STRUCTURAL EVOLUTION OF THE SOUTH AMERICAN ANDES.

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ABSTRACT. Upon a closer geological and tectonic study, the great Andean orogenic belt can be divided into two main geological provinces, forming the western and eastern Cordilleras of the Andes. Each of these shows distinct characteristics, geological composition, age and mechanism of uplift.

Thus the western Cordilleras represent an extensive and almost continuous batholith of a continental character, composed largely of acid and semi-acid rocks. Tectonically the western Andes show a normal block faulted and folded structure, such as would be produced by vertical forces. The age of the uplift of the western Andes is mainly Upper Mesozoic.

The eastern Cordilleras are formed of sedimentary and metamorphic rocks, frequently exposing their crystalline core. The age of the sediments varies from early Paleozoic to late Tertiary. The thickness of the strata is generally considerable, and geosynclinal conditions of deposition are clearly outlined in the eastern Cordilleras. Structurally the eastern ranges are also predominantly block-faulted, but thrusting is evident in the easternmost Cordilleras. The age of uplift of the eastern Andes is mainly late Tertiary and Quaternary.

The uplift of the great Andean batholith, or the western Cordilleras, thus preceded the emergence of the eastern geosyncline, which was uplifted long after the batholith was formed and consolidated. The batholith was thus acting as borderland west of the geosynclinal trough; this explains the eastward thrusting of the eastern Cordilleras against the continental foreland.

The study shows that, in the structural evolution of the Andes, there is no evidence pointing toward the existence of a western borderland in the Pacific, west of South America. The present concept thus eliminates the hypothetical Pacific Continent due to which, according to some authors, the compression of the Andean geosyncline from the west, took place. The Andean orogenic belt and its uplift were consequently formed by the growth of the western batholith due to vertical forces and by the subsequent rise of the eastern geosyncline, involving static and not dynamic tangential stresses along the continental foreland.

INTRODUCTION.

THE gap in our geological knowledge of western South America in general and the Andean orogenic belt in particular, calls for a synthetic study of this part of the continent. Recent publications on north-western South America, as well as the First Geological Map of South America[1] have helped considerably to clear many obscure points in the interpretation of the structure of the Andes.

In the present contribution the writer will attempt to outline and interpret the elements of the Andean Geosyncline composing it. Only the main Cordilleras will be treated, while the secondary mountain chains are here considered as part of the main ranges. The map "Structural Elements of Western South America" shows graphically the distribution of the ranges and main structural elements of the Andean Geosyncline.

A synthetic study of these elements indicates that the Andean uplift was caused not by the classical tangential forces compressing a geosynclinal trough between two continental shield areas, thus forming an orogenic belt of the Alpine type; but rather by deep-seated sub-crustal forces responsible for the great magmatic activity and the formation of the western Andean batholith as well as the distinct tectonic unit of the Andean type.

CONTINENTAL FORELANDS.

The Andean orogenic belt has developed along the western edge of an old continental land-mass, which acted as foreland to the geosynclinal trough of western South America. The main now exposed continental shield areas of the foreland facing the geosyncline are: the northern and western limits of the Guiana Shield; the western limits of the Brazilian Shield; the Sierras de Tandil, isolated remains of ancient shield rocks south of Buenos Aires in Argentina. The Falkland Islands probably formed part of a distinct Antarctic land-mass.

A western borderland in the present day Pacific, such as would be expected in a normal geosyncline of an Alpine or Himalayan structure, is not evident west of the Andes. The Coastal Range of southern Chile, between 34° S. Lat. and 45° S. Lat., which exposes presumably Archean rocks and granites bordering the Andean belt, can hardly be interpreted as remains of a Pacific Continent, among other reasons because the true age of these rocks has never been proven and structurally they form an inseparable unit with the younger granodioritic Coastal Range. The shelf and the Pacific Ocean floor indicate nothing suggesting a former continent west of South America. In any case, between about 10° N. Lat. and 34° S. Lat. there is nothing pointing toward the former existence of a western counterpart to the eastern foreland. North of 10° S. Lat., however, the Sierra Nevada de Santa Marta and the Goajira massives could be interpreted, according to Schuchert[2] as remains of an old borderland.

The suggestion of an extensive Pacific Continent west of the Andes, as proposed by several authors (Burckhard,[3], Steinmann,[4] Olsson,[5] consequently is not based on conclusive evidence, but is obviously conjectural.

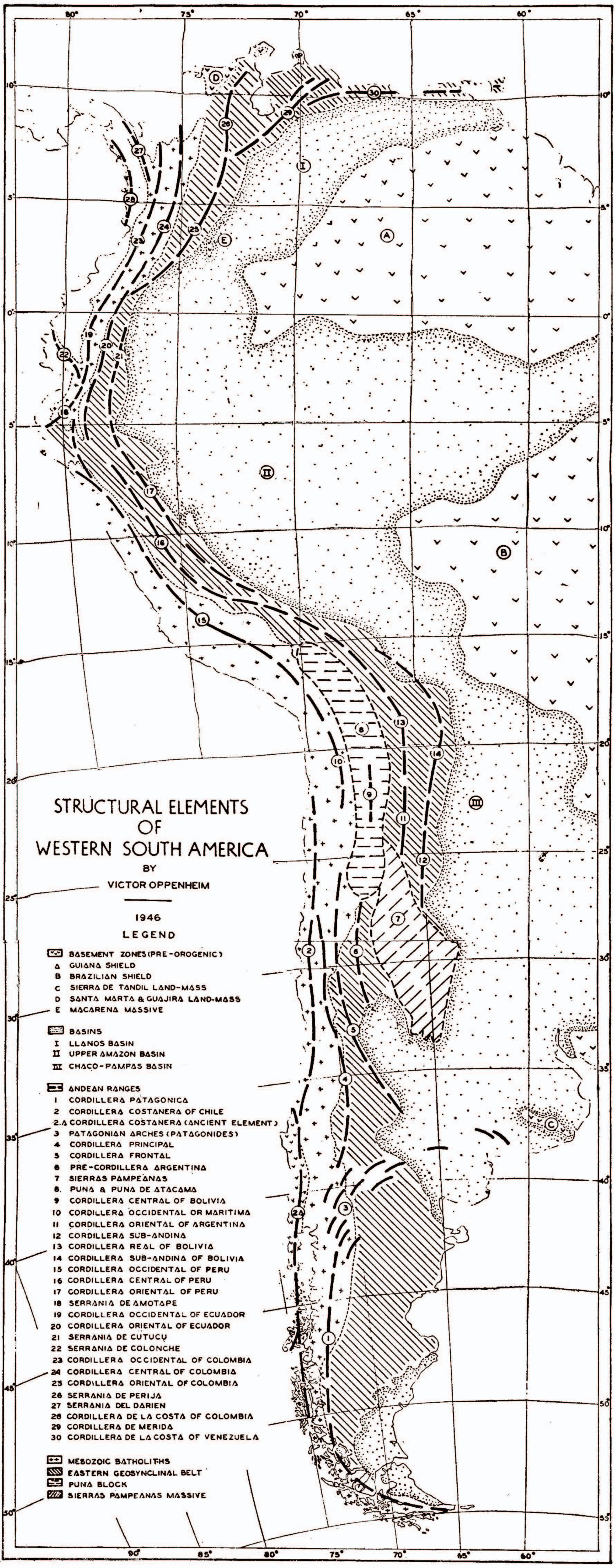
PRE-ANDEAN BASINS.

The Andean geosyncline has evidently been a zone of continental weakness since Pre-Cambrian times, as there are in the Andean belt rocks and sediments that underwent deformations of the Caledonian and Hercynian diastrophic cycles. The latest Tertiary Andean cycle began in the Upper Cretaceous and culminated in the Pliocene and Quaternary periods. During this cycle, the subsidence of the geosynclinal trough proper involved also the outer edges of the rigid foreland, or Pre-Andean platform to the east of the trough. This was considerably lowered by denudation and repeatedly invaded by transgressive seas. The Pre-Andean platform was largely the source of the clastic materials that were continuously filling the subsiding trough of the geosyncline to the west.

With the uplift of the geosyncline, which did not take place simultaneously, but developed individually in different zones of the great trough, the edges of the platform were also raised to a different degree along its border. Thus Pre-Andean basins of sedimentation were formed east of the rising mountain ranges. These basins were rapidly filled with continental deposits from the newly exposed and rugged mountain lands to the west.

At the close of the Andean orogenic cycle, during Pliocene and Quaternary times, with the renewed and final stages of diastrophism and uplift and the intense erosion that followed them, the platform and its basins were covered by an almost continuous blanket of continental young Tertiary sediments. These extend presently between the Andean ranges and the partly exposed shield areas, from eastern Venezuela to eastern Argentina; their thickness, however, varies in different basins; it generally increases from east to west.

In some parts of the platform, old rocks forming its basement appear exposed by erosion from under the Tertiary sedimentary cover, suggesting swells between the basins. Conspicuous nar-


STRUCTURAL ELEMENTS
OF
WESTERN SOUTH AMERICA
BY
VICTOR OPPENHEIM
1946
LEGEND
BASEMENT ZONES (PRE-OROGENIC)
A GUIANA SHIELD
B BRAZILIAN SHIELD
C SIERRA DE TANDIL LAND-MASS
D SANTA MARTA & GUAJIRA LAND-MASS
E MACARENA MASSIVE
BASINS
I LLANOS BASIN
II UPPER AMAZON BASIN
III CHACO-PAMPAS BASIN
ANDEAN RANGES
1 CORDILLERA PATAGONICA
2 CORDILLERA COSTANERA OF CHILE
2.A CORDILLERA COSTANERA (ANCIENT ELEMENT)
3 PATAGONIAN ARCHES (PATAGONIDES)
4 CORDILLERA PRINCIPAL
5 CORDILLERA FRONTAL
6 PRE-CORDILLERA ARGENTINA
7 SIERRAS PAMPEANAS
8. PUNA & PUNA DE ATACAMA
9 CORDILLERA CENTRAL OF BOLIVIA
10 CORDILLERA OCCIDENTAL OR MARITIMA
11 CORDILLERA ORIENTAL OF ARGENTINA
12 CORDILLERA SUB-ANDINA
13 CORDILLERA REAL OF BOLIVIA
14 CORDILLERA SUB-ANDINA OF BOLIVIA
15 CORDILLERA OCCIDENTAL OF PERU
16 CORDILLERA CENTRAL OF PERU
17 CORDILLERA ORIENTAL OF PERU
18 SERRANIA DE AMOTAPE
19 CORDILLERA OCCIDENTAL OF ECUADOR
20 CORDILLERA ORIENTAL OF ECUADOR
21 SERRANIA DE CUTUCU
22 SERRANIA DE COLONCHE
23 CORDILLERA OCCIDENTAL OF COLOMBIA
24 CORDILLERA CENTRAL OF COLOMBIA
25 CORDILLERA ORIENTAL OF COLOMBIA
26 SERRANIA DE PERIJA
27 SERRANIA DEL DARIEN
28 CORDILLERA DE LA COSTA OF COLOMBIA
29 CORDILLERA DE MERIDA
30 CORDILLERA DE LA COSTA OF VENEZUELA
MESOZOIC BATHOLITHS
EASTERN GEOSYNCLINAL BELT
PUNA BLOCK
SIERRAS PAMPEANAS MASSIVE

rowing of the platform indicating basement swells or land-bridges occur at about 7° N. Lat., at the Macarena massive and the San Jose hills in the Colombian Llanos,[6] and at about 18° S. Lat., east of Santa Cruz, in eastern Bolivia. Three extensive Pre-Andean Tertiary basins can thus be outlined to the east: the Llanos basin, covering the eastern Venezuelan and north-eastern Colombian Llanos; the upper Amazonian basin, covering the southern Colombian Llanos, the Ecuadorian Oriente, the Peruvian Montaña with the adjoining north-eastern Beni plains in Bolivia; the Chaco-Pampas basin, covering the south-eastern Bolivian plains, the whole Paraguayan and Argentine Chaco and the Argentine Pampas. Upon closer study it appears that the modern drainage systems follow broadly the outline of these three main basins east of the Andes.

The Patagonian mesa, forms the southernmost part of the Continental Platform; but is not considered as a basin zone. It exposes extensive igneous flows with only a small and isolated sedimentary, Magellan basin, at the south of the Continent. Windhausen[7] considered Patagonia as an element not belonging to the original frame-work of South America, and more related to the Antarctic Continent, than to South America proper.

THE ANDEAN OROGENIC BELT.

Forming one of the highest mountain chains of the world, the Andes upon a closer geological study, appear of a complex and heterogeneous constitution both geologically and tectonically; yet a systematic arrangement of its elements is evident.

The Andean orogenic belt can be divided into two principal geologic provinces: eastern and western. Each of these provinces can be broadly outlined along the whole Andean geosyncline from south to north, and bears distinct characteristics of rock formations.

Both the eastern and western Cordilleras have been uplifted at different periods during the last Andean orogenic cycle, which was roughly contemporaneous with the Alpine cycle, but it began somewhat earlier, in the Upper Mesozoic era. Evidence of the first orogenic movements of the last cycle appear in the Andes in the Upper Cretaceous, Senonian period. The principal stages of the orogenic revolution, however, evolved during late Tertiary times. The first stage of the Tertiary period, or the second of the cycle, is evident during the Eocene; the second stage took place between the Oligocene and Miocene, and the third, the most active, developed during Pliocene and early Quaternary times. The last stage has not concluded as yet and some orogenic activity still finds its expression in many parts of the Andes.

During the initial stages of the Andean orogenesis, a marine transgression has covered the newly emerged lands, shortly after their uplift. It was only during the Upper Tertiary and mainly Pleistocene stages of the cycle that continuous emergence and persistent vertical growth of the orogenic belt were not affected by subsidence.

The Andean orogenic belt appears to have been a mobile zone of weakness of the South American Continent long before the latest orogenesis. Thus, there is considerable evidence in the Andes of Upper Paleozoic formations, affected by the Hercynian orogenesis; to a lesser extent Lower Paleozoic formations are found affected by the Caleodonian diastrophism. Consequently, it can be assumed that the evolution of the Andean belt has followed an old pattern of repeated orogenic cycles, the causes of which do not seem to have depended on tangential forces, exercised by a hypothetic Pacific land-mass, but are probably related to a deep seated sub-crustal activity of the sima, such as could be produced by convection forces.

The division of the Andes into an eastern and western orogenic province, as based upon a different geological composition and prevailing structural character of each of these provinces, is also justified by the time of uplift and emergence of the two parts of the geosyncline, which evidently was not simultaneous in the Andean mobile belt. It was a process which evolved quite differently and individually in each geologic province or part of geosyncline, as the closer study of the elements composing the present day Andes shows.

GEOLOGIC OUTLINE OF THE ANDEAN RANGES.

To visualize the geological and structural composition of the Andes we shall briefly outline its principal mountain ranges between the Island of States at the extreme south-east and the Peninsula de Paria at the extreme north-east.

At the south and south-east, at about 56° S. Lat., the Andes appear as a narrow and steep mountain chain generally forming a single range, crossed by transversal valleys. This range is known as Cordillera Patagónica and continues in a northern direction up to about 44° S. Lat. where, in the region of the Lake Fontana, the first branching of secondary ranges begins to take place. The eastern flank of the Cordillera Patagónica is formed by Tertiary and Cretaceous sediments, which to the east overlie igneous rocks of Upper Jurassic age; to the west, and forming the island-arc in southern Chilean coast, extend Upper Mesozoic granodiorites of the Andean batholith.

Along the whole Coast of Chile and up to about 22° S. Lat., extends the Cordillera Costanera; it includes the island-arcs off the coast, which generally have no high orographic relief. The extreme western part of this Cordillera, between about 47° and 36° S. Lat., is composed of granites and crystalline rocks which are considered to be of Archean age.

A series of arched ranges, convex to the west and north, extend north of the Cordillera in the Andean zone up to about 41° S. Lat.; they are referred to by Argentine geologists (Groeber[8]) as "Patagonides." These ranges encircle Patagonia from the north, leaving the Andean mountain chains to the west. The Patagonides or Patagonian folds, in the Andean zone, are formed by crystalline basement rocks in their arches, generally thrusted over Mesozoic and particularly Jurassic sediments, which are intensely crumpled in front of these arches. The age of the Patagonian folds is Upper Cretaceous, probably Senonian.

North of about 40° S. Lat., the main Andean range continues subdivided in several parallel Cordilleras. Groeber[8] (also personal communication) distinguishes the following main elements composing the Andes up to about 22° S. Lat. in Argentina and Chile: Cordillera Principal; Cordillera Frontal; Pre-Cordillera; Sierras Pampeanas; Puna; Cordillera Oriental and Cordillera Sub-Andina.

The Cordillera Principal, or Cordillera del Geosinclinal, as it is known, appears in the main Argentine Andes at about 38° S. Lat. and trending to the north north-west merges with the northern extension of the Cordillera de la Costa of Chile. Geologically it is formed of a great thickness, up to 7,000 metres of Mesozoic sediments mainly Jurassic, Triassic and Cretaceous in age. Great masses of volcanic rocks appear interposed with some sedimentary rocks; the whole is intensely folded and faulted. Covering the underlying Mesozoic rocks are great extensions of semi-acid volcanic rocks, predominantly andesites. The age of this range is early Tertiary. Bordering the Cordillera del Geosinclinal to the east, between about 37° and 26° S. Lat., there extends the eastern branch of the Cordillera Principal, known as Cordillera Frontal. The Cordillera Frontal is made up mainly by Paleozoic sediments, mostly Carboniferous in age. The sediments were first folded during Hercynian orogenesis; they are associated with masses of granites of Permo-Triassic age. Extensive flows of quartz-porphyries covers the Paleozoic sediments over a large area; these were not affected by folding. To the east and along the eastern edge of the Cordillera Frontal, there appears a great fault of over 1,000 kilometres long, along which some minor thrusting of the Cordillera took place. The Cordillera Frontal reaches to the north, the southern edge of the Puna de Atacama, forming its southern fringe. The age of the Cordillera Frontal is Tertiary.

The Pre-Cordillera extends east of the Cordillera Frontal; it continues northwards disappearing under the volcanic cover of the Puna. Geologically the Pre-Cordillera is formed by Paleozoic, Silurian, Devonian and Carboniferous sediments of a very great thickness. Here again the Hercynian diastrophism has intensely folded and faulted the formations. However, the orogenesis that shaped the Pre-Cordillera was of Tertiary age.

Bordering the Pre-Cordillera in a broad area, extending as far east as the Central Pampas, down almost to the Rio Colorado, and to the north abutting against the southern edge of the Puna, extend the Sierras Pampeanas. They are formed by different blocks of crystalline basement rocks which often appear covered with their original Permo-Triassic sediments. Small Tertiary basins have developed between some of these blocks. The largest of these basement massives, like the Sierras de Córdoba, San Luis and some others, show an eastern dip with a faulted western escarpent. Most of the other and smaller blocks, however, are limited by faults on both sides. The orogenesis that brought about the vertical uplift of the Sierras Pampeanas was undoubtedly of Upper Tertiary age, Miocene and Post-Pliocene.

Puna is the high plateau of Central Bolivia. It has its southernmost limits at about 27° S. Lat.; to the west it is limited by the Argentine-Chile boundary and then by the Domeiko range;

to the east it passes near La Quiaca and is limited by the Cordillera Oriental; to the north it continues as the great altiplano of Bolivia, to the region of Lake Titicaca. In the southern, Argentine, part of the Puna, the previously described structural elements of the Andes appear to be fused, as it is bordered to the west by the Cordillera Principal, to the east by the Cordillera Oriental and to the south by the Cordillera Frontal, and the Sierras Pampeanas. Geologically the Puna is formed in its eastern part by Paleozoic sedimentary formations, partly covered by Cretaceous beds and large areas of semi-acid Miocene and Quaternary igneous rocks. The whole western part of the Puna is formed by eruptive igneous rocks of Upper Tertiary age. The age of the Puna uplift is probably uppermost Tertiary and Quaternary.

The Cordillera Oriental extends along the eastern edge of the Puna and is partly thrust against it. Its southern edge appears at about 24° S. Lat., at the limit with the Sierras Pampeanas. Geologically it is formed by great thicknesses of Lower Paleozoic sediments overlain along its eastern flank by Cretaceous and Tertiary strata. Structurally the Cordillera is intensely folded in imbricated folds and thrust to the east. The age of the Cordillera Oriental is largely Miocene, but its main uplift apparently took place in the Pliocene and Quaternary times.

The Cordillera Sub-Andina adjoins the Cordillera Oriental to the east of it and forms the western edge of the great Chaco basin. Geologically it is built up of thick Tertiary sediments with Paleozoic rocks appearing in the cores of the folds and along faults. It is thrust to the east like the Cordillera Oriental. Its age is largely Quaternary.

North of 22° S. Lat. the Puna element continues up to about 15° S. Lat. forming the great Altiplano or Central Plateau of Bolivia.[9] Structurally it is formed of long and narrow faulted blocks. It may be significant that this plateau appears in the continental bend of western South America, where the trend of the Andean ranges changes sharply from south-north to south-east north-west. The great oceanic troughs off the coast of northern Chile, reaching depth of 8,000 metres also occur west of the Puna. East of it, is outlined the promontory of the Brazilian shield that separates the Amazonian from the Chaco-Pampas basin.

Bordering the Puna to the east, throughout Bolivia, runs the high Cordillera Real of Bolivia, which is the continuation of the Argentine-Cordillera Oriental. It is formed by great thicknesses of Silurian and Devonian sediments. Permian and some Cretaceous strata form long and narrow folds along the foothills of the Cordillera. Tertiary granites break through the Paleozoic sediments along the western edge of the Puna. The structure of the Cordillera Real shows intense folding and faulting. Its age is largely young Tertiary. Extensive faults are exposed in the foothills of the Cordillera Real, where it borders the eastern plains.

To the west of Puna and all along Bolivian border with Chile extends the Cordillera Occidental or Marítima, a totally volcanic range made up of semi-acid igneous rocks, mostly andesites. The Cordillera Marítima merges, geologically, with the northern part of the Coastal Cordillera of Chile.

The Puna proper is covered by a thick blanket of recent volcanic rocks and ashes. A range known as Cordillera Central or Lipes is outlined in the southern part of the Bolivian Puna; it is mostly formed by Paleozoic and igneous rocks.

In Peru, the Cordillera Real joins the Nudo de Vilcanota[1] at about 14° S. Lat. and geologically continues to the north as the Cordillera Central of Perú. Thus the Central Cordillera of Perú is largely made up of Paleozoic sediments. The old crystalline core appears exposed in long stretches of the Cordillera. In its northern extension, the Central Peruvian Cordillera is flanked by considerable thicknesses of Lower Mesozoic and Cretaceous sediments.

The western Cordillera or the main mountain range of Perú runs some 100 to 200 kilometres from the coast, in a south-east north-west direction and parallel to the shore-line. In its largest south-eastern part it appears formed by Tertiary volcanic rocks, mainly andesites, and thus represents a continuation of the Cordillera Marítima of western Bolivia and north-eastern Chile. It borders the Central Cordillera of Paleozoic formations, from which it is separated by the deep longitudinal trough of the Marañón valley, to the east; the division is apparent north of about 13° S. Lat. East of the main western range, the great canyons of Marañón and Huallaga rivers divide the Peruvian Andes into western, central and eastern ranges. The western range, except for its southern part, is formed largely by great masses of granodiorites which to the east are associated with considerably developed Mesozoic, mainly Jurassic, shales and thick Cretaceous strata.

The Central Cordillera of Perú or the range limited by the Marañón and Huallaga troughs as was stated, represents geologically the continuation of the Cordillera Real of Bolivia. It is formed by Paleozoic sediments exposing some crystalline, probably Pre-Cambrian rocks, similar to those of the Vilcanota and Coraballo ranges of south-eastern Perú.

The true eastern range of Perú also begins at about 13° S. Lat. north-west of the Nudo de Vilcanota and running west of the Ucayali valley, between that valley and the Huallaga trough; it crosses the Huallaga and Marañón valleys where these rivers form a marked bend in their courses, and joins the easternmost Cutucú range of eastern Ecuador. The eastern Cordillera of Perú is mostly made up of Cretaceous and Tertiary sediments, with Jurassic and Paleozoic rocks exposed in its core. The uplift of the Cordillera took place in late Tertiary times.

The main or western Cordillera of Perú gradually lowers to the north and near Piura reaches one of its lowest elevations. Farther north the range follows an uncertain trend and at the Nudo de Sabanilla in southern Ecuador, joins the mountain system of Ecuador.

Near Zaruma, at about 3°30′ S. Lat., a distinct separation of the Ecuadorean Andes into Cordillera Oriental and Cordillera Occidental takes place; both continue with a north-north-east trend towards southern Colombia. Near Cuenca, however, the western Cordillera develops a wide spur, which trending about 60° south-west eventually joins the Amotape range of north-western Perú. Throughout Ecuador, between the eastern and western Cordilleras, there extends an inter-Andean Plateau, mostly filled and covered with volcanic materials of recent ejection. The plateau, which is cut by numerous valleys forming separate basins, is probably bounded by extensive faults to the east and west.

The Cordillera Oriental of Ecuador is made up of crystalline rocks, mostly metamorphic schists and granites, while the Cordillera Occidental, besides metamorphic rocks also consists of dark slates interbedded with diorites, grandiorites and various intrusive rocks mostly of Mesozoic age. The age of this

Cordillera Occidental is also Mesozoic. To the east of the Cordillera Oriental, in the Oriente, there appears a mountain range which runs parallel to the main Cordillera, the Sierra de Cutucú.[10] It is made up of Cretaceous and Jurassic sediments covered partly by early Tertiary strata. To the south it joins the easternmost spur of the Eastern Cordillera of Perú; to the north it plunges under the Tertiary plains of the Napo valley.

The Cordillera Occidental and Cordillera Oriental of Ecuador merge in southern Colombia with the Western and Central Cordilleras of Colombia.[11] These branching out from the Nudo de Pasto, trend as parallel ranges in a north-eastern direction, till they disappear as several hilly ranges under the Tertiary cover of the Atlantic coast of northern Colombia. At about 7°30′ Lat. N., the Cordillera Occidental forms a spur in a north-western direction, which, except for the isolated igneous hills, known as Cerro del Cuchillo and Cerro de Tangara, is completely covered by Tertiary sediments of the lower Atrato valley. At Sautata, at about 7°50′ N. Lat., the spur merges obviously with the Serranía de Darién and continues as mostly an igneous range into north-western Panamá. Thus it is evident that the Cordillera Occidental of Colombia has a direct connection with the igneous ranges of Panamá, across the lower Atrato valley.

At about 4° N. Lat., there appear the first folds of the Serranía de Baudo, on the Pacific coast of Colombia, which further north become the Coastal Range or Cordillera de la Costa—the westernmost range of Colombia. The Coastal Range is built up mostly of igneous, semi-acid rocks of a Meso-Cenozoic age. It follows closely the Pacific coast of Colombia and merges to the north with the south-eastern, igneous range of Panamá. A narrow Miocene-Oligocene sedimentary basin separates the north-eastern and south-eastern igneous ranges of Panamá and extends into the Colombian Chocó, to the south. The Serranía de Baudo is also made up of folded, young Tertiary strata.

The Cordillera Occidental is separated from Cordillera de la Costa by broad, longitudinal valleys of Atrato and San Juan rivers, which undoubtedly formed a connection between the Pacific and Atlantic waters in late Tertiary times.

The age of the Cordillera Occidental is late Mesozoic. It is made up mostly of semi-metamorphic and metamorphic slates and quartzites interbedded with great masses of diorites, granodiorites and other igneous rocks. Tertiary andesites are also widespread in its southern part. It is evident that the core of this Cordillera is entirely igneous; some folded early Cretaceous sediments are known to occur on its western flanks. Thus it appears that the uplift of this range took place at the end of Cretaceous time.

The Cordillera Occidental is separated from the Cordillera Central by a longitudinal trough—the Cauca and the upper Patía valleys; this is filled with fresh water and marine Tertiary sediments.

The Cordillera Central is composed almost totally of crystalline rocks, granites, granodiorites and metamorphics; its age is not well defined, but as Ordovician outcrops are known to occur on its eastern flanks, part of it could be of pre-Paleozoic age, but is probably largely of early Mesozoic age.

To the east, the Cordillera Central is separated from the easternmost Cordillera Oriental, by the extensive and deep longitudinal trough of the Magdalena valley and the upper Caquetá basin.

The Cordillera Oriental, geologically and by its origin, is quite different from the other three ranges of Colombia. Beginning as an eastern spur of the Cordillera Central at the Nudo de Pasto, it continues in a north-easterly direction to the depression of Cucuto, where it curves to the north, as the Sierra de Perijá, and at Montes de Oca ends in the Goajira plains.

The Colombian Cordillera Oriental is formed mainly of great thicknesses of marine Cretaceous sediments, in places exceeding 7,000 metres; these overlie Paleozoic strata which rest on older metamorphic rocks. The granitic core of the Cordillera appears along its southeastern ranges until it joins the Cordillera Central and also at its northern continuation, along the whole Cordillera de Perijá. The uplift of the Cordillera Oriental and its age are unmistakably Tertiary.

An old basement swell is the Macarena massive, at about 2°30′ N. Lat., east of the Cordillera in the eastern Llanos.[6] Formed of early Paleozoic rocks with a thin Cretaceous cover, the massive appears as part of the old land-bridge or promontory, that separated the Llanos basin from the southern Amazon basin.

The Sierra Nevada de Santa Marta, on the northern Caribbean Coast of Colombia, appears as a high isolated massive, foreign to the general pattern of the Colombian Cordilleras.[2] It is a triangular rock mass limited by a fault zone to the west and separated from the Perijá range by the rivers Cesar and Ranchería depression. The Sierra Nevada is largely formed of granites and gneiss with abundance of syenites and crystalline schists. Andesites or Tertiary extrusives are apparently absent. The massive appears to be very ancient; although it could have been partly transgressed by Cretaceous seas, it still remained as a high massive throughout Tertiary times. The general strike of the Sierra Nevada rocks is mostly east-west.

Related by composition to the Sierra Nevada are the old basement rocks of the Goajira Peninsula, north-east of it, and the Paraquana Peninsula of Venezuela. Geologically they consist of gneisses, mica-schists and other crystalline rocks which appear to strike in a north east south-west direction. These rocks are certainly not connected with the Perijá range and could be related besides Sierra Nevada to rocks of the island of Curacao. The possibility that these presently isolated elements of the Caribbean coast once formed part of an old borderland, as Schuchert[2] points out, is very suggestive.

The Venezuelan Andes[12] begin north of the Cucuta depression, at the Colombian-Venezuelan border, as Cordillera de Mérida; although it is possible that this range is a continuation of the Cordillera Oriental of Columbia, its geological connection with the Cucuta depression is not quite clear. The Cordillera de Mérida continues north-east and gradually lowering in elevation forms several secondary branches and becomes parallel with the Caribbean range. The Coastal Cordillera of Venezuela, trends east-west and crossing the Peninsula de Paria continues across Trinidad; it breaks off on the eastern coast of that island.

The Cordillera de Mérida is formed of a crystalline core of gneiss and granite, that is overlain by metamorphic schists and early Paleozoic strata. Cretaceous and Tertiary sediments appear to the south and on both flanks of the range. The Caribbean or Coastal Cordillera[13] is largely formed by metamorphic and crystalline rocks overlain to the east, west and south by Cretaceous and Tertiary sediments. The Cordilleras of Venezuela are cross-faulted and somewhat thrust to the south. The age of their uplift is mainly Tertiary.

VOLCANISM.

The volcanic activity is centered in the Andean orogenic belt mainly in the western ranges facing the Pacific. One of the exceptions to this is the volcanic activity in the eastern ranges of Ecuador and the latent volcanism of the Central Cordillera of Colombia.

The Andean volcanoes can be broadly separated in the following groups:[8]

Between 51° and 34° S. Lat. the volcanoes are of Pliocene to Quaternary age and in some instances are distinctly post glacial with a tendency to an increased activity.

Between 28° to 16° S. Lat. there appear hundreds of volcanic cones mainly along the western edge of the Puna. As in the previous group many of these volcanoes follow the longitudinal valleys of northern Chile. Where the longitudinal valleys end the volcanic belt also appears interrupted. The volcanic activity is here related to the Upper Tertiary, Miocene and Quaternary periods. The volcanism represents a continuation of the far more intensive Mesozoic volcanic activity.

Between 5° S. Lat. and 7° N. Lat. the volcanism has been relatively active in recent times; it is mainly Quaternary; the roots of the volcanoes probably reach into Upper Cretaceous and Jurassic sources, since the volcanic cones superpose the Mesozoic batholiths.

The predominating type of volcanic rocks is semi-acid, mainly andesites, and characteristic of a continental, diastrophic volcanism. Basaltic volcanism or lavas such as would be characteristic of ocean basins or great continental fractures appear in very limited areas in isolated cones, mainly in the southern Andean ranges.

EASTERN AND WESTERN RANGES.

The analytical outline of the Andean orogenic belt brings out the persistent radical difference in the composition of the western and eastern Cordilleras of the Andes.

The western ranges are formed totally, or in some instances partly, by great masses of igneous rocks. Thus an extensive batholith of a continental character forms the core of the western Andean ranges. Only in one area at about 6° S. Lat. in northern Perú, is this batholith interrupted by sedimentary

Mesozoic cover. From there on the batholith continues in a broad belt of igneous ranges ending in northern Colombia. A north-western spur of the Cordillera Occidental of Colombia connects it, however, with the igneous ranges of Panamá and Central America. The batholith is composed largely of semi-acid and acid rocks; andesites, diorites, granodiorites and granites, etc. Basalts, gabbro and other basic rocks appear to be less commonly associated with the batholith.

Tectonically the western ranges of the Andes show a normal block faulted structure, such as would be produced by vertical forces. The age of the orogenic uplift of the Western Cordilleras is mostly Upper Mesozoic, but also the Tertiary orogenesis was involved in its later uplift.

In contrast with the western Cordilleras the eastern ranges of the Andes are formed mainly by sedimentary and metamorphic rocks with the crystalline core appearing in long stretches. Great thicknesses of strata varying in age from early Paleozoic to late Tertiary built up these eastern ranges. Mesozoic strata are particularly well developed south of about 33° S. Lat. and north of about 13° S. Lat. Between these latitudes predominate Paleozoic formations exposed in a broad belt of the eastern ranges. Geosynclinal conditions of deposition appear clearly outlined in the eastern Cordilleras of the Andes, north of the Patagonian mesa in Argentina and up to the coastal Cordillera of Venezuela.

At about 6° S. Lat., the eastern Andean geosyncline was evidently connected with the Pacific Ocean through the break in the western Andean ranges; a sea connection between the Pre-Andean basins and the Pacific probably existed through that gap up to Tertiary times.

The structure of the eastern ranges is also predominantly normally faulted and folded; however, moderate thrust faults evidently occur in the easternmost ranges mainly facing the basin plains to the east. Overthrusts of an Alpine type, "nappes de charriage" of a regional character on a large scale, are not known in the Andes.

The age of the eastern ranges is mainly late Tertiary and Quaternary.

The uplift of the western ranges has thus preceded the emergence of the eastern Cordilleras, which appeared in the Andean orogenic belt somewhat after the Andean batholith was formed.

The existence of this barrier west of the geosynclinal trough could explain the eastward thrusts of the eastern Andean ranges. The batholith was thus acting as a borderland west of the trough.

MECHANISM OF THE ANDEAN OROGENESIS.

Having established the difference in time of uplift and age of the main eastern and western ranges of the Andes, we have seen that the western ranges must have formed a more or less continuous batholith since the Mesozoic era, while isolated zones of ancient, probably Pre-Cambrian, massives such as the Sierra Nevada de Santa Marta, Goajira and the southern part of the Cordillera Costanera de Chile, point out that the roots of the batholith might be placed on a Pre-Cambrian or earlier foundation.

The great troughs off the coast of Chile and Perú, as well as the bathymetric maps of the Pacific Ocean which show the lack of a developed continental shelf off the western coast of South America, and the basic igneous composition of the islands distant from the coast (Galapagos Islands), indicate that the idea of a Pacific Continent west of the Andes, as suggested by some authors, who based their theories on apparently fragmentary geological data, lacks evidence. Minor continental extensions, however, did exist in Tertiary times in some areas of the Pacific coast (Pacific coast of Colombia and Ecuador) as can be seen from the stratigraphic development of their coastal sediments.

As a whole, the western outline of the Continent did not change much since the emergence of the western Andean ranges, in the late Mesozoic era. The floor of the marine basins that extended east of the batholith in late Mesozoic times, was partly raised with the orogenic uplift of the western geosyncline. However, at the time of culmination of the uplift of the eastern geosynclinal zone, the western batholith acted as a borderland, thus causing the compressional folding and thrusting of the eastern sedimentary ranges against the continental foreland.

The compression was not caused in the Andean geosyncline by a continental land-mass compressing it from the west; therefore there are no Alpine thrusting effects in the Andes. The tectonic characteristic of the western Cordilleras is of normal faulting, while the eastern Cordilleras show a very moderate thrusting to the east, such as could be produced by static and not dynamic tangential stresses. In other words, thrusting appeared in the eastern ranges because, having met with the resistant wall of the batholith to the west, the rising strata of the geosyncline reclined to the east, against the low-lying edge of the foreland.

This interpretation of the Andean orogenic evolution explains the differences of the Andean tectonic zone, as compared to the contemporaneous Alpine foldings. It also eliminates the conjectural hypothesis of a northern and southern Pacific Continent, west of the Andes, for which there is no evidence.

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