That the Altai folded mountains are probably the most primary theatre of the Caledonian orogeny is shown by the fact that this Central Asian basin has been the scene of continuous post-Cambrian geosynclinal sedimentation and is successively folded by the Caledonian, Variscan and even by the Alpine orogenies as seen in their widest development in Altai, Tienshen, Kunlun, Karakoram and the Himalayas in the regular order. Nowhere else on the earth's surface do we see this massive development of intracontinental geosynclinal sedimentation for such a long duration and in such a wide areal expanse. It is, however, a moot problem as to how the various Caledonian fold belts, faunistically closely related, are connected among themselves in their regional development.

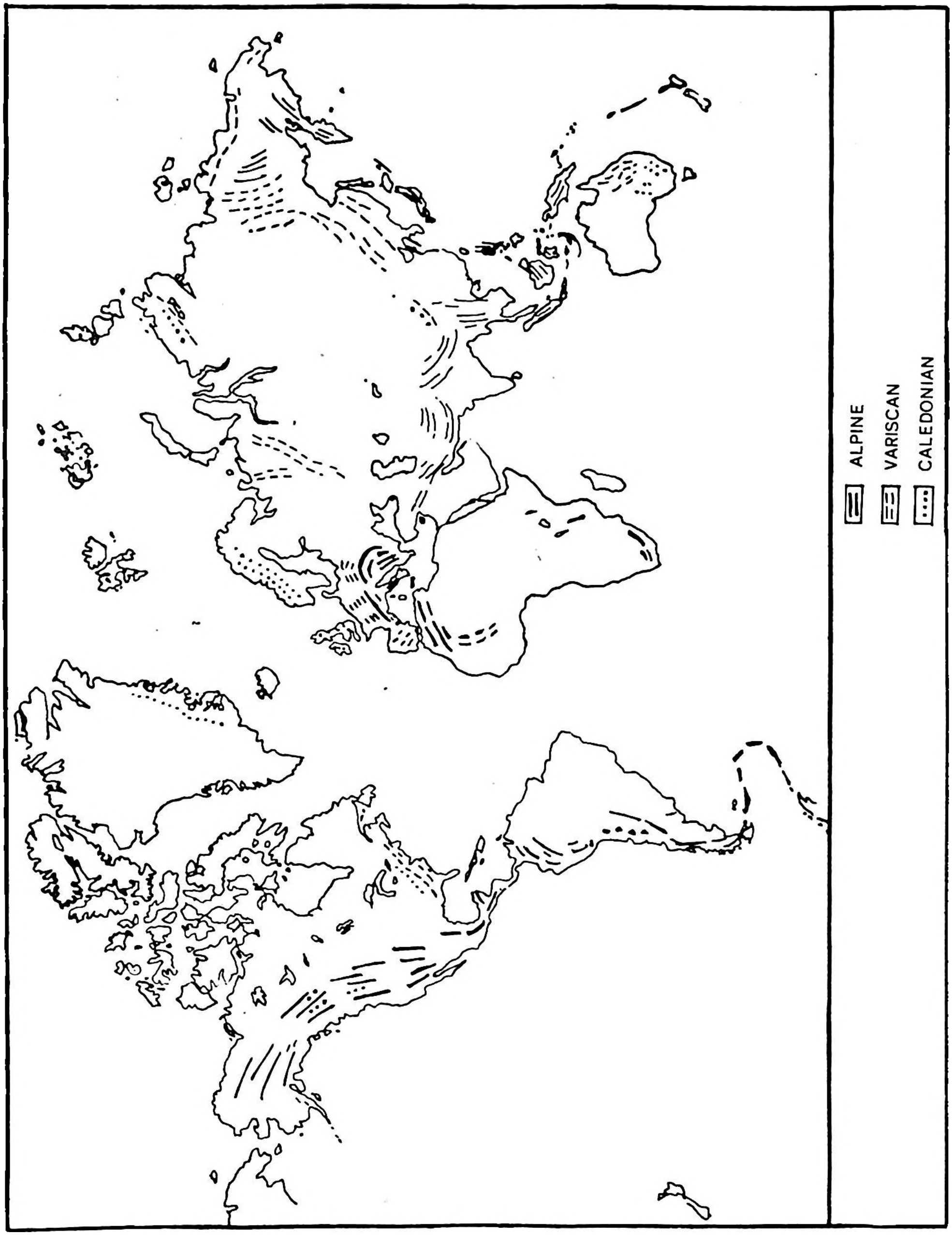


Fig. 7. Major Orogenies of the World

Variscan Orogeny

This essentially Upper Palaeozoic folding, covering the earth movements from Upper Devonian to Upper Permian, is, as would be seen from Umbgrove's Plate 2, quite widespread in the Eastern, Central and Western Asia, Central and Western Europe and in the Eastern North America and also in parts of South America and Western Australia. In several regions it closely follows the trends of the Caledonides as in parts of the Appalachians, South American Andes, Central Asia, Taimyr Peninsula, Lena basin and in southeastern Australia.

In some other areas, it is parallel to the Alpine trends as in Tibet, Central Asia, Turko-Persian region, Burma, Japan, North African Atlas and in South American Andes. Though the faunal relations are quite intimate among the various Variscan fold belts, their present distribution and particularly that of the Urals, precludes the possibility of channel of free intermigration. The palaeogeographical distribution of the Upper Palaeozoic continental mass of Laurasia is highly vitiated. The primary character of the Tibeto-Central Asian Variscan basin is maintainable on the strength of its massive development in this region both areally and in elevation.

Alpine Orogeny

This Upper Mesozoic-Tertiary orogeny is areally the most widespread and is also the most imposing due to its elevation in places to more than 8500 m above sea level. It has encompassed the whole land hemisphere latitudinally as Alpine Himalayan Belt and longitudinally as CircumPacific Cordilleran Ranges and Island Arcs. Longitudinally, the Rockyan, Andean and the East Asiatic mountain ranges run almost from North Pole to South Pole along the western and the eastern borders of the continental hemisphere against the Pacific Ocean and truly constitute the CircumPacific mountain system. The principal folding movements in these CircumPacific ranges are essentially Upper Mesozoic in age. The latitudinal Alpine Himalayan mountain system runs roughly from Central America on the west to Indonesia-Australasia on the east, almost continuously except for a possible gap in the central Atlantic region and thus completely separates the northern continents from the southern ones along the equatorial belt. The principal foldings of this system are essentially Tertiary in age, slightly younger than the CircumPacific foldings. These two systems of Orogeny in the CircumPacific and Alpine-Himalayan belts are intimately involved in the positioning of almost every continent on the earth's surface, including Antarctica.

Among the CircumPacific belts, the Rockies dominate in the northern hemisphere and the Andes in the southern hemisphere, rising at places to more than 6100 m above sea level. These two belts are linked in the central American region through a series of Isthmanian volcanic belts and also by a series of Island Arcs of the West Indies.

The Rockies running along the eastern flanks of the Pacific meet the East Asiatic Arcs running along the western flanks of the Pacific rather transversely through the Aleutian arc round the North Pole and longitudinally near the Bering Straits. The Andes similarly running N-S along the eastern flanks of the Pacific meets the Antarctic-Australasian CircumPacific belt running along the western flanks of the Pacific.

RIVER VALLEY SYSTEMS

River valleys constitute a very important element in the physiographic features of the earth. Besides their impact on human life and civilization, they have a very significant role in the evolution of the earth's surface. Mountains and other high regions are being drained and denuded and their detritus distributed and deposited over low-lying lands and basins. This process, going on incessantly since early periods of the earth's history, has brought about considerable modifications in the surface features of the earth. Many lofty mountainous regions have been levelled down to low plains. Their detritus is deposited in lakes, rivers valleys, gulfs, bays and seas thus filling low depressions. Many of these deposits have again been folded into high mountain ranges during later crustal disturbances.

Apart from this work of denudation, transportation and deposition of sediments, the rivers have not been thought of as having played any other significant role in the structural history of the earth surface. The rivers may have taken advantage of slopes and certain structural features like folds, faults etc. to carve out their valleys or cut across mountain ranges or circumvent other surface features obstructing their courses, but more than this, the rivers are not thought of having any deeper significance in the structural evolution of the region.

However, a deeper study of the various river systems and their relation to geological structures of the region they pass through, brings out the remarkable significance they assume in the evolutionary history of their drainage basins. A few examples would suffice to bring out the nature of the role they have played in crustal evolution.

The Indus, the Ganges and the Brahmaputra all draining into the Indian Ocean have their sources in and around Mansarovar depression in Tibet, far behind the line of highest mountain peaks. They cut their courses through the broad and tough granitic core regions of the ranges in a series of mighty gorges several kilometres deep and extending over lengths of scores of kilometres. These have been considered as antecedent rivers cutting their courses faster than the rate of rise of the Himalayas, and keeping to their courses, braving stupendous convulsions of the crust during the upheaval of the whole region (A. Holmes p. 595). This is probably too simple an explanation to be convincing. When we see that these rivers as also their mighty tributaries all exhibit systematically the same delineation of their courses involving sudden changes of direction as syntaxial bends in their courses, it appears possible that they are connected with a definite pattern of structural movements involving vast tracts of the Himalayan terrain. Almost every major tributary of the Ganges originating in the Central Himalayas west of the Mt. Everest, e.g. the Gandak, Ghogra, Mandakini, Jamuna, develops an acute bend in the river course convex to the west or north-west. The same feature is to be observed in the tributaries of the Indus, viz. the Sutlaj, Bias, Ravi, Chenab and Jhelum. The acute bends often attended with gorges appear just where the rivers finish their mountain course and emerge on to the plains. In the mountain region, the rivers have a general westward course but as soon as they reach the outer ranges or plains, the course suddenly becomes eastward or south-eastward. Why should all these rivers rising in different parts of the Himalayan range, encompassing differently constituted structural terrains, behave in a common fashion? The behaviour of the Ganges and its tributaries is seen carried over by the Indus and its tributaries (Fig. 8).

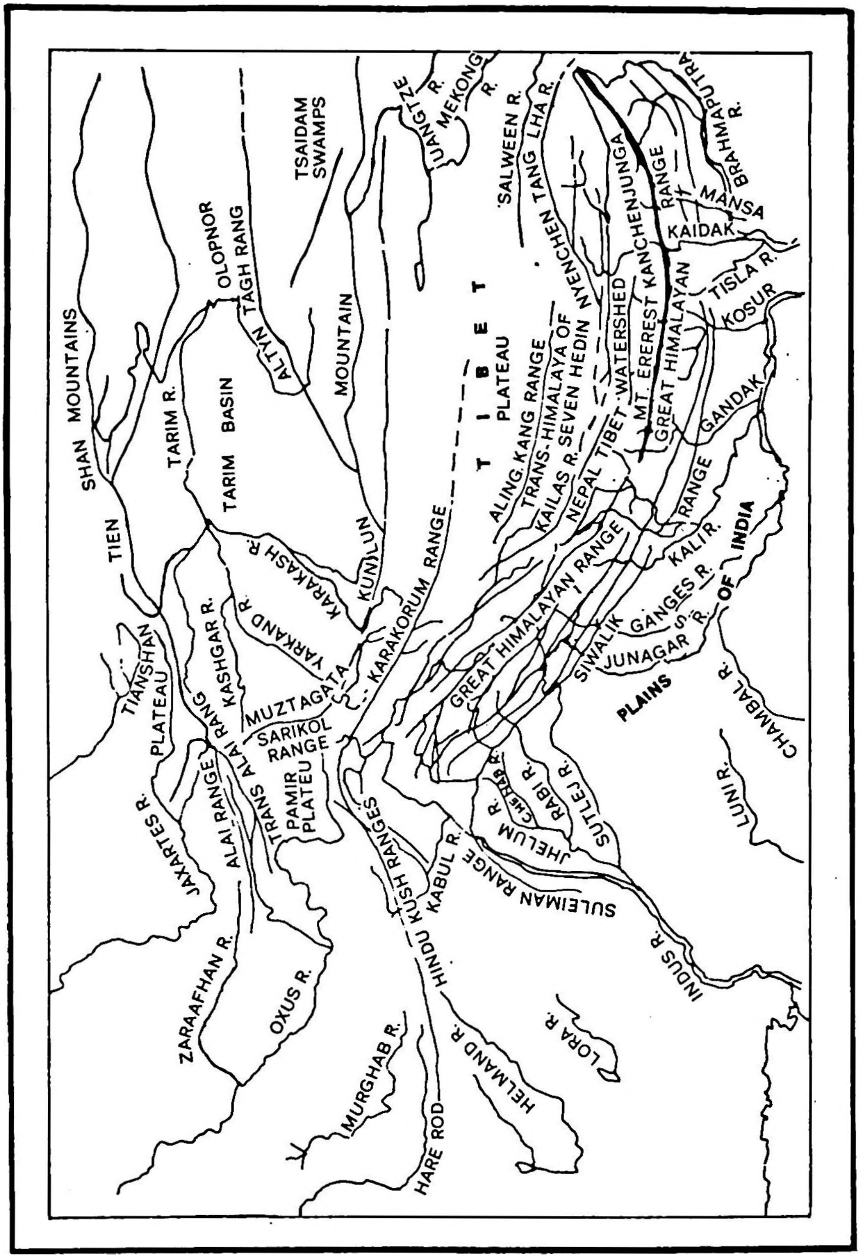


Fig. 8. Himalayan and Tibetan Systems of Rivers

In the case of the Brahmaputra, it also rises from the same Mansarovar depression but in contrast to westward-flowing Indus, it flows straight eastward under the name of Tsangpo for over 800 miles upto Namcha Barwa where it takes a sudden turn to the south as Dihang and again suddenly reverses its flow westward as continuation of the Luhit tributary, straight upto Dhubri in Assam as Brahmaputra where it again takes a sudden turn to the south to join the Ganges west of Dacca before the latter joins the Bay of Bengal.

In this case, the tributaries of the Brahmaputra, viz. the Tista, Raidak, Manas and Subansiri, exhibit a curvature which in all these cases is convex to the east or northeast exhibiting remarkable correspondence with the trend changes of the hill ranges of the region. This type of behaviour, uniform over vast regions, calls for a cause which cannot be local or superficial but must be subcrustal and regional. None of the existing concepts has any satisfactory explanation for this phenomenon.

We may now examine the courses of the Brahmaputra (Tsangpo), Salween, Mekong and Yangtsekiang all rising in the Tibetan Plateau in the Trans-Himalayan region. They flow first eastward, soon bend southward and run in closely parallel arcuate courses separated by very narrow partings. After descending from the Tibetan Plateau, they splay out radially. The Brahmaputra and its subsidiaries Meghna and Berak, the Irrawaddy and its subsidiaries, Manipur and Chindwin, all have courses broadly convex to the west. The Salween has almost a straight southward course with a distinct westward bend in its lower course. The Mekong, on the other hand, has a very irregular course with several acute bends shifting the course repeatedly eastward and southward. Subsidiary to the courses of the Mekong are seen parallel courses of the Black and Red rivers of Vietnam taking their source in the region of Yunnan. This radial fanning out of river courses appears accentuated in the river Yangtsekiang which after running parallel to the Mekong course for a considerable distance over the Tibetan Plateau takes several reversals, ultimately to flow ENE to meet the East China Sea near Shanghai. The river Sikiang in South China behaves as a subsidiary to Yangtze Kiang and takes an intermediate position between the Mekong and the Yangtsekiang to flow ESE to meet the sea near Hongkong. We thus see the four Tibetan rivers — Brahmaputra, Salween, Mekong and Yangtsekiang — which originate in a small area in Central Tibet and which run closely spaced in parallel arcuate courses for long distances over the Tibetan Plateau suddenly suffer radial divergence in their courses in the region of Assam-Yunnan ultimately to join the sea and thereby encompassing a vast region stretching from Calcutta to Shanghai. What should be the cause of this systematic fanning of the mighty river courses, turning a full angle of 180° in the region between Sadia on the Brahmaputra and Chungtien on the Yangtsekiang, barely 400 kms apart, along the southeastern foot-hills of the Tibetan Plateau? The same phenomenon is seen at the northwest end (Pamir) of the Himalayas.

These features are certainly not the erosive work of the downward flowing river waters running along surface slopes or due to obstructions in the drainage basin. These systematic changes in the trends of the rivers are superimposed by crustal movements suffered by the region. The changes in the river courses are clearly reflected in the changes in the structural trends of the rock-formations in the region and it is evident that the river courses faithfully register the structural changes which the region has undergone.

It may further be noticed that the Yangtsekiang trend pattern is largely repeated by the river Hwang Ho further north except for very minor differences. Many portions of its course are for a considerable part almost identical in pattern and even in dimensions.

The same pattern is again repeated remarkably faithfully further north in the region of Mongolia and Manchuria along Sino-Siberian border by the Sungari-Amur River system. This can be appreciated by placing the traces of their courses side by side.

Thus, the three major rivers of China in the southern, central and northern territories exhibit almost identical patterns throughout their courses from the Central Asian highlands to the Pacific borders. These peculiar features of the river courses exhibited over vast regions of the crust must have some deep significance not yet realised.

Numerous such examples can be cited showing the remarkably intimate relationship of the river courses with the structural changes of the region and as such they appear as important guides to the understanding of the crustal evolution of the region.

RIVER SYSTEMS AS ARTERIES OF CONTINENTS

River Systems of Asia

Asia is the biggest continuous land mass on the earth's surface but it has also the most complex structure among the continents. The Himalayas may serve as the backbone of this continent but there are yet several outflanking ranges which are not directly connected with this Himalayan backbone and appear to have an independent structural build. It has, therefore, hardly any single arterial river system which could reach and sustain its various outlying parts. It would, however, be seen that the patterns set by the Himalayan rivers — the Indus in the west, the Ganges in the south, the Brahmaputra in the southeast and also by the Tibetan rivers Tarim and the Hwang Ho in the north — have, to a variable extent, influenced river patterns in distant parts of the continents in different directions. Thus, the Indus pattern is seen carried in large part by rivers Helmand, Harirud and even by the Tigris and Euphrates in West Asia. The Ganges trend pattern is carried southward by the Damodar, Subarnrekha, Mahanadi, Godavary and Krishna systems of rivers in Peninsular India.

The Tsangpo-Brahmaputra trend pattern, as already mentioned above, is clearly visible, in parts, in the courses of the Salween, Mekong and partly even in the Upper Yangtsekiang course along east Tibet slopes. However, now a new pattern is seen superimposed on this South China river where it reverses its course from southward flow to northward and northeastward flow in its lower course.

This new pattern of the Yangtsekiang is seen repeated in the Hwang Ho, in the Amur, and partly even in the Lena and its southern tributaries.

The case of the Lena, the next important river in the region, is still more impressive. It takes its source near the western border of the lake Baikal, flows north and NNE parallel to the Cis Baikal ranges, then NE and east and in sweeping serpentine arcs, curves round to the west, NW and north and back again NW finally to join the Laptev Sea of the Arctic Ocean. Its tributaries Amga and Aldan follow arcuate courses convex to the east and run remarkably parallel to the course of the Lena before they join the main river. The Maya tributary of the Alden rises in the ridge overlooking the Pacific Ocean along the Sea of Okhotsk. The Maya-Aldan-Lena system thus cuts off almost completely the mountainous Kolyma Peninsula of NE Siberia from the plateau region of the Siberian mainland.

The remarkable sinuous course S of the Lena and its tributaries reflect, very faithfully, the changes in structural trends of the mountain ranges like Yoblonovyy, Stanovoy, Verkhoyansk etc. in the basin of the Lena.

The Lena later assumes a yet newer pattern in its lower course which is seen largely repeated in the rivers of the Kolyma Peninsula; viz. Yana, Indigirka, Kolyma etc., all flowing north with convexity to the west. Here the regulating factor includes the arcuate mountain ranges of Verkhoyansk and Cherskogo which are parallel to the lower Lena course.

The Tunguska-Yenisey system also, like the Lena, starts from the SW end of the Baikal depression but has a slightly different pattern influenced by the Vilyuy-Lena and Olenek systems. It is further modified by the Angara-Tunguska Structural trends. This Yenisey trend is seen abundantly repeated in parts in the Irtysh-Ishim-Tobol courses of the Ob system now spread out over a vast region.

These Amur-Lena-Yenisey-Ob systems of river courses in the northern parts of Asia thus appear to be distinctly related to the Hwang Ho-Tarim trends, characterising the northern borders of the Tibetan Plateau and the Mongolian Uplands (Fig. 9).

Thus, most portions of the Asian continental terrain are characterised by drainage patterns which carry the distinct impress of the Tibet-Himalayan river systems Indus, Ganges, Brahmaputra, Hwang Ho, and Tarim and may indicate deep-seated relationships connected with crustal evolution in these parts, both in time and space.

River Systems of Europe

Among the important rivers of the European sub-continent, the most noteworthy are the Volga and the Danube which among themselves cover nearly two-thirds of the European terrain (Fig. 10). The Volga has its source in the low Valdai Uplands not far from the Baltic Sea and, though with very low gradient, flows through a highly zigzag course in a general eastward direction upto Kazan. Here it meets its northern tributary the Kama and forms a vast lake reservoir. From here as a mighty river it follows a fairly straight course to the south upto Stalingrad almost in close proximity of the river Don but takes a sudden turn to the southeast to join the Caspian Sea. The tributary Kama in its southward course drains the western slopes of the Ural Range over a large region. Thus, the Volga-Kama system covers nearly the whole of the Russian platform, almost from the Baltic to the Aral Sea.

The course of the Lower Volga South of Kazan simulates the course of the Ural River which drains the southern and western slopes of the Ural Range. One of the tributaries of the Volga east of Kubishev rises within the sight of the Ural river and appears to have had direct link with the same river in the past. Both the rivers — Ural and Volga— drain into the Caspian Sea. All these features suggest the possibility that the Volga has inherited much of its trends from the Ural river and thus together with the Kama was draining the whole of the western face of the Ural mountains. The Volga

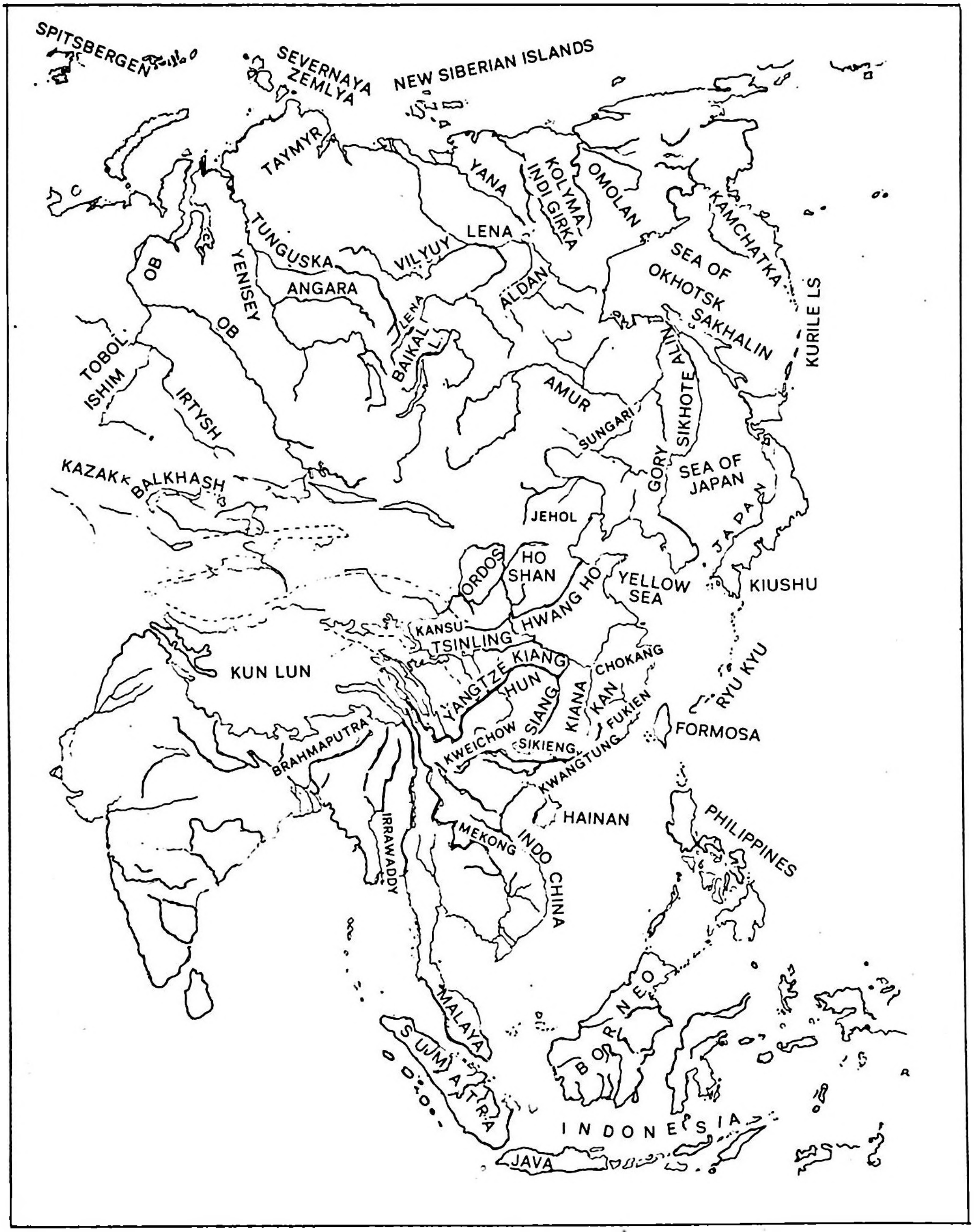


Fig. 9. River Systems of East and North East Asia

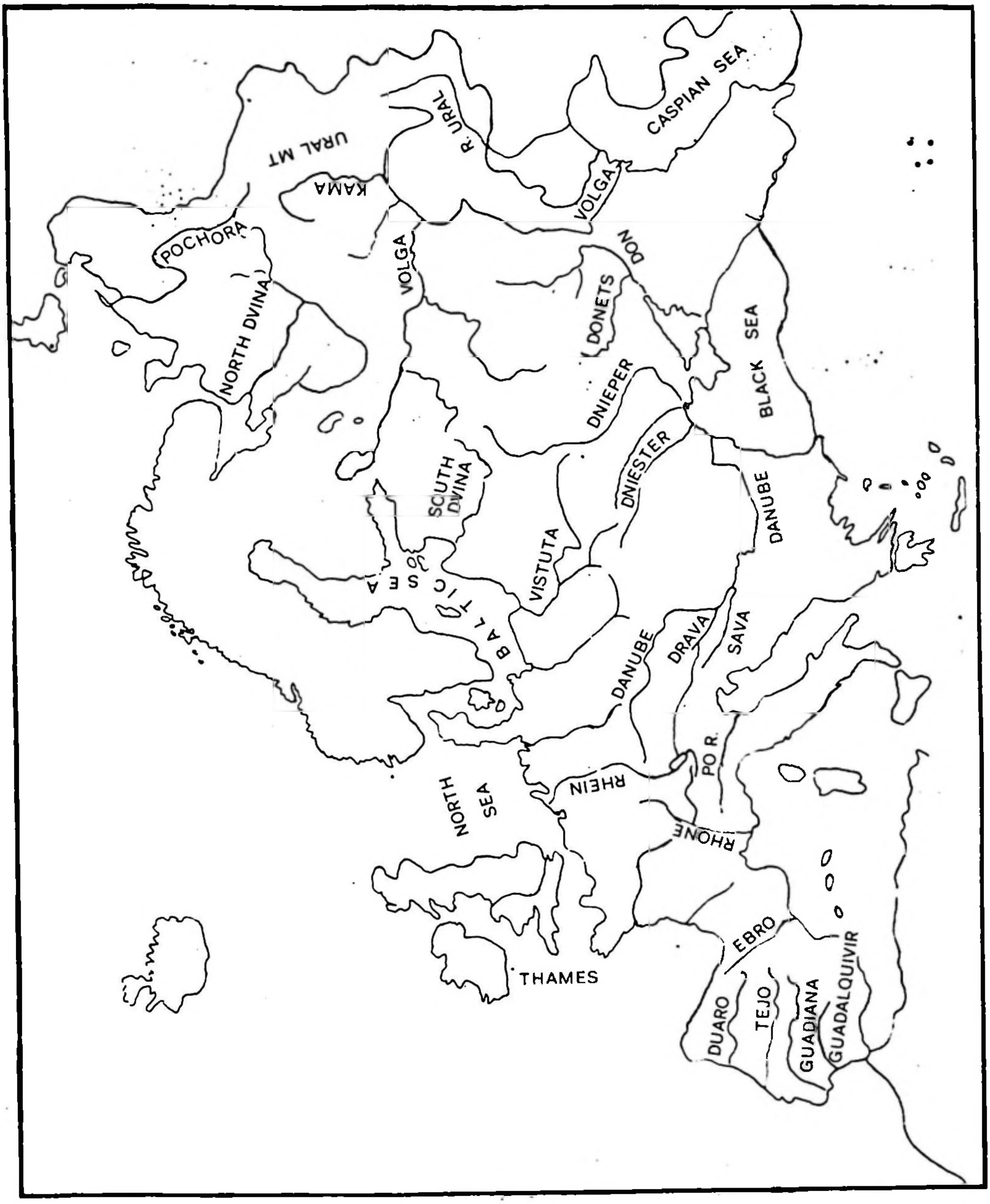


Fig.10. River Systems of Europe

assumed its present zigzag course through the development of a series of loops in the upper courses of the river.

Similar trends are seen developed in the course of the North Dvina now flowing from east to west as opposed to the eastward flow of the Upper Volga. The North Dvina takes its source near the source of the Kama and also that of the north-flowing river Patchora.

The Danube

Besides the Volga, the next important river, and with an equally irregular course, is the Danube, originating near Feldberg (1500 m high) in the Black Forest not far from the Rhine Rift valley in Central Europe. It runs along the northern border of the Molasse trough north of the Eastern Alps, and skirts the Bohemian mass along its south-west border and then enters Carpathian arcuate ranges with rapids and gorges. Later it takes an abrupt southward turn near Budapest. On meeting its southern tributaries—Drava and Sava—it takes sudden turns, partly to the east and partly to the south. It again cuts across the arcuate ranges, now of the Balkan Alps near Belgrade, with steep rapids and waterfalls and takes a long zigzag eastward course. It ultimately joins the Black Sea, north of Dobruja. On the way it collects the drainage of the whole of the inner Carpathian basin of Czechoslovakia, Hungary and Romania through a peculiar system of arcuate courses of its northern tributaries, e.g. Morava, Tisa and others, partly parallel and partly transverse to the Carpathian arcuate ranges. From this zigzag course between the Black Forest in Central Europe to the Black Sea in southeastern Europe, it would be clear that the channel the river has adopted for itself, is highly beset with numerous structural hurdles which it had to negotiate during its downward course. Why it should have preferred such a difficult path and how with its low gradient the river has succeeded in cutting its course through a complex tectonic terrain as that of the Black Forest and Bohemian horsts and of the Carpathian and Alpine folds are questions not easy to answer. Evidently, the river in this case is not an active channel cutter by itself but is merely a trace of interaction of various crustal movements which have governed the structural evolution of the region.

The terrain between the Volga and the Danube is traversed by a number of rivers Don, Donetz, Dinepr and Dniester, all having more or less parallel arcuate courses from northwest to southeast with a sudden bend to the southwest (except in Dniester) before joining the Black Sea. The interdigitation of Oka, the southern tributary of the Volga, with some of these major rivers is very instructive.

The terrain of the Central and Western Europe is drained by a number of medium-sized rivers with a general NNW trend with their sources lying between the Alps and the Variscan horsts and taking an arcuate S-shaped course to join the Baltic Sea, the North Sea or the Atlantic Ocean.

The Rhine and the Rhone rise south of the Bernese (Swiss) Alps near Andermatt, flow in opposite directions, the Rhine to the east and northeast and north utlimately to join the North Sea while the Rhone flows to the west, southwest and south to join the Mediterranean. These two together thus cut across the European subcontinent from north to south. The rivers of France have in general northwest trends with their arcuate courses all having convexity towards the east. The four rivers of Spain—Duero, Tejo, Guadiana and Guadalquivir—all run from east to west parallel to the Almeria-Gibraltar coast of the Mediterranean with a distinct southward bend in their lower courses. Why should all the four rivers exhibit this peculiar characteristic? The fifth river, Ebro, originates in the Cantabrean ranges in the sight of the Bay of Biscay and runs southeast to fall into the Mediterranean. Thus, all the rivers of Europe exhibit some peculiar characteristics which indicate a definite impress of structural elements governing the geological evolution of the different regions and as such these river courses also serve as a good guide to the structural history of the European sub-continent.

Rivers of North America

Among the most outstanding rivers of North America are the St. Lawrence in northeastern region, the Mississippi in the central region, Mackenzie and Yukon in the northwestern region, Frazer, Columbia and Colorado in the western region and Rio Grande in the southern region. Of these, the Mississippi alone controls more than one-third of the total drainage area of the North American continent (Fig. 11).

The St. Lawrence River, however, has a unique drainage course among the rivers of the world. This river is in the nature of linking of vast lake basins with the Atlantic Ocean through an ever-widening rift valley opening out into a gulf prior to meeting the ocean. These vast lakes in the nature of arcuate lobes of depressions are considered as products of scoopings by Pleistocene glaciers. The lower course of the St. Lawrence is obviously a rift, a product of tectonism in the region, but the nature of crustal movements involved is not fully understood.

The Mississippi is the most dominant river system in the whole of North American continent, spanning almost two-thirds' surface of the United States. Its tributaries, individuallly by themselves mighty rivers, meet the main Mississippi river like veins joining the midrib in a leaf and encompass the whole interior region between the Appalachians and the Rockies. The eastern tributaries, viz. the Ohio, the Cumberland and the Tennessi drain the whole western slopes of the Appalachians and curiously, the southwest flowing Tennessi and Cumberland suddenly reverse their southwest course to flow north and meet the northern tributary Ohio just before the latter joins the Mississippi. Remarkably, even the Wabash which takes its source in the region between lakes Michigan and Erie also joins the Ohio not far from the junction of Tennessi with Ohio. All these four eastern tributaries merge into a single course. This peculiar behaviour of the four eastern rivers and their jointly meeting the Mississippi quite high in the upper course, must have some relation with the tectonic structure of the region which needs deeper study.

Among the western tributaries of the Mississippi the Missourie together with the Yellowstone, and the Platta, the Arkansas together with the Canadian and the Red rivers are all mighty rivers, some of them even exceeding the Mississippi in their length, drain the eastern slopes of the Rockies south of the US-Canadian border. All these western tributaries have first a general easterly course, then bend southeast and ESE about the longitude 95-98° W before they join the Mississippi. The whole drainage basin of the Mississippi system between the Rockies and the Appalachians is much wider in the north and gradually narrows down in the south towards the lower reaches of the main river. This is rather curious and needs explanation.

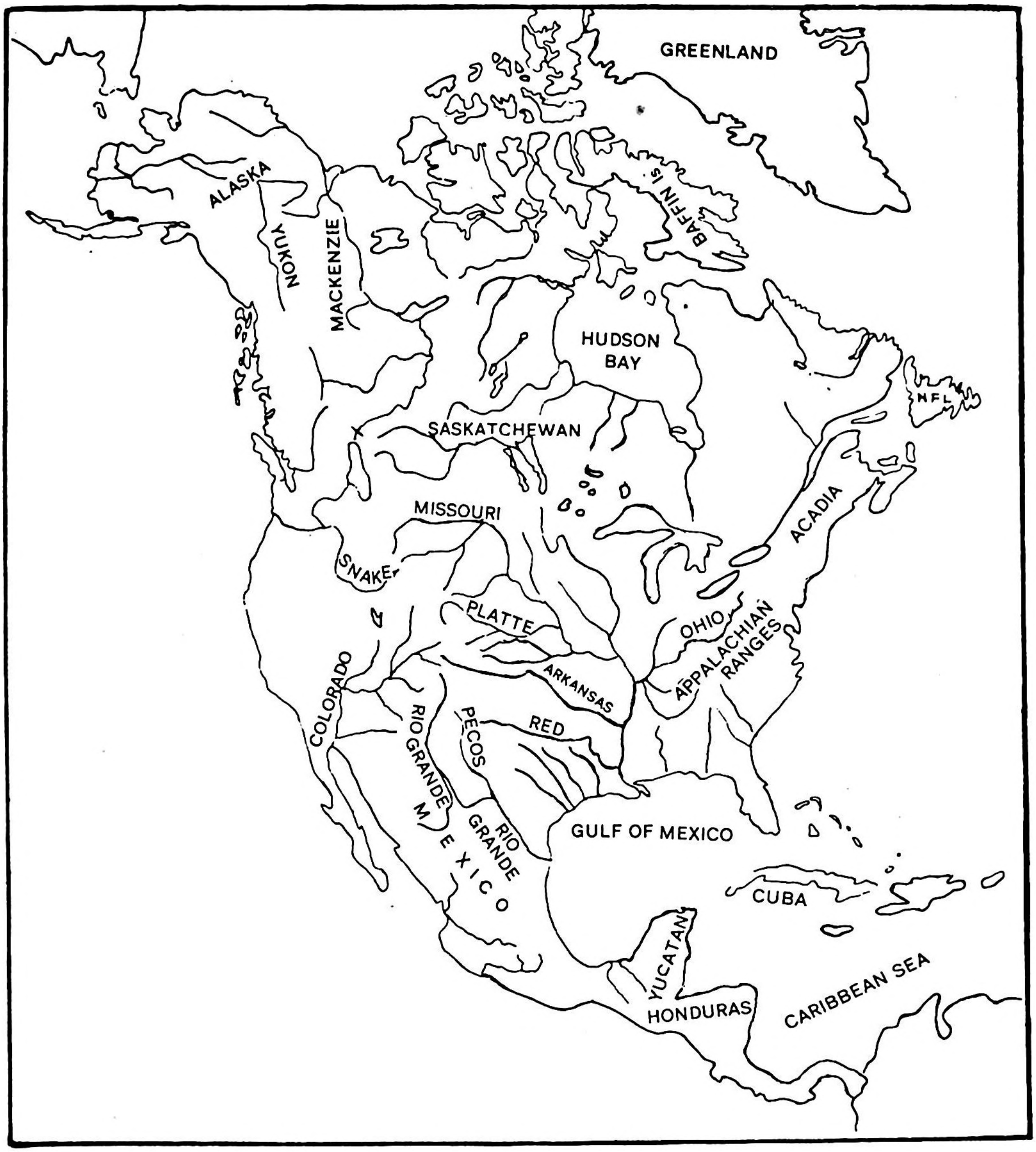


Fig. 11.˙ River Systems of North America

The Rio Grande system in the southern region of the continent has essentially a N-S to NW-SE trend parallel to the Rockies in the Mexican Cordillera. It marks the frontal zone of the southern Rockies against the Central Plains to the east. This river originates on the Blanca peak (4364 m) on the Colorado plateau, not far from the source of the west flowing Colorado river, and those of the east-flowing Arkansas and Canadian tributaries of the Mississippi. The Pecos, the eastern tributary of the Rio Grande, follows a parallel course to the south and is in direct trend of the lower course of the main river. Apparently, it represents the earlier course of the Rio Grande.

The Colorado river with its eastern tributary, the Gila, and the western tributary, the Green river, traverses almost the whole Colorado plateau from the eastern front of the Rockies to the western front represented by the Baja-Californian coastal ranges, in a general NE-SW trend oblique to the general trend of the Rockies. These courses are attended by numerous sharp bends, loops and deep canyons over long distances in their channel. The structure of the plateau is dominated by faults more than by folds. Some of the faults are tear faults or wrench faults which have determined the formation of canyons within the river course.

The Columbia river system dominates the Rocky Cordilleran region along the United States-Canadian border. The main tributary of this system to the south, the Snake river, takes its source in the same region as that of the Yellowstone and Missourie tributaries of the Mississippi in the east. This trijunction point near the Yellowstone National Park is one of the most complex structural knots of the Cordilleran system. This was the centre of Tertiary-Quaternary volcanism which is now in its decadent phase. The whole structural complex is girdled by a belt of Quaternary eruptives and the Snake river has carved out its circuitous route encompassing the Volcanic Plateau.

The Columbia river, though constituting the main river, is much less prominent in its sweep than its tributary the Snake. It takes its source in the north in the heart of the Canadian Rockies from where also start such big rivers as Saskatchewan, Athabasca and the Peace on the northeast and east and the Frazer river in the northwest. This source region thus forms another complex trijunction knot near the Jasper National Park northwest of Calgary. The Columbia river traverses the zone of Miocene volcanics, both intrusive and extrusive, in the same way as its tributary the Snake river does in the zone of Quaternary volcanics. These two rivers bring about the linking of the simpler Canadian Rockies on the north with the more complex Rockies of the United States on the south.

The Frazer river has its source just north of that of the Columbia river. It flows first due north along the strike of the Rockies and, like the Columbia river, takes one acute bend to the west across the Rockies and flows due south with a course more or less parallel to that of the Columbia although separated by a wide belt of the Palaeozoic and Mesozoic rocks interspersed with Tertiary eruptives. In a series of sweeping loops to the west like the Columbia, the Frazer joins the Pacific Ocean through the Vancouver Inlet. Curiously, almost the whole S-shape course of the Frazer parallels that of the Columbia river.

The Saskatchewan River drains the southeastern slopes of the Canadian Rockies along the interior plains constituted of the Mesozoic and Tertiary formations, interrupted through a series of straggling streams and lakes, and flows further east over the Canadian shield to join the Hudson Bay. The region further north is drained by the Athabasca, Peace, Laird and Mackenzie rivers interconnected thfough a series of lakes, e.g. the Athabasca, the Great Slave and the Great Bear, ultimately to join the Arctic Ocean. The Yukon river drains the northernmost slopes of the Alaskan Rockies along a longitudinal valley. It takes its source in Mt. Cassier, a little east of the Alexander Archipelago, flows north along with its tributaries and takes a sweeping bend to the west following the trends of the structural ranges running parallel to the Pacific coastline along the gulf of Alaska.

Thus, all the major rivers of the North American continent along with most of their prominent tributaries are essentially tectonic in their development and appear to register the structural changes which the continent has suffered while assuming its present shape and size during the later stages of the geological history.

Rivers of South America

Among the most important rivers of South America are the Amazon system and the Parana-Paraguay-La Plata System. These two systems of rivers among themselves drain nearly three-fourth surface of the continent. Besides these, the other significant rivers are the Sao Francisco, Parnaiba and Tocantins along the north and northeast Brazilian region, the Orinoco in the northwest and the Solado, Colorado, Negro, Chibut and Descado in the south, in the Chile-Argentina region (Fig. 12).

Among the northern rivers, Sao Francisco, Tocantins and several important tributaries of the Amazon, e.g. Xingu, Tapajos, start in the central highlands of Mato Grosso, Goias and Mines Garais, flow due north and after some sharp bends flow into the Atlantic Ocean to the north either directly or through the Amazon. They have nearly parallel courses but the southern tributaries of the Amazon west of Mato Grosso such as the Guapore, Madeira, Ucayali, Maranon have a long westerly or north-westerly course and after a sudden north-easterly bend in their trend, have a long course before they join the Amazon. This tendency is dominant in all the tributaries right upto the source region of the Amazon itself almost overlooking the Pacific Ocean, near Ecuador. The southern tributaries of the Amazon, viz. Madeira, Ucayali and Maranon, appear to have penetrated deeply into the inner folds of the Bolivian and Peruvian Andes both longitudinally and transversely and appear to have bodily displaced vast portions of these Andean Ranges from their basement. The northern tributaries of the Amazon such as Japura and Negro have long parallel easterly courses followed by a short southeasterly course before they meet the Amazon. These northern tributaries have considerably penetrated into the drainage basin of the Orinoco, materially deflecting the course of the latter farther north.

The Guaviare-Orinoco river system, dominating the Colombian and Venezuelan territories, has a long easterly or ENE course, impinges on the Guiana shield and is suddenly deflected to the north and northeasterly course round the shield and later develops a vast plain between the Andean Cordillera Oriental and the Guiana Plateau. The Magdalina river wholely within the Colombian Andes is a typical longitudinal drainage, separating the Cordillera Oriental from the Cordillera Central and has apparently participated in the northward fanning out of the Cordilleran ranges in conjunction with its tributary Cauca which has separated Cordillera Central from Cordillera Occidental.

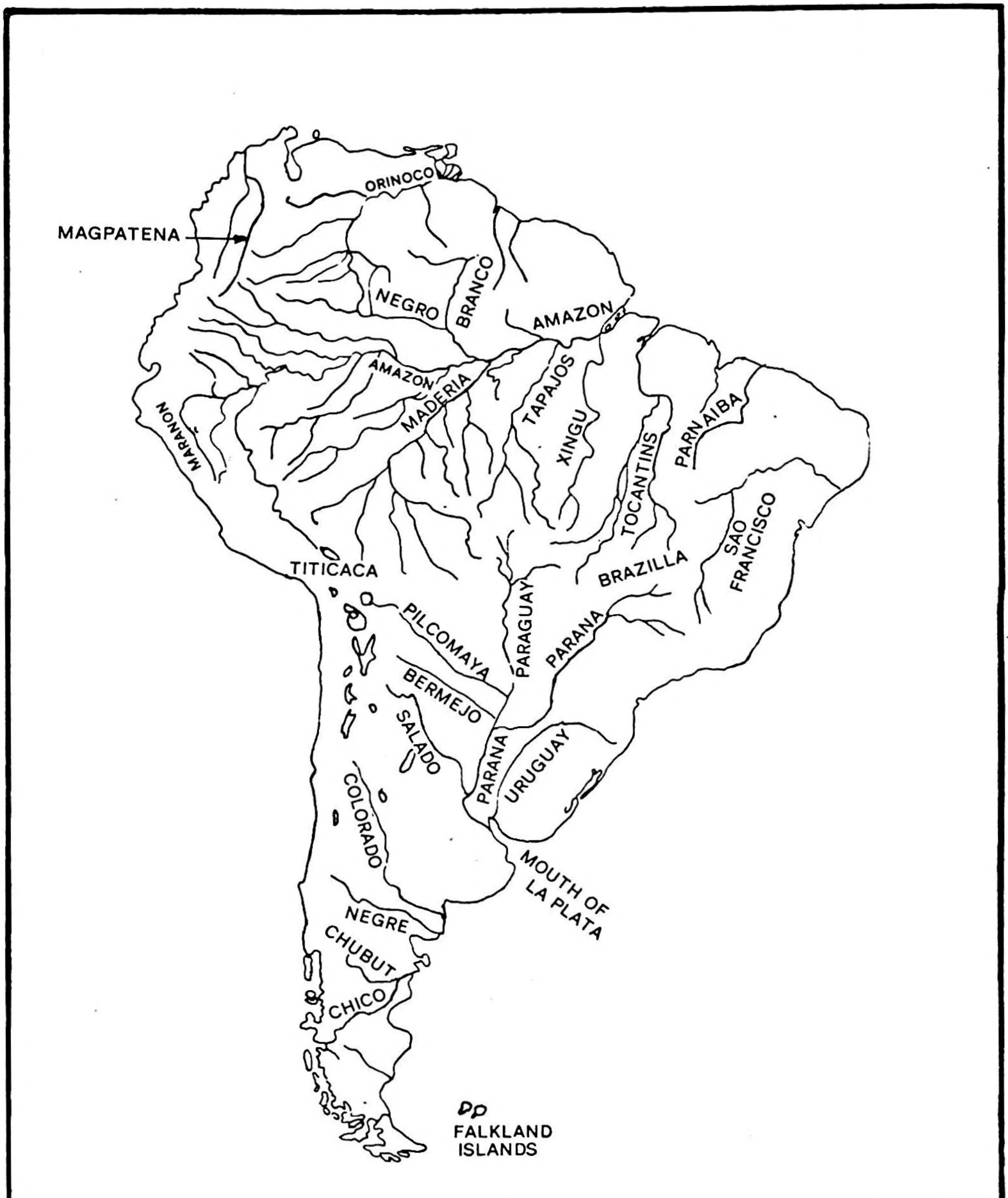


Fig. 12. River Systems of South America

When we go to the peninsular part of the South American continent south of the Central Highlands of Mato Grosso and Minas Geras, tbe Parana-Paraguay system of rivers dominates the scene.

The Parana starts with a southward course from the Highlands of the Federal District of Brazil from which also start the Tocantins but with a northerly course and the Sao Francisco with a northeasterly course. This source region thus serves as a trijunction. Almost halfway along its course the Parana suddenly changes its southward course, turns west to meet and take the trend of the almost parallel running Paraguay but it turns again southeast to meet the Atlantic Ocean through the La Plata.

The Paraguay River originating in the Central Highlands of Mato Grosso from where the Amazon tributary Tapajos also starts but with a northerly trend, flows due south draining the low marshy plains of Paraguay along the eastern slopes of the Andean Cordillera through its western tributaries Palcomayo and Bermejo and meets the deflected Parana to continue its course southward.

The river Uruguay rising almost in the sight of the Atlantic Ocean near Sta Catarine flows west and southwest, takes up the southward trend in continuation of the upper Parana without actually meeting it there and flows south to meet the Atlantic again through the La Plata embayment.

The behaviour of the Parana river with respect to Uruguay and Paraguay is curious and interesting. The other southern rivers of the peninsular South America, viz. the Bermajo, Colorado, Negro, Chibut, Descado etc., all rise in the southern Andes, first flow due south longitudinally along Andean strike valleys, bend east cutting across almost transversely the Andean strike, run in a southeast direction along the eastern slopes of the Precordillera and with a complex curvature, convex to the southwest, join the Atlantic Ocean. This characteristic trend behaviour, common to all southern rivers of the peninsular South America, is very instructive.

Rivers of Africa

When we study the river systems of the African continent, only a few rivers appear conspicuous. These are the Nile and the Nigar in the Sahara in North Africa, the Congo in the central part, and the Zambesi, the Limpopo and the Orange in the southern peninsular parts of Africa (Fig. 13). Among these, the Nile is the world's longest, having a length of more than 6690 km. It has its source in Lake Albert on the Ugandan uplands and is structurally connected with the East African Rift System, particularly with the Tanganyika system of Rifts. Many of the upper tributaries of the White Nile extend far to the west into the drainage basin of the upper Congo in southwest Sudan while those of the Blue Nile extend to the east in the Ethiopian trappean highlands in the zone of the Eastern Rift. The typical serpentine course of the Nile is essentially controlled by the fault systems crossing each other obliquely in NW-SE and NE-SW directions. The winding course of the Nile has enclosed a strip of land area about two hundred miles wide which remarkably simulates the region of the Red Sea, with its arcuate borders and which are also controlled by a similar system of oblique faults.

The Blue Nile together with the east-flowing Awash encloses an area west of the Red Sea which very much stimulates the southwestern part of Arabia (Yemen and Aden Pro-

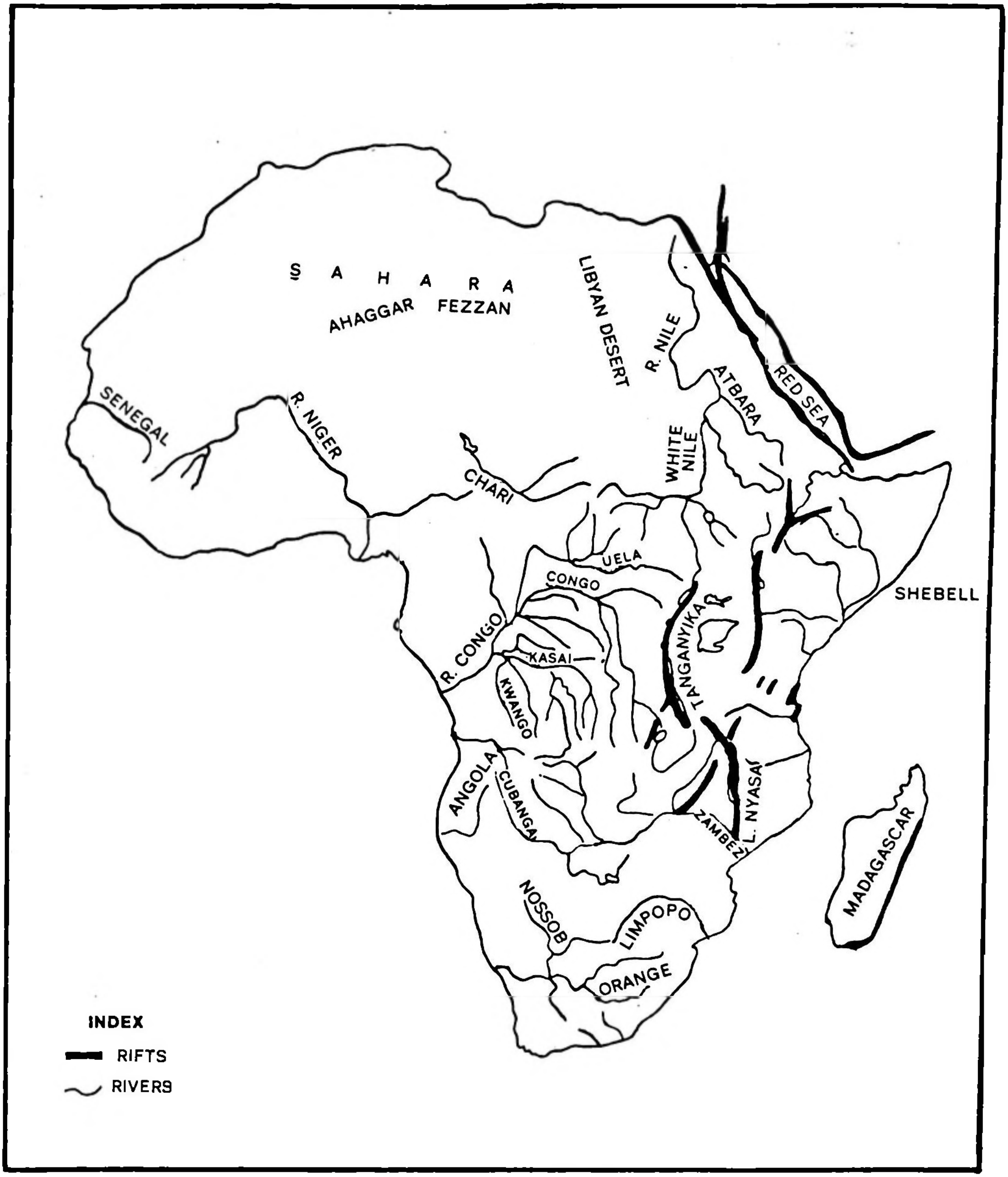


Fig. 13. River Systems of Africa

tectorate). The terrain on both sides of the Red Sea is desertic but has abundant patchy developments of trap flows and in general, similar geological formations occur on the two sides of the Red Sea.

The other river of any consequence in North Africa is the Niger. This rises not far from the Atlantic coast of Sierra Leone, flows northeast for over 900 km and then bends east and southeast for an equally long distance to meet the Atlantic Ocean in the Gulf of Guinea, thus making an inverted V with apex in the north near Timbuktu in Mali.

The Congo River which, in many respects, is the most important among central African rivers, takes its source not far from the Tanganyka Rift valley where the White Nile also originates. The Ubangi tributary of the Congo flows due west and takes a sudden southward bend to meet the Congo. The main stream of the Congo as Lualaba starts from the lake Mweru near the southern end of L. Tanganyika, flows due north, northwest, and again turns south and southwest to meet the Atlantic Ocean and thus makes an inverted U. The other tributaries of the Congo, viz. Sankura Ishuapa, Lulua, Kasai and Kwango, starting from different parts of the Katanga range all follow the same U-shaped course convex to the north like Lualaba. Why should this peculiar trend characterise the courses of all the tributaries of the Congo System?

Just the same peculiarity characterises the tributaries of the next important river, the Zambezi but in the reverse direction. The Zambezi has a S-shaped course trending W-E and most of its northern tributaries also exhibit the same arcuate tendency with their convexity to the southwest. This is clearly visible in the Cubango, Cuito, Kwando as well as in Kafui and partly in Luangwa. The same pattern of the river course is again met with in the Limpopo whose S-shaped course is almost parallel to that of the Zambezi. The southernmost significant river, the Orange, has a zigzag course from east to west but this also exhibits the same S-shaped arcuate tendency, though on a minor scale.

Curiously, the same S-shaped pattern is visible also in the Tanganyika-Nyasa basin though now trending N-S. Thus, most of the rivers of the peninsular Africa exhibit the same S-shaped pattern which can be traced even in their tributaries. It is very difficult to account for these peculiarities in the morphological features exhibited by most of the rivers of the region unless they are connected with the structural evolution of this continental land mass.

The River Systems of Australia

The continental mass of Australia has a rather poor drainage system and all that exists is largely peripheral in distribution. The interior parts of Australian shield are largely peneplaned and desertic with a skeleton of the older river system still traceable in the inland depression culminating in the lake Eyre. Among the Australian rivers, the Darling-Murray System in the southeastern part of the continent is the most important. Flowing southwest and west, this Darling-Murray river system taps the western slopes of the Great Dividing Range, particularly of its southern half (Fig. 14).

Separated from the Darling system by the N-S trending Flinders and Gray Ranges, occur the straggling desert streams, the Thomson, Diamantina, Georgina, Hay and Finke, all converging and draining into the Eyre inland basin depressed even below sea level.

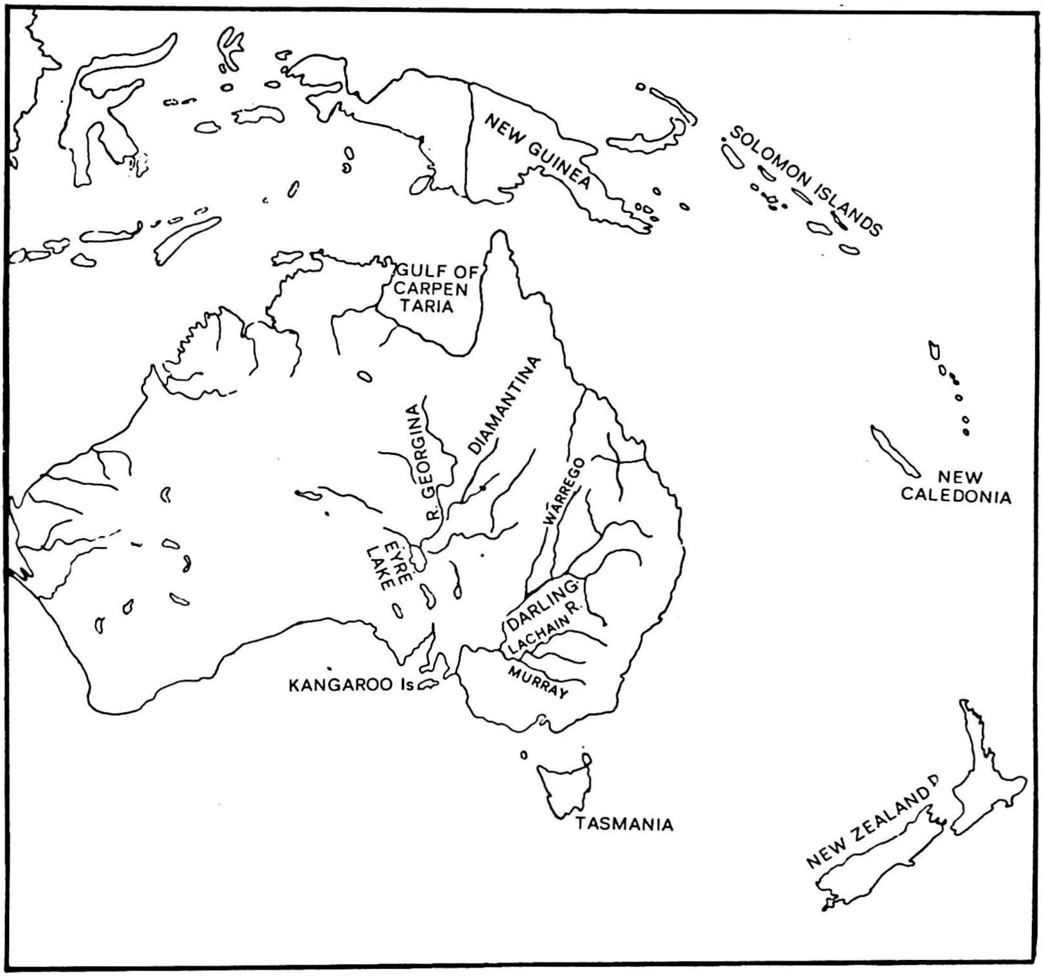


Fig. 14. River Systems of Australia

Draining a wide region in the central parts of the continent between Musgrave and Macdonnell Ranges on the northwest, the Barkly Tableland on the north and the northern part of the Great Dividing Range on the northeast, the general pattern of these rivers is on the whole very similar to that of the Darling-Murray system. Besides these there are a number of minor river courses which are all confined to the peripheral borders of the continent. Among them are the Fitzroy, Belyando, Flinders on the east and northeast, the Daly, Victoria, Ord and Fitzroy on the northwest and the Ashburton, Gascoyne and Murchison on the east. These peripheral rivers have hardly any regional signifiance though their trends faithfully depict the structural grain of the region which they traverse either longitudinally or transversely.

The rivers belonging to the Lake Eyre and Darling-Murrey systems in the central and southeastern parts of the continent taken together exhibit a remarkable fanning of the river courses, systematically from almost W-E through NW-SE, N-S, NE-SW and E-W and finally to SE-NW covering an area more than half of the continent. This peculiar disposition of the river courses must have some deep-seated structural significance connected with the evolution of the continental mass of East Australia as a whole.

Drainage System in Antarctica

The drainage system of the Antarctic continent is all buried deep under ice and nothing positive can be made out of the possible pre-ice drainage. Moreover, the continent is bordered by peripheral ranges paralleling the coast as seen in Enderby, Queen Maudland, the Transantarctic mountain range from the Weddel sea coast to Ross Sea shelf envisaging a system of wide basins in the central parts of East Antarctica, possibly draining to the east towards Adelie land and Wilkes land. These inland basins have been demarcated by geophysical surveys on the ice cover.

RIFT VALLEYS

Rift Valleys or Graben exhibit a special system of river valleys which have originated through tectonic movements. They constitute an important morphostructural phenomenon on the earth's surface starting from minute cracks and fault traces and culminating in vast oceanic expanses with all gradations in the size of these fault-bounded depressions.

Rift valleys were first recognised as a special phenomenon of block faulting due to wedgelike subsidence of the middle block now constituting the valley between the two major side blocks as during tensional movement. A study of the Rhine valley showed that the valley block was subjected to folding attended by repeated faulting. This indicates that compression rather than tension was the cause of rift valley formation. This gave rise to a long controversy whether tension or compression was the motive force behind the Graben formation. The abundance of slicken sides along steeply-inclined as also on horizontal surfaces attended by thick breccia point to the tear faulting or transcurrent nature of crustal movements in the region of the rift valleys. The updoming attended by ascent of eruptives as lava flows and fragmental ash beds showed the importance of tension due to magmatic intrusion as a necessary ingredient of the mechanism of rift valley formation. Such alkaline eruptives are abundantly met with over wide areas not only in the Rhine valley but also in the Elbe valley in the Bohemian horst, and again in the Loire valley in the heart of the Central Plateau of France. This phenomenon of alkaline magmas erupting simultaneously through rifts in the core regions of these widely separated Variscan horsts is very significant. Alkaline igneous activity is also found associated in the metamorphic basement in the Alpine-Carpathian structures in southern Europe and in Turko-Armenian region of West Asia. What is the significance of this Tertiary alkaline activity in the core regions of Variscan as well as Alpine basements leading to the formation of Graben structures?

We may also study the conditions in other rift valleys. We have the well-known African Rift Valleys in the eastern parts of the African mainland. Starting from the Dead

Sea and continuing into the Red Sea along the common border between Asia and Africa, we have the typical rift valleys in the region of Ethiopia, Somaliland, Kenya (Lake Rudolf), Tanganyika (Lakes Natron, Manyara) continuing into the Lake Nyasa. Another rift valley passes along the Nile through Egypt, Sudan along the lakes Albert, Edward, Kiva and Tanganyika apparently passing through the Rukwa to meet the Eastern rift valley near the northern end of Lake Nyasa.

The alkaline eruptive activity is quite prominent right within the rift valleys in both the eastern as well as the western rift systems forming wall-like hills rising to over 3050 m height in the eastern rift and to over 4575 m height in the western rift. The relation of the Alkaline eruptives *vis-a-vis* the rift valley formation is yet to be fully understood.

The Red Sea Rift

The Red Sea and the Gulf of Aden form a structural couple that separates the African mass from the Asian continent. These depressions are bounded by what are considered as normal faults without subsidence of the central wedge block and are suggestive of crustal separation through drifting apart. The fissure development in the crust got widened and was filled by basic magmas from below. There is also a relative northward movement of Arabia with respect to Africa as due to a transcurrent fault. This is easily seen if the two coastal borders of the Red Sea are brought close together and the bulges and embayments on the one side get fitted into the embayments and bulges respectively on the other. During this fitting, the Aden Gulf coasts also gets automatically fitted. Even the geological formations, which are complementary in the two sides, get fitted together.

The Persian Gulf

The same phenomenon is again observable in the case of the Oman and the Persian Gulfs in continuation of the Tigris-Euphrates river alluvia separating Arabia from Iran. The complementary nature of the coast lines and the geological structures on the two sides are remarkable. These point to a mechanism of their formation which would be discussed in a later chapter (Ch. VII).

In the above pages, we have dealt with rivers and rift valleys as morphological features both of which are seen to be intimately related to the fault structure of the region. In the case of rift valleys, the fault system involved is of the transcurrent nature involving significant horizontal displacement.

CHAPTER IV

Geomorphological Features of the Sea and Ocean Floor

Continental Shelves

The shallow gently inclined borders of the continental masses submerged under sea upto a depth of 200 m constitute continental shelf zones which project for variable distances into the sea. They are gently sloping towards the sea and serve as the main basin of deposition of materials brought down by rivers from the hinterland. These submerged zones are usually terminated rather abruptly by steep continental slopes extending to oceanic depths. The continental shelves generally reach a depth of roughly 200 m below the sea level near the continental edges and mark the real border of the continents. Some shallow shelf seas may be due to active subsidence of the continental borders leading to transgression of the seas. Some others may be due to the active erosion of the land surface caused by marine denudation leading to encroachment of the seas as embayments giving an irregular coastline.

Bathymetric maps of the earth show enormously broad shelf regions along the Pacific coast of certain continents extending over several hundreds km. into the ocean and are frequently terminated by the emergence of island arcs or clusters of islands before they abruptly end against a deep oceanic trench. This is well illustrated along the west Pacific coast right from Kamchatka in the north down to Antarctica in the south. Here we see the development of extensive shelf sea of Okhotsk, Sea of Japan, East China Sea, Java Sea, Gulf of Carpentaria and Ross sea shelf.

The enormous extent of uninterrupted shelf zones bordering the continents for hundreds of km attended by girdles of island arcs and oceanic trenches make it difficult to believe in the subsidence or erosional theories in the formation of these shelf zones, particularly along the Pacific coast. The continental shelf zones are, however, not confined to the Pacific coasts, but are also found along the Arctic coast of Europe, Atlantic coast of British Isles and France, the Baltic Sea, and North Sea, as also along the New Foundland-Novascotia coasts, the Hattaras, the Florida, the Bahama Banks etc.

In the Indian ocean, we have the Malabar coastal shelf, the Persian Gulf shelf, as also along the borders of the Bay of Bengal, Dampier land, Timor and Arafura Sea shelves.the Great Australian Bight etc. When we see that many continental coasts exhibit very narrow shelf zones, the formation of broad zones hundreds of kilometres wide and thousands of kilometres long cannot be explained merely by crustal subsidence or through marine denudation and call for other modes for their evolution.

Continental Slopes

The border of a continent often grades unevenly against the ocean. The gentle slope along the continental shelf ranging from tidal plains to Nerific depths (about 200 m) rapidly falls to great depths of over (4000 m) below which it again becomes gentler to form an uneven ocean floor platform. The steep slope of the continental border between the gentle shelf and the oceanic floor platform is called the continental slope. Such steep continental slopes are seen quite commonly developed along the borders of the Indian and Atlantic oceans.

The mode of evolution of these continental slopes is as yet not fully understood. The terrestrial debris barely reaches the edge of the shelf against the slope where erosive action of the ocean is also comparatively minor. The bathyal deposits along the continental slopes are usually muds, fine clays, volcanic ash, coralline and other organic muds, deep sea palagic oozes, red clays etc. which are mostly products of decomposition and degradation of sub-oceanic eruptives. In some cases, we find alternate development of shallow terrigenous deposits and pelegic oozes and red clays. These have been attributed to turbidity currents of uncertain origin (A.Holmes, p. 847).

The Atlantic borders of Europe exhibit a wide belt of continental shelf which, west of the British Isles, France and Spain suddenly drops to more than 4000 m. Similarly, the western shelf of peninsular India 160 km wide suddenly drops to 4000 m depth within a short distance, particularly west of Laccadiv Island Arc. The formation of such steep continental slopes running down precipitously to great depths cutting through hard gneissic and other basement rocks and extending for thousands of miles along the continental margin, calls for an explanation. They are definitely no erosional features. Do they represent subsidence of oceanic floor along regional faults? Are they traces of tear faults with ever-widening horizontal component as during a continental drift?

The Ocean Floor

The oceanic waters, for all appearances,look quite placid and unruffled on the surface but at great depths, these waters hide a pretty irregular floor almost comparable in unevenness to the continental surface. A number of deep basins are interrupted by suboceanic rises, platforms and by elongated submarine ridges which at places culminate in island arcs and archipelagos.

The Pacific Ocean Floor

In the Pacific Ocean, some of the islands are active centres of volcanism even today. While a good part of the Pacific floor is between 4000m-5000m deep, vast regions are between 5000m-7000m deep. Many of these deep basins culminate in deep narrow trenches reaching more than 10000 m depth. In the western Pacific Ocean, there is a regular system of narrow elongated trenches arranged more or less en echelon some distance away from the continental mainland of Asia and Australia bringing about violent disturbances in the submarine topography of the region.

The ocean floor in the eastern Pacific is comparatively much smoother with hardly any island arc or oceanic trench south of the Aleutian trench almost up to the equator. In this part of the Pacific, the morphological features in the ocean floor exhibit pronounced east-west trends in contrast to the north-south trends of the west Pacific.

Here in the otherwise-smooth East Pacific floor, several linear eastwest trending structural features are recognised, named from north to south as (1) Mendacino Sea-Scarp, (2) Murray Sea-Scarp, (3) Clarion Fracture Zone and (4) Cliperton Fracture Zone. Each of these is found to extend transversely for several thousand-kilometres from the west coast of North America and almost parallel to the Aleutian oceanic trench. The origin of all these features is still uncertain (Menard, H.W. 1955. Bull. Geol. Society Am. Vol. 60 pp 1149-1198).

In the southeastern Pacific region of South America, the east-west trends of the NE Pacific are again replaced by a parallel series of NS trending submarine features in the nature of Peru-Chile Trench, followed westward by San Felix Juan Fernandis Ridge and later by the Pacific Antarctic Ridge, all more or less parallel to the western coast of South America.

This differential behaviour of the various sectors of the Pacific has so far not been satisfactorily explained. The incidence of post-Cretaceous volcanism in the western Pacific Ocean has, apparently, been mainly responsible for the highly irregular surface of the western Pacific floor beset with numerous en echelon systems of Island Arcs and oceanic trenches trending in north-south and northwest-southeast directions. The floor of Eastern Pacific bordering the Americas is apparently affected by the crustal movements responsible for the emplacement of Rockies and Andes system of orogenic belts along with their continental hinterland. possibly in the nature of vast unitary structural plates.

The Indian Ocean Floor

The largest part of the Indian Ocean is between 4000m-5000m deep but some fairly large basins show depths of 5000m-6500m and only at a few localities do they exceed these depths to correspond with the oceanic deeps. The Indian Ocean floor is traversed by a system of sub-oceanic ridges mainly trending north-south, the most prominent being the Mid-Indian Rise starting from the Gulf of Cambay along the Laccadiv linear archipelago through Chagos, Rodriguez merging in the vast Amsterdam-St. Paul Plateau. This plateau is linked with the East Antarctic continent through Kerguelen Gaussberg Ridge and through the Indian-Antarctic Ridge. Besides this main Mid-Indian Ridge. there are other arcuate ridges between India and Africa, all convex to the northeast, namely (a) the Socotra-Chagos ridge, (b) the Seychelles-Mauritius Ridge and (c) the Madagascar Island Ridge.

East of the Mid-Indian rise occurs the vast Cocos-Keeling Basin extending and deepening eastward almost upto the Indonesian Island Arc against which it culminates into the 7400 m deep Sunda Trench. This Cocos-Keeling Basin extends southeast and abuts abruptly against the Australian continent while its southern border terminates against Diamantina Fracture Zone. Curiously, the Cocos basin east of the Mid-Indian Rise has the shape and size comparable to that of the Australian continental mass on the east. Oceanic ridges west of Chagos on the Mid-Indian rise parallel the east coast of Peninsular Africa whereas the Amsterdam-St. Paul Plateau in the southern Indian ocean has the form and dimensions comparable with those of the Antarctic continent. Have these features any significance?

The Atlantic Ocean Floor

The Atlantic Ocean floor is characterised primarily by the development of the famous Mid-Atlantic Ridge which, in its sinuous course, divides the ocean into two halfs, each half consisting of a number of deep sea basins 5000m-6500m reaching at places depths of about 7000m corresponding to oceanic deeps. The most prominent among these are the Puerto Rico-Jamaica trench system, reaching a depth of 10000m and the arcuate South Sandwich about 9000m deep at the eastern end of the Scotia sea in the South Atlantic region. East of the Mid-Atlantic Ridge the shape of the Cape Verde Basin as also of the Angola basin conforms remarkably with the delineation of the Mid-Atlantic Ridge and the Walvis Ridge, indicative of the control exercised by the latter on the formation of these basins.

In the northern portion of the Atlantic Ocean between Labrador and Europe, the ocean floor is highly irregular and is comparatively shallow being less than 3000m deep. This region is bridged by shallow submarine ridges and Island Arcs indicative of more intimate linkages between the continents on either side of the ocean.

Oceanic Deeps and Trenches

Many of the deep oceanic basins, usually 5000m-6500m in depth, often culminate in yet deeper depressions fairly localised in areal extent. These are known as oceanic deeps and when they occur as narrow elongated depressions of more than 6500m depth, they constitute Oceanic Trenches. Such deeps and trenches occur extensively in the Pacific Ocean and occur only sparsely in the Indian and Atlantic Oceans. They are commonly associated with island arcs many of which carry active volcanoes.

Oceanic Trenches in the Inner Pacific Ocean

The crustal features seen developed within the heart of the Pacific Ocean constitute a category by themselves since they are too far away from any continental mass to be related to or to be influenced by processes operating in the continental region. The limit of continental processes as exemplified by CircumPacific volcanism and geosynclinal deposition, can be recognised upto what is called the Andesite Line which marks the limit of continental Sialic Crust against the Pacific Simatic Crust. Beyond this Andesite Line, the Pacific floor has no trace of sialic rocks exposed or involved in any of the island arcs emerging from the bed of the Pacific Ocean. Yet we find a vast region within the west central Pacific which is comparatively shallow and is studded with a vast number of islands often exhibiting arcuate arrangement in their distribution. It is a moot question as to the actual mode of their evolution.

The Island Archipelagos grouped under Melanesia, Micronesia and Polynesia are all essentially volcanic in origin and do not involve any constituent material which could be dated as older than the Cretaceous Period. A system of linear depressions in the nature of minor trenches or lanes separate one island arc from the other, whereas they, as a group, are separated from those of the continental origin by a prominent but interrupted system of deep oceanic trenches to which all other Pacific depressions exhibit rough parallelism in their disposition. The peculiar behaviour of the system of oceanic trenches large and small within the Pacific ocean, calls for some explanation which could throw positive light on the mode of their evolution.

Let us first examine the distribution of the major oceanic trenches in the West Pacific region. Starting from Kamchatka in the north, we follow the Kurile Trench reaching a depth of over 10000m up to Hokkaido where with a short knick it continues southward into the Japanese Trench almost along the longitude 142° E. With a small break near the latitude 30° N it bends southeast to continue into the arcuate Mariana Trench convex to the east and encloses the Mariana-Guam Island Arc. South of Guam Island this Mariana Trench reaches the greatest depth so far known to over 11500 m in the Challenger deep.

The southwestern course of this Mariana Trench is almost abruptly checked by a transverse, eastwest running shallow bank of Carolina Islands of the Melanesian Group and is detached from the trench running south along the West Carolina Basin. This latter trench appears to continue southwest and meet the Mindanao Trench northeast of Halmahera. It is curious that the Mindanao Trench of the Philippines reaches a depth next only to the Mariana trench and appears to be linked with it through the West Carolina depression. The nature of this linkage in depth is not clear but it appears possible that another trench parallel to the Mariana Trench in an earlier period was situated north of the Mindanao Trench as its direct continuation in the region east of Taiwan. At that time, the Japanese trench also was running east of the Ryukyu Arc between Tokyo and Taiwan. The present position of the Mariana-Japan trench east of 140° E longitude is in all likelihood a result of subsequent lateral displacement eastward through the same Pacific volcanism which was responsible for the development of Caroline volcanic archipelago. The southern continuation of the Mariana Trench appears displaced successively eastward roughly parallel to the 10° N latitude in the region of Micronesia in the alignment of Marshall Islands almost upto the Hilgard deep northeast of Phoenix Islands. Here it meets the northern alignment of the Kermadec-Tonga Trench. Similarly, the southern continuation of the Mindanao Trench appears displaced successively southeastward parallel to the Bismark Archipelago-Santa Cruz-New Hebrides through the South Fiji Basin to meet the southern end of the Kermadec Trench NE of New Zealand.

The nature of the crustal processes responsible for this peculiar arrangement of oceanic trenches along with the associated Island Arcs is still largely ill understood.

The oceanic trenches independent of the above groups occur in the eastern Pacific along the western border of South America. They reach depths of over 8000m along the Chilean coast but disappear north of the Peruvian coast except for a small Guatemala Trench. Curiously, these deep linear depressions are altogether absent all along the Pacific coast of North America until we reach the Alaskan Bay. From here starts the Aleutian trench directed westward along the 50° latitude to meet the Kurile Trench transversely near Kamchatka.

The oceanic deeps and trenches have depths in general exceeding 6000m and reaching at places over 11000m. The greatest depth recorded is more than 11035m. reached in the Mariana Trench. These depths are far in excess of the general depths reached by the floor of even the Pacific Ocean. The problem of their origin is still not fully solved. The localised occurrence of such oceanic deeps and trenches often confined to narrow arcuate depressions and their common association with volcanic Island Arcs invests them with a tectonic significance connected with deep magmatism in sub-crustal part of the Upper Mantle.

The association of regular system of deep trenches with CircumPacific volcanic belts, particularly along the East Asiatic border zones, leads to the possibility that CircumPacific magmatism is intimately involved in the formation of the oceanic trenches as also of the Island Arcs closely associated with them.

When we study the region of the Indian and Atlantic Oceans, we rarely come across the Pacific type of oceanic trench system. However, in the Indian Ocean region, we do meet with the Sunda Trench along the Indonesian Island Arc which approaches the Pacific type. This reaches a depth of over 7500m (24000 ft.). Apparently connected with this and radiating away from it, is another linear development of oceanic deep within the Cocos Keeling Basin, meeting the West Australian coast near Perth and apparently continuing further southeast along the southern shelf border of Australia trending towards Tasmania-Macquerrie submarine ridge. Similarly, within the region of the Atlantic ocean, we have stray occurrences of oceanic deeps distributed irregularly. Among these only the Puerto Rico-Cayman Trench in the region of the West Indies, reaching a depth of over 9150m (30200 ft.) and the South Sandwich Trench in the region of South Scotia Sea in the southern Atlantic, over 8250m (270000ft.) deep, are of significance. The Puerto Rico Trench is in the linkage zone of North and South Americas while the South Sandwich Trench is in the linkage zone of South America and Antarctica. Apparently, they are connected with relative displacements of the concerned continental masses.

It is significant that the magma type of the island arcs associated with these trenches, as also those of the Sunda region, exhibit intimate relationship with CircumPacific magmas.

Mid-Oceanic Ridges

The Mid-Oceanic Ridges which constitute peculiar features of the oceanic floor have posed important problems concerning the evolution of earth's crust. They have led to a number of new concepts in the field of geodynamics. These features have become unique owing to a sudden uprise of the ocean floor linearly for thousands of kilometres and at places culminating in volcanic islands. These ridges often assume peculiar trend alignments in relation to the continental margins on either side of the ocean. In dimensions they almost rival subareal mountain ranges in height, extension and surface irregularities. Like the controversies connected with the evolution of mountain ranges, these mid-oceanic ridges have also become subject of intensive discussion. The association of volcanism with the Mid-Atlantic Ridge has invested peculiar significance as to the evolution of these submarine features.

Recent discoveries of deep fractures in the medial sectors of the ridges have added a new dimension to the problem of the ridges and have led to quite a new concept of Ocean Floor Spreading and its role in global evolution. Among the numerous mid-oceanic ridges, the one in the Atlantic Ocean has become by far the most important and as such is the most discussed one (Fig. 15).

As a physical feature, this ridge is unique in having a peculiar sinuous course, following the sinuations in the outline of bordering continents. It is divisible near the equator into two portions, north and south of the Romancho deep (almost 7600 m deep). The northern part of the Ridge north of equator is semicircular, bulging to the west and is

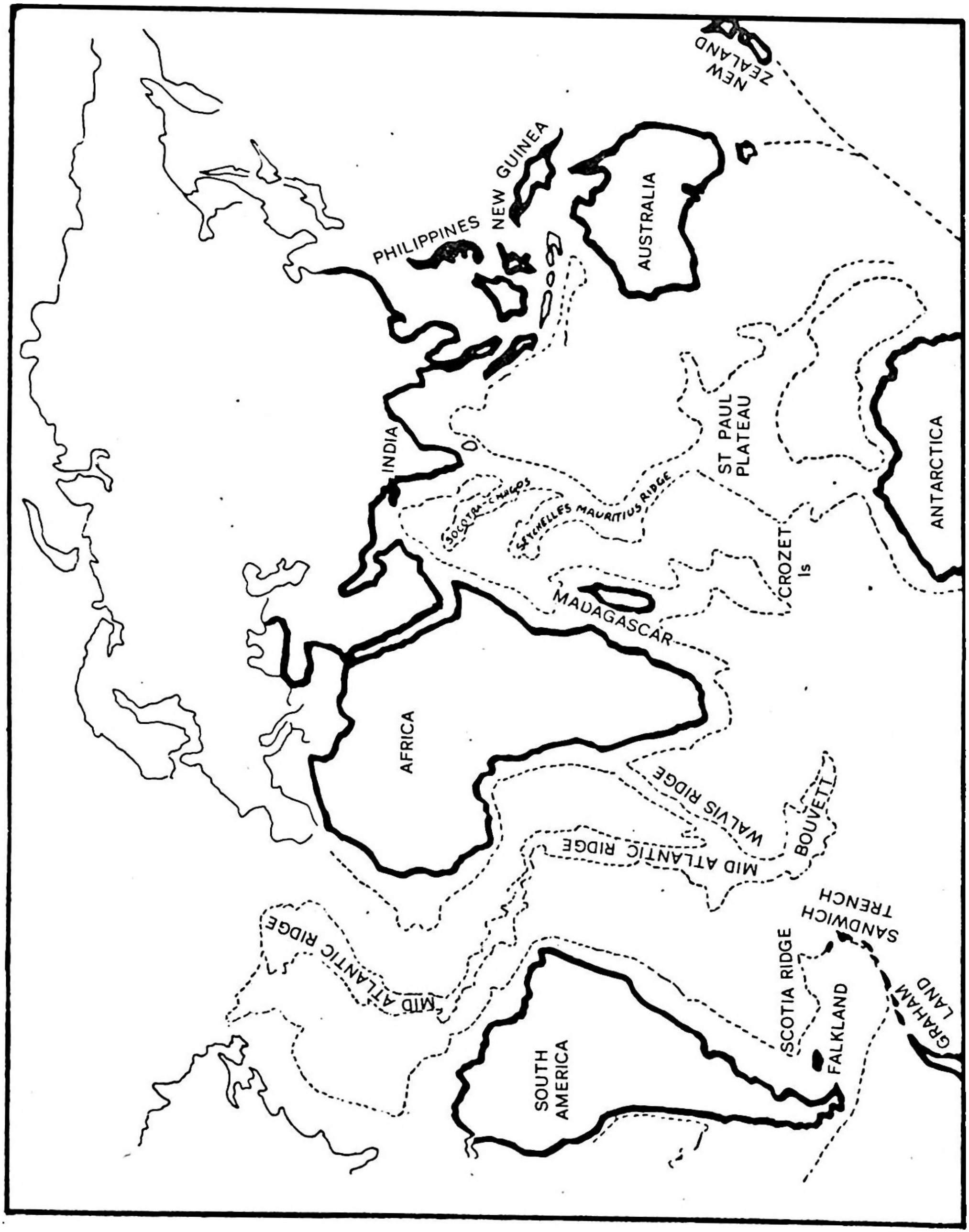


Fig. 15. Submarine Features of Southern Oceans

remarkably parallel to the Atlantic coast of North Africa north of Cameroon while the southern part is quite straight and is roughly parallel to the Atlantic coast of peninsular Africa south of Cameroon. This Mid-Atlantic Ridge curiously simulates also the Pacific coast of South America right from Venezuela-Colombia in the north to Terra del Fuego in the south. The southern Mid-Atlantic Ridge is joined near the islands of Tristan da Cunha and Gough by another oceanic ridge, the Walvis Ridge, which links the main Atlantic Ridge with the African mainland near the Angola-Namibia border. Remarkably, this Walvis Ridge simulates the Atlantic coast of Argentina and southern Brazil and these two mid-oceanic ridges together remarkably simulate the shape, size and delineation of the peninsular part of South America. It is again very striking that the Terra del Fuego-Falkland-Scotia Ridge also finds an exact counterpart in the southeastern prolongation of the Mid-Atlantic Ridge in the form of the Atlantic Antarctic Ridge carrying the Bouvet island. What is the significance of these remarkable series of similarities of the Mid-Atlantic Ridge system with the continental borders on either side?

Ridges in the Indian Ocean

That the floor of the Indian Ocean is not smooth but extremely uneven, beset with irregular ridges and basins, fractures and furrows is nicely brought out in the map of the Indian Ocean floor published in the *National Geographical Magazine* (October 1967). The most important among the submarine ridges in this ocean is the Mid-Indian Ocean Ridge, running almost continuously southward along a belt in between the longitudes of 70 and 80° East and extending from Cambay in the north passing through Maldive-Chagos, Rodrigues to Amsterdam-St. Paul Plateau, continuing farther south almost upto Antarctica. In the northwestern part of the Indian Ocean, we find a series of arcuate ridges, the Socotra-Chagos Ridge, the Seychelles-Mauritius Ridge and the Madagascar Ridge each simulating a part of the East African coast arranged roughly parallel and in en echelon manner between Peninsular India and Mozambique but oblique to the main Indian Ridge.

East of the main Indian Ridge occurs another, the Diamantina Ridge, running E-W south of the Cocos-Keeling Basin in alignment with the southern coast of Australia.

The geodynamic significance of these various suboceanic ridges, in particular reference to the evolution of peripheral continental masses, has not been adequately appreciated so far. The Mid-Atlantic Ridge is regarded by many followers of the Drift Theory as the place where the Old and the New Worlds parted company. This old idea has been revived lately by B.C. Heezen and others by attributing special significance to the Rift Valleys observed occurring along the central parts of the Ridge. These Rifts are supposed to be repeatedly pouring out subcrustal lavas and thereby pushing the bordering continents apart with the spreading of the ocean floor. They consider this spreading of the sea floor as the principal process in Crustal Evolution. The Rift Valleys along the central parts of the Oceanic Ridges have thus assumed overriding significance above that of the Ridges themselves.

The Mid-Oceanic Ridges occurring in the Atlantic and the Indian Ocean are considered to continue into those in the Pacific Ocean, thus constituting a world encircling system of Ridges studded with Rift Valleys. According to T. Wilson, the Mid-Atlantic Ridge continues at its southern end through Crozet and Rodriguez into the Indian Ocean

Ridge. Later, it follows northward along the Chagos-Socotra Ridge to join the East Africa Rift system which passes through the Red Sea.

These Mid-Oceanic Ridges are considered as focii of upwelling convection currents bringing with them eruptive lavas from the deeper zones of the Mantle through the deep rifts to the surface and thus generate new Sial which pushes the old continents on either side away from the Oceanic Ridge. These ridges are thus considered as lines of divergence of continental masses in contrast to the orogenic belts and the oceanic trenches which are considered as lines of convergence of continental masses through the approaching convection currents, thus becoming regions of the digestion of continental sial.

CHAPTER V

Geological Formations of the Earth (Some Biostratigraphic Problems)

The stratigraphic evolution of a region concerns with the processes of erosion, sedimentation, succession of rock formations, volcanism, earth movements and with the life forms which got fossilised at different periods of the earth's history. They had been studied very extensively in certain areas while vast areas had been studied only cursorily with the result that reliability of our data varied from region to region. With the passage of time, more and more areas have come under detailed investigations and the ideas gained have led to modification of our ideas, enabling us to freshly reassess the palaeogeographical conditions in different periods and thus to visualise more correctly the mode of evolution of major features of the earth's surface (Plate 1).

The most important aids in these studies have been the laws of superposition of rock formations and the succession of fossil faunas and floras in time and space. Any lacunae in these evidences tend to vitiate the reliability of the conclusions drawn from them. The law of superposition in a sedimentary basin gives us information on the sequence of sediments formed during a given period of time, whereas fossil contents give us a fairly precise idea as to the geological period during which sedimentation took place. From the lithology and fossil contents, some idea concerning the palaeogeographical conditions in a particular region can be formed for the duration of the period of sedimentation. The sequence of formations in an area may be highly disturbed if involved in severe crustal disturbance. It may even be reversed through overfolding and overthrusting. Correct sequence can be ascertained by a study of fossils in each stratum in succession. A lithological study of sediments may also, in certain cases, help us in ascertaining the correct sequence but this may not always be as unequivocal as the fossil evidence is.

When we see that the Pre-Cambrian formations are almost wholely unfossiliferous and are subjected to different degrees of folding and metamorphism, it is very difficult to unravel the correct sequence in many Pre-Cambrian terrains. Many metamorphosed sequences in orogenic belts had been regarded as Pre-Cambrian until some rare find of fossils indicated much younger age for them. Again many igneous, particularly basic, rocks of much younger ages occurring as intrusive sills, on structural and tectonic crushing, decomposition and metamorphism assume the form of a regular sedimentary bed in the nature of laminated clays, variegated shales and slates, phyllites, schists, grits and breccias, microconglomerates, red beds etc. When such unfossiliferous rock formations are found interbedded with fossiliferous sedimentary formations, they have frequently been mistaken for normal conformable sedimentary formations of the same age as that of the associated fossiliferous formations. Such accession of much younger eruptive formations often leads to an unusual and abrupt increase in the thickness of true sedimentary sequences.

It is obvious that we are not always on sure grounds when we speculate on the palaeogeographical conditions obtaining during the deposition of unfossiliferous rock formations, particularly when they have been involved in complex orogenic movements. Many rock formations of the Pre-Cambrian sequences come under this uncertainty, particularly when found separated from the overlying fossiliferous sequences by strong discordance. Most continental masses are characterised by the occurrence of metamorphosed core regions which are largely devoid of post-Cambrian folded marine rock formations. Such regions are thought to have escaped marine sedimentation or have withstood post-Cambrian orogenic movements. These rigid portions of the continents are largely constituted of Pre-Cambrian and older rock formations. Among such cratonic masses are the Canadian Shield, Scandinavian and Baltic Shields, Russian Platform, Angara Shield, Sinian Platform, Brazilian and African Shields, Indian and Australian Platforms, Antarctic Shield etc. The status of many of such shield masses as truly Archaean or Pre-Cambrian in age may need further scrutiny (Fig. 16).

THE PALAEOZOIC ERA

Cambrian Formations

Cambrian is the earliest geological period in the earth's history which is well-authenticated for its age and sequence on the basis of well-recognised fossil forms. These formations are well-developed in a number of areas in the different parts of the world and most of these have been correlated more or less precisely on the basis of fossil contents. These Cambrian formations are found occurring in highly detached areas, often separated by vast oceans or continents with hardly any facilities for intermigration, and yet they are related closely by common occurrence of identical or allied fossil forms and faunal assemblages. It is only rarely that any one area shows the development of complete sequence of rock formation even for a single geological period but partial zonal sequences are found in identical succession in vastly separated regions often in a complementary manner.

It is noteworthy that most of the great groups of invertebrates are represented in the Cambrian life forms. Among these, however, Trilobites and Brachiopods are the most dominant groups, the former affording numerous zonal fossils for this period, whereas Cephalopods and Gastropods appear to become quite appreciable constituents of the faunas before the end of the Cambrian. On the other hand, Archaeocyathids of somewhat uncertain affinity occur widespread in different parts of the world at the junction of Lower and Middle Cambrian (Fig. 17).

The exclusive occurrence of certain faunal associations during certain divisions had enabled stratigraphers to recognise three faunal provinces during the Cambrian (Fig. 18):

(1) The Pacific Province, characterised by Olenellus in the Lower Cambrian, Orictocephalus in the Middle Cambrian and Dikellocephalus in the Upper Cambrian.

(2) The Atlantic Province, characterised by Holmia, Paradoxides and Olenus in the three sub-divisions respectively.

(3) The Indian Ocean Province similarly characterised by Redlichia, Ptychoparia and Ptychoapis in the three corresponding sub-divisions.

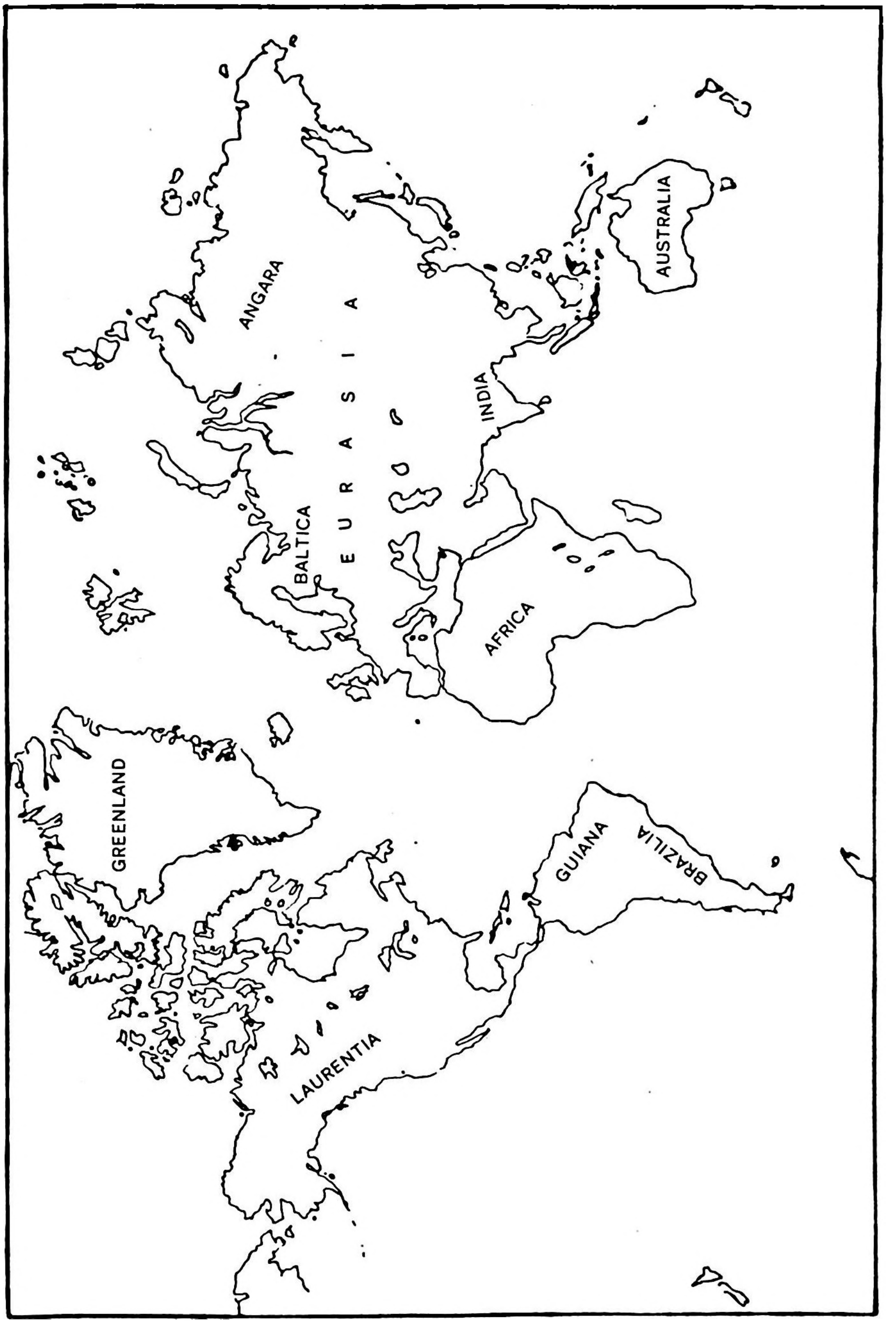
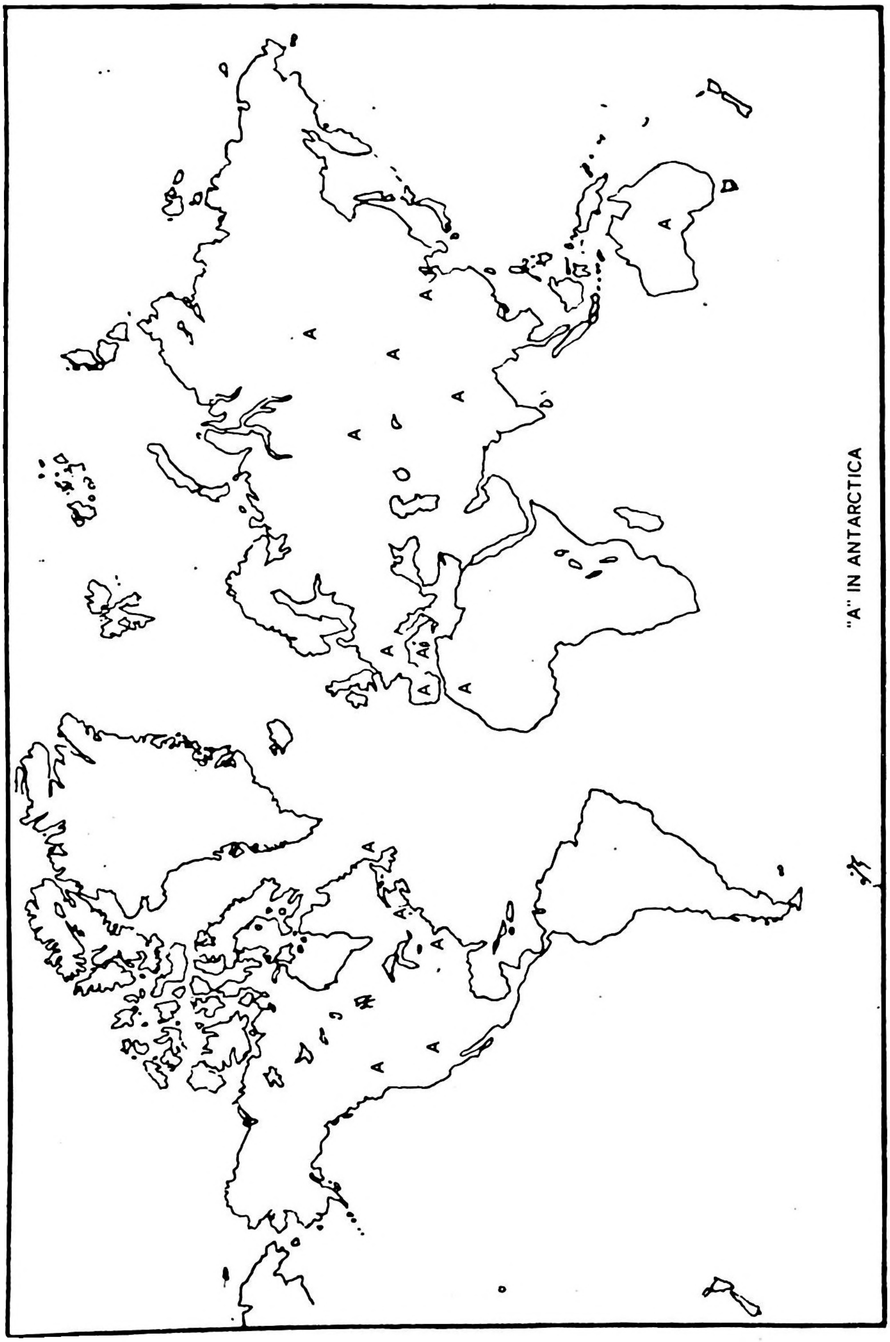


Fig. 16. Pre-Cambrian Continental Shields



"A" IN ANTARCTICA

A = ARCHAEOCYATHID FAUNA.

Fig. 17. Low. Cambrian World

When we study the geographical distribution of these three faunal provinces, it is remarkable that the Pacific faunas are not confined to the Pacific Board of North America (Rocky mountain region) but occur distributed over vast areas in the Central and Interior regions of North America, west of the Green Mountain in New England region and also North Europe and Asia as well, in the circum-Arctic Belt. The Atlantic faunas also are not confined to the Atlantic Board of North America and Western Europe but extend eastward into the southern Scandinavia-Baltic region, also into the Amazon basin of South America, the Mediterranean board of North Africa further partly in Tienshan, Kashmir as also in east Australia. The Indian Ocean Province covers the rest of Asia from Persia through the Himalayas to China, Manchuria and Korea on the east and south-eastward to parts of Australia (Fig. 18).

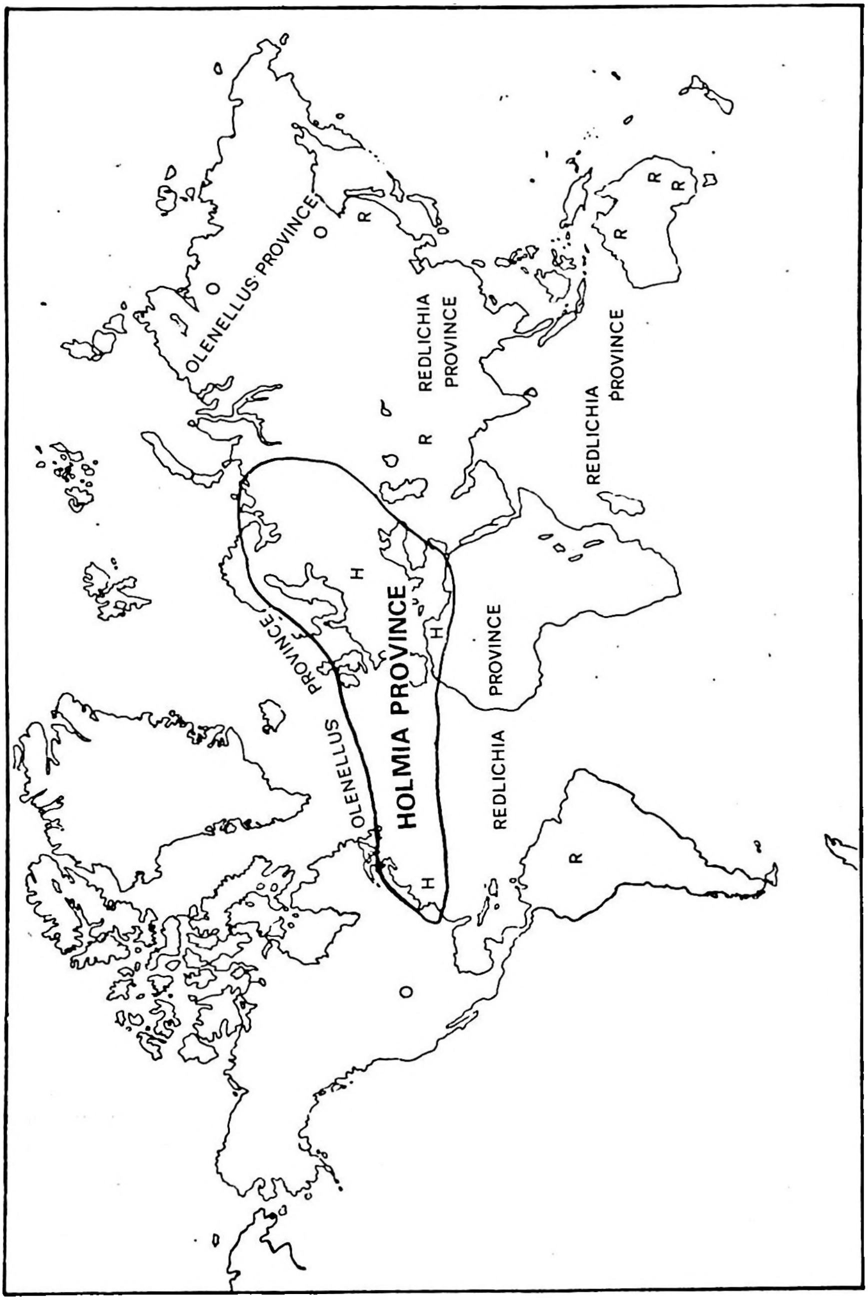
This type of geographical distribution of the three faunal provinces yields an overall picture of latitudinal distribution of the three Provinces, the Pacific in the north and the west, the Indian Ocean Province in the south and east, while the Atlantic Province forms a narrow belt in between these two major life Provinces but mainly in the Atlantic boards of North America and Europe. The Pacific and the Indian Ocean Provinces meet in Central America and in China thus enclosing the Atlantic Provinces on all sides. The Atlantic Faunal Province thus behaves as a medial basin of the Cambrian palaeogeography.

The three life Provinces of this period exhibit numerous transitional zones with mixed faunas indicative of free intercommunication along border zones. This is more particularly so with respect to Indian and Pacific Provinces where they contain numerous common faunal forms. There are, however, no indications of strong barriers, continental or oceanic, separating the life Provinces and it is possible that the faunal differences may be referable to the depth of marine basins or to other environmental conditions. The existence of continents during the Cambrian period is not proved by fossil evidence anywhere on the earth's surface.

The uniformity of faunal assemblage in any life Province cannot be maintained over vast regions since depth and other environmental conditions would vary appreciably even within the relatively small regions. The uniformity as exhibited by Cambrian faunas within each of the three world encompassing broad latitudinal life belts is difficult to explain.

Ordovician Formations

The Ordovician Rock Formations in most cases constitute conformable sequences over the Cambrian formations, indicating that the basins of deposition of the Cambrian period continued as basins of deposition uninterruptedly during the Ordovician period also and possibly even later. These sedimentary basins in many cases have been involved in common folding at the end of the lower Palaeozoic (Silurian). Remarkably, the three faunal provinces recognised during the Cambrian Period were also found to persist during the Ordovician as well even when new life forms came to dominate the scene. This was particularly true of the Atlantic life province which now became dominated by the Graptolites which did not figure during the greater part of the Cambrian. This new group soon monopolised the basin of the Atlantic life province and even encroached on portions of the other two provinces as well. The Trilobites and Brachiopods, now joined by Cephalopods in a larger measure, continued to dominate the Pacific and Indian Ocean



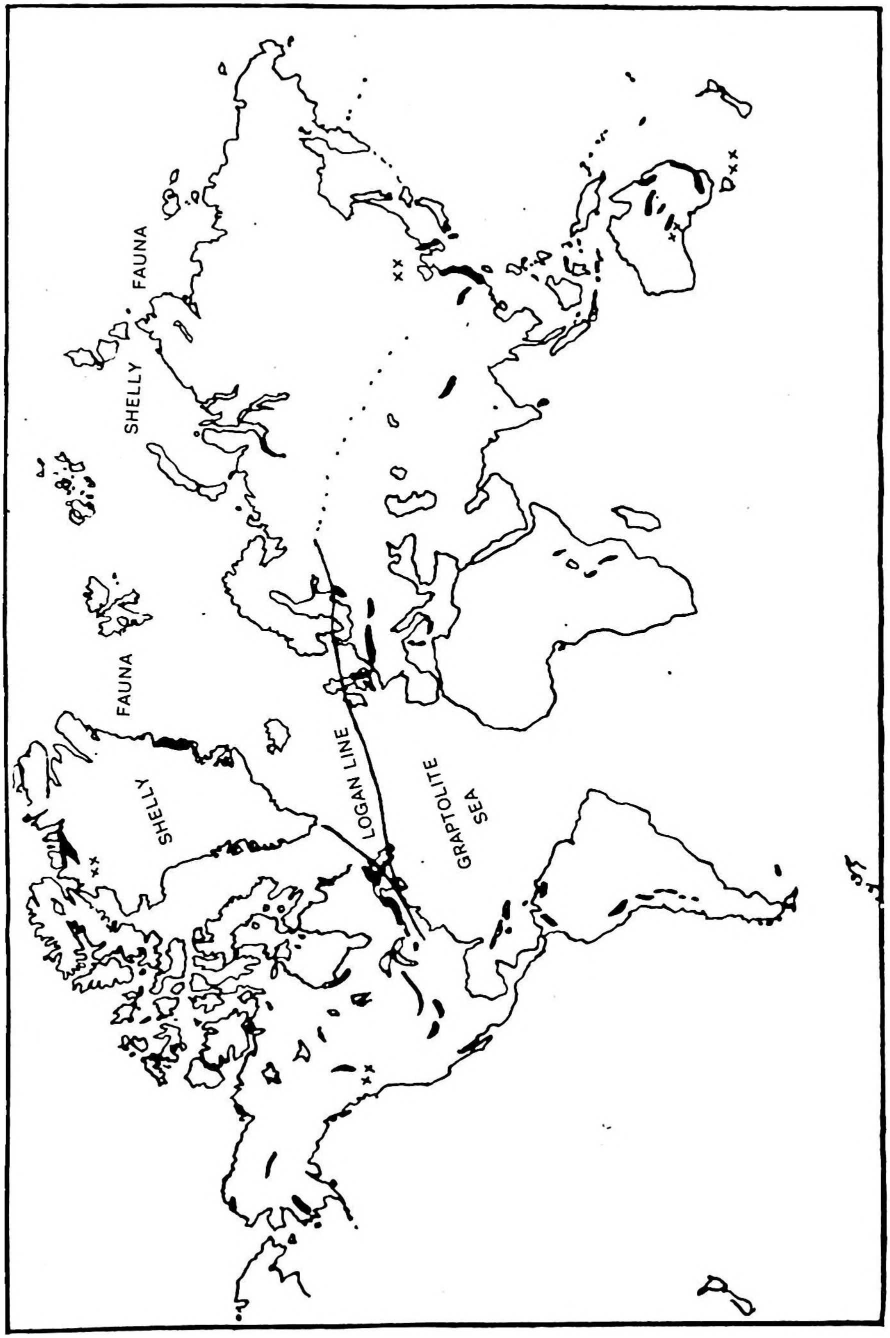
R REDLICHIA FAUNA
O OLENELLUS FAUNA
H HOLMIA FAUNA

Fig 18. Cambrian Life Provinces of the World

Faunal Provinces. Thus, we now have only two faunal facies of which the one represented by Graptolite facies is lithologically characterised by shales, mudstones or/and volcanic tuffs occupying the central basin, whereas the other is a shelly facies abounding in Trilobites, Brachiopods, Cephalopods and Gastropods set in limestone and calcareous sandstone formations surrounding the Graptolite Province on all sides. The Graptolite group though appearing first only during Upper Cambrian soon became diversified and dominated the Atlantic basins during the Ordovician and Silurian periods sufficient to serve as zonal fossils for the periods (Fig. 19).

In certain regions as in Girvan, Bornholm, Jamtland, Oslo etc., the Graptolite bearing shales are found interbedded with shelly limestones, thus enabling the time correlation of the stages of the two facies. Geographically, the Graptolitic shaly facies is found confined to central parts of British Isles, e.g. Wales, the Lake Districts, eastern Ireland and extending to Scania (South Sweden) while most other parts of British Isles and Europe exhibit shelly facies. On the other side of the Atlantic Ocean, the Graptolitic shales are developed in a far wider area, particularly in the Appalachians and extend on to the Rockies even when shelly limestones dominate the western interior and further west. The boundary line between the eastern, predominantly Graptolite bearing province and the western mainly shelly province can be recognised over a long belt called the Logan Line traceable right from New Foundland southward through the Acadian region, Hudson river to the western belt of the folded Appalachian Range. The Logan Line recalls the Green Mountain Belt similarly marking the boundary between the Pacific and Atlantic faunal provinces of the Cambrian in North America. But this time, in the Ordovician, the Logan Line is not the western limit of the Graptolite facies since the same is seen developed particularly in Lower Ordovician all along the Rockies even up to Alaska. Many of the Graptolite species occurring in the eastern belt of North America are common to the west American Cordillera.

The succession of the Ordovician Graptolites in North America is closely comparable to that of the British Isles. Many species are common to both the regions. Again many of the Graptolite forms of the eastern American belt occur also in the interior region of North America. Both the faunal facies are also recorded from many localities in South America right from the north Andes upto north Argentina. Graptolite facies dominates eastern Peru, while shelly facies dominates from Bolivia to north Argentina. All these developments in South America exhibit close faunal relationship with those in North America. In Australia also we get the development of both the facies. Almost all the Graptolite zones of the European Ordovician are found developed in Australia, particularly in Victoria. The succession of Graptolites in Victoria has been largely repeated in New Zealand. Many of the Ordovician Graptolite zones found in Victoria are again found developed in the same sequence in Great Britain as also in the New York State. The central parts of Australia between the Macdonnell and Musgrave Ranges as also parts of Tasmania and New Zealand show good developments of the Ordovician in shelly facies mainly composed of Brachiopods and Cephalopods with a few Trilobites. These show close relationship with the east Asian forms. The shelly facies also finds development in the Central Himalayas and in east Asia from Yunnan, Shan States, central, southern as also from northern China and South Korea. The fauna of South China is related to that of Europe while that of North China and Korea show affinity with the North American assemblages. What was the nature of the routes which permitted such widespread intermigration of both Graptolitic and shelly forms?



GRAPTOLITE FAUNA ××× SHELLY FAUNA

Fig. 19. Ordovician World

The Silurian Formations

The face of the earth during most of the Silurian period was hardly changed from that obtaining during the Cambro-Ordovician period. Most of the Silurian formations lie over the Cambro-Ordovician sequences with hardly any discontinuity or unconformity intervening in between. The basins of deposition were more or less the same which existed during the Ordovician with the difference that the basins became appreciably shallower, though still all marine, until the upper stages of the Silurian period (Ludlow). This time they developed esturine, brackish conditions and led to the first appearance of land faunas and floras on the geological record.

Again the Silurian, depositional basins met with in different parts of the world exhibit unformity of marine faunas both in the Graptolite as well as in the shelly facies. Most basins have mixed development of Graptolitic and shelly faunas, there being hardly any indication of distinct marine life provinces over the earth's surface during this period.

The environmental conditions during most of the Silurian Period were almost the same as those during the Ordovician and the same faunal groups persisted almost unaffected, from the Ordovician to the Silurian so much so that even today many authorities group the Ordovician with the Silurian to constitute one system. It is only towards the upper part of the Silurian that some of the depositional basins emerged above the sea level to constitute esturine, lagoonal, brackish or marshy basins. These basins later got involved in the mighty Caledonian folding movements resulting in the emergence of a regular continental land.

Though the life forms in the Silurian marine basins were essentially those already established during the Ordovician, the Graptolites continued to serve as Zonal forms. The branched or biseriate forms of the Ordovician graptolites now gave place to unbranched uniseriate Monograptids which persisted during the greater part of the Silurian upto the lower Ludlow when they suddenly disappeared (Fig. 20).

Among the shelly faunas the Trilobites and Brachiopods so prominent in the earlier periods continue to dominate even in the Silurian. Besides these two groups, Corals of the Tabulate types now come into prominence as important reef builders while Crinoids and Molluses are quite common constituents of the Silurian shelly faunas. During the younger stages in Ludlow and Downton, the esturine elements—Lamellibranchs etc. become abundant and are also locally associated with Eurypterids and primitive fishes indicative of the gradual shallowing of the depositional basins and the imminent emergence of land conditions above the sea level. This shallowing of depositional basins was not probably due to normal eustatic movements but was more likely due to actual incidence of submarine volcanism which initiated the powerful Caledonian Orogeny and which ultimately led to the development of the Devonian Old Red Continent.

The present pattern of distribution of land and sea could not have existed during the Silurian period since the development of intimately related faunas, particularly of the shallow water facies like the peculiar Eurypterids over such widely separated basins on the earth's surface, require closer interlinkages. Routes of long distance migration of such organisms cannot be easily visualised. Solution of such problems needs modification of our present concepts of crustal evolution.

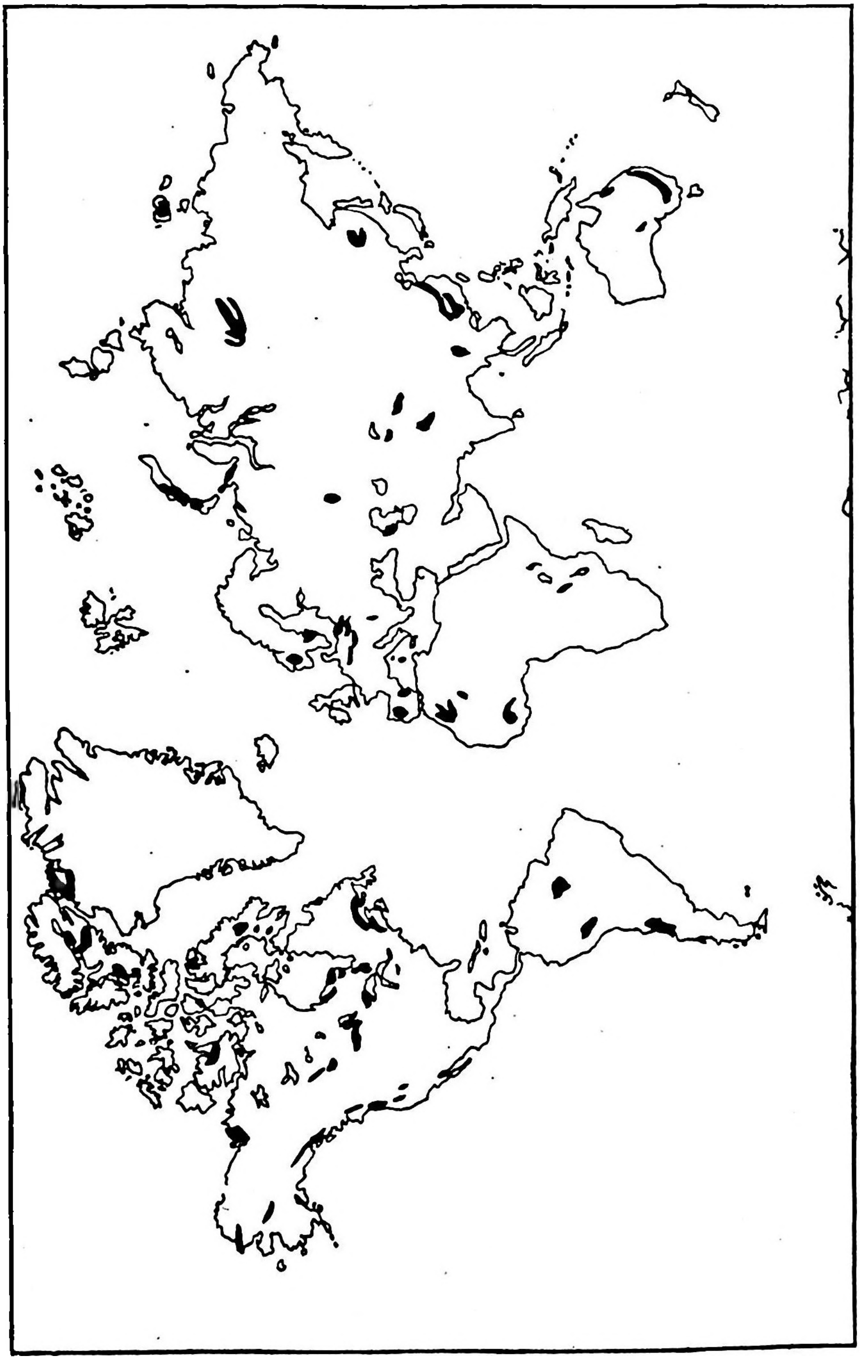


Fig.20. Silurian World

The Devonian Formations

The Devonian formations serve as a variable landmark in the evolutionary stages of the earth's surface, bringing a new environment in the evolution of life. The first positive evidence of land life on this earth is met with simultaneously in many parts of the world only during the Devonian period. The earth's crust had only in the immediate past passed through the mighty Caledonian Orogeny which threw up highly folded mountain ranges out of the marine sedimentary basins then existing. The remains of these folded mountains are now found spread over prominently in northwestern Europe from Spitzbergen through Norway, Scotland and Ireland along the eastern margin of the Atlantic Ocean and also in the Greenland, Acadian and Appalachian ranges along the western border of the Atlantic Ocean. Traces of this orogeny are recognisable in the Canadian Rockies and Arctic Islands. This orogeny, however, is much more extensively developed in the Altai Ranges along the Sino-Mongolian border.

Most of these Caledonian ranges are found associated with a peculiar rock formation typified by the famous Old Red Sandstone of Great Britain with clear and well-preserved remains of the most primitive land life both as plant and animal organisms. Some of them exhibit parts in their body structure which are suitable for living both on land and in water to suggest that they have newly adapted themselves to lead an amphibious life from their original marine life. They exhibit the first march of life on land as soon as land became available for sustaining a subareal life. This clearly shows that before the Devonian period, such land surface was not available anywhere on the earth's surface, all the crustal surface possibly being covered by marine waters (Fig. 21).

The Old Red Sandstone which is the first home of these primitive land plants and animals of the Devonian period gives abundant evidence of its mode of evolution as a land mass emerging above the sea level. According to A. Geikie (II P 1008), "one of the most marked lithological features of this Old Red Sandstone Group in central Scottish basin is the occurrence in it of extensive masses of interbedded volcanic rocks. These consist of andesites, dacites, diabases, agglomerates and tuffs, attain a thickness of more than 6000 ft. and form important chains of hills like the Pentland, Ochil and Sidlaw ranges. They lie several thousand feet above the base of the system and are regularly interstratified with bands of ordinary sedimentary strata. They point to the outbursts of numerous volcanic vents along the lake or inland sea in which the Lower Old Red Sandstone of Central Scotland was laid down." Some portions of these deposits are rich in the remains of crustacae and fishes. Numerous species of Eurypterids, often of great size (6′ by 1½′) and fishes as also compressed stems of Psilophytons and Lycopods, have been obtained from these formations.

The Old Red Sandstone formation though typically occurring in Scotland has a very wide development on both sides of the Atlantic Ocean. East of the Atlantic they are developed extensively in Scandinavia and Baltic region Russian platform almost to the foot of the Ural ranges and with small breaks, they are again met with in the Siberian platform, Kirgiz and Maniussinsk basins, and in eastern China, with the same typical land faunas and floras. West of the Atlantic, the Old Red facies is found developed along the Atlantic board of North America east of the Logan Line (St. Lawrence valley in the New England region upto the New York State). The Old Red Sandstone facies of Upper Devonian age also occurs in the Southern Continents in South Africa, Falkland Islands,

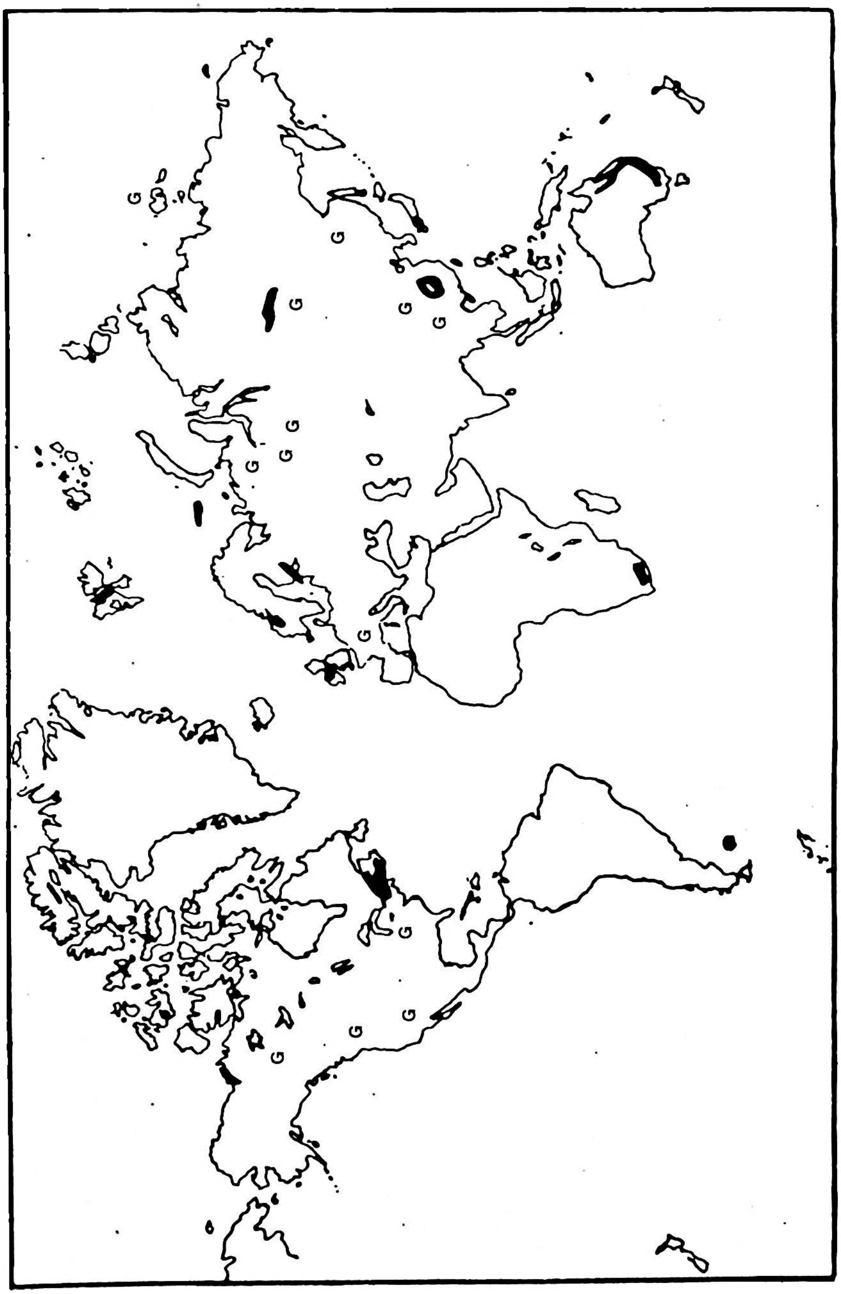


Fig. 21. Mid-Palaeozoic World

Australia and in Antarctica. These continental formations are in many regions closely associated with Devonian marine formations containing Goniatite and Coral faunas interbedded with them, indicating that these land masses were just emerging out from the associated marine basins.

Among the marine formations, the largest regional distribution of the Devonian is in North American Cordillera, from Alaska to north Mexican Borders, Appalachian basin, again in Central and Southern Europe, in the Urals, in parts of Central Asia, Central China, Amur basin etc. In the Southern Hemisphere there is a fair development in East Australia, New Zealand, South American Andes, parts of Brazil, Argentina, Falkland Islands and in the Cape basin of South Africa. This world spanning distribution of marine as well as continental Devonian formations is in strong contrast to the striking uniformity exhibited by life forms, marine as well as continental. The cause of this worldwide uniformity of the marine faunas as well as land faunas and floras cannot be easily explained, particularly when the sedimentary basins are so widely separated and have no obvious channels of intermigration.

The Carboniferous Formations

The Carboniferous is amongst the most important periods in the earth's history for the abundant development of plant life on the earth's surface. This period witnessed the prolific growth of extensive forests which led to the formation of richest coal fields of the world and as such has been fittingly called the Coal Measure Period. Land conditions were most conducive to the thick growth of hardy vegetation. The Pteridophytic plants, which came into existence only during the Devonian, soon assumed anatomical structures which enabled them to grow in bulk and length and to spread over vast regions through dispersal of spores. The lower Carboniferous vegetation known as the Rhacopteris Flora is largely a more evolved aspect of the Devonian plant life and includes Lycopods, Equisetales, Ferns and, a little later, of several seed-bearing Pteridosperms. This flora has been recorded from widely scattered regions extending from the north Arctic latitudes of Bear Island, Spitzbergen, Canadian Arctics through temperate and tropical latitudes of Asia, Europe and North America, South America, South Africa and Australia right upto Antarctica at the South Pole without any indications of botanical provinces natural to such wide latitudinal climatic belts on the earth's surface.

This Rhacopteris flora appears cosmopolitan upto the middle of the Carboniferous period. This feature led to the concept of a Middle Palaeozoic Pangaea, when all continental masses then existing were interconnected by continuous land to permit free migration of land plants from one part to the other without intervention of any marine barriers. Though this concept of Pangaea solves the problem of intermigration of floral elements, the problem of climatic zoning over the vast region of Pangaea stretching over all latitudinal climatic belts still remains unsolved. No period in the earth's geological history can be vizualised when latitudinal climatic zoning was ever absent nor could the lowly-evolved Middle Palaeozoic plant forms adapt themselves to diverse climates from Polar to Torrid Zones. A much smaller-sized Pangaea, even smaller than that conceived by Wegener and confined to a single climatic belt, alone can serve to solve the problem of world-wide uniformity of the Mid-Palaeozoic floras.

At the end of the Mid-Palaeozoic, we find a distinct latitudinal rift which divided this monolithic Pangaea into two continental masses. The formation of this rift coincided with the Hercynian Revolution. This latitudinal rift enlarged into a deep marine channel, the forerunner of the Tethys intervening between Laurasia and Gondwanaland continents of the Mesozoic periods. During the Upper Carboniferous Period, the Northern Continent was inhabited by the Pecopteris Flora while the Southern Continent was occupied by the Glossopteris Flora. The Pecopteris flora covered all land masses north of the Mediterranean, viz. North America, Arctic lands, Europe, as also parts of Siberia and China while the Glossopteris Flora covered peninsular parts of South America, Africa and India, most parts of Australia and even of East Antarctica.

Along the common border of the two floral provinces there are some zones of mixed development, some elements of one province encroaching into parts of the other. The southern elements encroaching into the northern domain are met with in the Dwina basin in Russia and Kussnetzsk in Siberia while northern elements are found in the Southern Floral Province in Sahara, Argentina, Java etc. The difference in the two floral Provinces is not so much in the nature of floral families as in the presence or absence of certain generic types. The climatic conditions obtaining in the two floral provinces were, therefore, not very different, many genera being common to both. But the marine barrier between the two brought about restrictions in the migration of certain types. This only indicates that the marine barrier was pretty narrow and that the two land masses were not very far apart. The extraordinary exuberance of vegetable growth leading to the formation of very thick coal seams necessitates rainy tropical or temperate climates for such growth and, therefore, the concept of original location of the two continents near the two poles, as suggested by some, is altogether unwarranted.

During the later part of the Carboniferous, a third floral province appears to have come into existence called the Cathaysia characterised by Gigantopteris Flora. This is of restricted occurrence, both in time and space, being dominant only in South China though its traces are met with in Sumatra and in Texas and Oklahoma in the U.S.A. It is remarkable that Malaya contains typical European (Northern) flora with no Gigantopteris while Sumatra further south exhibits occurrence of Gigantopteris along with European forms. Such wide-reaching encroachment of elements of one floral province far into the domain of the other cannot be easily explained. These floral encroachments testify to the closeness of areas of original deposition of the Parmocarboniferous continental formations of the Northern, Southern and Eastern floral provinces with limited opportunities for intermigration.

The fitful encroachment of floral elements in different floral provinces is also reflected in the irregular distribution of marine Tethyan faunal forms, especially the fusulinae and aberrant Brachiopods during this period. Starting from British Columbia on the Canadian Pacific coast and Texas in the Mexican Gulf region, they are seen developed through Southern Europe, Eastern Alps, Dinarides, Tunis, Crimea, Caucasus, Armenia, Darwaz, continued into the Ural and Timan Ranges, again in Kokonor, farther northeast in South and North China, Mongolia and Ussuri to Japan on the northeast and in the southeast through the Salt Range, Indochina, Sumatra to Timor in the Western Pacific region.

Such widespread development of aberrant Brachiopods and Fusulinae in the newly-fromed Tethyan basins could not have been possible if the depositional basins were so

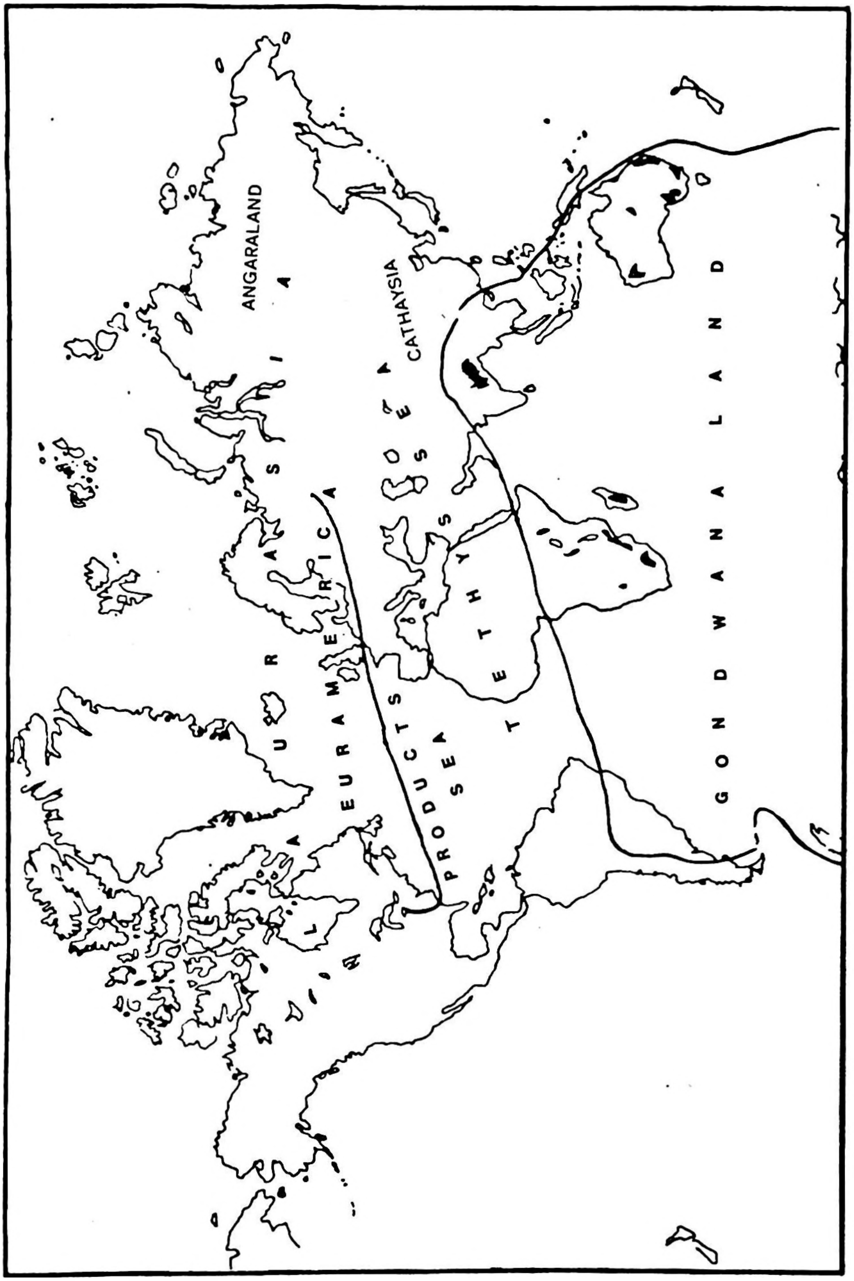


Fig. 22. Permocarboniferous World

disconnected as they are today stretching from the western end of the continental hemisphere to its eastern end. This uniformity of the uncommon faunas demands a closely-spaced unitary basin, permitting free intermigration of faunal elements of both shallow and deep sea habitat (Fig. 22).

The Permian Formations

The Permian period witnessed continued upraising of the continental land masses already emerging since the Devonian-Carboniferous Period. Since there was no break in this process, the Permian deposits show a gradual change from the Upper Carboniferous to the Permian, making it difficult to mark the boundary between these systems. Many geologists have, therefore, combined part of the Lower Permian with the Upper Carboniferous to constitute the Permocarboniferous system. For similar reasons, part of the Upper Permian is combined with the Triassic under the term Permotriassic. The Permian, therefore, for many regions does not figure as an independent system. Land conditions were developing rapidly on a wider scale in regions which were marine basins till lately and in the process were rapidly passing through littoral, lagoonal and marshy conditions, leaving behind widespread deposits of saline residues often rich in potash and other salts. Land terrains developed basins of continental deposition giving rise to vast deposits of coal often with diversification of floral provinces (Fig. 23).

The deepening and widening of the Tethyan rift gave rise to a differentiation of the basins of marine deposition into deep sea facies characterised by Fusuline and Ammonoid faunas and shelf sea facies characterised by Brachiopods, Lamellibranchs, Gastropods and Corals along the borders of both the Northern and Southern Continents.

During the Permian period, volcanic activity was quite vigorous which brought about widespread elevation of the continental masses together with their lateral expansion. This volcanic activity was a continuation of the one largely responsible for the Variscan Orogeny during Upper Carboniferous and which also initiated the Tethyan Rift. The Upper Permian in many western European continental regions is developed in a very peculiar facies known as the Zechstein Formation, extending from England on the west to Poland on the east. It represents a shallow inland sea deposit with basal conglomerate overlain by a thin bed of Kupferschiefer, rich in ores of copper, associated with silver, lead, zinc and uranium. Middle Zechstein is the main fossiliferous marine formation with dolomite, bituminous limestone associated with saline residues. The Upper Zechstein is dominated by saline deposits as unusually thick beds of potash-rich salts and gypsum. These diverse facies of Zechstein are not amenable to simple explanation. The association of conglomerate with Kupferschiefer in the lower part is more likely to be of thrust origin brought about through basic eruptives which are profusely associated with them. The ores of copper, lead, zinc, silver, uranium etc. have their original home usually in eruptive magmas rather than in simple sediments. The dominant red colour of the associated Rotliegende Sandstone is also referable to decomposition of ferrugenous contents of basic eruptives which have permeated and seeped into pre-existing sandstones.

The purely geosynclinal facies is developed in the E-W trending tropical Mediterranean belt of Tethyan sediments bearing both the Ammonoid and Fusuline faunas. These sediments are met with intermittently right from British Columbia and Rockies (Guadaluppe, Texas) eastward through Pyrenees, Sicily, Carnic Alps, Crotia, Crimea,

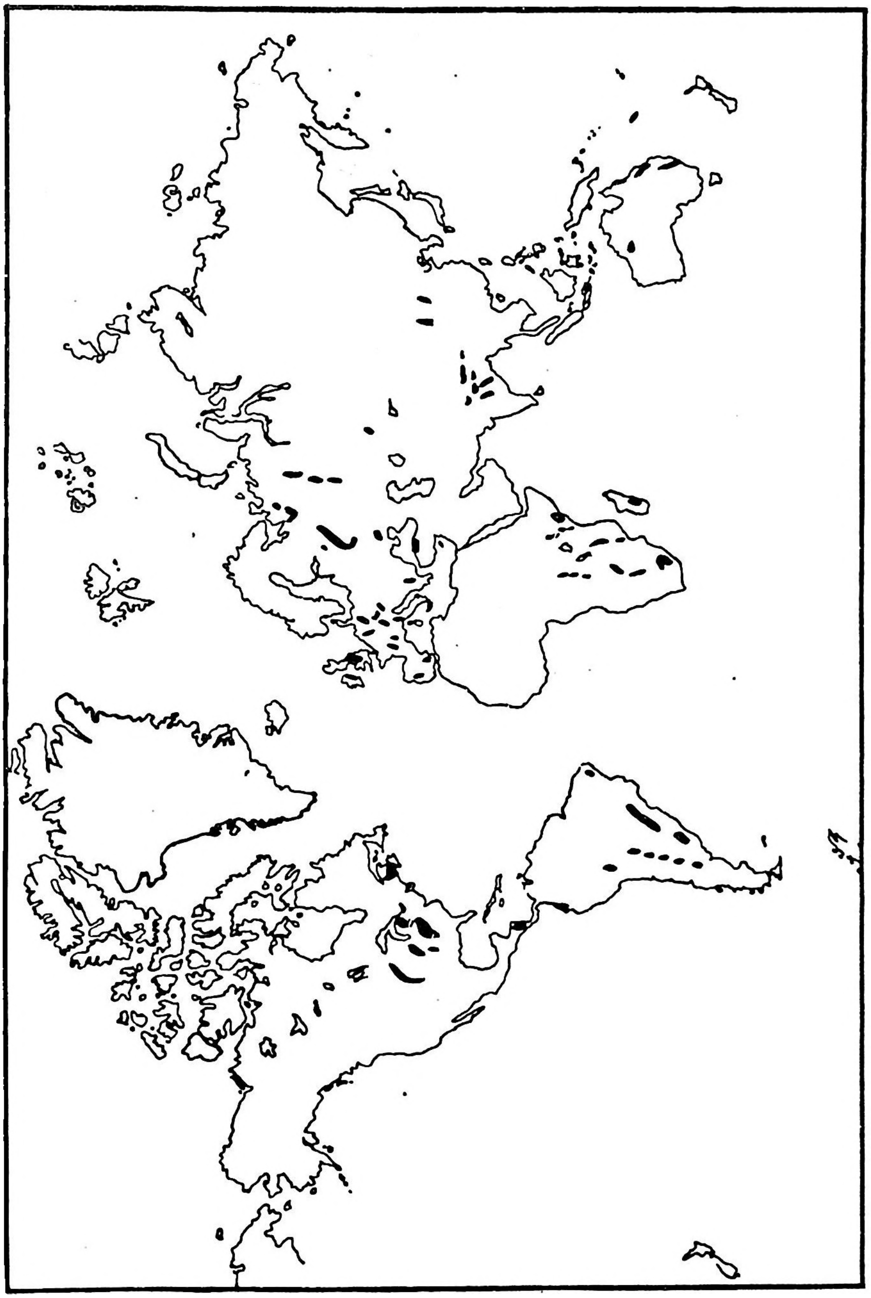


Fig. 23. Upper Palaeozoic Coal Fields of the World

Armenia (Djulfa), Urals, Darwaz, Salt Range, Madagascar, as far east as Timor and West Australia. Most of the occurrences exhibit parts of identical sequences containing the comparable ammonoid and fusuline zonal assemblages. The occurrences of common faunal elements, often characterising deep sea facies, over a vast belt interrupted by oceanic or continental barriers pose problems of free intermigration and suggest much closer spacing of the depositional basins during the Permian times.

THE MESOZOIC ERA

The Triassic Formations

During the Triassic Period, the continental masses had assumed significant proportions to interfere with intercommunications between marine basins of sedimentation. The continental fluvio-limnic zones as basins of terrestrial deposition often merged with marine, lagoonal and shelf basins to give rise to mixed facies as obtain in the Germanic and Rhaetic basins. Here alternations of marine and continental deposits have helped us to ascertain the age relationships and correlation of terrestrial deposits (Fig. 24). The lower Triassic continental deposits are developed in pure sandstone facies called the Bunter or Bunt Sandstein with terrestrial fossils representing the land life of the Period. In some of the Germanic basins, the Middle Triassic fluviatile facies is interdigitated with marine shelf facies named as Muschelkalk and is characterised by Lamellibranchs, Gastropods and Branchiopods. This mixed facies continued later into the Upper Triassic-Rhaetic formations which are common along the northern shelf zones of the Tethys against the Mercynian massives. Shelf deposits are found in Spain, France, Germany, England, southeast Russia, Donetz and in the far east, in south China. They also occur in the far west in the Great Basin of North America. Along the southern shelf zones of the Tethys, the Germanic facies occurs in Parana in South America, in the Ethiopian Province of Africa, Madagascar and in parts of the Himalayas.

The typical geosynclinal sediments of the Triassic period are developed in the Tethyan Tropical Belt where Lower Triassic formations are better developed in the Himalayan region (Byans, Painkhanda, Spiti, Kashmir) and in the Salt Range, continued further east and southeast in the Malaysian Timor region, and also in the northeast in the region of Ussuri. They are again developed in the Arctic region of Olenek, Spitzbergen and Greenland. Similar Lower Triassic formations again occur in the Cordilleran States of Idaho, Utah, Nevada and California, where they show close faunal relationships with Himalayan and Timor Triassic formations. The Middle Triassic Tethyan formations are best developed in the Himalayas, Asia Minor, the Balkans and the Alps and also in the North American Cordillera. Timor and Malayan faunas have also many typical Himalayan Ammonite species, including some uncommon forms. The Ammonite bearing Hallstadt facies of the Middle Trias is well developed in Turkey, Greece, Balkans, California and Nevada.

The Upper Triassic geosynclinal facies is best developed in the Eastern Alps and to a lesser extent in the Himalayas. Partial development is seen in the Balkans, Carpathians and also in North America, Malaysia, Timor, New Caledonia and New Zealand.

The Himalayan Geosyncline has thus been a continuous repository of the Alpine as well as of the Malayan faunas for a major part of the Triassic Period.

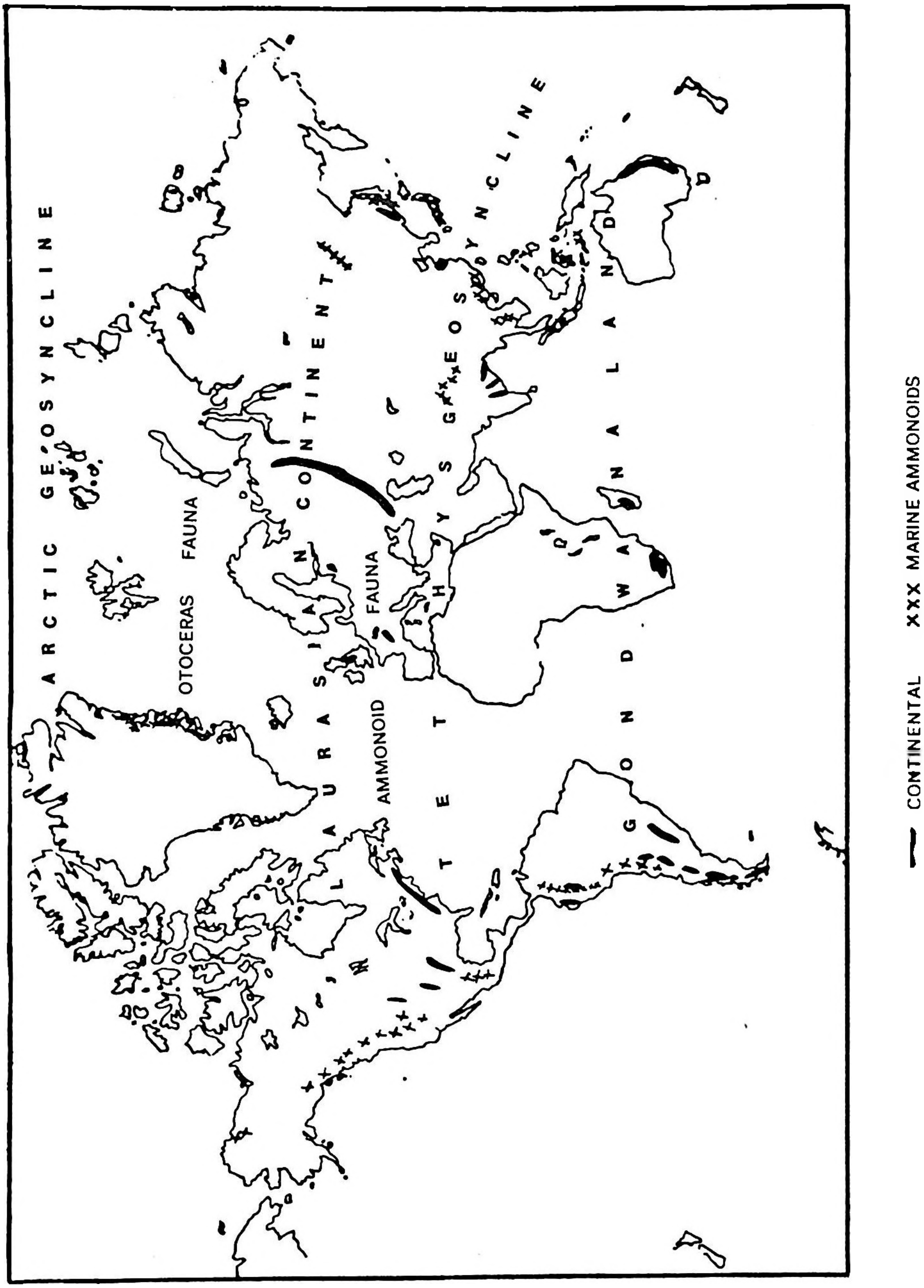


Fig. 24. Triassic World

The Upper Triassic formations also are well developed in south central China between Yangtsekiang and Hwang Ho basins. Malaya and the Indonesian Islands exhibit good development of the Upper Triassic Halorite Limestone facies of the Himalayas and the Alps while the exotic Tibetan facies is found developed in Timor. They form a connecting link between the Tethyan and the Pacific faunas abundantly developed in New Caledonia and New Zealand. In North America, the Upper Triassic formations are thickly developed in Mexico, California, British Columbia, Alaska and also in Ellesmere, Spitzbergen, New Siberian Islands of the Arctic region. Many of these also exhibit Reef Corals typical of the Alps.

The development of diverse facies of the Lower, Middle and Upper Triassic formations in widely separated regions of the world, yet exhibiting close faunal or floral relations with the Tibeto-Himalayan basins of deposition, calls for an adequate assessment of regional linkages which enabled diverse life-organisms to migrate from one basin to the other without any obstruction

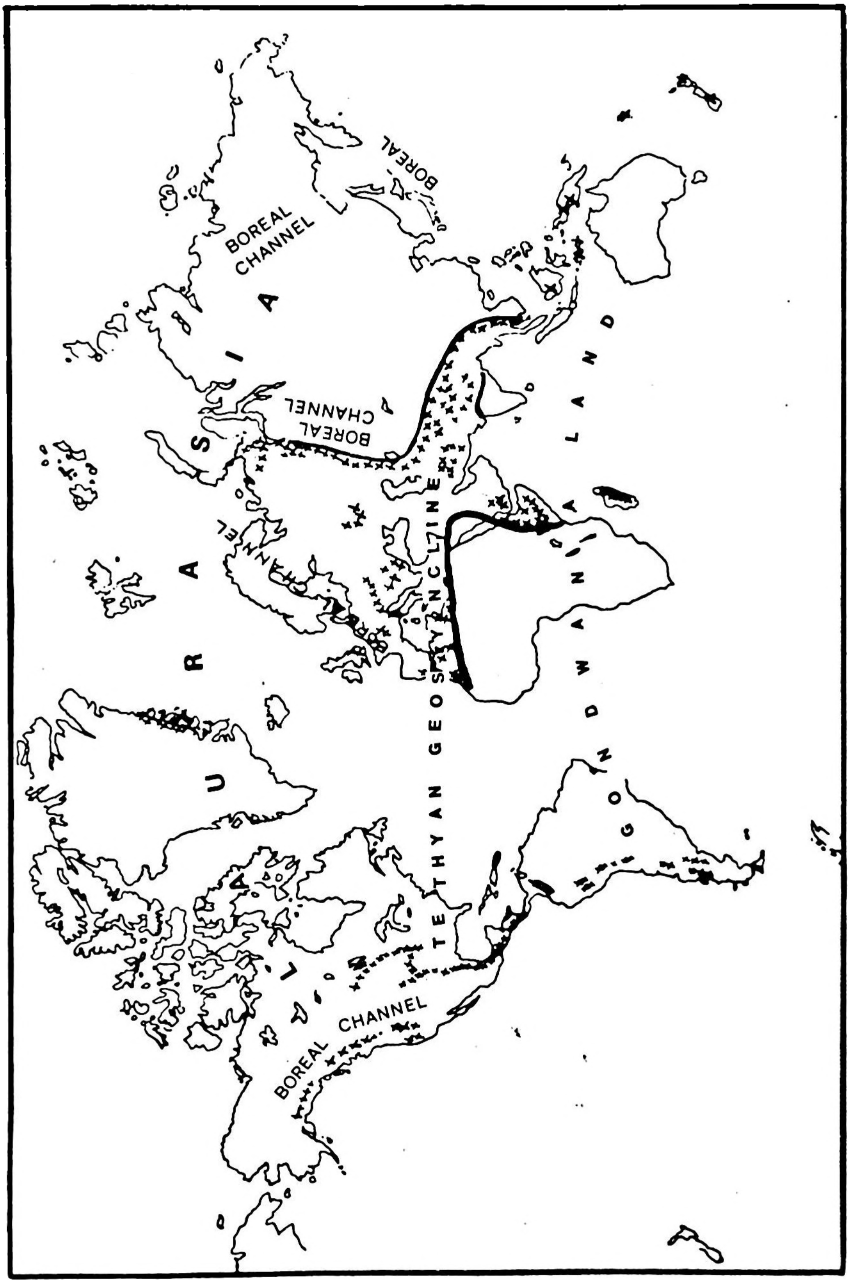
Jurassic Formations

The Jurassic Period exhibits essentially the same pattern of land and sea distribution as in the Trias, only more complicated by extensive indentations of the Tethys into the adjoining continents on either side and particularly in the northern one during the Callovian transgression. Many bordering continental regions suffered inundation by neritic shelf seas. This is particularly evident in central Europe, southern Russia, North American Sundance region in the north, and in the Ethiopian region in the south. We also see the repeated development of Boreal seas in the northern Arctic regions, particularly during the upper Jurassic. The Tethys as a deep geosynclinal basin continued to separate the Northern Continent from the Southern right from Mexico in the west through the Mediterranean-Alpine-Himalayan belt extending upto New Zealand on the southeast This distribution leads to more or less seven life provinces with no sharp boundaries and represents only wider development of the pattern observed in the Triassic period (Fig. 25).

1. North Pacific Eugeosyncline with frequent development of boreal facies as seen in North American Rockies and the Arctic region of Eurasia.
2. Northern or Laurasian continent from Appalachian Range of North America through Central Europe to Angaraland.
3. Miogeosynclinal shelf zone along the southern border of the Northern Continent.
4. Eugeosyncline of the Tethys all along the tropical zone.
5. Miogeosynclinal shelf zone along the northern borders of the Southern Continent.
6. Southern or Gondwana Continent from Brazil through Africa and India extending to Australia and Antarctica.
7. South Pacific Eugeosyncline—the Andean basin—along the southern border of the Southern Continent; against the S. Pacific Ocean.

These seven Life Provinces exhibit the following distribution:

(1) The North Pacific Eugeosyncline is developed all along the Pacific coast of North America from California to Alaska and continued further east all along the Arctic region.



CONTINENTAL XXX MARINE

Fig. 25. Jurassic World

This is at times characterised by the development of faunal association described as Boreal. Such Boreal elements have been recognised in the Upper Jurassic formations of the CircumPacific zones of North America and East Asia and are also seen periodically to encroach on the Tethyan shelf zones of northern continents at a number of places in the intervening regions of Asia and Europe.

(2) The Northern or Laurasian Continent is observed as a series of detached horsts from Spain through France, England, Germany to West Poland and Fennoscandia and further east at larger intervals, from Angaraland to Sinia. West of the Atlantic, this land mass is again seen in East Canada, Appalachia and Western Interior with a flora similar to Purbeck-Wealden Flora of Europe.

. (3) The miogeosynclinal shelf zones on the southern side of the Northern Continent in typical neritic littoral and esturine facies giving a three-fold division of (a) Shaly carbonaceous or Black Jura (Lias), (b) ferruginous Oolite or Brown Jura (Dogger) and (c) Calcareous or White Jura (Malm). These are characteristically developed in Central and Western Europe.

(4) The Eugeosynclinal Tethys Province: This is the most important province being richly fossiliferous and amenable to detailed zoning and classification which is applicable over the whole of the tropical belt. East of the Atlantic, this belt extends from N.W. Africa and southern Spain through central and southern France, the Alps, Apennine, Carpathian, Dinaride and Balkan Ranges, further through Greece, Turkey, Armenia, Iran, Afghanistan and the Pamirs to the Himalayas. Further east they continue through Burma, Indo-China, Indonesia, New Guinea to New Zealand in the southeast and also to Japan in the northeast. West of the Atlantic, this province can be traced along the borders of the Gulf of Mexico, where it is highly mixed with CircumPacific Rockyan-Andean Provinces.

(5) The Southern miogeosynclinal Tethyan shelf zone associated with Southern Continents: This zone, partly comprising the Ethiopian Province, is developed along the southern flanks of the Tethys in N.W. Africa, Libya, Egypt and Arabia. It is better developed in East Africa in Abyssinia, Somalia, along the East African coast, Madagascar and continues eastward in the classical developments in Cutch and the Salt Range.

(6) The Southern Continent (Gondwanaland) with terrestrial facies is largely developed in Brazil, Argentine, Central and Southern Africa, Peninsular India, Australia and in Western Antarctica. Parts of these may be Cretaceous in age. The littoral facies represented by Tendaguru beds of Tanganyika contains rich vertebrate fauna interbedded with Ammonite-bearing marine formations.

(7) The South Pacific-Andean Eugeosyncline best developed along the Pacific coast of Peru, Chile, Argentina and Patagonia continues further into West Antarctica. In places, these formations are interbedded with Parana volcanic products while the fauna included European Tethyan and Indo-Pacific faunal elements.

It is remarkable that these various facies provinces are latitudinal in their regional development extending over vast distances in an East-West direction and yet maintaining their characteristic lithological and faunal facies.

Besides the above seven life provinces, certain peculiar Boreal facies of formations are seen developed in parts of the Arctic region in the Northern Hemisphere during the

Middle and Upper Jurassic period. This boreal facies is characterised lithologically by the dark clays poor in lime, with abundant development of a specialised fauna not common in the Tethyan geosyncline. This fauna consists of certain Belemnites, Ammonites and Lamellibranchs (Buchia). These appear at intervals to mingle with the Tethyan faunas along certain narrow canals joining the Arctic with the Tethys. Such canals are recognised along the routes:

1. Alaska-California-Mexico Basin.
2. Mackenzie-Sundance-Colorado Basin.
3. Greenland-Scandinavia-South England-the Rhine-Rhone Basins.
4. East European Ukraine-Poland-Pommern Basin
5. Kummero-Caucasus-Donetz-North Sea Basin.
6. Siberian Lena to Okhotsk Sea-Japan Basin.

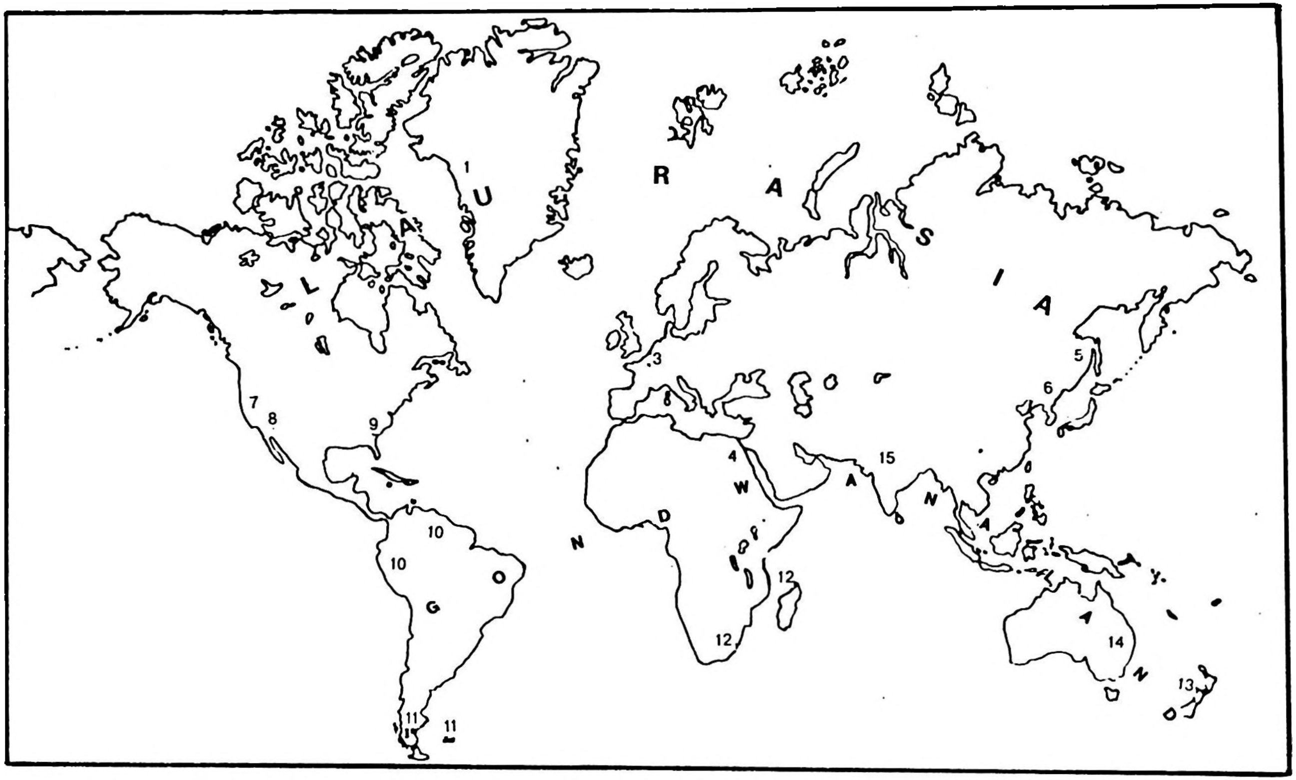
The same canals are seen to persist even during the Lower Cretaceous period.

The continents of the Jurassic period exhibit, more or less, a uniform Flora consisting of Ferns, Conifers and Cycadophytes occurring in both the hemispheres as seen in northern Europe and California in the north and in India and Western Antarctica in the south. There is extensive generic uniformity, including many common species in the plant associations. The existence of a common uniform flora over all the land masses extending from the northern polar region to the southern polar region, irrespective of the diverse latitudinal climatic belts, and this inspite of the intervening vast oceanic basins, poses problems of biogeographic nature which are difficult to be solved on the basis of any of the existing concepts.

Cretaceous Formations

During the Lower Cretaceous period the palaeogeographical conditions of the earth's crust were essentially a continuation of those prevailing during the Upper Jurassic. During this period the Boreal faunal province which came into existence during the Mid-Jurassic continued uninterrupted till the Mid-Cretaceous in the northern hemisphere. The linkage canals between the Arctic (Boreal) sea and the Tethys during the Jurassic continued to function during the Lower Cretaceous. In the Southern Hemisphere a new boreal province came into being during the Cretaceous as the Uitenhage Facies which linked the Ethiopian shelf sea with the Antarctic Polar Province.

The terrestrial formations deposited during the Lower Cretaceous on the Laurasian Continent were characterised by the Wealden type flora dominated by Ferns and Gymnosperms and now associated with a few newly-evolved Angiosperms. This Wealden Flora is uniformly developed in western, central and eastern Europe, in the Appalachian mountain belt and in the Central Interior plains of North America (Fig. 26). It is also developed in the Asiatic regions of Siberia and China. The Southern Continent, the Gondwanaland, also exhibits the same Wealden type flora in Brazil, Patagonia, South Africa (Uitenhage), Madagascar, India (Cutch and Rajasthan), Australia (Queensland), New Zealand and as far south as Western Antarctica (Grahamland). It is surprising that, as in the Jurassic, the Lower Cretaceous flora exhibits remarkable uniformity extending in some cases to the level of species, right from the North Polar regions through temperate and tropical regions upto the South Polar regions unaffected by the global climatic belts even when plants are so highly susceptible to climatic variations.



CRETACEOUS ANGIOSPERMS:

(1) WESTERN GREENLAND
(2) SPITZBERGEN
(3) ENGLAND, BOHEMIA
(4) N. AFRICA, SYRIA
(5) SIBERIA, SAKHALIN
(6) JAPAN, CHINA
(7) NORTH AMERICA
(8) NORTH AMERICA
(9) PATAPSKO E N. AMR
(10) S. AMR PERU, VENEZUELA
(11) S. AMR. ARGENTINA, GRAHAMLAND
(12) S. AFRICA, UITENHAGE, MADAGASCAR
(13) NEW ZEALAND
(14) QUEENSLAND
(15) INDIA (BARMER)

Fig. 26. Cretaceous World

The marine sedimentary formations, on the other hand, exhibit diverse facies, distributed in different parts of the world in the nature of latitudinal zones. As in the Jurassic Period, the Lower and Middle Cretaceous periods also show the same seven Facies Provinces (Fig. 27):

(1) The Arctic or Boreal marine life province stretching from Alaska and the Canadian Arctic Islands through Greenland, Spitzbergen, to Lena and Kolyma basins turning SE through Okhotsk and Ussuri to Japan. In North America this Boreal Province extends from Alaska southward along the coastal Cordillera upto Mexico terminating against the Tethyan Province of the Gulf region.

(2) The Northern Continent (Laurasia) constituted of a number of disconnected Caledonian and Hercynian horsts with intervening canals permitting the mixing of Boreal faunas with Tethyan faunal elements during the Lower and Middle Cretaceous. These horst regions support terrestrial Wealdan Flora.

((3) The Northern Shelf Zone of the Tethys against the Laurasian horsts. This persisted as a distinct province during the lower Cretaceous but suffered enormous broadening during the Cenomanian transgression, permitting general mixing of the boreal and Tethyan faunas thus obliterating boreal as a distinct life province during the Upper Cretaceous.

(4) The Tethys Geosynclinal Province. It was narrow and deep upto the Middle Cretaceous but suddenly expanded during Upper Cretaceous and became largely a shallow neritic basin characterised by Riff Calc facies with Rudists, Corals, Nerineas etc. It extended from Mexico on the west through the Mediterranean and the Himalayan region and further upto Indonesia on the east.

(5) The Southern Shelf Zone of the Tethys against the Gondwanaland, constituted distinct Ithiopean Life Province during the Lower and Mid-Cretaceous. This got spread over during the Upper Cretaceous as a shallow sea over vast areas leading to the fragmentation of Gondwanaland. This shelf basin in clayey facies constituted the extensive Indo-Pacific Realm spread over from South America and West Antarctic through Africa and India to Australia and is also recognisable over the Pacific Board of East Asia upto Kamchatka and Bering Strait on the east and over the Pacific board of North America even upto California on the west.

(6) The Southern Continent of Gondwanaland which was a unitary land mass upto Mid-Cretaceous got fragmented into a number of distinct continental masses permitting free inter-mixing of Tethyan shelf faunas with the South Pacific faunas.

(7) The South Pacific Andean Geosyncline existed as a distinct Boreal Province (Uitenhage) during the Lower Cretaceous but lost its individuality during the Upper Cretaceous through merging into the general Indo-Pacific Province.

The Middle Cretaceous Cenomanian epoch was the time of the most extensive marine transgressions affecting the largest part of the world and marks the fragmentation of the Mesozoic supercontinents into a number of smaller units leading to drastic changes in the palaeogeography of the world. This also permitted the widespread distribution and dominance of the Angiosperms, first appearing in the Lower Cretaceous into the worldwide Flora of the Upper Cretaceous and later periods.

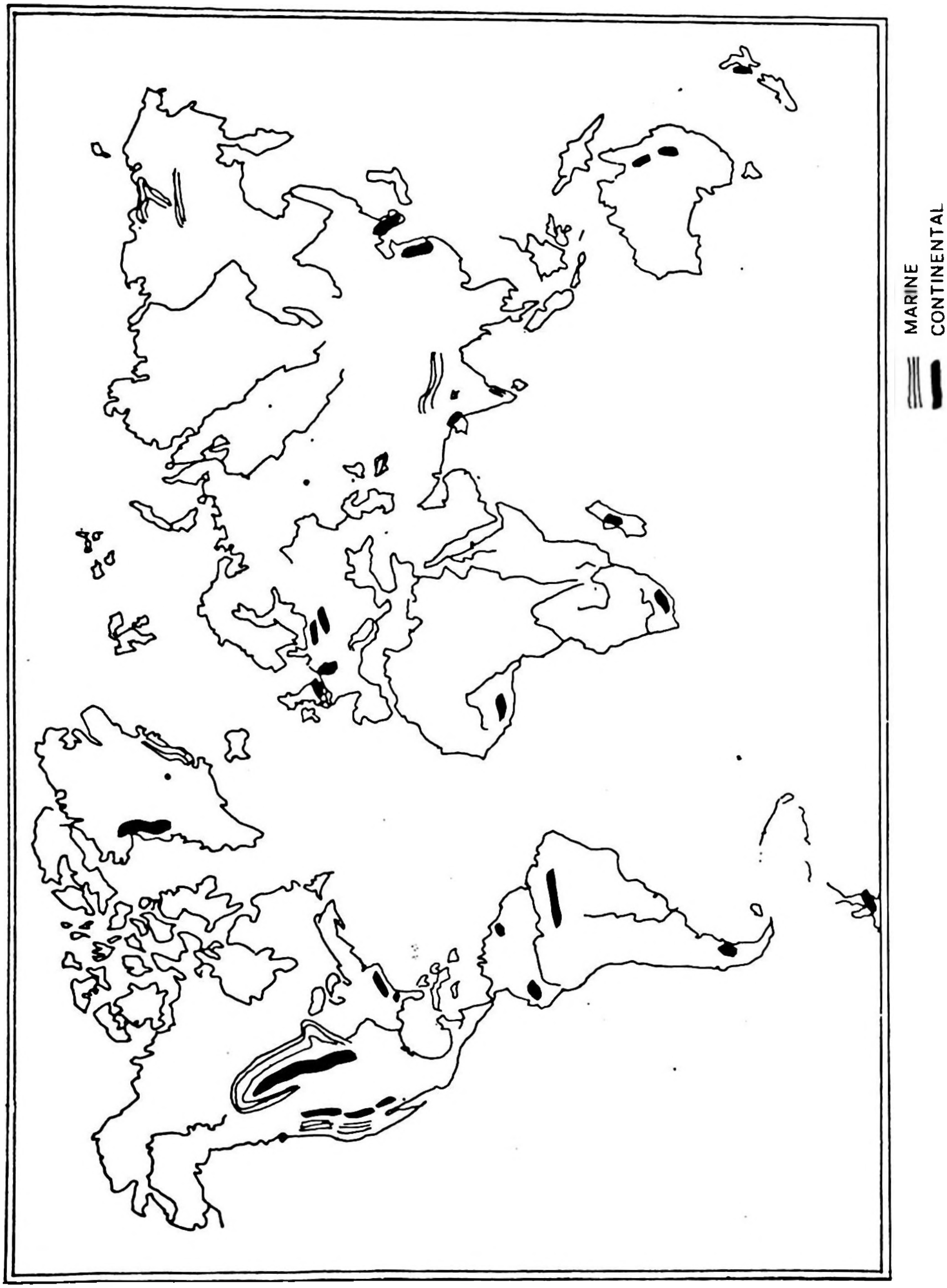


Fig. 27. Cretaceous World

THE TERTIARY ERA

Lower Tertiary Formations

The Lower Tertiary marks a period of tremendous igneous activity and of extensive crustal movements, both vertical and lateral. The Lower Tertiary formations exhibit diverse facies extending roughly in E-W belts. Starting with the European subcontinent (Fig. 28):

(1) The Northern Continental facies is developed in Arcto-Scandinavian region, mainly in volcanic facies as Thouleitic Plateau Basalts from Greenland to Scandinavia and Scotland.

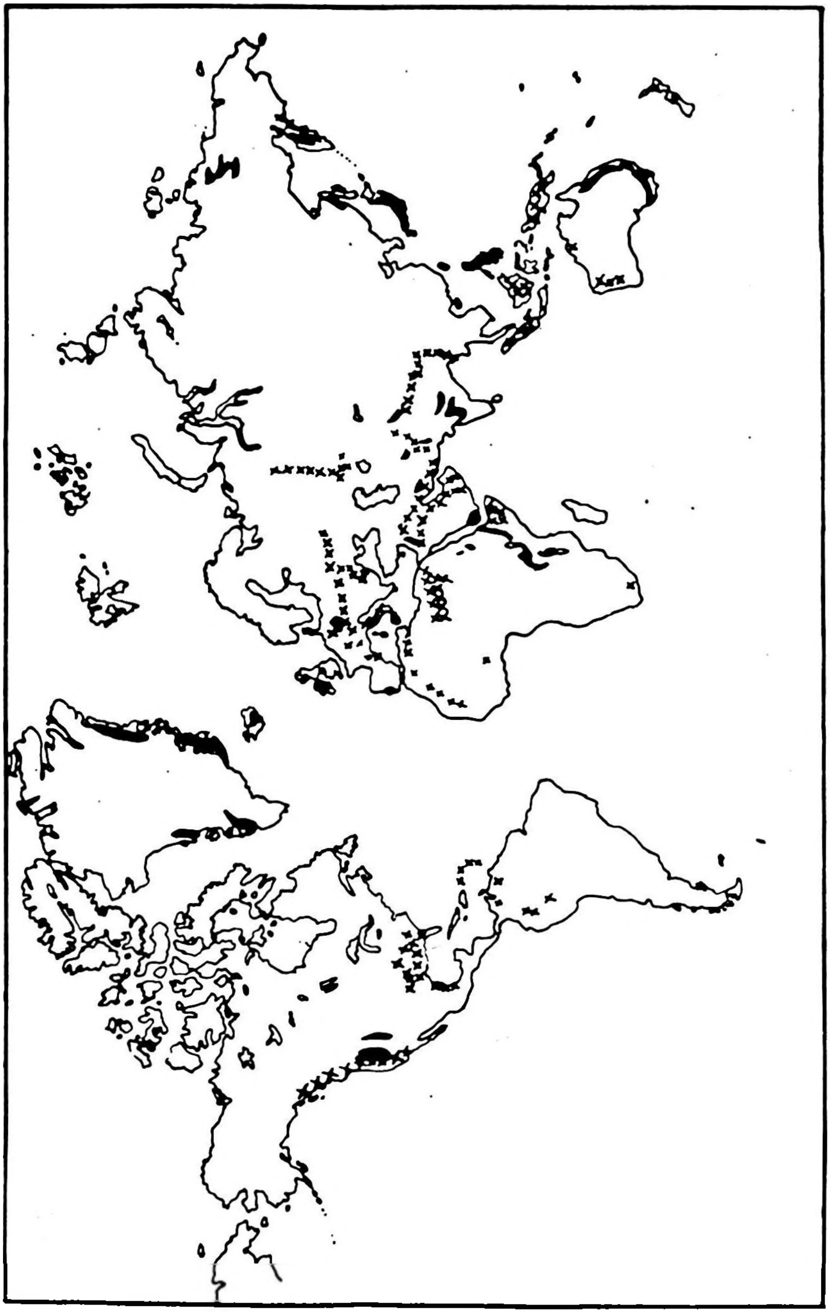
(2) The Central European Shelf sea facies from England and France through Belgium, Holland, Germany, Denmark to South Russia with partly marine and partly lacustrine sediments often studded here and there with alkaline basalts as seen developed in the Hercynian massives of France, Rhone valley, Rhine Valley, Black Forest, Bohemia, extending into South Russia.

(3) The main Tethyan Geosynclinal belt with abundant Nummulitic Limestone is complexly infolded with enormous flysch type of orogenic sediments and profuse ophiolitic eruptives. This belt extends from Gibraltar with numerous sinuations and apparent interruptions along the northern and southern border zones of the Mediterranean sea and extending even beyond the Turkish Peninsula.

This Tethyan belt in Nummulitic facies continues eastward in Asia through Armenia upto the Aral sea region where it meets the Boreal facies of the Eastern Ural. Volcanism in Armenia separated this northern Tethyan belt from the southern Nummulitic belt running through Crete, Syria, Central and SW Persia through Baluchistan into the Himalayas where again it is overwhelmed by ophiolitic volcanism. This Lower Tertiary belt is apparently in communication with the one in Assam, Burma, and Indonesia. The Lower Tertiary in Nummulitic Limestone facies is again developed in South Australia and Tasmania while the same is continental in Queensland.

In Africa, the Lower Tertiary in marine facies is seen developed in Sahara from Senegal to Tripoli as also in East Africa, Arabia and Madagascar. In South America the Lower Tertiary is developed in both continental and marine facies interbedded as seen in Patagonia.

In North America the Lower Tertiary in marine facies is developed mainly along the Atlantic continental borders south of Maryland continuing along the Mexican Gulf borders deep into the lower Mississippi Valley and southward into the La Grande valley in Texas and Mexico. It is also partly developed along the Pacific coast in California. The Lower Tertiary in continental facies, on the other hand, is extensively developed in mid-continental depression facing the Rockies continuing along the inner arcs of the Mexican Gulf where it is bordered by marine facies. These Mid-Continental Lower Tertiary deposits are flooded by Columbian plateau basalts and contain an abundant vertebrate fauna (Wasatch, Wind River Bed) very closely related to that of Europe.



xxx PALAEOGENE (Pg.)
(NUMMULITIC LIMESTONE)

▬ ERUPTIVES

Fig. 28. Low. Tertiary World

Upper Tertiary Formations

The Tethyan marine facies continues in Upper Tertiary in localized developments in Central Mediterranean basin in Sardinia, Western Apennine and as flysch in Eastern Apennine, Malta, Crete, Turkey, Syria and Palestine while in southern Europe, it is mostly developed in molasse facies, first as a marine foredeep, followed by lagoonal-brakish water facies and finally as fresh water facies during the post-orogenic period of adjustment of the crust. They are also associated with Upper Tertiary volcanism as in Hegau (Fig. 29).

In Asia the Central Mediterranean belt of marine deposition continues upto Syria and Palestine but elsewhere it is in continental facies as Fars Series in Iran, and as Siwalik Series in sub-Himalayan Indo-Gangetic basin, both possessing a similar vertebrate fauna.

East of the Himalayas the Upper Tertiary Foraminiferal Limestone, highly folded in Malaya, is seen to continue southeastward into New Guinea and northeastward through Philippines is extending towards Japan. In other regions, it is largely in continental facies. It is coal-bearing in Siberia, east of Ural even upto New Siberia and other Arctic islands. Most of the Arctic land masses show continental coal-bearing formations rich in European floral forms whereas in Mongolia and in part of China, they are rich in vertebrate fossils.

In Australasia the Upper Tertiary in marine facies is seen developed in South Australia, New Guinea and New Zealand with a fauna closely related to that of Patagonia. Similar formation occurs in the Seymore Island of Antarctica. There is also an abundant development of Upper Tertiary volcanism in Victoria, Queensland and in parts of New Zealand.

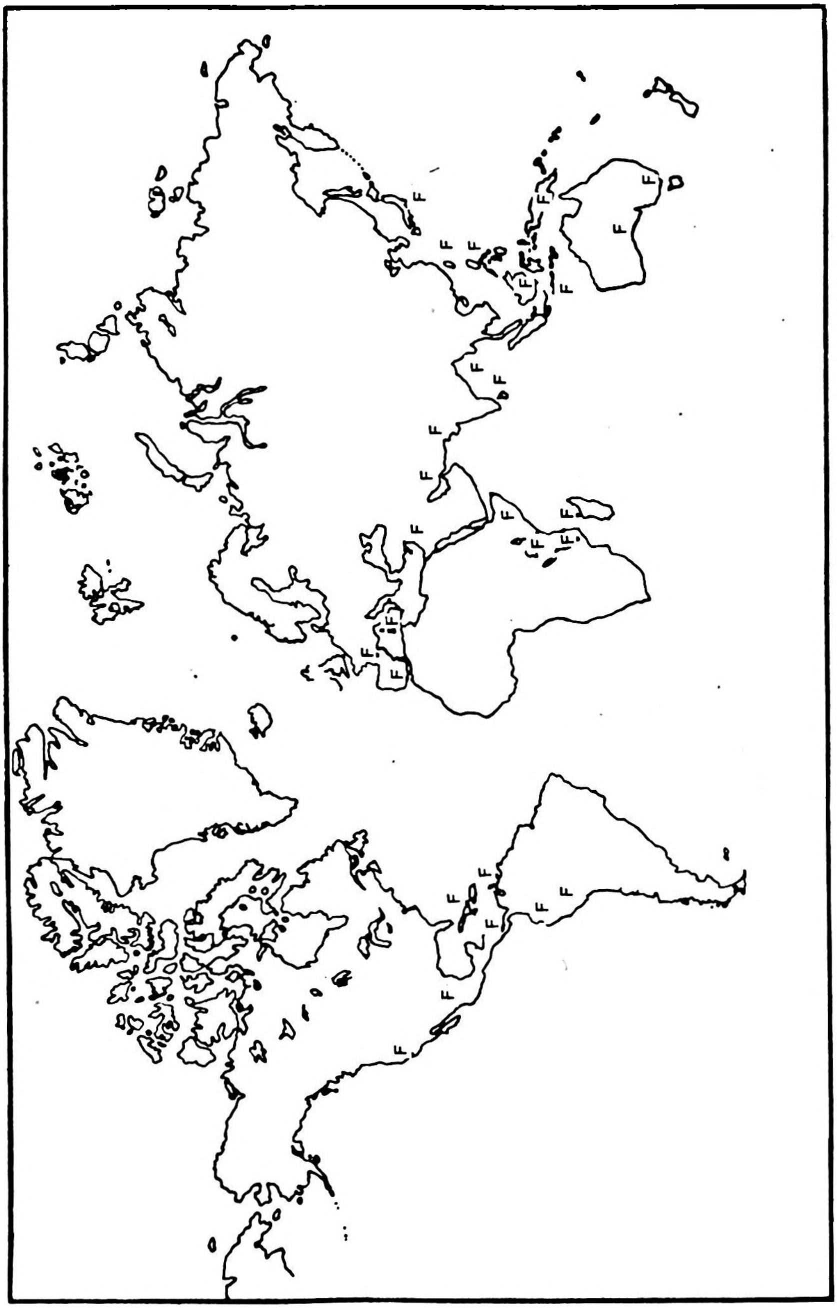
In Africa the Upper Tertiary in marine facies is developed along the Atlantic coast of Africa in Azores, Canaris Islands, Angola etc., whereas East Africa shows the development of continental formations. Upper Tertiary volcanism is seen developed in Madagascar and in the East African Rift valley region.

In South America the Upper Tertiary marine formations are seen developed in the Peruvian Pacific coast. Mixed development of continental and marine formations occurs in Patagonia and Chile while continental facies is seen developed in west Parana.

In North America the Upper Tertiary in richly fossiliferous marine facies is developed from New Jersey to Florida and in the Gulf coast region in places rich in phosphatic beds. In the whole of the mid-continental depression facing the Rockies, the Upper Tertiaries, like the Lower Tertiaries, are in continental facies with rich vertebrate fauna closely related to that of Western Europe.

THE TERTIARY CRUSTAL MOVEMENTS

The Tertiary is the period of greatest orogenic activity the world has ever witnessed. It has led to the development of the longest belts of folded mountain ranges extending from Pole to Pole and from one end of the equatorial belt to the other, encompassing the whole land hemisphere (Fig. 30). In elevation also some of the ranges have attained exceptional heights of over 7600 m above the sea level, far exceeding those ever attained



F. FORAMINIFERS (UP. TERT.)

Fig. 29. Up. Tertiary World

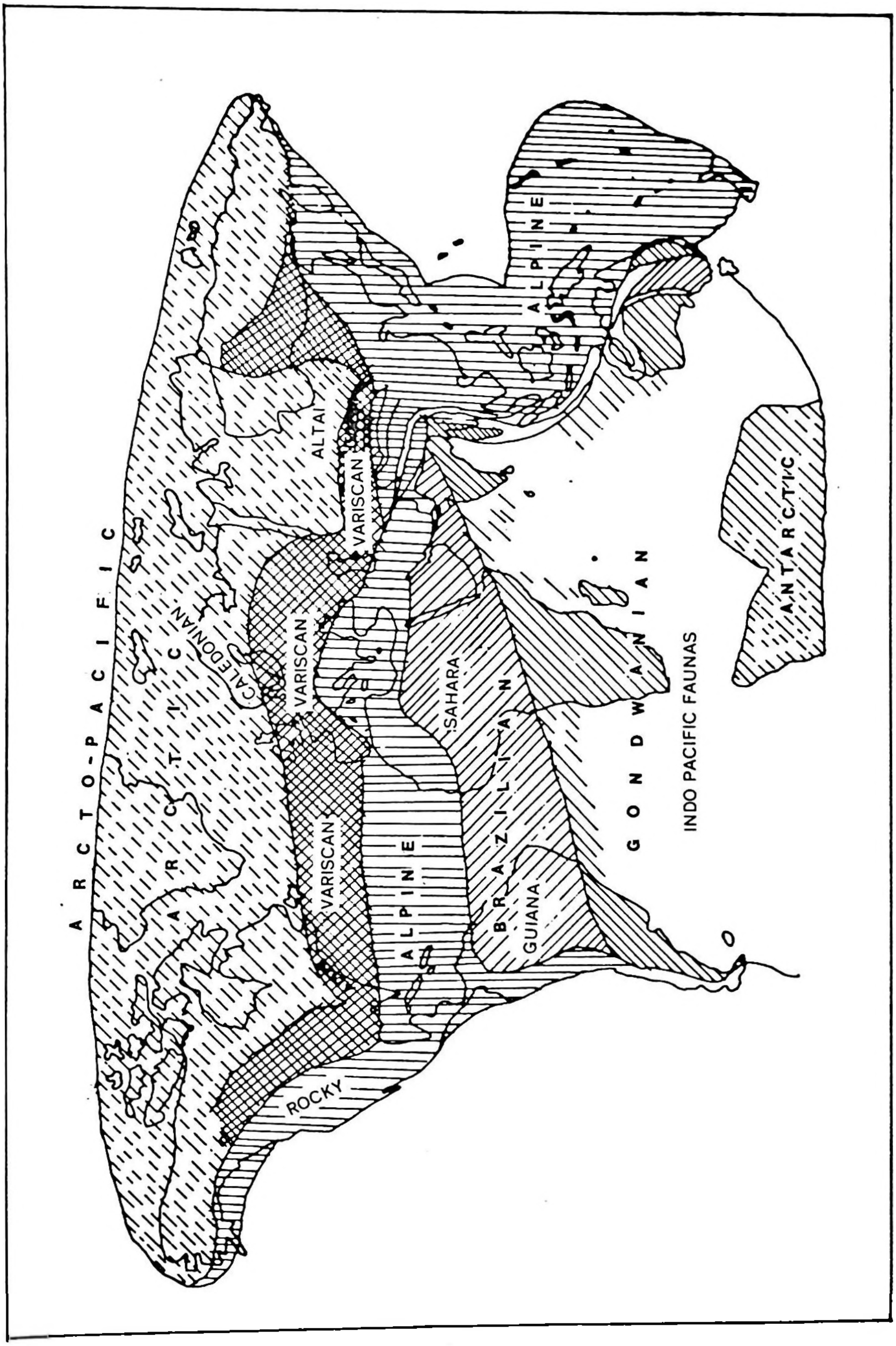


Fig.30. Faunal Trends Stratigraphical Data

by earlier orogenies. These Tertiary mountain ranges are developed in two distinct systems of belts: (1) the longitudinal CircumPacific system and (2) the latitudinal Alpine-Himalayan system. The former runs almost from the North Pole to the South Pole along two independent longitudinal arcs while the latter runs from western end of the equatorial belt of the land hemisphere in Mexico to the eastern end of the same belt in Indonesia. At both of its ends, this equatorial belt meets and almost merges into the CircumPacific belts. The genetic relations subsisting between these two Tertiary orogenic systems, however, are not adequately understood. The CircumPacific belt running along the eastern Pacific borders starts from the Aleutian Arc near Kamchatka Peninsula, runs along the Alaskan Rockies to Mexico. From here, with sharp bends and loops in the Central American sector, it merges with the Venezuelan-Colombian Andes of South America and continues along the Peruvian-Chilean Andes into Patagonian Terra del Fuigo ranges. The submarine arcuate ridge of Scotia-S. Sandwich links the Patagonian Andes with the Grahamland Tertiary ranges of Western Antarctica. This, in turn, after a sharp loop merges with the Trans-Antarctic Range of East Antarctica traversing right across the South Pole.

From the terminal of this range in the Victorialand (East Antarctica) starts a submarine ridge of Balleny-Macquarie island arc which links the Trans-Antarctic Range with the New Zealand Tertiary range along the southwestern border of the Pacific Ocean. From New Zealand northward runs the CircumPacific arcuate belt through New Caledonia, New Guinea, Philippines, Formosa, Ryukyu, Japan and Kurile Arcs into the Kamchatka Range continued further northward into Chukotskie Peninsula near the Bering Strait. The nature of the relationship between the Kurile-Kamchatka Circum-Pacific Arc and the Aleutian Pacific Arc is, however, not clearly understood.

Thus, the two CircumPacific orogenic belts, one near the East Asiatic border and the other near the West American border, traverse the whole globe almost from Pole to Pole along two independent longitudinal arcs encompassing the whole continental hemisphere. It is to be noted that large parts of this CircumPacific orogeny, particularly along the Pacific borders of the Americas were folded during the Upper Cretaceous period, whereas the major part of the latitudinal Alpine belt was folded during the Tertiary Era.

The Tertiary Alpine belt starts at its western end in the region of Central American Antillean Arcs trending roughly E-W. It appears interrupted in the region of the Central Atlantic Ocean but reappears near Gibraltar in the nature of Andalusian Betic and Balliaric arcs and Rif-Atlas Mountain Arcs near the northern and southern borders of the Mediterranean Sea. Further east the orogenic belt continues in the form of arcs and loops of Western and Eastern Alps, Carpathian, Apennine and Dinarid ranges. Further east the Turkish peninsular Tarus and Pontian ranges get condensed into the Armenian knot. From this knot, they fan out again east-ward through the Elburze-Hindukush-Zagros-Baluchistan ranges, again to get condensed into the mightiest Pamir knot. From here start the highest mountain ranges, the Himalayas and the Karakoram (rising to more than 8500 m.) and the Kunlun traversing the vast Tibetan plateau roughly eastward and southeastward upto the eastern borders of the Tibetan Plateau. Here they suffer southward bending and condensation in the basins of the Brahmaputra, Salween, Mekong and Yangtsekiang. In the region of Yunnan, Indo-China and South China they again suffer splaying in a southeastern and eastern direction apparently exhibiting abrupt termination against the South China Sea. They, however, continue further south and southeast through submarine ridges into the Tertiary mountain ranges of Indonesia, Philippines and New Guinea to be merged into the CircumPacific belt of East Asiatic mountain ranges.

The whole of this latitudinal Alpine Orogeny has been attributed to the approach of the two Mesozoic Super Continents, Laurasia from the north and Gondwanaland from the south bringing about squeezing, folding and overthrusting of the sediments of the intervening Tethyan geosyncline. In this the accompanying volcanic activity in the geosynclinal region is supposed to be only consequential and subsidiary. The Circumpacific orogeny, on the other hand, cannot be explained on this basis. Moreover, this circumpacific geosyncline exhibits enormous volcanism which appears to have played a dominant role in the Orogeny of the region.

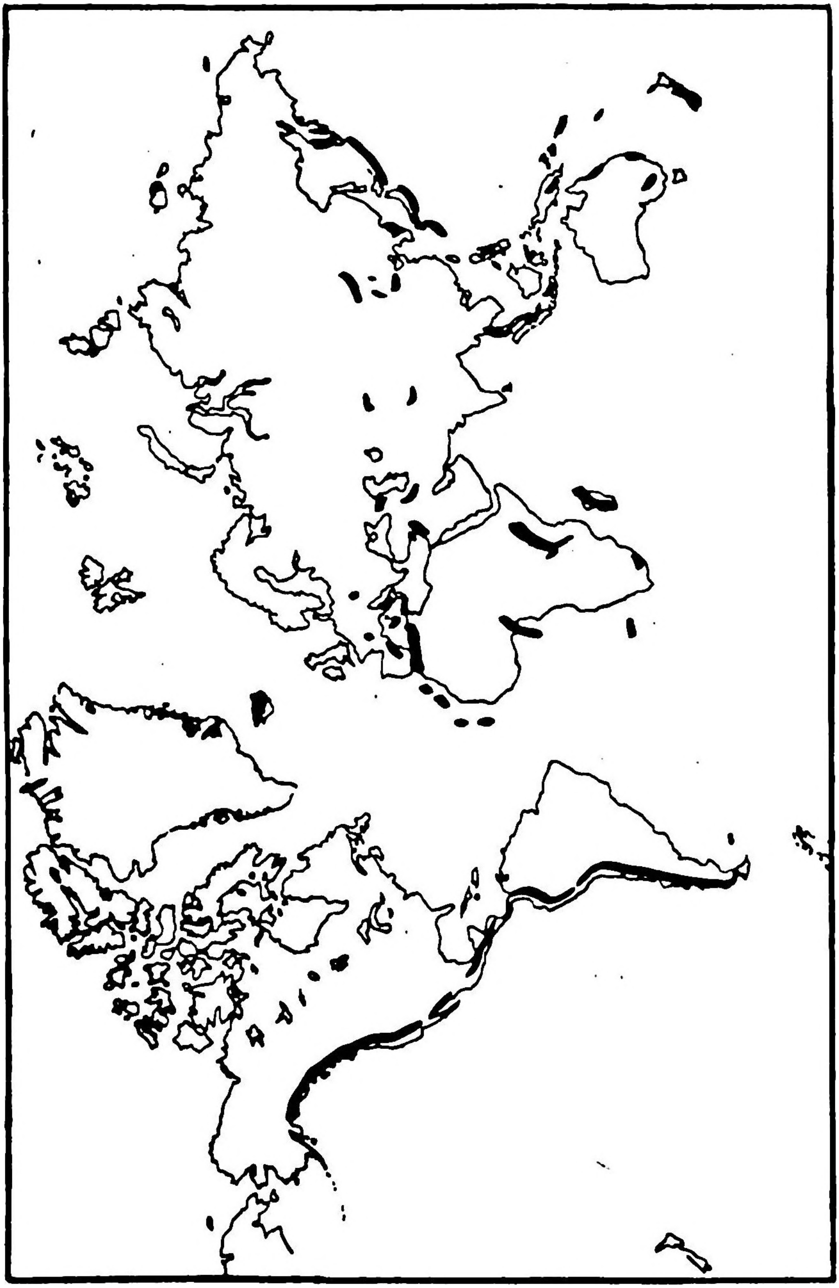
Magmatic Activity During the Tertiary and Quaternary Eras

There is evidence of considerable magmatic activity in the Tethyan region during pre-orogeny, synorogeny as also post-orogenic phases, during the major part of the Tertiary and Quaternary periods (Fig.31). This magmatic activity has contributed substantially to the volume of geosynclinal Tethyan sediments and particularly, in the development of enormous flysch sediments which have played a significant role in the evolution of folded and overthrust structures. Besides this magmatic activity all along the Tethyan geosynclinal belt, we also meet with extensive flooding of Plateau Basalts in continental and oceanic regions in intrusive as well as extrusive phases on either side of the tropical Tethyan belt. Among the important Plateau Basalt eruptions of this period, we have the Deccan Plateau Basalts right at the onset of the Tertiary Era which flooded large parts of the Peninsular India extending farther into the Extra-Peninsular regions of Cutch and Baluchistan on the west and Assam and Burma on the east. The same plateau basalt activity apprarently extended westward into East Africa through Persia, Arabia, Abyssinia and Somaliland. Similar plateau basalts have flooded large parts of Mongolia, Siberia, and as Thouleitic Plateau Basalts in central and northwestern parts of Europe continued westward through the British Isles and Iceland into Greenland. The Columbian Plateau Basalts have flooded large parts of western North America. We also have enormous basalts sheets and flows of Tertiary age along the eastern borders of Australia in Queenland, New South Wales and Victoria. Large parts of Antarctica are covered by Tertiary eruptions and these apparently continue into the Plateau Basalts of Patagonia in South America.

These vast basaltic floods of the Tertiary period have not only led to the expansion of continental masses both vertically and laterally but, as shown later, have also played a significant role later in the emplacement of land masses.

THE QUATERNARY "GLACIATION"

During the latest stages of geomorphological evolution of continents in the Quaternary Period, glaciers are thought to have played a conspicuous role in the sculpturing of



Pleistocene Volcanic Activity

Fig. 31. Quaternary World

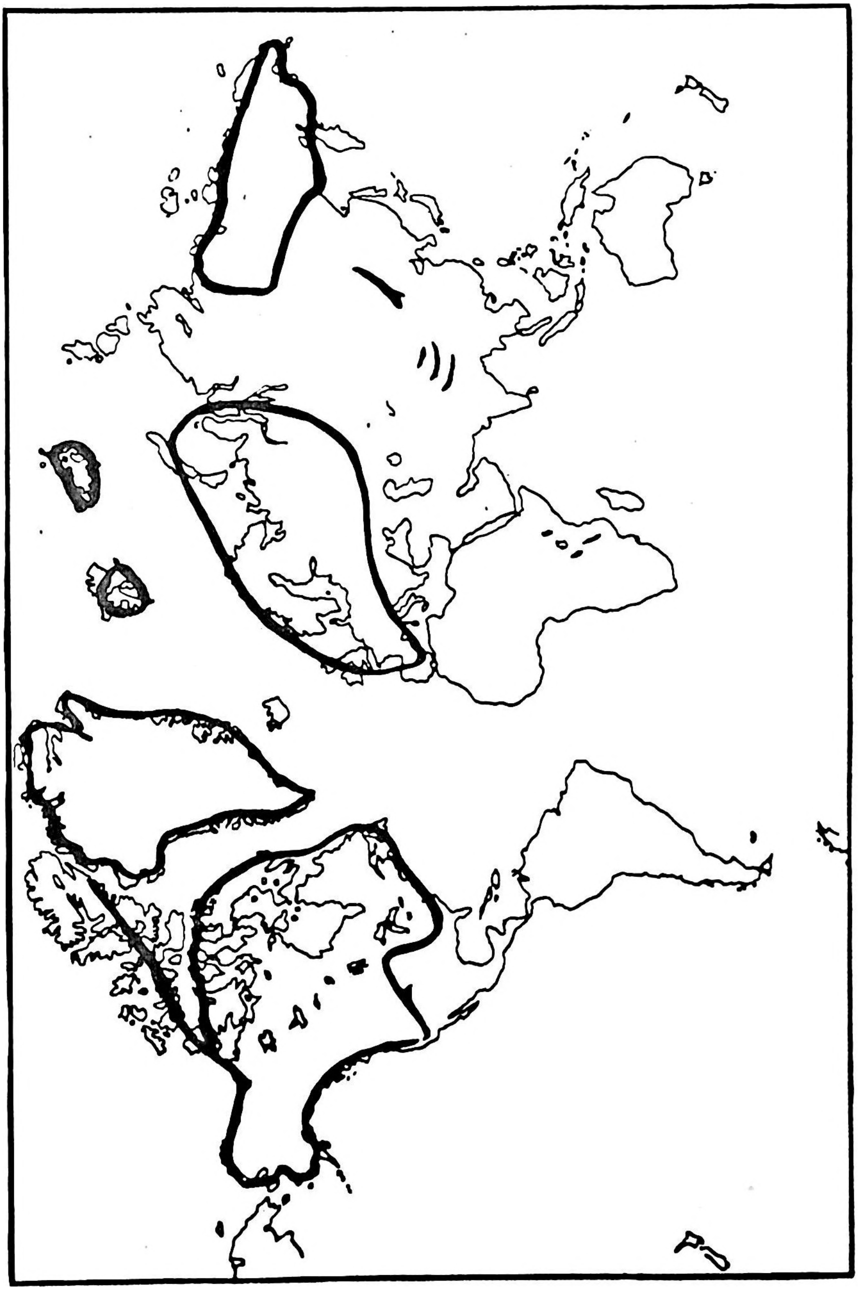


Fig. 32. Quaternary World

Pleistocene "Glaciation"

many exposed and even submerged land surfaces. Long irregular ridges of unconsolidated sediments consist of fine clays carrying, embedded within them, unassorted, fragmentary angular, erratic boulders often of enormous dimensions. This loose rocky waste occurs strewn irregularly over vast terrains, particularly in the circumpolar regions in North America, Greenland, northern Europe and Siberia. These deposits resemble remarkably the morainic material found along slopes of mountains which are or have been the abode of live glaciers till lately and it was only reasonable to attribute the deposits of these loose materials to the fluctuations of glacial activity in the region. This resemblance makes it possible that the loose unconsolidated bouldary material found covering thousands of square kilometres area in the north polar region may also have been the product of glaciation in the early Quaternary period. Due to the extraordinary extent of such deposits formed during the early Quaternary period, this geological epoch of Pleistocene has been taken as synonymous with the Glacial Epoch. Since vast continental regions even of low altitude are involved in this process only continental type of low level glaciers must have been responsible for this glacial erosion. Such continental glaciers extending to lower latitudes could have been induced only by the general refrigeration of global climates. The surfaces over which the glaciers are thought to have moved are seen to be smoothened, polished, scratched, striated and even deeply grooved for hundreds of square kilometres at a stretch. So also are the enclosed hard boulders facetted and scratched (Fig. 32).

In this connection, it has to be remembered that ice being very soft often induces smooth slippage without the least resistance and thereby prevents even scratching. It is, therefore, worth considering whether glaciers are, by themselves, capable of inducing facetting, scratching and grooving attributed to them. Hard boulders when set in a matrix of ice would, during lateral movements, be pressed against hard resistant rocks of the basement. The differential pressure developed on the ice surrounding the boulder would induce local melting of ice cover, thereby permitting the boulder to be pushed deeper in ice and on the release of pressure, the ice would again thaw to hold the boulder in a new position further inside the ice. Thus, the boulder would not be in a position to scratch the basement rock and would move over the basement surface smoothly without any resistance. In the face of such smooth movements, it is difficult to imagine how such vast polished, scratched and grooved surfaces could be brought about by the glaciers.

The glacial erosion is more in the nature of volume increase when water entering crevices of rocks gets frozen into ice. This increase in volume serves to widen the cracks and to loosen the rock fabric, thus leading to the crumbling of the surrounding wall rocks. This can never lead to polishing and grooving. Again the erosive activity of ice is proportional to the cube of the velocity of the moving ice. Since ice movements are very slow and particularly in continental glaciers with hardly any gradient, it is inconceivable that vast terrains often constituted of hard granitic rocks could be bevelled and grooved by almost stationary glaciers as those in Greenland or Antarctica. It is obvious we must seek some other agency which would be responsible for sculpturing of such continental surfaces as those in the Scandinavian and Canadian Shields. This has been attempted in a later chapter.

CHAPTER VI
The Problem of Gondwanaland

INTRODUCTION

Diverse Concepts of Continental Drift

From the foregoing treatment, it would be observed that many of the Geomorphological features, including coastal lines, river courses, mountain ranges and their wide-ranging linkages, the intimate relations in floral and faunal assemblages in widely-separated basins, all indicate absence of barriers and the possibilities of effective interlinkages including closer packing of continental masses. The orthodox view of former land connection between continents in the region now submerged under seas and oceans, like the hypothetical Atlantis, Lemuria or of land bridges to serve as linkages among continents facilitating intermigration of faunal and floral elements has not been found feasible or tenable in the face of available evidence. It was, therefore, suggested that the continents themselves were more closely packed—juxtaposed, in earlier geological periods and that they suffered fragmentation and lateral migration of constituent land masses during the later geological periods.

The compressional theory of mountain formation led F.B.Taylor to propose in 1910 some type of continental movement from Poles towards the Equator (Pole Fluct) to account for the Tertiary Alpine Orogeny. The concept of drifting of continents, however, was more forcefully presented by A.Wegener independently in 1912 (Fig 33) Wegener was struck by the similarity of the eastern coastal outline of South America with the western coastline of Peninsular Africa which fit in quite remarkably when juxtaposed. Being a meteorologist, he was also impressed by the distribution of Upper Carboniferous glacial deposits in the southern continents. These deposits being those of continental glaciers could be developed in such vast areas only in polar regions and as such, he suggested the former close grouping of all the southern continents round the South Pole which he postulated to be situated in South Africa during the Upper Carboniferous Period.

He starts with the idea of a Pangaea with all southern continents in their present size and outline, grouping round Africa during the Palaeozoic Era. For some reason, this unitary continent broke down into fragments corresponding to present continents and they started moving over a mobile substratum largely in a westernly direction during the Mesozoic and later periods. These movements resulted in the evolution of CircumPacific Andean-Rockyan system of mountain ranges as frontal folds along the west coast of the Americas. This, however, fails to explain satisfactorily the formation of the Alpine-Himalayan system of tropical ranges. Wegener was also unable to suggest the nature of forces suffi-

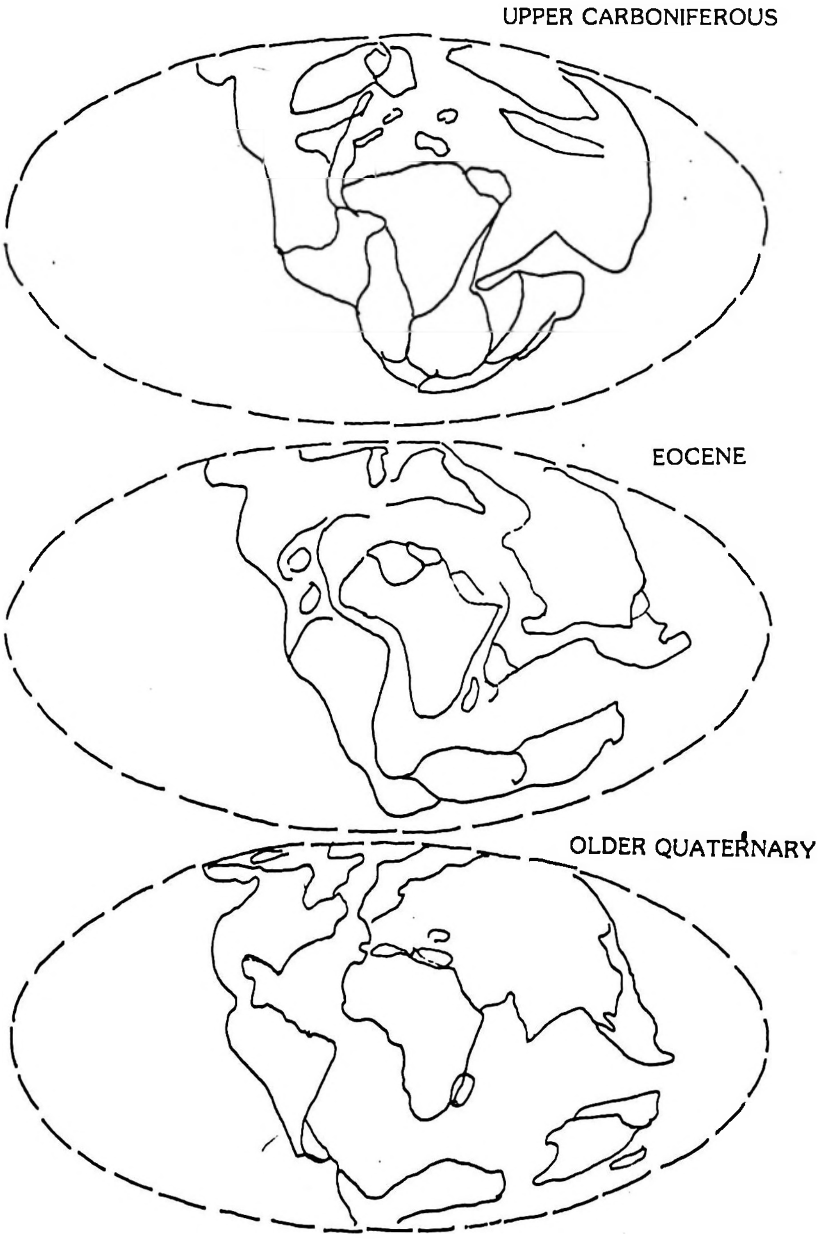


Fig. 33. Wegener's Concept of Drifting Continents.

ciently strong to bring about drift of vast continental masses through the subcrustal Sima beyond surmising that Tidal Friction during the earth's rotation due to attraction of the moon may have brought about an apparent westerly drift of the continents. Wegener postulated the earlier juxtaposition of continental masses of South America and Africa along the present coastline of the continents. In this close fit he did not take into consideration the existence of the wide shelf-belts projecting into the intervening ocean. For these reasons and particularly for his failure to suggest the propelling forces adequate for drift of vast continents that his Drift Theory was opposed by several geologists and by most geophysicists.

The Expanding Earth

The Geophysicists on their part were trying to explain Wegener's evidences favouring drift, purely on orthodox lines without introducing drift. The concept of Expanding Earth is one such attempt. It is partly based on P.A.M. Dirac's observation in 1937 that the earth's sphere was expanding due to lowering of the value of Constant of Gravity G through geological ages and partly also to the fact that the subcrustal mantle is subject to expansion due to paramorphic changes into lighter rocks. It envisaged a Palaeozoic Pangaea not different from that of Wegener's concept but on a smaller globe when contiguous margins of continents in their present size had comparable geological structure. These continents got separated since then due to the expansion of the earth's subcrustal mantle. The continents, on the other hand, maintained their original size and continued to rest on their original basement. Due to expansion of the Mantle almost doubling the Earth's diameter since the Palaeozoic, the size of the intervening seas got magnified, accentuating the apparent distances between the neighbouring continents without changing their angular distance. This concept may explain the evolution of the Atlantic Ocean as one such expanding longitudinal Rift but cannot explain the evolution of the Indian Ocean. Nor can this explain the evolution of the Tertiary Alpine Orogeny along the tropical belt across the supposed longitudinal rift. There is again the problem of the total volume of oceanic waters. How was this accommodated in the Palaeozoic oceans when the earth's diameter was only half of the present size? The geological history of the individual continents since the Mesozoic can also not be explained on the basis of global expansion.

Palaeomagnetism

The vehement opposition of the geophysicists to the Wegenerian concept of Continental Drift suddenly suffered, softening even into supporting the drift when data concerning Palaeomagnetism of the rocks became available from different parts of the world. Sediments and lava flows are influenced by the geomagnetic field of the region when minute ferruginous particles of rock forming minerals get magnetised and oriented in the field of regional magnetism during that particular geological period. This fossil magnetism of the rocks helps us to work out the palaeogeographical position of magnetic Poles for that period. On the assumption that the earth's mean magnetic field had always been that of the Axial Dipole, the position of the geographical Poles can also be ascertained for different geological periods. The positions of the Poles calculated from the directions of magnetisation of rocks of the same age from different continental masses do not agree among themselves. This suggests that the continents must have moved relative to each other. This could also suggest the possibility of shifting of geographical poles and the corresponding shifting of latitudinal climatic belts. These possibilities have given rise to diverse types of Palaeogeographical maps of the world for the same periods of the geological history.

The main assumption about the Axial Dipole nature of the earth's magnetic field though fairly valid today may not, however, be valid for all the past geological history. We are not quite certain about the actual cause of magnetism of the earth. The earth is hot in the interior, the temperature increasing with depth and at not great depths reaches geothermic temperatures above 580°C which is the Curie Point for magnetite. Above this temperature the thermal energies are able to randomise orientation and consequent demagnetisation of ferromagnetic substances and only below this temperature can paramagnetic substances acquire magnetism. With increasing pressures as in depth the Curie Point drops, precluding the magnetism of particles even below the Curie temperature 580°C. Only electromagnetism can persist. The Earth's liquid core is thought to behave like a dynamo giving rise to an electromagnetic field on the surface but being at the core region, this electromagnetic field should be regular and systematic over the earth's surface and should develop a uniform background effect over large parts of the earth's surface and not pinpoint the N & S magnetic Poles near the geographical Poles. The widespread deviations and distortion of the magnetic field over the continental surfaces and their comparative regular field over the Pacific region suggest the presence of magnetic sources intimately connected with the continental crust and the Upper Mantle.

It is thus possible that large magnetic bodies lying in the Upper Mantle above the level of 580°C Geoisotherm and at lower atmospheric pressures can be highly magnetic. The iron ore bodies of vast dimensions such as those of Sudbury, Canada and of Keruna, Sweden, developed subcrustally during the different stages of evolution of continental masses, can have a vast magnetic field enough to bring about distortion of the initial background geomagnetic field generated by the primary electromagnetic source thought to be situated at the earth's core.

If this is plausible, we can explain the diverse orientations of the geomagnetic field, including the position of Magnetic Pole as indicated by Palaeomagnetic evidence in different continents without affecting the position of the geographical Poles or of the climate belts of the earth.

Plate Tectonics

The geophysicists being impressed by the testimony of remanent magnetism of rock formations have accepted the concept of Continental Drift without yet identifying the crustal forces which could engineer lateral drifting of vast continental masses over their simatic substratum. They accepted the possibility of Convection Currents as the agency which may be responsible for the drifting of continental masses. These convection currents are attributed to the temperature differences between the deeper and upper zones of the Mantle. The transfer of heat from the deeper Mantle is obvious but whether it would be through conduction in a solid medium or through convection in a liquid medium would depend on the physical state of the Mantle. All seismological evidence points to the Mantle being in a solid state with high rigidity and enough strength. There is, however, an indication of a low velocity zone in the region of Upper Mantle which may suggest a slightly lower rigidity for this layer of the Upper Mantle which has been identified as Asthenosphere. For all practical purposes, it is solid with low rigidity; whether this zone would permit heat transfer through convection or conduction is still a moot question. Rheoid properties of solids under long continued pressures are supposed to permit convection currents through the Asthenosphere and these currents are held responsible for the lateral migration of the continental masses floating over this weak zone. In their later version of Plate Tectonics, the geophysicists divide the whole surface of the earth, continental as well as oceanic, into about six closely-juxtaposed primary Lithospheric Plates, each about 100 km. thick floating over the weak zone of Asthenosphere (Fig 34). The Plates are American, Eurasian, African, Indo-Australian, Antarctic and Pacific. These lithospheric plates are constituted of the Upper Mantle overlain by Crustal Sima with or without Sial. The Moho Discontinuity separating crustal sima from the Mantle plays no role in Plate Tectonics. Convection currents originating in the deeper Mantle ascend into the Asthenosphere and appear to converge at some points and diverge at others. Tension is developed in the regions of divergence and compression in the regions of convergence. Tension causes the convecting fluids to force their way up as volcanic lavas through rifts and fissures in Mid-Oceanic Ridges while compression forces these fluids down through oceanic deeps and trenches. The Continental Sial is thought to be created at the Mid-Oceanic Ridges forcing the flanking continents on either side to drift farther apart whereas the Lithospheric Plate is forced down along the CircumPacific Trenches through subduction, thus to be digested thereby keeping the total volume of Crustal Sial constant through ages.

The Mid-Atlantic Ridge assumes a peculiar significance in the whole scheme of Plate Tectonics. This is the region where the continental masses of South America and Africa were originally united as parts of the primary Pangaean continent upto the Palaeozoic period. Due to volcanic eruptions through the Rift along the middle of this Ridge, the ocean floor was flooded with the lavas which spread widely over the ocean floor on either side. This pushed the two continental masses flanking the Ridge, forcing them to drift apart in opposite directions. Other oceanic ridges have played a similar role in the Continental Drift.

Thus, the ocean floor spreading at the Mid-Oceanic Ridges and the subduction of Lithospheric plates at the oceanic trenches are thought to have effected the evolution of the most of the crust through orogeny and continental drift.

The Theory of Plate Tectonics which has attracted quite a large number of geophysicists, lately, is based on several postulates, the validity of which needs to be tested:

1. Whether the heat transfer from the lower Mantle to the upper Mantle is effected through conduction in the solid Mantle or through convection involving material transfer in liquid state. Seismically, the Mantle behaves as a solid of fairly high rigidity.

2. If somehow convection currents are set up in the Mantle Asthenospheric region, will these currents be strong enough to pull or push continents of enormous lateral and vertical dimensions? Again, is the low rigidity of the Asthenosphere a permanent or temporary feature?

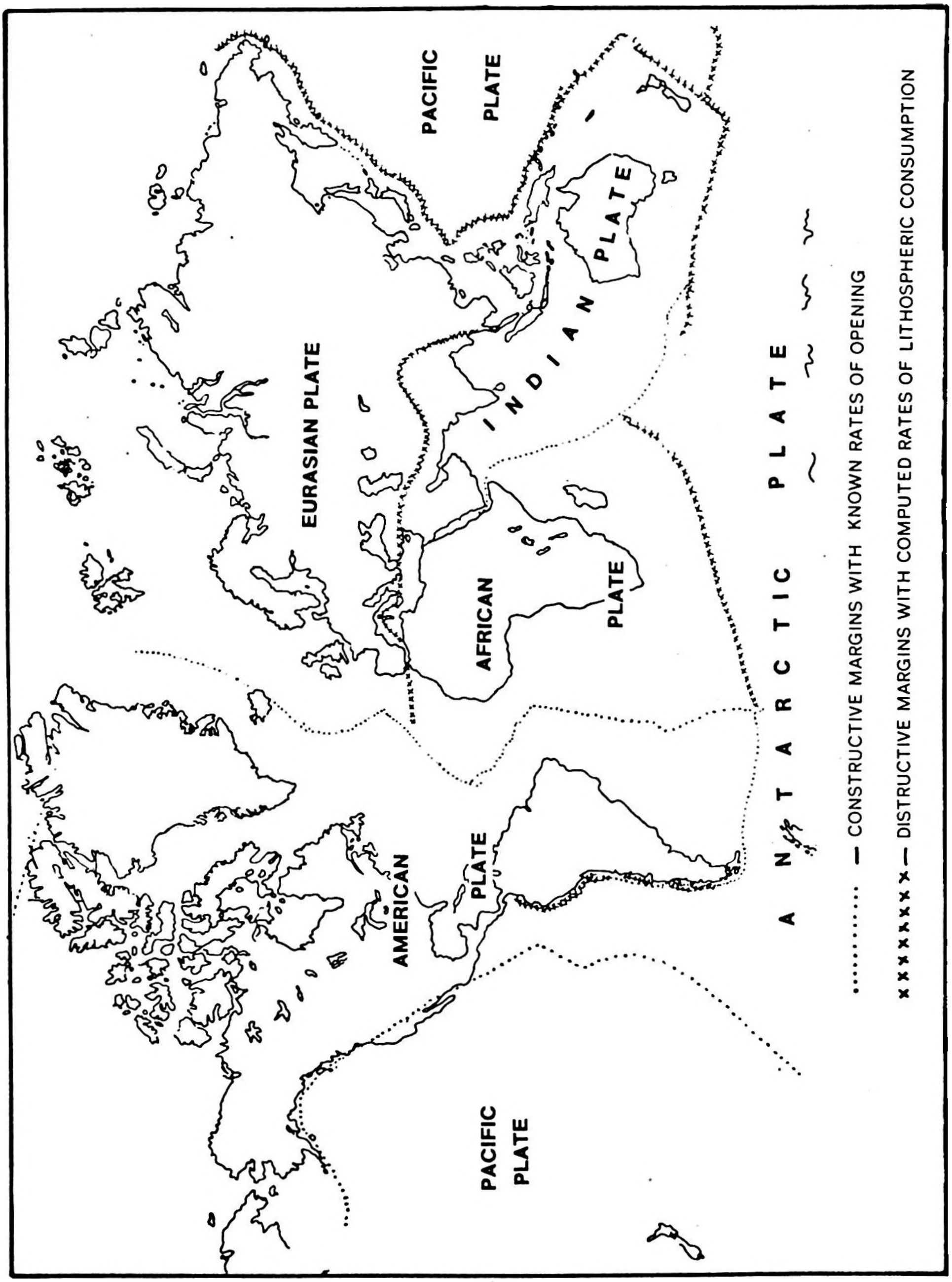


Fig. 34. Lithospheric Plates of the World

3. Do the convection currents in the Mantle not bring about homogenisation of the Asthenosphere layer with the surrounding Mantle of higher rigidity, both above and below?

4. The Lithospheric Plates constituted of upper Mantle, crustal sima and sial each several million sq. kms. in area are thought to be 100 km. thick, rooted in the deep Asthenosphere. The whole earth's surface is constituted of plates, all closely juxtaposed. Due to this close jacketing up to a depth of 100 km, where is the space for relative lateral movements among the plates themselves?

5. It is not clear whether, during the drift, it is the continental sialic portion that moves laterally over the stationary simatic substructure in the lithosphere or whether the whole lithospheric plate, 100 km. thick, that moves en masse over the Asthenosphere. Any movement of lithosphere plates would open rifts 100 km. deep. Is there any evidence of such deep rifts?

6. The concept of Continental Drift through the ocean floor spreading envisages large-scale pushing of thick continental plates laterally by surface eruptives issuing through rifts along the Oceanic Ridges. This appears untenable as eruptives would rather pile up vertically one over the other in the open space than exert lateral pressures at a depth to push over any significant distance the deep-rooted continental plates apart on either side of the Ridge.

7. The profile across the oceanic ridges as depicted by Holmes (p. 934) shows a series of steep narrow ridges alternating with deep rifts. If any one of these rifts served as the channel of volcanic eruptions, all these narrow ridges and rifts on either side would have been buried under the lava flow leaving no trace of rifts. Again these eruptives during the ocean floor spreading would have first filled up the oceanic basins and other depressions before they could reach and push apart the distant continental masses on either side of the Mid-Oceanic Ridges. The existence of deep depressions in the Atlantic Ocean like those of Brazilian and Angolan basins and of the oceanic deeps and trenches on either side of the Mid-Atlantic Ridge counters this concept.

8. The subduction of one lithospheric plate, 100 km. thick, below another equally thick plate would involve uplifting of the latter plate over the surface of the former to the extent of 100 km., causing enormous displacement of a heavier Mantle mass against gravity and solid resistance. Nowhere is there any evidence of this.

9. The concept of Plate Tectonics envisages the formation of the orogenic belts in the region of Oceanic Trenches which are supposed to be zones of subduction. These trenches are far from continental borders, and where geosynclinal sedimentation characteristic of orogenic belts hardly takes place. Moreover, trenches are considered as sites of digestion of sial rather than of generation of sialic geosynclinal deposits commonly found piled up in orogenic belts.

10. Plate Tectonics has hardly any solution for the numerous problems of Geomorphology, Geology, Geostructures, Faunal assemblages etc., which are vitally concerned with the evolution of continents individually and collectively apart from their emplacement.

CHAPTER VII

The Theory of Sheet Movement and Continental Expansion

We see that the latest attempt of Plate Tectonists as presented by its protagonists is based on many assumptions which hardly stand scrutiny. Many variants of geodynamic concepts have been proposed from time to time which appear wanting in satisfactory explanation of the structural phenomena met with in the geological build of the earth's crust.

Certain fragmentary evidences have been elucidated losing sight of the phenomena as a whole. The similarity of the Atlantic coasts of South America and peninsular Africa had provoked Wegener to assume the erstwhile contiguity of the two continental masses. But the Morocco-Liberian Coast of N.W. Africa and the peninsular part of South America, south of LaPlatta have no place in this Wegenerian scheme. Where are the westward continuations of the Atlas Ranges of North Africa on the South American side? Which are the African counterparts of Venezuelan Andes? We know that the Venezuelan Andes are intimately related faunistically and structurally with the Atlas Ranges of North Africa. But the juxtaposition of the two continents in Wegenerian sense leaves a vast gap in between the Andes and the Atlas with no trace of these in the intervening region. Even the geological fits on the two sides of the Atlantic are not very convincing. Beyond the presence of Gondwana formations on the two sides, structurally the Parana trends are highly oblique to those of the Karroo. The Cape Folds of the South Africa have no match on the Parana side. The organic continuity of the Karroo structure is not evident on the Parana side.

The positions of Europe and North America in Wegenerian reconstruction are much less satisfactory though demanded by faunal, floral and other geological evidences. In this scheme, the Atlantic board of North America is juxtaposed with the Mauritanian Coast of North Africa which is geologically quite dissimilar.

It is thus observed that most of the existing concepts of geodynamics which are able to explain parts have hardly any satisfactory solutions for the numerous problems posed by geomorphological, geostructural and other aspects of Geology.

The Theory of Sheet Movements

It is in this context that the concept of Sheet Movements and Continental Expansion was suggested by the present author in the early fifties of this century. For the first time, two papers were read at the XIX Session of the International Geological Congress held at Alger in 1952 (published in its proceeding as Abstract while the full papers were published as Memoirs 1 and 2 of the Rajputana University Geology Department in 1953). The same concept was further elaborated in papers at the later sessions of the International

Geological Congress held in Mexico (1956), Copenhagen (1960) and New Delhi (1964) and also at the various sessions of the Indian Science Congress, Special Seminars and Symposia.

Some Major Features of the New Theory

On the basis of his studies, published in separate papers, the author has brought out the significance of a number of morphological features and structural patterns, their geographical distribution as also of the morphostructural linkages in the intervening region. These studies have brought out many features which go to illustrate the modus operandi of this all-pervasive process of crustal evolution through Sheet Movements. They give us:

(A) the Indications of the operation of sheet movements in the geological past.
(B) the guides as to the course of sheet movements from their original site of sedimentation upto the site of their final emplacement.
(C) the Agency and the forces responsible for effecting lateral movements of continental sheets over enormous distances.
(D) the actual Mechanism of sheet movements.
(E) the Trends of sheet movements in different sectors of the earth crust.
(F) the Stages of movements of major sheet complexes.

We see that through these studies, we are in a position to work out purely on morphostructural evidences the complete process of evolution, including the mechanism, both in time and place, of almost every crustal feature singly or jointly.

A. Indications of Sheet Movements

As for indications for the possible operation of the process of lateral movements of sheets in the past, we have a number of geomorphological features such as coastal outline, river courses, Rift Valleys, Continental shelves, Island Arcs etc. Besides these morphological features, we also have peculiar stratigraphical features like unconformities, the Exotic Blocks, Boulder Beds, often associated with fine clayey flysch type materials, peculiar sediments such as rocksalt and gypsum beds found frequently associated with Diapyr structures and grooved slicken side surfaces commonly met with in orogenic belts as parts of Nappe structures or in supposed glaciated terrains, karot topography etc.

1. **Coastal Lines:** Some of the continental coastlines exhibit similarity in their shape as also in size even when they are separated by long distances. Thus, the outline maps on a suitable scale and projection of E. Antarctica and Australia and even of Indonesia-Philippine regions exhibit considerable correspondence in their general shape and size except for some minor differences. The east coast of South China has a great resemblance to that of North China along Manchuria-Sikhota Alin coast. The west coast of Australia has a general resemblance, though in a complementary way, to the east coast of peninsular India and also to the Somalian coast of East Africa, both in size and form. The Atlantic coast of northern Africa has also remarkable resemblance to the Pacific coast of Peruvian and Colombian coast in South America. The Andean and precordilleran belts of Chile have a general shape and size of the west coast of Peninsular Africa.

Many more instances could be added wherein simple geomorphological features exhibit intimate resemblance both in size and shape among themselves even when they are separated by wide oceans or continents.

Either these resemblances are fortuitous and have no intrinsic significance or that they are real and have a genetic significance. Our present concepts cannot explain them and as such many consider them as of no significance. But they become intelligible and quite significant the moment we apply the concept of Sheet Movements. Thus, the relation between Australia and Antarctica, both parts of the Gondwanaland, appear under the Sheet Theory (as has been shown elsewhere) as one of superposition wherein East Antarctic cratonic mass (bordered by elevated ranges on three sides and depressed in the middle) served as the basement over which the Australian plate rested as an upper sheet during most of its evolution up to the Tertiary period. As superposed sheet complex they rested over the Tibeto-Himalayan region and later moved to the Bay of Bengal-Indochina region. It is from this position that the two sheets got separated, the upper or Australian sheet moving east and south through Philippines and Indonesia positions while the lower sheet of Antarctica migrated from the Bay of Bengal, due south along the Mid-Indian Ocean Ridge. This explains the resemblance of outlines of these continental masses. S. China, similarly, behaved as a basement for the northern China when R. Hwang Ho was more or less coincident with the R. Yangtsekiang and the Japan Island Arc was occupying the S. China coast from where they were detached and moved north and NNE, due to Hwang Ho movements.

Similarly, South America as a sheet was superposed over Africa with its east coast coinciding with the Nile Rift zone of E. Africa and the northern Andes were in continuation of the Atlas ranges. The Peruvian coast was, at that time, superposed over the Mauritanian coast of Africa and Chilean Andes were juxtaposed and partly superposed over the Angola Namibia coast of Peninsular Africa. The Terra del Fuego ranges became a continuation of the Cape folds. This explains the similarity in the various coastlines of the two continents. Similarity of coastlines is thus indicative of sheet movements.

2. **River Courses:** River courses with syntaxial bends in their courses are indicative of sheet movements in a radial way. The syntaxial bends in each of the Punjab tributaries of the Indus mark the separation of the Salt Range and Suleiman Kirthar Range successively away from their Himalayan basement.

The same phenomenon is met with in the Brahmaputra Syntaxial region where the Tertiary belts of Assam-Burma Ranges got separated from the Tibeto-Himalayan Ranges through the Brahmaputra-Irrawaddy movements.

3. **The Red Sea Rift** marks the separation of African mainland from the Arabian land mass which was earlier in superposed condition along with the region of the Nile basin of the African continental sheet. The Nile-Congo Rift system marks the zone of separation of South American structural sheet from its African basement.

4. **The submarine features like the Mid-oceanic Ridges** also have a similar significance as indicating stages in the migratory history of continental sheets. Thus, the Laccadiv-Maldiv, the Sacotra-Chagos, and the Seychelles-Mauritius ridges indicate the successive positions which the African continental mass (east coast) occupied at different stages of its westward migration from the Indian basement. The Mid-Atlantic Ridge represents a stage occupied by the S. American continent (west coast) while migrating from the African basement to its present position. Other submarine features are equally indicative of similar sheet movements.

5. **Marine Shelves** bordering continents are often considered merely as submerged parts of the continents but they may be only regions from which continental sheets have moved away towards the ocean. Thus, the Yellow Sea shelf and the East China Sea shelf represent the regions of migration of the Korean and Japanese arcs from their basement on the Chinese mainland. The South China Sea and Banda Sea shelves mark the region of migration of the Philippine and Borneo Island sheets from their Indochina-Thailand-Malayan position. The North Sea shelf of Europe similarly represents the region of migration of the British Isles sheet from the German Polish mainland of Central Europe.

6. **Island Arcs and Oceanic Trenches** as those in the Western Pacific region of Melanesia, Micronesia etc. probably represent different stages of migration of continental and Pacific Sima sheets as they moved from the Asian mainland towards the interior of the Pacific Ocean. Submarine Banks, Coral reefs and Guyots are only remnants of basement sheets left behind as the main sheets moved further away from the region.

7. **Unconformities:** Boulder Beds, Exotic Blocks associated with flysch materials, Agglomerates, Erratics etc. may also indicate sheet movements. Exotic Blocks have been described from several orogenic belts in different parts of the world and have been variously explained. Blocks often of enormous sizes of rock formations not traceable in situ in the neighbouring region are thought to have been carried by volcanic floods, by glaciers or by thrust movements. A classical example is that of the Exotic Blocks of Malla Johar on the Tibeto-Himalayan border in which large masses of fossiliferous limestones and other rocks, Permian to Cretaceous in age, are lying pell-mell in a mass of Palaeocene lavas (Plate 2). These fossiliferous blocks are lithologically and palaeontologically almost identical with the Hallstatt marble of the Alps. The same phenomenon in identical setting is to be met with the Peshin and Kalat districts of Baluchistan (Rec., G.S.I., Vol. 28, p. 8; Vol. 31, p. 165 and Rec. G.S.I, Vol. 38, p. 201). This may be an indication that the Hallstatt types of Alpine formations possibly had their original home in the Tibeto-Himalayan region from which the moving Alpine sheets left fragments as exotic blocks along the route of their migration.

These Exotic Blocks floating over eruptive rocks are also commonly associated with flysch formations which are impure mixtures of various pyroclastic and sedimentary materials and which have participated in the orogenic movements. The presence of these flysch masses may indicate the operation of sheet movements at some stage of orogeny. Similarly, Boulder Beds, Erratics, grooved and striated surfaces which are commonly assumed to represent glacial episodes during sedimentation, may be only products of tectonism during sheet movements.

8. **Diapyr:** Structures commonly found associated with rock salt deposits in petroliferous terrains may also represent remnants of sedimentary folds caught in sheet movements in which rock salt or gypsum may have served as lubricants along the plane of movement. These Diapyrs may then also serve as indicators for a regime of sheet movements.

B. Guides to Sheet Movement

A sheet packet is floating on a lava mass flowing laterally along a downward slope and in course of time, leaves its lower sheet on the way as it moves forward. The actual path along which the sheet packet has moved during the course of the flow needs to be ascertained to bring out the correlation of the sheets with their parent sheet packet.

River Courses as Guides: River courses of the region are a sure guide to the path of sheet movement. A river flows from its source to the mouth and its course records the movement of a sheet packet during a significant part of the journey. This has been illustrated by examples from the British Isles as given later in the sequel. The deviations in the river course are seen to be intimately connected with the movements of the sheet packet, and by a careful analysis, the whole path of migration of any sheet can be worked out in detail (elaborated in Chapter VIII).

Structural Patterns as Guides: The geological map of a large area often exhibits a number of independent basins of deposition related among themselves by geological formations, often with common lithology and faunal or floral elements. These basins often exhibit structural forms and outline with several common characteristics. These invest the basins with structural patterns which point to their inter-relations as parts of a common sheet packet. The geographical distribution of these patterns are important guides to the actual path as followed by the sheet packet during the course of its migration (elaborated in Chapter IX).

C. Agencies of Sheet Movements

A stratified column of rock-formations may be likened to a set of books piled one over the other. This pile is stable so long as the basement is horizontal and there is no side pressure. A slight tilt may be tolerated if the basement is rough, otherwise even a small tilt may topple the pile.

The presence of weak planes within the pile in the nature of pore water, volatiles, gases, unconsolidated clays, soft shales, loose sands, conglomerates, bands of rock salt, gypsum etc., would reduce the rigidity of the stratified pile and if unaccompanied by side support, the pile may topple at the slightest disturbance. The pile of formations would be split into a number of sheets separated through lateral movement along planes of weakness.

Gravity alone would cause displacement essentially in a vertically downward direction but when gravity works on an inclined plane, the lateral displacement effected in the process would be limited by the extent of the inclined place and by the friction along the plane of movement. When we consider the displacement of rock sheets, the area of operation of the process is very large and if the friction along the plane of movement is reduced through the availability of lubricants, lateral displacement brought about may be quite extensive.

Magmas as Agents of Sheet Movement

Volcanic eruption is one of the most spectacular and awe-inspiring phenomena. This brings out enormous quantity of rock materials in a molten condition from the deeper levels of the earth to the surface. This incandescent molten material comes out as a regular or intermittant flow from cone-like orifices along mountain tops and slopes and spread over the slopes on to the surrounding plains. In the earlier stages, vast volumes of steam and gases attended with enormous quantities of ashes and fragmental ejecta are thrown out with a great force depositing them over vast areas in the surrounding region. The whole region experiences earthquake shocks of varying intensity owing to the force of ejection.

In many cases these volcanic eruptions take place simultaneously through numerous cones situated along linear tracks obviously indicating that they are interconnected underground in the nature of deep fissures or cracks. Owing to these fissures, vast regions are covered by lava flows of the same period of volcanic activity. These are the fissure eruptions which manifest themselves remarkably in the CircumPacific belts. Here we find the largest number of active volcanoes linearly situated along mountain ranges and island arcs facing the Pacific Ocean (Fig. 35).

Volcanism has also manifested itself over enormous areas of continental dimensions in the nature of flat or gently-inclined lava sheets and flows, tens and even hundreds of metres thick. These are the Plateau Basalts or flood basalts which are also essentially fissure eruptions but whose linear channels of intrusion are obscured by subsequent flows. In deeply-eroded tracts, stumps of these fissures are exposed in the nature of thick wall-like dikes running for hundreds of kilometres. The Great Dike of South Rhodesia is the most spectacular example of such intrusive bodies connected with either the Bushveld Complex or the Karroo Plateau Basalts. Swarms of radial dikes in Scotland, north England and north Ireland are nice examples of the Thouleiitic Plateau Basalts in the North Atlantic region. The great Whin Sill system of basic intrusives is again a fine example of horizontal or concordant intrusive sheets which are spread over hundreds of square kms. in the region of the Pennine Range of North England (Fig.36 and 37). These thick intrusive sills must have induced considerable displacement of overlying sedimentary packets in the vertical direction. Their effects of horizontal displacement have, however, not been fully appreciated (Plate 3).

Volcanism is again extensive in the Mediterranean Alpine belts where submarine eruptives as ophiolites and spilites have, in many regions, been metamorphosed to green rocks—green shales, green schists, amphibolites, epidiorites etc. and which have been intensely involved in the folding, overthrusting and in Nappe formation. We thus find that the Plateau Basalts in the Cratonic continental regions are flanked, on the one side, by the eugeosynclinal CircumPacific Volcanism and on the other, by the eugeosynclinal Mediterranean Volcanism. The inter-relations between these three types of subcrustal magmatic activities have not been adequately appreciated and at present, all the three types are treated largely as independent activities.

The example of the Deccan Plateau Basalts may be instructive in understanding their relations. These Plateau Basalts are dominating the peninsular Indian shield south of the Indo-Gangetic Plain but evidences indicate that they also continued into the Tethyan zone of the Himalayas. Deccan Traps are extensively developed in close association with the Mesozoic-Tertiary geosynclinal formations in the Cutch and Sind-Baluchistan Ranges on the west and in Assam-Burma Ranges on the east. Similar geosynclinal formations in the Himalayas are extensively associated with the ophiolites in the Upper Indus Suture zone of the Mansarovar-Hanle-Karghil region. The related Plateau Basalt activity is again traceable in Afghanistan, Arabia, Sudan, Ethiopia, Somalia, Uganda, Rhodesia and further south in South Africa. Closely related Plateau Basalt eruptives are again found in Patagonia in South America. An earlier or deeper phase of this Plateau Basalt activity is

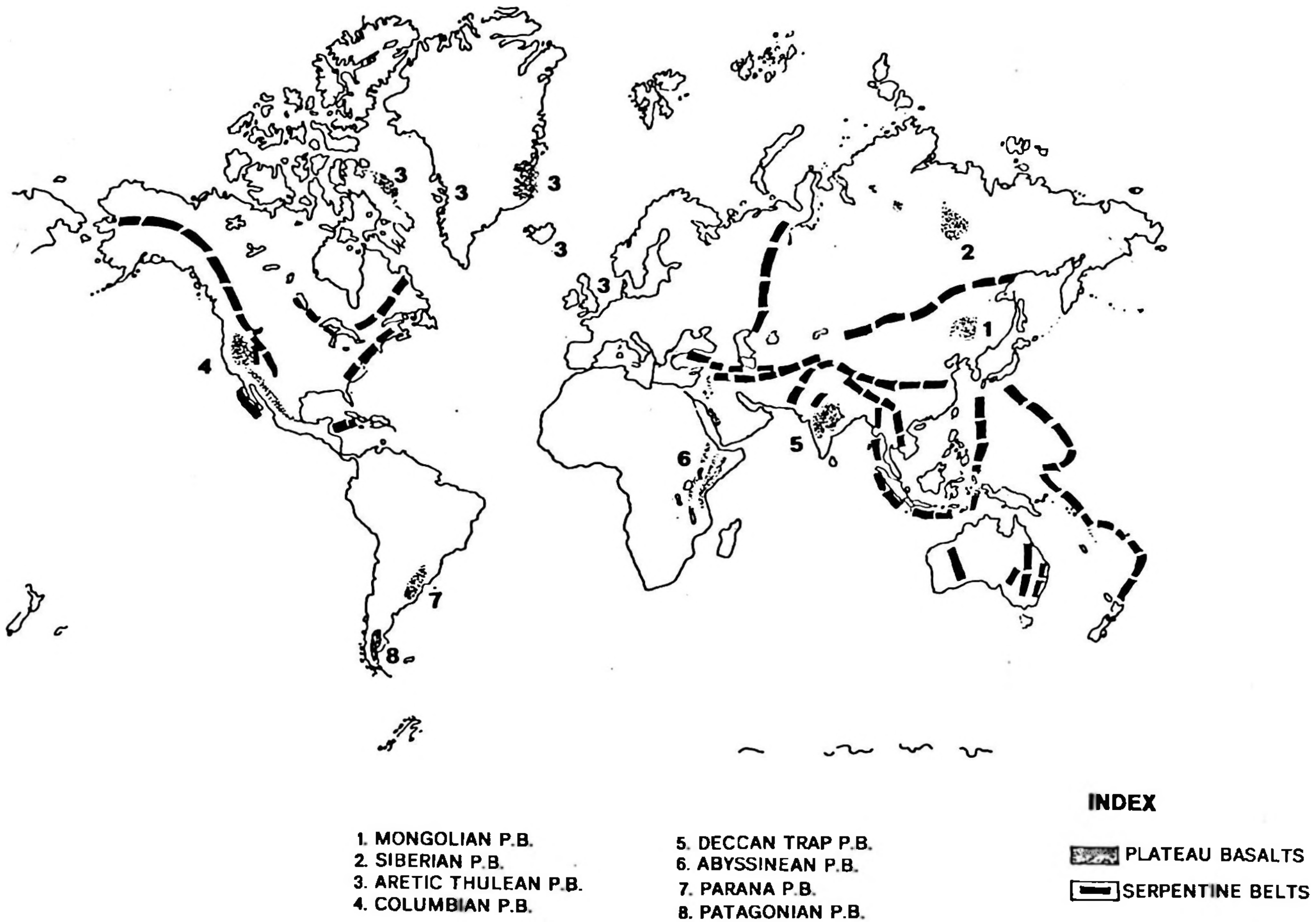


Fig. 35. Igneous Activity: Network of Plateau Basalts and Serpentine Belts

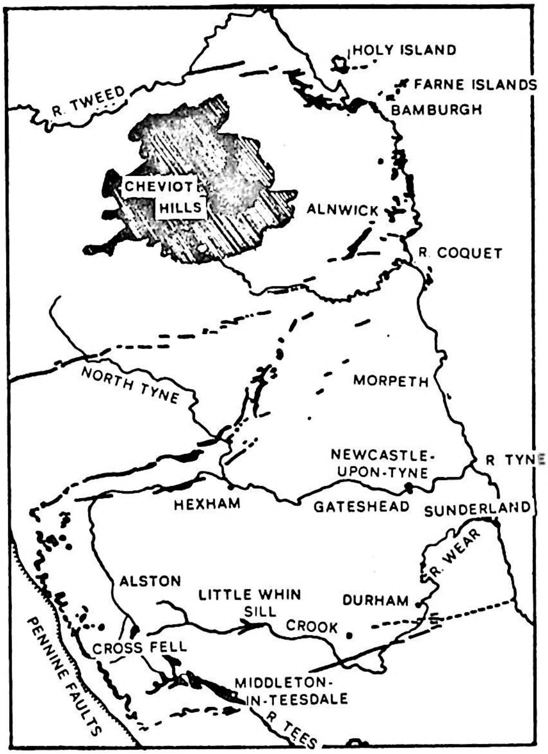


Fig. 36 Outcrop of Whin Sill

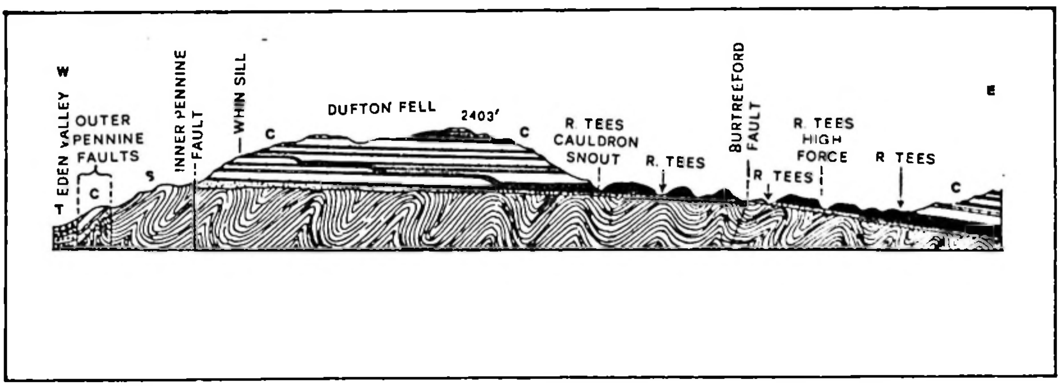


Fig. 37. Whin Sill in Section

extensively developed in the Parana Basin. The Patagonian Plateau Basalts are closely flanked on the west by the CircumPacific eruptives in the Chilean Andes.

It is plausible that the CircumPacific igneous activity in the Andes was linked with the Himalayan Tethyan activity through the intervening continental Plateau Basalts in the peninsular parts of India, Africa and South America.

Similarly, the Colorado Plateau Basalt activity is flanked on the east by the Mediterranean igneous activity in the Antillean Gulf region and on the west by the CircumPacific activity in the Coastal Ranges.

The presence of igneous rocks, intrusive as well as extrusive, in almost, every sedimentary basin and in rock formations of every age makes Volcanism an omnipresent and omnipotent agency in crustal dynamics and lends it the power to influence the evolution of sedimentary basins petrologically, structurally and even in respect of their later emplacement. Through the process of metasomatic granitisation, it brings about the formation of Cratonic nuclei of continents; through metamorphism, it contributes largely to the development of basement complex; through decomposition and disintegration, it adds pyroclastic material enormously to the thickness of the stratified columns; through intrusive dykes and sills, it helps in the subdivision of the sedimentary basin into blocks and sheet packets and as magmatic fluids, provides heavy molten media to lift and when aided by gravity to transport large sedimentary sheet packets laterally to considerable distances and thus helps in the expansion of the continental crust.

Through repeated eruptive activity in eugeosynclinal basins in both CircumPacific and Mediterranean regions, it has helped in the extensive folding of sedimentary formations (Tectogenesis) and in their uplift (Orogenesis) and in the diversification (Cordillera formation). As plateau basalt on continental scale, it has uprooted the continental sheets from their simatic foundations and thereby facilitated their lateral migration almost undisturbed. The CircumPacific eruptive activity in the fore-deeps aided by gravity, drags the continental masses together with their folded zones along gently sloping planes towards deep oceanic trenches. This pulling of continental masses by CircumPacific magmas in the fore-deep side is also facilitated by the pushing effect of the Mediterranean magmas at the everwidening intracontinental Rift Zone in the hinterland. The subcrustal magmatic activity is thus the all powerful, all pervading geological agency in crustal evolution, including expansion and emplacement of continents and in the formation of secondary oceans.

D. Mechanism of Sheet Movements

Sediments derived from the disintegration and decomposition of surface rocks are transported and deposited in aqueous basins more or less on horizontal or slightly inclined planes. The basin gradually becomes filled up more rapidly towards the margin and less rapidly further towards its deeper interior. The sediments become compacted through diagenesis in course of time with the development of bedding planes. In a geosyncline, the basin is gradually widening and deepening towards the interior and vast pile of sediments gets deposited. The subcrustal processes now become active and a mobile zone is developed at the base, through which magmatic fluids ascend upwards into the geosynclinal sediments along cracks, fissures and other weaker zones. Under the weight of overlying sediments, the magmatic fluids largely spread out laterally along bedding planes at different levels in the nature of sills and partly ascend to higher levels through faults as dikes and fissures. The sediment-packet gets upheaved and folded in the nature of a dome or a anticline above the intrusive channel. With the intrusive magmas still hot and fluid the overlying sedimentary packet gets floating over the sill mass and when tilted the sheet packet starts sliding along the slope. Owing to differential stresses the sheet packet gets split into a number of sheets along the lubricated planes and these sheets, now detached from their substructure, migrate along gently inclined surfaces, in stages over a wide region. The higher sheets move farther along the slope while the basal sheets stop at shorter distances along the sloping plane.

With the fall of temperature and consequent solidification of intrusive magma, the movement of sheets stops for a while and the centre of intrusive activity now shifts laterally away from the continental border towards the deeper seas and a new series of lateral movements takes place moving the remaining part of sheet packet yet farther seaward. In this way, a thick sequence of stratified formations is split into a number of thinner constituent blocks, packets and sheets of sedimentary formations which are transported laterally far away from the original basin of deposition.

This phenomenon is best illustrated by the East Asiatic Island Arcs separated from the continental coast by a stretch of shallow shelf seas and bounded on the ocean side by deep oceanic trenches.

The Japanese Island Arc has a curvature identical with that of the Chinese coast between Shantung and Amoy again with that of the Ryukyu Island Arc along the border of the East China Sea shelf. It is, therefore, likely that the Japanese Arc along with the Korean peninsular mass on the north and Taiwan island mass on the south, was situated, during one of its earlier stages of evolution, superposed along the East China Sea coast between Peking and Hongkong, as a border range. Under the influence of East China eruptives, this Korea-Japan-Taiwan folded Arc was detached from the Chinese basement and was made to slide eastward into the region of East China Sea along an inclined shelf plane reaching a depth of 50 m and later farther east to a depth of more than 200 m. The Kyushu island of the Japanese Arc this time occupied the position of Taiwan whereas the Honshu Arc was partly superposed over the present Korean peninsular mass while still in the Yellow sea region. This time the Japanese and the Mariana Trenches were situated closer to the mainland in the region of Japanese Sea and the East China Sea as a direct northern continuation of the Philippine Trench. With the onset of fresh CircumPacific igneous activity, the Honshu and Kyushu parts of the Japanese Arc were detached from the Korean and Taiwan land masses and the Arc slid eastward towards the Pacific along an inclined plane, reaching 2000 m deep to occupy the position of the Ryukyu Arc. Later, being tugged up with the Sikhote Alin-Sakhalin fold arc, the Japanese Island Arc was dragged northeast to its present position. Thus, from its earlier position along the East China coast, the Japanese Island Arc shifted, in successive stages, to its present position along inclined planes provided by deep CircumPacific eruptives and sloping towards the ocean trench.

In the same way and almost during the same period, the Queensland-New Zealand-New Guinea-Philippines folded Arcs originally in superposed condition also shifted south-eastward from the position of Indochina in successive stages to their respective positions under the influence of CircumPacific eruptivity.

The CircumPacific magmas thus brought about not only the splitting and detachment of rock sheets from their basement but also provided the sloping base and the lubricant to facilitate easy sliding under the influence of gravity, unobstructed, towards the Pacific depths.

This mechanism of sheet movement solves the problem of forces responsible for the movement of vast sheets of even continental dimensions and also the problem of space for their unobstructed migration.

E. Routes of Sheet Movements

A packet of sheets slides under the influence of gravity while aided by magmatic fluids but as the lubricant cools, it leaves portions of its basal rock formations, in the nature of structural sheets, fused with the basement along the route of migration. This route of migration may be unidirectional or more commonly angular round a pivot or along a hinge if two parts of the same sheet complex are united at one end. The changes in the trends of migration along the route are often imprinted in the course of a river which registers the route of sheet migration more or less closely. When the trends of sheet movements are correctly determined for different parts of the earth's surface and marked on a world map, it is seen that they invariably converge towards the Tibetan Plateau as the primary focal region from which they appear to radiate in all directions.

The Indo-Gangetic system of rivers draining the Himalayan ramparts of the Tibetan Plateau marks the trends of sheet movements to the south, southwest and the west. The Brahmaputra, also starting from the same Mansarovar region, marks the trends to the east and southeast, so also do the Salween and the Mekong though mainly to the southeast.

The Yangtsekiang, starting from central parts of Tibet, marks the trends to the east and southeast and then northeast. The Hwang Ho, starting from the Tsaidam region of North Tibet, marks the trends to the east and northeast. The Tarim system of rivers marks the trends to the north while the Amu and the Syr Darya starting from the Pamirs mark the trends to the west and northwest.

This centrifugal pattern of the rivers round the Tibetan Plateau gives a faithful picture of the original location of most rock sheets of the world and their early trends of migration. Their subsequent trends of migration to distant parts of the world are given by other river systems which mark the continuation, though with small deviations, of the main trends initiated in the region peripheral to the Tibetan Plateau. Beyond the Asiatic mainland, particularly westward, the trends become dominantly E-W. In the region of the Indian ocean, the trends of sheet movements are prevailingly southward directed towards Antarctica and partly southeastward towards Australasia.

F. Stages of Movement of Major Sheet Complexes

The trends of sheet movements mark the directions of movements of individual sheets. It is, however, seen that these sheets are only parts of larger sheet complexes and their movements are regulated by the movements of larger complexes. These movements are engineered and controlled by subcrustal magmatic activities of global significance which also exhibit waxing and waning in their frequency. During the waning period the magmatic eruptives suffer cooling and solidification of intrusive masses and the consolidated magma nearly fuses the sheet complex to the basement. When a new igneous activity starts, the intrusives detach portions of younger sheets at higher levels from their basement, leaving large parts behind fused to the basement and mark a stage in the nature of pause, in the course of the sheet movement. These stages of cessation of sheet movement are related to the interval between the ending of one igneous activity and beginning of the next activity. Since these subcrustal igneous activities are on a continental scale, they affect the sheet movements over a vast area simultaneously. It is thus possible that these pauses in sheet movements are recorded by the remnants of sheets seen continuously or discontinuously along lines of outcrop at times thousands of kilometres in length. These lines of outcrop mark the stages of halt of continental sheet at different periods of the earth's history. These stage lines, particularly in later stages, are oriented roughly north-south.

CHAPTER VIII
Guides to the Course of Sheet Movements

RIVER SYSTEMS AS GUIDES

River Systems of the British Isles

When we study the physical features of the British Isles, we are struck by certain peculiar traits connected with the river courses and their valleys, hills and uplands and even the coastlines, and their relations with the regional geological structures (Fig. 38).

Starting from the Wales, we find that the rivers Towy, Usk, Wye and the Savern originate in the Cambrian Mountains to the northwest not far from the Cardigan Bay and flow south with arcuate courses convex to the east, before they flow into the Bristol Channel. Among themselves they have a systematic radial arcuate pattern as we go from West to East. The Wye flows due south whereas the Savern flows first east through the gorges, turns southeast and south and back to southwest to debouch in the Irish sea through the Bristol Channel. The Savern thus appears to shift its course systematically relatively eastwards through the positions of the Usk, Wye and Teme to take its present position. Further shifting eastward of the Savern System is discernible in the course of its eastern tributary the Avon, which also passed through the upper course of the Trent almost in sight of the Liverpool Bay of the Irish Sea.

The cause of these systematic everwidening arcuate courses of these rivers cannot be attributed to mere superficial morphogenic agencies. A look at the geological map of this region shows similar arcuate trends of the rock formations systematically widening, shifting, and enlarging eastward as shown by the Ordovician, Silurian, Devonian, Lower Carboniferous and the Coal Measure formations right from Dembigh on the Liverpool Bay in the north to the Bristol Channel in the south.

The intimate relations of the river courses with the geological formations of the region are undeniable but the cause of this relationship is not so obvious. The river courses exhibit the latest shifting relatively from the west to the east during the recent geological period. Does the repetition of the rock outcrops on a similar pattern indicate a similar process?

Let us study the trends of river courses east of the Savern. The Avon rises east of the Lias escarpment, cuts through it westward and flows southwest along the outcrop of the Keuper Marl, joins the Savern to flow into the Bristol Channel. The Trent starting in the junction zone of the Avon and the Savern, flows in the opposite direction to the northeast, flows over the Kauper Marl along the western side of the Lias escarpment and joins the Humber before the latter cuts across the Lias escarpment to the east. Just near the

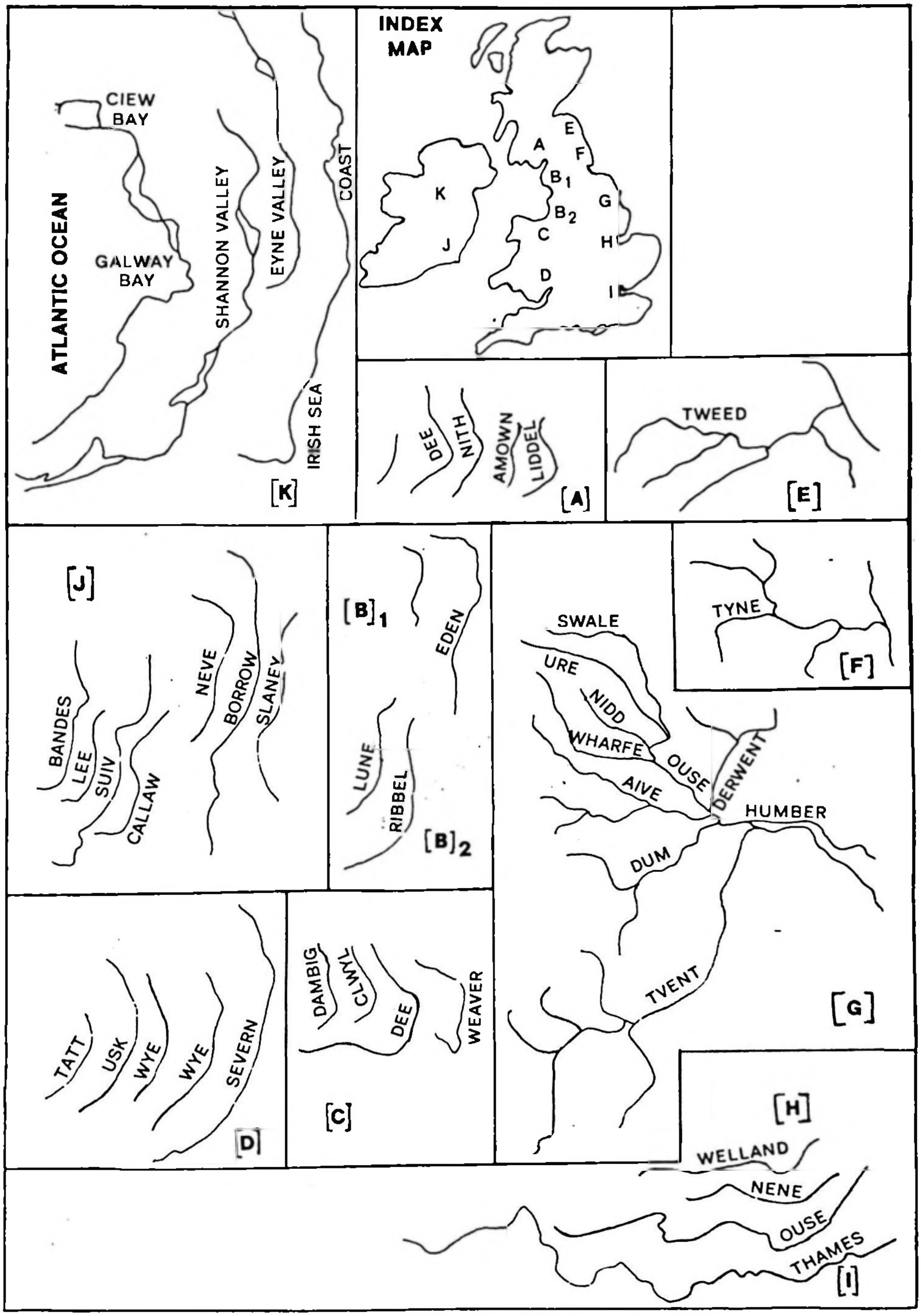


Fig. 38. River Systems of British Isles

source of the Avon and in the same trend line starts the Welland along the eastern slopes of the Lias but unlike Avon, flows to the ENE, cuts through the Oolite and the Quaternary formations to join the North Sea through the Wash. Here the higher beds of the Cretaceous and the Lower Tertiary are obscure.

Almost parallel to the Welland runs the Nene also rising along the eastern slopes of the Lias escarpment passing through the Oolite and the Quaternary to join the North Sea again through the same Wash embayment. Curiously, Nene has nearly the same pattern of the river channel paralleling the Welland course even in its loops and bends though separated by a distance of 8—16 kilometres. Further southeast rises another river—the Ouse—along the eastern fringes of the Lias, flows through the Oolite and the Quaternary formations and falls into the same embayment of the Wash. The Ouse also has the same pattern of the channel as the Nene and thus the three rivers Welland, Nene and Ouse though starting from different regions of the Lias and separated by stretches of several kilometres, fall into the same embayment of the Wash after flowing through remarkably similar channels. The cause of parallelism of these river courses must again be sought not in the superficial agencies but in deeper subsurface structures. The similarity of the river courses is not limited to these three river courses but is seen continued even in the Thames though considerably modified by the later earth movements. The Thames starts, as in the case of the above three rivers along the eastern slopes of the Lias belt further south in the Cotswald range, cuts across eastward through the Oolite and follows for some distance an eastward course in the trend continuation of the Ouse but suddenly turns south an southeast and cutting through the Chalk escarpment emerges into the Eocene London Clay to follow its zigzag eastward course before joining the North Sea. Here, the Cretaceous and Tertiary formations found missing in the course of the Welland, Nene and the Ouse are seen outcropping, for the first time, in the Valley of Thames.

The major irregularities as loops and bends as seen in the Ouse are still recognisable in the course of the Thames.

Several other river systems exhibit similar correspondences among their courses. The North Wales system of rivers Denbigh, Clwyd, Dee and the Weaver all flow north into the Liverpool Bay. All exhibit parallel arcuate courses convex to the east. In the Southern Uplands of Scotland, the group of the south-flowing rivers Dee, Nith, Annan and Liddel all flowing into the Solway Firth exhibit a curvature convex to the east. These various rivers flowing into the Irish Sea (Solway Firth) have all a pattern similar to that of the Weavern system of Wales whereas those flowing east into the North Sea such as the Tweed, Tyne, Wear, Tees etc. have a pattern roughly similar to that of the Swale, Uri, Wharfe which are tributaries of the Humber system.

Curiously, the same curvature patterns in the courses of rivers are also observable in Ireland across the Irish sea. Thus, in southeast Ireland, the rivers Black Water, Suir, Nore and Barrow have gently arcuate courses convex to the east and exhibit a radial pattern of distribution with a fulcrum near Waterford. The Shannon river, in the central parts of Ireland with a number of narrow elongated lakes in its course, has a broad curvature convex to the east and southeast and finally flows southwest into the Atlantic Ocean. Its course is parallel to and simulates the Wicklow coast of SE Ireland. Another river Erne, also with a number of lakes in its course, runs parallel to the Shannon but flows north and northwest and has a broad arcuate course convex to the east and northeast and simulates the Antrim coast of N.E. Ireland.

What is the significance of this Erne-Shannon system of rivers behaving almost like an arcuate rift dividing Ireland into two parts, the eastern resembling the Northeast England west of the Pennine chain and the western resembling the Wales both in size and form?

When we study the drainage pattern in Scotland, most river systems have been considered as of tectonic origin occupying deep fracture faults with a high vertical throw. They exhibit a certain amount of fanning out from almost N.S. in Hebrides and Cromery Suderland· (Northern Highland), NNE-SSW in Moray Kairn-Argyll blocks, NE-SW in Grampian mountain belt in Banff-Perth block, to ENE-WSW in the Scottish Lake District between Clyde and Forth zone, finally to almost E-W in the Southern Upland block of Lanark and Berwick.

This fracturing of the Highland region into a number of blocks appears connected with the Thouleian Plateau Basalt activity of the North Atlantic region.

Inter-relations between Various River Systems

The rivers Clyde, Tweed, Liddel and the Annon radiate from a common focal point of Broadland(Hartfell eruptive hill mass about 840 m high) in the Selkirk region of the Southern Uplands. This hill mass is probably the most important structural knot since it appears to be the meeting point of a number of primary structural units of the British Isles. The river pattern of the Tweed with its younger Palaeozoics and associated eruptives is continued in the basins of the Forth and the Tay in the north and again in those of the Tyne,Tee, Rye and the Humber and further south in the Witham basin.

The Liddel Pattern with Lower Palaeozoic formations is continued in the north in the Clyde basin and in the south in the basins of the Eden, Ribbel, Derwent and the Savern. The same pattern appears continued in the west in Ireland with Pre-Cambrian and Palaeozoic formations in the basins of the Shannon, Erne and Borrow systems.

These river patterns also characterise the shape of the eastern coastal outline both in England and Ireland. Thus, the Liddel-Savern curvature pattern is to be observed in the Berwick-Durham coast in the northeast, in Linkolnshire Norfolk and Suffolk in the east and southeast. Further, it can be recognised in the Antrim and Meath Wicklow coast of eastern Ireland as well. The western coast in many parts of England and Ireland also carry the impress of the Savern curvature as the Cardigan coast in Wales, Galway Clare coast in West Ireland and in Donegal bay in N.W. Ireland. These peculiar characteristics of river courses and coastal outline appear to have deep genetic bearing on the evolution of landforms in the British Isles as a whole (Fig. 39).

The repetition of the same geomorphological pattern successively over a large region cannot be explained on the basis of any of our present concepts of physical geology or geodynamics, dominated as they are by the static, epeirogenic processes of crustal evolution in which crustal blocks move only vertically up or down in response to Isostasy.

The only process which is capable of explaining this phenomenon of morphostructural repetition is that of migration of sheets laterally, engineered by eruptive processes found recurring from time to time in the earth's history.

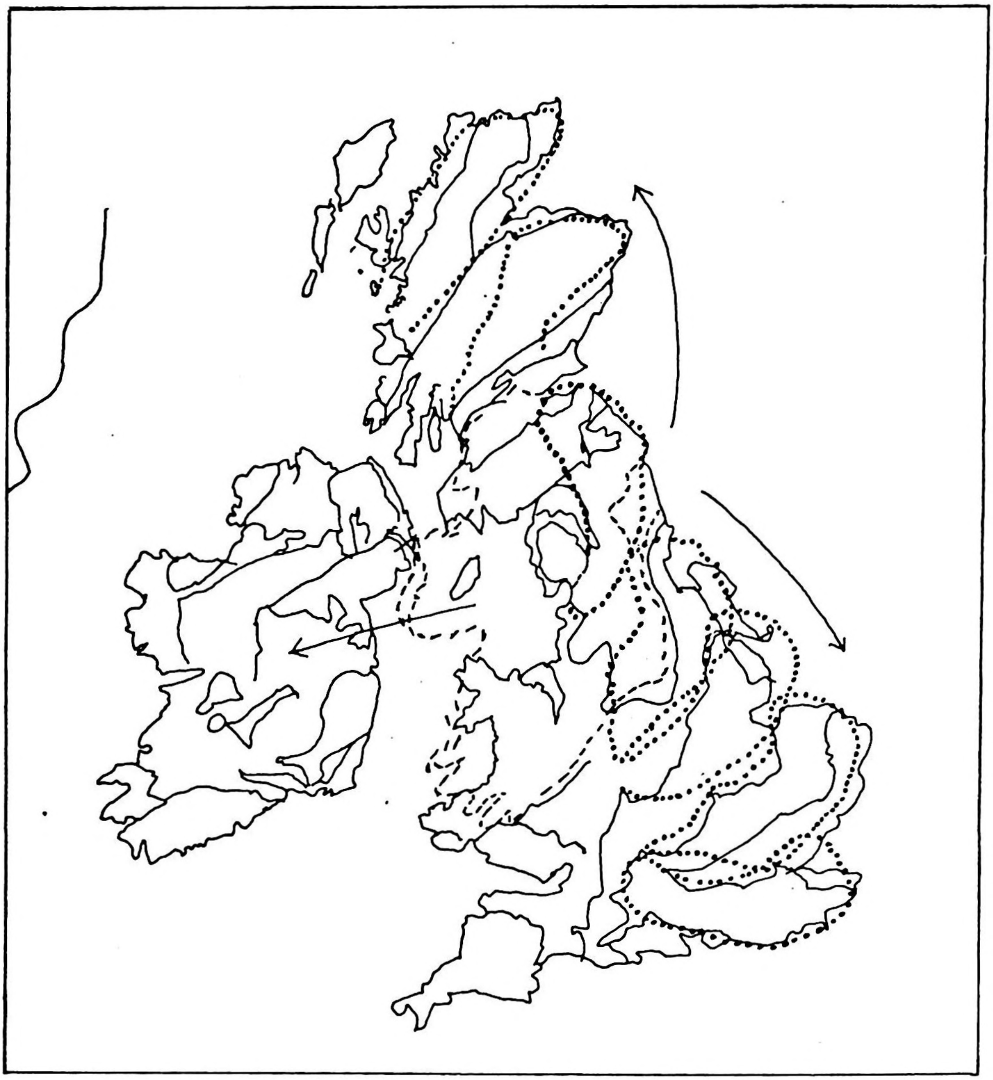


Fig. 39. Sheet Migration in British Isles

The evolution of the British Isles may be taken as an example of Sheet Movements in which the river systems can be taken as a guide in determining the trends and stages of structural evolution of the region.

For this purpose, we can take the Moffat Selkirk region of the Southern Uplands of Scotland as the starting point. Here, in the Dumfriesshire-Pebblestone-Selkirk region, we get a terrain consisting of the Pre-Cambrian and the Lower Palaeozoics (Ordovician, Silurian, Devonian) as the basal formations overlain by Lower and Upper Carboniferous formations in Berwickshire Northumberland, in parts of Scottish Lake District and in South Dumfreisshire and by the Permian formation in the valleys of Annan and Nith. This region has also been the scene of intense Permocarboniferous and Tertiary intrusive and extrusive igneous activities.

The Whin sill intrusive, in its distribution, shows a sudden change in the direction of its outcrop from NNW-SSE in the Esk Annan Eden Valley (Pennine direction) to one of E-W or NE-SW in the Tyne valley in Northumberland.

The Liddel river trend is found repeated successively in the Eden, Ribble, Weaver and Savern river system. So also are the outcrops of Lower, Middle and Upper Palaeozoic formations repeated right from Moffat Hills to the Bristol Channel along the Irish sea coast of western England and Wales.

The Tweed-Tyne trend involving the younger Palaeozoic and Mesozoic formations repeat the outcrops of Upper Palaeozoic upto the Tees and of the Mesozoics further south in the drainage basins of Rye, Humber, Welland, Ouse and the Thames right upto the English Channel in the south and southeast.

These trends of repetition of the stratigraphic formations older in the west and younger in the east gradually widening in their areal development as we go from north to south leads us to the possibility of their being once situated in the region of the Scottish Southern Uplands possibly in a system of superposed sheet complexes: Indications of their presence in this region are provided also by the traces of the Mesozoic formations along the eastern and western coasts of Scotland in Arran, Skye and Aberdeenshire.

The similarity of the structural and river patterns of Ireland with those of Great Britain also makes it possible that even the Irish structural mass existed as a sheet superposed over the Southern Uplands of Scotland, the Antrim border of N.E. Ireland being coincident with the Berwickshire Coast of the Firth of Forth and the North Sea. In this position of Ireland over the Scottish Uplands, the Wales sheet also appears to have occupied the position of Cumberland Lancashire (Eden-Ribbel basin). In this position, the outcrops of various rock formations of the Irish sheet appear only as complementary to those of Scotland, North England and Wales. The lithological, structural and palaeontological characteristics of the two regions are also most intimately related. Even some of the morphological features of one sheet are found repeated in the other. Thus, the Shannon and the Erne Valleys with numerous lakes along their course are reflected in the western coast line of Cumberland-Lancashire Denbigh region. The east coast of Antrim is reflected in the Berwickshire-Durham Coast with all its intrusive and extrusive igneous rocks. Even the Norfolk coast of southeast England was apparently existing in the north as a superposed sheet over the Berwickshire coast.

At this stage, the British Isles had the shape and size of Ireland with all the structural belts occurring superposed as a unitary sheet complex. The succession of sheets in this complex was possibly somewhat as follows:

(Top)/Cambridgeshire (P1)/Essex (Eo)/Norfork(Cr)/Yorkshire (Ju.Cr.)/Kent/Bedford/Cheshire-Lancaster/Lancashire-Cornwall. Somersett/Ireland/Cumberland/Selkirk-Wales/Scottish Highlands (Pal-Precamb) (Bottom).

It is possible that the various intrusive and extrusive igneous rocks found in the British Isles constitute an almost continuous succession occurring for a large part as sills at different levels and have suffered different degrees of metamorphism during magmation and sheet movements. The areal extent of the Whin Sill as also of the Tertiary igneous rocks appears to be of the size of Ireland when in close packed condition.

It appears that the various sheets constituting the British Isles started splaying out in various directions only in post-Eocene period to give rise to the present shape and size of the British Isles, mainly as a result of Tertiary and younger basaltic activity.

The Wales-Cornwall-Devonshire sheet got detached from the overlying South Ireland sheet and started moving south and southwest along the route of the Ribbel, Mersery, Derwent, Doy and the Savern while the overlying Ireland Sheet on being freed from the Armenian Grampian group started moving west along the Nith, Dee (Scot) in the north and along the rivers Dee (Cheshire), Clwyd, Donbigh in the south, the whole Irish sheet passing westward through the positions of Isle of Man and Anglesey.

The Mesozoic Tertiary sheets on the east and southeast in the basin of the Tees and the Humber, started moving southeast along the trends of the Wharfe, Trent,Welland, Nene, Ouse and the Thames.

During the same crustal movements under the impulse of Tertiary eruptive activity, the northern. Scottish sheets, constituted of basement Pre-Cambrian and Palaeozoic formations with traces of Mesozoics, started moving north and northwest along the course of the Clyde, Forth, Tay, Spey and the Morrey rivers. The Islands of Orkney and Shetland connect the British Isles through a submarine ridge, with the Scandinavian Caledonides, on the one hand, and with those of Greenland through Iceland, on the other.

This mode of structural evolution of the British Isles would explain the recurrence of a series of arcuate river courses, outcrops of rock formations and even coastal outlines. This would also explain the differences in the nature of eastern and western coastlines both of Great Britain and Ireland. It would then be seen that the evolution of British Isles in their morphological, geological and structural characteristics is best explained on the basis of lateral movements of sheets under the influence of intrusive and extrusive igneous activities. We can go still further and trace the actual route of migration of sheet packets which go to build the British Isles.

We thus find that a study of the geomorphological features, particularly the River Systems in relation to the associated geostructures, helps us in working out the evolution and emplacement of continental masses in sufficient detail.

River Systems and their Tectonic Significance

In our study of the British Isles and their river systems, we have seen how particular patterns of river courses appear repeated more than once over a wide region even when separated by sea basins as in the case of Great Britain and Ireland. The repetition of these patterns is also accompanied by the repetition of geological formations and often exhibit close relations between the river courses and the geological structures of the region. In many cases, it is easier to ascertain the route of migration of rock sheets if we follow the river courses. It is most commonly seen that in a river basin, the rock formations near the source regions of the river are the oldest in the region while those towards the mouth are successively younger in age except in the case of eruptive masses. A river basin often chalks out the structural history of the sheet packet involved during a particular sequence of earth movements. An extremely complex example of such structurally determined River Valley, which may be cited, is that of the Danube system in southeastern Europe (Fig. 40).

The Danube which starts from the Central region of the Black Forest Massive almost overlooking the Rhine valley flows east along the Jurassic edge of the massive against East Alpine Molasse, turning SE again along the edge of the Bohemian massive against the Austrian Molasse trough, enters the Carpathian Arc near Vienna, crosses the eruptive infested Tatra-Baskedy basement formations of the western Carpathian, takes a sudden right-angled turn to the south near Budapest. It again takes a right-angled turn to the east soon after it is joined by its tributary Drava and after collecting most of the drainage of the east Carpathian inner region through the tributary Tisza makes its way through the Pannonian basement structure in numerous zigzag turns, enters the Balkan Alps east of Belgrade. With numerous rapids it passes eastward through the Walachian plain of Rumania, again takes a sudden bend to the north near Dobruja and yet another sudden turn to the east near Golati finally to join the Black Sea.

This extraordinary rugged zigzag course of the river attended by rapids and acute turns is not an expression of simple erosional river valley development but bespeaks of deep-seated tectonic control at every stage. In this, both the Variscan massives and Alpine thrust structures, infested with alkaline eruptives, have been intricately involved in lateral movements and the river course merely registers the interaction between these two major structural entities during the course of their mutual disentanglement. Here the original succession of different sheets of the structural complex appears somewhat as follows:

Top

7. Walachian Quaternary Deposits
6. Upper Tertiary Molasse
5. Alpine Folded Nappe Balkan Alps
4. Carpathian Nappe Arc within Cretaceous-Palaeocene Flysch
3. Carpathian basement with eruptives
2. Bohemian Massive (Variscan)
1. Black Forest Massive (Variscan)

Base

The Variscan Horst structures which were in the Core region (Walachian plains) of the Alpine Arc in the Balkan region rotated anticlockwise to the NW while the Alpine Arc structure moved due west. The upper courses of the Danube gradually adjusted themselves westward to mark the relative positions of the two structures at various stages. The Variscan massive got completely free from the overlying and encircling Alpine Arcs near Vienna in the nature of Bohemian-Black Forest massive and in the process developed the Carpathian arcuate zone of thrust sheets over the Cretaceous-Low Tertiary flysch. Further westward movement separated Black Forest by a wide stretch of the Up. Tertiary Molasse trough. This explains the extraordinary zigzag curves and the abrupt changes in the course of the Danube in the different portions.

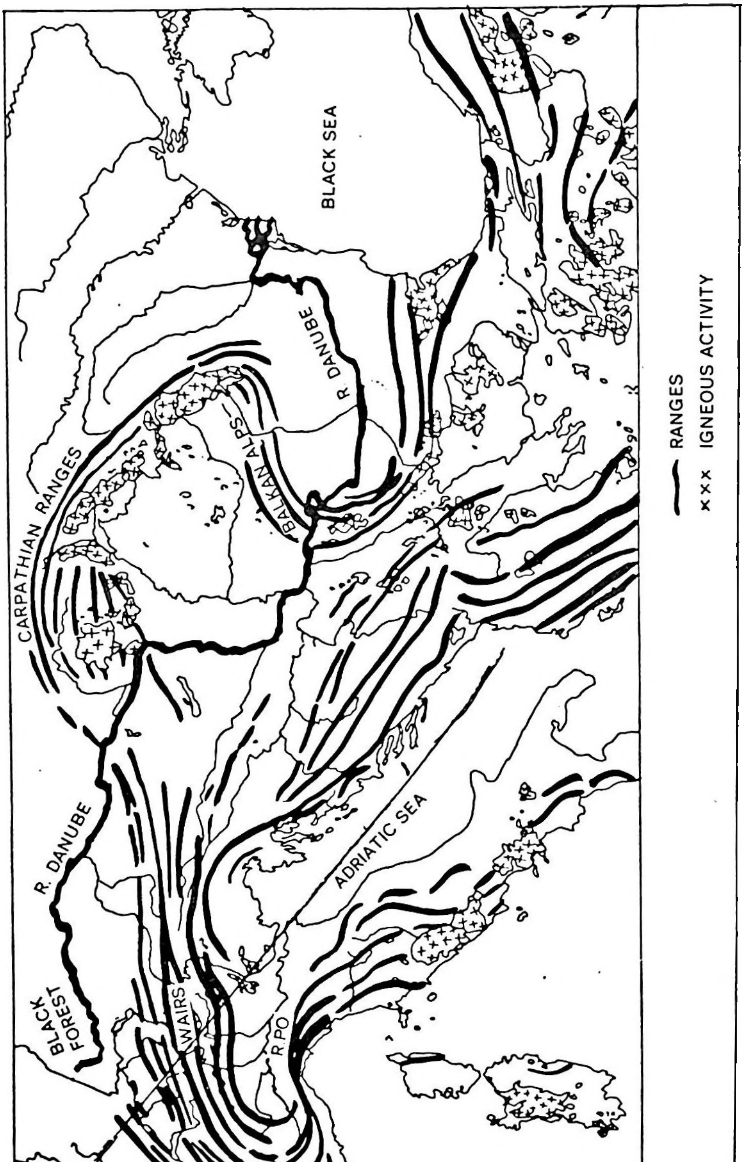


Fig.40. Drainage Basin of the Danube

This type of control of the river course by geological structures can be discerned in the courses of most of the rivers of the world.

Syntaxial Bends in River Courses

The form which a river course takes is, in most cases, the expression of the structure and nature of crustal movements which have taken place in the region. We have seen that rivers often develop very sharp and acute bends in their courses which can be referred to the structural movement of rock sheets in the region as has been demonstrated by the Danube. Many a times we see a river exhibiting a complete reversal of its flow direction even by 180°. Such sharp bends in river courses as those of the Jhelum. Brahmaputra etc. have attracted repeated attention of geologists and geomorphologists. In the region of such a bend in the course of the river Jhelum near Muzaffarabad, the rock formations also exhibit a sharp change of strike. Such structural bends, called Syntaxial bends, have been variously interpreted. E. Suess thought this as due to compressional approach of two different orogenic belts (Scharung). Wadia considered this as merely moulding of advancing rock folds against a protruding continental mass. B. Sahni thought it as due to kneelike bending under compressive forces, etc.

The present author considers this as radial divergence of parts of the same system of folds along a hinge due to wedge action of deep-seated intrusives.

In the case of Jhelum syntaxis, the western limb of the syntaxial fold consisting of the Hazara-Salt Range (as also the Suleiman-Kirthar folds) was originally an integral part of the Himalayan fold system on the eastern side of the syntaxis till the Cretaceous-Low Tertiary period but due to wedge-like intrusion of Indus ophiolites and other eruptives, the southwestern limb of the Himalayan fold was lifted up from its Himalayan basement and moved radically clockwise round a pivot which in the case of Jhelum Syntaxis was situated in the Muzaffarabad region. Similar syntaxial movements had already preceded this in the syntaxial bends of Sutlej near Bhakra, of Bias near Gurdaspur, of Ravi near Dalhousie and of Chenab near Riasi and also succeeded by the Indus bend round Nanga Parbat. These series of syntaxial movements resulted in the continued widening of angle between the eastern (Himalayan) and the western (Kirthar-Sulaiman-Hazara-Salt Range) fold belts. (Fig. 41).

This interpretation of the Syntaxis would explain the close relationships which exist in lithology, sequences and faunas between those of the Hazara-Salt Range and Baluchistan-Sind ranges on the west and those of the Kashmir-Punjab-Kumaon Himalayas, including a part of Tibet, on the east.

Another spectacular example of the syntaxial bend in the river course is that of the Brahmaputra. (Fig. 42). However, the nature of sheet movements involved in this Assam Syntaxis is more complex and is not readily comprehensible. The river Brahmaputra has first a long eastward course along the longitudinal valley north of the Main Axis of the Himalayas under the name Tsangpo, then a southward course after turning round Namcha Barwa under the name of Dihang and again a westward course after meeting the Dibang and Lohit tributaries under the name of Brahmaputra. This is followed by a further southward course after turning round the Garo hills near Dhubri near its junction with Raidak as Jumna when it meets the Ganges in Bangladesh.

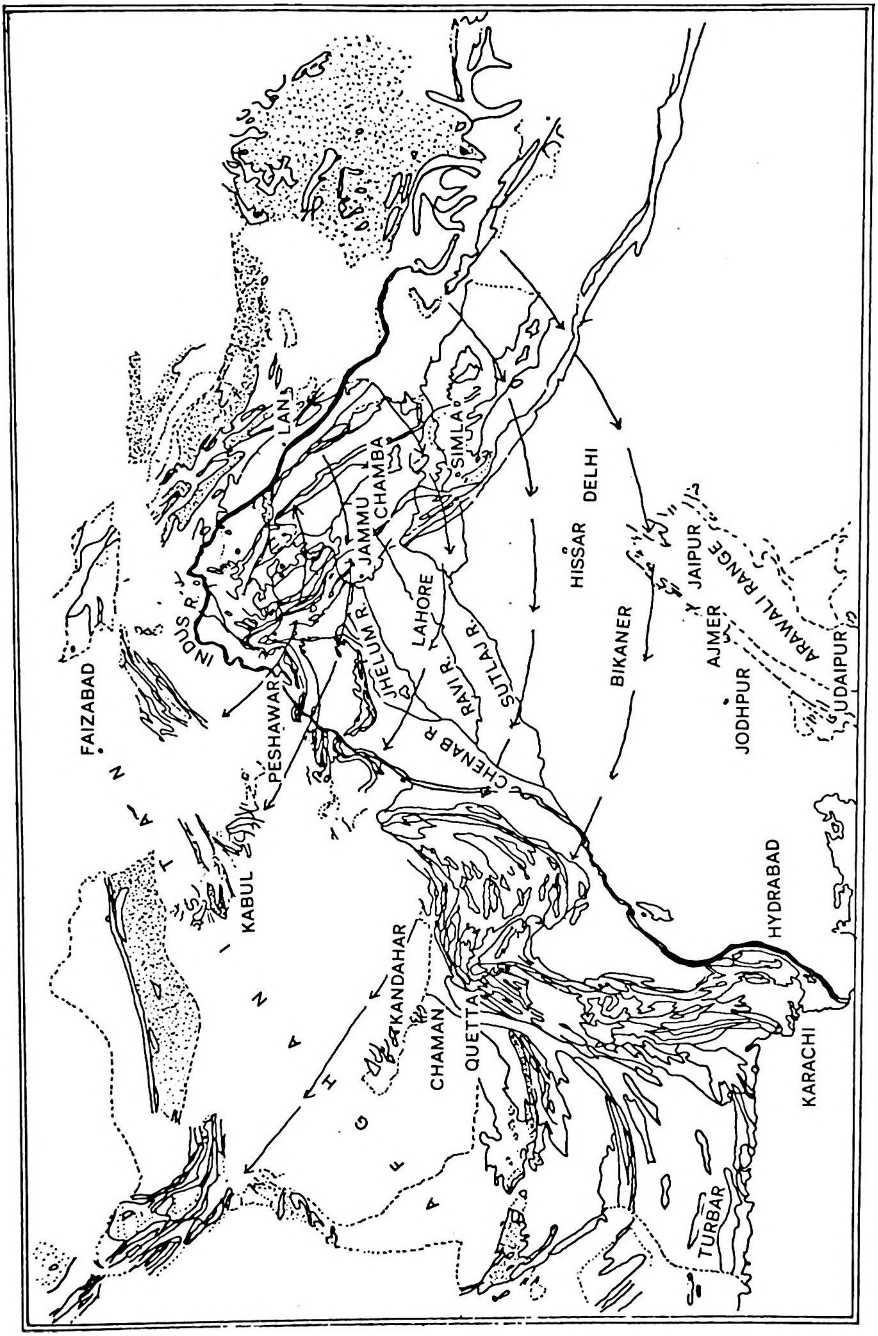


Fig. 41. The Indus Syntaxis

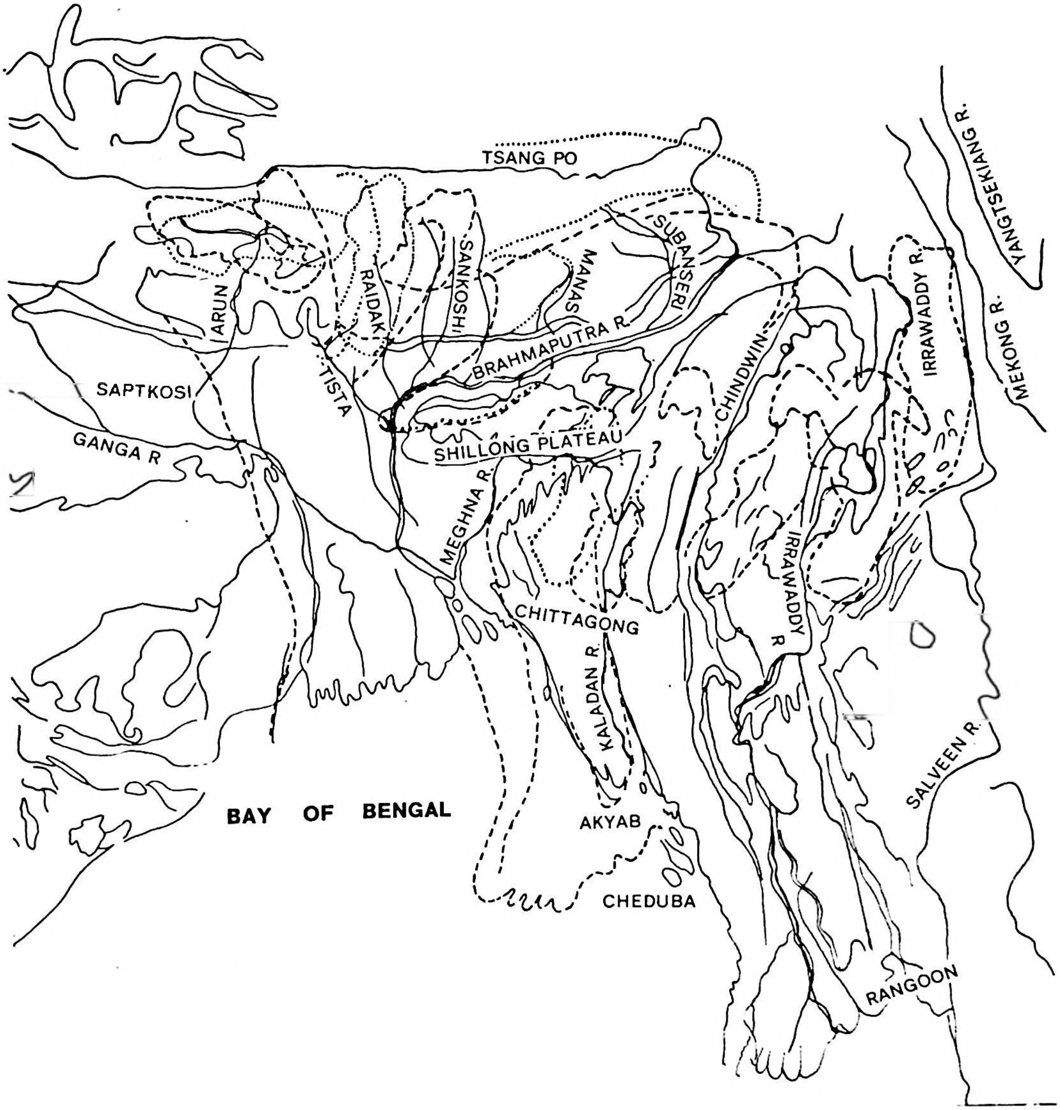


Fig. 42. Bramhaputra Syntaxis

These repeated sharp turnings in the course of the Brahmaputra reflect the complex nature of the structural movements which must have determined them.

On an analysis of structural evolution of the region on the basis of sheet movements, the actual course of crustal movements can be worked out. The main trends of evolution appear as follows:

The sheet packet constituting the Assam-Burma ranges all closely packed originally was resting on the Tibet-Nepal-Bhutan Himalayas with E-W trends in the source regions of the Ganges and of its tributaries Ghogra, Gandak and Arun Kosi. In its eastward movement along the Tsangpo, the sheet packet got tied up with the Mt. Everest Granite mass. The Shillong-Mikir Granite mass with its vaneer of Mesozoic-Tertiary sediments and the Sylhet Trap was sheared off from the top of the Mt. Everest mass. The basement Granite mass of Shillong-Mikir Plateau got rotated clockwise with its pivot in Sikkim from E-W trend in Arun Basin to NW-SE trend in the Tista, then to N-S trend in the Raidak, to NE trend in the Manas to ENE trend in Subansiri while the Assam-Burma sedimentary belt continued to move anti-clockwise with its pivot at Namaha Barwa in the basins successively of the Surma, Barak (Langai, Dhaleshwari), Manipur, Chindwin and Irravaddy systems of N-S trending rivers. This separation of the Shillong Granite mass from the base of the Burma Ranges during their eastward shift brought about the complete reversal of the Brahmaputra course in this region, whereas the Salween and Mekong river courses remained unaffected by this deviation as the pivot of anti-clockwise rotation of overlying Fold sheets which migrated further east towards Kachin and Yunnan.

This interpretation of the Brahmaputra Syntaxial bend both in the river course as also in the structural trends of rock formations of the region explains all the geomorphological, geological and geostructural features of the region. The fitful occurrence of young eruptives in the valleys of the Surma, Manipur, Chindwin, Irravaddy as also those of Sylhat testifies to the role played by these young eruptives in bringing about sheet movements in this region.

CHAPTER IX

Structural Homomorphy

The Nature of Crustal Processes

Most of the geological phenomena observed in the building of different land masses have been explained, till lately, on the basis of *in situ* processes involving faulting, folding, overthrusting, etc. with a minimum horizontal displacement. Studies in orogenic mountain belts, however, have brought to light large-sized nappe structures which demand large-scale lateral displacement. These nappe structures which involve extensive overthrusting were attributed to the squeezing of thick geosynclinal sedimentary packets during the approach of two foreland masses from opposite directions. The approach of two supercontinents—the Laurasia from the north and the Gondwanaland from the south—is held responsible for folding and overthrusting of the Tethyan geosynclinal sediments into a complex Alpine-Orogenic Belt extending from the West Indies to the East Indes, right across the continental hemisphere, envisaging overriding of one continent over the other for scores or even hundreds of kilometres. The forces capable of accomplishing such continental overriding against solid resistance have not been properly identified. Indications for such underthrusting or overthrusting are also not quite unequivocal and could be interpreted in other ways.

The problems posed by the occurrence of similar or closely related fossil faunas or floras often zonewise in widely separated basins were being explained by postulating hypothetical marine or continental channels connecting the basins, oceanic currents (cold or warm), transport of organisms during larval stage etc., or even by postulating independent evolution. Besides closely-related faunal or floral associations, the distantly situated sedimentary basins often show several morphological or structural characters which mark them out as belonging to a common pattern. The same characteristics are seen repeated several times along certain trends. This repetition of morphostructural characteristics cannot be explained on the basis of any of our current geological concepts.

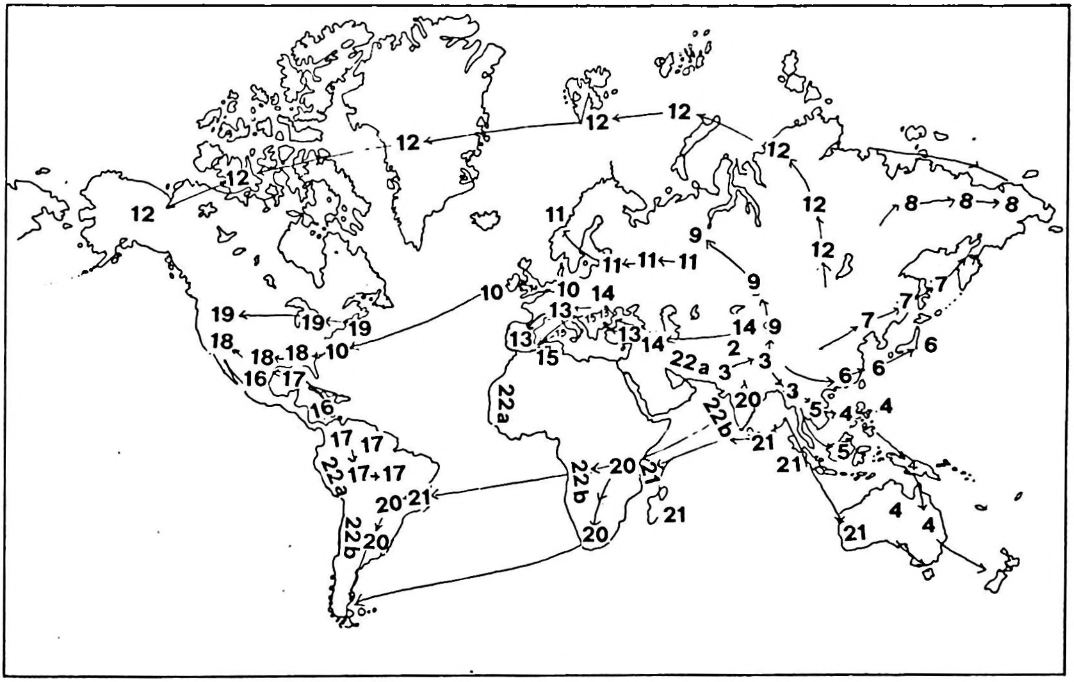
The characteristics of the pattern may refer to size, shape, outline, stratigraphic formations, their biological relations, structural peculiarities, igneous intrusives, mineral associations etc. The repetition of common pattern characteristics, several times over a large area, is not an isolated phenomenon but is universal and is found in all continents. As such this phenomenon is a problem of utmost significance in crustal evolution.

When geological maps, on a suitable scale, covering vast areas are examined closely, diverse structural patterns stand out prominently exhibiting different characteristics in different trend lines. One pattern with certain characteristics is found repeated in basins along a particular trend, though with different degrees of completeness. Among these characteristics typical of patterns, the most noteworthy is the mode of development of stratigraphic formations in different basins belonging to a particular pattern. This development of geological formations in different basins is such that it is irregular or incomplete in one basin but is found to continue in another basin belonging to this same pattern almost in a corresponding position so that when the outcrops of a particular formation in different basins are brought together superposed, they appear to fit together to form one complete, continuous development thereby showing complementary relations among themselves. This mode of complementary development in different basins is probably the strongest proof of their original sedimentation in a common unitary basin. This phenomenon of complementary development is best illustrated by the basins belonging to the New Guinea Pattern, viz. Indochina, Philippines, New Guinea and Queensland. Each of these of basins shows an irregular and incomplete development of the individual rock formations, e.g. the Precretaceous, Cretaceous and Lower Tertiary sediments and younger Eruptives. When the outcrops of each of these formations are traced in each of the sheets of the four basins and brought together through superpositions, they give the full development of that formation as a continuous whole, proving conclusively that the four sheets were together in superposed condition during the period of deposition of all the rock formations upto the Tertiary. It is in this combined superposed condition of the four sheets within a single complex basin that the various characteristics of the pattern, viz. shape, size, rock formations, mineral associations, faunal and floral assemblages, igneous intrusions, structural peculiarities, metamorphism etc. were largely acquired in common by the sheet complex as a whole. It is through splitting or peeling of the stratified fold complex during successive lateral migration that the various sheets with a common pattern got separately emplaced in their present positions.

The numerous examples of structural patterns described in this chapter are enumerated in the following list. They cover almost every sector of the land hemisphere and refer to rock formations ranging in age from the oldest-Archaeans right upto the Tertiary and even younger. With the help of these studies, we are in a position to work out the complete course of structural evolution of the earth's surface stage by stage during different periods of the earth's history (Fig. 43).

List of Patterns described

1. Satpura-Rewa Coal Belts of Peninsular India and other Gondwana Basins of India.
2. Jhelum-Indus Syntaxis.
3. Himalaya-Burma-Baluchistan Interrelations.
4. New Guinea Pattern.
5. Borneo Pattern.
6. Japanese Island Arc.
7. Kamchatka Pattern.
8. Verkhoyansk-Kolyma Pattern.
9. Ural Pattern.
10. Great Britain Pattern.
11. Scandinavian Pattern.
12. Alaska Pattern.
13. Alpine Arcs.
14. Carpathian Pattern.



1. SATPURA REWAH COAL BELTS.
2. JHELUM INDUS SYNTAXIS.
3. HIMALAYA-BURMA- BALUCHISTAN.
4. NEW GUINEA PATTERN.
5. BORNEO PATTERN.
6. JAPANESE ISLAND ARC.
7. KAMCHATKA PATTERN.
8. VERKHOYANSK-KOLYMA PATTERN.
9. URAL PATTERN.
10. GREAT BRITAIN PATTERN.
11. SCANDINAVIAN PATTERN.
12. ALASKA GREENLAND PATTERN.
13. ALPINE ARCS.
14. CARPATHIAN PATTERN.
15. APENNINE PATTERN.
16. ANTILLEAN ARCS.
17. GUIANA PATTERN.
18. ALABAMA PATTERN.
19. MICHIGAN PATTERN.
20. KARROO GONDWANA PATTERN.
21. MADAGASCAR PATTERN.
22. ARCUATE COAST LINES. a) PERU b) CHILE.

Fig. 43. Structural Homomorphic Patterns

15. Apennine Pattern.
16. Antillean Arcs.
17. Guiana Pattern.
18. Alabama Pattern.
19. Michigan Pattern.
20. Karroo Pattern.
21. Madagascar Pattern.
22. Homomorphous Coast Lines.
23. Dome Structures—
    (a) Pamir, (b) Armenia, (c) Carpathian Range.
24. Guiana Rotational Movements.
25. Brahmaputra Rotational Movements.

1. The Satpura-Rewa Gondwana Basins of India

The Gondwana formations, including the principal coal fields of India, occur in about five more or less independent yet interlinked belts in Peninsular India south of the Son-Narbada Axis. (Fig. 44). Among these we have two basins, the Satpura Coal Basin largely in the Narbada Valley and the Rewa Coal Basin mainly in the Son Valley. These two river systems are peculiar in that they both originate in the same plateau of Amarkantak in the Maikal Range rising to 1127 m and have their early course in a general NW direction before they abruptly take to transverse WSW-ENE alignment while they flow in the opposite directions. The two coal basins of Satpura and Rewa though separated by a vast stretch (320 Km wide) of Deccan Trap yet exhibit identical rock formations, the same stratigraphic succession, identical floral association and even the same types of Deccan Trap eruptives as would be evident from Table 1 given below:

Table 1

	Satpura Basin	**Rewa Basin**
Post-Gondwanas	Alluvium, Laterite Deccan Trap Sills dikes and flows and Intertrappeans Lametas	Laterite Deccan Trap Sills Dikes and flows and Intertrappeans Lametas
Upper Gondwanas	Jabalpur Clays Bagra Conglomerate Pachmarhi Sandstones and Clays	Mahadeo Sandstones Clays and Conglomerates
Lower Gondwanas	Bijori Coal Measures Motur Clays Barakar Coal Measures Talchir Conglomerates and Clays	Raniganj Coal Measures Ironstone Shales Barakar Coal Measures Talchir Conglomerates and Clays
Pre-Gondwanas	Submetamorphic Phyllites and Schists Granites and Gneisses	Submetamorphic Phyllites and Schists Granites and Gneisses

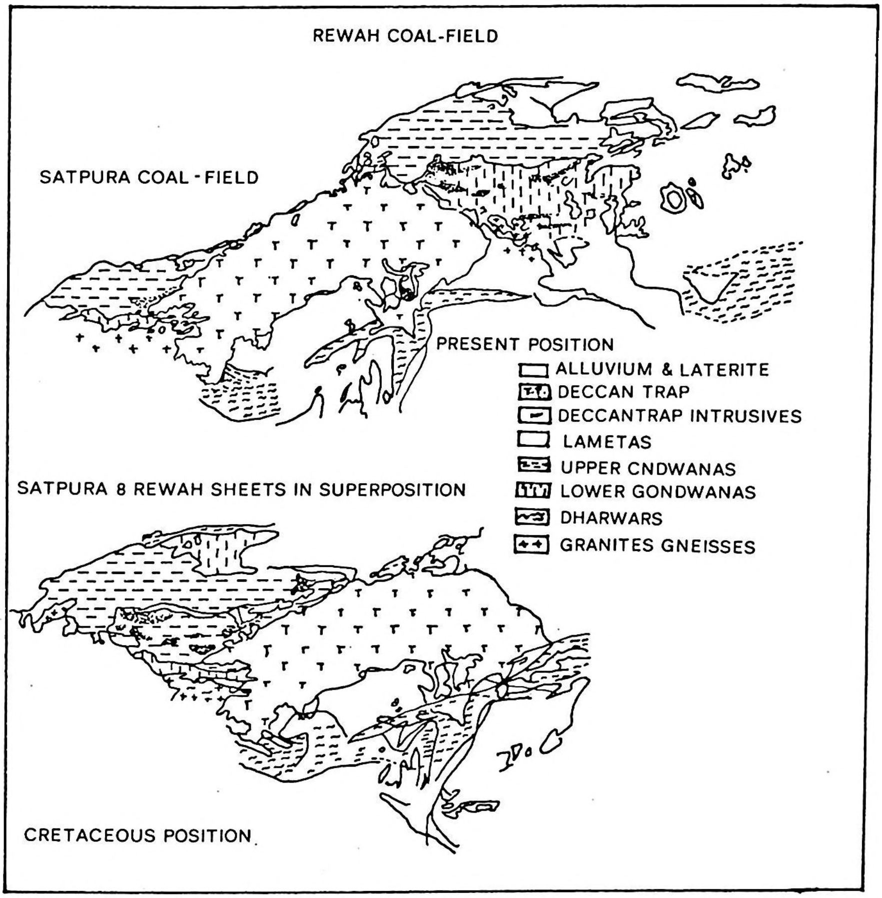


Fig. 44. Relations Between the Gondwana Basins of Narbada and Son Belts

The identity of the geological history of these two widely-separated basins from the Archaean right upto the Tertiary is by itself extraordinary but even more remarkable than this is the identity or complementary nature of their structural plans. This will be brought out most vividly if we place the geological traces of these two regions superposed as shown in Fig. 44. The correspondences of rock formations and mineral deposits in the two sheets would be obvious from the following occurrences from the Satpura and the Rewa Sheets respectively.

Table 2

	Satpura Basin	Rewa Basin
1.	Laterite outcrop of Seoni	= Laterite outcrop of Dharam—Jaigarh
2.	Arcuate trap dikes and sills of Mahadeo Hills	= Arcuate trap dikes and sills of Sohagpur, Kurasia Jhilmili
3.	Upper Gondwanas of Narbada Valley	= Upper Gondwanas of Chand Bhakar
	Upper Gondwanas of Jabalpur	= Upper Gondwanas of Palamau
4.	Barakars of Pench-Kanhan Valleys	= Barakars of Surguja
	Barakars of Mohpani C.F.	= Barakars of Sanhat C.F.
5.	Talchirs of Pench-Kanhan Valley	= Talchirs of Sohagpur
	Talchirs of Narbada Valley	= Talchirs of Surguja
6.	Dharwars of Narbada Valley	= Dharwars of Surguja
7.	Manganiferous Sausar Series of Nagpur-Balaghat	= Manganiferous Gangpur Series of Gangpur and Chaibasa
8.	Iron Ores of Bilaspur-Durg	= Iron Ores of Singhbhum
9.	Kyanite and Sillimanite of Bhandara	= Kyanite of Lapsa Buru
10.	Granites of Amla Chhindwara	= Granites of Pendra

It would thus be seen that the various rock formations and mineral deposits of these two regions are part of the same structural plan. Even the dike system of the one is only a counterpart of the other. What is more significant is that what is missing in one is to be found developed in the other in its corresponding position. It is, therefore, impossible to escape from the conclusion that the two areas, not long back in the geological past, were actually superposed, forming one composite structural unit right upto the Deccan Trap Period. The sheets later suffered lateral movements under the influence of subcrustal magmatic activity which gave rise to the Deccan Traps.

1. The Gondwana Basins of India

The relationships subsisting between the Rewa and Narbada Gondwana basins as indicated above are also found to persist in the case of other Gondwana Basins of Barakar Damodar, Son, Mahanadi, Godavari Valleys as well (Fig. 45). For a proper appreciation of these relationships, we may take the Godavari Basin as a type pattern. It is narrow and rectangular in the eastern part between Chanda and Singareni and becomes constricted further eastward before it terminates abruptly against the Upper Gondwanas of Rajamahendri developed transversely to the Godavari strike of the main basin. West of Chandrapur, the basin is broad, spatulate in shape extending upto Betul and is largely covered by the Deccan Traps. In size, shape and geological build, this Godavari basin shows a series of remarkable similarities with other Gondwana belts as those of Son-Mahanadi, Son-Damodar etc. These are easily brought out if we superpose the trace of the Godavari Basin over each of the other basins. Thus, the Upper Gondwanas of the Rajamahendri trending transversely to the main Gondwana strike corresponds with the Upper Gondwana outcrop of the Mahanadi Basin near Cuttack and also with the Rajmahal formation of the Upper Gondwanas near the region of Damodar Basin again with transverse trends. In these positions of superposition of the various Gondwana Belts, the structural lines of the various belts become coincident or parallel while the stratigraphic formations right from Pre-Cambrian, including the Dharwars, Cuddapahs and Vindhyans, and the Lower Gondwanas, the Upper Gondwanas and the post-

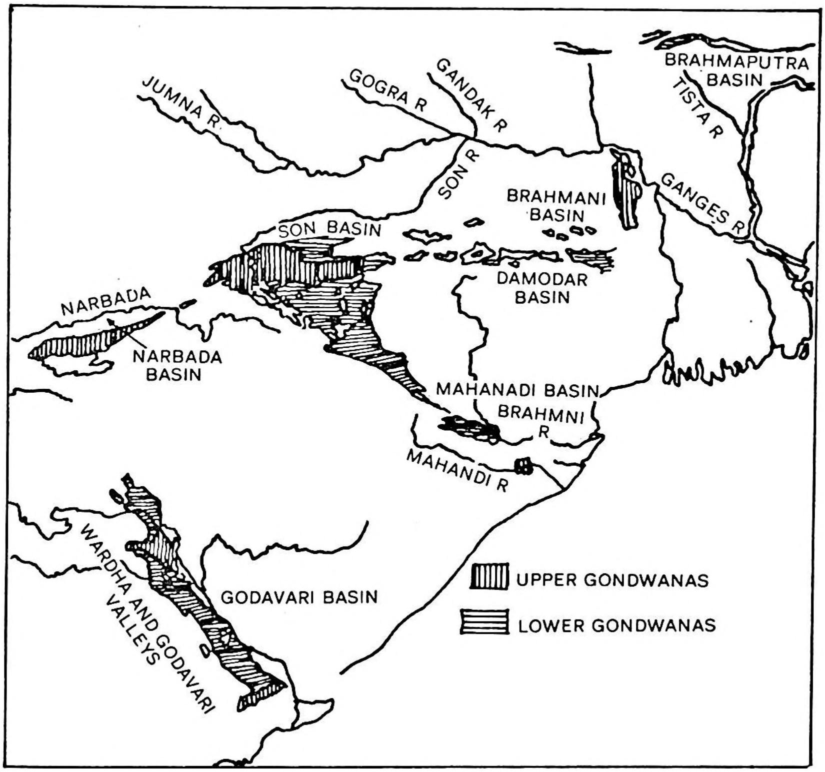


Fig. 45. Gondwana Belts of India.

Gondwana Lametas—all exhibit complementary relationships among themselves (Figs. A, B, C, D, E, F Plate 4 to 13). These are illustrated most remarkably also by the outcrops of the productive coal fields of the different basins as shown in Plate 14. These relations are extremely close and it is impossible to explain them in any way except that the various belts, as sheets, were in actual superposition throughout the period of deposition of the diverse rock formations from the Archaean right upto the Lametas of Upper Mesozoic age and even during the outpourings of the early phases of the Deccan Trap activity. The later stages of emplacement as separate basins can be worked out very precisely and from these it appears that the evolution of the Peninsular Shield of India, south of the Indo-Gangetic Plains, was actually brought about by the clockwise rotation of the Dharwar belt successively through the positions of the Damodar, Mahanadi, Godavari and Krishna basins.

2. The Jhelum-Indus Syntaxis

The nature of the festoons of the Sulaiman-Kirthar and the Hazara-Salt Ranges on the west and of the Burmese Ranges of Arakan and Pegu Yoma on the east, at the two terminals of the Himalayan Arc is still ill-understood, particularly in respect of their relations with the Himalayan orogenic belt. Diverse interpretations have been given which as already mentioned elsewhere, ranges from coalescence of independent orogenic belts, mouldings of identical geosynclinal fold belt against the Indian Peninsular promontaries, knee-like bending of the range by crustal squeezing of the mobile belt from NW and NE respectively. All these interpretations are unsatisfactory as they create as many new problems as they claim to solve and have relied on numerous postulates which have not been substantiated. The concept of Sheet Tectonics offers an eminently satisfactory solution of this problem. This would be clear by taking the example of the Jhelum syntaxis (Fig. 46). (Rode, K.P. Mar. 3, 1954, p. 9—20).

The Jhelum takes its source at the foot of the Zanskar Range, flows NW and suddenly takes a sharp reversal of its flow in a southward direction near Muzaffarabad on the Indo-Pakistan border. This acute bend brings about a very sharp change in the trends of the rock formations on the two sides from NNW trends of the Kashmir Himalayan formations on the east to WSW trends of the Hazara-Salt Range formations of Pakistan on the west. The Salt Range trending WSW parallel to the course of the Jhelum between Jhelum and Miawali cities of Pakistan has a peculiar hockey stick bend. The tip of the bent blade is breached by the Indus, while the broken shreds continue beyond the Indus to link the Salt Range with the Sulaiman Range.

The Salt Range is famous for its stratigraphic record and structure. The range includes marine sequence beginning with Salt Marl of the presumed Cambrian or Pre-Cambrian age, fossiliferous Khusak series of the Cambrian age, Upper Carboniferous formations including Boulder bed followed upwards by a remarkable development of the Permian, parts of the Trias, the Jurassic and the Cretaceous with a fuller development of the Lower Tertiary Nummulitic Limestone and of Upper Tertiary Siwalic continental formations in the Soan basin. The older formations are exposed along the southern scarp facing the Jhelum while younger formations are developed further north with gentle dips to the north.

The enclosed marine faunas are closely related to those of the Tibetan facies curiously represented in the Exotic Blocks of Mallajohar and in the vast belts of Ladakh-Kargil-Hanle zone in the upper basin of the Indus as also those of the Chenab and Jhelum in Kashmir.

Though exhibiting a detached nature of its basin the Salt Range Soan-Hazara basin is linked with the Himalayan basin on the east through continuous development of various Tertiary rock formations right from the Eocene Nummulitic Limestone through the Murries to the Mio-Pliocene Siwaliks, their trends making a conspicuously sharp angle along the Jhelum. The nature of the straight Jhelum suture line between the townships of Muzaffarabad and Jhelum is most enigmatic and has been subjected to diverse interpretations.

A closer examination of the geological map of the region as the one published by the Geological Survey of India on the 32-miles scale (2 mill. scale) reveals that the hockey stick bend of the Salt Range finds a remarkable counterpart in the lower Himalayas of the Punjab between Dalhousie in Chamba and Mandi in Bilaspur on the Sutlej near the Bhakra Dam. Both the regions are characterised by a unique development of Rock Salt deposits and are associated with traps, Murries and the Siwaliks.

Though these two regions of Salt Range and Mandi are separated by a distance of over 400 kilometres, they are linked in the intervening region by a continuous band of the

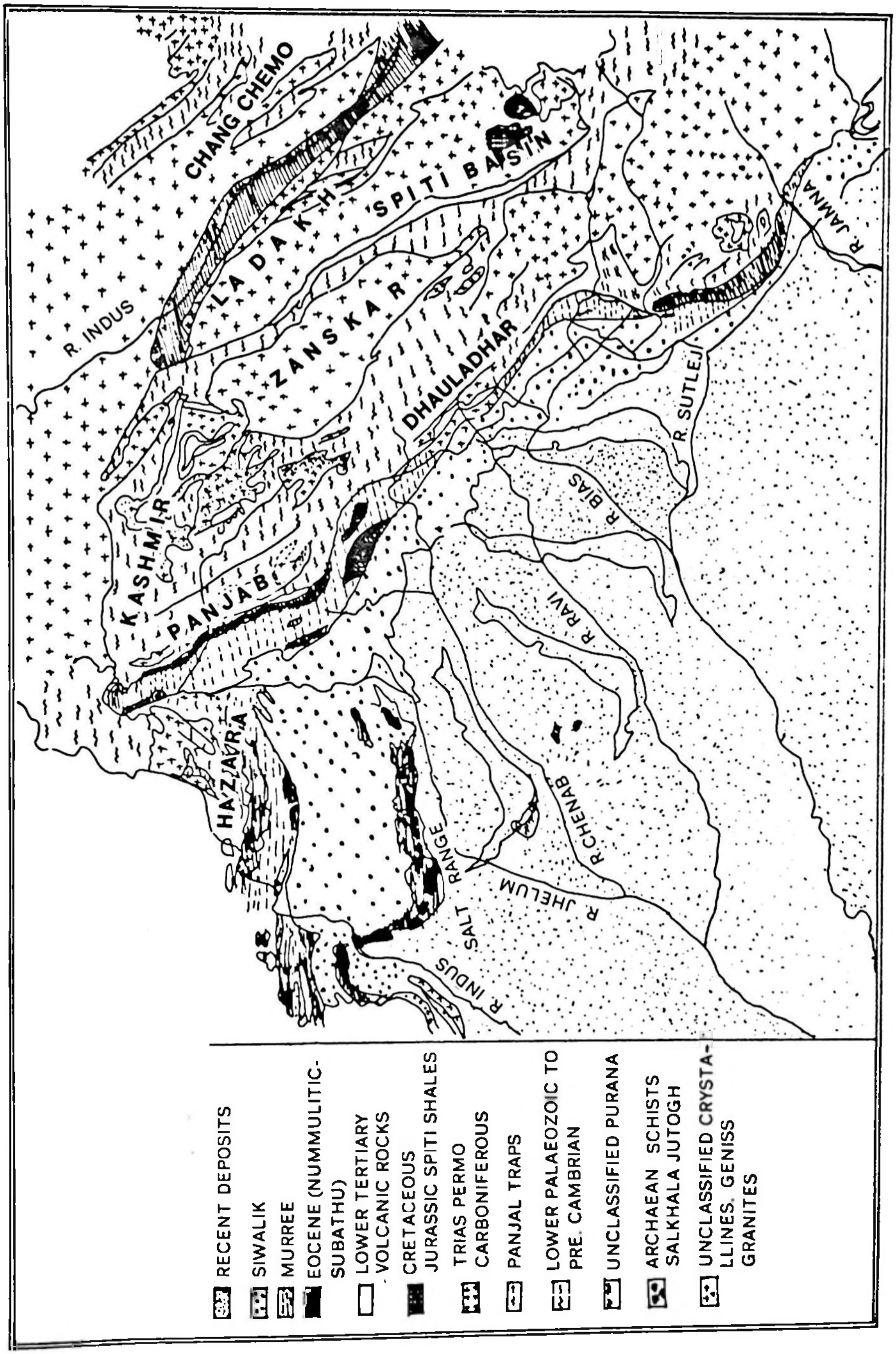


Fig. 46. The Jhelum Syntaxis

Siwaliks and Murries and by a system of tributaries of the Indus, viz. Sutlej, Bias, Ravi, Chenab and Jhelum, all exhibiting peculiar sharp syntaxial bends in their courses across the common Siwalik belt.

These various features, curious as they are, and common to the two regions, become intelligible if we transpose the trace of the Salt Range structure on the Mandi structure of the outer Himalayas. We find a series of parallelism in the stratigraphic, structural and geomorphological features as also in mineral deposits of the two regions. The fragile indented border of the Siwaliks against the Punjab Alluvium between Bhakra and Jhelum city indicates that portions of the Siwalik formations have been shorn off and removed, and alluvium is deposited in their place. The alluvial courses of the tributaries, the Sutlej, Bias, Ravi, Chenab and Jhelum, show a systematic opening of the angle against the Himalayan strike. It looks as if the river courses mark the position of the Salt Range structural sheet successively as it shifted from Mandi to its present position as shown in Fig. 46. During these pivotal movements the sheet left portions of its metamorphic basement now appearing as Kirana and Sangla hills jutting out like islands, in the Punjab Alluvium. These outcrops just mark the route of migration of the Salt Range Sheet from Mandi northwestward to its present position beyond the Jhelum.

The same mode of structural evolution would lead us to its earlier stages of migration if we follow the Himalayan course of the Sutlej right up to its source in the Mansarovar region. Here we have a vast development of the Lower Tertiary flysch, Nummulitic Limestone and Indus Ophiolites closely integrated with the vast basin of Palaeozoic and Mesozoic formations of the Kumaun-Garhwal Himalayas and where they are associated with the enormous development of Exotic blocks. It becomes easily comprehensible that the Salt Range was originally an integral part of the Tibetan zone of the Mansarovar Basin with which all the formations of the Salt Range have the closest faunal and lithological similarities and the same eruptive activity which was responsible for the Exotic Blocks was also instrumental in shifting the Salt Range sheet in successive stages along the Upper Sutlej, Middle Sutlej, Beas, Ravi, Chenab and Jhelum to its present position.

A similar relationship appears to exist between the Sulaiman-Kirthar ranges of Baluchistan region on the Lower Indus and the Tibetan-Spiti Himalayan sedimentary basins in the source region of the Indus. These two basins are linked through the trans-Indus Salt Range, the Hazara and the Kashmir ranges in the Indus Syntaxial region round Nanga Parbat. The stratigrahic relations with the Tibetan Himalayan Basin can be seen from Table 3.

Table 3 shows that right from the Permo-Carboniferous upto the Eocene, we get identical succession, faunal assemblages and even volcanic eruptives.

Such remarkable identities of stratigraphical formations extending continuously from Permo-Carboniferous to Eocene and developed in two widely separated regions with no indication of direct communication, is incapable of being explained except on the basis of their original continuity during deposition and their later separation and migration as sheets. Their mode and stages of migration can be made out precisely by following the Jamuna and its tributaries, viz. Chambal, Banganga, Mendha in the SW and later the rivers Luni, Nara and Lower Indus and its tributaries in the west. The structural pattern of

Table 3

Correlation of Stratigraphic Formations of Baluchistan and Tibetan Himalayas

	Sind Baluchistan	*Tibetan Himalayas*
Pliocene	Manchars	Siwaliks
Oligo-Miocene	Gaj, Nari; Khojak Shales; Bugti beds	of Mansarovar region part of Malla Johar Flysch may belong here Kasauli, Dagshai of Lower Himalayas.
Eocene	Kirthar Limestone Laki Ranikot	Orbitolina limestone Operculina limestone Gastropod limestone (Kampa System)
Cretaceous	Cardita beaumonti bed Pab Sandstone Olive Shales Hemipneustes beds Lituola beds Parh Limestone Belemnite Beds	Flysch of Malla Johar (in part) Tuna-Limestone Scarp Limestone Hippurite Limestone Belemnite Sh. Kampa Sh. of Malla Johar (Kampa System)
Upper Jurassic	Polyphemus beds	Ladakh Macrocephelites bed
Lower Jurassic	Massive Limestones	Massive Grey Limestone of Byans
Upper Trias	Monotis salinaria Shales & Limestones Phacophyllites bed	Kioto Limestone of Painkhands and Ngari Khorsum Phacophyllites bed
Permo Carb.	Productus Limestone of Kalat Fusulina Limestone of Mach.	Productus Limestone of Chitichum-Hundes Exotics Mt. Everest Limestone

Sind-Baluchistan Ranges is remarkably similar to that of the Aravalli-Delhi Ranges of Rajasthan as would be seen from Fig. 47. Stratigraphically, the Aravalli-Delhi formations are largely Pre-Cambrian while those of Sind-Baluchistan are post-Triassic and as such appear to have rested as a sheet over the Aravallis. The Aravallis basement was left behind as the overlying Baluchistan sheet migrated further west as a part of the Sutlej-Indus Syntaxis. The phenomenon of Exotic Blocks in Hindubag Pishin area of Baluchistan in which the Permocarboniferous and Triassic blocks are found floating over the Cretaceous traps is a clear evidence of these movements (Rec. GSI, Vol. 28, p. 8). The Deccan Traps which abound along the western and northern periphery of the Sind-Baluchistan Ranges appear to have played a prime role in the clockwise lateral movement of the Kirthar-Sulaiman sheet from the Tibeto-Himalayan basement passing through the stage of the Aravalli's, to their present position.

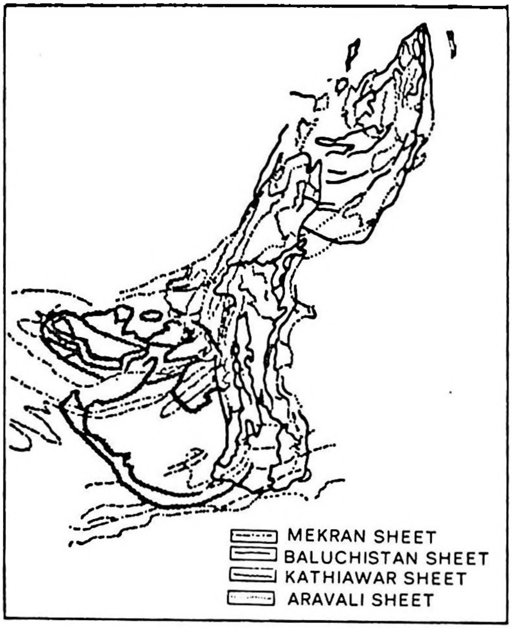


Fig. 47. Aravalli Baluchistan Relations

3. Himalaya-Burma-Baluchistan Relationships

The Kirthar-Sulaiman ranges of Sind-Baluchistan run oblique to the strike of the Himalayas and are linked with them through Indus syntaxial bend round the Nanga Parbat pivot. They also exhibit intimate faunal relationships with the Tibeto-Himalayan life province throughout their marine regime since the Permocarboniferous. Similarly, the Burmese ranges running transversely to the Himalayan strike at the eastern end are also linked with the Himalayan Range through the Arunachal-Mishmi Ranges in the syntaxial bend of the Brahmaptura round Namcha Barwa peak. For the most part of their marine regime since Ordovician, they exhibit close faunal relations with the Tibeto-Himalayan faunas and also with the Baluchistan faunas of the corresponding ages.

The structural relations of the Burmese Ranges with the Himalayas are, however, highly complex and their understanding depends on the interpretation of the Brahmaputra syntaxis.

The paucity of adequately fossiliferous formations in the Himalayas east of Nepal makes it difficult for us to work out the detailed faunal relationships of Burmese formations with those of the Himalayas.

The Burmese formations, however, show more extensive relationships with those of the Baluchistan ranges, particularly those belonging to the Post-Triassic ages and with the Spiti-Salt Range formations of the Pre-Triassic ages. This would be evident from Table 4.

Table 4

Stratigraphic Correlation of Baluchistan, Himalayas, Burma.

Baluchistan	*Tibetan Himalayas*	*Assam*	*Burma*
Manchars	Siwaliks	Dihing	Irrawaddy
Nari	Murrees	Tipam	Pegu
Gaj		Surma	Pegu
		Barail	
Kirthar	Subathu		Yaw, Pondaung
			Tabyin
Laki			
Ranikot		Jaintea	Tilin Laungshe
Deccan Traps	Indus Ophiolites	Sylhat Traps	Paunggyi
Cardita-beaumoni	Kampa System	Cherra	Serpentine and basic
			intrusives
Pab. Sd.		Mahadeo	Axial
Parh. Limestone			Negrais
Massive Limestone			L. Cretaceous
Polyphemus bed			Namyau
Grey Massive	Ladakh		
Limestones	Byans		Loi An Series
Jurassic Shales	Spiti Shales		Napeng beds
Up. Trias.	C. Himalayas		Karenni, Amherst
			(Kamawkala Limestone)
Permo	Productus		Up. Plateau Limestone
Carboniferous	Limestone		
Prod. Lmst.	of Karakoram		Moulmein Limestone
of Kalat and	Hundes		
Mach	Tibetan Zone		
Chitral			
Devonian ·······	Muth Syst ········	················	L. Plateau
			Limestone
			(Paudaukpin)

The routes of migration between these two distinct disconnected basins are, however, not immediately traceable. The structural patterns of the two basins exhibit many points of correspondence as will be seen from Fig. 73. The eastern belt of Burma is largely made of Pre-Jurassic formations while the Baluchistan structure is largely Post-Triassic in build and as such the two are complementary in their development. The structural lines are mostly coincidental or parallel. The Upper Cretaceous Eocene (Deccan) Trap Activity is common to the two structural belts (F.H. Pascoe 1405, 1412). Both the basins exhibit faunistic relations with the Central Himalayan basins of Kumaun-Spiti and the Salt Range.

It was shown earlier that that Baluchistan sheet was situated originally in the Tibetan Himalayas of Kumaun and Nepal in the source region of the Indus and the Ganges. It seems possible that the Irrawaddy basin of Burma was also originally situated in the source region of the Brahmaputra (Tsangpo) closely juxtaposed with the Baluchistan sheet in the Mansarovar region during the whole of the geological period upto the Lower

Tertiary. The Gangetic syntaxial movements caused rotation of Baluchistan sheet clockwise along the route of the Lower Ganges, Jamuna, Chambal, Banas, Luni, Nara and the Lower Indus while the Brahmaputra syntaxial movements shifted the Burma Sheet eastward along the Tsangpo upto the Arun Basin. Later, the Burma Sheet rotated anti-clockwise along the route represented by the Tista, Raidak, Manas, Subansiri and later also by the Meghna, Manipur, Chindwin and the Irrawaddy to its present position beyond the Brahmaputra syntaxial bend near Sadiya. In this process, the Shillong-Mikir Plateau mass after some rotation was left behind trending WSW-ENE between the Brahmaputra and Irrawaddy Basins.

From the above treatment, it would be observed that the two mountain belts of Burma and Baluchistan, running transversely to the Himalayan trend at its eastern and western extremities, were originally integral structural components of the upper Indus-Tsangpo Basins in the Tibeto-Himalayan region proper and that they got opened out and extended enechelon to the east to Namcha Barwa and the other to the NW in Nanga Parbat before they rotated southwards anti-clockwise, round the pivot of Namcha Barwa on the east and clockwise on the Nanga Parbat pivot on the NW.

Since the Dharwar-Gondwana basins of India also give indications of clockwise rotational movements, it is obvious that the whole of Peninsular India south of the Indo-Gangetic Plains came into existence in its present form through the clockwise rotational movements connected with the evolution of the Ganges-Mahanadi-Godavari-Krishna system of rivers.

4. The New Guinea Pattern

One of the finest examples of structural patterns is afforded by the New Guinea Type. The island of New Guinea constituting an important link in Australasian Circum-Pacific Arc System is situated along the southeastern border of the Indonesian Islands, between Philippines and New Zealand. Morphologically, this island has a peculiar shape resembling the figure of a bird and exhibits in its structure a head (Vogel Kop), a neck (Wanggar), a trunk and belly (Digoel and Fly River plains) and a tail (Owen Stanley Range), with the vertebral column represented by the Sneeuw-Owen Stanley Range running all along the body from head to tail and often rising to a height of over 4880 m. Wings are also represented by the Bismark-Soloman Archipelago.

Geologically, the Mesozoic and Tertiary rocks go into the composition of the highly-folded Central Range with traces of Palaeozoic in the core regions whereas the plains on either side are made up of gently dipping or horizontal late or post-Tertiary formations associated with enormous expanses of Tertiary and Quaternary eruptives often developed in belts parallel to the longitudinal structural ranges.

This peculiar bird-shaped structural pattern, however, is not confined to New Guinea alone. Remarkably, it is found in the neighbouring regions with a structure almost identical in shape and even in size, repeated a number of times along a particular trend (Fig. 48). Thus, we find it in the Philippines Archipelago exhibiting the same overall pattern even when the structure is formed of disconnected islands. The Luson Island corresponds to the head, the narrow central chain of folded ranges running through the Eastern Island and accompanied by ultrabasic intrusives, forming the backbone, the

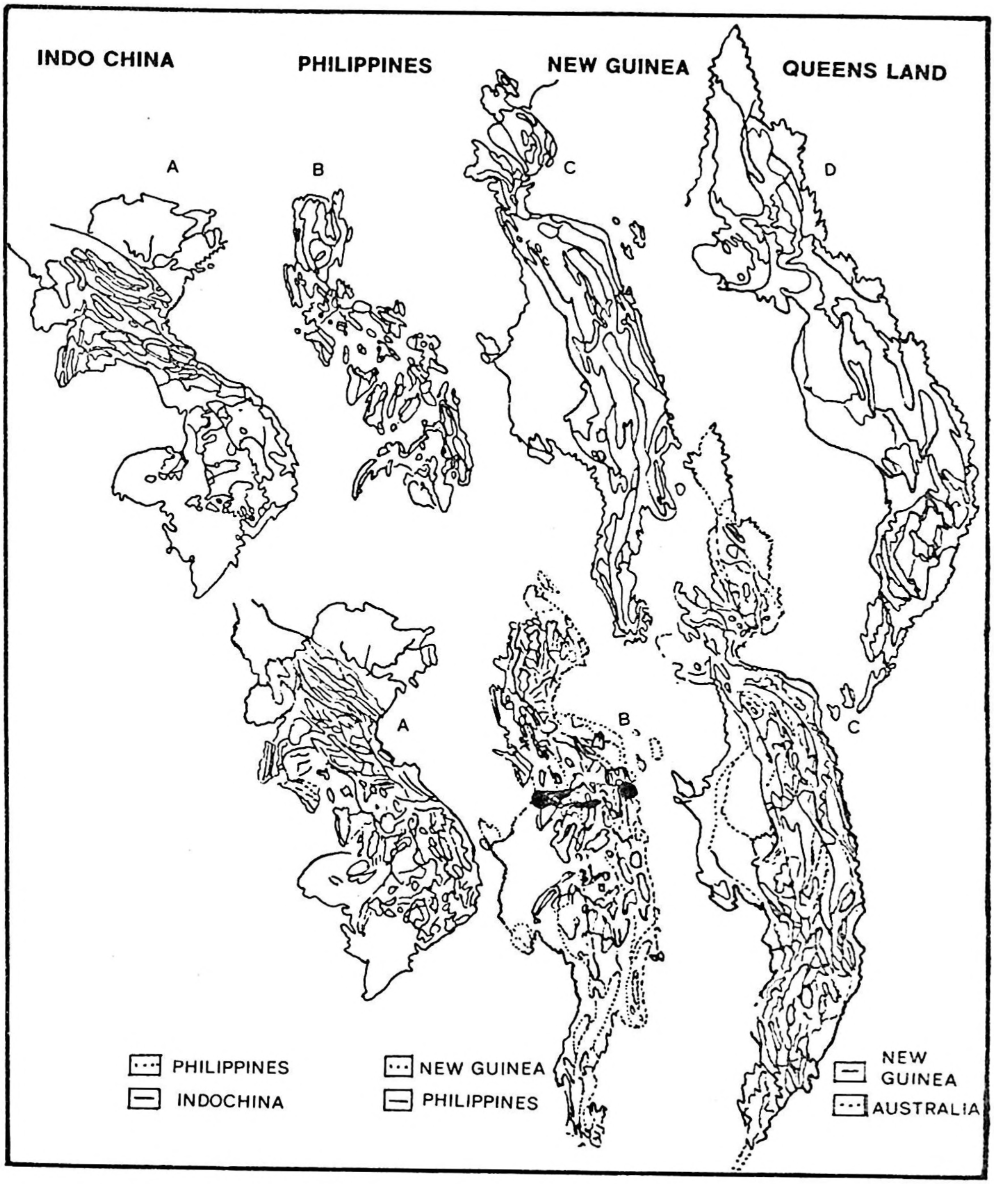


Fig. 48. Structural Similarities in New Guinea Patterns

Mindanao-Talaud (Singhe) Island Arc, forming the rudimentary tail, Palawan and Sulu Arcs on either side of the Sulu Sea form the pair of legs.

Geologically, the Philippines Arch constituted essentially of Tertiary formations is intimately interspersed with widespread Tertiary eruptives largely arranged in a linear belt parallel to the Pacific coast. If the tracings of the geological maps of the two island masses of the Philippines and New Guinea are superposed, a series of remarkable correspondences in the form, size, structural lines, complementary development of eruptives and Tertiary formations, all come out very vividly and it becomes apparent that the two island masses must have been genetically connected and actually superposed even till the late geological periods.

The same New Guinea pattern is again found developed in the Indo-China region east of the Lower Mekong bordering Thailand. The same 'S'-shaped bird-like form with the head near Luang Prabang, the trunk along Vietnam-Laos border, and the plains forming the belly, all come out strikingly with the difference that the tail portion is not so clearly developed in Indo-China except possibly as an incipient submarine rise.

Geologically, the Indo-China terrain is constituted of Pre-Jurassic formations including Glossopteris bearing Rhact in Tongking with a vast spread of Tertiary eruptives. When the trace of the geological map of Philippines is superposed over that of Indo-China, the parallelism of the structural lines and the complementary development of Tertiary traps come out very clearly, strongly suggesting that the Philippines sheet together with the New Guinea structure was resting superposed over the Indo-China basement at least till the period of Tertiary eruptive activity.

Most remarkably, we get the same pattern yet again further south of New Guinea Arc along the eastern sea board of Australia, east of the Great Dividing Range forming the large part of Queensland. In this region, the head part of the bird-like pattern is recognisable in the Atherston Plateau near Cairns, the trunk along the eastern board of the Dividing Range, the tail along the New England Range between Brisbane and New Castle and the belly in the westward bulge of the Great Dividing Range in southwest Queensland.

Geologically, this coastal belt of Queensland is built up of folded Palaeozoic and Mesozoic formations with traces of Tertiaries with stupendous development of the Tertiary and Quaternary eruptives covering a belt of over 400 km wide running from Torres Strait in the north almost continuously upto the Victorian coast and continues even further south into Tasmania forming a plateau often rising to 600-900 m in altitude.

Traces of the New Guinea structural pattern can again be recognised, though only faintly, in Adelie land, Wilkes land and Queen Mary land, along the coastal belt of Eastern Antarctica composed largely of charnockitic basement rocks.

Thus, we see that the New Guinea structural pattern occurs repeatedly in Indo-China, Philippines, New Guinea, and Queensland and even on the eastern board of East Antarctica with the pattern gradually enlarging in size as we go from the northwest to the southeast. Older formations are preserved in East Antarctica, Queensland and Indo-China while the younger ones are developed in Philippines and New Guinea belts. The Tertiary eruptives, however, appear common to all these structural sheets with complementary relations in their regional development.

The conclusion is inevitable that all the five sheets with a common structural pattern were actually in superposition upto the period of the Tertiary eruptivity in the region of Indo-China and still earlier, in the position of eastern Tibet upto the Cretaceous. Due to sheet movements, Queensland as a subplatform moved successively from Indo-China to Philippines and from there to Arafura sea region when New Guinea sheet separated from the Queensland basement. These Sheet Movements left *en route* part of its substructure as the Great Barrier east of Queensland before the latter moved further SSE to its present position. The Antarctic basement substructure moved from the Tibetan stage southward along the Mid-Indian Ocean Ridge through the Amsterdam Plateau to its present South Polar position.

It may further be mentioned here that the New Zealand (which also had Glossopteris flora (Milden Hall D.C. 1970. Aust. Jour. sc. Vol. 32(12)/2-474-75.1970) was also occurring closely superposed over the Pacific board of Australia along the New South Wales-Victoria coast as a continuation of New Guinea tail structure. This was separated from the mainland some time in Quaternary-Recent geological period, simultaneously with the separation of New Guinea from Queensland. Tasmania, originally a southern continuation of the Great Dividing Range, also got separated from Victoria during the separation of Antarctica from Australia.

5. Borneo Structural Pattern

Borneo is an important constituent of the arcuate Indonesian Archipelago detached from the Asian mainland by the South China Sea. It has a deformed 'D'-like shape with a zigzag irregularly projecting outline. The numerous projections in the coastline are termination of the arcuate hill ranges branching out from the main NE-SW trending Penambo Range. This range rises to more than 4000 m at the northeastern end and to about 2140 m at the southwestern end. In outline it is crudely triangular with blunt corners and crenulated arcuate sides.

Geologically, the island is composed essentially of Tertiary formations with unclassified metamorphosed Palaeozoics in the core zone trending NW-SW, in the middle. In the south, it is fringed by a broad belt of Quaternary alluvial deposits. This pattern with its peculiar outline is recognisable negatively in the depressed central region of Thailand bounded on the east by the zigzag course of the Mekong river along the border with Laos and Cambodia. Here the Mekong river makes a number of sudden and acute bends in its lower course and reproduces curiously, the irregularities both in form and size of the northern and eastern coasts of Borneo while River Ping Chao reproduces the Sarawak coastline and if we superpose the outline trace of the island of Borneo over the central part of Thailand, the fit in the outline is very precise and the geological formations of Borneo also fit in very well with those of the surrounding Thai-Indochina region, particularly the Mesozoic intrusives and Quaternary deposits in the region of the Gulf of Siam. Thus, there is a strong possibility that Borneo then with N-S trends did occupy the Thailand position before it migrated as a sheet to its present position right across the Gulf of Siam and the South China sea (Fig. 49).

With this Thailand position of Borneo, we can easily explain its intimate faunal relationships with Philippines and New Guinea on the east and with the Sumatra-Malaya ranges on the west. From the N-S orientation in the Thailand position, the Borneo sheet

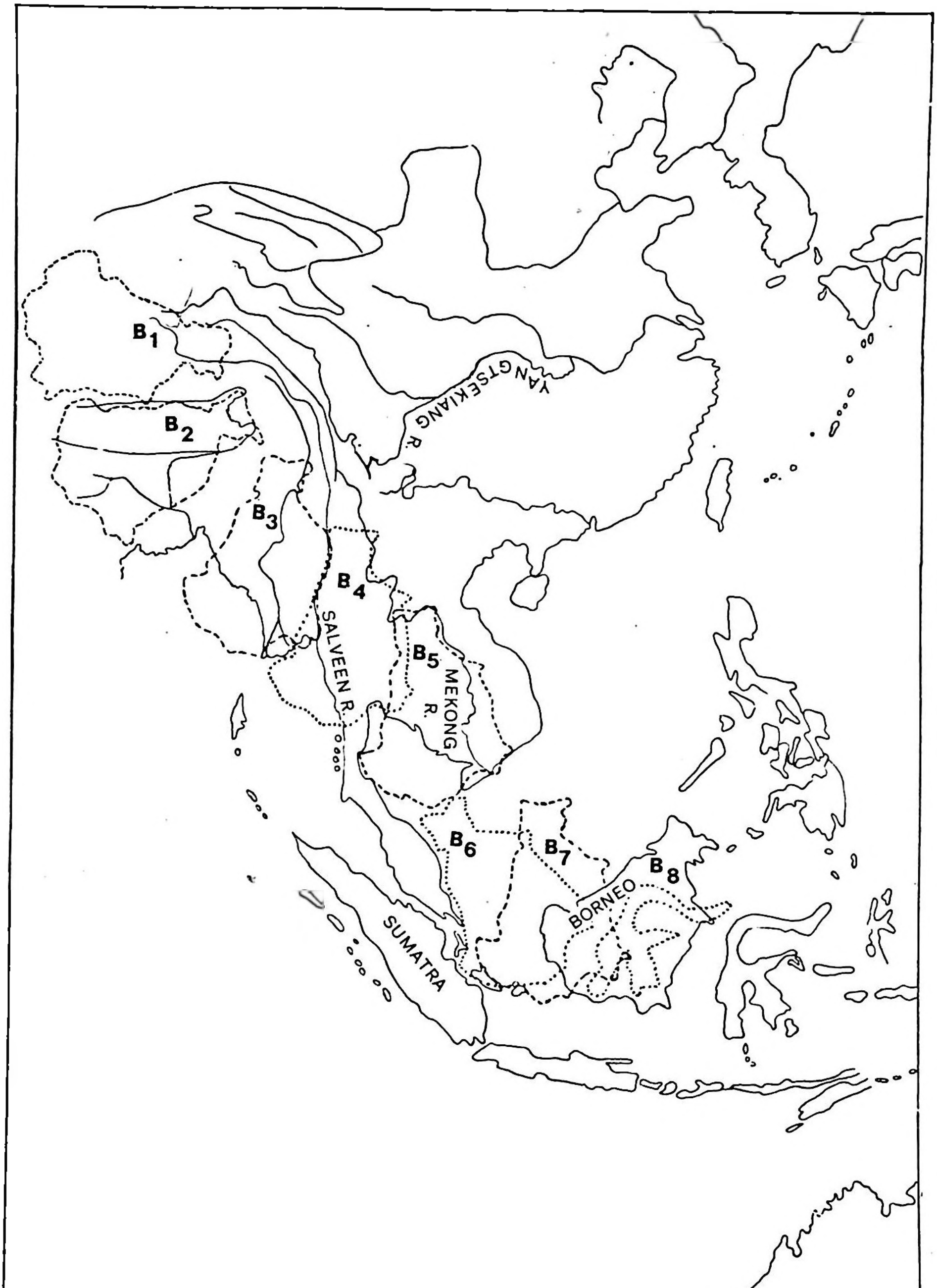


Fig. 49. Migration of Borneo Structures

shifted southward to extricate itself from the Tennasserim-Indochina grip and moved along with the Malaya mass through the Gulf of Siam to the position of Singapore and later to the position of Bangka, Billiton and then rotated clockwise to its present position, leaving a shallow shelf sea in the intervening region. During this period, Philippines with New Guinea moved east and southeast through the South China Sea still maintaining linkages with Borneo in the nature of Palawan and Sulu Island Arcs.

Traces of the Borneo structure are also recognisable in the Eyre-Darling and Murray river basins in North, South and SE Australia and these indicate an earlier position of Australian continental plate, then serving as a substructure for Indonesian sheets.

6. Japanese Arc Pattern

The Japanese Arc, consisting of the islands of Kyushu, Shikoku, Tokyo and Hokkaido, is a part of the CircumPacific orogenic belt along the east coast of Asia and separated from the mainland of Asia by the Sea of Japan. This Arc approaches the mainland near the Korean Peninsula through a shallow bank studded with islands of the Nagasaki group. This Island Arc of Japan continues southward with a knick, into the Ryukyu Island Arc which also has a curvature and size very similar to those of the Japanese Arc. This curvature of the Ryukyu Arc is again remarkably similar to the Chinese coast against the East China Sea between Hongkong and Shanghai and is also parallel to the continental slope (200 m contour) against the Chinese shelf between Formosa (Taiwan) and Japan (Fig. 50).

The coastal Arc of China between the mouths of Sikiang and the Yangtsekiang appears to be repeated in the continental interior in parallel trends several times through the southern tributaries of the Yangtsekiang, though systematically decreasing in length as we go westward. Strike trends of rock formations also repeat in the same direction NE-SW, south of the Yangtsekiang Basin. In the region of syntaxial bends of the Yangtse north of Kun-ming, the trends of rock formations change as we go from E to W, gradually from NE to north and partly to NNW parallel to the upper Yangtsekiang along the eastern border of Tibet and this upper course of the Yangtsekiang has the same curvature and size as those of the Japanese arc. This curvature is further repeated roughly in the upper courses of the Mekong and Salween as well, in eastern Tibet with trends changing to NW and WNW. These upper Yangtsekiang curvatures as well as those of its tributaries Yalung and Tatu are parallel to the Chinese Yellow Sea coast NW of Shanghai and also to that of the Korean Peninsular coast against the Sea of Japan.

These correspondences in the trends of river courses, sea coast and folded rock formations, repeated a number of times between eastern Tibet on the west and Japanese Arc on the north-east are quite significant and are apparently intimately related to the course of evolution of these geomorphological and structural features of the region.

Geologically, the Japanese Arc is composed of thin shreds and strands of Palaeozoic and Mesozoic fossiliferous formations, all caught up in a vast development of Tertiary and Quaternary volcanic flows and pyroclastics. These Palaeozoic formations show close faunal relationships with those of Korea and China, on the one hand, and with those of the Himalayas and the Indonesian Islands, on the other.

A closer study of the geology and structure of the Japanese Islands indicates the possibility that originally this Island Arc was much smaller in size, probably of the size of

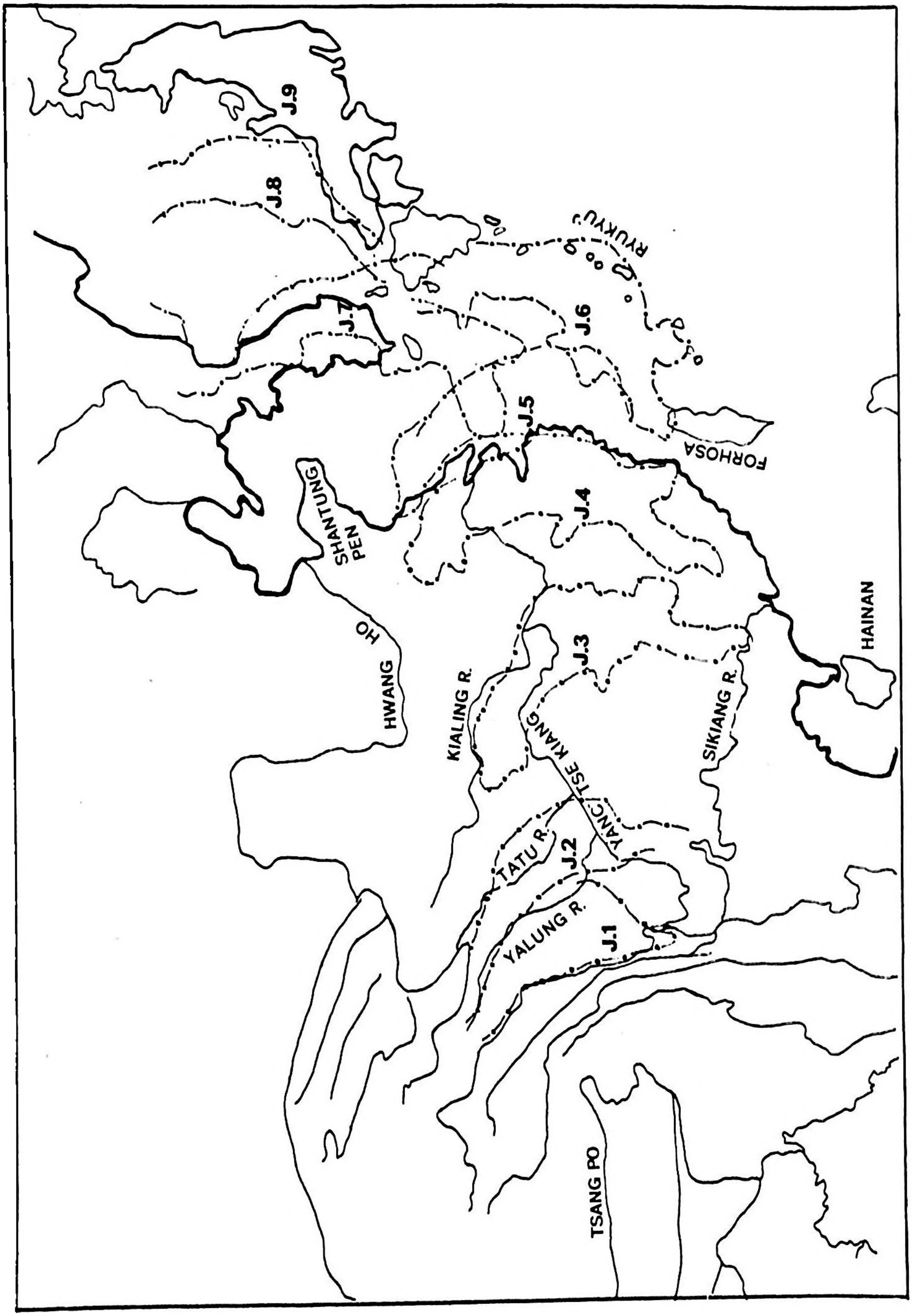


Fig.50. Evolution and Emplacement of Japan

Korea, and closely forming an integral part of the same as its superstructure. During the early geological stages, this whole compact arcuate mass was situated in the source region of Yangtsekiang in NE Tibet north of Chungtien. During its early southward movements, the overlying sheets of Kyoto and Kyashu were separated and carried much further south, and the Tokyo part of Honshu remained superposed over the Korean mass while still lying in the basin of the upper Yangtse. In the region of reversal of the Yangtse drainage in N. Yunnan and in the basin of its northern tributaries Yalung and Tatu, there was differentiation and separation of sheets. The Tokyo part of the Arc got separated from the Korean basal sheet and also from the Kyoto part of the arcuate sheet. It rotated clockwise through a much wider angle. The Tokyo Arc, however, remained linked with its basal sheet of Kyoto at its eastern end and these two shifted eastward along the trends of the southern system of tributaries Wu Kiang and Kan Kiang while the Korean mass was shifting east-north-east along the northern tributaries Hon Kiang and Sha Ho of the Yangsekiang. In this way, the Japanese Arc reached the East China Sea coast south of Shanghai while its southern island Kyushu was still attached to Taiwan along the southern Chinese coast between Swatow and Foochao. From this position along the East China Coast the Japanese Arc shifted eastward along the East China shelf Zone up to the position of Ryukyu Island Arc. The Korea Peninsular mass shifted over the Yellow Sea shelf to the northeast to its present position. From the Ryukyu position, the Japanese Arc, now completely separated from Korea, moved northeast to Oki-Takesh position now partly linked with Kamchatka which was then resting over Sikhote Alin mass. From the Oki-Takesh position, the Honshu arc rotated eastward to its present position; simultaneously, the Kamchatka sheet moved to the Sakhalin-Hokkaido position.

The Yangtsekiang with its northern and southern tributaries thus records the earlier evolution and migration of the Japanese Island Arc as also of the Korean peninsular mass systematically from their Tibetan homeland up to the coastal belt of the Chinese mainland. Their further migration into the Pacific Ocean is marked by continental shelves and slopes along the continental margin and the shiftings of the Oceanic Trenches on the south from the Ryukyu-Taiwan-Philippine position through Kyushu Palav Trench to the position of the Mariana-Japanese Trench along with their associated submarine ridges and Island Arcs.

7. Kamchatka Structural Pattern

The peninsular mass of Kamchatka constitutes almost the northern terminus of the East Asiatic Circumpacific orogenic belt. It is projecting into the Pacific with the Kurile Trench on its east and the Okhotsk shelf sea on its west. It is connected with the Sakhalin and Japanese Island Arc through the Kurile Island Arc and the Island of Hokkaido (Fig. 51).

The Kamchatka peninsular mass has a lanceolate leaf-like form with crenulated eastern border and is attached to the Siberian mainland by a narrow stalk of Koryakski Range running along its length like a mid-rib and often rising to a height of nearly 5000 metres. On the east and southeast, the continental slope falls rapidly, culminating into an Oceanic Trench over 10000 metres deep. Geologically, the Peninsula is made up of Tertiary marine sediments overwhelmed by Tertiary Quaternary Circumpacific eruptives ac-

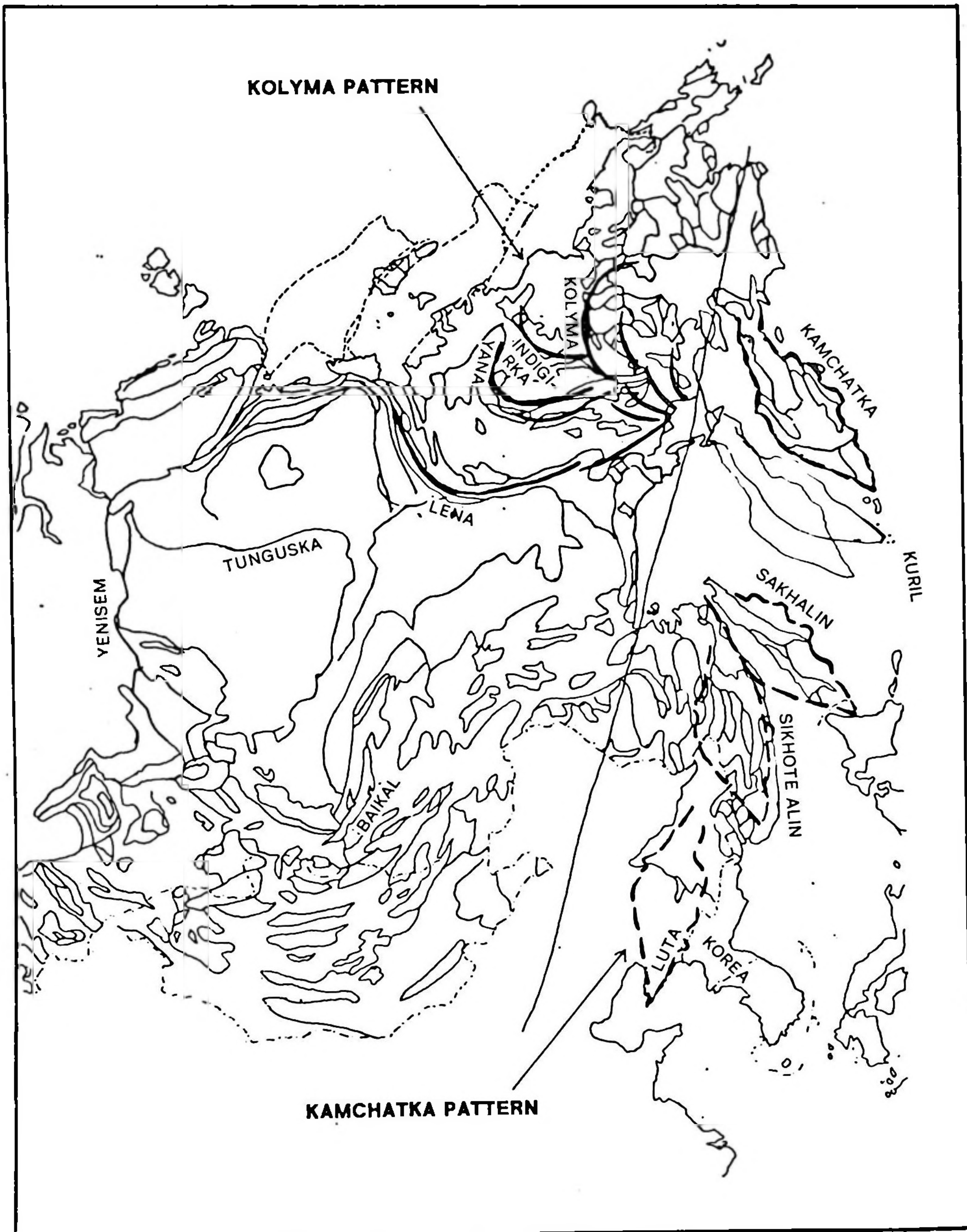

KOLYMA PATTERN
KOLYMA
INDIGI-RKA
YANA
KAMCHATKA
LENA
TUNGUSKA
YENISEM
KURIL
SAKHALIN
SIKHOTE ALIN
BAIKAL
LUTA
KOREA
KAMCHATKA PATTERN

Fig. 51

companied by altrabasic intrusives and is folded into Alpine type mountain chain running all along its length.

This lanceolate structural pattern with allied Tertiary rock formations is again met with in the Gori Sikhote Alin east of the Ussuri-Amur valley and partly also as a rudiment in the Sakhalin Island continuing into the Hokkaido Island of Japan. The same form is further recognisable in the valley of Liao Ho in south Manchuria continued southward into the Antung Luta Peninsula and again further southward as a negative feature of low plains in the lower Hwang Ho-Tzaya Ho valley south of Peking. Further west, we again get a similar lanceolate structure in the Nan Shan ranges in the Kokonor region of the Tsaidam marshes north of the Kunlun. These repetitions indicate that the Kamchatka peninsular mass with abundant eruptives was originally situated in the Tsaidam region upto the Tertiary. Due to the intrusion of Hingan Ling and related eruptives, it was transported northeastward partly with a clockwise rotation in the Ordos region. Through successive lateral movements in the northeastern direction, it migrated further along the route marked by the Hwang Ho, Liao Ho and by the Sungari and Ussuri tributaries of the Amur upto the position of Sikhota-Alin. From here the Kamchatka mass radially moved over to the Sakhalin position through a pivotal Tatari rift into the sea of Okhotsk, whereas the trace of its later movements is registered by the Kurile Island Arc. During all these movements, the Kamchatka mass formed an integral part of the Kolyma peninsular mass which also suffered more or less corresponding movements from the Hwang Ho Basin to the Amur Basin followed by those of the Aldan, Lena, Indigirka and the Kolyma rivers.

8. The Verkhoyansk-Kolyma Structural Pattern

In the mountainous region of northeastern Siberia east of the Lena and culminating in the Chukoski Range of the Bering strait we have a series of arcuate structural ranges which exhibit certain peculiarities indicative of genetic relationships among the various ranges now seen distributed over a large area from the Lena to the Bering strait. The range of Verkhoyansk on the west facing the lower Lena exhibits a grand semicircular curvature concentric with the lower Lena with convexity facing the S, SW of west. This range is followed to the east by the Cherskogo range also arcuate in development, roughly parallel to the Adycha Yana course, roughly concentric with the lower Lena. This is followed on the east by the rivers Indigirka and Kolyma with N-S courses with convexity again to the west. These ranges Verkhoyansk, Cherskogo and Kolyma as also their associated intervening river courses of Lena, Yana, Indigirka and Kolyma all exhibit an arcuate pattern all convex to the west, radiating from a common area in the source region of the Kolyma series of rivers not far from the Sea of Okhotsk (cf. refer to fig. 51B).

Geologically, the Verkhoyansk Range is mainly constituted of Permo Triassic formations fringed by Jurassics and a large component of Cretaceous, with trends remarkably parallel to the Aldan-lower Lena course. The Cherskogo range has a core of lower Palaeozoics, including Ordovician Silurian, overlain by Triassic and Jurassic rocks and abundantly invaded by lower Tertiary intrusives. The Kolyma range, on the other hand, along its western face is made up of Pre-Cambrian, through Cambrian to Middle Palaeozoic rock formations in the core region overlain by the Permian and a full sequence of Mesozoic formations. The eastern face of the Kolyma range is composed almost wholely of Upper Cretaceous and younger eruptives. Thus, these ranges exhibit systematically a greater development of Lower Palaeozoic and older rocks in the core region of the Kolyma Basin in the east and are covered by Permo Triassic and Jurassic formations on the west, while Cretaceous and Tertiary volcanics are developed more abundantly in the east as also all along the north coastal belt of the Okhotsk Sea.

These characteristics of the geological development indicate the folding of Pre-Jurassic formations during the Cretaceous-Tertiary period and diversification of folded belts through the uncoiling radial movements during the Quaternary.

9. Ural Structural Pattern

The Ural Range occupies a very distinctive position in the structure of the northern continents, particularly the Eurasia. Though fairly subdued in relief with peaks rarely reaching 2000 metres, it has played a remarkable role in the geological evolution of the northern region. It has divided the Eurasian continent longitudinally into two unequal portions—the Asiatic and the European.

Physically, it is a low relief mountain range running almost NS extending for 2000 Km from the Caspian Sea to Novaya Zemlya in the Kara Sea portion of the Arctic Ocean. The mountain has a characteristic composite structure with ranges running longitudinally, waxing and waning in their width. In the region south of Chelyabinsk and Ufa, the western chain of the range suddenly bends into a spoon-shaped semi-circular arc, almost doubling the width of the range. In the northern part of the range, it takes a sudden bend to the NE near its highest point Narodnaya (1892 m) to take yet another bend to the northwest as Pay-Khoy range which apparently continues into the sickle-shaped Novaya Zemlya Arc.

Geologically, the Ural ranges include most of the rock formations from Pre-Cambrain through Palaeozoic and parts of the Mesozoic along its western flank and Tertiary along its eastern flank. The whole range is abundantly invaded by basic and acid intrusives and extrusives, particularly during the Variscan Orogeny which is its major folding period. Evidences of Caledonian orogeny are not lacking, especially in the core zones of the northern range.

The Ural Range appears unique since no similar structural range appears over a large region round about it. The nearest approach to the Uralian Pattern is that of the Tienshan in the southeast along the Tarim basin though trending E-W. Both these ranges belong to the Variscan orogeny and most of the rock formations going into their constitution are common. It is, however, in the structural pattern that the two ranges show wide-ranging similarities including size, form and also in variations in their trends.

The southeastern bulge in the Urals between Ufa and Orenburg has its counterpart in the bulge of the Tienshan between Tashkent and Frunze. The tapering curved southern end of the Urals near Mugodzhary, north of the Aral sea, corresponds very well with a similar curved prolongation of the Tienshan, northwest of Samarkand in the Uzbek-Kyzilkum region along the Amu Darya. The 'S'-shaped double curvature in the northern parts of the Ural Range continued into Novaya Zemlya has a counterpart in the somewhat detached prolongation of the Tienshan Range in the region of the Nan Shan, Ala Shan, and Yin Shan round the Ordos plateau. If we superpose the tracing of the Ural Range over that of the Tienshan, the correspondences are remarkable, strongly indicating the possibility that the Ural Range was once juxtaposed with the Tienshan as its integral part.

The Ural Pattern can further be recognised south of the Tarim Basin, in the Kunlun Range as also in the source region of the Yangtsekiang. The spoon-shaped bulge of the Southern Ural between Ufa and Orenburg has its counterpart in the Pamir semi-circular arc in the source region of the Syr Darya. The 'S'-shaped double curvature in the Ural-Novaya Zemlya region finds its equivalent in Szechwan in the Yangtsekiang syntaxial region.

Thus, in the Central Asian region between the Himalayas and the present Urals, we can recognise fairly clearly the route of migration of the Ural structural sheet gradually rotating anti-clockwise over the region spanned by the Tarim and the Obtributaries and passing through the positions of the Kunlun and Tienshan Ranges and the Kazakh Plateau.

10. Great Britain Structural Pattern

Great Britain, stratigraphically considered, is about the most complete structural unit of its size having rock formations almost continuously from the Archaean right up to the Quaternary with the possible exception of Miocene. The stratigraphic and structural relations are well established and now serve as a standard stratigraphic scale for most of the world.

The shape of this structural pattern is unique and is quite distinctive. It is highly irregular in its coastal outline, particularly along the west coast, while its eastern coast line though sinuous is less indented. In expanse it is wide along its southern border and is irregularly tapering towards northern England. It again widens abruptly in South Scotland and, with repeated waxing and waning, ultimately narrows in the north into a bluntended land mass of Caithness.

Structurally, Great Britain has abundant elements of the Pre-Cambrian and a fuller development of the Caledonian Orogeny in Scotland and of Armorican (Variscan) Orogeny in southwest England, whereas the last major orogeny, the Alpine, can be recognised only in its milder-epeirogenic effects in the southeastern parts of England. Great Britain, thus, epitomises the structure of the European subcontinent with the successive development of the three Post-Cambrian orogenies from northwest to southeast.

The land mass of Great Britain with its peculiar outline, geomorphology and structure, is separated from the European mainland by a narrow shallow shelf lane of the English Channel in the south, widening and deepening westward and by a wide North Sea shelf in the east. It is also separated from Ireland on the west largely by Irish Sea shelf with a narrow deep sea channel in the middle, parallel to the east coast of Ireland.

Though appearning as a detached, independent structural entity, Great Britain has very close relations — geomorphological, geological, and even structural—with the neighbouring land masses right from Scandinavia in the northeast, Central Europe on the east, West Europe in the south and Ireland in the west and even with the eastern seaboard of North America far in the west beyond the Atlantic Ocean. The nature of these relationships throws ample light on the evolutionary history of this vast region, stretching from the Appalachian North America in the west to Central Europe on the east.

The two island masses of Great Britain and Ireland though of unequal size and separated by a 15-60 km wide and at places more than 100 metres deep Irish Sea, exhibit numerous points of similarity in their morphostructural and even more in their geological features. Both the Islands have comparatively low relief not exceeding 1500 metres in elevation, a highly serrated or crenulated western coastline and a much less indented eastern coastline. The northern coast of Ireland from Donegal Bay in the west to Dundrum Bay in the east, finds a remarkably similar outline in Central Great Britain, from Firth of Clyde and Glasgow in the NW to Berwick and New Castle in the east. The southwestern and western coast of Ireland exhibits great similarity with the western coast of Wales. The eastern coast of Ireland between Dunkalk and Wexford finds its representation along the eastern margin of the Pennine Chain, characterised by the widespread development of the Whin Sill.

Geologically, both the regions are characterised by the abundant development of the Lower and Upper Palaeozonic formations almost with the same structural trends, while the northern and northeastern portions of Ireland and the Cheviot Hill region of North England have identical development of igneous activity both Tertiary as well as Pre-Tertiary (Fig. 52). The eastern and southern borders of Ireland find representation repeatedly in the arcuate occurrences of Permocarboniferous formations, in mid-England and Wales, whereas the Devonian outcrops of southern Ireland have their complementary development in southern Wales. Such extensive correspondence in the morphology, structure and complementary geological formations cannot be casual or accidental and must reflect their past geological history. The Ireland mass must have been an integral part of the Great Britain mass as a superposed sheet along the western flanks of the Pennine Chain of north England during the earlier stages, and must have separated from the English basement during Quaternary earth movements as shown elsewhere.

The Great Britain structural pattern also finds a partial representation in the parts of Central Europe in the structure of Bohemian massive and Southern Polish Highlands, in the upper reaches of the rivers Elbe, Oder and Vistula. The Bohemian massive is a peneplained Variscan Horst from which much of the sedimentary cover has been largely removed while the Polish Ranges to the northeast represent the Mesozoic sedimentary cover with its basement concealed.

If the combined structure of the Bohemian and Polish Ranges is compared with that of Great Britain, placing their traces side by side, many correspondences emerge, the broad southern zones of England with Mesozoic and Tertiary sediments would simulate, in outline, the broad southern border of the Bohemian massive along the Danube while the central region of England and Scotland with Palaeozoic sedimentary basins would correspond in outline with the upper Palaeozoic-Mesozoic belt of Krakow and Kielce of southern Poland. If we superpose the trace of Great Britain over that of the combined Bohemian-Polish structure, various points of similarity stand out prominently.

These two regions are far apart but the intervening region has preserved traces of similar Variscan structures along with faunally very intimately related marine as well as terrestrial formations as those of the Franco-German territories.

These correspondences of the Great Britain structure with those of the Bohemian-Polish structures indicate that the Great Britain sheet in its earlier stages of evolution and emplacement was situated along with the intervening Franco-German structures on the

Fig. 52. Tertiary Dyke Systems in British Isles

basement of Bohemian and still earlier even on those of Donetz and Ukraine structures and that during its westward movements, it left behind fragments of its constituent sheets on the route of migration in the nature of Thuringia, Harz, Hessen, Westphalia, Ardennen, Brabant, etc.

Great Britain also shows close relationship with the Appalachian structure on the west beyond the Atlantic Ocean (Fig. 53). The Appalachian Mountain is a conspicuous structural feature running NE-SW along the watershed between the Mississippi drainage on the west and Atlantic drainage on the east. It is an Upper Palaeozoic orogenic belt exposing in its core the lower Palaeozoic marine formations faunally closely related to the Atlantic faunal province of England and Wales. On the west of the Appalachian Range is the Allegheny Plateau, consisting of thick coal-bearing terrestrial formations of Permo-Carboniferous and Triassic ages with floras and faunas identical with those of the Coal Measures of the British Isles. The Createaceous-Tertiary sequences along the Atlantic coastal belt correspond with the similar formations of southeast England east of the Pennine Range, and to which they bear fairly close faunal relations. The Appalachian Range exhibits four distinct morphostructural regions: (1) The Allegheny Plateau on the west with flat lying Upper Palaeozoic formations. (2) The Appalachian Mountain Range with highly-folded metamorphosed Palaeozoic formations forming the Blue Ridge as the central axis and along which passes the Serpentine belt all along the range. (3) The Piedment Plateau on the east of the folded Range. This Piedmont is composed of a complex of schistose and igneous formations worn down into a plateau, gently-sloping east. This is succeeded on the east by (4) The Coastal Belt of Cretaceous and Tertiary rock formations, the junction of the Piedmont with the Coastal Belt being marked by a Fall Line characterised by waterfalls and rapids in river courses traversing this line.

It is the region of zones 3 and 4 east of the Blue Ridge and characterised by the easterly drainage which has the greatest correspondence with the Great Britain structure. The Coastal Belt along the Atlantic Ocean, north of the latitude 35°, has a very peculiar coastline characterised by several deep embayments like the Chesapeake and Delaware and by the Sand Banks of Pamlico, Hattaras etc. These embayments find their equivalents in those of Thames, the Wash, Humber etc. along the east coast of Great Britain in corresponding positions. The wide extent of correspondence in the two regions across the Atlantic Ocean becomes more obvious if we superpose the trace of the Great Britain structure over that of the eastern United States such that the east coast of Great Britain coincides with the east coast of the United States between New York and Welmington as shown in Fig. 54. The great Serpentine Belt along the Blue Ridge marks the western limit of the condensed Great Britain-Ireland sheet, while in superposition, the peninsular projections along the west coast of Great Britain and Ireland correspond with the irregular boundary line along the Serpentine Belt of the folded Appalachian mountain marking the site from which the British sheet got detached and separated.

These correspondences do suggest that the Britain sheet was once situated over the eastern belt of the Appalachian structures as a supersheet and that the same was left behind in Europe while the Appalachian structural sheet migrated westward from the position of Western Europe, through the activity of the Thouleitic Eruptives. These movements culminated into the formation of the Atlantic Ocean.

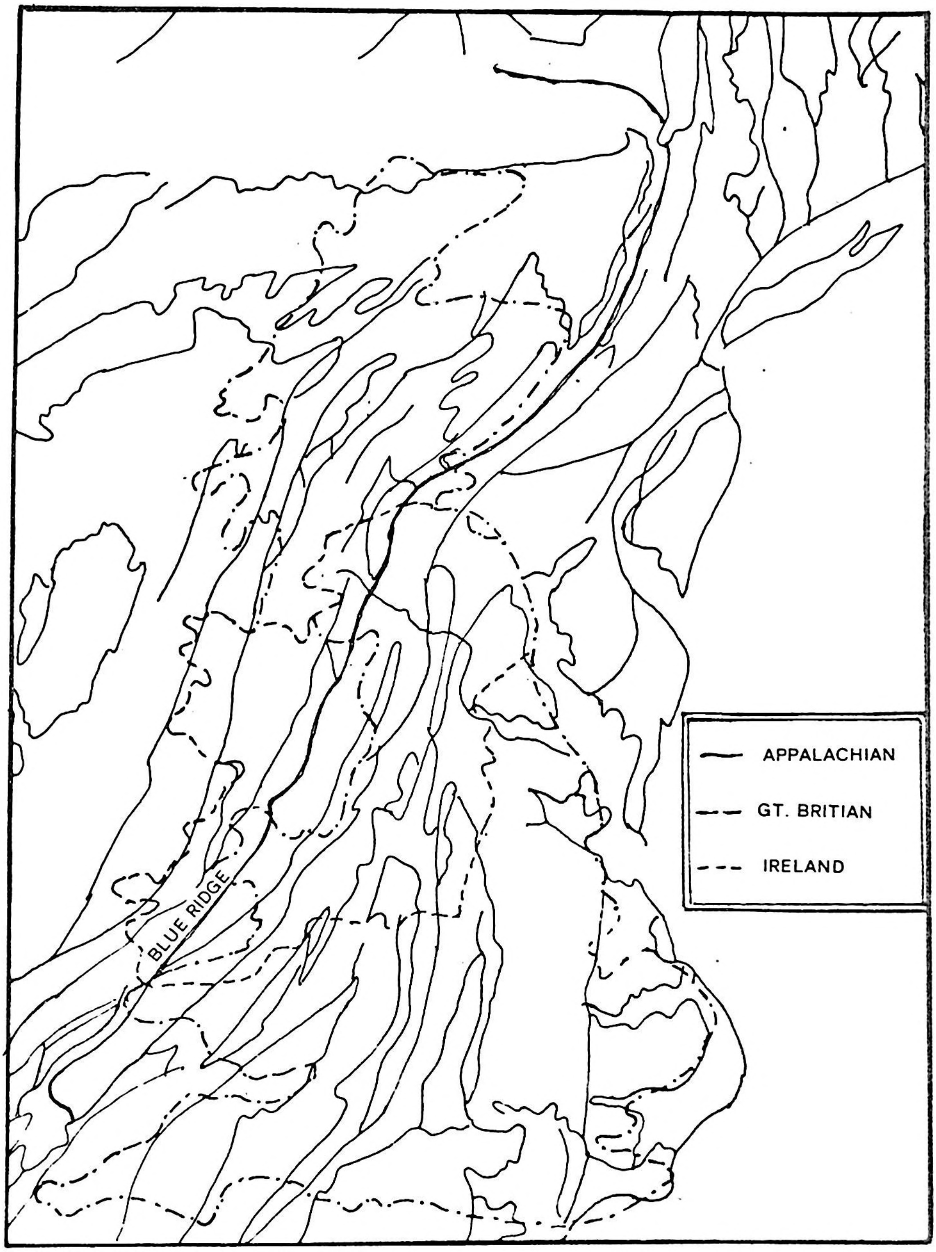


Fig. 53. Appalachian British Isles Correspondence

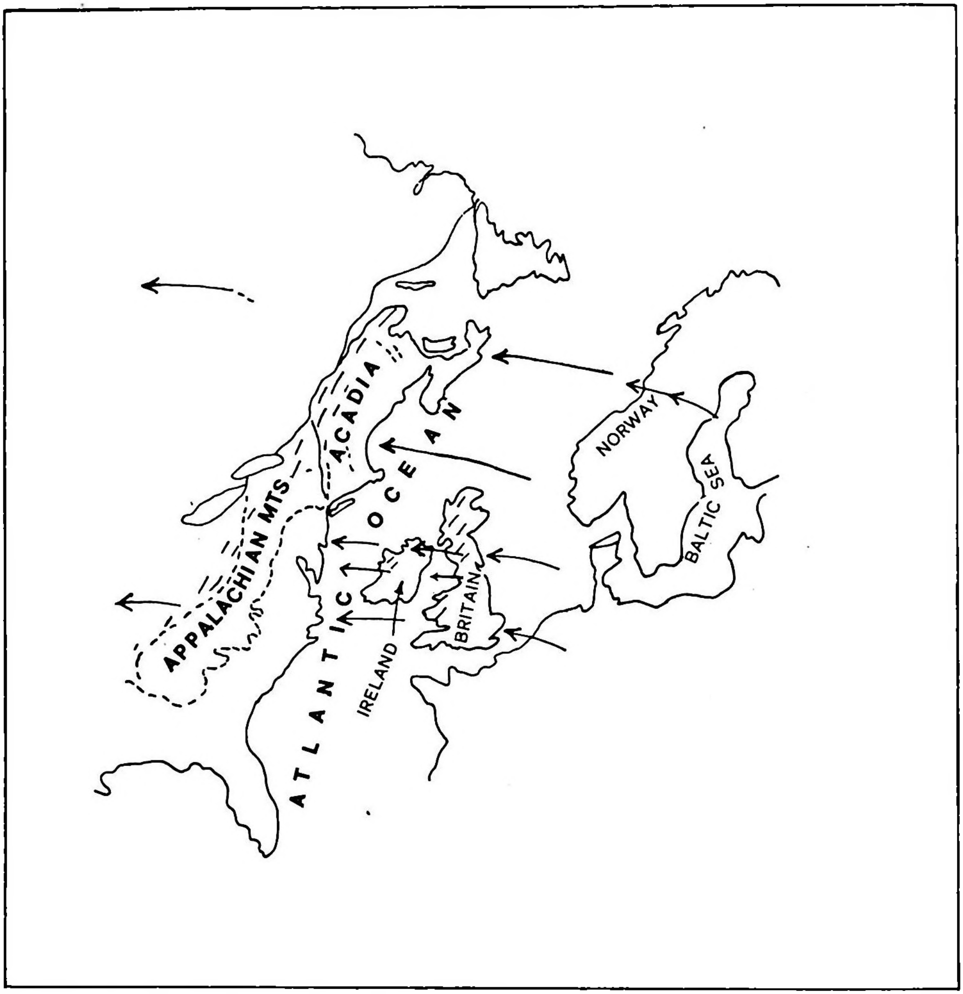


Fig. 54. Structural Relations of the Atlantic Coastal Belts of Europe and North America

11. Scandinavian Structural Pattern

The structural pattern typified by the highland of Norway and Sweden is a prominent feature in the structural build of the European continental mass.

The highly dissected, serrated, heavily fiorded Atlantic coast of Norway with a deep indentation in the Lofoten region, a marked bulge in the region of Trondheim and Bergen, a rounded nose against the Skagerrak near Kristianasand, and a less serrated, comparatively smooth, Swedish coastline against the Gulf of Bothnia and the Baltic sea, are some of the peculiar features of the Scandinavian Pattern (Fig. 55).

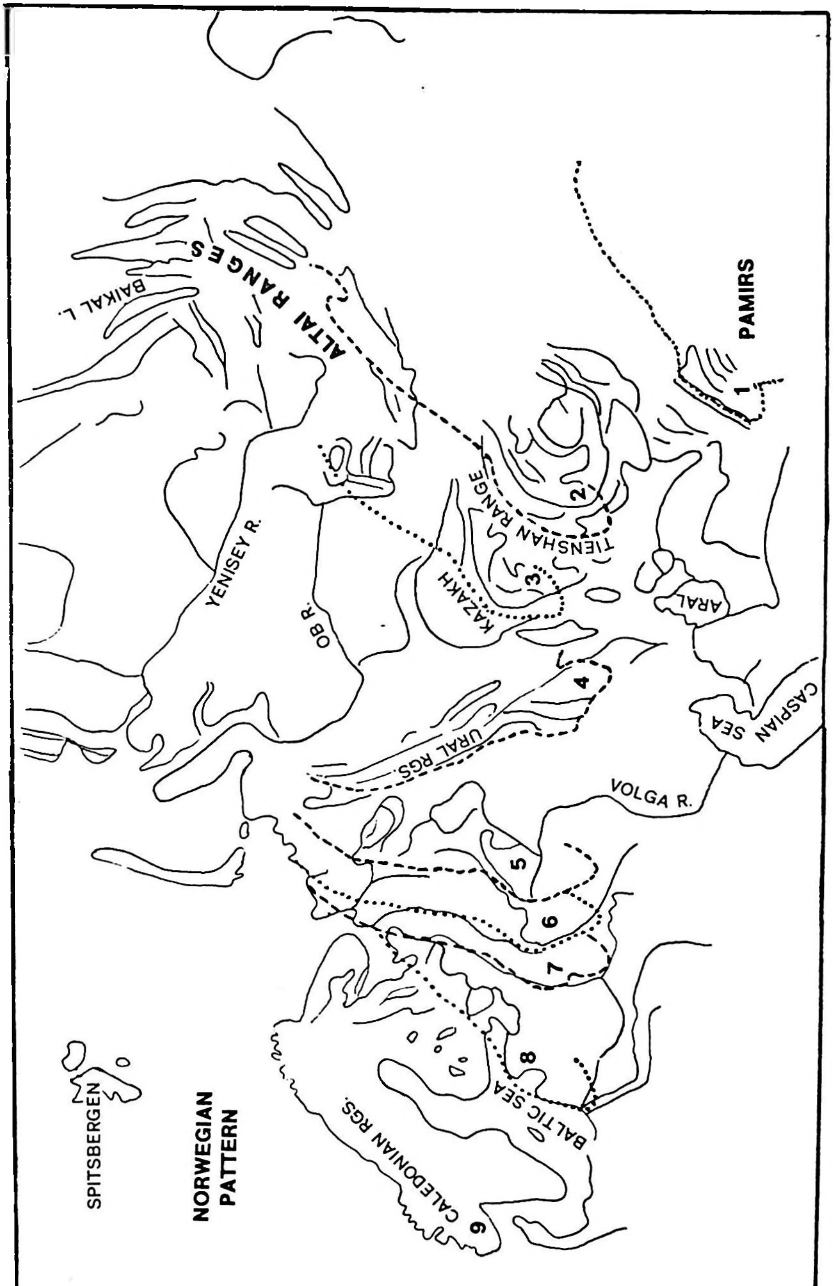


Fig. 55. The Norwegian Pattern and its Migration From The Pamirs

The Caledonian mountain range often rising to an altitude of almost 2500 m running along the Atlantic coast of Norway, a highly peneplained, "glaciated" hinterland in Swedish low plains along the Baltic and the Bothnian coastal belt are some of the notable morphostructural features associated with this pattern.

Geologically, the Scandinavian land mass is essentially a PreCambrian shield, the western flanks of which were involved in the Caledonian Orogeny in the Middle Palaeozoic Period bringing about extensive folding and metamorphism and even granitisation of basement formation, including the Lower Palaeozoic. This Caledonian shield is intimately associated with the still older shield masses of Finland, Karelia and Kola which are fused with the Swedish shield in the region of Lapland with a roughly fan-wise arrangement.

The Norwegian portion of the shield with the highly-folded Caledonides has a structural pattern which appears duplicated in the Baltic coast of Russia from near Riga Lithuania extending through Leningrad and Arkhangelsk to Kanin Peninsula in the region drained by the South and North Dvinas. This west Russian region is also geologically made up of Lower and Middle Palaeozoic formations except that, unlike in the Caledonian region, these formations are largely unfolded and less metamorphosed. Thus, in form and geology, the Baltic zone of Russia has the same pattern as that of Norway, even though structurally no trace of the Caledonian Orogeny is noticeable in this Baltic part. We again find the same geological trend pattern in the source region of the Volga extending from Bryansk and Smolensk right upto the Kanin Peninsula. In the Bryansk-Kanin region this pattern is characterised by flat-lying Carboniferous and Permian formations closely associated with the Lower Palaeozoics in the north and abutting against the Cretaceous in the south.

Another similar pattern can be traced along the western flank of the Ural Range in contact with the overlying Permian deposits. The Bergen bulge of the Norwegian coast has its counterpart in the bulge of the Urals between Ufa and Orenburg. Here the Middle Palaeozoic formations constitute the main rocks of the pattern. Even the Kola, Karelia and Finland masses, in condensed form, can be matched by their counterpart on the Russian Platform west of the Urals in the drainage basin of the upper courses of the Pechora and the Kama. These repetitions of the Scandinavian structural pattern in outline several times between the Urals and the Norwegian Atlantic coast indicate the possibility that the Norwegian Caledonides were integral juxtaposed parts of the Ural structure and that they separated from the Ural in a series of later radial movements with a pivot in the Novaya Zemlya region.

It is possible to recognise the structural outline of the Norwegian coast, on the other side of the Atlantic, in the Acadian coast of North America. Here the New England element already a part of another Caledonian orogenic belt, reproduces part of the Scandinavian structure. The same structure, in parts,can again be recognised prepeatedly in the far west in the Rockies of Columbia and Alaska along the Pacific coast.

12. Alaska Structural Pattern

The Yukon-Alaskan peninsular mass with its southern continuation in the Canadian Rockies forms a very typical structural unit with a distinctive pattern. The Alaskan ranges constitute a grand terminal of the CircumPacific orogenic belt facing the Pacific all along the western coast of the Americas. They include a strong element of Mesozoic-Tertiary Orogeny but also possess an appreciable content of the Palaeozoic fold belts as well, without any marked trend deviations. The Lower Palaeozoic orogenic elements form the core of the Columbian Rockies and run longitudinally parallel to the Pacific coast of Canada almost upto the middle of the Yukon River where they take a sudden bend to the west and southewest in the region of the eruptive masses of Mt. Logan, Mt. St. Elias and Mt. Kinlay continuing into the Aleutian Island Arc. In this region, the continental coastline against the Pacific Ocean itself turns sharply west and southwest, controlled as it is by the orogenic trends and the same trend changes are shown by the Yukon river as well. Numerous longitudinal tear faults have thrown the region into radial fanning of fold belts with the pivotal region in the upper reaches of the Yukon River.

Geologically, the Columbian-Alaskan belt consists of a vast development of Palaeozoic metamorphosed sediments involved in folded Cretaceous formations and invaded mainly by Tertiary and Quaternary eruptives and separated by Quaternary alluvia. The structure exhibits involvement of the region in diverse eruptive activities and orogenic foldings accompanied by extensive lateral, en echelon and radial movements along tear faults.

The Columbia-Alaska structural pattern in its morphological form is remarkably duplicated in the large northern part in the Greenland mass. The western coastline of Greenland with fiord-like indentations is an exact replica of the Pacific coastline of Alaskan-Columbian mass, including the sharp bend of the coastline near Melvelle Bay reproducing the Bay of Alaska. The eastern coastline of Greenland with Scoresby Sund inlet corresponds with the Mackenzie-Peace River valley associated with the Great Slave Lake of the NW Canadian region.

The geological structure of Greenland is largely hidden under a thick blanket of ice but the peripheral dissected coastal belt, all round, exhibits fragmentary outcrops of Pre-Cambrian, Palaeozoic and Mesozoic formations associated with a great spread of Tertiary eruptives. Greenland has, however, been considered as a highly glaciated, peneplained, plateau mass.

Being in Arctic latitudes; most maps adopting different projections give a very distorted representation of the size and shape of the land masses in this region. They can, however, to a certain extent, be compared among themselves and it is noteworthy that the Alaskan Peninsula, the Canadian Arctic Islands and the Greenland mass among themselves exhibit, often in parts, a remarkable similarity in the structural pattern in respect of size, shape, trends and in complementary geological formations.

Thus, if we superpose the trace of Alaska structure over that of the Canadian Arctic Islands, the form, the size and the relative position of the numerous islands exhibit an identity of structural lines in the overall pattern. The island masses of Ellesmere, Sverdrup, Queen Elizabeth, Franklin District and Baffin, all find their appropriate positions both in the Alaskan and in the Greenland masses. Thus, the Alaskan structural pattern is largely represented in the Canadian Arctic Islands, on the one hand, and also in the Greenland mass, on the other. It is also remarkable that parts of this structure can be recognised in regions still farther away not only in the oceanic region but also on the mainland of Eurasia. Thus, Spitzbergen, Franz Joseph lands, Novaya Zemlya and even the Severnaya Zemlya of the Arctic region and the Taymyr peninsular mass in north Siberia are all characterised by the Caledonian orogeny and appear as fragmental representatives of the Alaskan structure. On the other hand, a fuller representation of the Alaskan structure can be recognised in the Caledonian Altai-Yablonovy ranges in the Transbaikalian part of South Siberia. The Seleng-Upper Amur basin on the Sino-Siberian border also shows, though faintly, trend curvatures of the Alaskan type. Traces of this can again be seen in the Dzungaria-Nanshan-Yinshan ranges of Inner Mongolia in the upper Hwang Ho basin.

Thus, the Alaskan structural pattern is seen developed, fitfully, right from the Tibetan Plateau mass through the Altai, Taymyr, Eurasian Arctics, Greenland and Canadian Arctic Islands right up to the Pacific coast of North America. Looking to the development of Caledonian orogenic trends and the association of similar Mesozoic sediments and Tertiary igneous activity in many of these regions, it looks quite likely that the Alaskan folded belts of the Rockies were themselves originally situated in the Central Asian Tibetan region as part of the Altai-Kunlun structure from where they migrated as parts of structural sheets through Taymyr, Novaya Zemlya, Spitzbergen, Greenland and the Arctic Islands to their present position in North America, leaving traces as a trail, marking the route of migration.

13. The Alpine Arcs Structural Pattern

The Alpine orogeny, best illustrated in the Mediterranean sector of the Tertiary orogenesis, is the most studied portion of the mountain ranges of the earth. This orogeny is developed almost continuously along the north tropical belt from Gibraltar on the west through the Mediterranean lands eastward through the Tibeto-Himalayan mountain ranges right upto Indonesia and Australasia, where it merges into the CircumPacific orogenic belt, on the east. The mountain ranges of Western Alps on the Franco-Swiss-Italian border and the Eastern Alps of Austria have been the earliest to be studied in great detail and have provided us with fundamental ideas in mountain structures and their evolution. The concepts developed during these studies have moulded geological thought during the historical development of the geological science. The concept of compressional orogeny, developed during these studies, envisages approach of the northern and southern Mesozoic continents towards each other bringing about squeezing of sediments of the intervening Tethyan geosyncline into folds, overthrusts and Nappe structures resulting in the evolution of the full-fledged orogenic mountains. The associated volcanism exemplified by ophiolites is considered as merely consequential to squeezing (Fig. 56).

A study of the Alpine Orogenic Belt brings out several mountain arcs which exhibit a peculiar horseshoe or semi-circular shape, all convex to the west. These include the Balkan Alps near Belgrade, Western Alps on the Franco-Swiss border near Turin and the Betic Alps near Gibraltar (Fig. 57). Among these mountain arcs, the Turin Arc is the most celebrated and the best studied. This Arc is typically semi-circular in outline and in the trends of its constituent rock formations including those of the Variscan massives in the core region. These massives at places rise to more than 4600 m in lattitude.

The Turin Arc is partly breached by the upper reaches of the Po river flowing east and is flanked by the Rhone on the west. The rock formations involved in this Arc are the

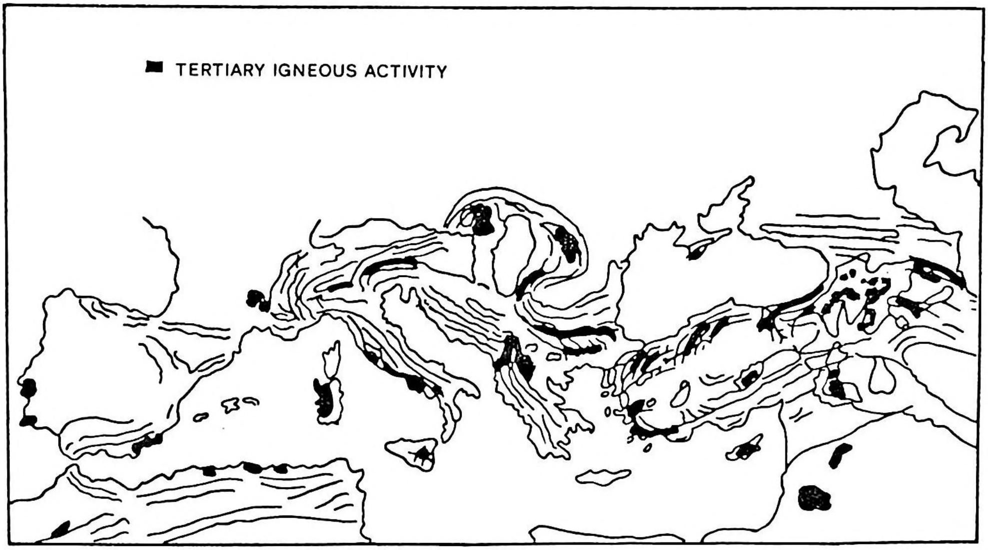


Fig. 56. Mediterranean Orogen With Tertiary Igneous Activity

Metamorphics, the Upper Palaeozoic-Mesozoic and Lower Tertiary formations in almost a regular succession as we go from inner to outer parts of the Arc giving the aspect of an eroded semi-circular dome.

Structurally, the Western Alps are constituted of concentric arcs; the outer and inner ones are made up of thick geosynclinal sediments of Mesozoic and Lower Tertiary periods showing different facies while the central arc consists of old massives. However, the structure is extremely complicated due to overriding of formation of the southern facies over those of the northern facies in the nature of nappes. The inner parts of the geosynclinal folds on either side are often highly metamorphosed and exhibit abundant development of ophiolites infolded with rocks of diverse ages.

These Western Alps form a typical example of the nappe structure, characteristic of many orogenic mountain ranges. This complicated structure is seen developed in varying degrees of overthrusting in many mountain ranges of the world, especially those of the Mediterranean fold system. The semi-circular pattern of the Western Alps is also seen developed in the Balkan ranges in the vicinity of Belgrade on either side of the Danube. The northern limb of this Balkan Arc merges with the south-eastern limb of the Carpathian Ranges beset with enormous development of eruptive activity. The size, shape and curvature of the Balkan Alps are quite comparable with those of the Western Alps such that the outer Arc of the latter would just fit into the inner Arc of the former when the traces of the two structures are placed in superposition. The development of different rock formations of the Variscan massives and the Mesozoic, Tertiary and the Quaternary formations exhibit complementary relationships in being continuous from one sheet to the other when placed in superposition, even the intrusive bodies show these relations.

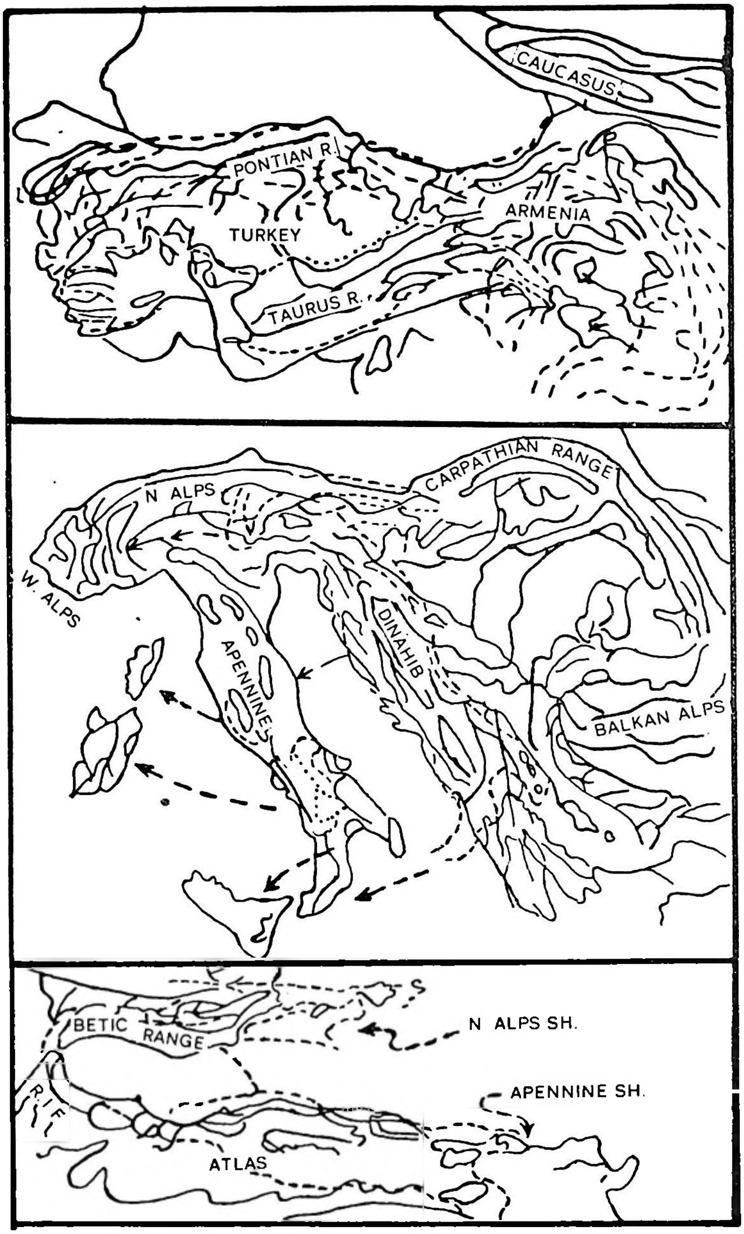


Fig. 57. Mediterranean Orogenic Arcs

Further, the younger formations are seen more widely developed in the Balkan sheet whereas the older ones dominate in the Western Alps sheet (Plate 15).

We further see that just as the Turin Alpine Arc is breached by the Po river, the Balkan Arc is seen similarly breached by the Danube. Thus, these two arc systems exhibit numerous points of resemblance in morphological, stratigraphical, structural and other features.

It is further remarkable that a very similar structural Arc is again seen developed in the western Mediterranean region near Gibraltar. This Betic Andalusian Arc of southern Spain curves round and continues south into the Rif Range of Morocco. This Arc which is breached in the centre by the Strait of Gibraltar has the same curvature and constitution as that of the Western Alps, except that even the Lower Palaeozoic formations go into structure of the Betic Arc in addition to the Mesozoic and Tertiary formations. A superposition of these Arcs would show wide-ranging correspondences in size, curvature and complementary relations in the development of constituent rock formations, including the eruptives in the two sheets. The Gibraltar sheet shows a wider development of older rock formations. Structurally, the Betic Arc corresponds in the size of its curvature with the inner arcs of the Western Alps. Thus, the three Arcs of the Alpine Orogenic Belt, the Betic Arc of Gibraltar, West Alpine Arc of Turin and the Balkan Arc of Belgrade exhibit very close relationships in respect of size, curvature, stratigraphy, and structure. When their traces are placed in superposition, the three Arcs appear as integral parts of a common structure. The Betic Arc corresponds to the inner curvatures and the Balkan Arc to the outer curvatures. The stratigraphic formations including eruptive bodies of the one sheet become continuous with those of the others, thus exhibiting complementary relationships. These relationships strongly indicate that the three arcs were actually in superposed condition during deposition in a common basin up to the Lower Tertiary and suffered common episodes of early foldings of the Tertiary orogeny before they migrated to their present, widely-separated positions.

It is possible that the three Arcs of Betic, Western and Balkan Alps were, during their earlier stages of evolution, in superposed condition on the basement of the Turkish peninsular mass, and that they got differentiated during their westward movement. The Betic Alpine Arc passed along the route of Taurus Ranges, Cyprus, Crete, Sicily, Tunis and Alger to Morocco; the West Alpine Arc migrated along the route of central Turkey via Aegean Sea, Serbia along Sava, Gulf of Venice, the Adige and the Po basins; while the Balkan Arc moved northwest along Pontius Range (northern Turkey), Kizil, Irmak and South Black Sea coast to the present Balkan site. We can go still further backwards in time to their earlier stages when these three 'C'-shaped structural Arcs of Betic, Western and Balkan Alps along with the Carpathian ellipsoidal Arcs were all superposed over the Hindukush, Pamir Ranges from where they migrated westward.

14. Carpathian Structural Pattern

The Carpathian mountain ranges stretching from Czechoslovakia through Hungary to Romania are an important element of the Alpine Orogenic Belt and form a link between the Austrian Alps on the west and Balkan Alps on the East. These Carpathian Ranges, rising at places to over 2450 m, form an oval or semi-circular Arc bulging to the north, extending from the eastern end of the Austrian Alps near Vienna, curve round southwest near Bucharest to join the Balkan Alpine Arc north of the Wasatch plains. It is drained in the interior by the northern tributaries of the Danube, particularly by the Tisza-Morava tributary system. These rivers breached the Carpathian Structural Arcs in a centripetal manner cutting across the strike of the ranges to meet the longitudinal valleys of major tributary system. The northern tributaries of the Danube give indication of the en echelon extension of the Carpathian Arc westward from Romania into Czechoslovakia in stages represented by Tisza, Hernad, Horn, Nitra, Vah, Morava etc.

Geologically, the Carpathian Range is constituted of the core of Palaeozoic formations surrounded by broad arcuate bands of Lower Tertiary formations complexly involved in Cretaceous and older formations in the nature of overthrust sheets in a thick mass of flysch. This rock mass is intimately associated with a vast development of lower Tertiary basic eruptives in the inner zones of the Arc (Plate 16.c).

This peculiar oval-shaped Carpathian structural pattern is found repeated in the Armenian Plateau mass rising to over 5000 m on the Turko-Iranian-Russian border (73.1). The form, size and the geological build, including the abundant development of Tertiary igneous activity in the Armenian structure are remarkably similar to those of the Carpathian Arcs. Further, this Armenian structure also forms a link between the vast development of Alpine structure in Turkey and Iran and thus exhibits a setting identical with that of the Carpathian structural Arc with the only difference that the Carpathians exhibit fuller development of the Lower Tertiary in the outer arcuate band and much less development of the associated internal structure, as compared to the Armenian Plateau structure which exhibits more of internal structure and much less of the peripheral Lower Tertiary zone and in this respect the two structures show complementary relationships in their geological build.

The same Carpathian-Armenian structural pattern is again seen developed in the Pamir Plateau (73.1) rising to over 7300 m in altitude, along the northwestern border of the Tibeto-Himalayan structural range. The arcuate Pamir structure with the form, size and curvature of the arcs closely simulates those of the Carpathian and Armenian structures (Plate 16.4).

Geologically, the outer arcs are constituted of the Cretaceous-Lower Tertiary flysch type sediments associated with the larger spread of Jurassics, all involved in the metamorphosed eruptives, while the inner core region is made up of the Palaeozoic and Lower Mesozoic formations with abundant intrusives, all involved in complicated fold and overthrust structures.

Structurally, the Pamir forms a complex syntaxial knot being the meeting place of some of the highest mountain ranges of the world, viz. the Himalayas, Ladakh, Kailas, Karakoram, Kunlun, Tienshan, Hindukush Ranges almost radiating from the Pamir Plateau in the same way as the Armenian knot forms the meeting place of a number of Turco-Persian ranges radiating in different directions.

The nature and extent of the correspondence between these widely-separated structural plateaux and Arcs are best realised if we superpose the tracings of the Carpathian and Armenian structures over that of the Pamir. Most of the morphostructural features find close correspondence, while the geological formations, sedimentary as well as igneous, appear complementary in their areal distributions. The older geological formations abound in the Pamirs while the youngest ones in the Carpathian structures.

All evidences point to their being intergral parts of a common structural sheet packet in which the Pamirs formed the basal structure while the Carpathians formed the top sheet and that they all actually occupied the position of the Pamirs in a not distant geological past. It becomes evident that these structures got detached and transported as crustal sheets in a series of lateral movements through the activity of eruptive masses so represented extensively in all the three structural sheets.

It is further noteworthy that the same structural framework though in a negative sense can be recognised in the outline of the Black Sea and in the structural shreds exposed along the borders of this sea. This makes it likely that the Carpathian Arcs while migrating from the Armenian position temporarily occupied the Black Sea position.

More or less the same pattern can again be visualised in the outline of the Mexican Gulf bordered by Teritary formations and repeated though partly, again in the Antillean region. Thus, the Carpathian structural pattern is seen developed repeatedly along the Tertiary Alpine orogenic belt between the Tibetan Plateau and the Pacific borders of Central America.

15. The Apennine Structural Pattern

The Apennine Range forms the backbone of the Italian Peninsula extending from Liguria in the NNW to Calabria in the SSE. This peninsula, trending NNW-SSE, is almost parallel to the Yugoslav-Albania-Greece belt of the SE Europe and is separated from it by the Adriatic Sea. This Italian Peninsula has a slightly arcuate form with convexity to the west. The western or the Tyrrhenian coast is remarkably parallel to the western, highly Karsted, Adriatic coast of Yugoslavia and Albania. The southern end exhibits forking with the formation of the Toronto Gulf.

The Apennine Range, though longitudinal, is not quite parallel to either of the coasts on the east or west but is obliquely arcuate running from the west coast near Liguria to the east coast near Ancone, and back again to the west coast meeting it near Naples and then follows the west coast upto Calabria and appears to continue SW into Sicily.

Geologically, the Apennine Range exhibits abundant development of Lower and Upper Tertiary together with the Cretaceous formations while the Jurassic and older formations occur only in traces infolded within the Lower Tertiary formations. There is a good development of younger eruptives closely associated with the Tertiaries along the western coast in the region of Rome and Naples. Some of these still carry active volcanoes (Vesuvius, Etna, etc.). The Apennnines are linked with the Maritime Arc of the Western Alps in Liguria with a slight twist in the trend, apparently due to the clockwise rotation of the Apennine Arc resulting in the eastward widening of the Po valley and in the opening of the Adriatic Sea.

The Apennine structural pattern is found repeated in the neighbouring regions to the east and also to the southwest. Thus, the Dinaride ranges in the Yugoslavia-Albania region bordering the Adriatic Sea have many elements of the Apennine pattern. The western coastline of Italy, including the bend along the Gulf of Genoa in the NW, corresponds pretty well with the Dalmatian coast of Yugoslavia including the westward bend of the coast near Triest. The bend along the Gulf of Pelicastro in SW Italy corresponds with the Gulf of Drin in Albania. The eastern coast of the Italian peninsula finds its rough representation in the river course of the Sava tributary of the Danube forming the eastern face of the Dinaric mountains against the Danube Plains and more particularly along the Zagreb-Skopje-Verdar alignment. The Sava valley belt of the Dinaric range is geologically constituted of the metamorphosed Palaeozoic formations and a large spread of Jurassic Cretaceous formations with copious development of basic intrusives and extrusives all along the Zagreb-Skopje alignment and in this respect, the geological structure is just complementary to that of the eastern belt of the Apennine Range. If we place a trace of the Apennine structure over that of the Yugoslav-Albanian structure, the correspondences are far-reaching. The Po valley coincides with the Sava Valley. The bands of Lower and Upper Tertiaries along the Sava Verdar alignment correspond with the Upper Tertiaries along the eastern coast of Italian Peninsula associated with the fitful development of the Lower Tertiary. The Jurassic-Cretaceous outcrops in the central parts of the Dinaride range correpond with the medial band of Jurassic-Cretaceous rocks of Italy between Anconia and Rome. It thus becomes plausible that the Italian peninsular sheet was once resting as an upper sheet over the Adriatic sea-board of Yugoslavia-Albania region with the western (Tyrrhenian) coast of Italy coinciding with the Adriatic coastline of Yugoslavia. In this the Genoa bend coincided with the Triest bend.

These eruptives along with those along the Sava-Verdar Belt in Yugolsavia appear to have engineered the detachment and westward migration of the Italian sheet from the Dinaride basement. In this process, the basement sheet of Dalmatian coastal belt got sheared resulting in typical Karst topography all along the Adriatic coast. In this westward movement of the Italian sheet, a number of arcuate outcrops, convex to the west, were left behind in the northern region in the basins of the Piave, Adige, Adda, and the Tichino as footprints of the West Alpine Arc during its migration from the Balkan Alps.

The Apennine structural pattern is again represented in the Tunisian-Algerian development of the Atlas Ranges along the Mediterraean coast (Fig. 58). Though trending E-W, the northern border of the Atlas Ranges corresponds remarkably well with the Adriatic coastal belt of the Italian Peninsula with vast development of the Cretaceous-Tertiary formations including eruptives. The western or Tyrrhenian borders of Italy have their representation in the Chott depression of Biskra, Djerid etc. in the Sahara region. It is quite possible that the Apennine and the Coastal Atlas sheets were in a state of superposition in earlier stages before the evolution of the Mediterranean sea. During these stages of migration, the islands of Corsica and Sardinia with their vast development of eruptives coincided with the volcanic belts of Rome and Naples on the Italian sheet and also with the volcanic zone east of Alger on the Atlas sheet.

It seems, therefore, possible that when the Betic-Rif•Alpine Arc together with the Atlas Arc was situated over the Tauras Ranges of the Turkish Peninsula, the Apennine-Dinarid combined arcs as also the West Alpine and the Balkan Arcs were all situated over the Turkish Peninsula in Ponlean region. With the westward movement of the African continental mass, the various Alpine structural arcs got differentiated en echelon and moved westward from the Turkish basement leaving behind successively the island masses of Cyprus, Crete, Sicily, Baleario as also Sardinia, Corsica and Elba though with modified trends on the way. The northward shiftings of the Western Alps relative to the Betic Alps, in stages, are also recorded along the arcuate embayments of Aguilas, Alicante and Valencia along the Mediterranean coast of Spain.

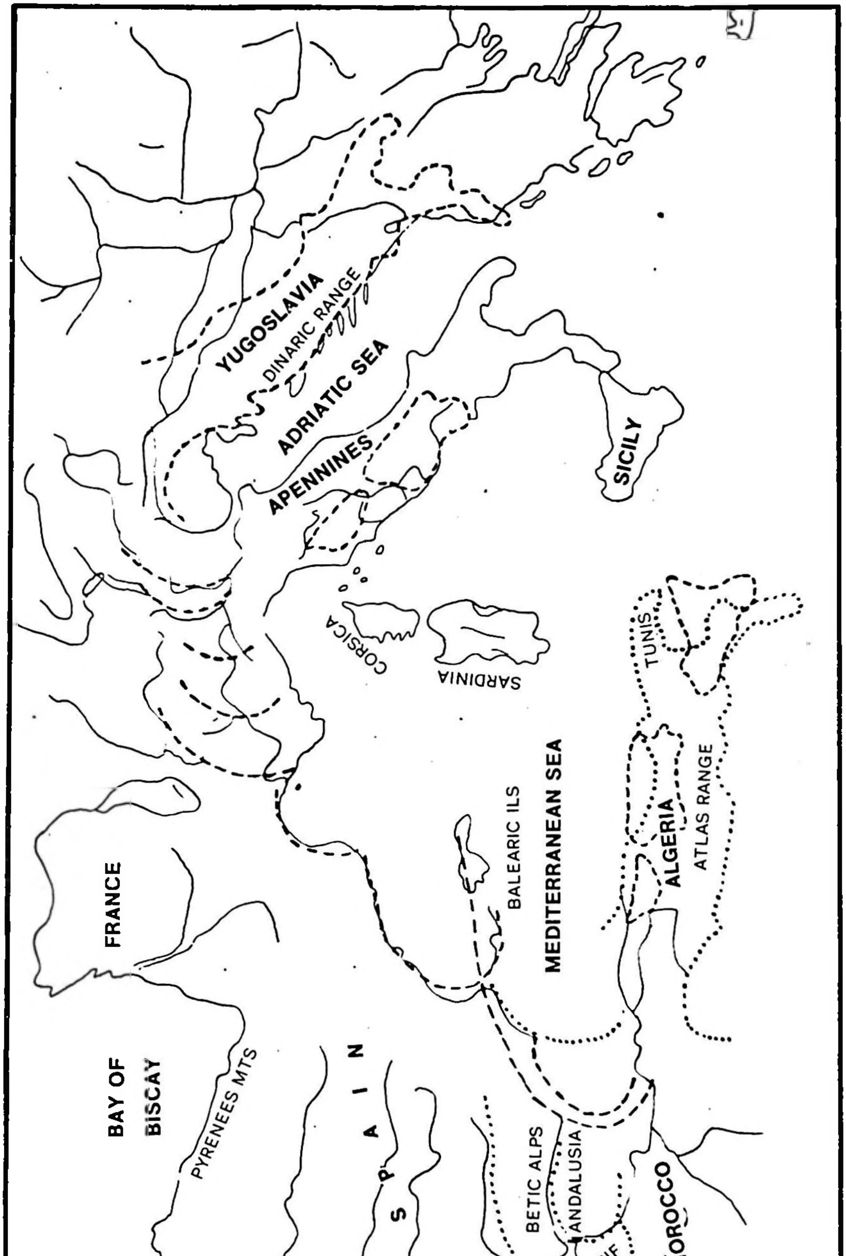


Fig. 58. The Apennine Structures in the Mediterranean Region

16. The Antillean Structural Pattern

The Antillean Arc System consists of the Greater Antilles comprising the islands of Cuba, Hispaniola (Haiti, Dominican Republic), Puerto Rico and the Lesser Antilles comprising a large number of small islands situated on a semi-circular compound arc convex to the east, joining Puerto Rico with Trinidad. The Greater Antillean Arc meets the Central American Isthmanian Arc along the northeastern tip of Yucatan. Another suboceanic ridge joins Hispaniola with Honduras of Central America through Jamaica. These Arcs divide the intracontinental sea basin between the North and South Americas into the Mexican Gulf and the Caribbean Sea while the Jamaica ridge subdivides the latter into Northern and Southern Caribbean Sea.

There is yet another arc, the Bahama Island Arc, almost joining the peninsular mass of Florida with Puerto Rico. The small island of Puerto Rico thus becomes the meeting point of three important island Arcs—the Bahama Arc in the north trending NW, the Cuban Arc in the middle trending WNW and the Jamaica Arc in the south trending due west. The Island of Puerto Rico is also unique in being the meeting ground of three deep sea trenches of Bartlet or Cayman, the Brownson (9144 m) and the Anegada, constituting the deepest part of the Atlantic Ocean.

These remarkable physiographic features in the region between the two vast continents of the Western Hemisphere are some of the most interesting and intriguing problems of Crustal Orogeny and Geodynamics (Fig. 59, 60 and Plate 17).

Stratigraphically, the Prejurassic rock formations are altogether absent in the Antillean Islands and are confined to the mainlands of the North and South Americas. These Palaeozoic and Mesozoic formations on the two mainlands exhibit the closest faunal and floral relationships with the South European rock formations and partly even with those of the Himalayas.

The upper Jurassics of Cuba are the oldest rock formations developed anywhere in the West Indies and these show clear relationships with Mexican and South European as also with the Himalayan Upper Jurassic formations.

The Lower Teritary formations are well-developed in the Gulf coastal regions, the Antillean Arcs, the Venezuelan coastal belts as also in the Isthmanian linkage region, all in identical facies, suggestive of a common geosynclinal basin covering all the Arcs. This tropical American basin was again very closely interlinked with the European Mediterranean basin without any deep marine barrier, like the present Atlantic Ocean intervening them.

Structurally, the Antillean Island Arcs are constituted of a number of islands, each having its complex trend systems which, however, appear to merge one into the other.

Thus, the arcuate trends along the northern coast of Cuba appear to continue into those of Yucatan on the west and into those of Haiti on the east. The straight E-W trends of Sierra Maestra of SE Cuba correspond with those of Sieerra de la Sella of Hispaniola.

The whole Antillean structural pattern taken together with the Isthmanian Arcs can be subdivided into five independent structural units, each with its own characteristic shape and size. These units from east to west are—

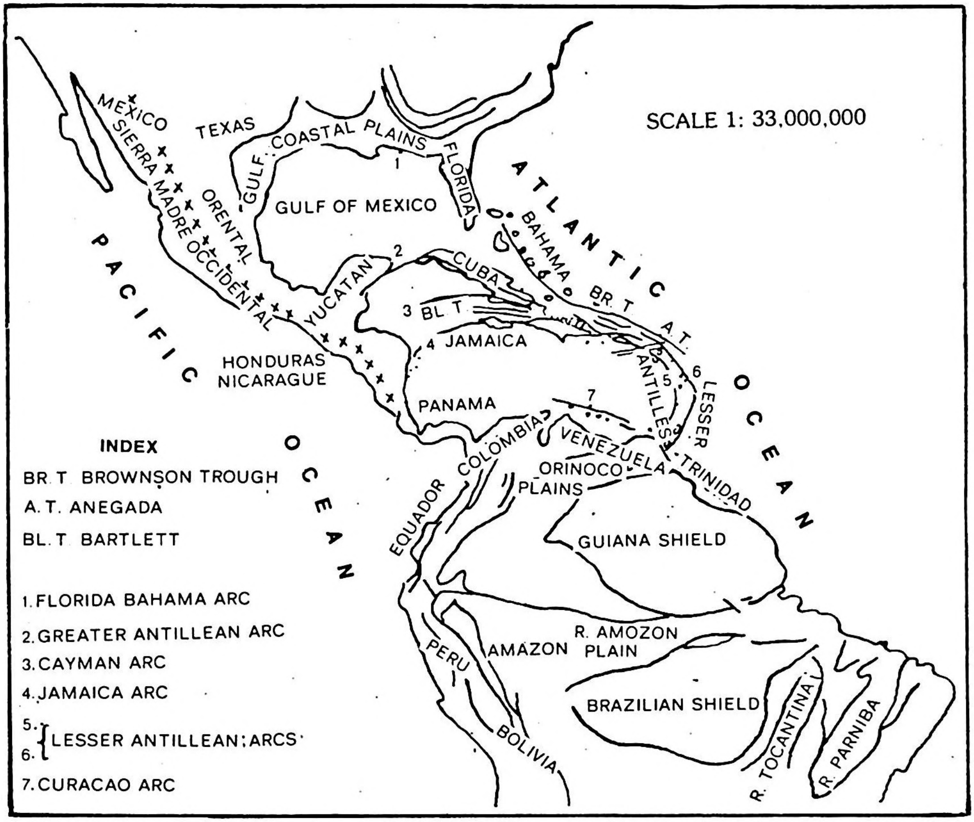


Fig. 59. Morpho Structural Map of the Central American Region

(A) Lesser Antillean semicircular compound, Arc on the East

(B) Hispaniola Puerto Rico.

(C) Cuba

(D) Yucatan

(E) Nicaragua on the West

The arcuate pattern of the Greater and Lesser Antillean Islands taken together appears to be repeated at least in three Arcs in the tropical American region itself:

(3) along the northern coastal belt of the Mexican Gulf from Mexico to Florida.
(2) the Guatemala-Yucatan-Cuba-Hispaniola-Lesser Antilles Arc.
(1) the Colombia-Venezuela-Guiana Amapa Arc along the Atlantic Coast of north Brazil.

It is most surprising that each of these three Arcs separated from one another by vast distances yet exhibit each of the five structural units A B C D E in the same sequence from east to west as shown in Plate 17.

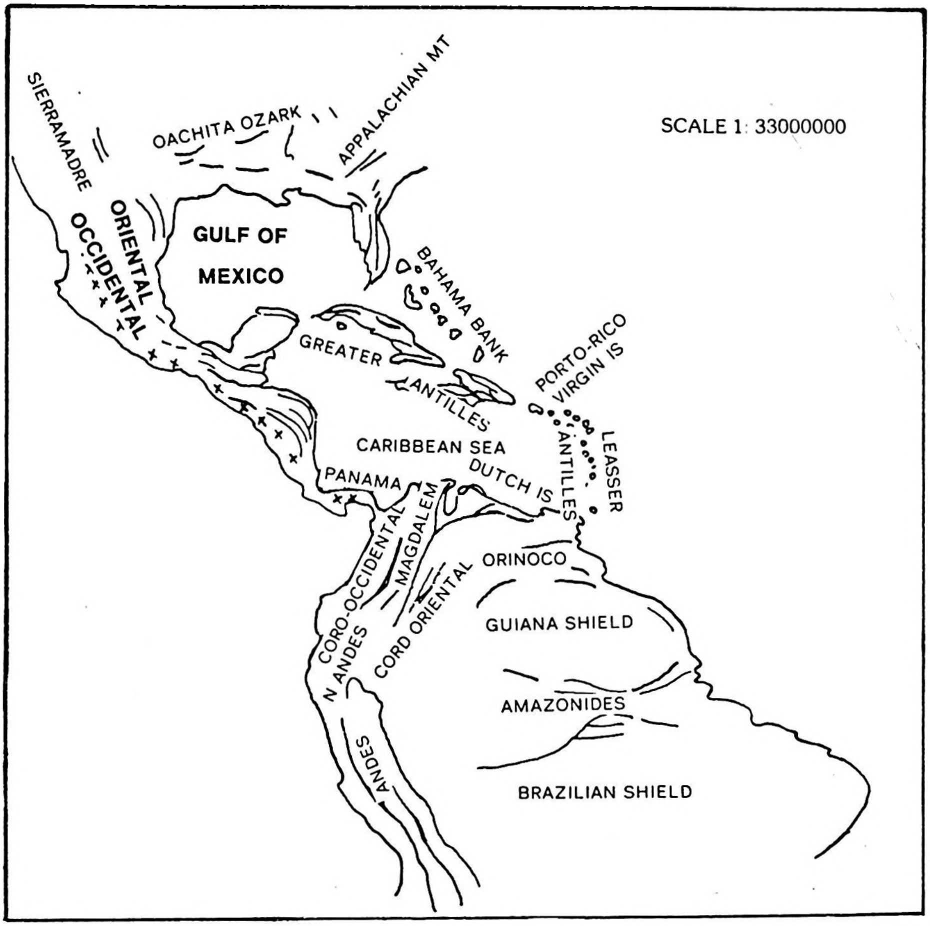


Fig.60. Central American Region Orogenic Trends

These numerous and extensive correspondences in the structural build of the three arcs clearly suggest that these arcs were originally in a superposed condition as sheets over one another. The sequence of superposition appears in general to be as follows:

(4) Mexico Gulf Coastal Belt at the top
(3) Yucatan-Cuba-Puerto Rico Arc in the middle and
(2) Colombia-Venezuela sheet, resting over
(1) Brazil-Guiana Shield at the base.

This superposed condition of the three arcs continued almost upto the Upper Tertiary when the Miocene formations Gatun, Bowden, Tempa etc. with their typcial fauna were being deposited simultaneously in different parts of the same basin.

It was during the Quaternary and recent geological period that these three sheets got separated due to the enormous igenous activity represented both in the Isthmanian linkage region of Central America as also in the Lesser Antilles. The emplacement of these three sheets was effected by the anti-clockwise rotation of the North American continental mass suffering simultaneous shifting through transcurrent faulting successively towards NW in the Isthmanian link region and during this process, the Antillean Arcs also got appreciably distended en echelon (Plate 17).

The author has dealt with this problem of the Antillean Arcs in greater detail separately (Abstract Int. Geol. Congr. Mexico 1956, Rode, K. P. 1965).

Here we have a fine example of the sheet movements which have shaped the evolution of vast crustal features in the Western Hemisphere and which can be followed stage by stage.

17. Guiana Structural Pattern

The Guiana Highland mass of South America on the Brazilean-Venezuelan border is quite prominent among the morphological features of the Amazon-Orinoco River Basin. It has a characteristic arcuate outline along its northern border comprising the Amapa-Surinam Arc on the east continued westward into the (British) Guiana, Bolivar uplands and bordered by the lower Orinoco River on the north and west. It is breached by the northern tributaries of the Amazon, particularly the Branco and the Negro on the south and southwest. It simulates two equal ovals fused together obliquely along one side, giving the figure of B.

Geologically, this Guiana structure is a shield mass characterised by Pre-Cambrian metamorphics, unfolded Palaeozoic marine formations and continental Roraima Sandstones and eruptives spread widely over the whole plateau, covering the basement metamorphics. Along its periphery we have a nice development of Lower Palaeozoic sequence in the Amazon basin on the south and also in the Colombian-Venezuelan Andes along the western and northern borders, separated by a wide stretch of Orinoco alluvium. The northwestern border of the Guiana mass thus follows closely the arcuate trends of the Colombian-Venezuelan Andes and thus appears to have moulded the Andean bulge in the Peru-Colombia region as also the drainage trends in the Amazon basin.

The Guiana outline is seen repeated in the basins of Urubamba, Madeira, Tapajos, Xingo and Tocantins. Some of these basins are also characterised by corresponding geological structures to which the river trends exhibit intimate correspondence. The centripetal drainage courses of the Amazon tributaries clearly point to the systematic changes in the structural trends and it seems possible that the Guiana shield mass itself was earlier situated in the basin of the Tocantins and later gradually rotated clockwise through the arcuate courses of the Xing, Tapajos, Madeira, Urubamba, Ucayali, Negro, Orinoco and simultaneously brought about the en echelon extension and present delineation of the Andean Arc in Peru, Ecuador, Colombia and Venezuela with pronounced convexity to the west.

As noted earlier; the Guiana Pattern is again repeated in the Greater and Lesser Antillean Arcs and also in the region of the Mexican Gulf. The Lesser Antillean Arc from Puerto Rico to Trinidad has the same size and curvature as that of the Amapa Altantic coast of Guiana near the mouth of the Amazon while the Greater Antillean Island Arc appears to correspond with the Caribbean coast of Venezuela. The Yucatan peninsular

mass has the same shape and size as that of the Perija Guajira Peninsula west of the Lake Maracaibo in north Colombia. When we superpose the Antillean sheet over the Guiana sheet the extent of identity of the pattern becomes evident. Again if we superpose the trace of the Mexican Gulf region over the Guiana sheet, the whole coastal belt from Mexico to Florida becomes coincident with the Guiana border zone. It is obvious that the whole region of the Andean Arcs from Bolivia in South America to Gulf States of the North America exhibits repetition of the Guiana structural pattern. This throws light on the course of evolution of the whole region, including the continents of North and South America.

The Guiana pattern is again seen developed, though in traces, repeatedly in the geological structure of the Sahara region of North Africa.The Amapa semi-circular Arc is recognisable successively from Nefoud region of Central Arabia, through Egypt, Libya, Ennedi, Tibesti, Murzuch, Tassili de Ahaggar and again in Hamada el Harich exhibiting the westward migration of the semi-circular structure. When superposed, the whole Guiana structure appears repeated in the north Sahara region. We find that the north Andean bulge of South America between Peru and Venezuela has the same curvature as that of NW Africa north of Liberia and that the Chilean Andes has the same size and trend as the western coast of peninsular Africa between Cameroon and the Cape. It is obvious that the northern part of South America with the Guiana structure was superposed over the Sahara part of North Africa and that the Ennedi-Ahaggur series of structures were left behind as the South American sheet migrated westward over the African basement.

18. U-Shaped Alabama Arc Pattern

In North America the Upper Palaeozoic Appalachian Orogenic Belt running southwest from New York abruptly disappears under the cover of Cretaceous Tertiary formations of the Gulf coastal region in the Alabama and Georgia states east of the Mississippi. These Cretaceous-Lower Tertiary formations occur in a remarkable U-shaped semi-circular outcrop extending upto North Carolina (Fig. 61). Further north, the Cretaceous-Lower Tertiary formations do not outcrop and the Upper Tertiaries directly abut against the metamorphics of the Appalachian piedmont along the Fall Line. Along the western limb the arcuate outcrop of the Cretaceous-Lower Tertiary formations abruptly ends along the Mississippi. Near Paducati, another U-shaped structure starts, consisting of the Lower and Upper Palaeozoic formations abutting against the cover of Quaternary Alluvium until we come to southern Arkansas where we again get the Cretaceous-Lower Tertiary sequence at the southern border of the U-shaped structure in the basin of the Red River in South Oklahoma. The other limb of the U-shaped structure is apparently missing here. From near Dallas southwards starts yet another U-shaped outcrop of the Cretaceous-Tertiary sequence. The western limb of the U-shaped structure expected along the Pecos tributary of the Rio Grande appears shifted laterally westward to the valley of the Rio Grande in New Mexico.

Beyond the Rio Grande del Norte to the west, we again find development of a complete dome structure in the Colorado Basin north of the Gila tributary, with a size more or less corresponding to that of the Alabama structure. This dome is constituted of Permian, Triassic, Jurassic and Cretaceous formations with a covering of Lower Tertiary rocks and

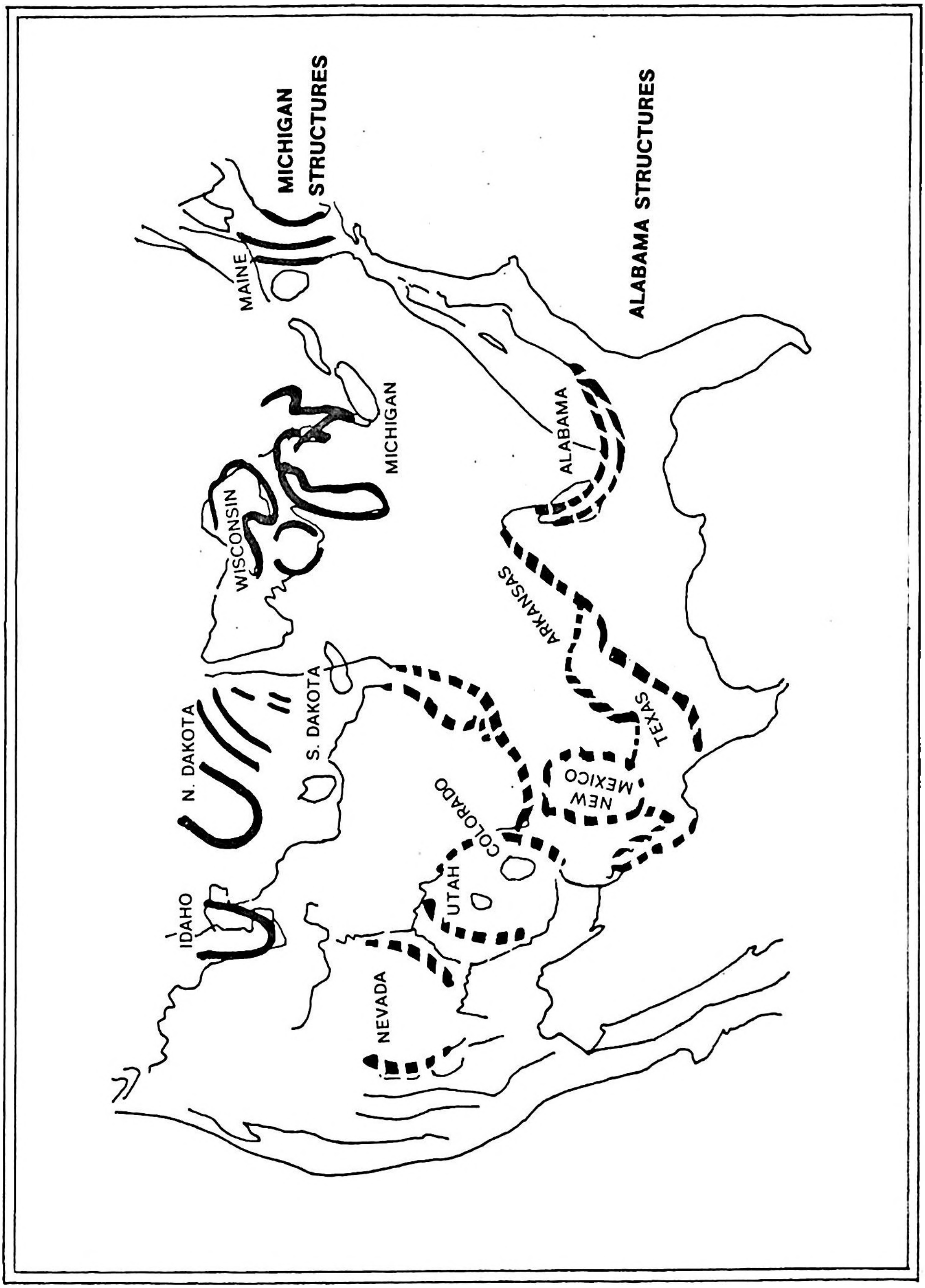


Fig. 61. Migration of Michigan and Alabama Structures

ringed by outcrops of the Tertiary and Quaternary eruptives. A similar U-shaped structure appears repeated in the region west of the Salt Lake in Nevada in what is described as Basin and Range structure constituted of N-S trending narrow bands of Palaeozoic formations involved in Tertiary Volcanism and covered by continental Quaternary formations with a ring of Quaternary Volcanics. Lower Tertiary limestones, bearing large Foraminifora, occur at intervals right from Florida along the Gulf coast through Mexico to California besides occurring in Antillean-North Andean Arcs.

The geological formations involved in U-shaped structures are also largely complementary and range from the Lower Palaeozoic upto the Tertiary.

What is the significance of these U-shaped structures and of their regular repetition successively westward right from the Appalachian Ranges not far from the Atlantic coast through Arkansas, Texas, New Mexico, Arizona and Nevada almost upto the Rockies on the Pacific board encompassing the whole width of the United States? Could they all be independent structural units accidentally possessing similar size and form? Why should they show complementary geological build with peculiar distribution of volcanic rocks as young as Quaternary in age? These features can be explained only on the basis of sheet movements through the activity of subcrustal magmas during as late as the Quaternary period.

19. Oval-Shaped Michigan Pattern

A similar phenomenon is again exhibited by the oval-shaped structural pattern as exemplified by the Michigan Dome and also by the Snake River basin in Idaho. Partial representation of this pattern can be seen round the Black Hills in the Dakota region, then in Wisconsin and again in New Hamsphire-Maine coastal belt east of the Hudson river. This oval pattern thus appears repeated in greater or lesser completeness from the Atlantic Coast to almost the Pacific Coast. Thus, both the U-shaped Alabama type and the oval-shaped Michigan type structures appear repeated several times between the Atlantic and the Pacific coasts. They leave us in no doubt that the Rockies as a structural sheet complex were earlier superposed over the Appalachian-Acadian structural complex and that during the Tertiary Quaternary Volcanism, the Rockyan sheet complex got detached from the Appalachian basement and moved laterally westward, with slight rotation, leaving traces of the Rockyan Sheet along the route.

20. The Karroo Gondwana Pattern

The continent of Africa is essentially a shield mass with folded orogenic belts confined to the northern coastal zone along the Mediterranean Sea and to the southern coastal border of Cape Colony. The rest of the continental mass exhibits stray outcrops of sedimentary formations occurring irregularly and disconnectedly over a metamorphosed basement.

The southeastern border of the Karroo Basin against the Indian Ocean is a smooth semi-circular curve which marks the abrupt ending of several geological formations of the Karroo basin from the Archean to the Cretaceous and as such is a tectonic border. The northwestern border against the Kalahari desert is a roughly S-shaped zone of older metamorpics, irregularly and unevenly covered by the desert sands.

The Karroo Formations consisting of the Dwyka, Ekka, Beaufort and Stormberg continental formations are intruded by the Karroo Dolerites and are capped by the Stormberg Volcanics in Basutoland. The peripheral parts of the basin exhibit detached outcrops of Pre-Karroo formations as those of the Cape system in the west, south and southeast and of the highly mineralized igneous and metamorphic rock formations on the north and the northeast. The rock formations of the Karroo basin are associated with rich mineral deposits as those of Gold, Nickel, Copper, Lead, Zinc, Chromium, Manganese, Tin, Coal, Diamond, etc.

The same rock formations, Pre-Karroo as well as Karroo, including Dwyka are seen developed in fragmentary, isolated outcrops in many areas of the peninsular Africa, south of the Cameroon-Aden Line as in Kenya, Uganda, Congo, Angola, Tanganyika, Katanga, North and South Rhodesia as well as S.W. Africa. Many of the rock outcrops in this region are associated with the same mineral deposits as those of the Karroo basin of South Africa.

These various detached fragmentary outcrops are seen interlinked by river systems which show many common characteristics among themselves as well as with the structural outline of the Karroo basin. Thus, the Limpopo-Molopo-Nossob river system with S-shaped trends along the northern border of the Karroo basin has a remarkably parallel S-shaped course in the Zambezi and its tributaries in the region of Nyasaland, Rhodesia and Angola. Again, if we rotate the sinuous Zambezi course clockwise with the pivot near its mouth in Mozambique, the Zambezi course would coincide with the rift lake system of Tanganyika and Nyasa with which it is interlinked through its tributaries Luangwa and Shire. This makes it possible that the Limpopo tectonic border of the Karroo basin at one time may have occupied the position of the Zambezi valley and still earlier that of the Tanganyika-Nyasa rift valley. Very significantly, the Cape Town-Durban coastal boundary of the Karroo Basin fits in exactly with the curvature of the Rift valley of the lakes Albert, Edward, Kiva and Tanganyika.

The region of the Lake Victoria east of the this Rift valley is largely composed of a vast spread of Basement Complex, detached outcrops of Muva, Ankola, Karagwe, Archaens, Newer Granites, small patches of Karroo sediments, Kisegi beds and Tertiary to recent volcanic rocks all very closely related to those of South African Karroo Basin and bearing similar mineral deposits including coal.

It is thus possible that the Karroo basin must have once occupied the position of the Uganda Tanganyika before its migration through anti-clockwise rotation along the routes of Zambezi and Limpopo to the present Orange River position at the southern tip of the peninsular Africa and in the process of migration, it must have left *en route* fragmentary outcrops of diverse type rock formations which were once integral components of the Karroo sheet complex.

The Cape Town-Durban coastal Arc can also be faintly recognised with some rotation along the west coast of the Indian Peninsula south of Cambay and possibly again in the arcuate course of the Ganges running E-W in the sub-Himalayan plains, between Delhi and Bhagalpur.

However, a much better representation of the Karroo Basin is found in the peninsular part of South America in the Parana Basin where many of the rock formations–

Gondwana and older constituting the Karroo basin—find their development under the cover of a vast sheet of Parana Volcanics. This Parana Volcanic sheet corresponds in age roughly with the Drakensberg Volcanics of the Karroo Basin. Most of the fossiliferous formations of the Parana Basin have the closest relations with those of the Karroo Basin. In structural pattern, the Parana Basin corresponds fairly well with the Karroo Basin in size as well as in form and if the tracing of the Karroo Basin is superposed after some rotation over that of the Parana Basin the structural correspondence becomes apparent (Fig. 62). It becomes plausible that during some earlier stages, the Karroo sheet was resting over the Parana sheet with the Parana eruptive sheet behaving as a sill in between. This is forcefully brought out by the Trappean plain of the Parana Plateau (vide Geological Section across the Parana Basin by Fernando, F.M. De Almeida, Geol. Soc. Am. Memoir, 65, 1954). This becomes likely when we see that the South American continental sheet was resting over the African continental shield as a superstructure, a possibility already shown earlier.

During the earlier stages of joint evolution of the Afro-American continental mass, the Parana-Karroo structural complex was resting over the Uganda-Tanganyika structure.

The evolution of peninsular parts of both Africa and South America took place jointly when the Karroo sheet left the Parana substructure in Uganda position and rotated anti-clockwise through the positions of Northern Rhodesia-Congo, Southern Rhodesia-Angola (upper Zambezi), Transvaal-Namibia (Southern Zambezi), to its present Orange River position of South Africa. These very movements also led to the simultaneous evolution of South American peninsular mass of Argentina (La Plata Basin), Patagonia, Terra del Fuego-Falkland Islands, etc. These rotational movements of the Karroo basin sheet over the eruptive basement of Africa also brought about the en echelon extension of the Chilean-Patagonian-Andes Range successively through the positions of Pulcomyo, Bermejo, Salado, Colorado, Negro, Chubut, Descado, Chico and Magellan basins (Fig. 63).

Thus, the elements of the Karroo-Gondwana pattern can be traced right from the Himalayan Gangetic basin through the western coast belt of peninsular India, then in east Africa through Uganda, Tanganyika, Northern and Southern Rhodesia, South Africa, yet farther west in South America in Parana, Chile-Patagonia, Terra del Fuego, Falkland Island and again in Antarctica in the Grahamland-Weddell Sea region and finally in the Transantarctic Mountain range. In this way it appears that the Karroo structural pattern was the main guiding structural element in the evolution of peninsular parts of the Southern Continents, west of the Mid-Indian Ocean Ridge.

21. Madagascar-Gondwana Pattern

The island of Madagascar off the Mozambique coast of Peninsular Africa has a distinctive shape with an obliquely tapering peninsular mass of Sambave north of the Antogil Bay and the irregularly rounded outline on the south. Its eastern margin is remarkably straight almost upto the Antogil Bay, whereas the western margin forms a gently sinuous coastline. The outline of Madagascar thus roughly resembles both in form and size, the outline of New Guinea without the tail portion.

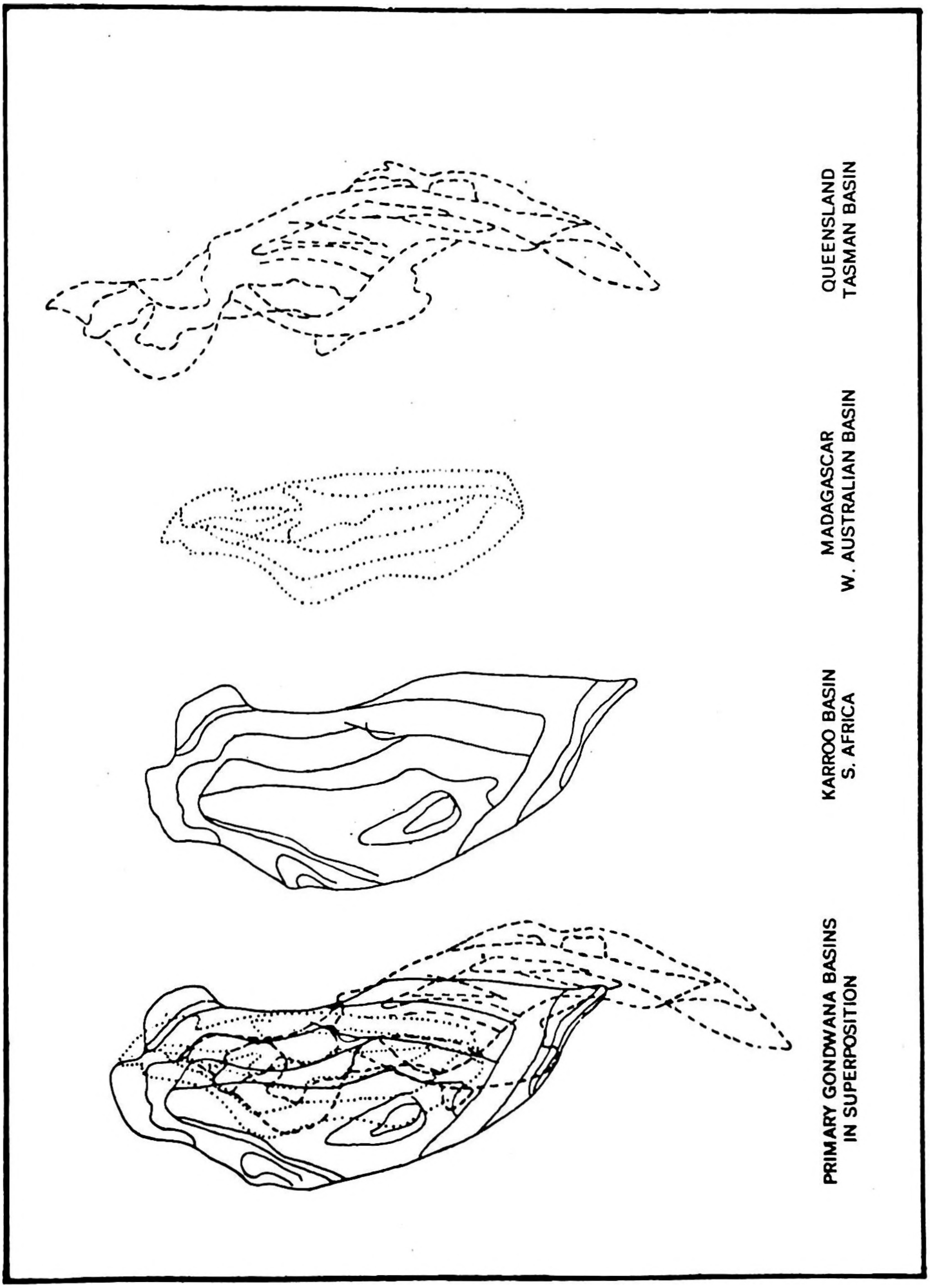


Fig. 62. Gondwana Basins

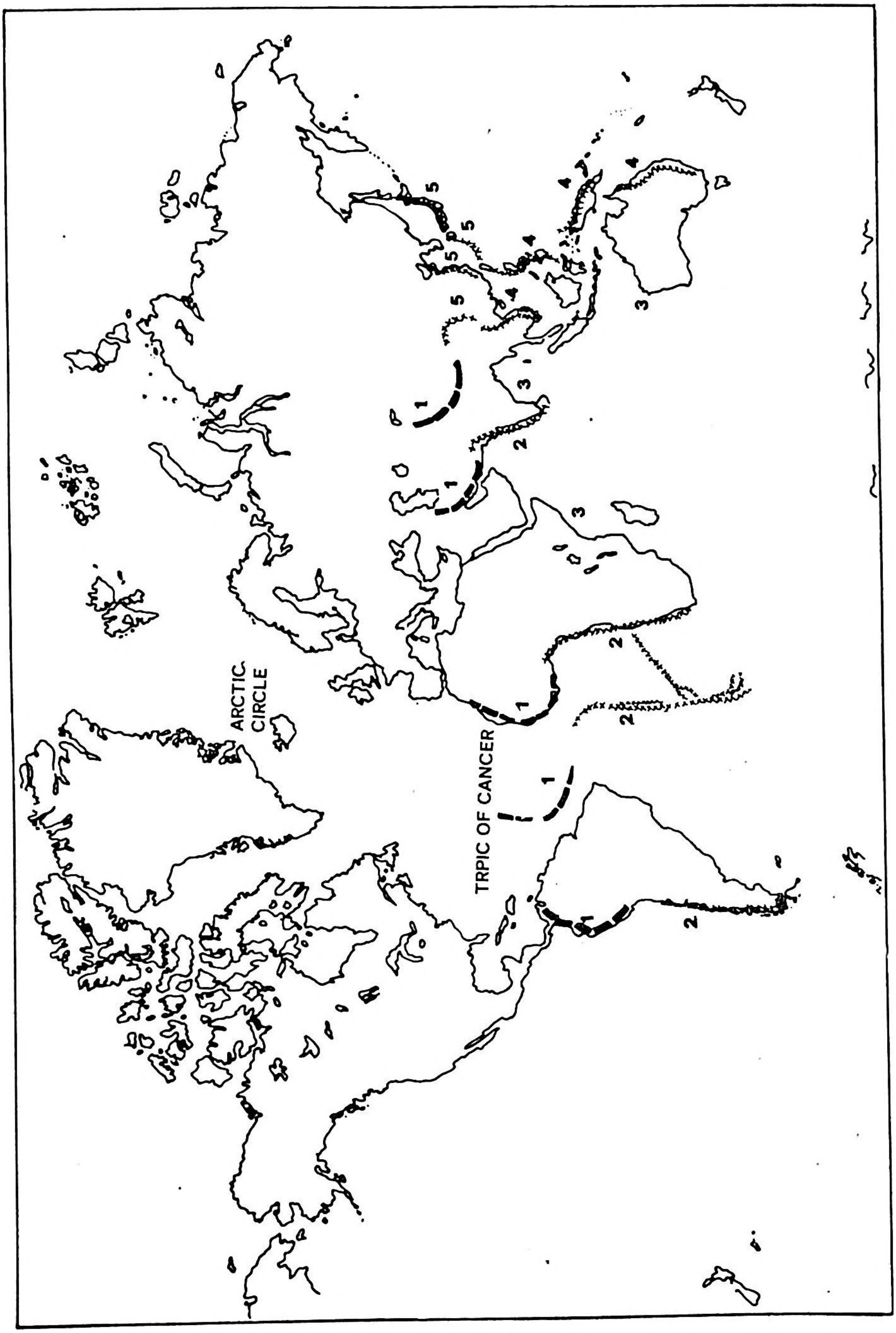


Fig. 63. Homomorphy in Coastal Lines

Geologically, the Upper Palaeozoic-Gondwana formations parallel the sinuous western border and are overlain by younger Mesozoic and Tertiary formations. The eastern half of the Inland is largely granitic-charnockitic and is covered irregularly by patches of younger volcanics.

This distinctive pattern is met with in parts several times in the region of the Indian Ocean. Nearest to Madagascar, the pattern appears impressed in part outline on the East African mainland along the Mozambique coastal plains north of the Limpopo and again north of the Zambezi upto Kilimanjaro. In the region east of the Lake Nyasa, the African coastline simulates the eastern and southern coastline of Madagascar, while the eastern border of Nyasa Lake simulates the sinuous west coast of Madagascar.

Geologically, the Mozambique plains show scattered outcrops of Gondwana formations surrounded by vast expanses of younger rock formations. The island of Madagascar is connected with the African mainland by the shallow Mozambique Channel dotted with the islands of Zanzibar, Aldabra and the Comores Archipelago. All these geomorphological features give an indication that Madagascar as a sheet once occupied the Mozambique belt of the African mainland east of the lake Nyasa, and that this island sheet shifted relatively southeast, successively through the positions of the tributaries of the Rufiji and then of the islands of Comores group. Another portion of the basement over which the Madagascar sheet got separated from the African mainland is seen in the southern Mozambique between the lower Zambezi and Limpopo. This coastal belt is characterised by the north-pointed projections of the Mozambique coastline south of Beira formed during separation. It is possible that the Madagascar Island sheet was once closely juxtaposed with the Karroo sheet in the region of the East African Rifts, marked by the lakes Magadi, Natron, Eyasi, while the Karroo structure occupied the region of L. Victoria.

The western coast of Madagascar finds considerable simulation in the eastern coast of Peninsular India south of the Godavary Delta. The northern peninsular mass of Sambave at the northern trip of Madagascar also finds its best counterpart in the island of Ceylon (Sri Lanka) matching in size, shape and in constitituion (Fig. 64).

The western coast of Madagascar can again be recognised in the Arakan-Irrawaddy belts of Burma which though made of much younger rock formations have the same shape and size.

The east coast of Madagascar again finds its simulation along the frayed and embayed coastal belt of Western Australia with matching geology, including the complementary development of the Gondwana formations.

In faunal relations during different geological ages, the Madagascar formations exhibit very close relations with those of the Himalayas, the Salt Range and Cutch and also possess continental formations of typical Gondwana affinities. Thus, structurally, faunistically, floristically and even in respect of peculiar mineral deposits, Madagscar appears to be closely interrelated with the Himalayas, on the one hand, and with the Southern Continents particularly with peninsular East Africa, India, Eastern Antarctica and Western Australia, on the other. We have seen earlier that the Karroo structural pattern dominates the evolution of peninsular South America, peninsular Africa, peninsular India and Western Antarctica whereas the Queensland-New Guinea Pattern

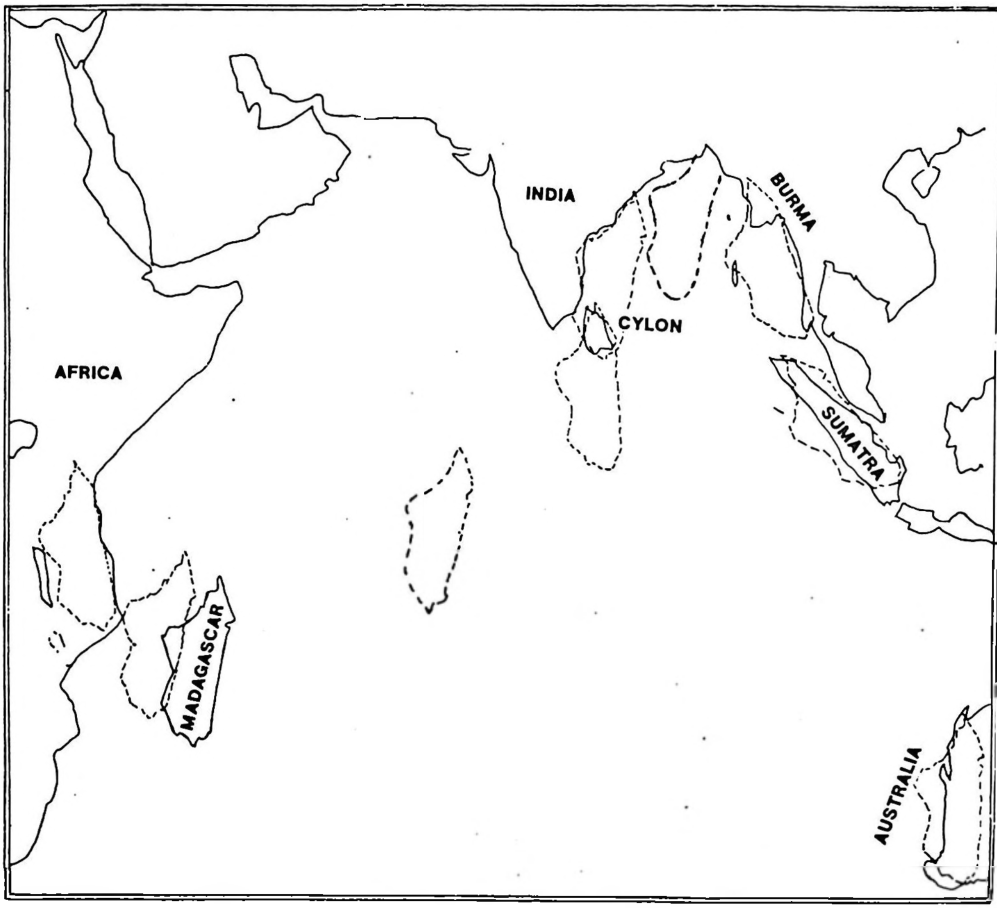


Fig. 64. Madagascar Pattern

dominates the South East Asia, Australasia and East Antarctica. Thus, the three structural patterns Karroo, Madagascar and Queensland among themselves control the structural evolution of most of the continental masses of the Southern Hemisphere including peninsular India. These three structural Basins appear to have originally developed juxtaposed and partly superposed in the Indo-Tibetan region south of the Tibetan Tethys from where they migrated, Karroo to the SW, Madagascar to the south and Queensland to SE, first as superstructure of the Antarctic continental mass but later as partly independent continental entities.

22. Homomorphous Linear Coastal Patterns

Coastal Lines

We have so far described the structural patterns of diverse areal extent exhibiting certain common characteristics repeated along particular trends over large parts of the earth's surface. We now refer to linear arcs of particular size and curvature which appear repeated several times along certain directions. Among these linear patterns, coastlines are very striking (Fig. 64).

The coastline of South China against the Pacific is a fine example. This coastline extending from Shantung to Hong Kong is found to be repeated northward in Manchuria, North Korea and Sikhota-Alin Coastal belt and southward along the Philippine-Celebes Island Arc against the Pacific and again along the east Australian coastal belt. This is again seen repeated yet further south along the coast of East Antarctica against the Indian Ocean between Kaiser Wilhelm II land and Victorialand. Another series of homomorphous curves is seen developed in the East Asiatic Island Arcs of Ryukyu, Japan and Kurile Islands. Part of this arcuate coastal pattern is recognisable in Indo-China. This loop-like development of continental arcuate coastlines along with parallel development of Island Arcs and Oceanic Trenches all along the West Pacific coastal belt from Kamchatka in the north to Antarctica in the south is very significant and calls for an explanation. During the study of Homomorphous structural patterns, we have seen that the Japanese Arc is intimately related to South China coast through Ryukyu Arc and these three Arcs appear to be originally situated in the source region of Yangtsekiang in the Tibeto-Chinese border region in the nature of a superposed sheet complex. From here the Korea-Japan sheet complex migrated eastward through successive radial and parallel movements of the sheet along the route marked by Yalung, Tatu, Kialing-Han Kiang tributaries of the Yangtsekiang and reached the position of Chinese coastal border along the East China Sea. This time the North China-Manchuria-Sikhota Alin sheets were in a superposed condition in the Lower Yangtsekiang basin. From this Yangtsekiang position the North China-Siberia sheet packets were shifted north and northeast through the parallel northward movements of the Hwang Ho and later of the Amur River basins.

The Philippine Arc was similarly related to Indo-China Arc and these two were originally situated in the source region of the Mekong-Yangtsekiang in eastern Tibet. From this Tibetan position the Philippine-New Guinea-Queensland sheet complex (as already described in an earlier section) moved south and southeast to occupy their present positions. In this way, we can account for the homomorphous relations of the various arcuate coastal lines and Island Arcs now in series of loops en echelon along the Pacific coast of Asia and Australia.

Another example of Homomorphous coastlines is that of the Peruvian-Colombian Pacific coastline of South America and the Liberian-Mauritanian Atlantic coastline of NW Africa. Both these west coastlines of the two southern continents, South America and Africa, are almost alike in shape and size as can be realised on superpositions. Both represent westward bulging of the continents against a long straight S-N coast of the peninsular tapering in the south. The narrow embayment near Dakar in Senegal on the African side has a corresponding embayment in the Gulf of Guayaquil in Ecuador part of the Andean Coast. Even the Canary Island Arc near the African coast has a corresponding counterpart in the Panama Arc of South America.

This wide-ranging homomorphy of the coastlines on the western sides of continents of either side of the Atlantic Ocean, suggests community of evolution of the two continental masses such that South America as a sheet, mostly constituted of sedimentary formations, was at one time, resting as a superstructure over the basement of African continent constituted of highly metamorphosed basement rocks as already shown earlier. The similiarity of the east coast of peninsular India with the east coast of peninsular Africa north of Zanzibar is also noteworthy. This physical similarity in coastlines is further enhanced by the geological formations, Gondwana, Mesozoic and Tertiary, exposed along these two coastal borders. The eastern coast of peninsular India finds its counterpart in outline, though in a complementary sense,.in the western and northwestern coast of Australia such that the convex NW coast of Western Australia gets well fitted in the concave Coromandel coastline of Indian Peninsula when placed juxtaposed. In this position, the eastern coast of Africa when superposed over the eastern coast of India gets closely juxtaposed with the NW coast of Australia. The southern and southeastern Cape Town-Durban coastline of South Africa in this position gets remarkably well fitted into the Weddell Sea embayment of Antarctica, both physically and geologically.

The homomorphous relations of the various coastlines of South America, Africa, India, Australia, and Antarctica together with very intimate relations of the fossil floras of these widely separated continental masses leaves us no choice but to visualise close juxtaposed and partly even superposed condition of the various continental masses in the early stages of their evolution. This superposition and juxtaposition of different continental masses gives us a picture of the Gondwana land in its earlier stages of evolution as a unitary Mesozoic supercontinent while various marine bands developed in linear strips in between indicate the stages of partial breaking of this unitary continent into separate continental entities and of their incipient drifting apart. The large-scale drifting of these individual continents away from each other took place only later during the Quaternary and even in Holocene period when the Indian and Atlantic oceans came into existence in their present enlarged dimensions.

These studies of Sheet Movements which explain homomorphy of coastlines enable us to follow very precisely the course of evolution of the Gondwanaland from its inception as a small submarine swell, to its present extended form spread over a large part of the Southern Hemisphere.

23. Dome Structures: Radial Movement of Sheets

In a previous section, we have dealt with the homomorphous relations of certain structural patterns exhibiting oval or domal outline. Among these oval structures are those of the Pamir Plateau, Armenia Plateau, Carpathian Ranges and also the negative oval structures like those of the Black Sea and the Gulf of Mexico which represent the open framework left behind when the inner positive Domal structures have migrated farther away. It was shown that these structural patterns were actually in superposition first in the Pamir position and it was from this position that the Armenian-Carpathian structures were transported as sheets. We may now study how these oval or domal structures themselves came to be formed.

23 (a) The Pamir Dome Structure

The Pamir Knot is the most complex of such structures forming the highest oval plateau mass on the earth's surface. It was considered as Scharung or collision of two or more orogenic belts. In this case, the orogenic belts of Karakoram, Kunlun, Tienshan, and Hindukush collided among themselves to produce this highly complex knot. However, there are indications that this knot-like oval structure has been produced not by collision of two or more independent systems of orogenic belts but through a system of divergent movements of portions of one and the same orogenic belt. The Tibeto-Himalayan Range suffered gaping at one end while the other end behaved as a pivot or a hinge. Here the gaping started through a system of Indus rifts initially in the region of the Mansarovar north of the Main Himalayan Axis. A vast sheet of rock formations was detached from its basement and rotated clockwise southward with its pivotal hinge gradually migrating northwest, first to the position of the Sutlej syntaxial bend near Bhakra, then to that of the Ravi near Gurdaspur, next to that of the Chenab near Riasi, later to that of the Jhelum near Muzaffarabad and lastly to that of the Indus near Nanga Parbat. By these diverging angular movements, the Suleiman- Kirthar sheet rotated successively southwest along the courses of the Jamuna, Chambal, Mendha, Luni, Nara and the Indus to its present position in Sind-Baluchistan region. The Hindukush orogenic belt originally an integral part of the Karakoram separated through the rifts of the Shyok, Hunza and the Gilgit with similar but gentler bends in their river courses followed westward by the rifts of Swat, Panjkora, Kunar, Alinger, Panjshir system of the Kabul tributaries draining the southern Pamir Plateau. A similar series of rotational movements can be recognised east and north of the Pamir knot but now in a lateral manner in the basin of the river Tarim, including its tributaries Khotan, Yarkand, Kashgar and Tienshan. After the Tienshan structure got detached from the Kunlun base, it was emplaced in its present E-W trending position north of the Tarim Basin. At this stage, the Ural structure got detached from the Tienshan and it started rotating anti-clockwise through the positions marked by the rivers Chu, Sari Su, Turgai, Ishim, Tobol to its present N-S trending position. It is during these rotational movements, clockwise in the Indus system and anti-clockwise in the Tarim-Amu-Syr Darya system, that the Pamir knot developed as a pile of oval-shaped superposed sheets in the stratified series of sediments including eruptives.

23 (b) The Armenian Dome Structure

As indicated earlier, identical type of radial movements can be recognised round the Armenian Plateau south-west of the Caspian Sea. This Plateau on the Turko-Iranian border is again a semi-circular or oval structure constituting the culmination of the Turko-Iranian-Alpine Arcs on the east, south and west and of the Caucasus structure on the NNE. The Karkheh, Tigris, Euphrates system of rivers records the rotation of Alpine orogenic belts from their earlier position, partly superposed over the Zagros Ranges of SW Iran successively through the positions of (1) Iraq-Persian Gulf, (2) Saudi Arabia, (3) Syria-Jordan, (4) Lebanon-Sinai and (5) Cyprus-Crete to occupy positions in the (6) Turkish Peninsula. The pivot of these movements was in the region of Mt. Ararat (5200 m). These sheet movements correspond with those of the Hindukush-Sulaiman-Kirthar sheets from the Himalayan basement. The Caucasus sheet movements were regulated by the Araks-Kura pivotal rifts tangential to the Armenian Arcs similar to the anti-clockwise Tarim movements of the Tienshan structure with respect to the Pamir-Kunlun basement Arcs.

Looking to the identity of the Armenian pattern with that of Pamir, in shape, size and structural trends, it is possible, as already discussed earlier, that a large part of the rotational movements associated with the Armenian knot had already been accomplished while the Armenian sheet was still resting superposed over the Pamir Plateau.

23 (c) The Carpathian Domal Structure

We may further recognise similar clockwise and anti-clockwise rotational movements in the structural evolution of the Carpathian semi-circular pattern, which in its shape, size and structure, appears to be homomorphous to the Armenian arcuate pattern and, as already mentioned earlier, appears to be the upper sheet complex originally covering the Armenian Pamir Composite structure. The clockwise movements of the Balkan Alpine Arcs shifting westward are represented in the basin of the northern tributaries of the Danube while the anti-clockwise movements of the Carpathian Arcs westward are recognisable in the basins of the north-flowing tributaries of the Vistula-Oder Systems.

In some of these structural movements, undirectional lateral migration appears to be more dominant than the rotational and this appears to be later than the rotational one and marks the migration of Carpathian structural sheet from the Armenian basement through the Black Sea Basin to its present position.

24. Guiana Rotational Movements

Another fine example of rotational movements round a pivot is provided by the Guiana shield mass in the drainage basins of the Amazon and the Orinoco in South America already described earlier. Here the Guiana Plateau mass appears to have been, at one time during its evolution, situated in the basin of the Tocantins with N-S trends as part of the Goias Range. It got rotated clockwise round a pivot situated near the mouth of the Amazon and occupied successively the bends in the courses of the Xingo, Tapajos, Madiera, Ucayali, Amazon and Negro before it reached its present position in the valleys of Branco and Orinoco, with E-W trend.

The Guiana movements are eminently clockwise whereas the Caribbean and the Mexican Gulf structures to the north exhibit anti-clockwise movements. These rotational movements, both clockwise and anti-clockwise, in the Brazilian Central American region correspond remarkably with those observed in the Carpathian, Armenian and the Pamir regions. This clearly indicates their simultaneous evolution while they all were in superposed condition on the Pamir Plateau.

25. Brahmaputra Rotational Movements

Mention may also be made of yet another system of rotation which is represented in the Assam-Indo-China region in the drainage basins of the Brahmaputra, Irrawaddy, Salween, Mekong and Sikiang river systems.

Here the rock formations show regular anti-clockwise fanning out of their structural trends from E-W in the Shillong Plateau, NE-SW in the Naga Manipur Hills, N-S in the Pegu-Shan States, NW-SE in the Mekong-Black and Red river basins, and almost E-W in the Sikiang basin. These structural changes in the nature of systematic fanning out of rock structures which were originally concentric Arcs in the Tibetan region can only be explained on the basis of sheet movements.

These rotational structural movements, both clockwise and anti-clockwise, as seen in different parts of the continental crust have materially brought about the expansion of continental masses from originally small areal dimensions. The stages and epochs of continental expansion can be deciphered very accurately both in time and space and these enable us to work out the palaeogeographical conditions of the earth's crust during the different periods of the geological history.

CHAPTER X

Structural Evolution of Continents and Oceans

INDIVIDUAL CONTINENTS

Most of the continents exhibit complexities in their structure. The most common characteristic in the structural build is usually the presence of a granitic mass surrounded by or associated with orogenic belts besides less folded sedimentary terrain affected by epeirogenic movements. The granitic cores are the oldest and toughest rock formations exhibiting varying degrees of metamorphism and reconstitution. The major constituent rock formations are granites and gneisses intricately interwoven with schists occasionally with bands of qartzite and marble. These are overlain, usually with a strong unconformity, by less metamorphosed but unfossiliferous clayey and shaly pebbly formations followed upwards by a thick series of marine or continental rock formations carrying fossil remains which help in determining the ages of their sedimentary sequences. The ages of intercalated unfossiliferous rock formations are determined, often arbitrarily, on the basis of the law of superposition. The granitic and gneissic core masses are very tough and do not yield to folding and as such escape orogenic deformation but may suffer epeirogenic faulting or tilting. They have remained as land masses exposed above the sea level except for temporary periods while the sediments deposited during their submergence remain flat and unfolded exhibiting discordant junction.

The continental shelf zones often suffer steep faulting and get submerged under deeper seas to become geosynclines for continuous thick sedimentation for long geological periods. When these get involved in orogenic movements, they get folded and overthrusted and get fused with the adjoining land mass to become peripheral mountain ranges and thus become integral parts of the continents. This process may get repeated several times during successive orogenies and the continent may get expanded from time to time. This phenomenon is nicely illustrated in Europe where Pre-Cambrian Fenoscandian landmass of NW Europe got expanded successively during the Caledonian, Hercynian and the Alpine orogenies.

The mobile belts of the geosynclinal period became folded during succeeding orogeny. This squeezed, folded and hardened mass behaved as a shield during succeeding orogenies. The Caledonian geosynclinal folded belt behaved as a shield mass during Variscan Orogeny, likewise the Variscan folded belt behaved as a rigid horst during Alpine orogeny.

The geosynclinal sediments formed at varying depths are folded, squeezed and raised up as high mountain ranges and in this uplifting magmatic intrusives have taken a prominent part. Large basic magma masses have intruded at the base bringing about granitisation of the associated sedimentary rocks and these go to constitute the core of the mountain ranges. It is thus likely that a large part of the basement formation is constituted of younger intrusive masses and later granitised sediments, and it may not always be correct to assign an older age merely because of their lower structural position or on the greater degree of metamorphism shown by the basement formations.

In the structural build of a continent, we often find diverse Tectonic Units which could be classified as:

(a) Cratonic Core which is generally granitic, often batholitic but largely granitised or even charnockitised into a Massive, grading into
(b) the Shield which is mainly a migmatitic mixture of gneisses, schists and eruptives with partly digested lenses and bands of quartzites, crystalline limestones etc. all exhibiting a high degree of metamorphism and peneplaination.
(c) Platform of peneplained metamorphosed formations with a marked unconformity, at the base of
(d) Sedimentary Formations, gently folded, terminating against
(e) Complex Folded Orogenic Belt of variously metamorphosed sediments and eruptives.

Structural Evolution of Eurasia

Eurasia is a multinuclear supercontinent with complex systems of structural trends. It extends from Scandinavia in the NW to Bering Strait on the NE and from Portugal on the west through Turkey, Arabia, India and Indonesia on the south to New Guinea in the SE. It is bounded on the north by the Arctic Ocean, on the west by the Atlantic Ocean, on the SW by the Mediterranean and Red Seas, on the south by the Indian Ocean and on the east by the Pacific Ocean. We could also include the large continental mass of Africa as an integral part of this supercontinent since the two are separated from each other by a comparatively shallow parting of the Mediterranean and the Red Sea.

The Eurasian Continent is highly complex in its built having a number of independent Cratonic nuclei each associated with its own system of mobile structural elements. Among these nuclei the Scandic Shield along the northwestern border extends into the Russian platform in the north and is detached from the Angara Shield on the NE. Along the southern border, we have the Arabian Shield on the SW and the Indian Shield in the south, while the nucleus in the SE is possibly submerged and is represented by the Banda submarine platform.

The northern cratonic nuclei though separated by vast distances exhibit intimate faunal and floral relationships of their fossiliferous rock formations suggestive of closer juxtaposition among themselves and are also related to a certain extent, with those of the south. The Angara continental Flora though dominated by the Northern forms included numerous elements characteristic of the Southern Flora.

The Angara shield is separated from the Indian shield by a vast development of Caledonian folds of the Altai Ranges, Variscan folds of the Tienshan, Kunlun and Karakoram ranges and by a wide development of the Alpine folds of the Himalayan mountain ranges encompassing the high Tibetan Plateau.

The Fenoscandian shield of the NW is separated from the Arabian shield of the SW by a vast development of the Alpine folds and a minor development of the Variscan folds.

It looks, therefore, possible that these cratonic masses before the Caledonian were closer together and that they have moved wider apart successively during the geosynclinal sedimentary and eruptive phases of the different post-Cambrian Orogenies.

The Structure and Evolution of Asia

Asia, even as a constituent of Eurasia, is the largest among the continents of the world. It has a most complex built being made up of several apparently independent subcontinents — Indian Subcontinent in the south, Turko-Iranian in the SW, Indochina-Indonesian in the SE and Sino-Siberian in the NE. In the same way, Europe forms a subcontinent of NW Eurasia. This supercontinent of Asia has a complicated system of fold ranges which, in general, appear to radiate centrifugally from the Central plateau mass of Tibet. In this plateau mass are seen some of the mightiest ranges on the earth's surface. The Himalayas (8848 m), the Karakoram (8611 m) and the Kunlun (7724 m) are fused at one end into a complex knot of the Pamir (7885 m) on the west and converging again at the other end into an open knot round Namcha Barwa (7756 m) on the east. These two knots which mark the syntaxial bends of two of the mightiest rivers, Indus on the west and Brahmaputra on the east, control the evolutionary trends of all the important mountain ranges of SW and SE Asia. The Indus trends have controlled the evolution of the Turko-Iranian-Afghan-Pakistan ranges of the West Asian subcontinent. The Brahamputra trends are continued into the Irrawaddy, Salween, Mekong and Sikiang rivers and determine the evolution of the Indo-China-Indonesia subcontinent of SE Asia. Similarly, the Yangtsekiang relayed further north and NE by the Hwang Ho, Amur and Lena regulate the evolutionary trends of China and NE Siberia in east and northeast Asia. The Tarim and Amu Darya, the Syr Darya and the various tributaries of the Ob control the evolutionary trends of Western Siberia in the NW Asia.

The onsetting of CircumPacific volcanism in the peripheral parts of Tibet towards the end of Mesozoic led to the evolution of the Rockyan-Andean and East Asian Orogenies while the Mediterranean Ophiolitic volcanism in the Central Tibetan region brought about the intense Alpine Orogenesis. The extensive flooding of the Plateau Basalts throughout the region elevated the whole Tibetan mass along with the central and peripheral geosynclinal folded belts and brought about their large-scale migration in different directions as recorded by the mighty rivers draining the Tibeto-Himalayan terrain.

The Gondwana basins of Peninsular India as part of Karroo-Madagascar basins and bordered by the Andean-Cape folds, migrated from their homeland in the Himalayan zone of south Tibet following the Ganges syntaxial trends. The Tibetan-Alpine folds migrated along the Indus syntaxial movements southwest and west to the Afghan-Iranian position.

The Ural folds migrated from their Kunlun-Tarim-Tienshan homeland to their present position as a consequence of anti-clockwise rotational movements of the Tarim followed by those of the Ob and its tributaries. The Verkhoyansk-Kolyma folds migrated first from the position of Nan Shan passing through Altai, Yablonovyy, through the movements connected with the Hwang Ho and Amur, followed by the Lena, Yana. Indigirka and Kolyma. Simultaneously, the Kamchatka structure migrated from the Tsaidam region through lower Hwang Ho-Liao-Sungari basin, Sikhota Alin, Sakhalin-Kurile Arc to its present position thus enclosing the Sea of Okhotsk.

In southeast Asia, the Indochina-Philippine-New Guinea series of folds which originated in the source region of the Mekong in Tibet migrated southeast to Yunnan and Indochina, then through Sikiang movements to Philippines and later to New Guinea while the Sumatra-Java-Borneo folded belts originally developed in upper Salween Basin of southeastern Tibet moved along the Tsangpo, Luhit, Irrawaddy and Salween to their Indonesia position in the S.E. Asia (Fig. 65 and 66).

Structure and Evolution of Europe

The European part of the Eurasian Continent has been generally treated as a continent by itself though its boundary with Asia is largely arbitrary. This continental mass is geologically most extensively studied and these studies have dominated the geological thought since early times.

The structure of Europe has been worked out variously by several eminent authorities. The consensus of views about the structural built of the region is that Fenoscandia constitutes the oldest part of Europe-Ureuropa which grew in surface dimensions through accretions of folded mountain belts successively during the Caledonian, the Variscan and the Alpine orogenies to attain its present size (Rutten MG 1969) (Fig. 67).

Europe behaved as a constituent of the geological North Continent—Laurasia which collided against the Southern Continent—the Gondwanaland during different orogenies. Parts of the intervening folded belts got fused with the Northern Continent during each of these orogenies to attain its present configuration. In this scheme, the position of the Ural mountain appears anomalous.

The mode of structural evolution of the European land mass appears to be materially different from this scheme when worked out on the basis of sheet movements. The Ural mountains which constitute the eastern border of Europe against Asia themselves appear originally as an integral part of the Tienshan mountains of Central Asia and are also structurally related to the Appalachian ranges of North America (Fig. 68)

Again the Alpine belts of Southern Europe appear in their condensed form as integral parts of the Tibeto-Himalayan and Turkish folds, on the one hand, and are structurally similar to the Gulf coastal Antillean and Andean folds of Central America, on the other.

On the basis of homomorphous relations, it appears plausible that the Caledonian structures of Norway as part of the Acadian structures of North America were juxtaposed with the Ural Structural Belt along its western flanks in the basins of the Pechora and the Kama. These Caledonian structures along with their Fenoscandian basement and the Mesozoic cover, moved westward as marked by the course of the North Dwina and Upper Volga, in stages, upto Latvia on the Baltic coast and later to their position west of the Baltic Sea.

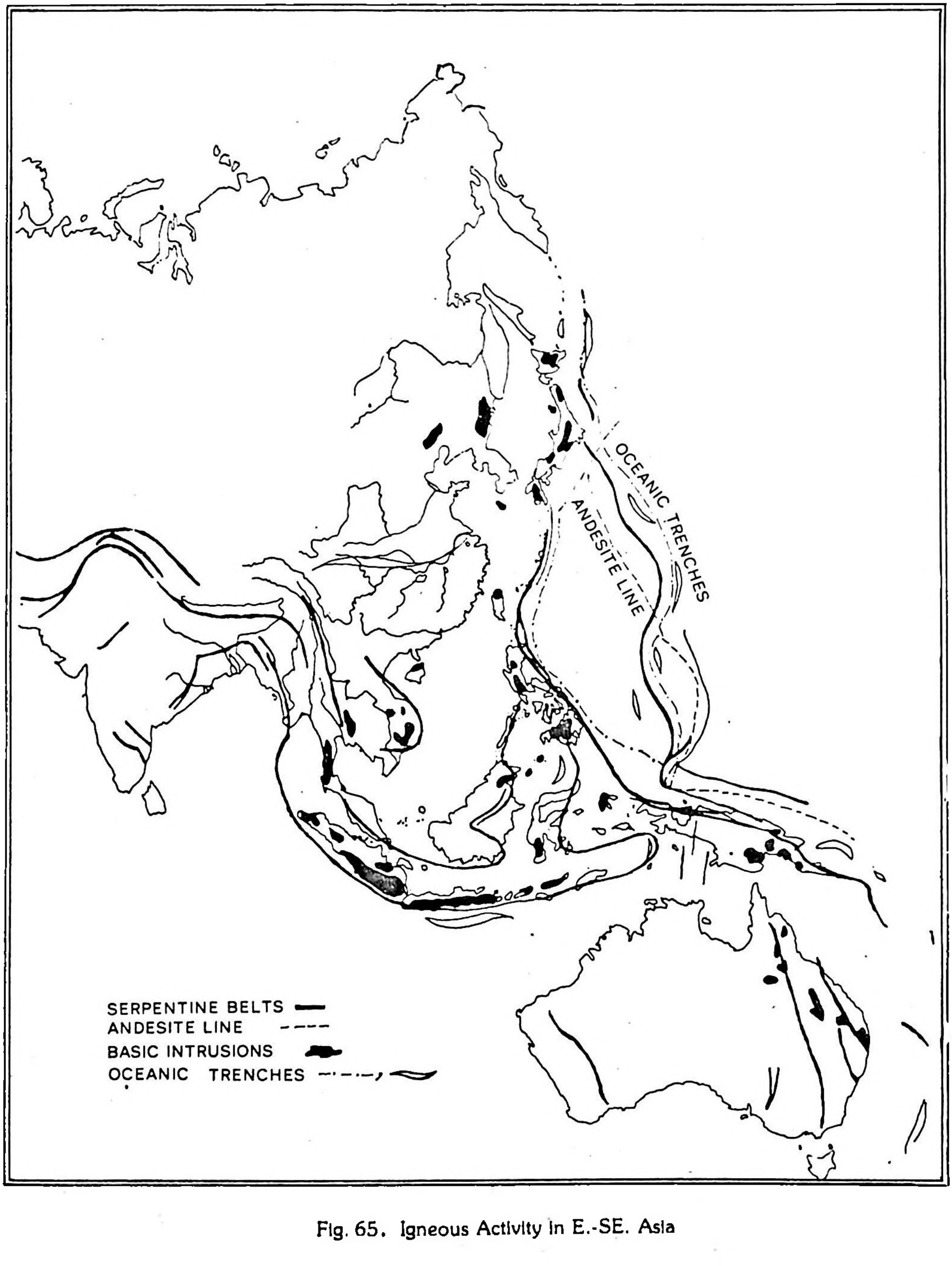
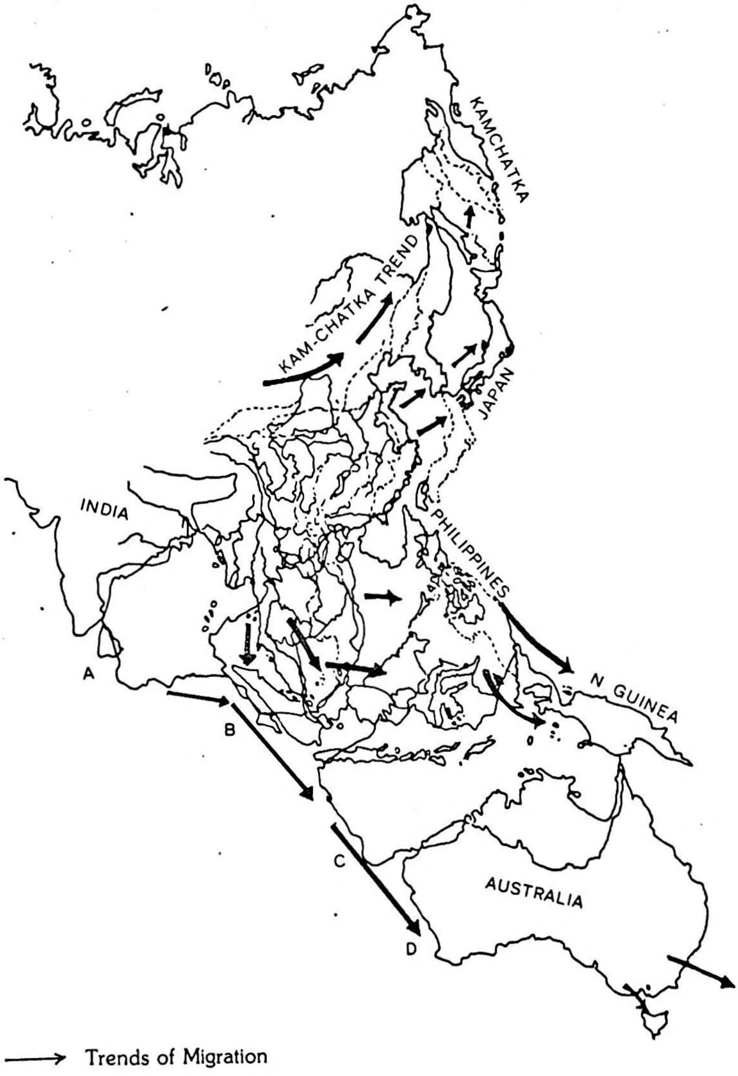


Fig. 65. Igneous Activity in E.-SE. Asia



Migrations of sheets from Eastern Tibet. The movement of Australia from its initial position in Bay of Bengal, juxtaposed with India, through successive stages to its present position may be particularly noted. Similar movements of New Zealand, Japan, Korea, etc., are also indicated.

Fig. 66

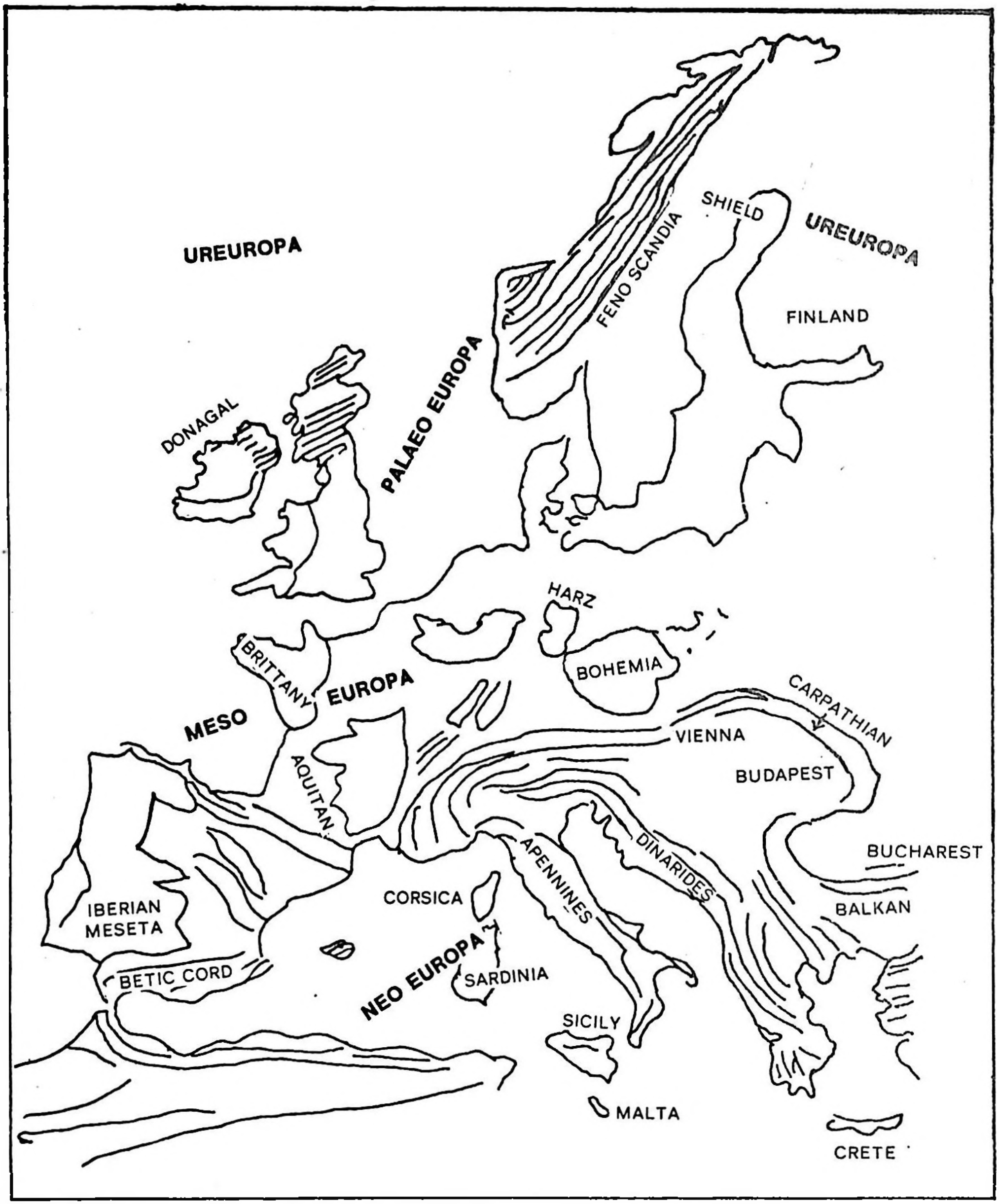


Fig. 67. Current Concepts of Structural Evolution of Europe

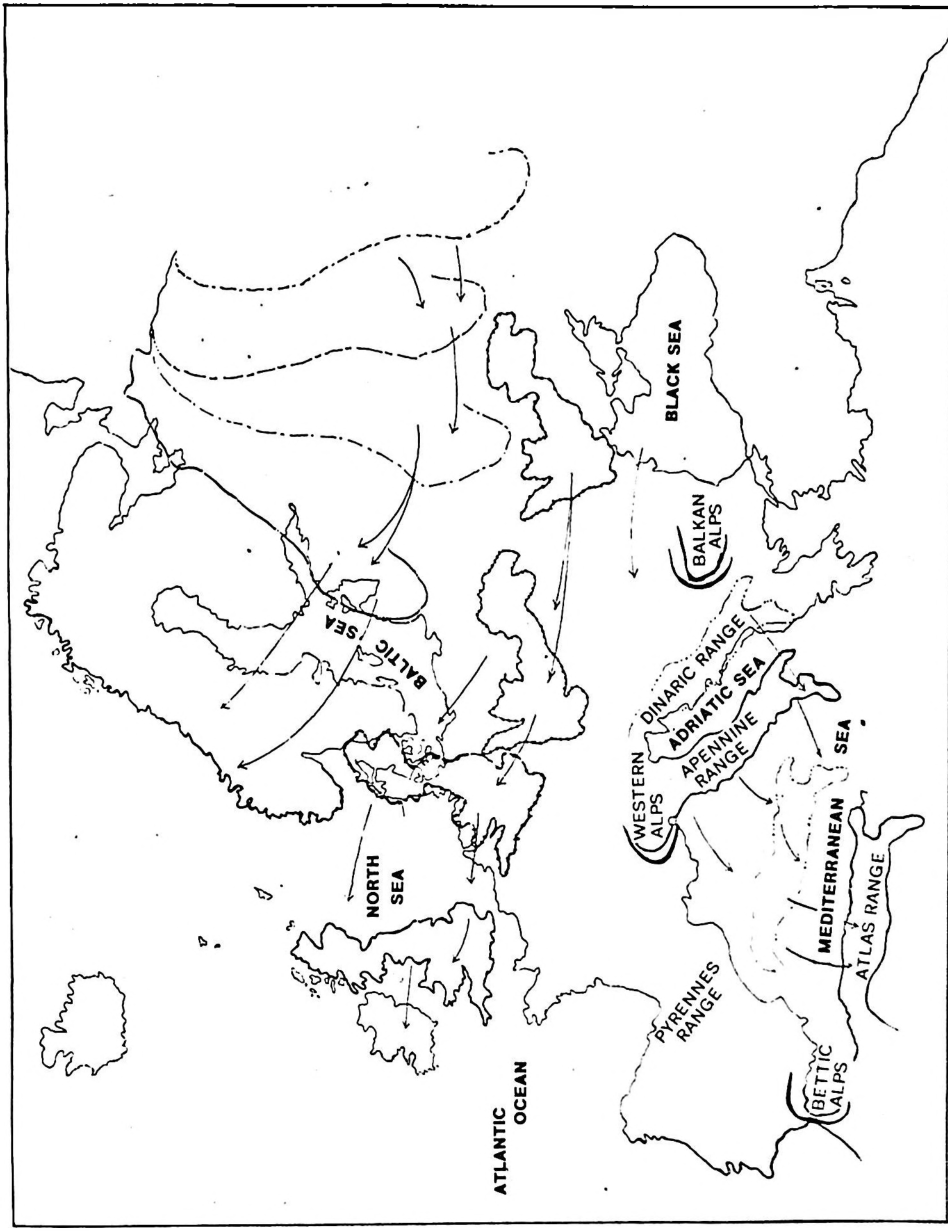


Fig. 68. Sheet Evolution of Europe

The Variscan structures of Central and Western Europe originally as constituents of the Appalachian structures were left behind as detached horsts in the nature of the Donetz basin, Ukrainian uplands, Sudetenland. Bohemia, Harz, Ardames Vosges, Brittany, Central Massive of France, Spanish Meseta etc. on the European mainland and the Cornwal massives in the British Isles. Simultaneously with these movements, the Alpine structures of the Betic, West Alpine and the Balkan Arcs, the Carpathian and the Appenine Dinaride Ranges which were resting superposed over the Anatolian-Armenian structures, shifted westward through the Black Sea-Mediterranean region (jointly with the westward movement of the African Atlas sheet), successively through the positions of Greece, Sicily, Balearic Islands to the present position near Gibraltar.

During these westward movements of the Alpine Arcs, there was a distinct component of anti-clockwise rotational movements to the northwest whereby the Dinaric and Apennine ranges assumed NW-SE trends oblique to the general E-W trends of the major Alpine structures in the Mediterranean region. This is also exhibited by wider gapping of the Mediterranean Sea to the east and its narrowing to the west. The general correspondence of the European structural patterns with those of Central Asia on the east and North America on the west makes it obvious that the European continental mass came into existence only during the intermediate stages of the westward migration of the North American structural elements from their original home in the Tibeto-Himalayan Central Asian region.

Structural Evolution of North America

North America has a typical continental structure characterised by a vast central granitic cratonic mass, the Canadian Shield, flanked by low interior plains and valleys and girdled by younger orogenic belts, the Rockies on the west and the Appalachians on the east and southeast and by the less folded Arctic structures on the north. It vastly broadens on the north and tapers to the south, ending into a narrow tenuous isthmanian linkage of Central America connecting the continents of North and South Americas.

The Rockies trend NNW-SSE while the Appalachians trend NE-SW but before they meet in the south, the Appalachian structures disappear rather abruptly under the Cretacean Tertiary formations of the Gulf plains of Georgia, Alabama and Mississippi region leaving hardly any trace of their southern continuation in the region of the Mexican Gulf. There are, however, some tenuous linkages between the Appalachians and the Rockies in the nature of Cincinnatti Dome, Ozark Plateau, Ouachita Mts., Wichita Arcs and the Black Hills which are clearly detached fragments of either the Appalachian or the Rockies with trends varying between those of the major belts on either side, ultimately merging in the frontal ranges of the Rockies in the New Mexico-Texas region of Rio Grande. The everwidening distances between the orogenic belts of the Rockies and the Appalachians in the northern parts of the United States are spanned by the tributaries of the Mississippi. Further north in the Canadian region, these two orogenic belts are spanned not by a continuous river but by a system of interconnected rivers and lakes and the Canadian Rockies are ultimately drained into the Atlantic Ocean directly through the Saskatchewan, L. Winnipeg, Hudson Bay and Hudson Strait or indirectly through the L. Superior series of Great Lakes and the St. Lawrence River Gulf System.

In the Canadian Territory, the Appalachians, as also the Acadian ranges, are eliminated and a vast stretch of granitic shield intervenes between the Canadian Rockies and the Atlantic Ocean. This shield itself gives way to permit the Atlantic waters to reach the heart of the North American continent through the Hudson Bay. Thus, we see a gradual widening and deepening of the interior terrain between the two orogenic belts as they diverge away from each other northwards. This behaviour has a definite significance and indicates that the two orogenic belts, one largely Palaeozoic and the other largely Mesozoic-Tertiary in their build, were much closer together, juxtaposed and even partly superposed in their earlier stages of evolution and that they separated through divergent radial movements of the one away from the other with their pivot in the south. In the earlier stages of superposition, the Llano Estacado and Edwårds Plateau regions of New Mexico and Texas were superposed over the southern Appalachians of Alabama, Tennessee.

The various western tributaries of the Mississippi, viz. the Canadian, Arkansas, North Platte, Yellowstone and the Missourie mark the relative westward movement of the Rockyan Range away from the Appalachian. The eastern tributaries of the Mississippi, viz. the Tennessee, Cumberland and the Ohio coupled with the Great Lakes—Ontario, Erie, Huron, Michigan and Superior—mark further stages of angular divergence of the Rockies from the northern Appalachian-Acadian Ranges brought about by the St. Lawrence and Ohio system of Rifts. These radial movements also brought about angular separation of the Labrador part of the shield from its basement of North-West Canadian shield, with the development of the Hudson Bay in the intervening region.

In this process of radial separation of the Appalachians from the Rockies, the various stages of separation have been recorded by fragments of structural sheets left along the route of migration. Thus, the Alaskan fold packet at the northwestern end of the Canadian Rockies was at one time situated superposed over the Greenland Sheet which was then part of the Labrador shield. Leaving Greenland behind with some rotation, the Alaskan sheet packet moved to the position of Baffin Island. Later, the Canadian Arctic Islands were left behind as the Alaskan sheet scoured out its way further west through the Hudson Bay and the Canadian North Western Territories. The Yukon-Alaskan Rockies finally moved further northwest through the Bathust Inlet, Copper mine, R. Huston, Anderson to beyond the Mackenzie R. to its present position (Fig. 69).

It is obvious that when the Alaskan fold belt was occupying the Greenland position, the Rockies of the United States were also superposed over the Acadian-Appalachian Orogenic Belt. Indications are that this superposed relationship of the Rockies over the Appalachians persisted almost upto the Tertiary when they were still part of Eurasia and it was only during the eruptions of the Columbian Flood Basalts that the separation of Rockies from their Appalachian basement started partly through radial movements.

The North American continent assumed its present form and size largely during the Upper Tertiary-Quaternary period while its present emplacement west of the Atlantic Ocean was brought about only during Pleistocene Holocene times.

North America exhibits very close relationships with Europe, on the one hand, and with the Sino-Siberian part of Asia, on the other, not only faunally but even structurally. Thus, the Acadian or north Appalachian belt is stratigraphically and structurally very

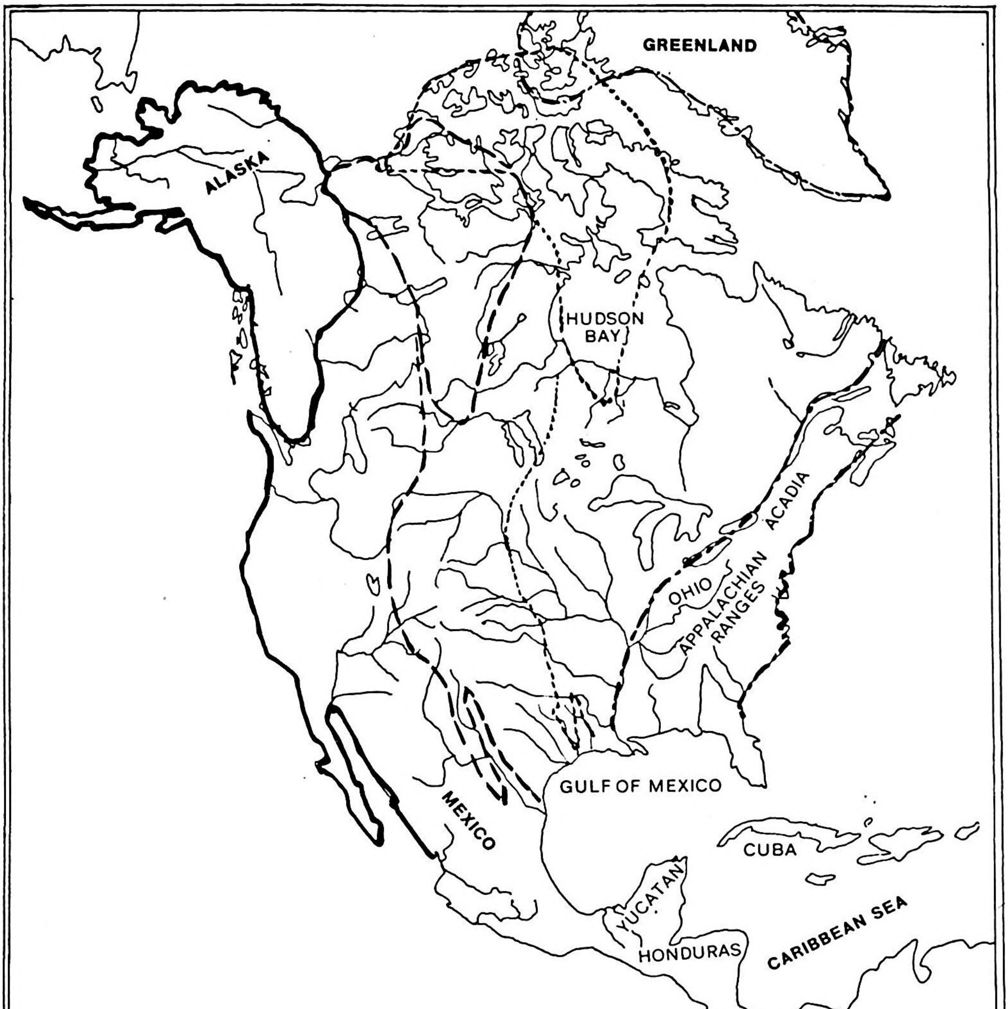


Fig. 69. Structural Evolution of North America

close to the Norwegian Scandinavian part of Europe both being parts of the Caledonian Orogenic belts. The Carolina and Virginia piedmont belt of the Appalachians along with the Atlantic Coastal Belt is closely related to the British Isles both in structure and fossil content. The Mexican Gulf Coastal Belt is essentially Alpine in structural build and faunal relationships and as such is related to Southern Europe. Thus, the whole eastern Belt of North America is closely related faunally and structurally with the European rock formations. On the other hand, the Rockies have close relationship with the Sino-Siberian region of Asia.

Structurally, Alaska is closely related to Verkhoyansk-Kolyma region of Siberia while the Aleutian Arc structurally belongs to Chukotski range of the Arctic Siberia.

The Arctic Islands as superstructure over Greenland were earlier part of Severnaya Zemlya Island group and Taymyr Peninsula of the Tunguska, Yenisey Basin and later of the Franz Josephland-Spitzbergen series of Arctic Islands.

The Appalo-Rockyan superposed sheet complex played a dominant role in the structural evolution of Europe west of the Urals while the Greenland-Alaskan structural complex played a similar role in the evolution of Sino-Siberian region east of the Urals. The Appalo-Rockyan condensed sheet complex was part of the Tienshan-Altai structural complex north of Tibet as part of the Variscan-Caledonian structures which later expanded, both lengthwise and breadthwise. During their westward migration during Upper Tertiary Quaternary period, they left portions of structural sheets which now constitute Siberia, on the one hand, and Europe, on the other.

Structural Evolution of Africa

The continent of Africa, next to the Antarctica is geologically the least known continent because of the thick sandy cover which conceals vast terrains of this continent. These extensive deserts are highly inhospitable for human habitation and as such have remained very thinly-populated and largely unemplored except in small patches. The geological outcrops are fragmentary and vast terrains have the aspect of a highly-eroded old shield mass. The rigours of weather have left vast sheets of rocky waste obscuring the solid geology of the region.

Some of its physical features are, however, very expressive. Thus, like South America and India, this continental mass also bulges in the northwest and tapers to the south with nearly a straight coastline in the west. The eastern coast of this continent in the region of Somalia-Kenya and Tanganyika simulates the eastern coastline of Peninsular India. Even the island of Ceylon finds representation near the East African coast in the islands of Pemba, Zanzibar, Comores and in northern tapering part of Madagascar.

The Mauritanian-Liberian coast of NW Africa has a remarkable parallel in the Peru-Colombia Coast of South America while the Teritary Atlas Ranges have their parallel in the Venezuelan Andes. The precordilleran ranges of Chile and Argentina, again, find similarity in the Angola-Namibia coast of SW Africa continuing into the Cape Folds.

With such extensive correspondences, if we now superpose the trace of South America over that of Africa, the fit is remarkable. In this the Atlas Range continues into the Venezuela-Colombia Andes while the Patagonian Andes continue into the Cape Folds. The eastern coast of South America coincides with the Nile-Tanganyika Rift zone. Even the river system of Argentina continues into the river system of Peninsular Africa when placed in superposition.

Looking at the geological correspondences, the Gondwanas of Uganda-Tanganyika correspond with those of the Parana Basin while those of Argentina and Falkland Islands correspond with those of Namibia and Karroo basin of South Africa.

These wide-ranging correspondences in the physical as well as in the geostructural features leave us in no doubt that the South American continental mass had existed as a sheet superposed over the basement of the African shield during the various stages of continental evolution and even during their displacement through the Indian Ocean.

This feature helps us in understanding the structural evolution of the African continent jointly with that of the South American continent (Fig. 70).

The two important structural units which through their rotational movements as sheets have helped in the evolution of the African continent are those of the Karroo basin of South Africa and Guiana basin of Brazil, South America. Upto the Cretaceous Period, the Karroo Basin was an integral part of the Indian Gondwana Basin of Peninsular India while the Guiana Basin was an integral part of the Kirthar-Sulaiman Basin of northwest India. During the flooding of the Deccan and Eritrian Plateau Basalts, the Karroo basin was lifted from its Western Ghat position in Peninsular India coinciding with the Eastern (Rudolf) Rift system of East Africa and was shifted westward to the Tanganyika Rift position. From there the Karroo basin suffered anti-clockwise rotation through the basins of the Congo, Upper Zambezi, Limpopo and the Vaal and finally the Orange rivers, all during the Upper Tertiary Period. These movements led to en echelon extension of the Andes ranges along the Chile-Argentina border. Simultaneously with this, the Madagascar sheet shifted southward through the Nyassa and Mozambique and later during Quaternary got detached from the mainland in the region of Rufiji Basin and Zanzibar.

During the same period, the Guiana mass as part of the Arabo-Saharan-Brazilian mass still resting over northwestern India suffered a clockwise rotation as a consequence of the Indus-Amazon series of syntaxial movements. Simultaneously, the Atlas and northern Andes fold belts as peripheral belts of the Guiana mass, suffered en echelon extension and also led to the westward bulging of the NW African-South American land mass. This expansion of the Afro-South American continental mass took place largely while the Proto-African mass east of the White Nile was still superposed over the Indian platform.

Further expansion of the North African Sahara in the region of Mauritania took place while the overlying South American continental sheet was getting separated from its African basement through westward movements while still in the Mediterranean region. It was due to the crushing suffered during these movements that the Great Sahara Desert came into existence.

The African continental mass jointly with its south American superstructure left the Indian basement during Lower Quaternary period and moved west through the positions of the Persian Gulf, the Red Sea and the Mediterranean, leaving behind the Iranian uplands and the Arabian platform. During these movements the Atlas Ranges left their Taurus basement in the Turkish Peninsula and moved westwards through Cyprus, Crete, Malta and Sicily to their present position in northwestern Sahara.

Thus, we see that the African continental shield mass is essentially a new structural basement acquired during rotational movements of the Guiana complex, clockwise, in the NW and of the Karroo sheet complex anticlockwise, in the south (Fig. 70). The African land mass acquired its identity as an independent continent after the South American continental sheet left the African basement during the Quaternary Period.

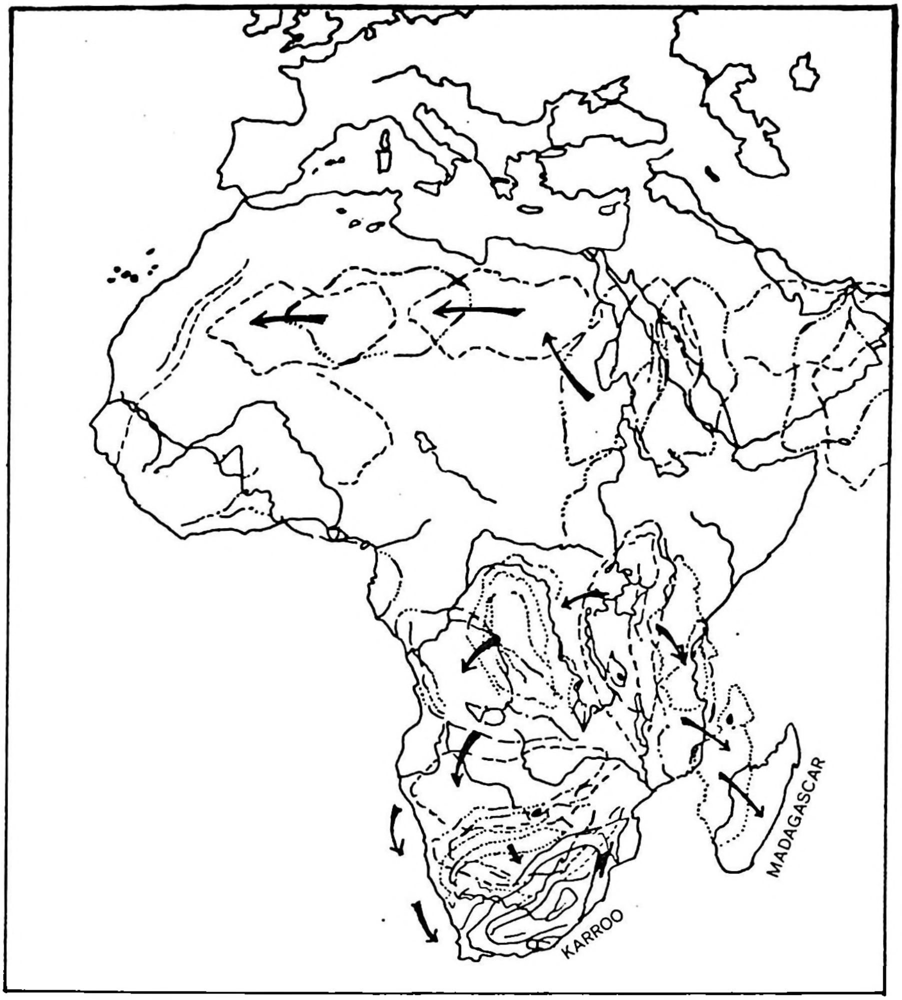


Fig.70. Trends of Sheet Movements in Africa

Structural Evolution of South American Continent

We have already seen that South America accomplished its full structural evolution as a cover sheet over the Indo-African basement through the rotational movements of the Karroo-Parana Sheet Complexes in the South (anti-clockwise) and of the Guiana-Andes Sheet Complex clockwise in the Amazon basin in the northwest. These rotational movements of the two shield masses in opposite directions led to the en echelon extension of the Andean Range complex from the Bolivia region northwards through Peru-Ecuador-Colombia to Venezuela and southward through Chile to Tierra del Fuego (Fig. 71).

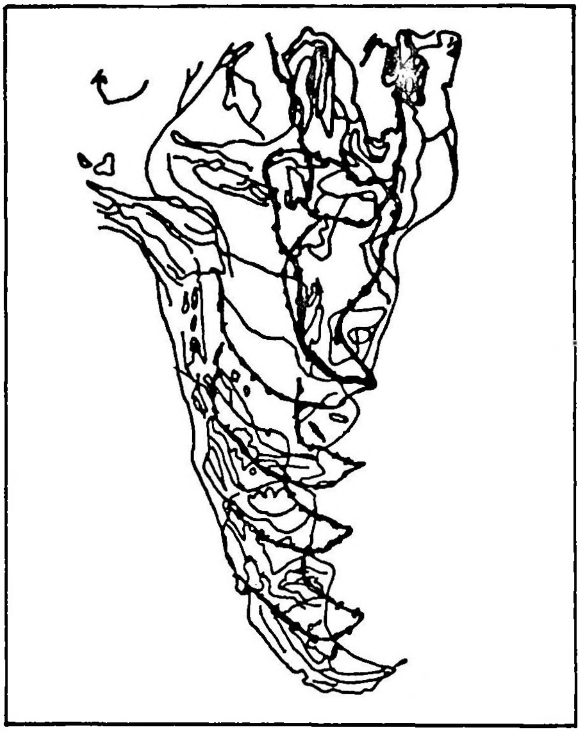


Fig. 71. The Trends of Evolution in S. America

All this structural evolution took place while East Africa was still superposed over Peninsular India. South America suffered westward movements as a superstructure of the African Continental mass until the latter occupied its present position south of the Mediterranean Sea. From this position onwards, the South American continental mass started separating from the African basement as a unitary sheet through clockwise angular movements with its fulcrum in the region of Morocco and in the process, the South American Sheet first occupied the position of Walvis ridge. This led to the separation of the Caribbean-Antillean Island Arcs in the region of Canaries Arc. Later, it occupied the Cape Verde position of the Mid-Atlantic Ridge after leaving most of the Saharan basement. Leaving its traces along the Mid-Atlantic-Antarctic Ridges and the South Sandwich Arc, the South American sheet moved SW and came to occupy its present position after it freed itself of the Floridan and the Antillean nooses.

Thus, the South American continental mass was only a cover sheet of the African continent during its early evolution and it gradually assumed its independent continental status with its present shape, size and emplacement later during its westward movements through the space of the Atlantic Ocean, still maintaining its link with North America.

Structural Evolution of the Indian Subcontinent

The Indian subcontinent, stretching from Baluchistan Ranges in the west to Assam-Burma Ranges in the east and from the Pamir-Karakoram and Himalayan Ranges in the north to Ceylon on the south, exhibits three distinctive physical subdivisions in its structure: (1) the Peninsular India in the south, (2) Extrapeninsular on the NW, north and NE with (3) Indo-Gangetic Plains intervening between the above two subdivisions (Fig. 72).

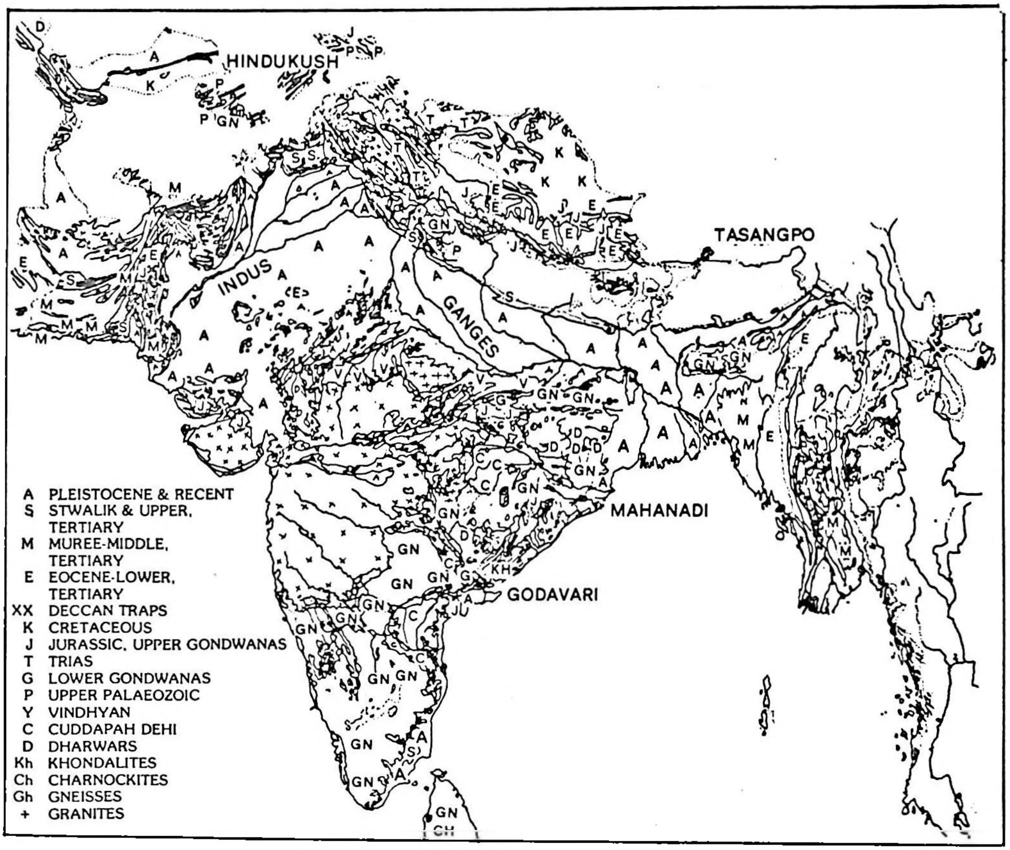


Fig. 72. Geological Sketch Map of Indian Sub-Continent

The Extrapeninsular Range of Baluchistan on the west and Assam-Burma Ranges on the east exhibit peculiar syntaxial relationships with the Himalayan Ranges but the actual nature of the syntaxial bends at the two ends is still not well understood. So far they have been considered as due to compression from NW and NE respectively but under the new concept of sheet movements, they appear to be due to divergent rotational movements of the Himalayan superstructural sheets clockwise in the west and anti-clockwise in the east, with their pivots at the two ends of the Himalayan Range, the Nanga Parbat in the west and Namcha Barwa in the east (Fig. 73).

Fig. 73. Primary Composite Sheet Structure of the Himalayas

The Baluchistan Ranges with the Aravallis as their substructure were originally part of the Punjab-Nepal Himalayas in the upper Gangetic basin; they rotated clockwise with a pivot in the Simla Himalayas through the positions represented successively by the Ganges-Jamuna and the various tributaries of the Chambal upto the position of the Aravalli ranges. Leaving the Aravalli substructure behind, further rotation of the Baluchistan sheet in the same sequence took place as part of the Indus Syntaxis with the pivot successively moving NW through the syntaxial bands of Sutlej, Ravi, Chenab, Jhelum and Indus involving the Salt Range, the Hazara and the Hindukush ranges as well in the successive series of sheet movements (Fig. 74).

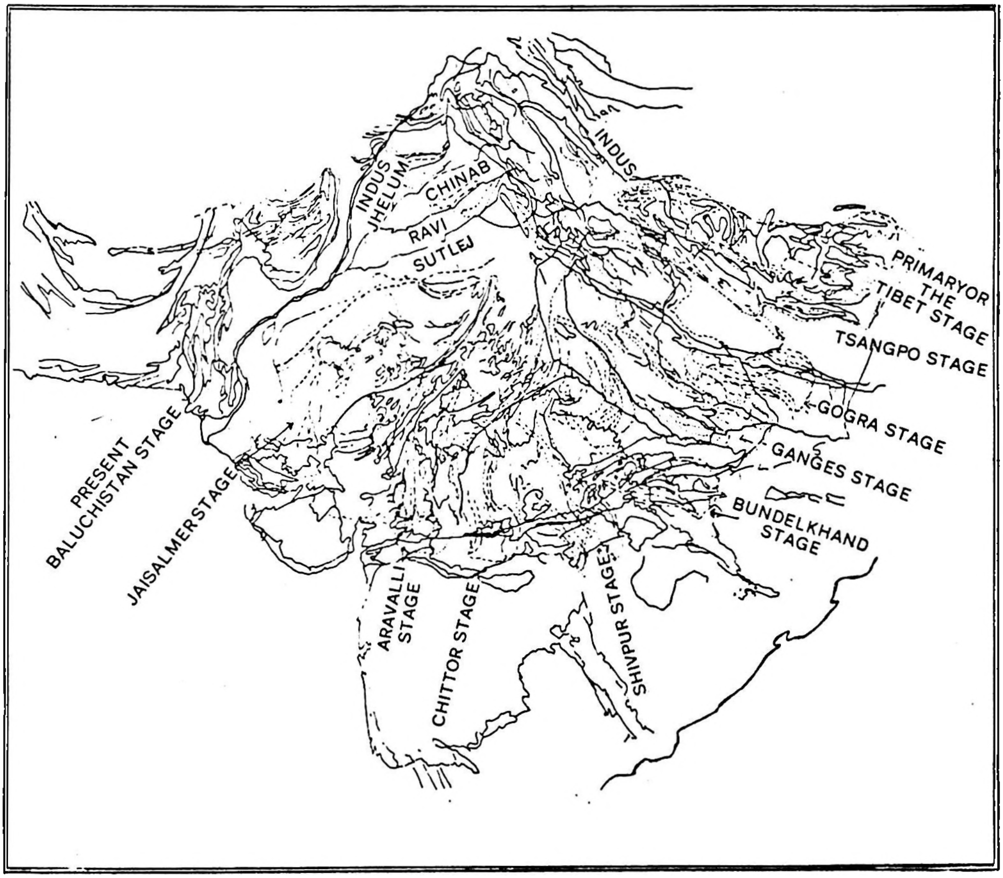


Fig. 74 Stages and Routes of Migration of the Aravalli-Baluchistan Sheets

The peninsular rock formations including the Pre- and Post-Gondwana formations also suffered similar syntaxial movements, first as part of the Ganges Syntaxis and later of the Son-Damodar, the Son-Mahanadi, the Godavari, the Bhima-Krishna and the Cauvery (Fig. 75). These sheet movements have involved even the Cretaceous and Miocene formations indicating clearly that peninsular India took its present shape some time in the post-Miocene period. The author has worked out this problem in detail elsewhere (Rode K.P., 1954).

The Brahmaputra Syntaxis involved not only the Assam-Burma structural ranges but had also influenced those of Malaysia, Thailand and Indochina ranges through the Irrawaddi, Salween and Mekong series of movements. These ranges were originally part of the Tibeto-Himalayan structures in the source regions of the above rivers. They rotated anti-clockwise through the Tista, Raidak, Manas, Subansiri, Dibong and Luhit series of angular and lateral movements with the pivot successively moving eastward from Kan-

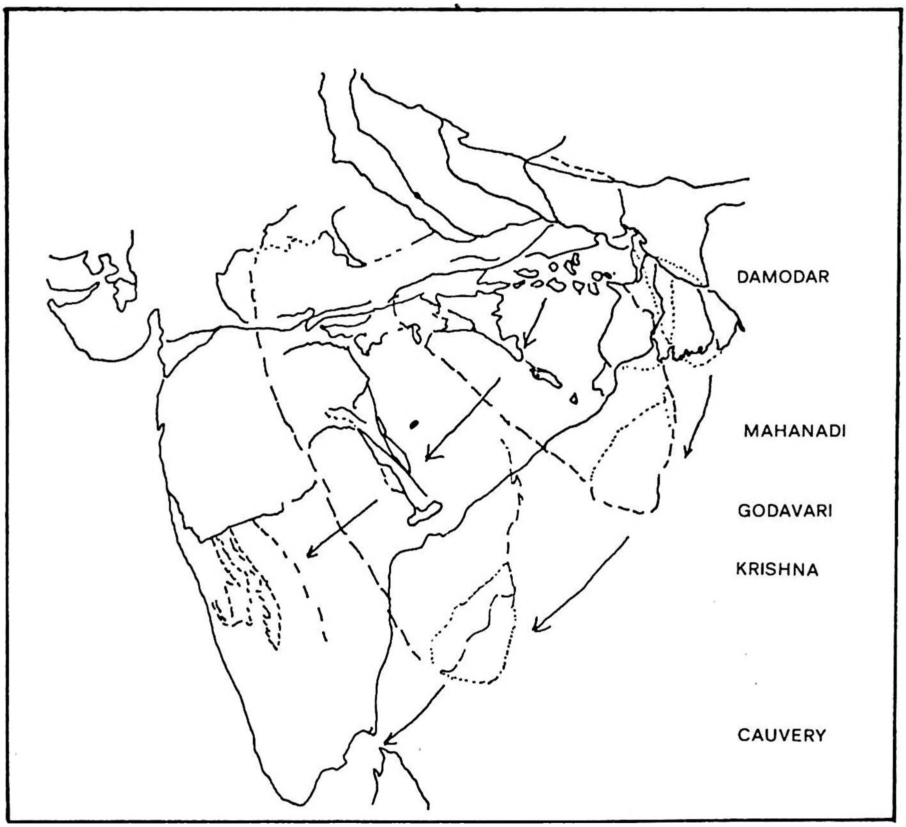


Fig. 75. The Evolution of Peninsular India

chanjhunga to Namcha Barwa and still further east, thus bringing about parallel as well as en echelon extension of the Burma-Indochina ranges.

The third structural component of the Indian subcontinent, viz. the Indo-Gangetic Plains, is clearly the result of the deep-seated migration to the south, SW and west, of the structural sheets in the nature of Peninsular and Extra Peninsular components from their Himalayan basement, mainly during Siwalik and post-Siwalik Period. This evolution of the Indian subcontinent took place in close association with the primary stages of the structural evolution of the Afro-Brazilian continental mass on the west and of the Antarcto-Australian mass on the south and southeast.

Structural Evolution of Australasia

Australia is almost the smallest of the continents and yet it possesses all the important structural attributes of a full continent. It has a Granitic Massive in Pilbara-Yilgarn complex, a Horst in the Great Dividing Range Plateau, a Platfrom in Barkly Tableland, a deep sedimentary basin in the Lake Eyre-Spencer, series of depressions and a peripheral Orogenic Belt in the New Guinea-New Zealand CircumPacific Island Arc.

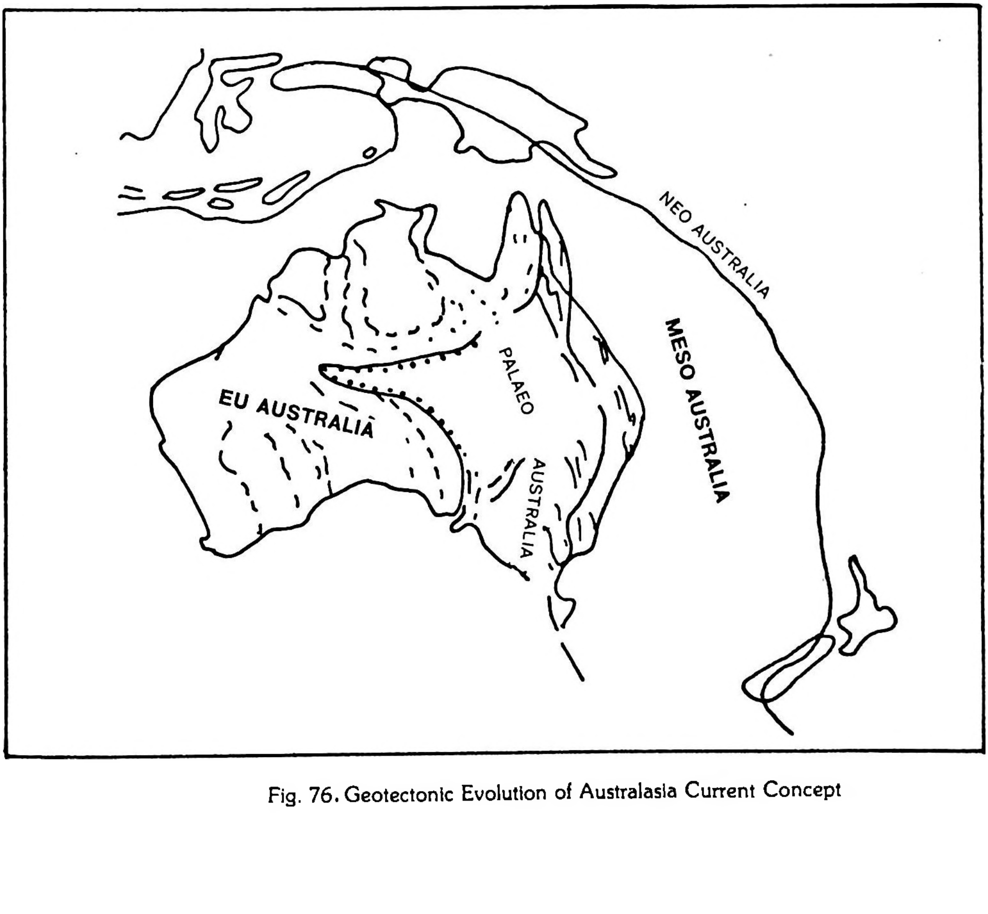


Fig. 76. Geotectonic Evolution of Australasia Current Concept

The Geotectonic evolution of Australia seems to conform to the present general concept of the continental expansion through successive accretion of orogenic belts during different geological upheavals, as illustrated by R.W. Fairbridge 1950 (in Arkel "Jurassic Geology of the World") (Fig. 76). In this the highland of west and north Australia constitute the primary Pre-Cambrian Shield, *Euaustralia*, which gradually expanded through accretion of the great Australian Basin as *Palaeo-australia*, followed by the accretion of the Great Dividing Range, as *Mesoaustralia* and finally through the evolution of the Tertiary Orogenic Belt of New Guinea-New Zealand Arc as *Neoaustralia*.

However, the picture of evolution of the Australisan region that emerges from the studies of sheet movement in the region is materially different from the above scheme (Fig. 77).

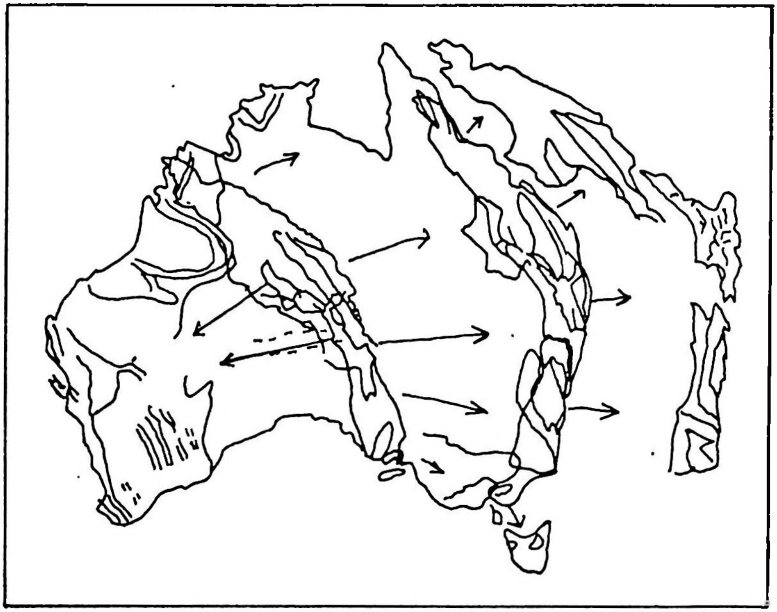


Fig. 77. The Trends of Evolution in Australia

The study of structural patterns has shown that the New Guinea has the same structural pattern as that of the Queensland part of the Great Dividing Range while New Zealand has the same pattern as that the southern portion of the same Range in N.S. Wales and Victoria. Similarly, Tasmania exhibits the pattern of the southern tip of the same range in Victoria. Thus, the whole New Guinea-New Zealand-Tasmania Island Arc had constituted, in a condensed form, an integral sheet superposed over the Great Dividing Range of east Australia. Indications are there to show that this Great Dividing Range sheet complex earlier was resting over the West Australian shield mass in the region of Kimberley-Macdonall-Finke-Eyre Basin, almost till the Cretaceous period. At this stage, the Queensland-Gondwana Basin was closely juxtaposed with the West

Australian—Gondwana Basin (of Perth), then in the region of the Gibson-Victoria Desert. Later, during the Tertiary, the Great Dividing Range sheet complex along with its superstructure of the New Guinia, New Zealand and Tasmania, shifted gradually eastward as marked by the radially-oriented Eyre-Murray River system. The Westralian-Gondwana Basin this time moved relatively west upto the present sea board near Perth, as marked by the Ashburton-Gascoyne series of the west-flowing rivers. The eastward migration of the Great Dividing Range is also indicated by the repetition of mineralized zones eastward from the West Australian Shield to New South Wales and even beyond to New Zealand (M. Solomon et.al 1972, 24th I.G.C., Section-4, pp. 137-145, 1972). The continental mass of Australia attained much of its present size while it still formed part of the Indochina-Indonesia with Antarctica as its substructure in the region of Bay of Bengal-South China Sea (Fig. 78). After it was detached from its Antarctic substructure, the Australasian continental sheet complex moved southeast to the position of the Moluc-

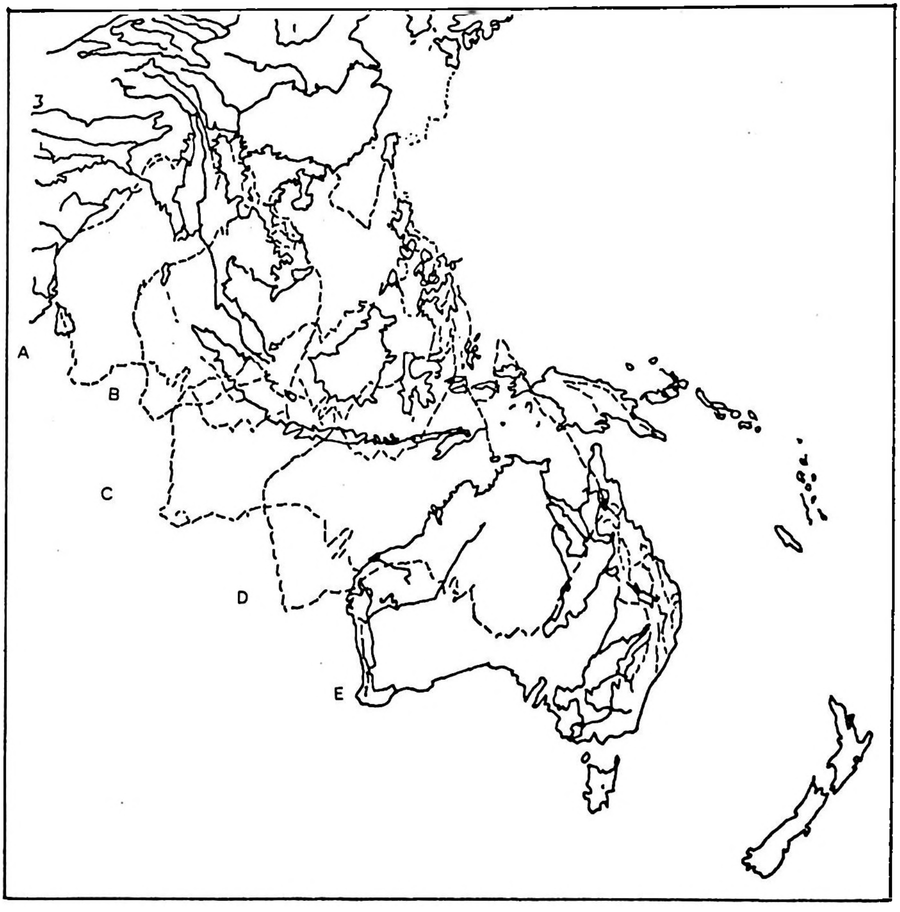


Fig. 78. Evolution and Emplacement of Australia

cas and the Banda Sea. It was at this stage that the New Guinea-New Zealand Arc sheet got detached from the Great Dividing Range substructure and made an angular movement to the east with a pivot in the region of Helmahera. This separation left a series of small peninsular projections all pointing north along the Queensland Pacific Coast. The Australian mass now moved SE giving rise to the sea of Arafura, Great Barrier Reef and Coral-Tasman Sea.Later movements of sheets, earlier overlying New Guinea and New Zealand, led to the development of the Island Arcs of (a) Bismark-Solomon-New Hebrides and (b) Ellice-Fiji-Tonga, *pari passu* with the eastward migration of the Pacific Kermadee-Tonga Trench System. Thus, the structural evolution of Australasia was brought about essentially by the migration of the Great Dividing Range structural sheet complex from the Pilbara-Yilgarn massive eastward in successive stages (Fig. 78). The Australian continent attained its present shape and dimensions essentially while the Australian continental sheet was still superposed over the Antarctic basement and the whole structural complex was still situated in the Indo-Burma-Indochina region closely juxtaposed with other Gondwana (Karroo-Madagascar) Continental sheets. The structural evolution of Australia as also its emplacement at the present position was brought about by CircumPacific magmas dragging the continental sheets from the borders of the Asiatic mainland towards the inner Pacific Ocean over a sloping basement regulated by the Oceanic Trenches successively migrating eastward in the Pacific domain.

This mode off evolution of the Australian Continent would explain its peculiar shape and size and its relations with other Gondwanaland Continents, including Antarctica.

Structural Evolution of Antarctica

This continental mass is unique in being at the trijunction of the three largest oceans on the earth's surface, the Pacific, the Indian and the Atlantic, and is thus isolated from the rest of the continental world. It is again unique in being the site of the South Pole and occupying most of the Antarctic circle. Most parts of the continent are buried under the thick cover of ice except the peripheral zones which often rise above ice as mountain ranges and hills. These ranges usually give some idea of the areal extent of the continent against the surrounding frozen oceans. The map of the continent as emerges from the study of the ice cover brings out a distinct two-fold division of the continent: (1) Eastern Antarctica which is larger, and is semi-circular in shape and (2) the western Antarctica which is much smaller and is pear-shaped arcuate peninsular mass attached along one side to the Eastern Antarctica through a broad link mass between the Weddell sea and the Ross sea. This peninsular mass terminates at the other end into a narrow tapering Grahamland Island Arc (Fig. 79).

The geological build of the two portions though somewhat contrasting, is complementary. The East Antarctica is a typical shield mass with Charnockitic granites and schists forming the large expanse of the continental interior whereas the border ranges exhibit largely Palaeozoic Gondwana type continental deposits. On the other hand, the Western Antarctica is largely made up of post-Triassic sediments folded into the Andean type series of radiating mountain ranges.

The Indian Ocean Coast of E. Antarctica between Amery Ice shelf and C. Adare is arcuate simulating the Queensland Victoria coast of Eastern Australia both in size and shape whereas its Atlantic coast from Enderby land upto the Filchner Ice shelf simulates

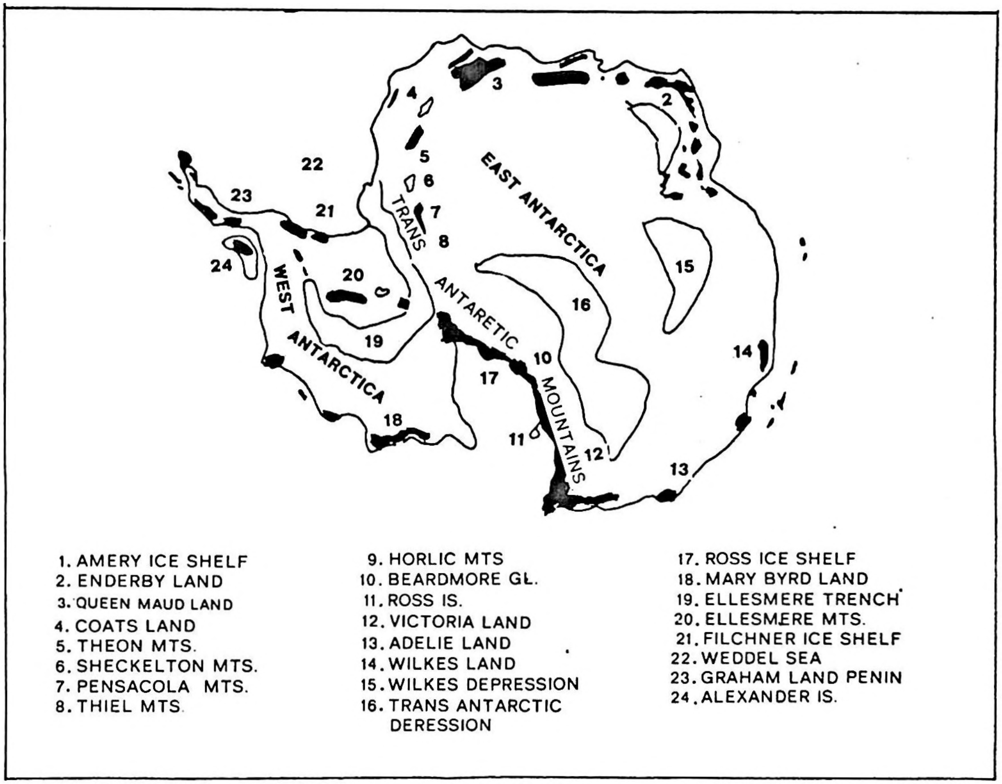


Fig. 79. Antarctica: It's Physical Features

the West Australian coast. The Trans-Antarctic Mountain Range from Queen Maud Land passing through the South Pole upto Cape Adare roughly simulates in size and shape the southern border of Australia between Perth and Melbourne.

Thus, in general, the East Antarctica with an area of about 3.3 million sq. miles corresponds in outline, form and size roughly with the Australian continent which has an area of about 3 million sq. miles. Geologically also, both the continental masses are members of the Gondwanaland and are characterised by the development of Cambrian Archaeocyathidae, Permocarbonaceous Glossopteris bearing Coal Measures and other later geological formations with intimate faunal and floral relationships. These features suggest original superposition of the two land masses, Australia resting on the East Antarctic substructure. East Antarctica attained its present shape and size simultaneously with the evolution of Australia.

West Antarctica was only the peripheral covering sheet of the Trans-Antarctic Mountain as an Andean geosynclinal sequence resting on East Antarctica north of Beardmore glacier upto Queen Maud Land. It got separated first in the south from Mac Murdo Sound-Beardmore region, with the evolution of Ross sea. Later the Whitmore-Ellesworth mountain and Grahamland Peninsular arc separated from the Horlick, Thiel and Pensacola mountains, and Queen Maud Land region of the Trans-Antarctic Mountain with the development of Ellesworth Trench and the Weddell Sea. The Trans-Antarctic Mountain is the faulted basement residual range due to the separation of Australian superstructure from Antarctica. This separation was initiated during the activity of the Ferrara Eruptives corresponding to Karroo Dolerite. The Queensland-Tasmania sheet moved east and southeast of Trans-Antarctic Range across the Wilkes and Amery depressions towards the Adare-Adelie Coast whereas the Karroo sheet rotated anticlockwise across the Weddell Sea. This resulted in the separation of Grahamland Peninsular Arc of West Antarctica as part of the Cape folds of South Africa and Tierra del Fuigo part of the Andes cordillera of South America. Later stages of westward drift of South America led to the rotation and shifting of the entire Antarctic land mass southward to the South Pole (Fig. 80).

We can thus explain the remarkable correspondence in the form, size and complementary geological formations of East Antarctica with those of Australia right from the Pre-Cambrian basement upto the Mesozoic and of the Grahamland Peninsula along with those of the Patagonian Andes on the west with post-Palaeozoic formations. The series of extracontinental submarine linkages (Fig. 81) between Antarctica, on the one hand, and the various Southern Gondwana Continents, viz. South America, Africa, India and Australia on the other, all lead us inevitably to the conclusion that all these Gondwana continental masses were, in earlier geological periods, not only closely juxtaposed but even partly superposed into a single land mass and that this land mass in a condensed form must have been situated in a single latitudinal tropical climatic belt. This permitted vigorous plant life of identical or intimately related species throughout the Gondwana land mass right upto the end of the Mesozoic Period.

The diverse lines of evidences indicate that all the various Gondwanalands in their primary miniature form were superposed to form a single Proto-Gondwanaland and this must have existed in the region of the Tibeto-Himalayas where we do find remnants of the Gondwanas in the foothills of Nepal-Bhutan-Eastern Himalayas. It looks, therefore, probable that Antarctica in its more compact and condensed form was situated in the region of Tibet such that the Trans-Antarctic Mountain Range was juxtaposed with the Main Himalayan Axis in the basin of the Ganges and the Brahmaputra (Fig. 82).

Here the three main Gondwana Basins of (a) Karroo (including Parana), (b) Madagascar (including Westralia and (c) Queensland-Tasmania were all closely juxtaposed and in a compacted condition to from a primary Gondwana continental basin (Fig. 83).

The Karroo sheet complex moved from the Gangetic Basin successively through the Mahanadi, Godavari, Krishna basins and in this process brought about the angular separation of peninsular West Antarctica from the East Antarctica which then was attached to the Burma-Indochina sheet. On the separation of Australian cover sheet which moved southeast, the Antarctic continental basement structure got linked up with the Afro-Brazilian mass through the Graham land hook and now moved south along the Mid-Indian Ocean Ridge successively through the positions of the Bay of Bengal, Cocos-

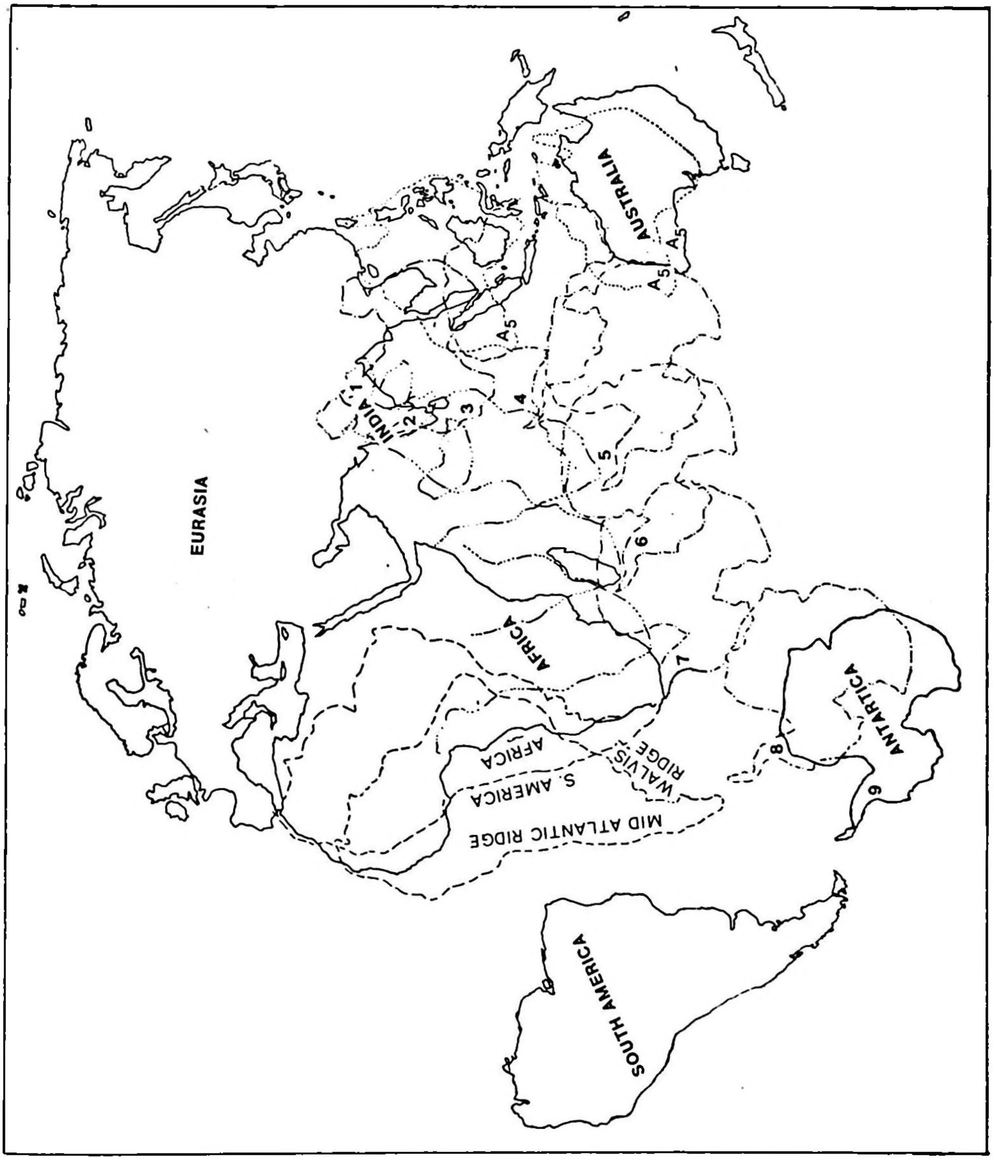


Fig.80: Evolution and Emplacement of the Gondwana Continents

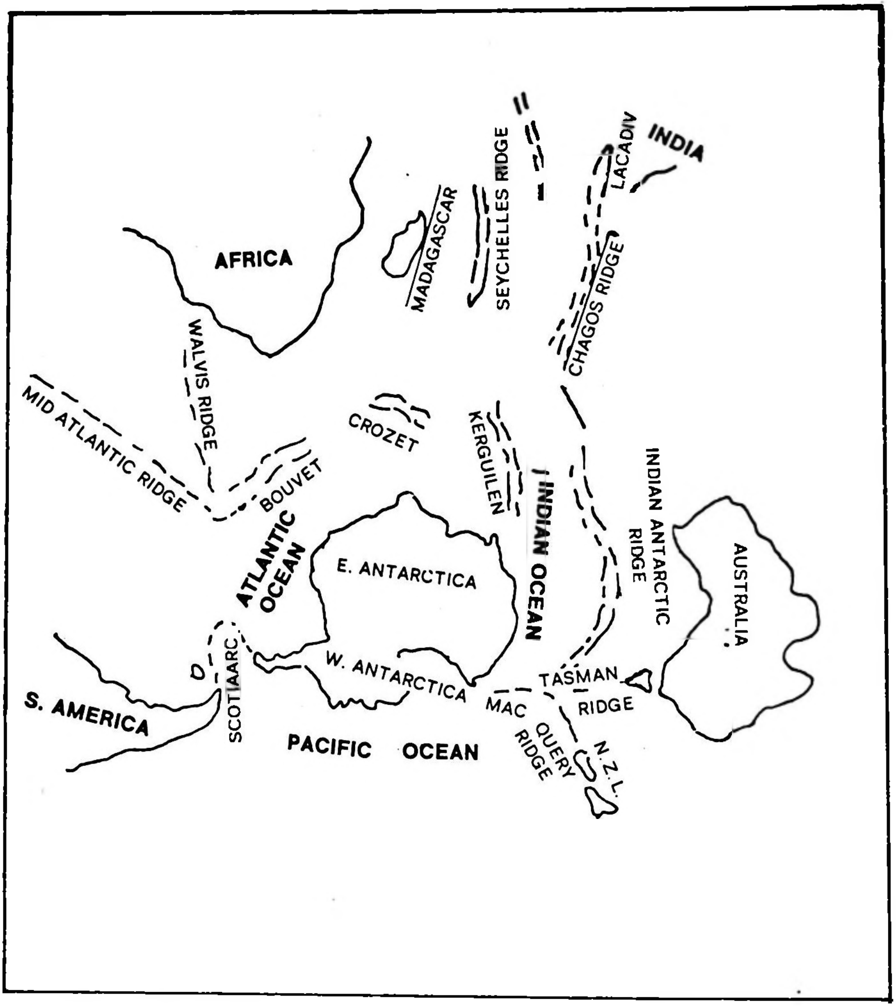


Fig. 81. Antarctica it's Extra Continental Linkages

Keeling Basin, and Amsterdam-St. Paul Plateau to its present insular position at the South Pole after a slight anti-clockwise rotation. The West Antarctic folded peninsular mass was for a long time girdling the Karroo structure as part of Cape folds, but later moved along with the Patagonian-Andean Belt upto the position of S. Sandwich Trench in the South Atlantic region. Here it got almost snapped from the South American mass and moved west along the South Scotia Ridge to its present position as part of the Antarctic Continent.

From the above treatment, it would be realised that all the existing continental masses whether of the Old World or the New World had their beginning as closely pack-

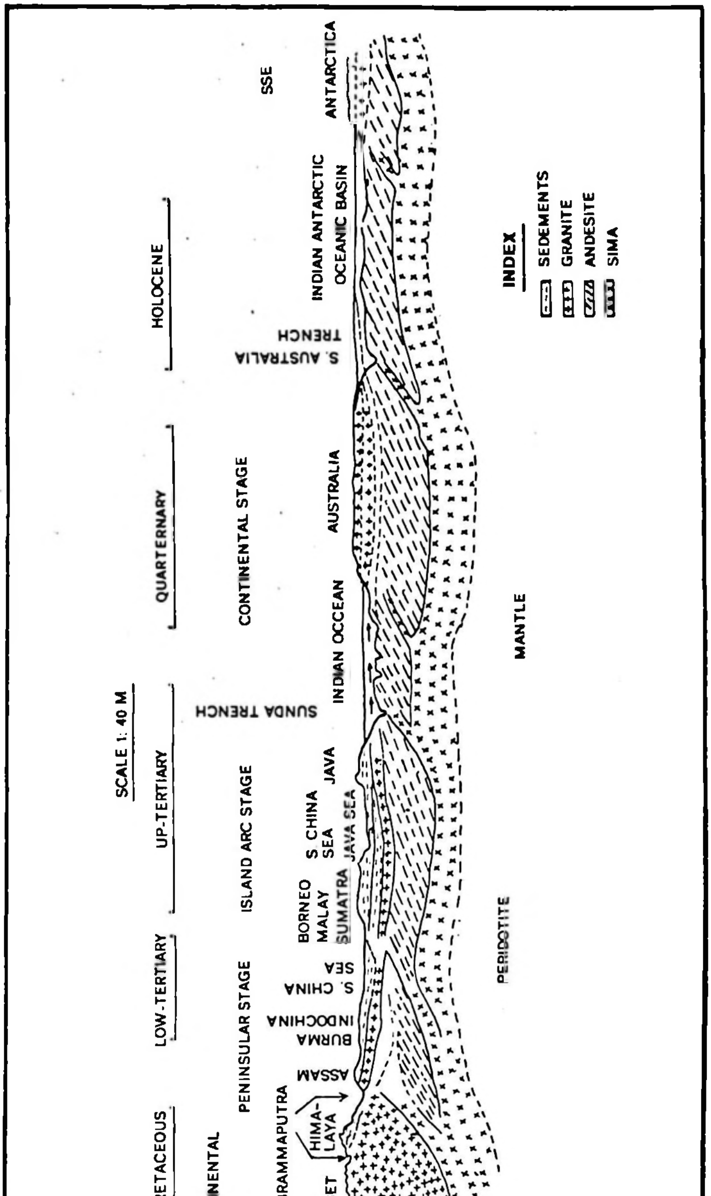


Fig. 82. Evolution of Australo-Antarctica

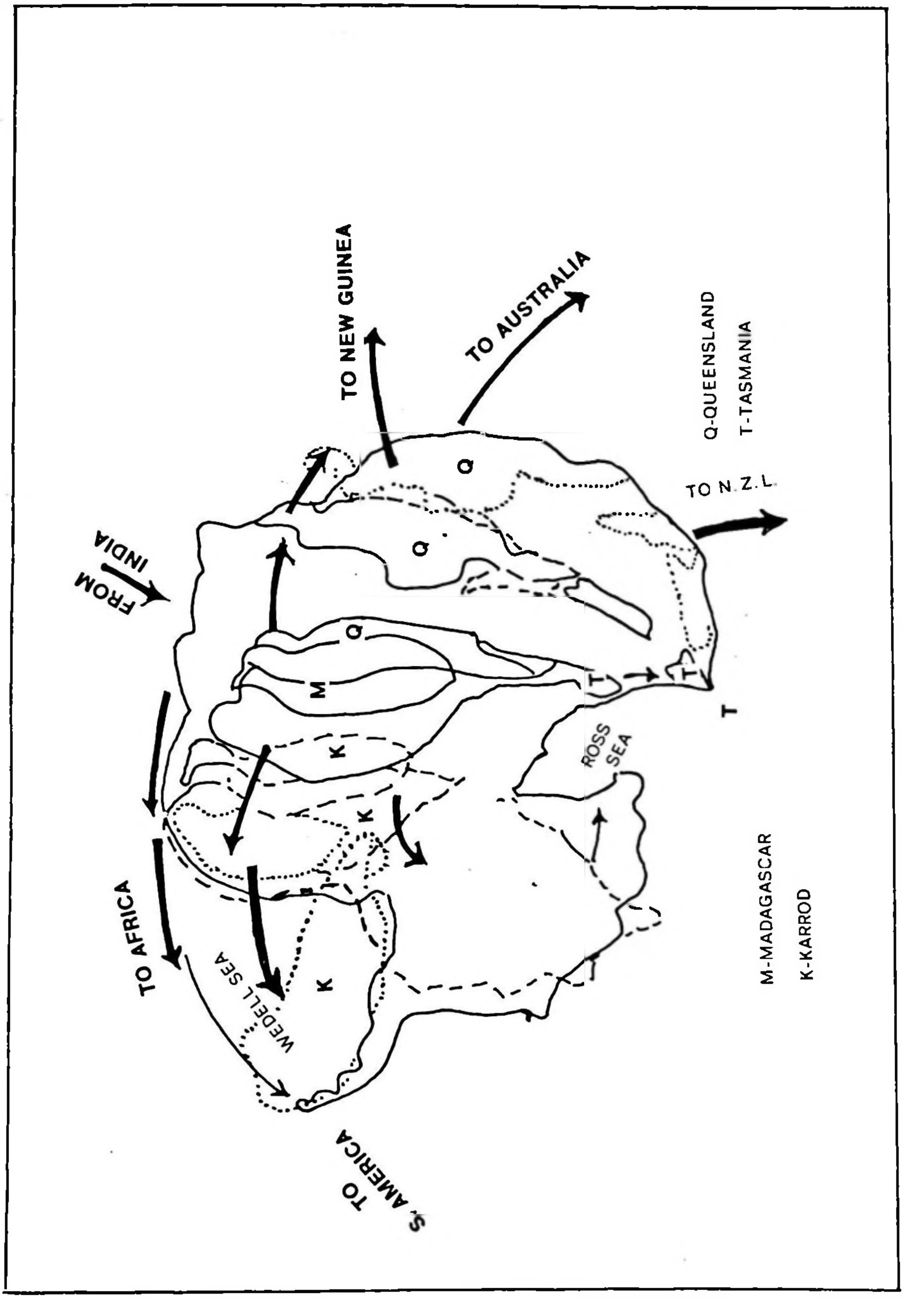


Fig. 83. The Proto Gondwanaland

ed (Fig. 84), partly superposed sheet masses constituting integral parts of the Tibeto-Himalayan and Central Asian land mass during these formative stages in the Palaeozoic and the Mesozoic Periods. These masses expanded to the size of the vast Afro-Eurasian compact land mass during the Tertiary Period. Fragmentation of this super-continent of the Old World enabled extensive lateral migration of these individual fragmented land masses as sheets to their present emplacement mainly during the Quaternary-Recent geological period.

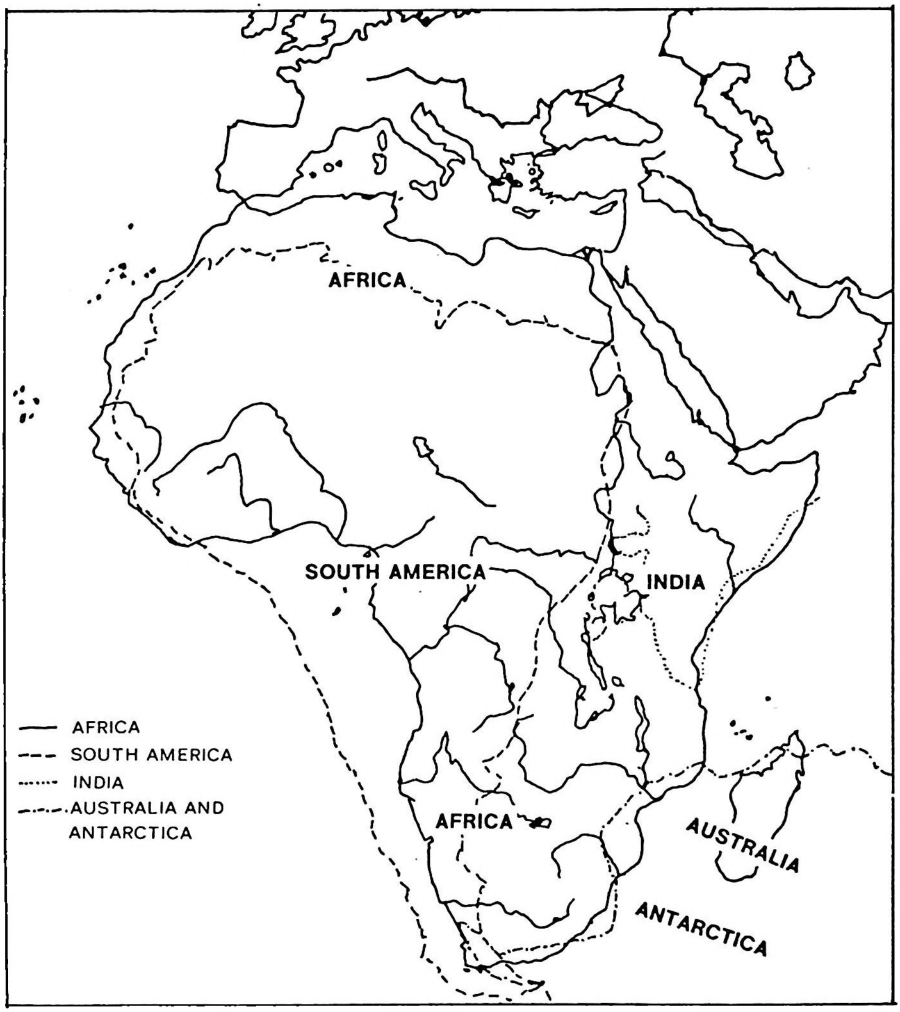


Fig. 84. Relations of the Gondwana Lands

THE ORIGIN AND EVOLUTION OF OCEANS

Oceans are the most extensive features of the earth's surface, constituting nearly three-fourths of the entire global surface. They form a continuous sheet of water round the earth and in this, the continents appear as elevated disconnected protrusions of the oceanic floor above the sea level. The irregular distribution of these land masses exposed above the sea level has served to divide the oceans into different oceanic realms which, however, are still all interconnected and have often ill-defined boundaries among themselves.

1. The Pacific Ocean

The most dominating among the Oceans is the great Pacific Ocean stretching almost from Pole to Pole and covering nearly half the earth's surface from the east coast of Asia to the west coast of the Americas and thus largely constitutes the Water Hemisphere. This mighty ocean is surrounded nearly continuously by a girdle of high mountain ranges often studded with active volcanoes. Deep within the domain of the Pacific Ocean we again find a number of Island Arcs and archipelagoes, also studded with active volcanoes and which are separated from one another by a series of long narrow oceanic trenches (Fig. 85). Vast stretches of this ocean have a uniformly deep oceanic floor, over 5,000 m in depth, and these are often associated with a series of oceanic deeps more than 6000 m deep against the CircumPacific Island Arcs. There are again vast stretches in the Pacific where the depths are uniformly between 3650-5000 m, the average depth of the Pacific Ocean being about 4270 m below SL.

It appears possible that large areas of the present Pacific Ocean floor are parts of the primordial simatic surface of the earth which it assumed after it cooled from a molten condition and which was later covered uniformly by the primordial ocean all over the earth's surface through condensation of primordial atmosphere. This was the Proto Pacific ocean which once completely covered the earth's surface almost uniformly to a depth of about 2.4 Km.

Continuous submarine eruptive activity utilized significant parts of the simatic ocean floor to generate basaltic, andesitic and granodioritic rock magmas which on consolidation constituted the sialic platforms rising through this primary ocean floor, later to form exposed continental land masses. These regions of active submarine volcanism were partly getting shallower due to accumulation of lighter products of volcanism while adjoining parts, which were utilised in the generation of Ande-basaltic magmas, became deeper basins to accommodate the original volume of sea water and in this way, continental regions were getting elevated and enlarged while oceanic areas were getting narrower and deeper. The present proportion of the land and sea which is about 30 to 70, represents only a stage in the evolution of the continental crust from the original proportion of 0 to 100. This proportion 0:100 continued to prevail till the lower Palaeozoic period. Indications are available to show that the land first became exposed above sea level only during Silurian-Devonian period of the earth's history. Before this, submarine volcanism was gradually raising the oceanic floor in restricted regions to shallower depths through accumulation of submarine lavas and other products of volcanism. This was still the Pan Pacific stage. The shallower portions of the ocean floor became geosynclinal sites for organic evolution which we see so vigorous during the Lower Palaeozoic yet without any development of land life.

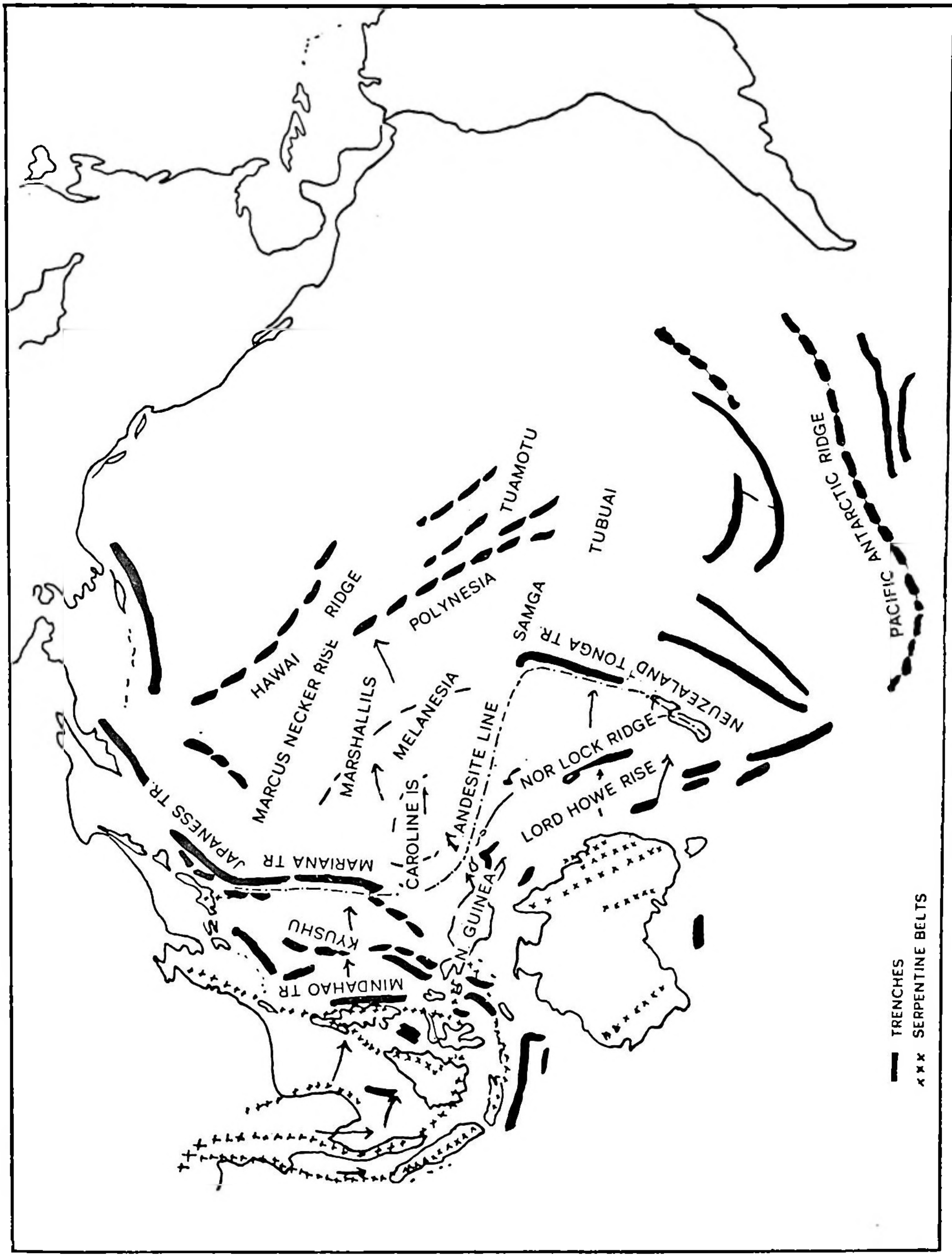


Fig. 85. Central Pacific Volcanicity (Holocene)

The Lower Palaeozoic submarine platform serving as a geosyncline in a portion of the Pacific Ocean emerged during the Caledonian earth movements into an island mass in the nature of *Old Red Sandstone Land* to develop into a Proto Pangae covering an area of about 20 m. sq.km. during Mid-Palaeozoic Period. This Proto Pangae permitted the evolution of the first land life, animal as well as plant, found uniform in all Devonian lands. This Pangae consisting of Greenland and Antarctica got rifted during Hercynean earth movements to give rise to two continental masses — the Proto Laurasian on the north and the Proto Gondwanaland on the south, both occupying the Tibeto-Himalayan region. These were separated by the intervening Tethyan Mesozoic Geosyncline which played an important role during the Tertiary Alpine Orogeny. These Northern and Southern continents continued to grow in volume and area to the extent of about 100 m. sq. km. covering Afro-Eurasia at the expense of the Pacific Ocean during the Tertiary Period.

These two supercontinental masses suffered intense sheeting and the widespread migration of the sheared continental plates occupied vast regions now covering almost 150 m. sq. km. of the earth's surface. Thus, the primary Pacific domain got correspondingly reduced in area to give place to the various continents and their intervening seas and oceans. The present Pacific Ocean now with an area of about 166 million sq. km. is only a remnant of once all-pervading continuous sheet of oceanic waters Panthalessa covering the whole earth's sphere with an area of about 510 million sq. km.

2. The Evolution of the Indian Ocean

The Indian Ocean extends from the Bay of Bengal on the north to Antarctica on the south and separates the Southern continents of Africa, India, Australia and Antarctica from one another. On the east and southeast, it joins the Pacific Ocean and on the west the Atlantic Ocean. It has an area of a little over 72.5 m. sq. km. and an average depth of about 4000 m. and reaches a depth of over 7300 m. in the Sunda Trench. Geological history of all the continental masses on the periphery of the Indian Ocean gives strong indications of intimate interlinking among these land masses to suggest the existence of a unitary Southern Continent during the major part of the Mesozoic and it is only towards the end of the Lower Tertiary that the various continental masses started separating from one another with the development of deep rifts culminating in the formation of the Indian Ocean. The primary rift initiating the fragmentation and separation of southern continents appears to be represented by the Ganges and the Brahmaputra. The Gangetic movements later widened into those of Mahanadi, Godavari, Krishna and Cauvery on the west while those of Brahmaputra later widened into those of Meghna, Kaladan, Chindwin, Irrawaddy and Salween in the east. These movements led to the evolution of the Bay of Bengal which is the precursor of the Indian Ocean.

The Arabian Sea was initiated by the Chambal-Luni-Sutlej-Indus series of angular movements followed later by the Helmand, Tigris and Euphrates movement in the northwest, when the Persian Gulf followed by the Red Sea Rift expanded southward into the Arabian Sea, through the westward migration of the Arabo-African continental mass away from the Indian Platform. The eastward migration of the Australasian sheet complex in the region of Burma-Indochina-Philippines was facilitated by the Irrawaddy-Salween-Mekong-Sikiang series of movements while the Antarctic substructure moved south along the Mid-Indian Ocean Ridge through the region of Cocos-Keeling, Christmas Islands southwest of the Sunda Trench.

The final westward migration of the Afro-Brazilian continental complex through the stages of Laccadiv-Chagos, Socotra-Chagos, Seychilles-Mauritius and Madagascar submarine ridges brought about the expansion of the northwestern part of the Indian Ocean whereas the southward migration of the Antarctic continent through Diamantina Fracture Zone. Kerguelen Amsterdam-St.Paul Submarine Plateau to the South Pole led to the expansion of the Indian Ocean in the south. The southeastward migration of Australia brought about the evolution of the eastern and southeastern parts of the Indian Ocean. All these movements took place largely during the Upper Tertiary-Quaternary Period.

3. Evolution of the Mediterranean Sea

The Mediterranean Sea is a highly complex structural basin nearly 2.6 million sq. km. in areal extent and is bordered both on the north and the south by complex Tertiary Alpine Ranges. It is also interspersed with irregularly-oriented structural arcs and massive in the interior, often associated with young eruptives some of them being active even at present. This sea marks the separation of European continental mass from the African. It is narrow in the west and is appreciably wider in the east.

A structural analysis of the region reveals that the whole region of the Mediterranean Basin was in earlier stages more compact and was situated superposed over the region of Asia Minor from the Aegean Sea to the Caspian Sea. The Carpathian arcuate structure was superposed over the Armenian plateau. The Austrian and the Western Alps were superposed over the Pontian ranges of northern Turkey whereas the Atlas Apennine-Dinaric coastal belts were superposed over or juxtaposed with the Taurus ranges of southern Turkey.

During the westward movement of the Euro-African continental sheets the Mediterranean structural basin got shifted from the Aegean Sea westward in stages to its present position. This shift also brought about *en/echelon* E-W extension of the Alpine structural arcs both in the north and the south. There was also a slight broadening of the Mediterranean basin in the east due to anti-clockwise rotation of Euro-American structural sheet and clockwise angular rotation of the African sheet with a hinge near Gibraltar.

Most of the evolution of the Mediterranean basin took place during the Upper Tertiary-Quaternary period and preceded the formation of the Atlantic Ocean.

4. Evolution of the Atlantic Ocean

The Atlantic Ocean stretches north-south between the Old World of Euro-African continental mass on the east and the New World of the American Continents on the west. It has an area of over 31 million sq. kms., almost half of that of the Pacific Ocean and is the second largest oceanic expanse. It also reaches depths upto 9144 m. next only to those in the Pacific Basin.

The Atlantic Ocean Basin is divided by the Mid-Atlantic Ridge longitudinally into Eastern and Western and latitudinally in Northern and Southern Atlantic Basins.

This ridge, as also many other structural features of the Atlantic Ocean, exhibits intimate correspondences with those of the bordering continents both to the east and the west, as already alluded to in an earlier chapter, and throws abundant light on the evolutionary history of the ocean. Structural studies on the basis of sheet movements have abundantly shown intimate relations subsisting between the African and South American continental masses bordering the South Atlantic Ocean as also between Europe and North America bordering the North Atlantic Ocean. It is thus obvious that these continental sheets on the eastern and western borders of the ocean must have been in juxtaposed and possibly even superposed condition in the not distant geological past and that their subsequent lateral separation brought about the existence of the Atlantic Ocean in its present form.

The opening of the Indian Ocean initially from the Bay of Bengal region led to the westward migration of Afro-Brazilian continental mass in the SW concomitantly with the westward migration of Euro-American continents from their original position in the region round Tarim basin to the present position of Europe. With the stabilisation of African continent in its present position, the overlying South American sheet got separated from its African basement west of the East African-Nile Rift and started moving westward with a slight clockwise rotation so that the Chilean-Argentinean part of South America, this time, occupied the Mid-Atlantic-Walvis Ridge position. The northern Brazilian part of the South American sheet still occupied a large part of the Sahara platform. The Cape Basin east of the Walvis Ridge constitutes the earliest part of the Atlantic Ocean to come into existence. With the continued westward shift of the South American sheet, the Peruvian Colombian Andes, earlier resting over the Senegalian-Mauritanian coastal belt, now moved west to occupy the central part of the Mid-Atlantic Ridge, north of the Equator. Till this time, the Caribbean-Mexican marine basins were not differentiated as distinct entities. The Mexican-Texan part of North America was closely juxtaposed with the Peruvian-Venezuelan part of South America at the time when the Andes were occupying the central part of the Mid-Atlantic Ridge bordering the Cape Verde Basin. The North American Rockies suffered anti-clockwise rotation and in the process gave rise to the Mexican, Central American and Antillean Arc Systems. The tenuously linked masses of North America and South America now suffered rapid westward movement, in stages, to give rise to the present wide Atlantic Ocean.

The vigorous volcanism still active in the Antillean-Central American region, coupled with that along the CircumPacific Andean Cordilleran belt, is an indication that the Atlantic Ocean is still expanding westward, encroaching over the marine domain which was previously part of the Pacific Ocean.

5. Evolution of the Arctic Ocean

The Arctic Ocean is the smallest and the shallowest among the oceanic basins, covering only about 14.25 million sq.km. area with an average depth of only 1280 m. This, verily an enlarged sea, occupying the north polar region, is extensively connected with the Atlantic Ocean through the Greenlandian and Norwegian seas and also through narrow channels in between the Canadian Arctic Islands. To all purposes, the Arctic constitutes a northerly extension of the Atlantic Ocean. It is also connected with the Pacific Ocean through the narrow Bering Strait.

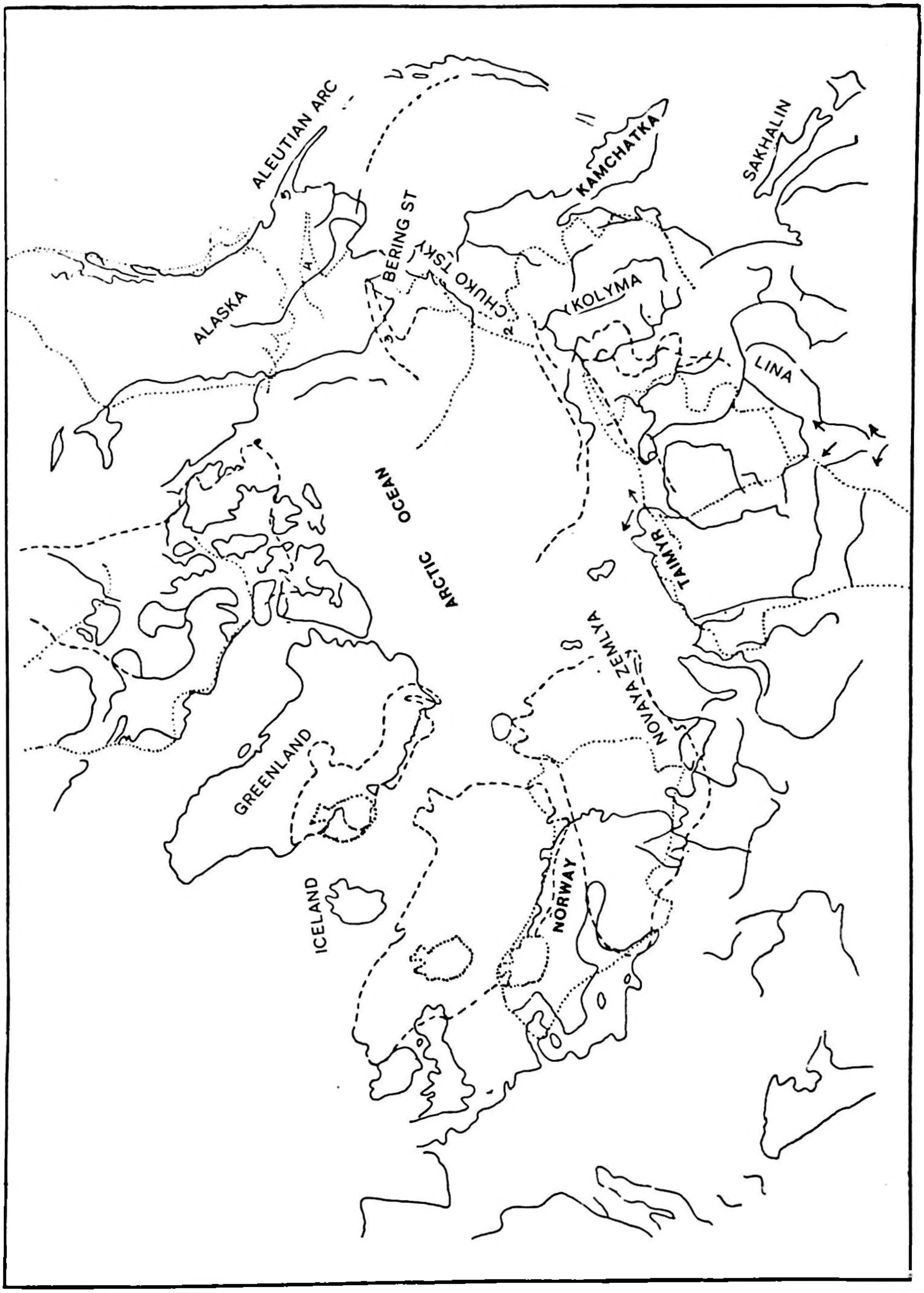


Fig. 86. Evolution of Arctic Ocean

Vast areas of the Arctic Ocean, particularly along the northern borders of the Eurasian Continent, are shallow shelf seas which terminate against the girdle of the Arctic Islands situated roughly along the 80° N latitude. The Alaskan peninsular mass forming the northern termination of the Rockyan Cordillera has a peculiar proboscis like Aleutian Island Arc which meets the Kamchatka peninsula of Siberia almost at right angles. Structural homomorphies have shown that this Alaskan peninsular mass was in earlier geological past an integral part of the Altai structural ranges of Mongolian-Siberian border in the Trans-Baikal region. Here it was, at that time, closely juxtaposed with the Verkhoyansk-Kolyma Kamchatka structures then in the basin of the Upper Amur. Leaving the Altai basement, the Alaskan sheet complex moved northwest along the Tungusk-Yenisey trends while the Kamchatka sheet moved northeast along the Amur-Kurile trends. The Alaskan Aleutian sheet rotated clockwise through an angle of 180° along the route of the Novo Siberian and Vrangelean Islands and round the Chukotski peninsula thereby enclosing more or less completely a portion of the Pacific Ocean to form the Bering Sea (Fig. 86)

Simltaneously, the Yukon Canadian Cordilleran sheet complex left the Siberian basement and rotated from the Taymyr peninsula along the route of Severnaya Zemlya-Franz Joseph-Spitzbergen Greenland Arctic Islands roughly along the 80° N latitude to its present Yukon position. In this way, the rotational movements of the Alaskan Cordilleran sheets from their Siberian basement brought about the enclosure of the Arctic ocean and the associated sea basins as extensions of the Atlantic Ocean all during Pleistocene Holocane Period.

CHAPTER XI

Palaeogeographical Evolution of the Earth's Crust

Earliest Stages in Crustal Evolution

The Earth is a member of the Solar System and its existence as an individual celestial body is closely connected with astronomical events leading to the evolution of the various planets. These astral processes are still to be fully comprehended and several theories are in the field to account for the birth of the planetary bodies. Whatever the processes actually involved in the birth of the earth, it is generally held that the earth has passed, at some early stages, through a hot molten phase which permitted the earth globe to assume a concentric internal structure consisting of an innermost heavy metallic Core, part liquid and part solid, surrounded by shells of Mantle and Crust. The earth gradually cooled to permit condensation of atmospheric steam and other gases to give rise to the hydrosphere in the nature of oceans. The preoceanic period of the earth's history is essentially pregeological and could be considered as a geoastronomical or geophysical stage. During this pregeological period, the earth had passed through a viscous stage before it consolidated into a hard surface. During its rotational movements while revolving round the sun, the earth developed the shape of an oblate spheroid of rotation reaaranging its diverse constituents into concentric shells of continually decreasing density. Heavier noble metals of the platinum-palladium group as also those of the nickel-iron group concentrated largely in the central core, Nife, mainly in metallic state, while lighter, chemically active metals such as oxides, sulphides and silicates, arranged themselves in the outer shells of the Mantle and Lithosphere roughly according to their specific gravity. The hydrous, volatile and inert gases got concentrated in the uncondensed atmosphere round the earth. With high temperatures on the then earth's surface, the earth's sphere gradually consolidated, lighter materials especially the silicates aggregated in the Crust whereas heavier metallic compounds such as oxides and sulphides concentrated at deeper levels in the Mantle.

At present, the solid surface of the earth's crust is essentially made up of oceanic sima covered here and there by continental masses made up of sial. The important problem before the geologists is whether the continental crust, as we know it today, was already formed during the primordial preoceanic stage of the cooling earth or later during the post-oceanic stages.

The oceanic sima forms a continuous layer all round the earth overlying the mantle both below the oceans as well as under the continents. It is, therefore, very likely that this suboceanic sima layer was already formed before the first condensation of atmospheric steam took place on the warm surface of the earth to form hot oceans. This preoceanic sima is formed of essentially unhydrous pyroxenic magmas derived from the molten ultrabasic portions of the mantle poured out on the dry hot surface of the earth during the primordial stages. It is this sima surface which later formed the receptacle for the formation of oceans due largely to condensation from the atmosphere. This primary ocean contained most of the volatile constituents of the atmosphere which would condense successively with the fall of temperature. As already mentioned earlier, this primordial ocean became deeper with increased condensation of the atmospheric vapour to form a continuous Panthalessa or Pan-Pacific Ocean, possibly enveloping the whole earth to a depth of about 2.4 km.

With the formation of this primordial ocean begins the regular geological history of the earth for which truly geological evidences could be available. There has long been a controversy among eminent geologists as to the primacy among oceans and continents.

Continents are largely granitic-gneissic in composition with a thin veneer of sediments. These granitic terrains of continents were, for long, considered as truly magmatic as the last differentiates of the primary basaltic magmas erupted during the cooling of the molten earth in its primordial stages. As such they should have formed the surface of the earth over which oceanic waters accumulated when the earth cooled. Under this concept, granites must be found almost as a continuous layer covering the whole surface of the earth even below the oceans. Actually, however, granitic rocks are altogether absent in the bed of the Pacific Ocean which by itself covers almost one-third of the earth's surface and even forms large portions of the other oceans. Continents, of which granites are the dominant constituents, form less than one-third of the earth's surface and as such continents cannot claim primacy over the oceans.

Moreover granites, in most regions, have exhibited metasomatic origin formed due to the transformation of sediments. These require prior existence of oceans for their deposition. This clearly shows the possibility that granitic continents must have formed long after the formation of oceans on the earth's surface when the earth had sufficiently cooled. It is, therefore, obvious that continents may not have been formed during the primordial stages of the earth's evolution.

Formation of oceans marks the end stages of the primordial earth during which it cooled from a molten state. With the progressive fall of temperatures of the earth's surface, the precipitation of steam and other volatiles must have progressed more vigorously adding to the volume of the oceanic waters. The present volume of oceanic water is estimated to be sufficient to drown the whole earth surface to a depth of 2.4 km if the surface was even. Looking to the young age of the major surface features of the earth like the Alpine and CircumPacific mountain systems, it is possible that in the Pre-Cambrian period the earth may have presented a still lower topography, and the oceanic waters in their present volume could have covered the earth's surface to such oceanic depths. This could have formed, as already discussed in an earlier chapter, the Primary, eogeological Panthalessa or the Pan-Pacific Ocean with hardly any trace of land surface exposed anywhere above the sea level (Plate 18). That the ocean actually covered the earth surface is indicated by the complete absence of land life, plant or animal, till as late as the end of the Silurian period even while marine life, both algal and invertebrate, was quite prolific. We see the emergence of most primitive land life for the first time only during the Silur-Devonian period which heralded the Caledonian orogeny. This evidence indicates the probability that, prior to the Caledonian orogeny, no land surface was available above the sea level for the evolution of plant or animal life capable of living on exposed land.

From these considerations, it looks quite probable that the earth surface was completely covered by oceanic waters during the whole of the Pre-Cambrian and also during the lower part of the Palaeozoic Era. The material for sedimentation during this period was constituted essentially of pyroclastics and chemical precipitates. Submarine lava flows were being piled up on the ocean floor raising its level in certain regions of vigorous volcanism to shallower depths. We can get a picture of the early stages of continental formation from a study of the recent formation of island arcs in the Central Pacific Ocean in the region of Malanesia, Micronesia and Polynesia. This region is studded with island arcs, each island being a centre of recent or subrecent volcanism. These island arcs, individually or in groups, are situated on submarine volcanic platforms or ridges which rise from the bed of the Pacific Ocean several kilometers deep through the accumulation of products of repeated submarine volcanism during the post-Cretaceous period and without any trace of terrigenous sediments.

Vigorous volcanism is again rampant in the CircumPacific belts abutting against continental borders where they were associated with eogeosynclinal sediments and which after orogenic upheaval got successively fused with the bordering continents. These are illustrative of the mode of evolution of Pre-Cambrian basement which was formed over the bed of the Archaepacific ocean and which later rose above S.L. to form continental cratons fringed by younger geosynclines of successive periods.

The Pre-Cambrian crustal formation is essentially connected with submarine volcanism, pyroclastic sedimentation and chemical precipitation with no contribution of terrigenous sediments from continents since they did not come into existence till then. Recurrence of volcanic activity entailed intrusion of basic magmas into the deep-lying sediments which got metamorphosed through contact effects, recrystallisation and metasomatism leading to the formation of quartzites, marbles, calc-silicate rocks, amphibolites, schists, gneisses, granites and even granulites which form the common constituents of Basement Complexes associated with the Archaean Cretons or Shields. The basin of sedimentation gradually rose from abyssal to bathyal depths through further accession of volcanic materials. Here environmental conditions improved and became favourable for microscopic, unorganised life to assume discrete forms, such as diatoms, oozes, yet too soft to be preserved as fossils. It was only when depositional basins rose to neritic levels that the marine life experienced vigorous growth with the adoption of diverse organisational structures. Some of these were capable of being preserved as fossils. These conditions heralded the Cambrian period when we find a sudden abundance of diverse, largely evolved, invertebrate orders and families with complex structures, occurring as recognisable fossils in the sediments of the period in different parts of the world. This is the beginning of the well-authenticated geological history of the earth.

The deep-lying rock formations in the Pre-Cambrian series of sedimentary sequences were being repeatedly subjected to magmatic intrusions which induced processes of cratonisation and there may have been many episodes of this process bringing about different grades or stages cratonisation in the deeplying sediments. During orogenic upheavals, many of these cratonised sequences of diverse ages may be intricately involved in complex folding in the root zones, giving rise to a Basement Complex from which it may be almost impossible to sort out components of different ages.

In the case of Pre-Cambrian rock formations, we can have no recourse to fossil evidence for the determination of their relative ages nor can we, in many cases, rely on structures for ascertaining their succession. During the last few decades geochronological methods have helped much in Pre-Cambrian dating but the complex nature of the basement metamorphic structures often give conflicting ages for portions of the same formation.

The Archaean rock complexes are very commonly associated with ore deposits and it may, in certain cases, be possible to use these mineral deposits for purposes of correlation, if not for absolute age determination.

Certain metallogenetic provinces are characterised by the abundance of particular metallic ores in typical rock associations of magmatic origin. Though they are now found in vastly separated regions, the ores, their petrographic associations and their tectonic settings are often so remarkably similar as to suggest common environment of ore formation. If the concept of sheet movement is applied to such cases it would appear that these ore deposits possibly owe their formation to the same magmatic activity in the same or closely juxtaposed Petrographic Provinces.

Many of the shield regions of the Northern and Southern Continents are characterised by the occurrence of vast deposits of important metals like platinum, chromium, nickel, iron, gold, copper, lead, zinc, etc. intimately associated with certain magmatic intrusives in closely similar tectonic setting. Such are, for example, the nickeliferous pyrrhotite, pantlandite and chromite bearing ultrabasic intrusive complexes of Sudbury, Ontario, Canada, and Bushveld Complex of South Africa, Rhodesia etc. The Sudbury type of metalliferous complexes are again found developed interruptedly in the Acadian belt of Quebec, New Bruinswick, Cape Britain, Nova-Scotia, New Foundland, again in N.W Canadian shield province of Winnipeg, Athabasca, the Great Slave lake and the Great Bear Lake Districts extending into the Mackenzie River basin. Similar deposits are again encountered in Silkirk and Purcell mountains of the Canadian Cordillera of British Columbia, Atlanta, continued further north into Yukon ranges. Southwards they have been found repeated in the Appalachians and in the Colorado Rockies of the United States. In many areas these Archaean and Pre-Cambrian rock formations are found overlain by fossiliferous Lower Palaeozoic formations and as such their Pre-Cambrian age has been fairly well-established. These formations have been enriched in polymetallic ores by vast intrusive complexes through magmatic, metasomatic and hydro-thermal processes of ore formation. It is, however, surprising that these belts, exhibiting similar mineralisation in almost identical geological setting are geographically so widely separated and are found repeated interruptedly over the whole breadth of North American continent from the Pacific to the Atlantic borders.

Most of the base metals exhibit the same trends of geographical distribution. Do they represent independent sedimentary belts mineralised by independent intrusives? Our studies in sheet movements, elucidated earlier, indicate a strong possibility that all these diverse developments of polymetallic ore bodies were originally developed in closely juxtaposed and even superposed thick sedimentary columns, simultaneously by the same mineralising magmatic activity and that these mineralised belts were later sheared and sliced and shifted to their present locations through the process of sheet movements during the later states of continental expansion. The same could be said of many other polymetallic deposits found developed in different continental shields such as Bushveld Complex of South Africa, Rhodesia and other parts of Peninsular Africa, Peninsular India, Pilbara Complex of West Australia, Angara shield of Siberia etc., where older Pre-Cambrian formations are found richly mineralised in diverse metals. Banded Hematite Quartzites often rich in manganese ore deposits, are also found extensively developed in Pre-Cambrian formations in diverse continental shields. These metallic mineralisations in the early Pre-Cambrian formations of diverse continents indicate a strong probability that these different shield masses were much closely juxtaposed during their period of formation and mineralised before migration to their present sites. It appears, therefore, very probable that the continental crust of the earth was all aggregated together into a relatively small Cratonic area not larger than the size of Greenland and that this craton may have occupied the geographical position of the Tibeto-Himalayan region during the early Pre-Cambrian period. This probability is further strengthened by the very close faunal relationships shown by the later, fossiliferous Lower Palaeozoic formations found closely associated with many shield masses both in the Northern and Southern Hemispheres.

The Cambrian Palaeogeography

The earliest recognisable well-evolved invertebrate fossils marked the Cambrian rock formations of the world and denote one of the most important stages in the earth's evolution. It is from this period that the well-documented geological history of the earth begins. With the help of these recognisable fossils, we can determine not only the age of the fossil-bearing formations but also make out the environmental conditions under which the rock formations were deposited and thereby conjecture the palaeogeographical conditions then prevailing in different parts of the world. Before the Cambrian period, the life organisms in the oceanic waters were too primitive, disorganised and devoid of hard parts. In the Cambrian period, environmental conditions improved significantly to permit vigorous growth of organic life in the seas. This change was essentially due to shallowing or elevation of depositional basins from deeper abyssal depths to shallow bathyal and even to neritic levels, within 400 metres below the sea level, where a fair amount of sunlight, moderate temperature, appropriate oxygen content, salinity, abundant food and several other factors which favoured vigorous growth of marine life with highly evolved shell structures. Absence of any evidence of land life during the Cambrian period indicates the probability of complete absence of land mass standing above the sea level to permit evolution of land plants or animals even when marine life was so abundant and highly evolved. The earth thus appears to have been completely covered by the Pan-pacific Ocean during the Cambrian period.

The Cambrian life is characterised by highly evolved Trilobites and Brachiopods besides minor development of Gastropods, Cephalopods, Lamellibranchs etc., as also a characteristic development of Archaeocyathide of uncertain biological affinity. Trilobites occupied a dominant position among the various faunal elements during the Cambrian and served as index fossils. They give indications of the existence of three Faunal Provinces. These life provinces during the Cambrian period are recognised not on the basis of groups or families but on the basis of certain generic associations which are present in one but are absent in others.

(a) The Pacific Life Province is characterised by the presence of *Qlenellus, Arctocephalus* and *Dicellocephalus* associations, respectively in the Lower, Middle and Upper Cambrian faunas: (b) The Atlantic Life Province, on the other hand, is characterised by the presence of *Holmia, Paradoxides* and *Olenus* and associations respectively in the above three divisions, whereas (c) the Indian Ocean Life Province is recognised by the presence of *Redlichia, Ptychoparia* and *Ptychiaspis* associations within the same three divisions of the Cambrian Period.

The distribution of these life provinces during the Cambrian is worldwide, the three belts being latitudinal in development. The association of numerous common elements emphasize the easy intercommunication among themselves as in juxtaposed basins.

The study of structural homomorphy as discussed earlier, strongly suggests that the primary basins of deposition were closely packed, juxtaposed and in some cases even superposed to form one interconnected basin differentiated by surface irregularities which prevented certain generic associations migrating from one part of the basin to the other. This all-comprehending basin of deposition common to all the three Cambrian life provinces appears to have been situated in the Tibeto-Himalayan region of Central Asia occupying the vast neritic submarine platform rising locally from the bed of the all-pervasive Pacific Ocean and formed through repeated episodes of volcanism since early Archaean times. The basal formations of this stratified sequence were cratonised and mineralised with polymetallic ore deposits. It was this primary early Caledonian geosyncline which, in an enlarged form, got differentiated into a centrally-raised shallow basin elongated E-W and characterised by repeated fissure eruptions and their clayey products of decomposition Plate 19. This medial basin with Atlantic faunas was surrounded by deeper basins of calcareous sediments both to the north and to the south. This differentiated basin continued to serve as the basin of deposition at least upto the advent of Caledonian earth movements during Upper Silurian when this comprehensive complex geosyncline got disrupted. The central volcanic basin (Atlantic Life Province) was elevated later to littoral depths. The northern geosyncline became the nucleus of the Pacific Life Province while the southern geosyncline became the nucleus of the Indian Ocean Life Province.

The Cambrian formations occurring in British Columbia, New England, Scandinavia, Arctic Islands and extending upto Siberia belong to the Pacific Life Province. From the structural studies they appear to have been closely juxtaposed during their original deposition in the northern portion of the Tibetan Basin in the source regions of the Tarim and the Hwang Ho. The Cambrian formations of the Appalachian Ranges, England, Central and Western Europe, Baltic States, Urals and Tienshan, all belong to Atlantic Life Province and were possibly deposited in the western and central lake districts, Tanghia region of Tibet. Those of the Andes, the Amazon basin, Atlas, Iran, the Salt Range, Kashmir, Spiti, China, Australia etc. belong to the Indian Ocean Life Province and were similarly deposited in the Punjab-Nepal-Himalayas in the source regions of the Ganges and the Indus. Those of China, Korea and Manchuria were deposited in the source region of the Yangtsekiang, while those of Australia were deposited in the S.E. Tibet in the source regions of the Tsang Po (Brahmaputra), Salween and the Mekong. The whole continental crust of the earth during the Cambrian period consisted of the cratonised submarine platform situated in the Tibeto-Himalayan region and this

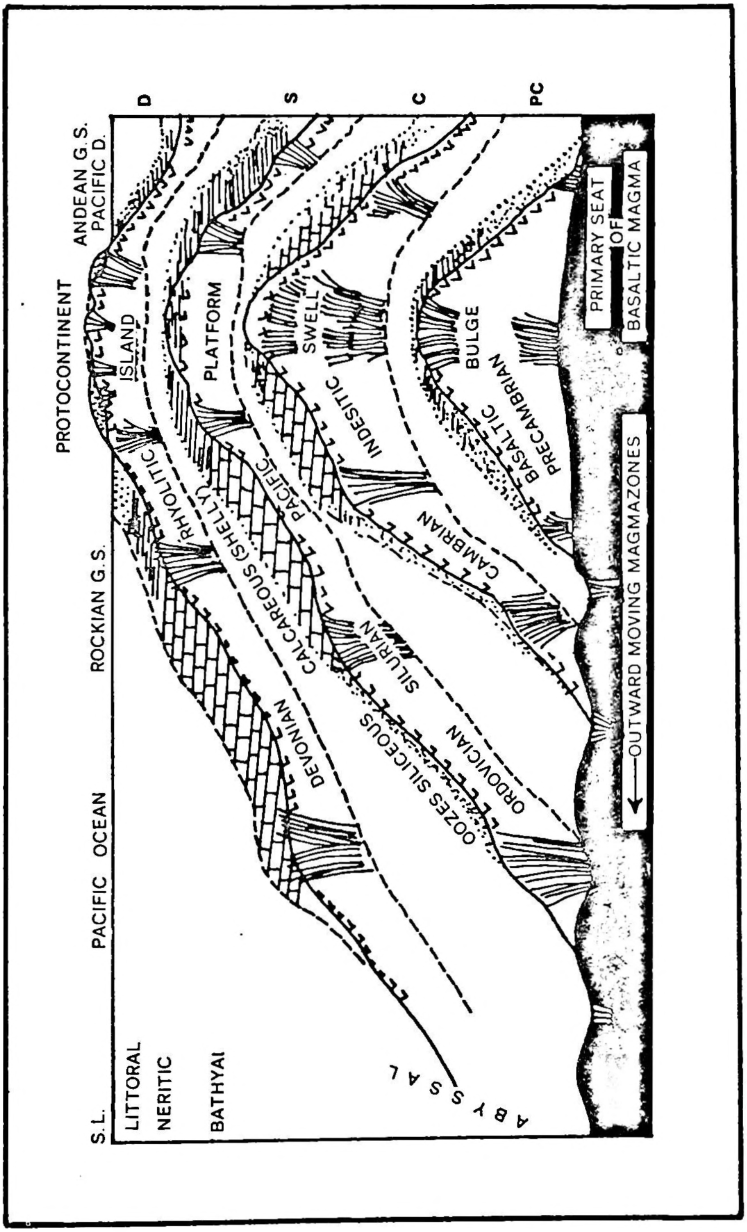


Fig. 87. Submarine Stages in Continental Evolution

became the basin of sedimentation of the Cambrian marine fossiliferous formations with no land mass exposed anywhere above the sea level (Fig. 87). Being a comparatively small marine basin of bathyal to neritic depths, the palaegeographical conditions were more or less uniform throughout the basin except for small differences in depth in that the central region being somewhat at a higher level were more abundantly fed with volcanic ashes and clays than the side basins which were deeper and richer in calcareous sediments. This would account for the appearance of somewhat distinct faunal facies in different parts of the common basin. Later movements of fossiliferous formations as sheets, during subsequent geological periods, would account for their world-wide distribution.

The Ordovician Palaeogeography

The three faunal Provinces of the Cambrian Period characterised by the presence or absence of certain Trilobite genera and now found distributed in vast latitudinal belts, appear, under the new concept, to have been deposited originally in basins which were only different parts of a common depositional basin. This basin, most likely, was situated in the Tibeto-Himalayan region.

The biostratigraphic evidence for the Ordovician period, however, points to only two faunal provinces, one characterised by the dominance of Graptolites and the other, by shelly faunas constituted of Trilobites, Brachiopods, Cephalopods, Gasteropods and other invertebrates. The Graptolite Faunas occur essentially in clayey sediments while shelly invertebrate groups occur largely in calcareous rock formations. Graptolites by their abundance and distinctive growth forms have proved important as zonal fossils and quite a number of zones, over 13 in number, have been recognised in the Ordovician formations alone. Numerous, widely separated, regions have developed this facies and it is remarkable that the same zones in the same order of succession are seen developed in widely separated parts of the world. It is further notable that the Graptolite facies is developed more or less in the same basins of deposition which during the Cambrian period were characterised by the Atlantic faunal association whereas the shelly faunas characterised regions of the Pacific and Indian Ocean Life Provinces. Moreoever, the Graptolite bearing shales commonly associated with volcanic products as such probably represent the medial raised depositional basins which were the centres of continued volcanism and which were thus being raised from neritic depths of the Cambrian period to shallower littoral depths in the Ordovician period.

The global relationships among the Graptolitic Faunas as also those among the shelly faunas pose problems of distribution of land and sea to permit unfettered and rapid means of intermigration over enormously long distances. This is explicable only if the original basins of deposition were closely juxtaposed and yet permitting separate habitat for the planktonic Graptolites and benthic shelly faunas through varied depth relationships.

This comprehensive composite geosyncline comprising the various Ordovician basins of sedimentation appears to be the same Caledonian Geosyncline which is thought to have persisted since the Cambrian period in the Tibeto-Himalayan region. In this the North American, the Scandinavian and the Siberian Ordovician formations were originally deposited in latitudinal belts in the northern portions of Tibet in the Kunlun-Tsaidam region and the upper Hwang Ho Basin, those of China were in the source regions of the Hwang Ho and the Yangtsekiang, those of Australia were in the source regions of the Brahmaputra, Salween and the Mekong, while those of South American Andes, Atlas and N.W. India were in the source regions of the Indus and the Ganges. It was from this Tibetan basin that, in the later period of basaltic floods, these rock formations were lifted up as sheets and shifted repeatedly in a series of lateral movements to their present locations.

The Silurian Palaeogeography

The stratigraphical and palaeontological records of the Silurian period (as briefly described in an earlier chapter) suggest the continuation of sedimentation of the Silurian Formations in the same basins as those in the Cambro-Ordovician period without any serious discordance. The faunas all still are marine except possibly towards the top zones of the period when esturine to brakish water faunas make their first appearance. Typical land faunas or land plants are, however, extremely rare and imperfectly preserved as in Ludlow Bone Bed. Among the marine faunas, any indications of distinct life provinces are altogether absent and both the Graptolites and shelly forms which during the Ordovician occupied separate basins now occur together in the same basin, closely interdigitated as seen in most Silurian developments. The Graptolites are now characterised by monoseriate forms of the Monograptids, which serve as zone fossils while among the shelly faunas, the same Ordovician groups continue with a slight change in their relative importance. Corals now assume added importance as reef builders while Crinoids and Mollusces become important constituents of shelly faunas. Towards the upper stages Lamellibranchs, characteristics of shallow water conditions, become prominent and are joined by Eurypterids and primitive fish ushering the imminent emergence of land above sea level. The actual emergence of land during Silurian is known only from Victoria, Australia, where pieces of stems of most primitive land plants of Thursophyton and Hostimella types have been found associated with Monograptids. These are among the earliest recorded land plants in the world.

The worldwide uniform type of faunal associations without any provincial traits, all exhibiting shallow marine habitat and occasional association of brakish water forms, all suggest the end stages of the geosynclinal regime through crustal upheavals connected with the Caledonian orogeny. These led to the emergence of land above the sea level for the first time in the earth's history in the nature of Old Red Sandstone more conspicuously during the Devonian period.

The original basin of sedimentation of the Silurian rock formations which are now seen occurring in widely separated regions of the world again appears to be the same which existed during the Cambro Ordovician period in the Tibeto-Himalayan region in the source region of the major rivers draining this area, viz. the Indus, Ganges and Brahmaptura (Tsangpo) in the SW and south, Salween and Mekong in the SE, Yangtse Kiang in the east, Hwang Ho in the NE, Tarim in the north and NW and the Amu and Syr Darya in the west and NW. It is from this source region that these Lower Palaeozoic fossiliferous rock formations which for a significant part were already metamorphosed during the Caledonian earth movements were transported, repeatedly in stages as sheets and sheet packets to different parts of the world during later geological periods.

The Devonian Palaeogeography

Towards the end stages of the Silurian period, the Caledonian volcanism and connected earth movements brought about the folding and upheaval of Lower Palaeozoic sediments and led to the emergence of a lenticular island archipelago in the medial zones of the Devonian geosyndine (plate 20). This archipelago was subjected to periodical flooding of sea waters and this provided an opportunity for certain marine organisms to adjust themselves to amphibian habit to sustain both on land and in sea, in fresh, as well as, brakish waters. The dawn of the Devonian marks a veritable landmark in the evolution of the earth's surface. Numerous terrestrial organisms, both animal and plant, with most primitive body structures appear suddenly on the earth surface for the first time during this period. This clearly suggests that the environmental conditions for their evolution did not exist prior to this period and that the land emerged above the sea level for the first time in the Devonian to provide such facilities. The island archipelago of the Upper Silurian now elevated into a continuous island mass of about the size of Greenland, sufficiently large to provide abundant land surface for an uninterrupted evolution of a large variety of land organisms. Large basins of fresh water also came into existence to provide for the evolution of fresh water fish and of pteridophytic plants,some of which could coexist in brakish water also. About a dozen fish genera have been recognised which are cosmopolitan and which are found in terrestrial Devonian formations in widely separated regions of the world, both in the northern and southern hemispheres, even in Arctic latitudes. The same is the case of land plants in which a number of Psilophytic genera without any means of disperal are yet found fossil in all the latitudinal climatic zones of the earth

The lower Devonian is characterised by the most primitive group of Pteridophytes—the Psilophytates, which gives place in the Upper Devonian to the Archaeopteris association in different parts of the world. These primitive plant associations suggesting warm temperate climate must have originated in narrow climatic belt near the equator but they are now found fossil in all regions extending from the North Polar to the South Polar latitudes. Does this denote absence of climatic zoning on the earth during the Devonian period? Geophysically, this is not possible. It is, therefore, most likely that all the terrestrial deposits containing these fossil plants must have been confined to the Old Red Sandstone Island mass which, according to the new concepts, was developed for the first time in the Devonian in central parts of Tibeto-Himalayan region surrounded by the CircumPacific geosyncline in the midst of the Pan-Pacific Ocean.

The marine life of the Devonian period eminently conforms to this pattern. The Devonian marine faunas are a continuation of the Lower Palaeozoic groups except that the Graptolites have totally disappeared and are now replaced by Goniatites to serve as zonal forms. Trilobites have dwindled to only a few genera (like *Goldius, Harpes, Proetus* etc.). The Brachiopods continue with unabated vigour and are represented by numerous genera. Some of the Brachiopods species are worldwide in their development like *Stringocephalus burtini, Hypothyroid cuboides, Trigonotreata verneuili,* occurring universally in most of the Devonian neritic marine basins of the world. Goniatites among the Cephalopods now dominated deeper parts of the geosynclines and were sufficiently varied to serve as zone fossils. Important among these are *Anarcestes, Tornoceras, Manticoceras, Beloceras, Cheiloceras, Timanites, Sporadoceras, Clymenia* etc. These

Goniatite forms are found in the same zonal sequence right from North America through Central and Southern Europe, Siberia and China to Australia.

Corals also form an important component of the shallow marine facies. Among the Devonian genera some have very wide geographical distribution. Among them are Favosites, Thamnopora, Heliolites, Phillipsastrac, Thamnophylla, Calceola. It is remarkable that these corals which are known for their trophical habitat are found in the Devonian period abundantly represented in the Arctic latitudes in North America, North Europe, Siberia and also in high southern latitudes of Australia.

The present worldwide distribution of Devonian faunas and floras which are almost homogeneous in their association cannot be explained on the present distribution of land and sea and definitely calls for a much closer, juxtaposed disposition of the basins of deposition, both marine and fluviatile, as is visualised in and around the Old Red Sandstone continental island of the size of Greenland and situated in the Central Tibeto-Himalayan region. Here the latitudinal climatic zones were most appropriate for the vigorous evolution and uniform development of land plants and corals which require tropical temperate climate. It is from this Tibeto-Himalayan homeland that rock formations containing uniform faunal and floral associations were transported to the different parts of the world, including polar latitudes in the form of sheets, during later geological periods.

The Carboniferous Palaeogeography

The Island Continent of the Devonian which came into existence during the Caledonian orogeny in the nature of Old Red Sandstone land mass permitted the evolution of the first land flora consisting of Psilophytals and some terrestrial algal plants. The Old Red Sandstone facies is extensively associated with igneous activity which was actually responsible for the formation of the Old Red Sandstone into a land mass exposed above sea level, first as an Island Archipelago and later elevated into an Island Continent. This miniature continental mass was confined to a single climate zone and as such gave opportunity for the evolution and growth of animal and plant life of a uniform composition as now seen in fossil state preserved in the Devonian rock formations in different parts of the world without any regard for latitudinal climatic zones.

During the Lower and Middle Carboniferous period, the flora became richer in variety and most of the remaining Pteridophytic classes came into existence in their primitive form. This floral association known as Rhaeopteris Flora is found both in northern and southern hemispheres and is again uniform in composition even when occurring in the Arctic regions such as the Bear Island and Spitzbergen in the north and in Australia in the far south. Here we get a true representation of the Pangaea wherein all the land masses of the Lower, Middle and a part of the Upper Carboniferous period were closely juxtaposed and united into one continuous continent with uniform land fauna and flora. This Pangaea was much different in size from the one envisaged by A. Wegener since he united in his Pangaea all continents individually with their existing size and shape, neglecting the fact that vast accretions were made to the individual continents during the Variscan and Alpine orogenies. The uniformity of floras during the Devonian and most of the Carboniferous period demands the Pangaea to be small in size enough to be accommodated in a single climatic belt of the earth.

This Carboniferous Pangaea was situated wholely within the tropical temperate climatic zone and from the trends of sheet movements, it looks most probable that the primary home of this Pangaea was in the central parts of the Tibeto-Himalayan region near the source of the Indus, the Ganges and the Brahmaputra. Here the Pangaea was surrounded by the same Pacific geosyncline which was the original basin of deposition of the Rockyan and Andean Palaeozoic sediments.

The Permo-Carboniferous Palaeogeography

The Pangaean land mass during the greater part of the Carboniferous period continued to expand through further volcanism as a unitary land mass, nourishing a uniform Lepidodendron Flora but towards the top stages of the Westphalian, signs of disruption of the Pangaea appear in the nature of an E-W rift which soon developed into the Tethys sea. (Plate 21). This Rift brought about differentiation of floral relam first into two provinces, the Pecopteris-Calamites Flora in the North and Gangamopteris-Glossopteris Flora in the South. Towards the commencement of the Permian period, a third floral province was initiated in the east as the Gigantopteris Flora. Portions of the Northern Continent are now found occurring widely spread in the northern hemisphere from Siberia on the NE through Europe into North America on the west and as such has been named Laurasia. Portions of the Southern Continent are found in Peninsular India and further west in South Africa and South America and again southeast in Australia and even in Antarctica in the south. This Southern Continent is named Gondwanaland. The Eastern or the Cathaysia Province with Gigantopteris Flora is restricted mainly to China in the basin of the Yangtsekiang. Traces of this Flora, however, are found isolated beyond the Cathaysian region as far south as Sumatra and as far west as Texas and Oklahoma in the U.S.A. The primary home of these three floral provinces is recognisable in the Tibeto-Himalayan region where traces of all the three floras are still found preserved. The Laurasian continental mass in its early miniature form was situated along the northern borders of Tibet in the region of Karakoram-Kunlun ranges while the Gondwanaland in its primary diminutive size was situated in the region of the Himalayas in the upper basins of the Indus, the Ganges and the Brahmaputra spread over partly into the upper basins of the Salween and Mekong in southeastern Tibet. The Cathaysian continent, on the other hand, was situated in its undeveloped form in the upper basin of the Yangtsekiang in Eastern Tibet. The various Permocarboniferous Coal deposits of the world were formed while all the terrestrial basins of the deposition were still in the Tibeto-Himalayan region.

The various floral provinces in their primary stages were not independent continental entities but were at places closely juxtaposed. This is seen in numerous localities where mixed floras are found developed. Here constituents of one flora crossed over into the region of the other obviously before the Tethyan rift widened into an impassable barrier. We thus find the partial mixing of Glossopteris elements with the Pecopteris Flora in the Dwina region of Russia and over a large part of Siberia—in Karaganda, Kuznetzk and Angara. Similarly, Pecopteris elements are found mixed with Glossopteris Flora in South Rhodesia-Zambezi Basin.

The Tethyan sea first developed as a narrow rift due to wedge action of Permocarboniferous intrusions in the Central Tibetan lake district, widened into a moderate gulf and later developed into a sea very much in the manner of the Red Sea and later enlarged into a Mediterranean Tethys pushing the northern continental mass further north and the southern continental mass further south. The Cathaysian mass extended eastward in the region of Tsaring Nor and Bayan Kara Shan.

The evolution of the Tethys as a new marine basin in between the fractured continental masses brought about extensive differentiation of the marine life of the Permo-Carboniferous period. The primary Pacific Rockyan geosyncline, bordering the Laurasian continent on the north was already in existence since Pre-Cambrian times; it differentiated during Caledonian orogeny. Besides this, we have some new types of marine basins. The central Tethyan geosyncline shallowing northwards against the Laurasian continent, gave rise to the north shelf sea and similar shallowing southward against the Gondwanaland brought about another, the south shelf sea. Finally, south of the Gondwanaland, the primary Pacific Andean Geosyncline which was already in existence since the Pre-Cambrian got further differentiated during later stages. The evolution of these marine basins of deposition alternating with continental masses had resulted in significant differentiation of life provinces. The northern shelf basin against the Laurasian massive developed a Zechstein facies frequently associated with dolomite, red shales, rock salt and gypsum and is characterised faunistically by the abundance of aberrant brachiopods. This facies is best developed in Western and Central Europe interruptedly, from Great Britain through Belgium, Germany, Poland to Donetz basin and south Russia. The southern shelf zone facing the Gondwanaland is characterised by Speckled Sandstone containing Eurydesma Fauna at the base of Productus Limestone as in the Salt Range, Central Himalaya, Burma, Indonesia, Australia, Madagascar, Brazil and Argentina. The main Tethyan geosyncline newly established since the Upper Carboniferous is characterised by Ammonoid and Fusuline faunas besides being rich in Brachiopods. These Tethyan Permian formations are now seen distributed from the Cordilleran regions of Guadaluppe and British Columbia in North America, the Peruvian and Colombian Andes of South America through south Europe, Armenia, Iran, Baluchistan, Afghanistan, Pamir, Tienshan to the Tarim basin. The Upper Productus Limestone series extends from the Salt Range, through Tibet-Central Himalayas (Chitichun facies), Burma, Timor to New Zealand. Branches of this Tethys are again seen extending into the Moscow Basin, Ural and Arctic Siberia, Dzungaria, Hwang Ho basin upto Japan, Ussuri and Kolyma. Such widespread development of the newly formed Tethys basin and its offshots with identical or closely related faunal suites is rather noteworthy and the probability exists that all the Permian formations of the Tethys basin were originally deposited in a series of closet basins in a limited region as that of Central Tibet, where it was flanked by the Laurasian continental mass of Karakoram-Tienshan ranges in the north and Gondwanaland of the Himalayan region in the south. The Uralian geosynclinal sheet was an integral part of the E-W trending Tethys in the region of the Kunlun Ranges. It was only in later geological periods, mainly during the Alpine crustal movements, that these Tethyan rock formations of the Tibetan region got differentiated and transported as sheets in a series of successive movements.

Permocarboniferous Glaciation

Before we pass on to the Triassic Palaeogeography, we may refer to the most prevalent concept of Permocarboniferous Ice Age.

Palaeogeographically, Gondwanaland is very interesting as it is considered to be the scene of a major glaciation during the Permocarboniferous period of the earth's history. This concept of widespread glaciation is based on the outcrops of a peculiar rock type the Tillite or Boulder Bed found extensively in all the Southern Continents. These outcrops of unassorted fine clays with scratched boulders and exhibiting deep grooving on the pavement are recorded in the basal formation of the Gondwana sequence: Itarare Tillite from Parana basin through Argentina to the Falkland Islands of South America; Owyka Tillite from Uganda and Angola through Katanga; Rhodesia to South Africa; Madagascar; Talchir Boulder Bed from Himalayan foot-hills to the Godavari valley of Peninsular India; Lochinwar Boulder Bed from South Australia, Queensland, N.S.W. Tasmania in the Australian region and again in the Horlick region of Trans-Antarctic Range in Antarctica.

Such widespread development of this peculiar rock type often at several horizons of the Basal Gondwana Coal-bearing sequence has been attributed to the worldwide lowering of temperature, particularly near the South Polar latitudes. This was the source of inspiration for A.Wegener to postulate crowding of all Southern Continents round the South Pole then situated near South Africa and to their drifting apart during the later geological periods.

Our present studies show that the various Tillite formations are intimately associated with eruptive rocks as pavements carrying scratching, grooving, as irregular strialed boulders, also as unbedded Khaki coloured or variegated clays and muds. Further, they are seen distributed particularly along certain trend lines which are also the routes of migration of Gondwana rock sheets.

It is, therefore, most likely that these Tillites and Boulder beds along with the markings on pavement rocks are products of crushing along shear zones during lateral movements of rock sheets and as such may have nothing to do with glaciation. There is, therefore, no unequivocal proof that Permocarboniferous period witnessed any worldwide Glaciation (Refer to Pleistocene Glaciation later in this chapter).

The Triassic Palaeogeography

The general distribution of the Triassic rock formations of the world with their faunal characteristics was briefly described in an earlier chapter. They give us a generalised picture of the palaeogeographical distribution of land and sea and their interrelations. The general faunal and floral relationships indicate the existence of two land masses, each with its own floral association and separated by a continuous E-W trending inland sea the Tethys with its characteristic geosynclinal Ammonoid faunas. They are attended with Molluscan shelf sea faunas on either side. These Triassic conditions appear only as a continuation of those which existed in the Permian, both in the marine as well as continental facies. The continental Red Bed facies found associated with terrestrial as well as shelf deposits during the Permian are only accentuated during the Trias without any break. So do the geosynclinal Tethyan deposits exhibit a wider development of the Triassic deposits without any interruption, over the Permian sediments. The Permian and Triassic formations are largely conformable without any sharp boundary so as to constitute in many cases a single continuous Permo-Trias sequence. The floral association in the northern continent exhibits a gradual change from the Pecopteris to the Equisitites Flora, while that of the Gondwanaland changes from the Glossopteris to Taeniopteris-Thinnfeldia Flora. The inter-digitation of fluviatile and marine shelf facies in many European and American Triassic basins only shows the repeated encroachments of the Tethyan seas into the low level terrestrial basins.

The Laurasian continent, fragments of which are now found distributed over a vast region in northern hemisphere, was a compact land mass comprised of the Acadian Appalachian basins of North America, Greenland, Scandinavia, the Variscan basins of Europe, and the Karaganda, Kuznetsk and Angara basins of Siberia extending upto Mongolia and northern China. During the Mesozoic period the Laurasian continent, in its compact juxtaposed or even superposed condition, was situated in the northern part of Tibet in the region of Kunlun-Altyn Tag-Tsaidam north of the upper Yangtsekiang basin. The Eastern Continent of Cathaysia was a small land mass situated between the upper valleys of Yangtsekiang and Hwang Ho. The Southern Continent was comprised of the Gondwana Basins of Brazil, Argentina, Falkland Islands, Peninsular Africa, Madagascar, Peninsular India, Australia and Antarctica all in compact partly superposed condition. This land mass was of the size, slightly bigger than the Karroo basin of South Africa and was originally situated during the Mesozoic period in the Himalayan Tsangpo-Gangetic Basin extending up to the Mekong in the SE part of Tibet (Plate 22).

The Tethys of the Triassic period occupied a narrow strip along region of the Tanglha Range of Central Tibet separating the Northern and Southern Continents. Here it had developed a uniform Ammonoid rich deep sea fauna mixed with shallow water Molluscan elements, the latter dominating in the shelf basins on either side. It was here that the Alpine faunas of the Lower, Middle and Upper Trias were coexisting with the Himalayan-Malaysian faunas of corresponding ages, including the typical Alpine species like *Pteria contart.* These were later transported as part of rock sheets to Burma, Timor and other regions of the Malaysian province. In a like manner, typical Malaysian elements like *Pectan clingniatti* were transported to Iran and Arabia embedded in Triassic rock sheets during later sheet movements.

The Pacific Geosyncline representing the Rockyan Cordillera along with the Arctic developments from North America, northern Europe and Siberia during the Triassic period were originally closely juxtaposed formations constituting a belt bordering the Laurasian continents and situated in the region of the Tarim Basin extending east from the Pamirs to the Inner Mongolia. The Andean Geosyncline was closely girdling the Gondwanaland along its southern border and was situated in the region of Indo-Gangetic trough south of the Himalayas.

The Jurassic Palaeogeography

The distribution of the Jurassic rock formations, marine as well as terrestrial, on the earth's surface, as mentioned elsewhere, exhibits a pattern in which seven zones of closely-related faunal or floral provinces can be recognised.

The seven-fold zoning of the Jurassic world, almost symmetrically on either side of the Tethys with extensions in East-West direction, roughly simulates the latitudinal climatic zoning of the earth about the equator. There is, however, hardly any relationship between these two sets of zoning: Land floras which are most susceptible to climatic variations are, during the Jurassic period, quite uniform throughout from near the North Pole (North Arctic region) through the tropical regions to Grahamland near the South Pole. The Cycadophytes and Conifers which constitute the bulk of the Jurassic flora have their normal habitat in tropical temperate forests. Their uniform development over both the northern and southern continents would imply that both these continental masses jointly must have been largely confined within this climatic zone on the earth's surface, unless Jurassic types had widely different habitat from their modern representatives. Alternatively, the earth surface may have had no climatic zoning during the Jurassic period but this last possibility is not supported by geophysical considerations.

The climatic requirements of the Jurassic flora would be amply fulfilled if we assume that as in earlier geological periods, the continental masses were closely packed and even partly superposed and were situated in the Tibeto-Himalayan region during the Jurassic period as well. It may be noted in this connection that this Tibeto-Himalayan region has almost the largest areal development of the Jurassic rock formations. The faunal relations of these marine Tethyan deposits extend to most Jurassic formations developed even in distant parts of the world extending from the Rockies through the European and Alpine regions to Indonesia and New Zealand, on the southeast, and to Japan and Siberia on the northeast. The remains of Laurasian and Gondwana continental formations with their common floral types are already known from this Tibeto-Himalayan region to suggest the former existence of these continental masses in this part of the world, which could be their primary home.

From these considerations, it seems plausible that the northern continental masses in their condensed aggregated form were originally situated during the Jurassic period in the region of the Karakoram-Kunlun-Altyn Tag-Nanshan Ranges along the northern borders of the Tibetan plateau. Similarly, the southern continents of the Gondwanaland in their condensed form were situated during the same period along the southern borders of the Tibetan plateau in the region of the Himalayas. The Andean eogeosyncline was situated along the southern borders of the Himalayan-Gangetic Basin. The Tethyan geosyncline with the two shelf basins on either side was situated in the central Tibet in the source region of Tsangpo, Salween, Mekong and Yangtsekiang, separating the two continental masses of Laurasia and Gondwanaland. This appears to be the palaeogeographical condition of the earth during the Jurassic period. It is in this Tibeto-Himalayan-Central Asian position, within a single climatic zone, that the Jurassic continental flora flourished uniformly over the two continental masses. It was again here, in the Tibetan geosyncline, that the Tethyan faunas of the European Alpine regions and those of the East Asia and Australasia developed jointly with many common forms both in the deep geosynclinal and shallow shelf facies.

The northern Tethyan shelf zone also developed boreal elements which periodically mingled with those of the North Pacific (Cordill. geosynclines). These elements are regarded as Arctic in habitat, though, except for their present Arctic location. they have hardly anything typically Arctic about them. Apparently, they were developed during the differential lateral movements of individual Variscan horsts so that in the intervening channels, the Tethyan shelf zones were periodically in communication with the Rocky Geosyncline along the northern side of the Laurasian continent.

The Southern continent, Gondwanaland, appears to have been partly breached, while still in Tibeto-Himalayan position, by Tethyan indentations along the rifts of Tsangpo, Salween and Mekong to give rise to marine channels between these juxtaposed land masses which later developed into three independent Gondwana basins, viz. (a) Karroo-Parana, (b) Madagascar-Westralia, and (c) Queensland-Tasmania. The marine embayments later developed in (1) Cutch-Baluchistan-Ethiopian basin and (2) Westralian basin which with lagoonal intercalations, extended into the Eyre-Murry depression, all still occupying the region of the Indian subcontinent.

The Cretaceous Palaeogeography

During the Lower Cretaceous period, there were hardly any significant palaeogeographical changes over those which obtained in the Upper Jurassic. The "Boreal" and Tethyan basins of the Jurassic continued uninterrupted into the Lower Cretaceous in the Northern Hemisphere periodically, intermingling through advances of one over the other as during the Jurassic Period. The "Boreal sea" which was developing as a shelf zone on the side of the Laurasian continent recorded stages of successive lateral shifts of the Rockyan Eugeosynclinal basin away from the continental mass towards the open Pacific Ocean, thus widening the northern shelf zone as seen represented by "Boreal facies" in North America, Arctic Islands, Greenland, Spitzbergen, Russian Volga basin, Novaya Zemlya, Taimyr and the Lena Basin. This "Boreal" development is also met with in Mexico, California and in the Mackenzie-Saskachewan basins. These movements are again recorded in the Mongolian-Tarim basins involving the Altai-Tienshan Ranges and those of Kolyma, Sakhalin, Japan, etc. The southern continental masses were also suffering similar lateral movements already initiated during the Jurassic. The Ethiopian shelf basin, now widened into the Uitenhage basin, extended upto the Antarctic basin. These movements were engineered and facilitated by the Rajmahal Drakensberg Parana Ferrara series of eruptives culminating later into the Deccan-Patagonian Traps. The Westralian Gulf from the Tethys also widened to separate the Queensland Tasmanian Gondwana basin from the Madagascar-Westralian Gondwana Basin. The Tethys geosyncline during Lower Cretaceous exhibits a deep sea facies in a few portions where it is dominated by the Ammonites *(Phylloceras, Lytoceras, Belemnites, Belemnopsis, Duvalia etc.)*. It has, however, shallowed in a large number of basins where it is characterised by neritic facies with Orbitolina, Nerinia etc.

The flora of the Lower Cretaceous continental basins is remarkably uniform in both the northern and southern continental masses as typified by the Wealden Flora. This flora includes essentially Ferns and Gymnosperms and is developed in S. England, in Bohemia (Perucer Series) etc. This Wealden type flora with subordinate content of newly evolved Angiosperms is found in the Atlantic coastal belt of North America, where it is known as Potomac Flora. The same flora is met with in Alberta, Greenland, Sakhalin, Ussuri etc. Thus, before the end of the Lower Cretaceous Period, development of many identical genera and species took place over wide areas in the Northern Hemisphere now occupying higher latitudes.

In the Southern Continental regions also, we have the same Wealden type flora often with identical species as in Cutch, Uitenhage (in SE. Africa), Grahamland, Queensland etc. but with a general paucity of Angiosperms. Early Angiosperms, however, have been recorded from Lower Cretaceous formations in Barmer (Rajasthan), Madagascar, Peru, Patagonia etc.

These records indicate a general uniformity in the Lower Cretaceous floras in continental basins of both the northern and southern hemispheres. This uniformity extending from high latitudes in Northern Hemisphere to high latitudes of Southern Hemisphere and from the Pacific coast on the west to the Pacific coast on the east, covering all climatic belts of the earth, can only be explained on the basis of close juxtaposition of all continental masses of the north and the south and accommodated within a single climatic belt in lower latitudes of the earth during the period of their deposition and their later dispersal as sheets to higher latitudes. On these indications, it looks most plausible that in the Lower Cretaceous, the northern continental masses were aggregated together to form a chain of horsts as part of the Tienshan, AltynTag-Nanshan Ranges along the northern border of the Tibetan Basin. The Rockyan Cordilleran basin stretched E-W south of the line joining Aral Sea, Balkash and Baikal lakes and separated from the Laurasian continental masses by an intervening shallow 'Boreal' Volgan sea (Plate 23).

The Gondwana continental masses of (a) Karroo (with Parana and central and south African and the Indian Gondwana Belts), (b) Madagascar-West Australian-Gondwana belts and (c) Queensland-Tasmanian-Gondwana Belts were situated along the southern margin of the Tibetan Plateau in the region of the northern Indo-Gangetic Basin. The whole of the intervening Tibetan Basin was occupied by the Tethyan geosyncline and its shelf zones on either side. The South Pacific Andean Geosyncline was stretching along the southern margins of the Gangetic Basin.

UPPER CRETACEOUS

More or less the same palaeogeographical conditions prevailed during the Upper Cretaceous period also, except that the Cenomanian transgression, heralded among others by early Plateau Basalt activity, had obliterated the separate existence of the northern "Boreal" sea whereas the widening of the shelf seas of the southern hemisphere had brought about the merger of the Uitenhage and other shelf basins with the Andean geosyncline into a single continuous Indo-Pacific Faunal Province extending southward right upto the Antarctic Gondwana land mass. Remains of this Indo-Pacific faunal province are recognisable upto California, British Columbia and Queen Charlotte Basin on the Pacific coast of North America on the west and upto Japan, Ussuri, Sakhalin on the east. The widespread Plateau Basalt activity of this period also brought about extensive fragmentation of northern and southern supercontinents into a number of smaller independent continental masses which started migrating widely under the influence of later flood basalts carrying with them rock formations containing most of the modern looking Angiosperm fossil forms.

Appearance of Angiosperms

The sudden appearance of the Angiosperms during the Lower Cretaceous in association with Ferns and Gymnosperms of the Mesozoic period first as a subsidiary constituent of the Lower Cretaceous flora and then soon dominating the whole flora during the Upper Cretaceous is indicative of significant changes in the physical and soil conditions which permitted the rapid evolution and extensive dispersal of the floral types. Angiosperms appear simultaneously in widely separated areas with Lower Cretaceous terrestrial formations in different parts of the world, irrespective of intervening oceans. They are recorded from Western, Central and Eastern North America, West Greenland, Central and Western Europe and Siberia in the northern hemisphere and in Argentina, Patagonia, Grahamland (West Antarctica), Madagascar, Central India, Queensland etc. in the Southern Hemisphere. There are no obvious routes of floral migration across the intervening wide oceans.

Curiously, Angiosperms appear earliest in Greenland situated quite within the Arctic Circle though the present range of Angiosperms does not extend beyond the low temperate zones. The geographical distribution of the Cretaceous Angiospermous Flora raises problems whether the early Angiosperms had Arctic habitat, only adapting to tropical climates in later ages, or whether the Cretaceous terrestrial basins with Angiosperms were originally situated in the Tropical climatic belt but later migrated as rock sheets to Arctic regions. This Cretaceous Angiospermous Flora consisting of about half a dozen leaf genera and of as many wood types are commonly met with in all Cretacous terrestrial occurrences, irrespective of the climatic zones. Since plants are highly susceptible to climatic variations, they could not have originated in such widely diverse climatic belts. It is, therefore, highly probable that these Angiosperm types must have all originated and evolved in a single belt or a system of interconnected belts, all confined to a single climatic zone and that portions of these terrestrial basins might have been transported through a process of sheet movements to distant regions in diverse climatic zones. As we have seen, most indications suggest that the Mesozoic continental masses must have been situated close-spaced in the Tibetan region, all accommodated within a single zone of tropical temperate climate. It is from that Tibetan homeland that under the influence of Plateau Basalt floods, continental sheets with uniform floral types were transported to distant regions now seen spread over different climatic belts of the earth.

The extensive trappean terrain laid bare during the sheet movements due to Plateau Basalt activity in the post-Cretaceous period must have offered virgin soil conditions for the growth and rapid dispersal of the newly-evolved Angiospermous flora almost in all continental masses.

The Lower Tertiary Palaegeography

During the closing stages of the Cretaceous period, the northern continental masses were all closely juxtaposed to constitute the Mesozoic Supercontinent of Laurasia all situated along the northern flanks of the Tibetan geosynclinal basin with numerous embayments of the Tethys. Similarly, all the southern continental masses with their Tethyan embayments were closely juxtaposed along the Himalayan flanks; south of the upper Indus-Tsangpo-Yangtse basins. The Cretaceous Tethys, now largely shallowed, was occupying a major part of the intervening Tibetan lake basin between the upper Hwang Ho and the Tsangpo with numerous indentations into the bordering continental masses. The Tertiary period begins in some places with the Palaeocene formations as transitional between the Cretaceous and the Eocene. The whole bed of the Tethyan basin was being uplifted above the sea level in the nature of folded ranges due to the onset of tremendous ophiolitic intrusions within the Tethyan geosyncline. This ophiolitic activity led to the development of an enormously thick flysch facies of mixed sediments associated with normal geosynclinal sediments. All of these got intricately infolded and overfolded, culminating in the formation of complex sheets of folded thrust belts. The continued flooding of basaltic magmas led to extensive lateral movements of these sheets in which even the cratonised horsts of earlier folding epochs got involved in the deep core regions as are witnessed in the Pennine cores of the Alpine folds (Plate 24).

The Palaeocene formations exhibit a vast diversity of lithological facies from deep sea to littoral and even to subaerial sedimentary types, but the shallow water facies mixed with eruptive material is the most common. As stated by E.H. Pascoe, "Palaeocene is one of the most restricted formations known and in a majority of continents is unrepresented." Yet it is recognised at a number of localities along the borders of the

Tethys and in the shelves associated with it. It is well represented in the Lhasa region of Tibet, Samana Range, Salt Range, Sind, Sakotra, Aden, Somalia. Libya, Egypt, Caucasus. Crimea, Turkey, Eastern Urals, Volga basin, Balkan Peninsula, Sahara, Morocco, Pyrenees, Belgium, Denmark, Oregon, California, Mexico, Texas, New Jersey, Patagonia, etc. The faunal and floral relations of these widely scattered formations do suggest that these formations were all deposited in closely interconnected basins probably in the Central Asian-Tibeto-Himalayan region during the early phases of the Alpine orogeny.

During this period while the ophiolitic igneous activity was dominating the Tethyan sedimentary basin, the peripheral continental masses were experiencing extraordinary flooding of the Plateau Basalts. Among such flood eruptions are the Siberian Plateau Basalts in the northeast, the Thouleitic Plateau Basalts of the North Atlantic region extending into Central Europe, the Columbia-Colorado-Plateau Basalts of western North America, the Parana-Patagonia Plateau Basalts of South America, the Plateau Basalts of Abyssinia, the Deccan Plateau Basalts of India and the Queensland Plateau Basalts of the East and S.E. Australia covering large terrains in the now widely-separated continents. These Plateau Basalts through their intrusive sills and dikes brought about extensive sheeting and block faulting of the various continental masses whereas the voluminous lava flows displaced these sheeted blocks, transporting them laterally in stages to enormous distances. The combined activity of the Ophiolites in the Tethyan geosyncline and of Plateau basalts within the continental regions brought about fragmentation of the Laurasian and Gondwana supercontinental masses and of orogenic arcs into a number of ranges which got extended en echelon.

Some of these continental and orogenic, fragmented units suffered marked rotational movements round certain pivotal knots under the influence of subcrustal magmas. Among such knots which served as pivots are: (1) The Nanga Parbat (8124 m) in the Indus syntaxial bend, (2) Namcha Barwa (7756 m) in the Brahmaputra syntaxial bends round Mynya Konka (7590 m) in Szechwan, China, (4) the Pamir Plateau (7559 m) in the source region of the Amu and Syr Darya. These four pivotal points in the four corners of Tibet led to the divergent radial movements of continental sheet blocks together with associated orogenic belts, thus permitting expansion of the continent in all the four directions. The Andean Orogenic Arc associated with the Guiana and Parana (Karroo) continental basins while still situated along the Gangetic Axis, suffered clockwise angular movement successively round the syntaxial bends of the Jammu, Sutlej, Jhelum and the Indus around the Nanga Parbat Pivot. These movements started in the Palaeocene and continued during the whole Tertiary and led to the partial evolution of Iran, Arabia, Africa and South America while still superposed in the Indo-Afghan region. During these movements, the Guiana mass as a constituent part of the Sulaiman-Kirthar Sheet Complex rotated clockwise in the Helmand-Hari-Rud Basin due mainly to the continued Indus syntaxial movements. The Karroo Parana Sheet packet rotated clockwise successively through the basins of the Ganges, Mahanadi, Godavari and the Krishna and later, mainly anti-clockwise, through the Zambezi, Limpopo and Orange Basins. During these movements, Peninsular Africa was evolving, taking its shape partly on the substratum of the Indian Peninsular Shield and partly in the region of the South Arabian Sea.

During this period the Antarctic Australian continental masses; then in a compact superposed condition, were part of the Tibeto-Himalayan mass in the southern part of Tibet. They suffered anti-clockwise rotation through the basins of the Brahmaputra, Irrawaddy, Salween and the Mekong and came to occupy the region extending from the Bay of Bengal to Indo-China. Here they were now juxtaposed with the newly-evolving continental mass of Indo-Africa along the Coromondel coast of Peninsular India.

In the northeast region, the East Asiatic, Chinese and Altai Ranges in their compact superposed condition were parts of Kunlun-Tanglha ranges in the source region of Yangtsekiang. They suffered clockwise rotational movements to occupy for a time the region of Central China south of the Hwang Ho basin.

In the northern and northwestern parts of Tibet near the Tarim basin, the continental masses of Western Laurasia such as the Appalachian Variscan Horsts with their associated folded belts of the Rockies, Arctic Island, Scandinavia and Ural were this time situated in closely juxtaposed and partly superposed condition over the northern fringe of the Tibetan Plateau. They were shifted from the Kunlun to the Tienshan position through the Tarim movements. Later leaving Tienshan behind, the Ural structure rotated anti-clockwise to beyond the Balkish Lake through Ito-Chu and Syr Darya series of movements.

In the Tethyan sector of central Tibet, the Alpine and the Carpathian fold belts together with the Mexican Antillean folded arcs which were originally situated in the Kashmir-Pamir-Afghan region were being shifted westward along the Helmand, Harirud and Amu Darya to the region of Turkmen-Kopet Dag-Eastern Persia as linkages between the Appalachian-Variscan structures of Laurasia, on the north and Guiana structures of the Gondwana continent on the south.

By the end of the Lower Tertiary, the Mexican and Alpine orogenic Arcs were still confined to the region between the Pamir Plateau and the Caspian Sea, and the Tethys Sea was completely banished from the Tibeto-Himalayan region leaving its traces in the nature of Central Tibetan salt lakes. The Laurasian continental masses, still largely juxtaposed and interlinked, occupied the major portion of N.W. China and Siberia, whereas the Gondwanaland masses occurred partly superposed over India and Indo-China and partly spread southward into the northern regions of the Indian Ocean, roughly upto the Tropic of Capricorn.

The remaining surface of the earth was covered by the Pan Pacific Ocean.

The Upper Tertiary Palaeogeography

The Lower Tertiary continental Plateau Basalt activity in conjunction with the geosynclinal Ophiolitic activity led to the elevation and expansion of the continental crust in the region peripheral to the Tibeto-Himalayan basin so as to cover regions of central, southern and southeastern Asia. These igneous activities continued uninterruptedly during the Upper Tertiary as well and led to the further expansion of the various continental masses almost up to the border regions of the Asian continent, still largely contiguous among themselves. The Tethys was now completely banished from the Tibeto-Himalayan region but it continued as a shallow basin in the West Asian region between Persia and Aegian Sea and in the South East Asian region between Burma and Indonesia (Celebes) as also in East Asia in the region of northern China (Plate 25).

The continued alkaline igneous activity among the different Variscan massives traceable from Urals and Bohemia to the Central Massive of France and northern England, led to the further breaking and differentiation of the Central European continental sheets still resting on central Asian basement permitting a further radial anti-clockwise movement of the Appalachian-Variscan continental masses, simultaneously with the westward movement of the Alpine orogenic arcs in the East Mediterranean region. The sheet packet consisting of Mexican Gulf Arcs, Carpathian Arcs, Armenian Arcs, originally resting over the Pamir Plateau upto Lower Tertiary now shifted westward through Iran to the Armenian Plateau during the upper Tertiary. The Tethys with Alpine Arcs now shifted westward to the position of Pontian and Taurus folded belts of the Turkish Peninsula.

Eastward from the Himalayas, one branch of the Tethys extended southeast to Burma and Malaysia along the route of Irrawaddy and Salween. The second branch shifted along the Mekong route to Borneo, Philippines and New Guinea. A third branch of the Tethys moved east and NE along the route of R. Sikiang and Yangtsekiang to the eastern border of China against the East China Sea.

The Southern Continent of Gondwanaland which was largely confined during the Lower Tertiary to the region of Indian subcontinent extending from Persia on the NW to Indochina on the southeast, expanded further during the Upper Tertiary to occupy the region extending from Turkey on the west to Philippines and Celebes on the southeast and southward to the Amsterdam submarine plateau near 40° south latitude. By the end of Upper Tertiary, the various constituent land masses of the Gondwanaland in South America, Africa, India, Australia and Antarctica had attained their full shape and size though some of them were in partly superposed and partly juxtaposed condition with the other constituent continents. Thus, though the African and South American continents could be recognised with their present shape and size, the South American continent was, for the most part, superposed over the African basement. Part of Africa, east of the Rift valley, was superposed over the Indian Peninsula, thus bringing about the continuity of the Arabo-Eritrian Plateau Basalts with the Deccan Traps. Part of Australia was possibly still resting on the Antarctic basement when the latter was occupying the position of the Cocos Keeling Basin of the Indian Ocean east of Chagos whereas the major part of the Australian Continental mass was occupying the position of Indonesia north of the Sunda Trench.

In the case of Laurasian continental masses, the shape and size of the various constituent land masses cannot be recognised until towards the end of Pleistocene. The North American continent, during the Upper Tertiary, was in the nature of an elongated Rocky Cordilleran Belt with large portions superposed over the Appalachian-Acadian and Greenlandian substructure and situated in the region of Siberia north of the Aral-Baikal line in the source region of the Ob-Yenisey system of rivers.

The continental crust of the earth as evolved during the Lower and the Upper Tertiary was essentially in the nature of an enlarged binary land mass breached by a prominent east-west Mediterranean shallow sea, encroaching in many places over the continental masses on either side in the nature of gulfs and shallow shelf seas. This binary land mass of the Upper Tertiary was largely confined to the region of the Asian continent extending from the Aeegian Sea on the west to Philippines in the east and from Siberian-

Taymyr Peninsula on the north to St. Paul-Amsterdam Plateau of the Indian Ocean on the south. The Indian and the Atlantic Oceans were still nonexistent while the Mediterranean Sea separating the Laurasian and Gondwana Lands was straggling as a narrow elongated shallow basin between Turkey and China. The two supercontinents were thus nearly juxtaposed on either side of the Alpine Himalayan fold belt.

The Laurasian land mass during the Upper Tertiary was largely in the nature of a compact packet of superposed sheets constituted of the Appalachian-Acadian sheets at the base and the Rockyan Alaskan sheets at the top occurring closely juxtaposed with the Variscan Uralian sheets of Europe in the region of the Kirgiz-Kazakh-Altai-Yablonovyy ranges.

Among the Gondwana Continents, the South American continental sheet was superposed over the African continental mass and both were contiguous with the Indian peninsular mass such that the Kenya Somalia Horn of East Africa was superposed over the peninsular India. The East Antarctic continental mass was juxtaposed with the Natal coast of Peninsular Africa in the region of Kergualen-Amsterdam Plateau along the Mid-Indian Ridge while the West Antarctic peninsular Arc was hooked up round the Cape Folds of South Africa, together with the Tierra del Fuigo folds of South America in the region of Crozet Is. The Australian continental sheet was in the region of Timor-Arafura Sea closely juxtaposed with E.Antarctica, then in the region of the Diamantina Fracture Zone. The Japanese Island Arc had reached almost its present position where it was linked with the Kamchatka mass then in the region of Sikhote Alin-Sakhalin mass. The Kolyma Peninsular mass was still superposed over Yablonovyy-Stanovoi mountain belt south of the Aldan Lena Basin.

The marine life of the Upper Tertiary is characterised by the extinction of the *Nummulites* while the *Lepidocyclines* persisted in deeper geosyncline until the Miocene times. The shelf facies were characterised by Mollusces and Echinoids which survived in the Indo-Pacific Seas and in the Caribbean Mexican Gulf parts of the Tethyan Basin.

Among the land faunas Mammals in their highly diversified families dominated the land fauna while equally diversified Angiosperms dominated the land flora.

The Quaternary Palaeogeography

The Palaeogeography of the continental crust at the end of the Tertiary period was that of the old world, compressed and compact, covering an area of about 85 million sq.km. while the remaining 425 m. sq.km of the earth's surface was occupied by one continuous Pan Pacific Ocean. The Indian, the Atlantic and the Arctic oceans did not have their separate identity as yet as the two American continental masses were integral parts of the old world while the Antarctic mass was also closely juxtaposed and sandwiched between the Afro-South American mass on the west and the Australasian mass on the east in the region of St.Paul-Amsterdam Plateau. The continental crust thus constituted almost an enlarged Pangae situated in the region of the Afro-Eurasian supercontinent.

The widespread volcanism of the Quaternary period brought about drastic changes in the disposition of the continental masses. The outburst of the subcrustal magmas brought about differential upheaval of portions of continental crust and their extensive migration laterally in successive stages away from the Asian mass towards and encroaching over the peripheral Pacific Basins (Plate 114).

The Afro-South American joint land mass moved westward from the Tertiary continent of Asia with the evolution of rifts represented successively by the Gulf of Cambay, the Persian Gulf, the Arabian sea, the Aden-Red Sea couple and the Mediterranean Sea. The successive positions of the Afro-American continent during its westward migration are represented by the submarine ridges of (a) the Laccadive-Maldive-Chagos, (b) the Sacotra-Chagos, (c) the Seychelles-Mauritius, and (d) the Aldabra-Madagascar Ridges. The Antarctic continental mass moved southward from the positions of Amsterdam-St.Paul Plateau through the Karguelen-Gaussberg ridge to its present position at the South Pole. At this very time Australia moved southeast from the position of the Timor Arafura Sea to its present position. These movements gave rise to the formation of Sunda trench. Owing to these lateral movements of the southern continents the Indian Ocean came into existence largely during the early Quaternary period. During this period the South American continental sheet had taken its present shape as a superstructure over the African platform. The Guiana shield with Colombian-Venezuelan Andes belt closely surrounding it, was moving west over the Sahara platform, through the positions of Egypt, Libya, Algeria, Morocco and Mauritania thus enlarging not only the South American continental plate but also part of its African basement platform in E-W direction. The Atlas-Alpine chains with N. Andean folded belts closely associated, also suffered echelon movements westward from their Turkish basement through the positions of Cyprus, Crete, Malta-Atlas-Balearic Island Arcs to Betic Andalusian Arcs in the west Mediterranean region. The Southern and Central European sheets as integral parts of the Mexican and Appalachian belts also suffered simultaneous westward movements from the Black sea-Caucasus region thus bringing about the westward expansion of the European continental mass in the region of the Mediterranean sea during the Quaternary period. These trends are recorded by the Danube, the Rhone and the Rhine system of rivers and further west by the Loire and the Ebro.

North America in a condensed form during the Upper Tertiary was an integral part of Europe. During the Lower Quaternary the Mexican structure of the North American Cordillera moved from the Aegean Sea to the Gibraltar position. It was at this stage that the North American continental mass suffered fan-wise expansion to its present shape and size. The New England element was tied with Norwegian Caledonises while the Appalachian belt was tied with the Armorican Variscan Horst system of western Europe and Great Britain. The Cordilleran fold belt of N. America which, up to the Upper Tertiary period, was largely superposed over the Appalachian Acadian system, later got freed from its Appalachian basement through Quaternary volcanism and started moving westward partly attended by anti-clockwise rotation with the pivot in the Mexican Gulf (Campeche) region, then in the West Mediterranean position. The Cordilleran Alaskan belt, which during the Upper Tertiary, was situated in the Kara sea-Russian platform region, moved together with its Greenland substructure to the Spitzbergen-Norwegian position during early Quaternary period with the development of the Baltic sea. Leaving the Spitzbergen-Norwegian basement structures behind, the Alaskan sheet moved successively to the positions of Greenland, Arctic Islands; North West Territory of Canada and finally to its present position west of the Mackenzie river. These movements which are recorded by the Mississippi River system also brought about the exposure of the Canadian Granitic shield, and the successive formation of the Great Lakes—Ontario, Erie-Huron, Michigan and Superior—and also of the Hudson Bay all during the Pleistocene period (Plate 22, 23). During the Post Pleistocene period the two continental masses of the North and South America got snapped from the grip of the Euro-African Alphine Atlas folds through the evolution of the Caribbean Central American structural moassic. Later, they could move westward more freely through the repeated expansion of the Atlantic rift system as recorded in the development of Walvis, Cape Verde, Mid-Atlantic Ridge and other submarine features in the intervening region. The Atlantic Ocean, thus, appears to have come into existence on the earth's surface mostly in the Upper Quaternary-Recent Period as shown by the extensive Thouleitic submarine volcanism in the Atlantic region. (Plate 23, 24, 25).

The Kolyma peninsular land mass which was earlier juxtaposed with the Alaskan sheet in the Altai-Baikal region also moved north and northeast successively through the positions of the lower Lena, Yana, Indigirka, Kolyma and Anadyr, while the Kamchatka sheet moved northeast through the positions of Sikhota-Alin and Sakhalin and later along the route of the Kurile Island Arc giving rise to the enclosed Sea of Okhotsk. During the recent geological period, the CircumPacific and Intra-Pacific volcanism brought about the emergence of numerous island arcs of Mariana Carolina, Melanesia, Micronesia and Polynesia, possibly foreshadowing the emergence of a new continent in the region of the Darwin Rise in the west Pacific Ocean.

Pleistocene "Glaciation"

It may be mentioned before we close that some of the stages of sheet movements during the Quaternary period refer to Circum-Arctic regions which, as it is at present believed, have undergone extensive glaciation during the Pleistocene period. The widespread loose unconsolidated material found distributed as irregular sinuous linear piles of fine clays strewn with boulders, often of enormous size, are thought to represent morainic materials left behind by the retreating glaciers during the successive epochs of glaciation. The area covered by these deposits is of continental size extending from the North Polar regions far into the temperate zones of lower latitudes in both the eastern and the western hemispheres. It is presumed that these regions of the earth were covered by vast continental glaciers during the Pleistocene period formed due to the general lowering of atmospheric temperatures, the cause of which is not clearly comprehended. This entailed the introduction of numerous postulates of wide-reaching implications. These have not been fully substantiated, nor is the capacity of the glaciers for such large-scale erosion of hard rocks tested, particularly in continental terrains where glaciers move with extremely low velocity along almost horizontal plains and where their erosional capacity is therefore minimal.

It has to be noted that the movement of one rock sheet over the other also causes crushing and pulverisation, scratching and grooving of associated rock formations along the plane of movement, thus producing all features which are being attributed to glaciation. It is, however, quite plausible that the moraine-like material found in the Circum-Arctic region is actually produced during the movement of Alaskan Cordilleran rock Sheet over the north Siberian basement and of New England-Acadian structural sheet over the Scandinavian sheet of Europe which took place during the same Pleistocene period as noted above. There is then no necessity of invoking glaciation along with i tendent postulates for the formation of loose unconsolidated moraine-like ma found scattered over this vast region, nor for all the scratching, grooving and pener structural features found over extensive areas of different continents.

EPILOGUE

In the previous pages, an attempt has been made to study the geological history of the land masses taking into account the various physical, geological and structural features bringing out the significance of each of these and trying to ascertain the process of evolution of most of the surface features of the world. It has sought the study of the mountain belts, their courses and role in distribution of the surface features, particularly the phenomena of the syntaxial bends in the river courses and their role in the emplacement of the physical features. The geological history of the earth has been depicted in the stratigraphy, rock formations, faunal and floral contents and their interrelationships. The intimate faunal relations among rock formations developed far away in regions often separated by vast lands and oceans, the role of palaeo-climates, the position of the poles have all been utilized to interpret the geological history of the land masses. The study of lithology has also revealed that the value of certain formations as indicators of climate have been questioned and re-interpreted. These various lines of studies have permitted the reassessment of the processes of evolution and it has been realized that the geological history of the earth's crust would be better understood and explained on the basis of sheet movements through the activities of the sub-crustal magmas. The role of igneous activity in areas even of continental dimensions has been recognised and utilised to bring out large-scale movements of the crustal masses and it has been possible to work out the evolution of the crust systematically stage by stage from one of no exposed land (all oceans) to the present stage when the land masses occupy about one-third of the earth's surface. The problem of adequate forces and the space involved in the sheet development of the crust can be easily followed up and the real significance of each of the surface features of the earth can be more appropriately realised by this one single process, without introducing any unvarified postulates. The theory has been developed mainly on the study of geological and physical maps of the world. This study has formed the basis of the systematic development of the evolutionary processes. The data culled from literature on stratigraphy, geomorphology, geotectonics, faunas and floras etc. as could be readily available has been utilized in these studies. The results of these studies have often been astounding and often bewildering but a patient consideration of the theory will mark out as the only solution of the difficult problem. Certain phenomena are impossible to be explained otherwise.

This would lead to a better understanding of the problems involved in the processes invoked. It is requested that the students of earth sciences will bear with patience and bring out the truth from the maze of possibilities and help in the better understanding of the earth's evolutionary history.

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PLATE 1. GEOLOGICAL SKETCH MAP OF THE WORLD

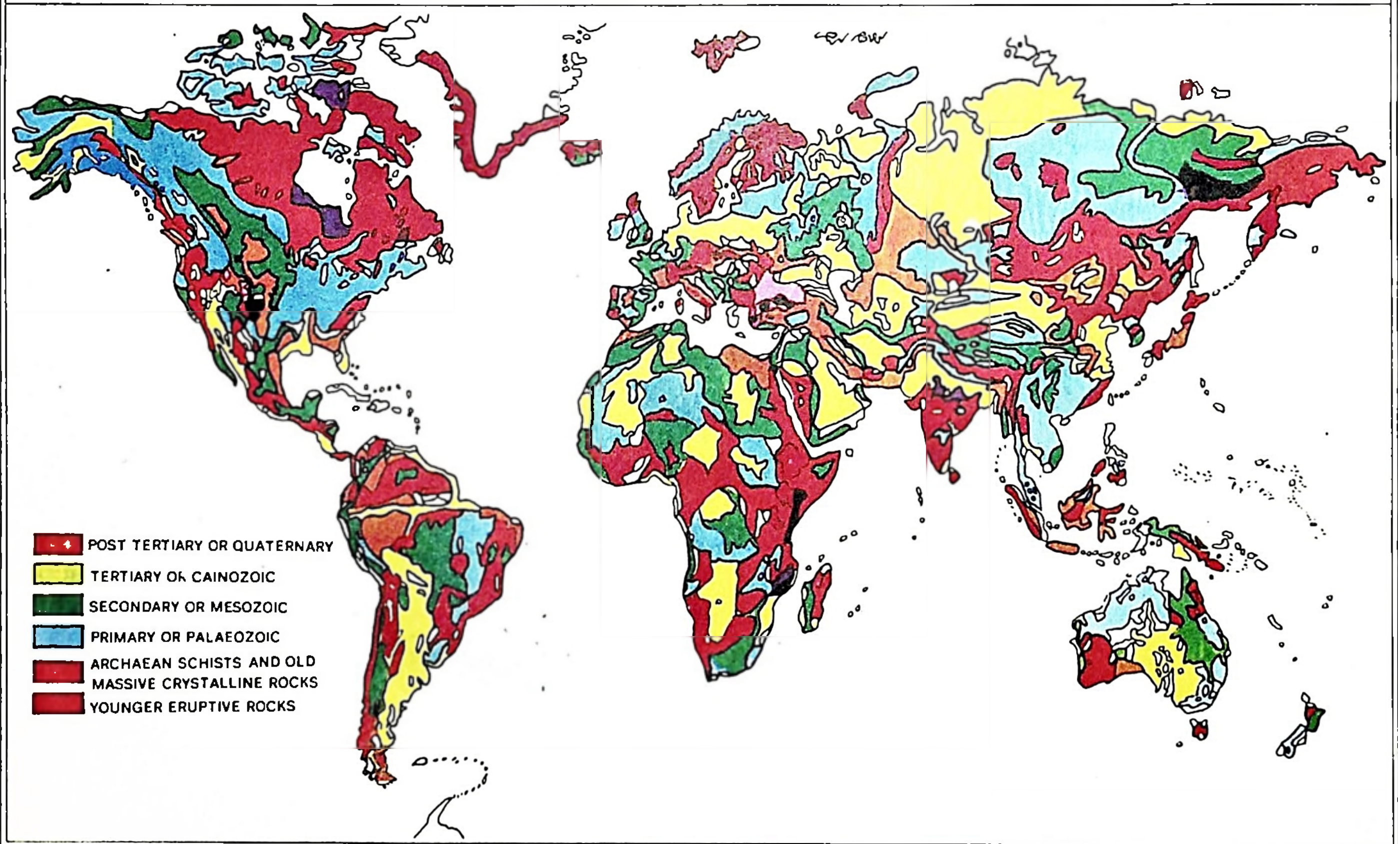


PLATE 2. EXOTIC BLOCKS OF MALLAJOHAR

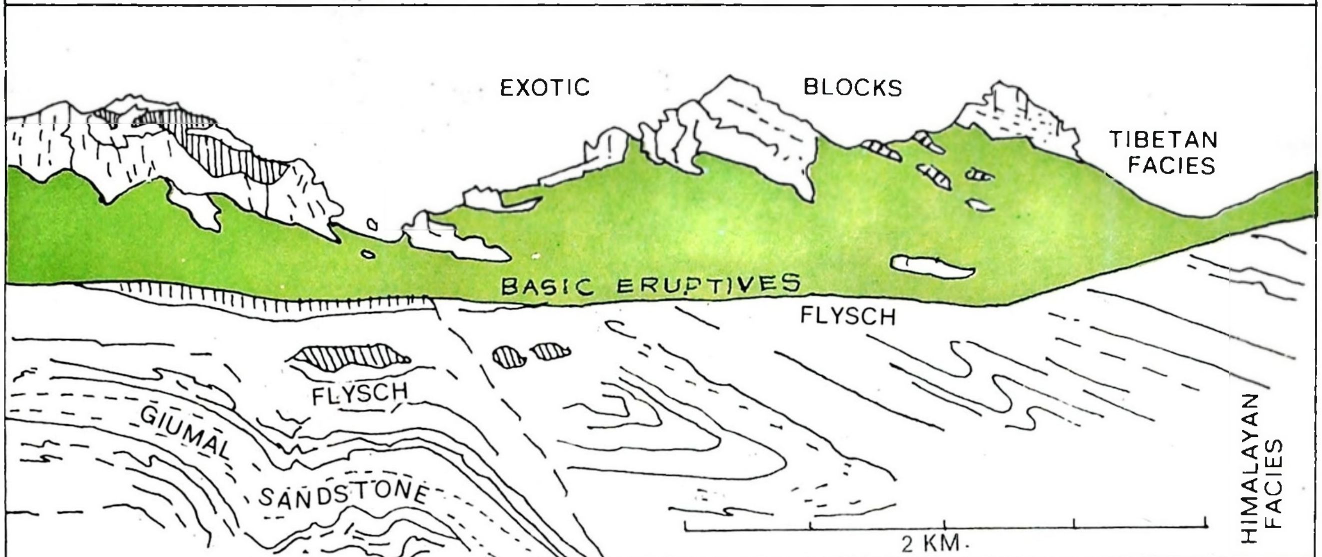
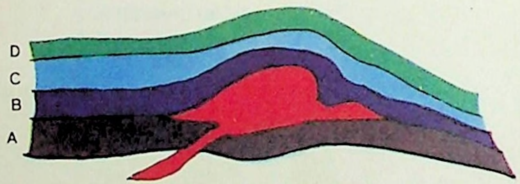
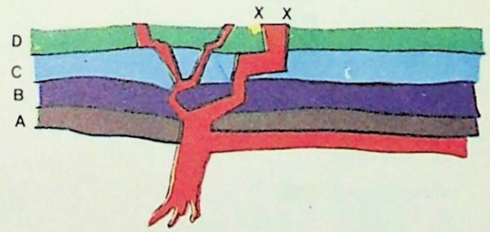


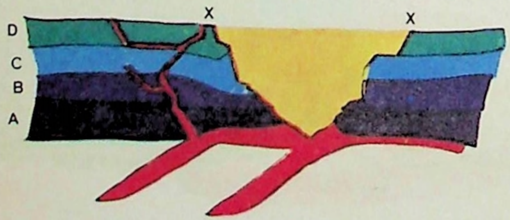
PLATE 3. SHEET MOVEMENTS THROUGH VOLCANISM



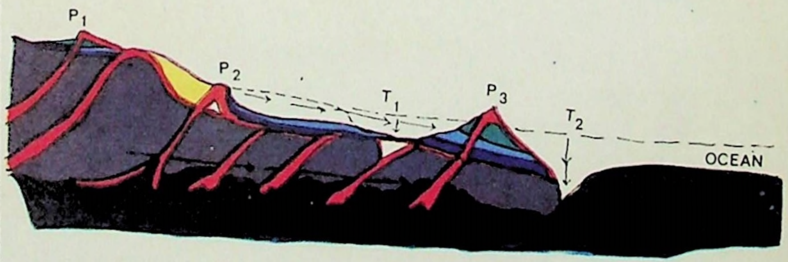
LACCOLITHIC INTRUSION INDUCED FOLDING IN THE UPPER LAYERS



DYKE-LIKE INTRUSIONS INDUCED BLOCK FORMATION IN THE UPPER LAYERS



SHIFTING OF ONE BLOCK AWAY FROM ANOTHER CAUSING VALLEY FORMATION INCLUDING TERRACING



SHIFTING OF OCEANIC TRENCHES AND ISLAND ARCS AWAY FROM THE MAINLAND INDUCING SIAL FORMATION OVER WIDE AREA OF THE OCEAN

PLATE 4. INDIAN GONDWANA BELTS IN SUPERPOSITION
(A) DHARWAR KRISHNA VALLEY

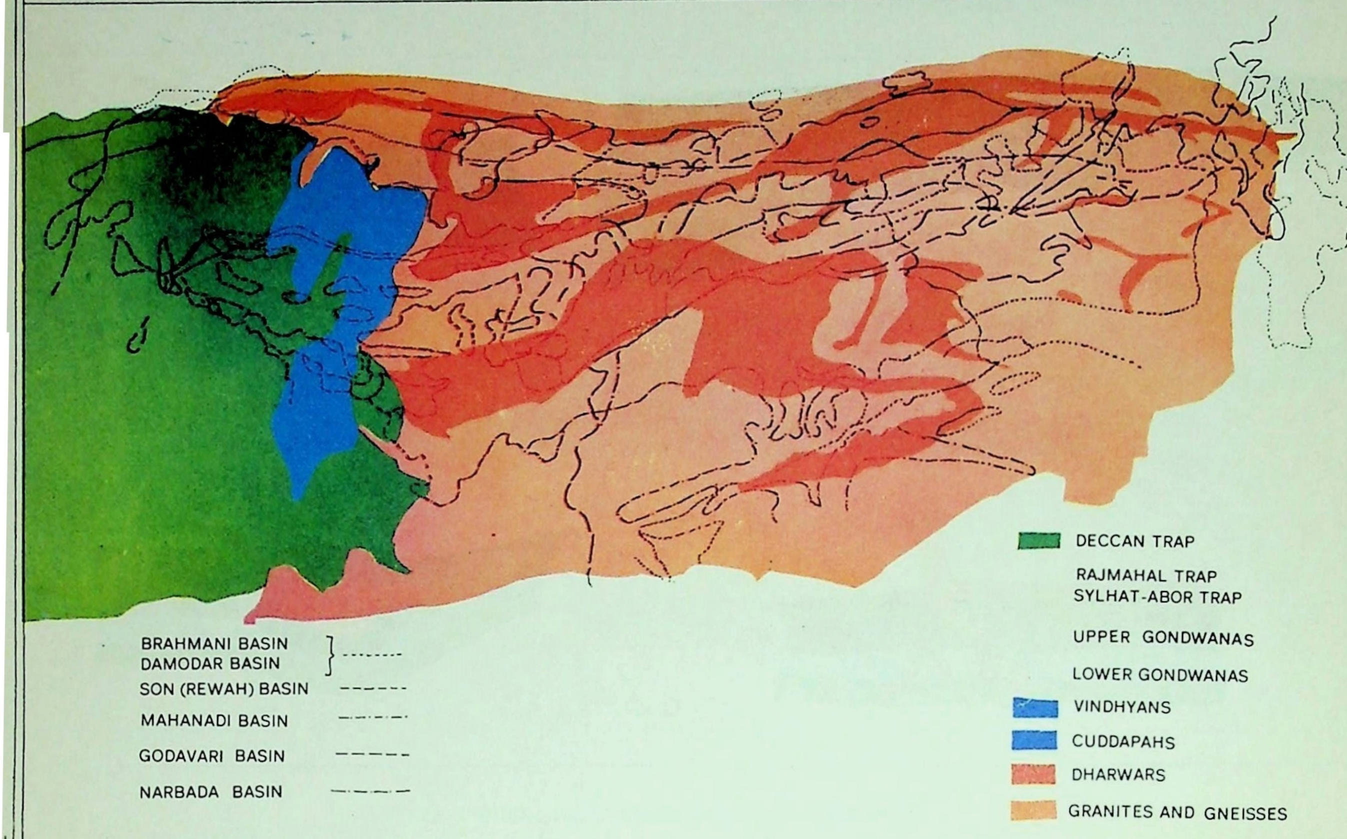
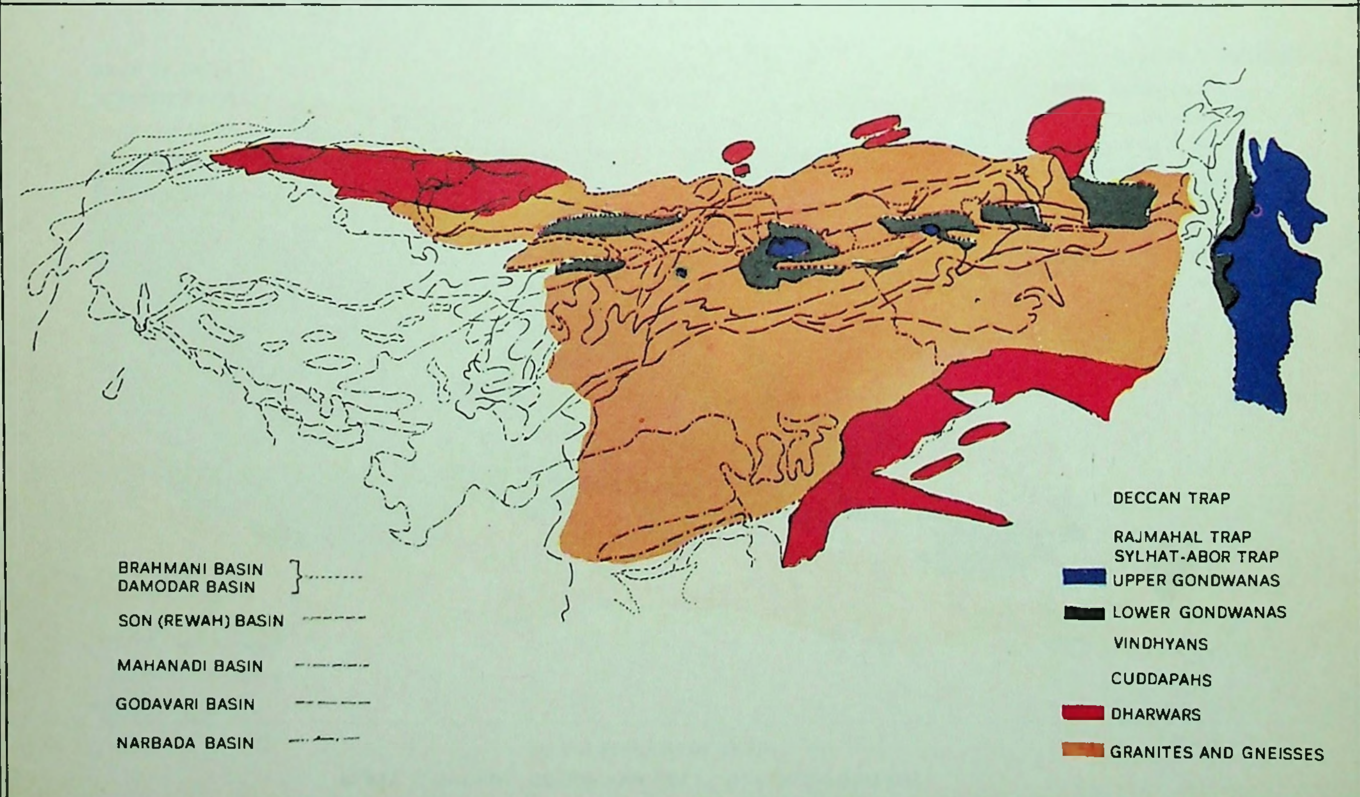


PLATE 5. INDIAN GONDWANA BELTS IN SUPERPOSITION
(B) DAMODAR BASIN



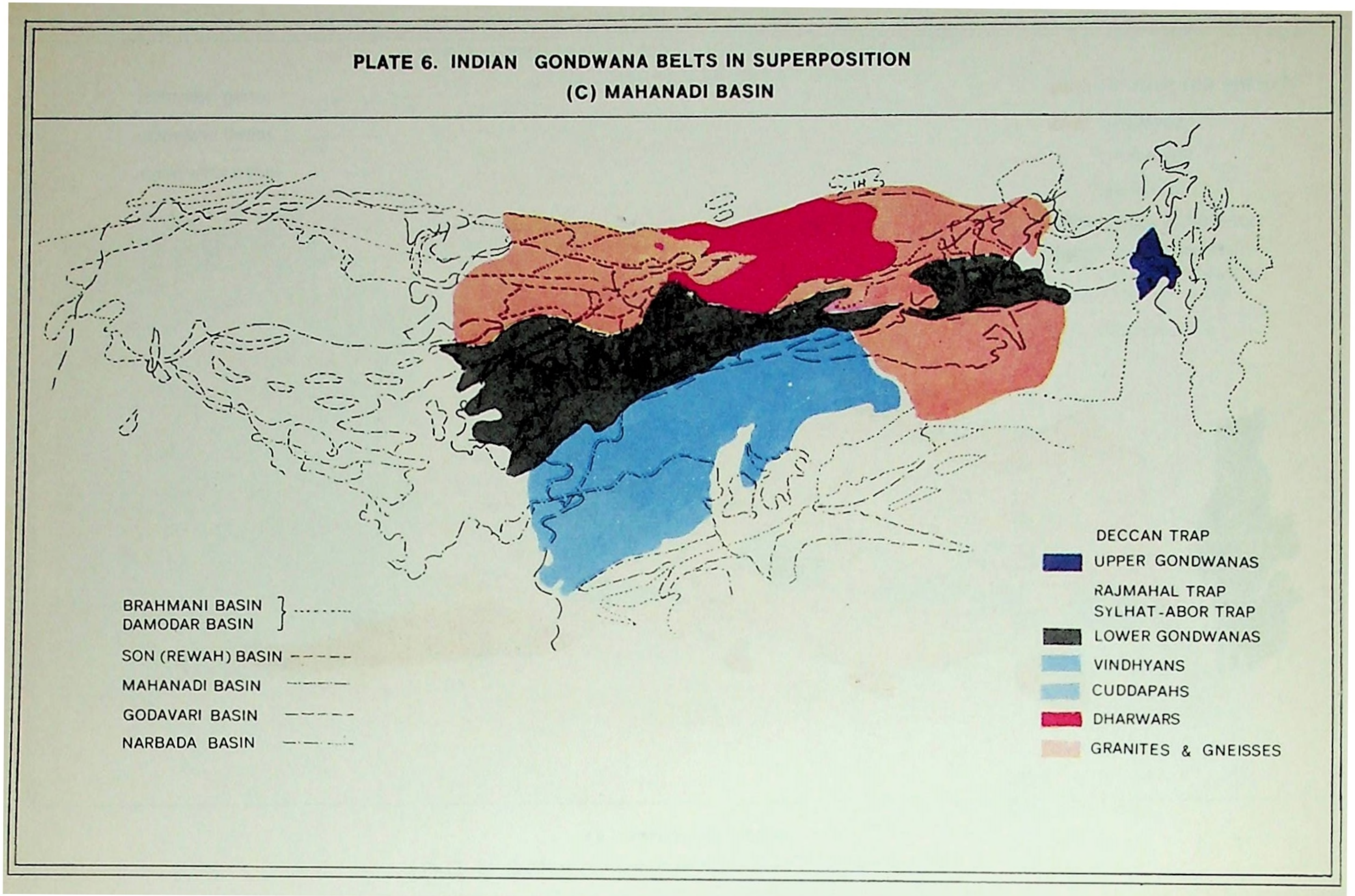


PLATE 6. INDIAN GONDWANA BELTS IN SUPERPOSITION
(C) MAHANADI BASIN
BRAHMANI BASIN
DAMODAR BASIN
SON (REWAH) BASIN
MAHANADI BASIN
GODAVARI BASIN
NARBADA BASIN
DECCAN TRAP
UPPER GONDWANAS
RAJMAHAL TRAP
SYLHAT-ABOR TRAP
LOWER GONDWANAS
VINDHYANS
CUDDAPAHS
DHARWARS
GRANITES & GNEISSES

PLATE 7. INDIAN GONDWANA BELTS IN SUPERPOSITION
(D) GODAVARI BASIN

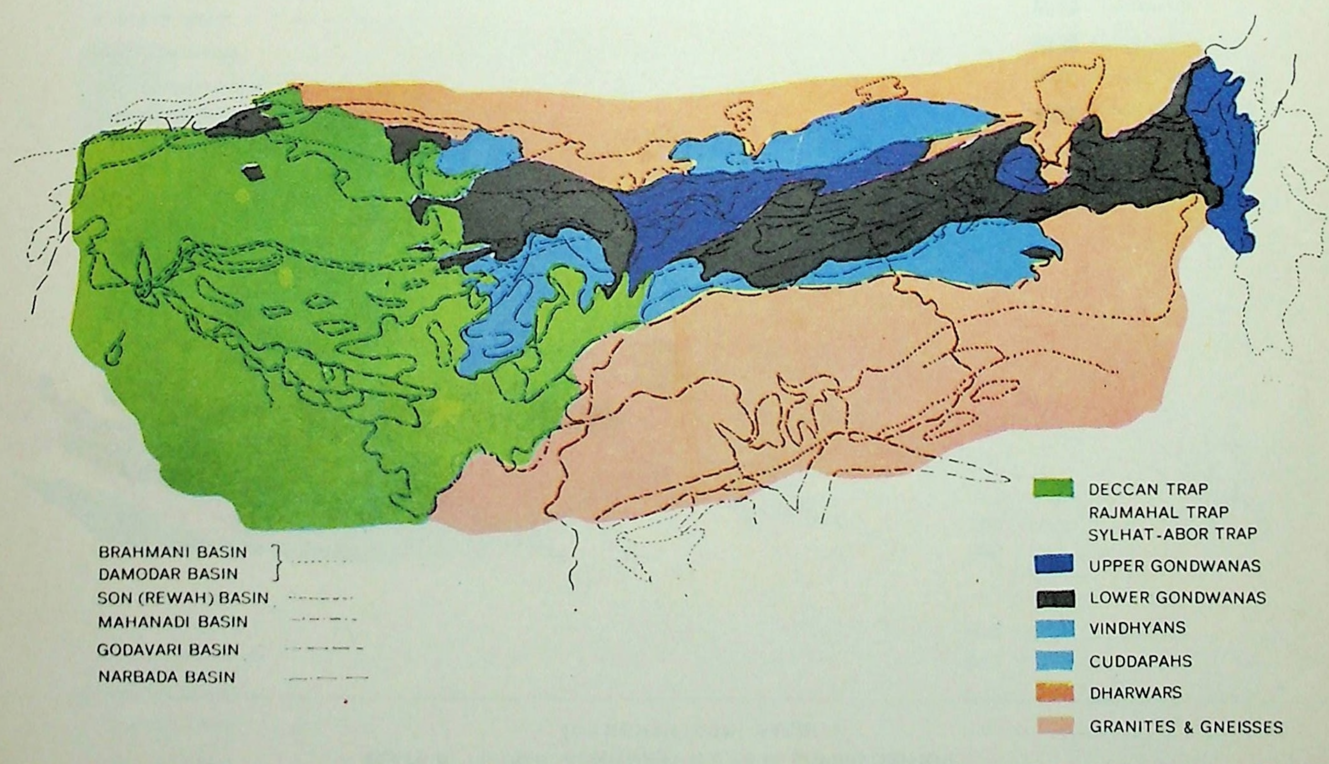


PLATE 8. INDIAN GONDWANA BELTS IN SUPERPOSITION
(E) REWAH (SON) BASIN

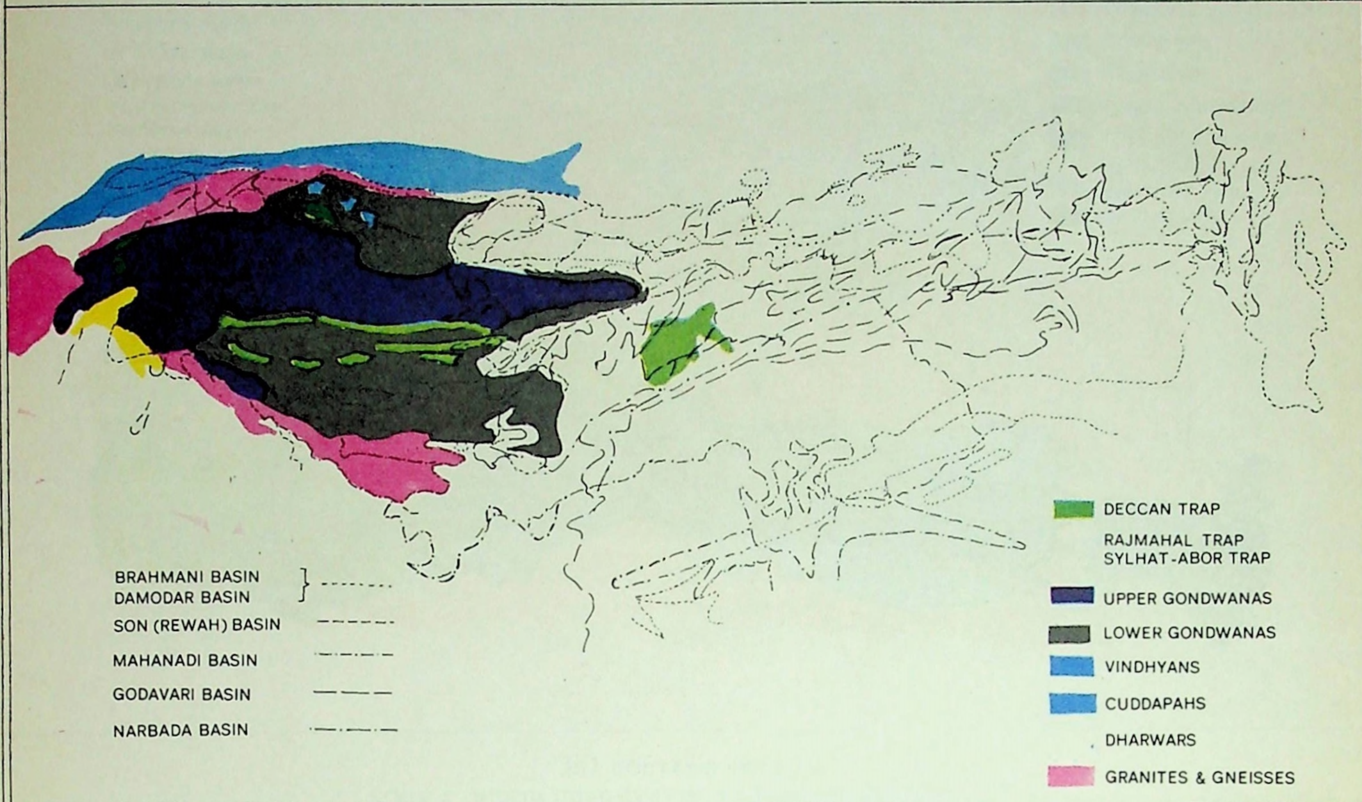


PLATE 9. INDIAN GONDWANA BELTS IN SUPERPOSITION
(F) SATPURA (NARBADA) BASIN

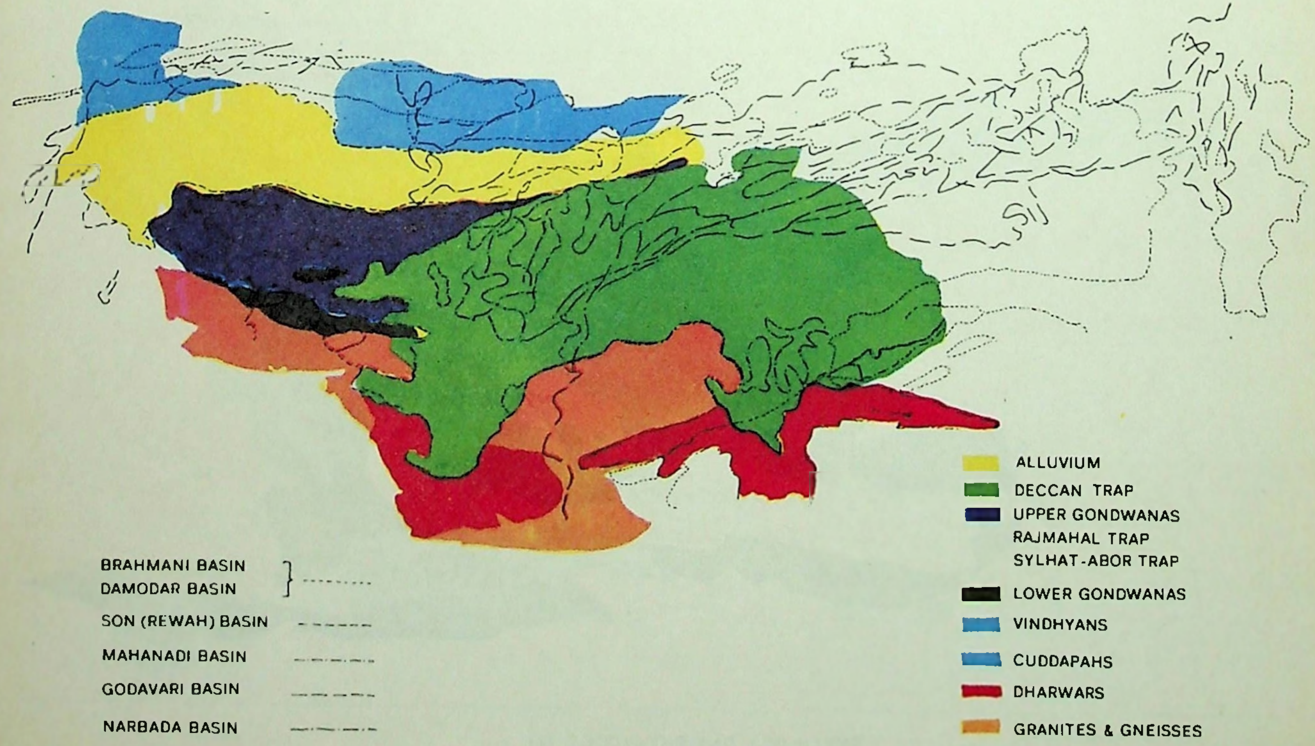


PLATE 10. INDIAN GONDWANA BELTS IN SUPERPOSITION
(1) CUDDAPAHS AND VINDHYANS

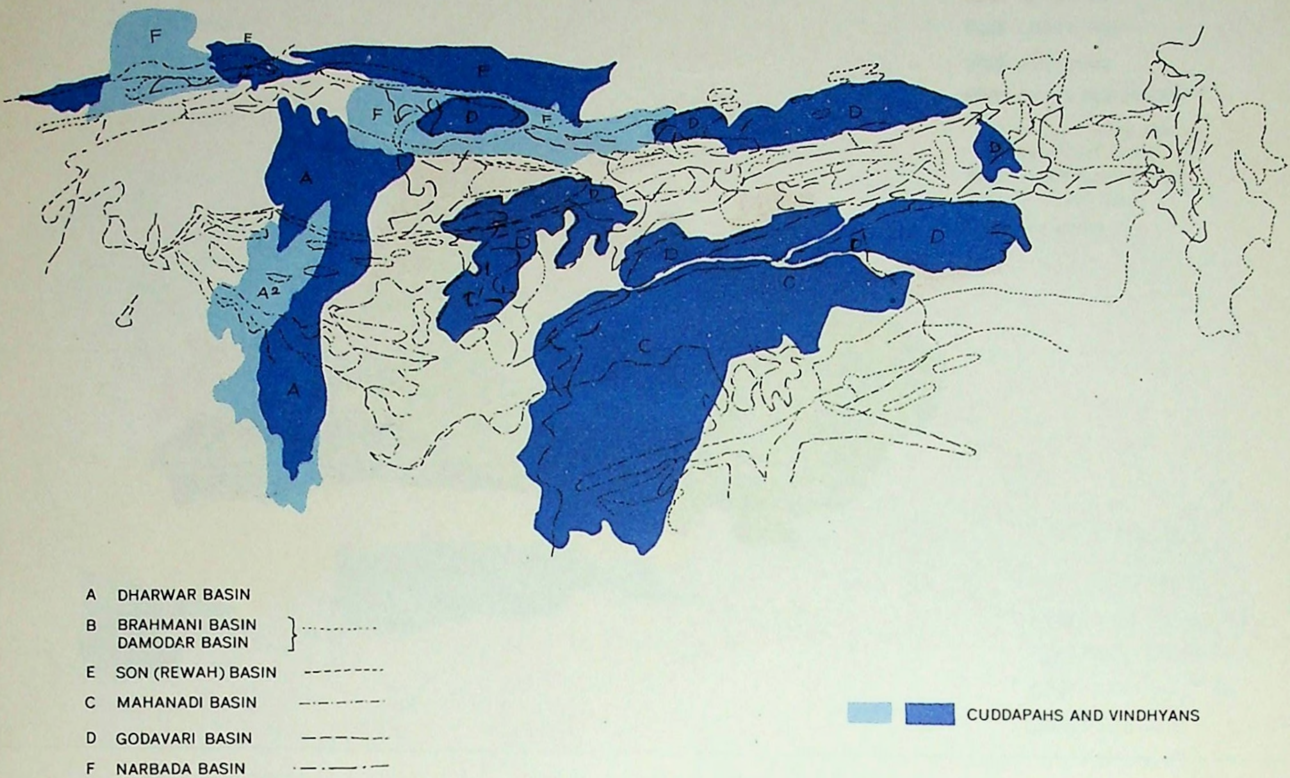
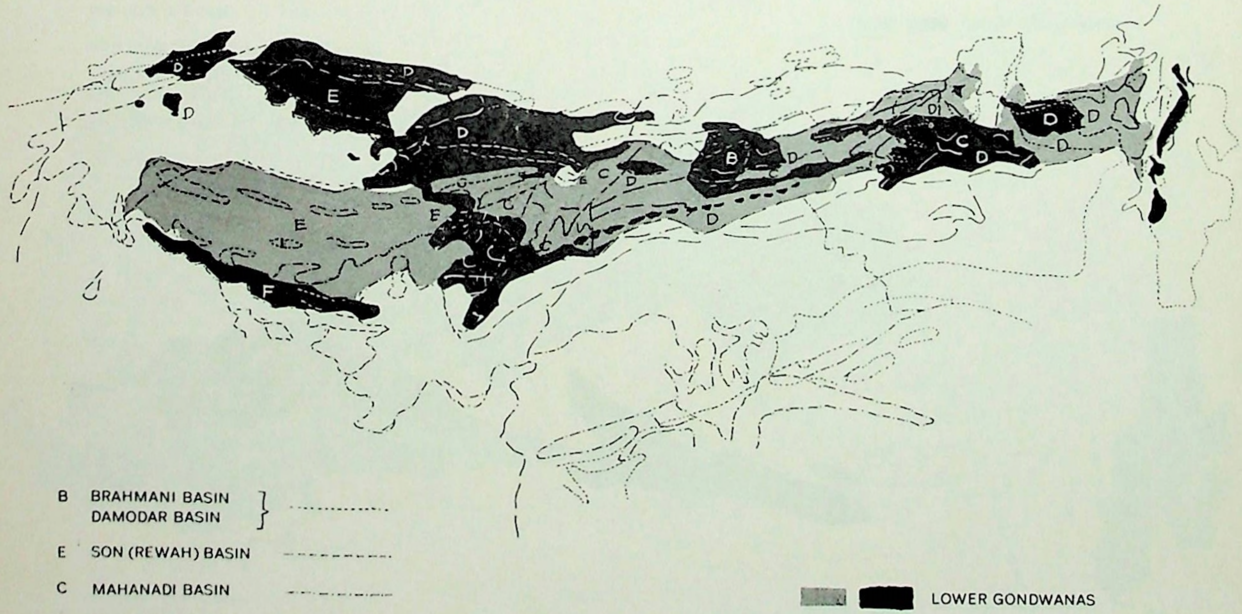


PLATE 11. INDIAN GONDWANA BELTS IN SUPERPOSITION
(2) LOWER GONDWANAS



B BRAHMANI BASIN
DAMODAR BASIN

E SON (REWAH) BASIN

C MAHANADI BASIN

D GODAVARI BASIN

F NARBADA BASIN

PLATE 12. INDIAN GONDWANA BELTS IN SUPERPOSITION
(3) UPPER GONDWANAS

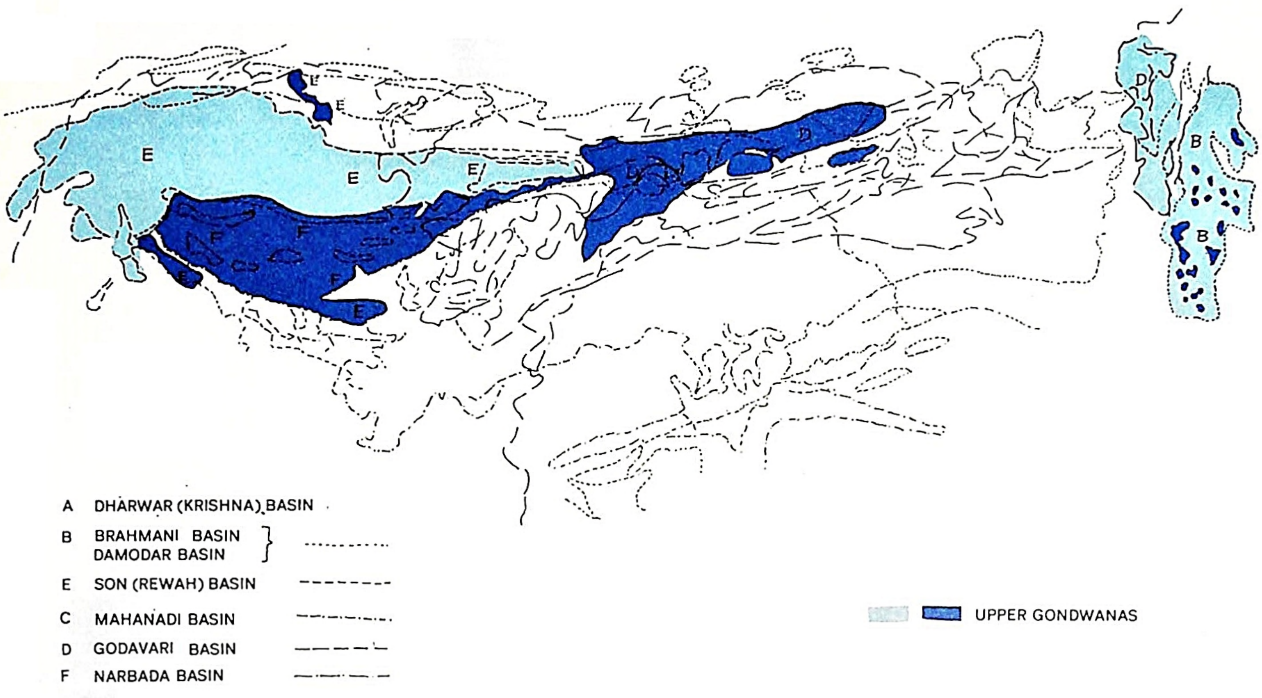


PLATE 13. INDIAN GONDWANA BELTS IN SUPERPOSITION
(4) DECCAN TRAP

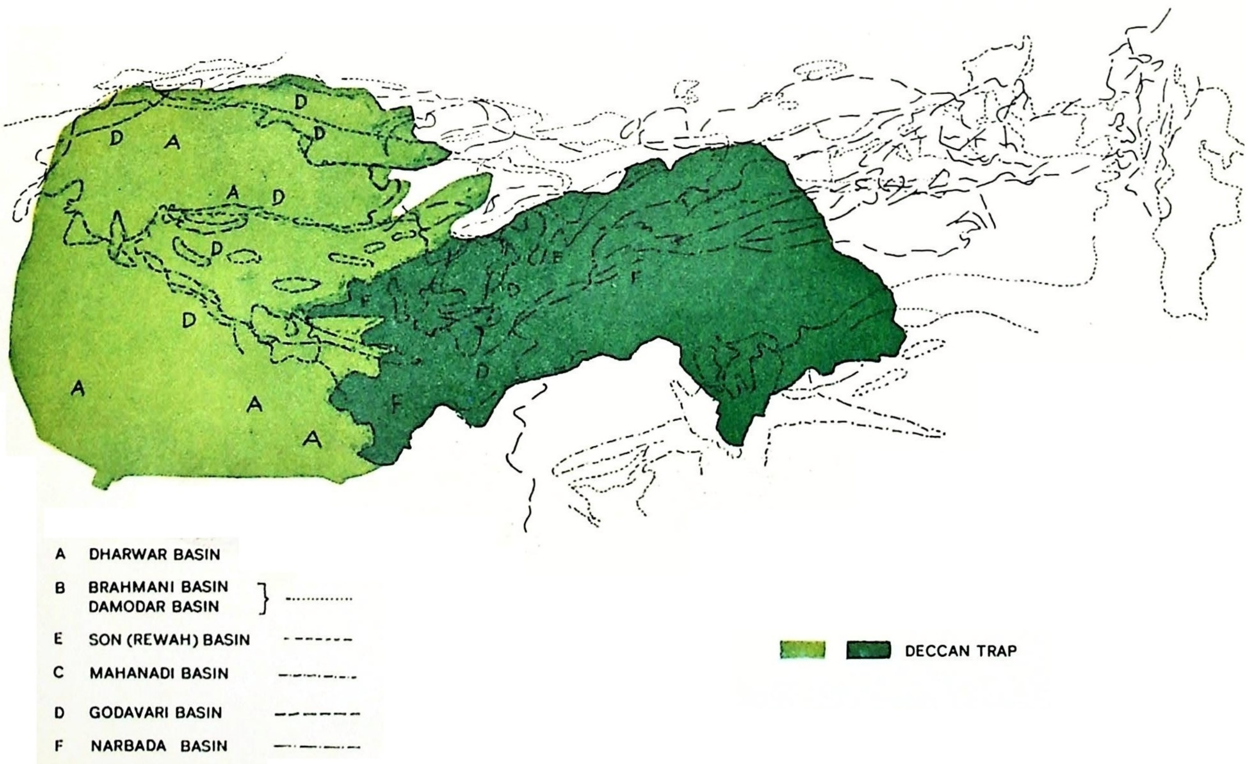
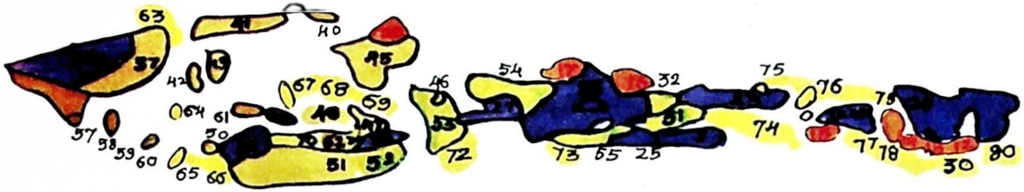
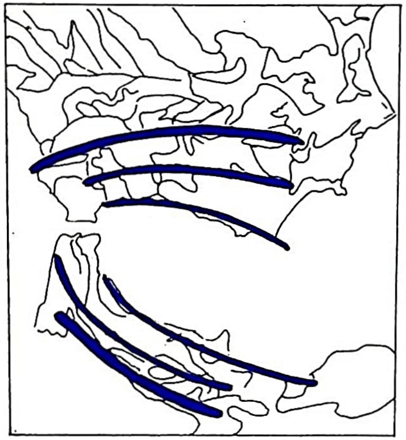


PLATE 14. GONDWANA COAL FIELDS OF INDIA IN PRE-TERTIARY PERIOD

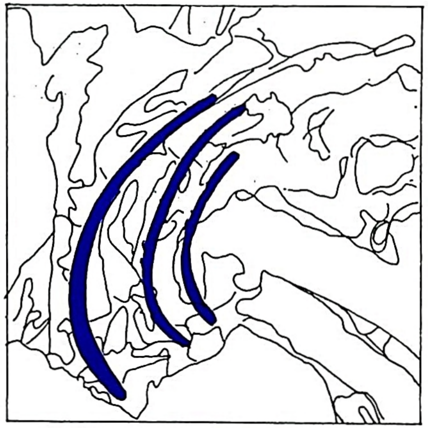


(red)	29, 17, 16, 15, 14, 13, 12.	DEOGARH-HAZARIBAG BELT.
(blue)	33, 38, 39. 28. 27. 26-18.	DAMODAR BELT.
(orange)	34-37. 40-51.	SON REWAH BELT.
(yellow-green)	52-55. 30-32.	MAHANADI BELT.
(dark red)	56-62.	SATPURA BELT.
(yellow)	63-80.	GODAVARI BELT.

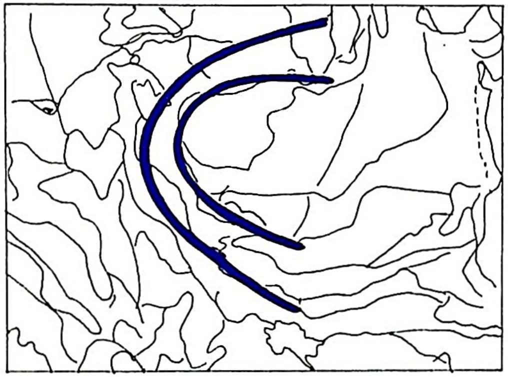
PLATE 15. HOMOMORPHIC ALPINE ARCS IN THE MEDITERRANEAN REGION



BETIC ALPS



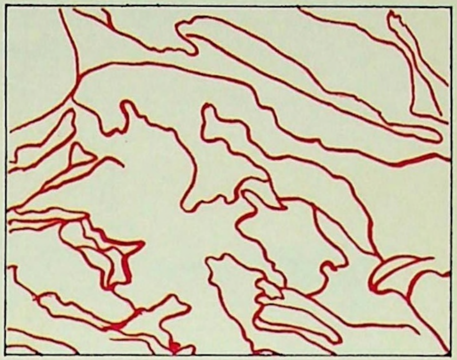
WESTERN ALPS



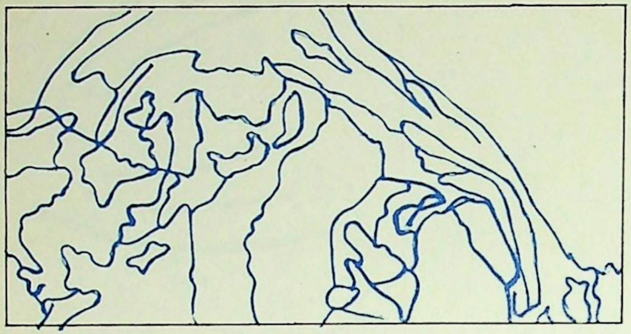
BALKAN ALPS

PLATE 16. PAMIR DOME PATTERN

PAMIR STRUCTURES



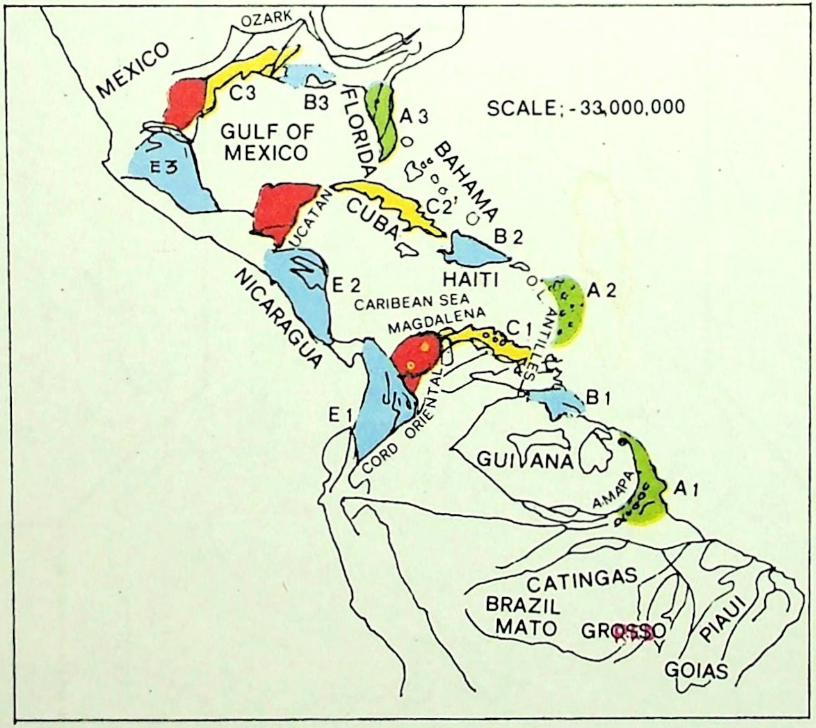
ARMENIA STRUCTURES



CARPATHIAN STRUCTURES

PAMIR-ARMENIA-CARPATHIAN COMPOUND STRUCTURES

PLATE 17. CENTRAL AMERICAN REGION STRUCTURAL CORRESPONDENCES



REPETITION OF STRUCTURAL TYPES

L. ANTILLEAN ARC

A { 1 IN GUIANA
2 IN WEST INDIES
3 IN GULF COAST

HISPANIOLA TYPE

B { 1 IN VENEZUELA
2 IN WEST INDIES
3 IN GULF COAST

CUBA TYPE

C { 1 IN VENEZUELA
2 IN WEST INDIES
3 IN GULF COAST

YUCATAN TYPE

D { 1 IN VENEZUELA
2 IN ISTHMIAN ZONE
3 IN MEXICAN COAST

NICARAGUA TYPE

E { 1 IN COLOMBIA
2 IN ISTHMIAN
3 IN MEXICAN COAST

PLATE 17. (A) JOINT EVOLUTION OF AMERICA-AFRICA

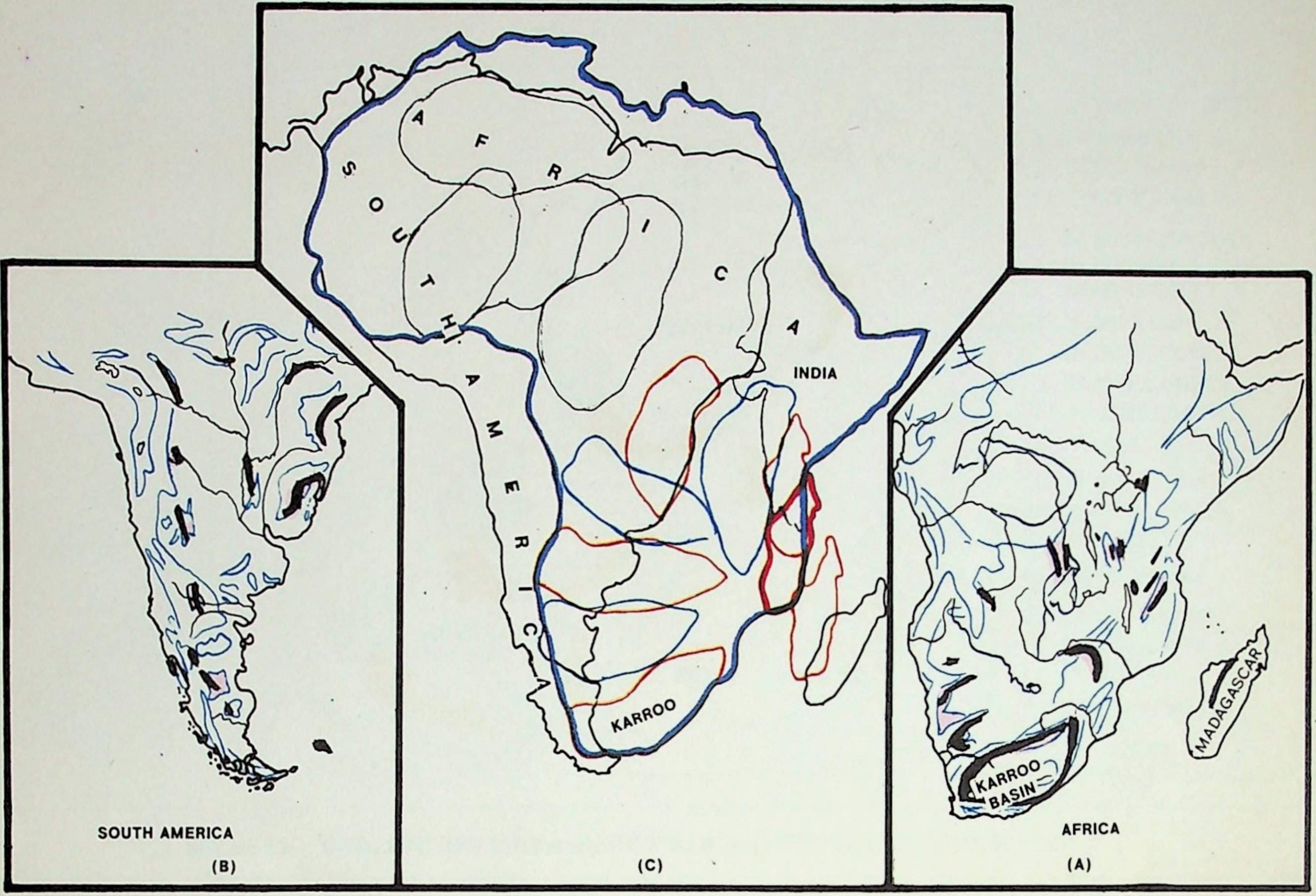
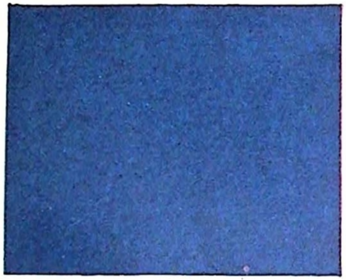
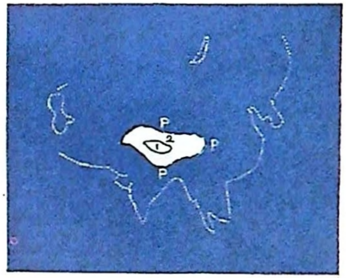


PLATE 18. EVOLUTION OF THE EARTH'S CRUST



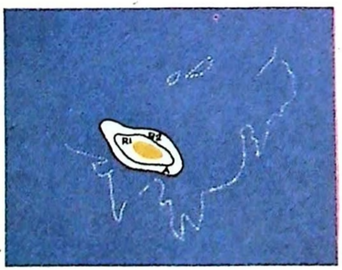
(0) ARCHAEAN PANTHALESSA



(1) LOW. PALAEOZOIC

P PACIFIC OCEAN

1 SHALLOW } PACIFIC GEOSYNCLINE
2 DEEP

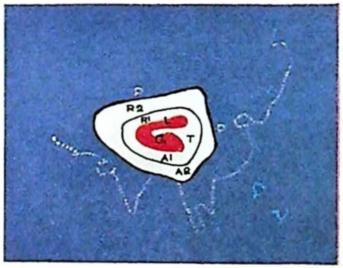


(2) MID. PALAEOZOIC

C.CONTINENTAL

R_1 R_2 - ROCKIAN G.S.

A_1 A_2 - ANDIEN G.S



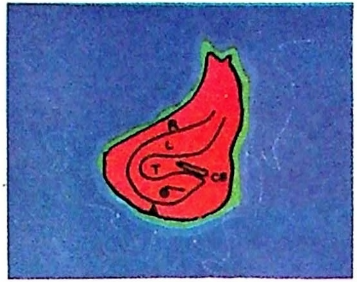
(3) UP. PALAEOZOIC

L. LAURASIA

G. GONDWANA LAND

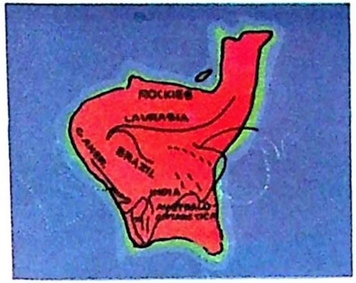
T. TETHYAN G.S.

PLATE 19. EVOLUTION OF THE EARTH'S CRUST



Ca - CATHAYSIA

(4) LOW. MESOZOIC

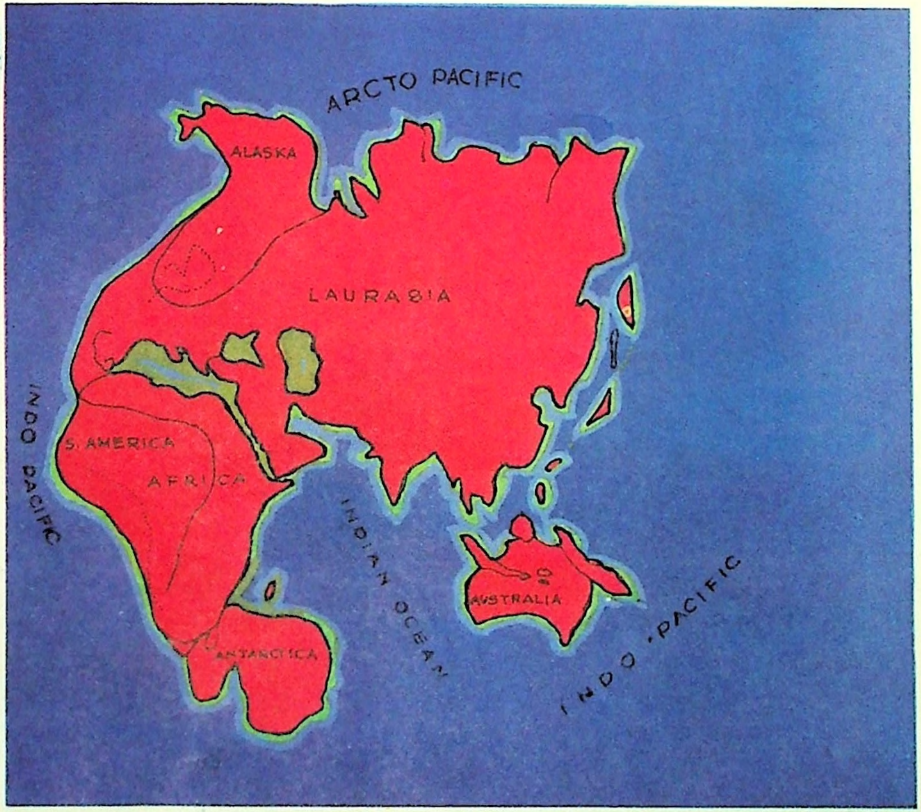


K - KARROO

(5) UP. MESOZOIC

(6) LOWER TERTIARY

PLATE 20 EVOLUTION OF THE EARTH'S CRUST

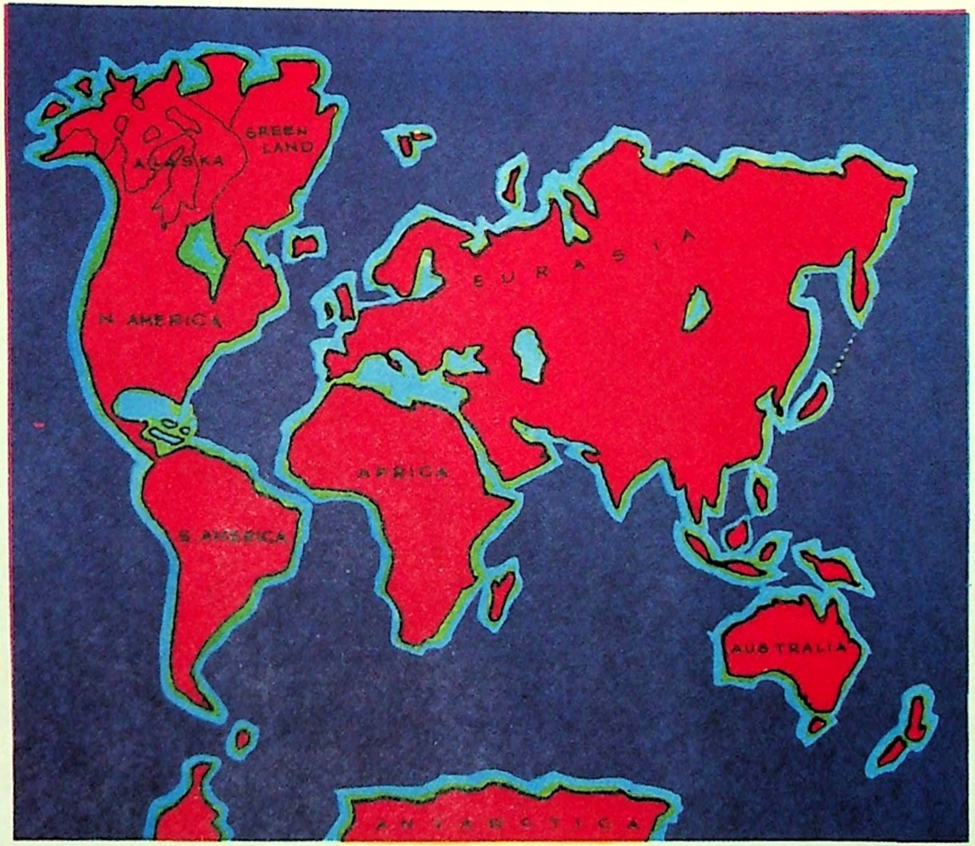


(7) UPPER TERTIARY

PLATE 21. EVOLUTION OF THE EARTH'S CRUST

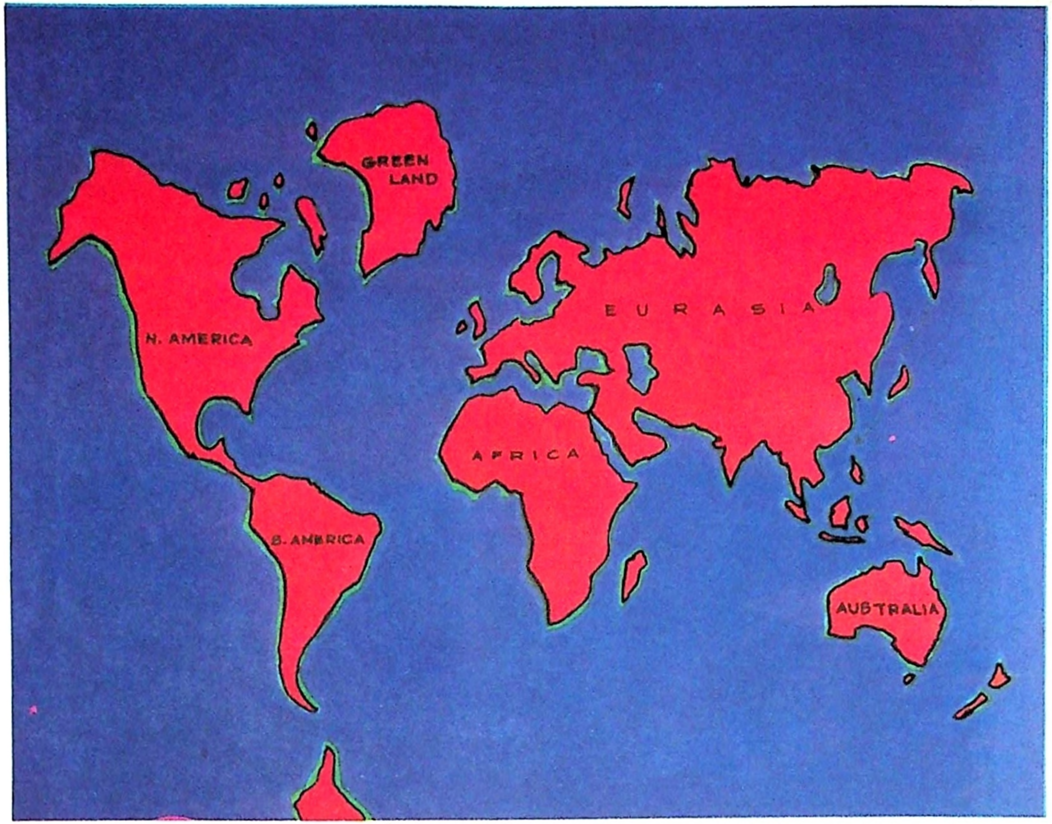
(8) LOWER QUATERNARY

PLATE 22. EVOLUTION OF THE EARTH'S CRUST



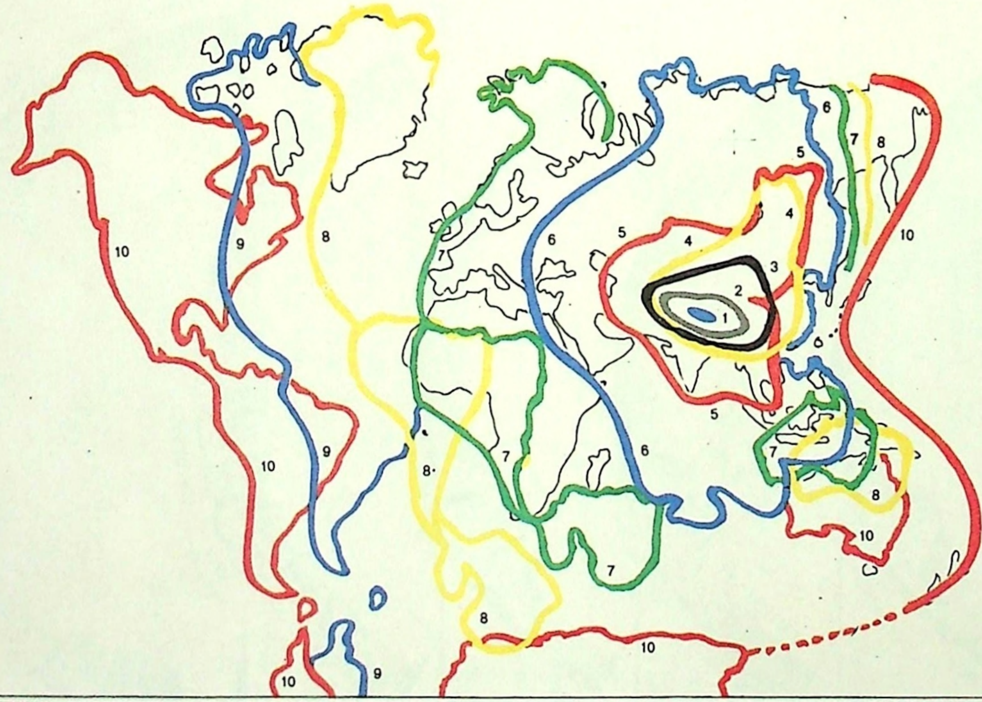
(9) MIDDLE QUATERNARY

PLATE 23. EVOLUTION OF THE EARTH'S CRUST



(10) UPPER QUATERNARY

PLATE 24. STAGES IN CONTINENTAL MIGRATION



1) LOW. PALAEOZOIC
2) MID. PALAEOZOIC
3) UP. PALAEOZOIC
4) LOW. MESOZOIC
5) UP. MESOZOIC
6) LOWER TERTIARY
7) UPPER TERTIARY
8) LOWER QUATERNARY
9) MIDDLE QUATERNARY
10) UPPER QUATERNARY

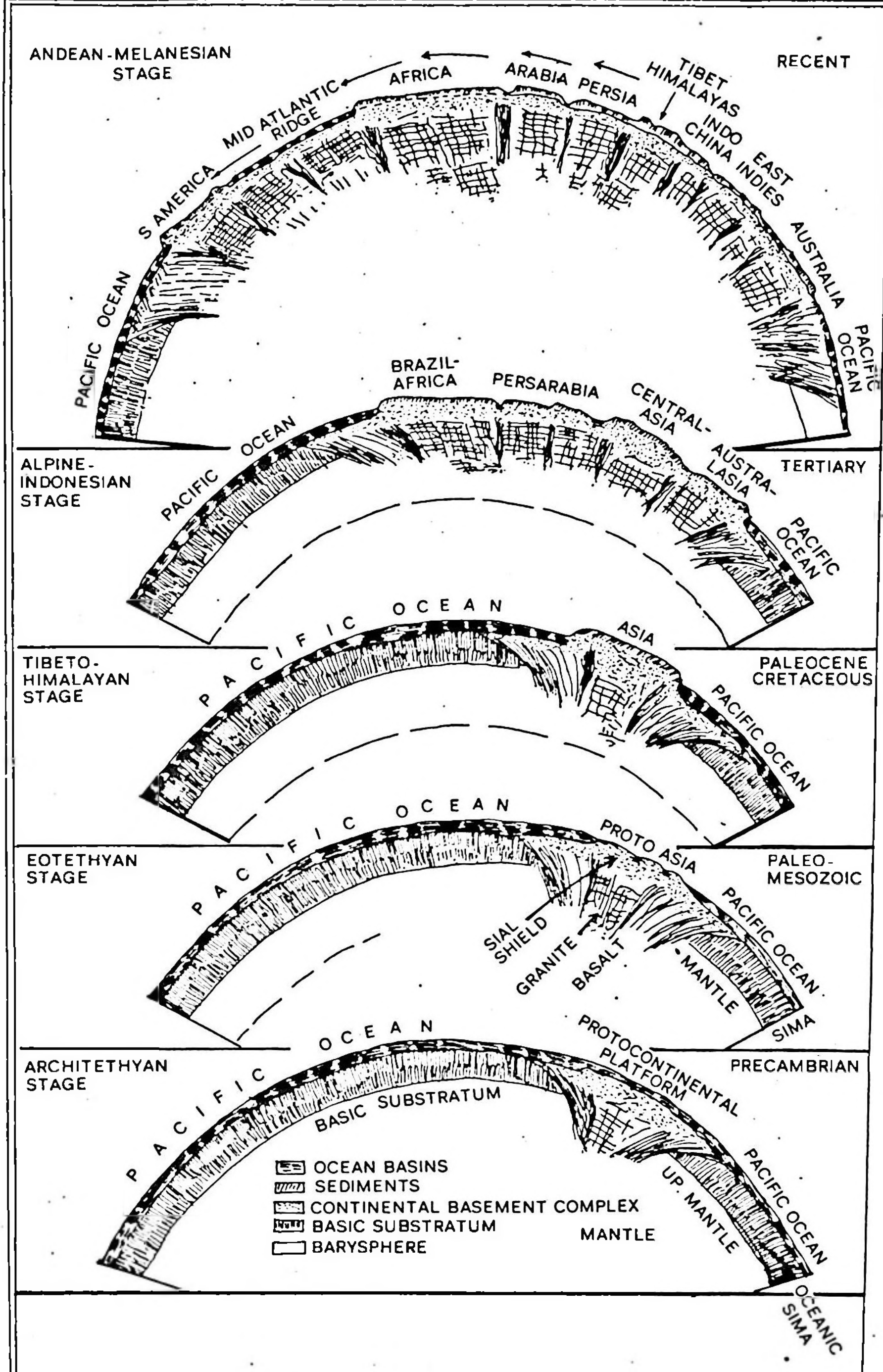


PLATE 25. CONTINENTAL EXPANSION STAGES IN THE EXPANSION OF THE EARTH'S CRUST

ERRATA

Page No.	Line No.	Incorrect	Correct
Acknowledgement	12	'Frontisplece and Bild der wissenschaft stu:tgart' for	Omit
List of Colour Plate	Plate 17 A		Joint Evolution of South America-Africa
Cover page	12th line	9th	19th
(about the author)	16th line	over the 20th	a section of 20th session
26	Fig. 8	Junagar R.	Jamuna R.
192	4th	Fig. 70	Plate 17 A
239	Last time	Plate 114	Plate 21
Plate 17 A		Evolution of America-Africa	Evolution of South America-Africa

ABOUT THE BOOK

In the history of geological thought the evolution of continents has been in the forefront in discussions. It is well-known that Wegener proposed the Drift Theory in the early years of this century. The theory has been repeatedly discussed but it remained unsatisfactory on many counts. The main hurdle in the acceptance of drift theory is the nature of forces invoked in engineering the drift of vast continental masses over such long distances. It is in this context that a new theory of Sheet Movements and Continental Evolution has been elaborated in this book which presents a detailed account of the principles and general working of the theory.

The principal feature of the new theory is that sedimentary rock formations have been deposited in closely set basins with adequate chances of intermingling and were piled up one above the other, in the manner of a pack of cards, in the Tibeto-Himalayan region. These were subjected to subcrustal magmatic activity which had uplifted these sedimentary blocks through fracturing, sheeted them through sills, brought about the detachment of blocks and sheets from their basement and transported them over molten lava mass which also served as a lubricant permitting free lateral movements. This has enabled migration of the structural patterns, stratigraphical sequences along with their fossil contents in stages over vast distances. In this whole process volcanism has played a dominent role. This theory has at no stage introduced any hypothetical postulate.

The book has elucidated various aspects of the theory and explained the evolution of land forms in a series of examples from different parts of the world by means of 112 figures, including 24 coloured plates. This has made the understanding of the concept of Sheet Movements much easier.

ABOUT THE AUTHOR

Prof. Dr. K. P. Rode, Ph. D., F. A. Sc., a well-known geologist of India, was born on 8th November, 1903 at Chhindwara (M.P.) After obtaining his M.Sc. degree from the Banaras Hindu University, he joined the teaching staff of the same University in 1927. During 1937-39, he completed his doctorate at Zurich under Prof. Paul Niggli. On his return from Switzerland he was soon chosen as Professor and Head of the Department of Geology, Erskine College of Natural Sciences, Andhra University, Waltair 1941-44. Later, he served the Rajasthan University as Professor and Head of the Department of Geology at Udaipur from 1950-68 and there he established one of the active centres of geological teaching and research.

He initiated a new theory of Sheet Movements and Continental Expansion on the basis of geomorphological and structural evidences.

His exposition of this theory first at the 9th Session of the International Geological Congress at Algiers in 1952, contributed to his election as Vice-President of the International Gondwana Commission (1952-56) and his re-election to the same post at Mexico in 1956, for a further period of four years (1956-60). Besides, he was invited to preside over the 20th Session of the International Geological Congress at Mexico. He was elected President of Geology and Geography Section of Indian Science Congress held at Cuttack (1962).

An original thinker, Prof. Rode is a Fellow of the Indian Academy of Sciences, Bangalore since 1944 and has to his credit over forty research contributions in diverse branches of geology.