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Paleogeography and History of the Geological Development of the Amazonas Basin

By Louis Loczy

(With 3 Tables)

Contents *)

Abstract

The huge Amazonas Basin, a sparsely inhabited and badly accessible jungle area, covering approximately 2,100.000 sq. km., stirs up the common interest at the present time. The petroleum explorations become chiefly conspicuous.

The Amazonas Basin can be subdivided into two principal morpho-structural units, which differ clearly by their stratigraphical and structural conditions. There are: I—The Lower, Middle and Upper Amazonas Trough in Brazil, and II—The Subandean Zone of Upper Amazonas.

*) Note: The redaction ventures to point out, that editing the above work of Prof. Dr. L. Loczy was impedet by the fact, that the author is living for the time being in South-America, whereas printing and corrections had to be done in Europe. We therefore apologize for eventual errors still remaining in the English text and even more in the Portugese literature titels. We trust that notwithstanding these drawbacks the presentation on the Amazonas basin will be a welcome addition to our knowledge.

H. K. December 1963

The Lower, Middle and Upper Amazonas Trough in Brazil represents an extensive Graben complex, containing chiefly Paleozoic marine rocks, which separates the formerly coherent Pre-Cambrian Guyana—Brazilian Shield.

Faunal and lithologic affinities suggest that during the Silurian and Devonian Periods there existed an intermittant sea connection from the north, through the Caribbean from the East into the submerging Amazonas Trough, through the Continent south-westward to the Bolivian Subandean Geosyncline, across the Rio Beni and Madre de Dios Regions. These Early Paleozoic marine transgressions probably advanced from the South, spreading out in the Middle Amazonas Trough, taking into consideration their predominant austral faunal elements.

In the subsequent late Paleozoic era, the transgression of the Pennsylvanian sea took place from a different direction, namely from the Northwest, from the Subandean Geosyncline area, considering that in Eastern Ecuador, and in the Peruvian Contamana Region the Pennsylvanian deposits which occur are similar to those in the Middle Amazonas Trough, while in the South, in Eastern Bolivia, the Permocarboniferous rocks are partly developed in a continental Gondwanic facies. The Pennsylvanian rocks of the Amazonas Trough contain boreal fauna elements.

After the Paleozoic period the sea receded and did not appear again in the Brazilian Amazonas Trough, with the exception of the Marajó Graben at the mouth of the Amazonas River, the area of which was submerged much later, since it contains 4000 *m* of thick Eocene, Oligocene and Miocene sediments, partly of marine deltaic facies.

During the Triassic and Jurassic eras the greatest part of the Middle Amazonas Trough was covered by lava flows. According to recent drilling results, the Basaltic lava flows overlie the Carboniferous Evaporites and underlie the continental Cretaceous and Tertiary rocks. The structural conditions of this area are chiefly characterized by secondary faults, trending in a SW—NE, SE—NW and N—S direction, which aided the igneous intrusions and extrusions. Compressional foldings are entirely missing.

Only continental and lacustrine Cretaceous sediments were deposited in the Brazilian part of the Amazonas Trough. The Tertiary clastic rocks are of continental origin.

During the Late Tertiary, the rivers were flowing toward the Pacific, effecting powerful erosion and depositing thick sediments in the Western part of Upper Amazonas. The former watershed was probably nearer to the Atlantic side, but at the close of the Tertiary period, during the second Andean Orogeny, due to the strong uplift of the Subandean Zone, the rivers reversed their course to the Atlantic, relinquishing the former watershed.

The Subandean Zone of Upper Amazonas represents one portion of the N—S trending Subandean Geosyncline. The primordial submergence of this Zone probably took place in the Cambrian period, because marine Ordovician rocks are also developed here.

The Subandean Trough of the Western Amazonas Area contains Ordovician, Pennsylvanian and Permian marine sediments, while the Devonian rocks are missing. This fact leads us to believe that during the Devonian formation of land took place.

In the late Triassic and early Jurassic a limited transgression of the sea took place depositing marine sediments, but later during the Middle Jurassic, the sea receded again due to a new emergence.

A general submergence of the Preandean Amazonas Zone occurred in the Lower Cretaceous era, and shallow seas intermittently flooded the whole region depositing thick marine and brackish sediments.

After the Middle Cretaceous period a general emergence began. Marine conditions still prevailed during the Upper Cretaceous and the Early Tertiary eras, however, due to the strong folding movements of the "Incan Orogeny" the sea retreated and thick brackish to fresh-water deposits filled up the basin, which gradually lost the connection with the open sea. The definitive withdrawal of the sea only occurred in the Middle Miocene period, during the paroxysm of the Andean Folding.

The whole Subandean Upper Amazonas Zone, from Colombia to Bolivia, is characterized by strong folding and minor faulting. The folding pressure was generally directed toward the East, to the Brazilian Shield. In general, eastward overthrusted asymmetric folds and faults predominate. The intensity of the folding diminishes eastward.

Introduction

The sedimentary Amazonas Basin of today, represents an immense depression area, extending from the eastern flanks of the Andes to the Atlantic coast. It is limited on the North and the South sides by the crystalline zones of the Guyana and the Brazilian Shield, respectively.

In the last decade, all countries around the Amazonas Basin started extensive petroleum exploration. Recently, especially in the Brazilian, Peruvian and Ecuadorian parts of the Amazonas Basin, intensive systematic geological and geophysical investigations were carried out, which highly contributed to our knowlodge of this vast territory.

Geological publications and reports available already contain very valuable scientific data. However, geological publications which treat larger geographical units, are relatively rare, and these often do not deal with the geological conditions of territories beyond the frontier of the neighboring country.

The object of the present study is to overcome this lack of information. The author has collected and critically evaluated all available geologic data of each geographical unit of the Amazonas Basin, basing his study on uniform principles which pay increased attention not only to precise facies researches and stratigraphical correlations, but also to tectonic and paleogeographic features. He also examined the major geological events, which have occurred in this huge area since the Pre-Cambrian period to the present times.

The author had opportunity to examine the original rock samples and fossils from the Amazonas Basin and from the Acre, in the Museum of the Brazilian Geological Institute (Departamento Nacional de Produção Mineral) in Rio de Janeiro. This study has been of great help in drawing conclusions concerning the history of geologic developments and paleogeography.

The Amazonas Basin can be subdivided into two morphogeological units, which are sharply distinguished by their stratigraphical and structural features. These are: I—The Lower, Middle and Upper Amazonas Trough in Brazil, and II—The Subandean Zone of Upper Amazonas.

However, the Amazonas Basin can practically be divided according to the countries lying therein. Taking into consideration various geological investigations, we can distinguish the following Amazonas Regions:

Lower, Middle and Upper Amazonas Trough in Brazil (States of Pará and Amazonas)

Upper Amazonas Area in Western Brazil (Territory of Acre and State of Amazonas)

Upper Amazonas Area in Northeastern Bolivia (Rio Beni and Caupolican Regions)

Upper Amazonas Area in Eastern Peru (Montana Region)

Upper Amazonas Area in Eastern Ecuador (El Oriente)

Upper Amazonas Area in Southeastern Colombia (Putomayo and Caqueta Regions).

In this paper we discussed the history of the geologic development and the paleogeography in relation to the rocks of the Pre-Cambrian, Ordovician, Sillurian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Tertiary and Quaternary ages, according to the countries lying in the Amazonas Basin, namely, Brazil, Bolivia, Peru, Ecuador and Colombia.

The author expresses his sincere appreciation to the Direction of "Petróleo Brasileiro S. A." (Petrobrás) for allowing the publication of this paper. He is indebted to Dr. Lamego A. R., former director of the Geological Division of the Departamento Nacional de Produção Mineral, for his assistance and permission to use the collections and laboratories of this Institute.

Special thanks are due to the "Geologische Bundesanstalt" for the publication of this paper.

I. Sedimentary Evolution of the Lower, Middle and Upper Amazonas Trough in Brazil

The area of the Lower Amazonas Trough covers the lower part of the present day Amazonas Valley from Monte Alegre eastward to the estuary, including the Marajó Island and the flat lowlands, drained by the lower courses of the large tributaries.

The Middle Amazonas Trough includes flat jungle territory, drained by the Amazonas River and by the lower courses of its tributaries, limited in the West by Manáus and in the East by the mouth of the Tapajós River. The Upper Amazonas Trough extends to the West of Manáus up to the Peruvian-Colombian border.

In the geological sense, the trough is limited on the North and South by the East-West trending contact lines of the Paleozoic sediments with the Pre-Cambrian crystalline complex of the Shields.

Stratigraphic Section of Lower, Middle and Upper Amazonas Trough, Brazil [1])

Quaternary Alluvium Pleistocene	Recent deposits "Varzeas", Terraces, Mud, Sand, etc. "terra firme", Older Terraces. (Continental & fluviatile)
Young Tertiary	Barreiras Formation, Sandstones and Argillites. In surface outcrops (Continental-fresh water) Alter do Chão Formation, Sandstone and clay (Continental-lacustrine) in wells.
Old Tertiary	Red shales in wells of Marajó Graben (Brackish-marine) Unconformity
Upper Cretaceous	Siltstones, shales, sandstones in wells of Marajó Graben (Brackish-marine) Itauajari Formation, sandstones and conglomerates, in Monte Alegre-Region (Terrestric-fresh water) Sucunduri Formation, Sandstone, Shale and Conglomerate with some chert (Continental-fresh water) in wells. Unconformity
Jurassic & Triassic	Basic Igneous Extrusions and Intrusions, Basalt and Diabase. Lava-flows and dikes, in wells. Unconformity
Upper Carboniferous (Pennsylvanian)	Evaporite Formation (Nova Olinda Formation), Salt-anhydrite with shale and sandstone (Marine) Itaituba Formation. Fossiliferous dark limestones and shales. (Marine) Monte Alegre Formation. Sandstone with some shale and conglomerate (Deltaic-marine) Unconformity
Upper Devonian	Ereré Formation. Shales with sandstones (Marine)
Middle Devonian	Curuá Formation. Black slatey, partly bituminous shales with sandstone interbeddings (Marine)
Lower Devonian	Maecurú Formation, White fine sandstones with dark slatey shale interbeddings. Fossiliferous (Marine) Unconformity
Silurian (Gotlandian)	Trombetas Formation. Dark slatey shales with some sandstone. Fossiliferous (Marine) Unconformity
Ordovician? & Cambrian	Acari Formation. Indurated red beds and dolomites, in wells. Uatuma Formation. Compact arcosic sandstone and quarzite (Basal) Unconformity
Pre-Cambrian	Basement, Metamorphic rocks, Porphyry, Granite, Gabbro, etc.

[1]) For more details regarding lithofacies, biofacies, thickness, unconformities, see the "Stratigraphic Correlation Chart of Amazonas Basin" (Table I).

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The first pioneers of geological exploration of this area were: HART C. F., DERBY O. A., and SMITH H. (1871—1877), KATZER F. (1903), ALBUQUERQUE R. de (1926), MOURA PEDRO (1921—1933), CARVAIHO FRANCO P. de (1922).

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The authors of the most important paleontological works are: MAURY C. JOAQUINA (1929), CLARKE JOHN M. (1895), KATZER F. (1903), DUARTE J. (1938), KEGEL W. (1951), SETEMBRINO PETRI (1950—1952), CAMARGO MENDES J. (1956—1957), LANGE F. W. (1956).

Pre-Cambrian

The basement of the Amazonas Trough is undoubtedly formed by Pre-Cambrian Crystalline rocks outcropping in the Guayana Shield on the North, and in the Brazilian Shield on the South which surround the present day Amazonas Trough. In general, very little is known about these immense areas, and the present condition of geological researches do not permit us to make any subdivisions concerning numerous intrusions of older and younger Granites, Granodiorites, Porphyries, Keratophyres, which seem to represent the Archean part, while the Phyllites, Quartzites and Slates presumably belong to the Algonkian era. In general the Metasedimentites are quite scarce. On the revised Geologic Map of the Amazonas Basin, annexed to this paper, the Late Pre-Cambrian and the Early Pre-Cambrian rocks are not divided (Table 2).

Cambrian and Ordovician ??

The Uatuma Formation (Age uncertain, possibly Ordovician), is a typical basement sediment, deposited probably during the transgression of the first sea, upon the metamorphic Precambrian rocks. It occurs not only in the area of the Amazonas Trough, but also in several places in the Central Brazilian Shield.

The Uatuma Formation is correlative with the Ordovician "Cosincho Quartzites" near Ixiamos in the Rio Beni Area (N.E. Bolivia).

The Acari Formation. Recent drillings made by Petrobrás proved the existence of these Pre-Silurian rocks, which underlie most of the central areas of the Upper Amazonas Trough. Its age is probably Ordovician.

Silurian (Gotlandian)

The Trombetas Formation, consists of clastic shallow marine deposits which transgressed on most of the Middle Amazonas Trough. It is correlative with the "Carmen Formation" of the Chiquitos Region (Bolivia) and with the Lower Silurian "Caacupe Group" of Eastern Paraguay (containing also Climatograptus innotatus var. Brasiliensis Rued.). The Silurian marine beds are also developed in the Parnaiba Basin, here, however, they have a different facies.

Devonian

The Lower Devonian Maecurú Formation lies unconformably on the Silurian. Its lithological features and fossil contents suggest shallow marine conditions with typical "Austral" character of the fossil fauna.

The Maecurú Formation is especially developed in the Middle Amazonas Trough. It is correlative with the "Caupolican Formation" in the Rio Beni Region (N.E. Bolivia), containing a similar Trilobites fauna.

The Lower Devonian "Pimenteira Formation" in the Parnaiba Basin has a different facies, containing also "Boreal" fauna elements.

The Middle Devonian petroleum bearing Curuá Formation represents neritic shallow sea deposits, containing typical "Austral" faunal elements. It is correlative whit the equally Austral "Sicasica Formation" in Bolivia. The Middle Devonian "Cabeças Formation" of the Parnaiba Basin has a different biofacies, containing also "Boreal" fauna elements.

The Upper Devonian Ereré Formation of the Middle Amazonas Trough is contemporaneous with the "Longa Formation" in the Parnaiba Basin, which, however, represents a marine-glacial deposition according to Kegel, W. (1957).

Upper Carboniferous (Pennsylvanian)

It consists of three members: The Monte Alegre Formation at the basis, the Itaituba Formation at the middle, and the Evaporite Formation (Nova Olinda Formation) at the top.

The Monte Alegre Formation represents a littoral marine deposition, which overlies transgressively the Devonian beds in the Middle Amazonas Trough.

The Itaituba Formation (limestone, shale, sediments), shows alternating shallow and not very deep marine conditions, with surrounding lowland areas. Its fauna shows distinct "Boreal" characters. The Itaituba Formation is developed in the entire area of the Upper, Middle and Lower Amazonas Trough with the exception of the Marajó Graben where it is absent.

The Evaporite Formation (Nova Olinda Formation), was first discovered in the deep well no. 1 at Nova Olinda. It consists of a sequence of salt and anhydrite, 600 to 1300 *m* with fossiliferous shale, sandstone and limestone interbeddings.

The Evaporite Formation is developed in the Middle and Lower Amazonas Trough, where the structural conditions formed a nearly closed basin which resulted in the sedimentation of purely chemical deposits.

It is remarkable that in the Marajó Graben the Evaporite Formation is evidently absent, according to the drilling results of Petrobrás.

In the Upper Amazonas Trough, from the Purus Arch westward, the evaporites are developed as a thick Itaituba limestone sequence.

The Itaituba Formation can be correlated with the "Tarma Formation" of Eastern Peru, with the "Macuma Formation" of Eastern Ecuador, and with the "Tarija and Rio Beni Formation" in N.E. Bolivia.

The Upper Carboniferous marine beds are also developed in the Parnaiba Basin, however, the so-called "Piaui Formation" shows quite different lithological characters.

Permian

No Permian rocks are known in the Amazonas Trough in Brazil.

Triassic and Jurassic

No sedimentary rocks are known. According to the recent drilling results of Petrobrás, the greatest part of the Middle Amazonas Trough appears to be underlain by basaltic lava flows of varying thickness, which cap the Upper Carboniferous sediments and underlie the terrestrial and fresh water Cretaceous and Tertiary rocks.

Cretaceous

The Sucunduri and Itauajari Formations are terrestrial and contain fresh water deposits, which were separated from the marine Cretaceous rocks of the Subandean Upper Amazonas Region (Acre and Montana).

Tertiary

The Alter do Chão and Barreiras Formations are equally lacustrine and fluviatile deposits, which cover the greatest part of the Amazonas Trough.

In the Marajó Graben, however, brackish marine Tertiary rocks were found by drilling.

II. Sedimentary Evolution of the Upper Amazonas Subandean Zone

II/1. Territory of Acre (Brazil)

This area is situated in the westernmost part of Brazil and covers the immense sedimentary region, which is drained by the Upper Juruá and Javari Rivers. It is limited in the West and the South by the Peruvian frontier. In general, the greatest part of this region is lowland, which gradually slopes downward. Only in the southwestern part of the basin, along the international boundary with Peru, rises the Serra do Divisor above the flooded plain of the tributaries of the Upper Amazonas River. Its highest peak (700 *m*) is in the Môa Mountains. This last mentioned region is a part of the broad foreland, filled with Cretaceous and Tertiary sediments, which spreads between the Andean Cordilleras and the newly emerged Brazilian Shield. It is directly connected with the Contamana Region of Eastern Peru.

References

The first geological expedition in the northwestern part of the Acre Territory was carried out by the "Departamento Nacional de Produção Mineral" in 1935, in which WANDERLEY A., MOURA PEDRO de, OPPENHEIM V., MIRANDA JOSE and BORGES L. X., took part. In 1956, a new paleontological expedition was carried out by the "Departamento Nacional de Produção Mineral" in the Acre region, under the leadership of LIEWELLYN I. PRICE and with the collaboration of the "American Museum of Natural History of New York". Recently, the Petrobrás carried out a reconnaissance survey in Acre.

Until now the publications of the following authors have contributed to the geological knowledge of the Acre Region: WANDERLEY A., and MOURA P. de (1937, 1938 and 1939), ROXO MATHIAS G. (1937), OPPENHEIM V. (1937, 1938 and 1956), BERRY E. W. (1937), MAURY CARLOTTA J. (1937), OLIVEIRA A. I. de, and LEONARDOS H. (1943), SINGWALD J. H. (1937), and OLIVEIRA A. I. de (1956), and LLEWELLYN J. PRICE (1957).

The basement consists of Pre-Cambrian crystalline rocks, which are exposed in the Peruvian part of the Divisor Mountains.

The oldest sediments are the Upper Carboniferous (Pennsylvanion) Quartzite Sandstones with Productus cora. However, it is possible that one part of the Quartzites is equivalent to the Ordovician "Contaya Formation" in the Contamana Region.

The Permian, Triassic and Jurassic are absent in the Acre.

The Lower Cretaceous "Môa Formation" (fresh water sediments rest unconformably upon the above-mentioned "Quartzitic Sandstone". It is correlative with the "Oriente Formation" in the Contamana Region and with the "Hollin Formation" in Eastern Ecuador.

The Middle Cretaceous (Albian) "Rio Azul Formation" represents marine shallow water deposits of the transgressive sea. Its facies equivalents are the "Chonta Formation" in Eastern Peru and the "Napo Formation" in Eastern Ecuador.

Stratigraphic Section of the Upper Amazonas Region of Acre [1])

Quaternary Alluvium Pleistocene	 Fluvial and continental deposits Terrestrial sandstone and conglomerates
Young Tertiary Pliocene and Miocene	 Barreiras Formation; Sandstone and Argillites (Continental-fresh water) Pebas Formation; Sandstones, argillites, lignites (Brackish to fresh water) Slight Unconformity
Old Tertiary Oligocene and Eocene	 Rio Branco Formation; Brown sandstones and argillites Cruzeiro Red Beds; Red shales with sandstone, siltstone and limestone interbeddings (Brackish to fresh water) Unconformity
Upper Cretaceous Danian Maestrichtian Senonian	 Rio Acre Formation; Argillites with evaporites (Brackish to marine) Divisor Formation; White sandstone with clay interbed (Bituminous brackish to marine)
Middle Cretaceous Coniacian Turonian Cenomanian Albian	 Rio Azul Formation; Bituminous shale and limestone (Brackish to marine)
Lower Cretaceous Aptian Neocomian	Môa Formation, Môa Member; Conglomeratic sandstone Capanaua Member; *Pink* sandstone with conglomerate (Fresh water) Unconformity
Upper Carboniferous Pennsylvanian	 Quartzitic Sandstone (Productus cora) (Neritic marine) Unconformity
Ordovician?	Quartzitic Sandstone—partly (Uncertain age determination) Unconformity
Pre-Cambrian	Crystalline Basement; Gneise, Amphibolite, Pegmatite.

[1]) For more details regarding lithofacies, biofacies, thickness, unconformities, see the "Stratigraphic Correlation Chart of Amazonas Basin", table I.

The probable Senonian "Divisor Formation" has a regressive shore facies. It is correlative with the "Vivian Formation" in Eastern Peru and with the "Tena Formation" in Eastern Ecuador.

The brackish marine Upper Cretaceous "Rio Acre Formation" may be correlated with the Maestrichtian "Cachyacu Formation" of Eastern Peru and probably also with the "Tena Formation" in Eastern Ecuador.

The Late Cretaceous ? to Middle Tertiary "Cruzeiro Red Beds" are brackish to fresh water deposits. They can be correlated with the "Puca [1]) Formation" of Eastern Peru.

The presumed Early-Miocene "Rio Branco Formation" seems to be correlative with the "Yahuarango Formation" of Eastern Peru.

The Mio-Pliocene brackish to fresh water "Pebas Formation" outcrops also in Peru between Iquitos and Tabatingo, along the Amazonas River.

The Upper Miocene to Pliocene "Barreiras Formation" is a fresh water sediment, which can be correlated with the "Ucuyali Formation" in Eastern Peru.

The Quaternary rocks contain Mammalian remains, recorded by MOURA P., WANDERLEY A., and LLEWELLYN I. PRICE.

II/2. Northeastern Bolivia, Rio Beni and Caupolican Regions

Geologically very little is known about this area of the Subandean Upper Amazonas Basin, which extends southward from the Brazilian Territory of Acre and the Territory of Guaporé. It is drained principally by the Rio Beni and the Rio Mamoré. The area is limited in the southwest by the Northeastern Bolivian Cordillera.

References

Only few authors have contributed with publications to the geological knowledge of the Rio Beni and Caupolican Regions: These are: EVANS J. W. (1903), LAKE P. (1906), WELTER (1931), SCHLAGINWEIT O. (1941), OPPENHEIM V. (1956), AHLFELD A. (1956), MAURY E. T. (1956), RÜEGG W. (1956).

In the northwest of the Bolivian Subandean Rio Beni and Caupolican Regions the oldest non-metamorphised sediments are the "Cosincho Quartzites", which contain remains of Vermes (Scolithus ?). They are considered of Ordivician age.

Overlying unconformably is the Lower Devonian "Caupolican Formation", which consists of black bituminous shales in the lower section, while in the upper section sandstones are also present. It is non-fossiliferous, and its facies is similar to the Devonian "Monos Shales" in southern Bolivia, which represent the chief oil-source rocks.

[1]) The name "Puca Formation" was, however, later substituted by "Contamana Group" which was the name proposed for this rock-sequence by the "Comission Geologica de la Montana" in 1943.

Stratigraphic Section of the Rio Beni and Caupolican Regions in N.E. Bolivia

Quaternary	Fluvial and continental deposits
Young Tertiary	Subandean Red Beds, Huachi Formation (Terrestrial)
Old Tertiary	Quendeque Clay; Red beds, clays and sandstones (Lacustrine)
Upper Cretaceous	? ? ?
Middle Cretaceous	Bala Sandstone, well bedded hard massive sandstone
Lower Cretaceous	? ? ?
Jurassic	(Absent)
Triassic	Beu Sandstone; Red Permo-Triassic sandstone with conglomerate and tillite (Continental-fluvial Gondwanic facies)
Permian	
Carboniferous	Permo-Carboniferous marine sandstones, marls and limestones with Spirifer and Productus (Marine)
Middle Devonian	Unconformity
Lower Devonian	Caupolican Formation; Bituminous shale and sandstone (Marine)
Silurian	? ? ?
Ordovician	Cosincho Quartzite
Cambrian	? ? ? Unconformity
Pre-Cambrian	Crystalline basement

The Permo-Carboniferous marine rocks, apparently rest conformably upon the Devonian "Caupolican Formation". The former consists of a sequence of marls, sandstones and limestones, occurring in the upper section. SCHLAGINWEIT described pink colored Carboniferous sandstones overlain by fossiliferous limestones containing Productus and Spirifer.

Above the marine "Caupolican Formation" follows the Permo-Triassic "Beu Sandstone" composed of massive red sandstones with conglomerate and tillite interbeddings. It is of continental fluvial facies and it is considered a "Gondwanic deposition". Its thickness is 1200 *m*.

The next overlying formation is the "Bala Sandstone" consisting of a sequence of light gray sandstone about 600 *m* thick, considered as Cretaceous.

The Tertiary "Quendeque Formation" rests directly upon the "Bala Sandstone". It consists of typical Red Beds; clays and sandstones, having an average thickness of 1200 *m* and are folded.

The youngest deposition is the "Huachi Formation" in the Subandean Tertiary Zone, which is composed of terrestrial beds. Its thickness is about 2500 *m* in some places.

II/3. Eastern Peru—Montana Region

The above named area covers the entire vast eastern subandean belt of Peru, extending east of the Andes Mauntains, which is drained by the large tributaries of the Upper Amazonas River, such as Rio Marañon, Rio Huallaga, Rio Ucuyali, Rio Aguaytia, Rio Pachytéa, Rio Urubamba and Rio Madre de Dios.

Geologically this region is part of the broad foreland, which spreads between the Andean Cordilleras and the Brazilian Shield, filled chiefly with Cretaceous and Tertiary sediments.

In general, the greatest part of this area is lowland forming a vast peneplane. Only the "Cordillera Oriental of the Andes" and the subandean ranges which trend NW, namely the "Cushabatay, Contamana Mountains", the "Contaya Dome", the "Pachytéia Mountains", etc., and the so-called "Montana Region", rise above the Ucuyali Peneplane.

References

The following authors have chiefly contributed geological information about the subandean and foreland regions of Eastern Peru, which belong to the vast Upper Amazonas Basin:

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Stratigraphic Section of Eastern Peru—Montana Region

Quaternary	Fluvial and continental deposits
Young Tertiary Pliocene and Miocene	Ucuyali Formation; Unconsolidated, flat-lying fresh water deposits Unconformity Contamana Group; Shale sequence with evaporites (folded) (Brackish to fresh water)
Old Tertiary Oligocene Eocene	Huchpayacu Formation; Red silty shales with siltstone (Brackish)
Upper Cretaceous Danian Maestrichtian Senonian	Cachiyacu Formation; Black shales with Ammonites & Gasteropodes (Brackish to marine) Vivian Formation; Crossbedded sandstone (Brackish-freshwater)
Middle Cretaceous Coniacian Turonian Cenomanian Albian	Chonta Formation; Shale, siltstone and limestone (fossiliferous) (Marine)
Lower Cretaceous Aptian Neocomian	Oriente Formation; Sandstone-sequence with shale interbeddings Huaya Member; (Marine) Agua Caliente Member; (fresh water) Paco Member; (fresh water) Esperanza Member; (fresh water) Aguanuya Member; (fresh water) Cushabatay Member; (fresh water) Unconformity
Upper Jurassic (Malm)	Sarayaquillo Formation (Continental)
Middle Jurassic Dogger	Unconformity
Lower Jurassic Lias	(Absent)
Triassic	(Absent)
Lower Permian	Blue limestone with Schwagerina (Marine)
Upper Carboniferous Pennsylvanian	Tarma Group. Fossiliferous silicious limestone with shale (Shallow marine)
Lower Carboniferous Mississippian	Disconformity (Absent)
Devonian	(Absent)
Silurian	(Absent)
Ordovician	Contaya Formation; Shale underlain by quartzite. Graptolithes (Marine)
Cambrian	? ? ?
Pre-Cambrian	Crystalline basement, Gneisse

(1956), GERTH H. (1955), HOEMPLER A. L. (1953), RUTSCH R. F. (1951), KOCH E. (1959), BELLIDO E. & SIMMONS F. S. (1957).

The descriptions below are chiefly based on the publications of KÜMMEL B., RÜEGG W. and JENKS F. W.

In the Upper Amazonas Contamana Region, the Pre-Cambrian crystalline rocks of the basement are only found by drilling in Cerro Azul and Canchahuaya as well as in the Divisor Mountains, near the Brazilian frontier.

The "Contaya Formation" represents the Graptolite-facies of the Middle Ordovician, which is extensively developed in Bolivia and Peru. It is of hemipelagic facies. The lower part consisting of quartzites, is a typical basement sediment, lying upon the Pre-Cambrian gneisses.

The Silurian, Devonian and Early Devonina Mississippian strata seem to be absent.

The Upper Carboniferous (Pennsylvanian) "Tarma Group" consists of silicious limestones with limy shale interbeddings. Its fossil fauna and lithology indicate a warm, shallow sea environment. The "Tarma Group" is correlative with the "Macuma Formation" in Eastern Ecuador and with the "Itaituba Formation" in the Middle Amazonas Trough.

The Lower Permian "Schwagerina Limestones", overlying unconformably, have been found in the wells drilled in the Ganzo Azul Oilfield, and along the Pongo de Mainique (Urubamba Valley). They are shallow to hemipelagic marine deposits.

The Upper Jurassic "Sarayaquillo Formation" rests with angular unconformity upon the "Schwagerina Limestones". It consists of terrestrial Red Beds (with basic Porphyry intrusions), which were deposited during an arid climate. It is remarkable that in the Huallaga Region there are 21 salt domes established, which penetrate the Middle Jurassic strata. Possibly the age of the primary salt formation is Upper Carboniferous, or Lower Permian.

The "Sarayaquillo Formation" can be correlated with the Upper Jurassic "Chapiza Formation" in Eastern Ecuador and with the Jurassic Section of the "Giron Formation" in Colombia.

The sequence and age of the Cretaceous strata of the Peruvian Upper Amazonas area have been especially investigated by KÜMMEL B. (1948). The sea encroached and regressed in this area four times during the Cretaceous period.

The Early Cretaceous "Oriente Formation" was deposited on a peneplaned surface of folded Ordivician, Pennsylvanian, Permian and Jurassic rocks. Its deepest section is the fluvial "Cushabatay Member" with depositions of coarse sands from the Brazilian Shield. Upon this was deposited the "Aguanuya Member" consisting of shales and sandstones of the encroaching sea. Then follows the "Esperanza Member" composed of black shales with limestone interbeddings, representing the marine depositions of the transgressive sea. Th subsequent "Paco Member" is the regressive shore facies of the Esperanza sea. This regression of the geosynclinal sea to the west culminated in the deposition of the fluvial "Agua Caliente Member". The highest strata of the "Oriente Formation" is the "Huaya Member" which represents the shore facies of the second

Cretaceous transgressive phase that took place in the Aptian time. The "Oriente Formation" is a facies equivalent to the "Môa Formation" in the Acre and to the "Hollin Formation" in Eastern Ecuador.

The Aptian-Turonian "Chonta Formation", consisting of fossiliferous marine shale and siltstone depositions, is equivalent to the "Rio Azul Formation" in the Acre and to the "Napo Formation" in Eastern Ecuador. The latter is considered a petroleum source-rock.

The Senonian "Vivian Formation", consisting of cross-bedded sandstones with shale interbeddings, represents a regressive sea deposit. It is correlative with the "Divisor Formation" in the Acre and with the "Tena Formation" in Eastern Ecuador.

The highest Cretaceous consists of the Maestrichtian-Senonian "Cachiyacu Formation" composed of shales, marls and siltstone with brackish marine fauna. It is correlative with the "Rio Acre Formation" in the Acre and probably with one part of the "Tena Formation" in Eastern Ecuador.

The Early Tertiary "Contamana Group", which apparently overlies the Upper Cretaceous strata conformably, represents a fresh water deposition, consisting of a thick series of red shales, with sandstone and siltstone interbeddings. It can be correlated with the "Cruzeiro Red Beds" in the Acre and the "Tiyuyacu-Chalcana Formation", as well as the "Araujano and Upper Pastaza Formation" in Eastern Ecuador. Kümmel B. (1948) has classified the "Contamana Group" into five formations, which are from top to bottom: the "Huchpayacu Formation" (Oligocene Eocene), "Casa Blanca Formation" (Miocene ?), "Jahuarango Formation" (Miocene ?), "Chambira Formation" (Miocene), and "Ipururo Formation" (Miocene).

Throughout Eastern Peru the folded "Contamana Group" is unconformably overlain by the flat-lying Pliocene "Ucuyali Formation" which consists of unconsolidated clays and sands. It may be compared with the "Peba Formation" of the Acre Territory.

The Quaternary is represented by fluvial and continental clastic deposits.

II/4. Eastern Ecuador—"El Oriente"

In the eastern subandean region, the socalled "El Oriente of Ecuador" extends from the Colombian frontier to the boundary with Peru, and it is limited in the east by Brazil. This area of nearly 100,000 *sq. km* is drained by the large tributaries of the Upper Amazonas River, and belongs morphologically to the Upper Amazonas Basin.

Geologically this region is the northern continuation of the Peruvian Subandean foreland, filled with Cretaceous Tertiary sediments which spread between the Cordilleras and the Brazilian Shield (The Subandean Geosyncline).

Morphologically the above-mentioned region is divided into two distinct areas: The Western Oriente, comprising the subandean zone of hills and mountains with intervening plains above 900 *m*, and the Eastern Oriente consisting of lowlands which gradually slope downward to less than 200 *m* near the eastern frontier with Peru and Brazil.

Stratigraphic Section of Eastern Ecuador—El Oriente

Quaternary	Fluvial and continental deposits, Mesa Formation
Young Tertiary Pliocene and Miocene	Rotuno Formation: Sandstone, clay, tuff, conglomerate (Continental) Unconformity Chambira & Ushpa Formations (Brackish to fresh water) Unconformity Araujuno-Curaray and Upper Pastaza Formations (Brackish to fresh water)
Old Tertiary Oligocene	Tiyuyacu-Chaleana Formation (in the north) (Brackish to fresh water) Cuzutca and Middle & Lower Pastaza Formations (in the south) (Brackish to fresh water) Unconformity
Upper Cretaceous Danian Maestrichtian Senonian	Tena Formation; Eocene-Cretaceous transition beds (Brackish to fresh water) Granitic and Porphyritic intrusions Disconformity
Middle Cretaceous Coniacian Turonian Cenomanian Albian	Napo Formation; Fossiliferous limestone with bituminous shale (Marine)
Lower Cretaceous Aptian Neocomian	Hollin Formation; Quartzitic sandstone (Brackish to fresh water) Unconformity
Upper Jurassic Malm	Chapiza Formation; Red sandstone with shale & evaporites (Brackish-continental)
Middle Jurassic Dogger	Angular Unconformity
Lower Jurassic Lias	Santiago Formation; limestone with shale (Radiolaria) (Marine abyssal) Unconformity
Triassic	(Absent)
Permian	(Absent)
Carboniferous Pennsylvanian Mississippian	Macuma Formation; Silicious limestone with shale and quartzitic sandstone. (Fossiliferous) (Shallow marine) Unconformity (Absent)
Devonian	(Absent)
Silurian	(Absent)
Ordovician	? Pumbuiza- and Margajites Formation; Dark slates with Lingula. Undefined age (Marine) Unconformity Crystalline basement; Granite, Gneisses

References

The first geological investigation in this area was performed by the "Leonard Exploration Company" in 1923, 1927 and 1928. However, the first extensive systematical geological survey was carried out by the "Shell Company of Ecuador Ltd.", later from 1938 to 1950 the "Esso Standard Oil Co. (Ecuador)" was active too.

The publications of the following authors have chiefly contributed to the geological knowledge of the Ecuadorian Subandean Upper Amazonas Area: WASSON THERON, and SINCLAIR J. H. (1927), COLONY R. J. and SINCLAIR J. H. (1928), THALMANN H. E. (1946), TSCHOPP H. J. (1945, 1948, 1953, 1956).

The descriptions below are chiefly based on the publications of TSCHOPP H. J.

The oldest sediments of this region are the Old Paleozoic "Pumbuiza and Margajites Formations", which consist of quartzitic sandstones and slates. They rest unconformably upon the Pre-Cambrian crystalline basement. Both are semi-metamorphic and they can hardly be correlated with any Ordovician or Devonian formation of the subandean zone.

The Upper Carboniferous (Pennsylvanian) "Macuma Formation" overlying unconformably, consists of richly fossiliferous silicious limestone alternating with black shales and quartzitic sandstones. Its lithology and fossil fauna indicate a restricted warm shallow sea with surrounding land areas of relatively low relief.

The Lower Jurassic (Liassic) "Santiago Formation" consists of silicious limestones with cherts and shales. Considering its Radiolaria contents, one may suppose that abyssal marine sedimentation took place. The "Santiago Formation" is correlative with the marine Lower Liassic Limestones of Central Peru.

The Middle to Upper Jurassic "Chapiza Formation" consists chiefly of clayey red sandstone with shale and evaporite interbeddings. Its facies is equivalent to the Jurassic section of the "Giron Formation" in Colombia and to the "Sarayaquillo Formation" in Eastern Peru.

The Lower Cretaceous "Hollin Formation", which overlies unconformably, consists of fresh water to brackish deposits, which represent the shore facies of the transgressive Cretaceous sea. It is correlative with the "Oriente Formation" in Eastern Peru, but it continues also northward into the area of Huila and Caquetá, in Colombia, where its white sandstones have been described by GROSSE E. (1935).

The overlying Middle Cretaceous marine "Napo Formation", with its limestone, sandstone and shale deposits, represents marine neritic depositions of the transgressive Albian sea, along its shelf region.

The Upper Cretaceous to Old Tertiary "Tena Formation", overlying unconformably, represents fresh water to brackish deposits with brief marine ingression at the base.

The Early Tertiary "Tiyuyacu and Chalcana Formations", as well as the "Lower Pastaza Formation" are, in general, brackish to fresh water deposits. They can be correlated with the "Gualanday Formation" of the Upper Magdalena Valley in Colombia and perhaps also with the lower section of the "Contamana Group" in Eastern Peru.

The Late Tertiary "Araujuno-Upper Pastaza and Cruraray Formations" are equally brackish to fresh water depositions, which are correlative with the "Honda Formation" of the Magdalena Valley in Colombia, and with "Chambira Formation" in Eastern Peru.

The Late Miocene to Pliocene "Chambira and Ushpa Formations" are continental and fresh water deposits, containing also pyroclastic rocks.

The Pliocene "Rotuno Formation" and the Quaternary "Mesa Formation" are likewise continental deposits.

II/5. Southeastern Colombia—Putomayo—and Caquetá Regions

The Colombian part of the subandean area of the Upper Amazonas Basin extends between the Eastern Cordillera and the Guayana Shield. It is limited in the north by the Macarena Mountains and in the south by the Ecuadorian frontier.

This pre-andean area of lowlands named the Putumayo and Caquety basins is filled with Cretaceous and Tertiary sediments, while the equally large sedimentary Eastern Cordillera of Southeastern Colombia is composed essentially of Tertiary and Mesozoic and of some Paleozoic rocks.

References

The respective geologic literature of Eastern Colombia deals with small geographical units or with special problems. The most important general studies were written by KARSTEN (1856) and RIEDEL L. (1938). Although very intensive geological studies have been recently carried out by the geologists of various oil companies, only a few of the records have been published. The author has taken into consideration the following publications: GROSSE E. (1935), KEHER W. (1935, 1936, 1939), DICKEY P. A. (1941), OPPENHEIM V. (1940, 1943, HUBACH E. (1945), ANDERSON J. L. (1945), BRUET C. (1947), GERTH H. (1956), and OLSSON A. A. (1956).

The rocks of the Pre-Cambrian shield outcrop only in few places along the southeastern border of Colombia. In general, they are covered by continental Tertiary rocks, the "Barreiras Formation".

Ordovician Graptolithe Shales and fossiliferous Devonian strata on the Macarena Range have been reported by the Shell Company geologists.

The Jurassic, Triassic and Permo Carboniferous marine deposits of the southeastern Cordillera are still little known and not yet differentiated in this part of Colombia.

The extensively developed Cretaceous strata are mostly of marine facies, in this area. The main zone of the Cretaceous depositions referred to as the Colombian Geosyncline, extended through the present Eastern Cordillera, and its eastern edge bordered the Pre-Cambrian rocks of the Guyana Shield. However, this Cretaceous Geosyncline was not everywhere a simple sedimentary trough, but in some places, in the north, it was divided into smaller basins by ridges.

Stratigraphic Section of Southeastern Colombia—Putomayo and Caquetá Regions

Quaternary	Fluvial and continental deposits Mesa Formation
Young Tertiary Pliocene Miocene	San Miguel Formation: Clastic continental deposits
Old Tertiary Oligocene	La Paloma Formation: sandstone and shale Pepino and Mirador Formation: sandstone and shale with basal conglomerate (Brackish — fresh water)
Upper Cretaceous Danian Maestrichtian Senonian	Rumiyacu Formation Mocoa Formation
Middle Cretaceous Coniacian Turonian Cenomanian Albian	Caballos Formation
Lower Cretaceous Aptian Neocomian	Misahualli Formation ? Chapiza Formation Unconformity
Upper Jurassic Malm	Upper Section of Giron Group
Middle Jurassic Dogger	(Absent)
Lower Jurassic Lias	(Absent)
Triassic	Lower section of Giron Group; Siliceous limestone with tuff and chert. (Myophoria and Pseudomonotis) Marine.
Permian	Permo-Carboniferous Strata *not* yet differentiated. Limestone, shale, slate, sandstone. (Productus & Spirifer) Marine
Carboniferous Pennsylvanian Mississippian	(Absent)
Devonian	Sandstones, quartzites, silty shales not yet differentiated. (Brachiopoda & Bryozoa) Marine
Silurian	(Absent)
Cambrian	(Absent)
Ordovician	Graptolithes Shales Unconformity
Pre-Cambrian	Crystalline basement

In the Putumayo and Caquetá Basins the "Chapiza and Misahuali Formations" represent the Lower Cretaceous Neocomian and Aptian. The "Caballos Formation", which is correlative with the "Hollin Formation" in Eastern Ecuador, represents the Middle Cretaceous Albian, while the "Mocoa Formation" (correlative with the "Napo Formation" in Eastern Ecuador) is of Middle Cretaceous Albian to Turonian age. During the great marine transgression of the Middle Cretaceous (Albian) and of the Early Upper Cretaceous (Cenomanian-Turonian and Coniacian), the Colombian trough was flooded, its waters swept south across the Nape Arch of Eastern Ecuador into Northeastern Peru.

III. Chronology of Geological Events and Paleogeography

(see table 3)

By collecting and evaluating a great amount of published and unpublished information available, the author drew conclusions concerning the geological events and also attempted to compile paleogeographic maps of the Amazonas Basin. In his study he has taken into consideration the progress of transgressions and regressions of the sea, the marine overlaps of different geological ages, the paleogeographic and facies changes, as well as the stratigraphical, structural and erosion features.

Pre-Cambrian

The Pre-Cambrian history of the Amazonas Basin area is very little known.

In the Lower and Middle Amazonas Basin, the Pre-Cambrian basement is generally formed by metamorphic rocks and porphyries, which outcrop below the Silurian "Trombetas Formation" along the northern border of the Guayana Shield and the northern border of the Brazilian Shield in the southern belt. The Gneisses, Granitic Porphyries, Granodiorites, Keratophyres are the dominant rocks, which are intensively folded.

In the Middle Pre-Cambrian period there extended probably over the greater part of the central and eastern part of the Brazilian continent an eugeosynclinal trough trending SSW—NNE. This ancient trough was filled with clastic sediments and considerable amount of volcanic material. The existence of Paraschists of undoubted sedimentary origin in the Guayana Shield, described by Choubert B., permit us to suggest that these rocks are also present in the basement of the Amazonas Trough.

At the close of the Pre-Cambrian era a tecto-magmatic cycle folded, metamorphosed, and intruded the amassed formations of the ancient eugeosynclinal trough, which was finally uplifted above sea level. The whole Lower and Middle Amazonas area seems to have remained uplifted above sea level during most of the Cambrian period. Presumably, only at the close of the Cambrian or at the early Ordovician, the area was again submerged and partly invaded by the sea.

Concerning the Subandean Upper Amazonas Basin, our knowledge of the Pre-Cambrian basement rocks in the Eastern Cordillera is equally very limited.

Pre-Cambrian rocks undoubtedly occur in the East Peruvian Cordilleran trough. The widely developed non-argillaceous metasediments are probably of Pre-Cambrian age. They underlie the Graptolite-bearing Ordovician rocks.

In the Ecuadorian Cordillera it is unknown whether all or part of the metamorphic rocks belong to the Pre-Cambrian, or whether all or part of it represent a metamorphic phase of the Early Paleozoic.

In the Andean belt of Peru and Ecuador, the Pre-Cambrian Geosyncline had probably a N—S direction.

At the end of Pre-Cambrian period, the whole Amazonas Area very probably was a coherent vast continent, forming the uniform Brazilian Shield at a time when, the Guayana and Brazilian Shields were not yet separated.

Cambrian

Until now no clearly Cambrian rocks have yet been identified in the Amazonas Basin area, and in its adjacent regions.

All evidences permit us to suggest that the major part of the whole area was land during at least the Upper Cambrian and Lower Ordovician periods. At the close of Pre-Cambrian era the metamorphosed rocks were uplifted and formed the uniform Brazilian-Guayana Shield. The orogenic movements, which have caused the consolidation of the continent, took place in a Pre-Caledonian diastrophic phase, probably due to the "Penokean Orogeny".

The semimetamorphic "Uatuma Formation" and the "Cosincho Quartzites" of questionable geologic age are basement depositions, rich in terrestric material, which were described as Late-Cambrian rocks from the Guayana and Brazilian Shields and as Ordovician from the N.E. Bolivian Caupolican Region respectively.

Ordovician

The oldest fossil-bearing Paleozoic strata of the Subandean Upper Amazonas area, is the Middle Ordovician "Contaya Formation" with Graptolites, which also occur in the Contamana Region in Eastern Peru, near the Brazilian frontier.

The distribution of rocks of this age in other parts of Peru and in Colombia indicates the existence of a Lower Paleozoic Geosyncline approximately in the area of the Eastern Cordillera. The transgression of the sea probably took place from the South, because of the great extension of the Graptolite-bearing Middle Ordovician sea in Southern Peru and in Bolivia, considering that here fossiliferous older rocks, such as the Lower Ordovician and Cambrian strata, are also present.

It is assumed that the Middle Ordovician strata were also deposited in the northern part of the continuous Old-Paleozoic Seaway trending S—N, considering that in Eastern Ecuador the probably Old Paleozoic "Pumbuiza and Margajites Formations" have a connection with the Colombian Middle Ordovician trough.

The limit between the Subandean Old Paleozoic Geosyncline trending S—N and the Brazilian Shield is unknown. It is possible that the Middle Ordovician sea trending eastward reached the Purus arch, considering that recent drilling discovered a Pre-Silurian sedimentary section in the central areas of Upper Amazonas Basin. This suggests an eastern extension of the Ordovician sea.

After the Middle Ordovician period a strong diastrophism took place. During the "Old Caledonian Orogeny", the "Pumbuiza and Margajistas Formations" were intensively compressed in Eastern Ecuador. Evidence of an "Old Caledonian or Taconian Orogeny" seems to be the non-deposition of Upper Ordovician and Silurian sediments in the Peruvian and Ecuadorian Subandean Region.

Until now it was considered that Ordovician beds were not deposited in the Middle and Lower Amazonas Trough and that this area was still land. However, contrary to this opinion, several reasons connected with paleogeography, stratigraphy and paleontology lead us to believe that Ordovician strata may also have been deposited in the Amazonas Trough in Brazil.

It is also possible that the last phase of the Old Caledonian-disturbance produced the gradual submergence of the primordial Amazonas Trough.

The problem of the Ordovician beds in the Amazonas area still has to be elucidated. The fossil content and the stratigraphy of the "Trombetas Formation" need to be restudied urgently. There is reason to believe that the new surface and subsurface surveys performed by Petrobrás will soon clear the above question.

Silurian

According to our present knowledge the advance of the sea in the Lower and Middle Amazonas Trough began in the Lower Silurian period. The first fossiliferous marine sediment was the "Trombetas Formation" which rests unconformably upon the Pre-Silurian basement.

The environment was littoral to shallow marine, as proved by its sandy facies and by its fauna, consisting principally of Brachiopods and Graptolites, including Climatograptus innovatus var. Brasiliensis, Rued.

It can be presumed that the "Trombetas Formation" covered originally not only the present Lower and Middle Amazonas Valley, but also wide parts of the Guyana Shield, as, generally, only littoral shallow marine deposits appear, while shelf depositions are no longer present; an erosion must have occurred later.

In the northern outcrop belt of the trough, the „Trombetas beds" are generally more sandy than in the southern belt, where increased black slatey shales occur, showing that the sea was much deeper southward. Undoubtedly, the fine sand material of the Trombetas rocks was transported from the Guyana Shield.

It is not yet definitely clear whether there exists a hiatus and unconformity between the Lower Silurian and the Lower Devonian strata, or whether a sedimentation more or less continuous took place at the time.

The presumed existence of an unconformity seems to be supported by the thin conglomerate bed at the top of Silurian strata in Itaituba wells, by the time break indicated by the determination of the fossil age and by the overlap of the Silurian by the Devonian from north to south.

On the other hand the high lithological similarity of the Devonian "Maecurú Formation" to the Silurian "Trombetas Formation" that made it impossible until now to locate the contact between the two formations suggests the possibility that the Upper Silurian rocks are also developed in the deepest part of the Trough. In any case, no major diastrophic events have taken place during this period.

The break in the sequence may be simply explained by non-deposition of the Upper Silurian sediments in a continuous marine environment. Especially in the case of an epicontinental sea, as the Amazonas Trough was, such a hiatus may perhaps be caused by non-sedimentation, emersion, or erosion without proceeding folding.

Further stratigraphic studies as well as collecting of fossils are still necessary in order to solve the above problem.

Based on its fauna the "Trombetas Formation" was correlated to the Lower Silurian "Medina" of North America by Derby O. A., and with the "Lower Llandovery" of Europe by Maury C. J.

These affinities suggest the existence of a possible connection of the Silurian sea from the north, through the Caribbean from the northeast, into the submerging Amazonas Trough, and across the middle of the continent, through Brazil, the more so, because they are indications of a probable connection between the Middle Amazonas Trough and the N.E. Bolivian Subandean Old-Paelozoic Geosyncline across the Madre de Dios and Rio Beni Regions.

In Bolivia and Paraguay the marine Silurian is well developed. The lower Silurian "Carmen Formation" of the Chiquitos Region in Northeastern Bolivia, and further southeastward the Silurian sequence in Paraguay with "Climatograptus innovatus var. Brasiliensis Ruedemann" may well be correlated with the "Trombetas Formation". (Recently—1955—Lange W. F. considered the "Carmen Formation" as Upper Silurian.)

There are several other evidences, which lead us to presume that the transgression of the Silurian sea in the Amazonas Trough advanced from the South, from Paraguay, and N.E. Bolivia along the ancient epicontinental shore line formed by the Pre-Cambrian Shield of Paraguay and Mato Grosso.

In the Subandean Upper Amazonas area, in Eastern Ecuador and in Northeastern Peru no formations of definite Silurian age have been recognized.

The Silurian sea appears to have withdrawn partly or completely from the present area of the northeastern half of the Andes along the whole Cordilleran Geosyncline in Eastern Ecuador and in Northeastern Peru. During the Silurian, Devonian and Lower Carboniferous (Mississippian) eras the major part of this region was gently uplifted and the Ordovician beds were strongly eroded. During the Permo-Carboniferous period only was the extension of this part of the Subandean Zone again invaded by the sea.

All these facts are evidence that during the Silurian, Devonian and Lower Carboniferous (Mississippian) ages the Subandean Zone was no longer a continuous sea, because land areas were established especially in the area of the Upper Amazonas, in Eastern Ecuador and in the Peruvian Contamana Region. These uplifts probably were caused by the "Young Caledonian Orogeny" and by the "Acadian Disturbance".

The occurrence of the slightly fossiliferous Silurian rocks of uncertain geologic position in the Sao Francisco Basins perhaps indicates a gulf spreading eastward of the Silurian Amazonas sea; however, a connection seems only possible via the present day Atlantic.

Devonian

In the Lower and Middle Amazonas Trough the advance of the sea which began in the early Silurian period continued in a similar way during the Lower Devonian after a short interruption in the Upper Silurian. During the whole of the Devonian period a continuous sedimentation took place.

The lower section of the Lower Devonian "Maecurú Formation" consists of fine sandstones with a few shale interbeddings at the bottom which turn into hard siltstones. The upper section of the "Maecurú Formation" is composed of silty shales, which have a gradational contact with the black bituminous shale of the Middle Devonian "Curuá Formation" (It contains petroleum).

The lithological conditions and fossil contents of the Devonian strata suggest shallow marine facies, developed along the littoral with expressive "austral" character of the fossil fauna.

According to the abundant plant remains of the "Curuá Formation", it is probable that an alternation of shallow marine and swampy sedimentation took place in the Middle Amazonas Trough.

The Devonian sea was quite extensive, especially in the Middle Amazonas Trough, probably covering also a part of the adjacent Shield areas. It is possible that the fine sands of the "Maecurú Formation" derived from the Guyana Ceará Shield. Katzer F. (1903) explains the sandy Lower Devonian rocks as debris from the surrounding Archaic Continent of Guyana and Ceará. However, the Middle Devonian sea trending eastward was already in communication with the Caribbean Sea.

In the northern area of the Amazonas Trough, the thickness of the Devonian rocks is about 300 *m*. However, much thicker Devonian sediments have been recorded in the deep wells drilled by Petrobrás along the axial line of the trough, where in some places the thickness of the Devonian strata exceeds 900 *m*.

After the deposition of the Upper Devonian "Ereré Formation" the sedimentation breaks off. At the close of the Devonian period a general uplift was in progress practically in the major part of the whole area. This fact is responsible for the regression of the sea and for the beginning of a long period of erosion. These events coincide with the "Acadian Disturbance", which influences the whole continent.

The "Maecurú Formation" is correlated with the Lower Devonian "Helderberg and Oriskany Groups" of North America, by CLARK (1913), based on the similar Trilobites and Mollusca fauna. According to EVANS J. W. (1902) the Devonian rocks of the Caupulican Region in Bolivia are characterized by a fauna very similar to that of the Lower Devonian of the Amazonas Trough.

According to more recent publications, the fauna of the Middle Devonian "Curuá Formation" allows a correlation with the "Sicasica Formation" in Bolivia, and perhaps also with the Upper Section of the Middle Devonian of the "Cabanillas Group" near the Titicaca Lake in southeastern Peru. [See the publications of HARRISON (1943 & 1951) and of NEWELL (1949).]

STEIMANN and KOZLOWSKI correlated equally the Bolivian Devonian with the "Lower Helderberg Formation" (North America), based on the fossil fauna.

Several lithologic and faunal evidences suggest that especially the Lower Devonian Sea did not transgress from the northeast, via the Caribbean, but from the south from N.E. Bolivia, along the northeastern border of the Brazilian Shield, perhaps on the right side of Rio Mamoré, Rio Sepatini and Rio Madeira.

In the south, in Bolivia, the Devonian shows the most extensive development on the South American Continent. According to KOZLOWSKI, in some places the thickness of the Devonian rocks in Bolivia is about 5000 *m*. The extension of the Devonian sediments increases from south to north.

The widest embayment of the Devonian Sea occurs in the latitude of Sucre—Santa Cruz, where the sea spread eastward to the Pre-Cambrian Shield in Mato Grosso.

Zones of different facies can be distinguished along the southwest-northeast section, such as the richly fossiliferous littoral "Icla Foramtion" in the northeast, while in the northern Central Zone, in the Cordillera Real, flysch-like bathyal Devonian rocks are developed.

In Bolivia, in the eastern Subandean Zone occur neritic fossiliferous Devonian sandstones and shales, spreading as far as Mato Grosso and Paraguay along the ancient shore line of the Shield region.

It should be mentioned that the Devonian rocks of the Lower and Middle Amazonas Trough are mainly comparable with the neritic Devonian strata in the Chiquitos Region and perhaps also with the fossiliferous "Itacurubi Formation" in Eastern Paraguay. It must be observed that everywhere in Bolivia and in Paraguay the Devonian rocks lie equally conformably upon the Silurian strata, and that Mississippian sediments are entirely absent. Stratigraphically, the next higher sediments are the fossiliferous Permo-Carboniferous rocks, described by SCHLAGINWEIT, which are present only in the northeastern part of the Bolivian Andes including the Subandean zone near Rio Beni.

Considering the similar conditions above mentioned, it can be presumed that like the Silurian, the Devonian Sea has also advanced from the south into the Middle and Lower Amazonas Trough.

Several authors considered the marine Devonian occurrence in the Parnaiba Basin as a southeastern Devonian embayment of the Amazonas Trough. However, the Devonian rocks of the Parnaiba Basin have different lithologic and paleontologic characters than the Devonian rocks of the Middle Amazonas Trough. This fact suggest that no direct communication to the Devonian sea existed southward across the present-day Toçantin Valley.

Different affinities and paleontologic evidences, such as some boreal fauna elements, including some European forms, suggest that the encroaching of the Devonian sea into the Parnaiba Basin took place from the north, from the Caribbean, via the present-day Atlantic. Thus, during the Devonian period the Parnaiba Basin may also have had a connection with the Middle Amazonas Trough, and through it, toward the N.E. Bolivian Subandean Seaway, at Devonian time.

It might be mentioned that the drilling performed by Petrobrás in the Middle Amazonas Trough give evidence that during the Devonian era a marine inland sea was formed between the Gurupá and Purus Arches, which was almost closed on both east and west sides. In the deep wells of the Marajó Graben no Devonian strata were found upon the crystalline basement.

Also, according to several evidences, there was no direct sea connection between the Amazonas Trough and the Paraná Basin.

The "austral" character of the Devonian strata of the Amazonas Trough allows us to presume that the transgression of the sea did not advance from the north, from the Caribbean, but from the south. However, the place where the sea invaded is still problematic; whether the encroaching Devonian Sea advanced from the southwest via Rio Mamoré and Rio Madeira Region or from the southeast through the present-day Tocantin Valley is uncertain.

The author examined critically all available geologic data on the Paleogeography of the Devonian Sea in South America and attempted to reconstruct an up-to-date Paleogeographic Map of the Lower Devonian Sea of the South American Continent.

In contrast to the Amazonas and Parnaiba Basin, only the Lower Devonian marine rocks are present in the Paraná Basin. They belong to the same marine province as the Devonian of Argentina and South Africa and show an extremely "austral" facies. The invasion of Lower Devonian Sea into the Paraná Basin took place from the south, from Argentina and Paraguay.

According to the newest investigations a probable Lower Devonian Sea-connection existed between the Parnaiba Basin and the Paraná Basin through the Tocantin.

On the other hand, between the Parnaiba and the Corumbá Basin, there existed possibly a short-lived intermittent sea communication during the Lower Devonian. However, the Pre-Cambrian Shield barrier between Cuiabá and Asunción trending N—S separated the two basins for long periods.

In the Western Part of the Subandean Amazonas Area, e. g. in the Peruvian Montana Region and in Eastern Ecuador, the Devonian strata are absent.

The nearest Middle Devonian occurrences are found in the north, in the Cordilleras of Colombia (Floresta-Cachiri-Manaure Regions) and of Venezuela (Memboy area). Further, the Devonian strata are extensively developed in the Northern part of the Perija Range both in Colombia and in Venezuela.

In the west, the next Devonian fauna occurrence, so far, was described from the Chaupihuarunga Valley, near Huanuco in Central Peru, where the underlying strata contain Middle Ordovician Graptolites.

The formation of land caused by the withdrawal of the sea may have continued in the Montana Region from the Upper Ordovician until the Pennsylvanian period. The uplift here was probably caused by the "Taconian and the Acadian Disturbances".

The absence of known marine Mississippian strata in Southern Peru and in Northeastern Bolivia further suggests the continued uplift at the end of Middle Devonian age (Acadian Orogeny).

Lower Carboniferous (Mississippian)

The marine Lower Carboniferous (Mississippian) rocks are entirely absent in the whole Amazonas area, which was a vast "terra firme" (land), where a strong erosion took place in some places, causing a considerable denudation.

At the same time the whole Cordilleran Zone of Ecuador, Peru and Bolivia was equally land.

The nearest occurrences of marine Mississippi sediments are only known in Northern Colombia, and in the south in the Regions of San Juan and Mendoza in Argentina.

The "Poti Formation", probably of the Lower Carboniferous, found in the Parnaiba Basin, is a continental deposition.

The absence of known marine Mississippian rocks in the whole Amazonas Area as well as in the Central Cordilleras is a further evidence of the existence of a strong diastrophic movement and uplift which began at the close of the Devonian age and continued until the Middle Pennsylvanian area, creating a vast land-mass which subdivides the ancient Cordillera Geosyncline.

Upper Carboniferous (Pennsylvanian)

At the beginning of the Middle Pennsylvanian period the Amazonas Trough suffered a downwarp and was gradually invaded by the sea.

The Pennsylvanian sequence begins with the "Monte Alegre Formation", which was unconformably deposited upon the partly peneplaned surface, formed by the Devonian rocks.

The sources of the Monte Alegre Sandstones were apparently not only the surrounding Pre-Cambrian Shields, but also the peneplaned land surfaces formed by old paleozoic rocks.

The absence of marine fossils and the paucity of plant remains suggest that the "Monte Alegre Group" about 250 *m* thick, consisting principally of sandstones and also conglomerate at the base, is a typical littoral deposition, which can be interpreted as a shelf deposition of the transgressive sea, alternating with terrestrial deposits. It consists of nearly 85% of coarse clastics, with a minor percentage of silt and clay.

The Middle Pennsylvanian marine transgression is well documented by the "Itaituba Limestone Formation", which lies conformably over the "Monte Alegre Formation". These richly fossiliferous strata, about 300 *m* thick, show apparently a certain facies change from north to south, as far as the "Itaituba Formation" which consists chiefly of shale, siltstone and some limestone in the northern outcrop belt, while in the southern belt the limestone dominates. This feature may indicate that the less shallow shore of the Pennsylvanian sea extended along the southern border of the Guyana Shield.

The lithology and the fossil content of the "Itaituba Formation" indicate a restricted warm shallow sea with surrounding land areas of low relief.

PETRI (1952), based on his study of the Fusulinas, concluded that the age of the "Itaituba Formation" is Middle Pennsylvanian (Desmoinaian).

As the "Itaituba Formation" can be well correlated with the Middle Pennsylvanian "Tarma Group" in Eastern Peru and with the "Macuma Formation" in Eastern Ecuador, both occurring in the Upper Amazonas Area, it seems to be evident that the Pennsylvanian Sea encroached into the Amazonas Trough from the West. The absence of "austral" fauna elements in the "Itaituba Formation", suggests also a climatic change from the cold or moderate climate of the Devonian era to the warmer sea of the Carboniferous, consequently one can believe that the transgression advanced no longer from the south, but from the west or northwest. Drilling has already proved that the Pennsylvanian strata are developed in the depth of the huge Upper Amazonas Trough, which extends between the Purus Arch and the Subandean Upper Amazonas Zone.

In the Subandean Upper Amazonas Region, in the Cushabatey Mountains, the isolated occurrence of the Middle Pennsylvanian "Tarma Group" (Desmoinaian), which consists of fossiliferous marine limestone rocks about 300 *m* thick, and the still questionable "Quartzite Sandstone", with Productus cora, found in the Môa Mountains in the Brazilian Acre, are the nearest known Pennsylvanian occurrences, which seem to be in direct connection with the "Itaituba Formation" of the Amazonas Trough.

According to LISSON and BOIT (1942) one isolated occurrence of fossiliferous Pennsylvanian rocks is also known farther south in the Madre de Dios Region.

In the north, in Eastern Ecuador, the "Macuma Formation" represents the Pennsylvanian rocks.

The "Tarma Group", like the "Itaituba Formation", is about 300 *m* thick, while the Eastern Ecuador "Macuma Formation" consisting of similar fossiliferous marine limestone and quartzitic sandstone, is about 1400 *m* thick.

The far-reaching lithologic and faunal affinity between the above mentioned Middle Pennsylvanian rocks suggests that large areas of the Upper Amazonas Trough, extending form the Subandean Zone toward the east, undoubtedly contain Pennsylvanian marine rocks in the subsurface.

As the deepest embayment of the Pennsylvanian sea was probably in Eastern Ecuador, it can be presumed that the encroachment of the sea spread out from the northwest into almost the whole Amazonas Trough.

In the Parnaiba Basin, the Middle Pennsylvanian rocks are represented by the "Piaui Formation", which was a marginal embayment of the Amazonas Trough. Although the "Piaui Formation" contains similar fauna to that of the "Itaituba Formation", its lithological conditions are quite different owing to the purplish siltstones, shales and sandstones which predominate.

In the Middle Amazonas Trough, the "Nova Olinda Evaporite Formation" lies conformably over the "Itaituba Formation" as evidenced by its lithological affinity and continuous transition.

The "Nova Olinda Formation" consists chiefly of evaporites (salt and anhydrite), which alternate with thin shale, siltstone and fossiliferous limestone beds. Its fauna indicates that this part of the Amazonas Trough was the site of deposition of alternative marine, brackish and continental deposits. All these facts are evidence that a dry and hot climate dominated during this period.

In the northern outcrop belt, the uppermost section of the "Nova Olinda Formation" shows an increased development of clastic rocks. This fact is confirmed by the shallow shore conditions of the northern Pennsylvanian sea, along the southern border of the Guyana Shield.

The considerable facies change of the Pennsylvanian rocks from west to east, indicates that in the Lower and Middle Amazonas Trough the late Paleozoic Disturbance must have already begun before the close of the Pennsylvanian age. Regional lands were formed in many places by the partial withdrawal of the sea, due to irregular uplift.

According to KATZER F. (1903, pp. 251—254), at the close of the Upper Carboniferous period the sea was partly swampy with narrow zones of land, alternating with relatively deep narrow sea troughs and gulfs, which were separated by low lands.

In the north and east, in Pará, there existed already a continent which closed the Pennsylvanian inland sea toward the east. The Eastern Brazilian Shield in Ceará was connected with the Guyana Shield at the mouth of the Amazonas River (Marajó Island), and along the present-day Atlantic shore. It is possible that at that time a coherent continent already closed the seaway toward the east, to the Atlantic.

In summary, it is probable that at the end of the Carboniferous era there existed an extended landmass at the eastern side of the Amazonas Trough, within the area of the modern Atlantic sea, so that the Amazonas Trough no longer formed an open channel from west to east, between the Subandean Geosyncline and the Caribbean Sea.

The "Itaituba Sea" has opened its way toward the west, to the Subandean seaway, trending N—S.

According to MORALES L. G., the "Nova Olinda Evaporite Formation" was deposited in a nearly closed basin which extended between the Purus and Gurupa Arches and was limited on both north and south sides by the Guyana and Brazilian Shields.

At the end of the Carboniferous the continued upheavel caused the recession of the shallow sea, which was followed by strong erosion. Deposition of Permian strata did not take place. Many reasons suggest that the regional uplift migrated progressively from east to west. The best evidence for this suggestion is the presence of the "Nova Olinda Evaporite Formation" in the Middle Amazonas Trough, which develops westward into marine limestone depositions.

Southward, the Pennsylvanian Amazonas Trough had an almost shallow connection through the Tocantins and Araguaia basins, possibly down to the Paraná Basin, where at that time glacial and fluvio-glacial sediments with very few local marine beds were deposited. In the Parnaiba Basin, however, from the East, the Upper Carboniferous marine "Piaui Formation" encroached from the Atlantic.

Possibly in the Subandean Upper Amazonas Trough there existed a circumstancial communication of the Pennsylvanian sea through a geosyncline trending N—S from Eastern Ecuador through the regions of Contamana, Madre de Dios and Rio Beni into N.E. Bolivia. Thence, eastward, the Upper Carboniferous marine deposits develop with continuous reduction into the continental Gondwanic "Aquidauana Formation" in Goiás, Mato Grosso, which is directly connected with the glacial "Itararé Formation" in the Paraná Basin.

It is noteworthy that according to the results of the most recent surveys, the continental "Aquidauana Formation" occurs also in the Upper Tapajós Valley. The "Parecis Sandstones", formerly considered as Cretaceous deposits, are recently recognized at least partly as Upper Carboniferous "Aquidauana Formation".

Permian

In the Amazonas Trough Permian rocks are absent. At the close of the Carboniferous period the "Appalachian Disturbance", which manifested itself at the same period in the whole northern part of the South American Continent, also occurred here causing a general uplift, a withdrawal of the sea and a subsequent strong erosion.

In the Parnaiba Basin, the sea equally withdrew at the end of the Pennsylvanian period, and the non-marine "Pedra-de-Fogo Beds" consisting of continental red shales and sandstones were deposited.

In the Subandean Upper Amazonas Basin marine Permian strata are present. In the Eastern Montana Region, in Peru, in the Ganzo Azul oilfield, thick marine Lower Permian limestone strata were discovered by drilling. The Lower Permian marine rocks described by KÜMMEL (1950), were also from the Northern Colla-Colla Region, in Peru. The wide Permian belt includes the long, narrow strip of late Paleozoic limestones, extending between the regions of the Pachytéia River and the

Pongo de Mainique. The Permian limestones generally underlie the Cretaceous strata of Agua Caliente.

In Eastern Ecuador, the upper section of the "Macuma Beds" may also represent the Lower Permian.

The Lower Permian marine limestone beds appear to have been deposited together with the Upper Carboniferous rocks in a continuous geosyncline, extending southward from Venezuela through the Eastern Andean Colombia, Ecuador and Peru to northeastern Bolivia.

However, certain divergences in the literature, concerning the definition of the Pennsylvanian and the Lower Permian strata, have to be pointed out. For instance, DUNBAR and NEWELL (1946) put the whole series of dark limestones found in the regions of the Titicaca Lake and Cochabamba, which contain Spirifer condor and Productus fauna, into the Lower Permian (Wolfcampian of U. S. America), taking into consideration their Fusulinas.

On the other hand, several geologists have classified the same dark limestone strata as Middle Pennsylvanian, on account of their extensive macrofauna.

The fossil contents and the stratigraphy of the Subandean Pennsylvanian and Permian is recommended for urgent revision.

At the close of the Lower Permian the beginning of a strong orogeny put an end to the transgression of the late Paleozoic sea and the whole area of the Cordilleran and Subandean Geosyncline became land.

In the whole Andean zone a general emergence, an intensive volcanic activity and a strong erosion took place during the Upper Permian era. Evidently, in the north, the former Cordilleran seaway was interrupted by land from the Middle Permian until at least the beginning of the Lower Jurassic period.

Triassic

No marine Triassic rocks are known in the whole Amazonas Basin. In the entire area uplift, formation of land, igneous activity, renewing of old faults and formation of new ones, as well as a strong erosion took place during this period.

Several morphological evidences seem to prove that during the Triassic the hydrographic gradient had an east-west inclination. Elevations caused by the late Carboniferous upheaval are to be assumed with some probability in the east, in the area of the present Atlantic. The continued emergence during the Triassic age probably contributed to the increase of a barrier which separated the Parnaiba Basin from the Amazonas Trough.

New faults and elongated fractures were possibly formed during this period due to the stress effects of the rising Guyana and Brazilian Shields. Along the elongated fault-planes and fractures generally trending SW—NE, basic igneous rocks intruded into the Paleozoic beds and later violent extrusions also took place covering the eroded and peneplaned surface with lava flows.

In the Subandean Upper Amazonas Basin, the former subandean late paleozoic geosynclinal zone was equally land during the Early and Middle Triassic period. No Lower and Middle Triassic marine depositions are known in Eastern Peru, Ecuador and in Bolivia.

In the south, the nearest Upper Triassic marine rocks occur in Peru, in the Acrotambo Region, and near Huanuco, where the fossiliferous shale-limestone series of Norian and Rhaetian age occur.

In the north, the nearest Upper Triassic (Norian-Rhaetian) marine rocks are known in the Colombian Eastern Cordillera. The "Giron Formation" which has a similar development in Peru, indicates that the marine transgression advanced from the west or from the Pacific region and encroached north-eastward. Their deposits change rapidly from marine to purely continental.

In the British, Dutch and French Guyanas, as well as in Southern Venezuela, occur "Roraima Sandstones" with their associated diabasic igneous rocks (Dolerites), which are generally considered continental Triassic deposits lying unconformably over the Pre-Cambrian rocks.

Recently, ANDRADE RAMOS and OCTAVIO BARBOSA recognized the "Roraima Formation" also in Brazil, in the territorió do Rio Branco; however, they believe that the Lower Roraima Rocks represent the Lower Devonian, while the Upper Roraima Rocks may be Cretaceous.

In the south, in the Parnaiba Basin, the "Motuca Formation" composed of continental sandstone beds and red shales with limestone and gypsum, probably represent the Triassic (see KEGEL W. 1957). However, no definite marine Triassic rocks are known in this area until now.

Jurassic

Marine Lower Jurassic rocks and brackish to fresh water Middle and Upper Jurassic rocks are only known in the Subandean Upper Amazonas Zone, while in the Amazonas Trough in Brazil the Jurassic strata are entirely absent. Land conditions prevailed for a long time in this area similar to those of the Triassic.

The relatively simple structural conditions of the Middle and Lower Amazonas Trough, still reflect the influence of the surrounding Shield areas. During this period no folds, but only faults were formed. Due to stress effects caused by the epeirogenic movements of the Guyana and Brazilian Shields, faults were formed anew chiefly trending SSE—NNE or S—N. Diabase intrusions and Basaltic extrusions also took place as during the Triassic. It is possible that the Monte Alegre Dome was formed continuously from the Triassic to the Jurassic period.

Very strong erosion took place during the Jurassic in the whole Amazonas Trough and enormous amounts of clastics were transported westward by the ancient rivers. Based on the recognizable ancient morphological features, one can presume that the whole area was drained by a river system sloping westward, taking into consideration that the deepest embayment was on the Pacific side, where the Cordillera Geosyncline was already overflooded by the Lower Jurassic sea.

At the same time, on the Atlantic side, there still existed high mountains, which were much more elevated at the end of Paleozoic age, probably extending also into a considerable part of the area of the present-day Atlantic sea.

The Subandean Western Zone of the Upper Amazonas suffered a strong submersion in the Early Jurassic period, but during the late Jurassic period the orogenic uplift commenced.

In the northeastern zone of the Subandean seaway the Triassic denudation phase was followed by the transgression of the Lower Jurassic sea. The Liassic (Sinemurian) "Santiago Formation", which occurs in the Cutucu Mountains in Eastern Ecuador, consists of limestones with bituminous shale interbeddings, about 2000 *m* thick. According to its Ammonites facies (Arietites), it shows close affinities to the Colombian Liassic occurrences in the El Banco area, indicating that the marine transgression advanced from the north.

On the other hand, in the Contamana Region, in Eastern Peru, no marine Lower Jurassic (Liassic) sediments are known. The marine transgression, seems to have reached only as far as the Utubamba Region in North Peru.

The Middle and Upper Jurassic "Chapiza Formation" occurring in the Cutucu Mountains, in Eastern Ecuador, marks the period of a retiring sea, followed by a period of continental flysch-like sedimentation with temporary volcanic activity toward the end of the Jurassic period. The "Chapiza Formation", about 3000 *m* thick, overlies the "Santiago Formation" with angular unconformity. The latter contains evaporites (anhydrite and salt) and also pyroclastics (tuffs and tuff-breccias).

In the Contamana Region, in Eastern Peru, only the Middle to Upper Jurassic "Sarayaquillo Formation" is developed. It is a typical continental "red bed formation", consisting of crossbedded sandstones and evaporites, penetrated by basic porphyry intrusions. It is correlative with the "Chapiza Formation" of Eastern Ecuador and the Jurassic part of the "Giron Formation", of Colombia.

The "Sarayaquillo Formation" indicates that the Contamana Region represents the eastern marginal zone of the Andean Jurassic seaway, as the source of its sediments was apparently the Brazilian Shield to the east.

The question arises whether the evaporites of the "Sarayaquillo Formation" in Eastern Peru, have any genetic affinities with the Pennsylvanian "Nova Olinda evaporites" of the Amazonas Trough. In the Huallaga Region, in Eastern Peru, diapiric salt domes occur in the Jurassic "Sarayaquillo Formation". According to RASSMUSS J. and GERTH H., these salt domes are probably secondary formations, and the source of the evaporites was perhaps the underlying Pennsylvanian estuarine rocks.

During the Middle and Upper Jurassic periods, considerable orogenic movements must have been taking place in the Central Andes Region, raising a barrier which prevented the direct advance of the Upper Jurassic sea from the Pacific into the area of Eastern Ecuador and Eastern Peru. According to TSCHOPP, this barrier must have been developed along the Andean trends, as the facies zones in the subsequent Cretaceious period are distincly caused by a north-south line.

The beginning of the "Nevada Orogeny" may also be well proved by the variety and facies change of the above mentioned Jurassic strata.

The Pre-Cretaceous substratum has been affected by Paleozoic and Jurassic folding along the north-south trends of the ancient Andes in Eastern Ecuador and in Eastern Peru, as evidenced by overlaps and angular unconformities at the base of the Pennsylvanian, of the Middle to Upper Jurassic and of the Cretaceous.

Cretaceous

The greatest part of the Amazonas Trough in Brazil was land during the Early Cretaceous period, where strong erosion, peneplanation took place continuously. Nevertheless, in the Late Cretaceous an increased continental sedimentation commenced in isolated lakes along the ancient valleys. The "Itauajari Formation" in the Monte Alegre Region,, as well as the "Sucunduri Formation" encountered in deep wells, suggest fresh water conditions of sedimentation.

However, in the eastern part of the Lower Amazonas area, in the delta and mouth region of the Amazonas River, the strong submersion continued in echelon faults, trending N—S. The subsurface features of the Marajó Graben, indicated by reflexion-seismic and gravimetric surveys and by several deep exploration wells, suggest that the disintegration of the Lower Amazonas land-belt toward the Atlantic Ocean probably began some time at the end of the Late Jurassic or at the Early Cretaceous.

The Marajó Graben is filled with sediments more than 4000 *m* thick, which include Upper Cretaceous and Old Tertiary marine sediments, however, the existence of Diabase intrusions also suggests the possible presence of Jurassic rocks.

It can be presumed that the Marajó Graben, as well as other contemporaneous Graben areas along the Atlantic side, all belong to the same extensive Graben-system, which was also responsible for the formation of the present-day Atlantic embayment due to the continued submergence of the eastern part of the Brazilian Shield.

Presumably, during the late Cretaceous, the ancient watershed in the Amazonas Trough was still near the Atlantic side, close to the Gurupa Arch.

During the Cretaceous period the emerged Amazonas Trough was separated from the much deeper Maranhão-Piaui Basin by a barrier where also marine Cretaceous strata occur.

In the Subandean Upper Amazonas area, a new general advance of the sea began in the early Cretaceous period. However, the encroachment of the sea did not take place from the west, directly from the Pacific, but from the north, along the present-day Eastern Andes, from the Venezuelan and Colombian huge geosyncline, the eastern edge or shore-line of each, respectively, bordered the ancient rocks of the Guyana Shield.

The base of the transgressive Early Cretaceous sequence, is a sandstone of dune type and of partly cross bedded littoral to fluviatile facies. The Neocomian to Aptian "Hollin Formation" in Eastern Ecuador, the "Cushabatay Member" of the "Oriente Formation" in Eastern Peru and the "Capuana Strata" of the "Lower Môa Formation" in West-Brazilian Acre, all represent the above mentioned lowest Cretaceous strata in the Subandean Amazonas Area.

They are followed by the Albian limestone and glauconite sandstones, showing chiefly marine conditions. The Albian to Coniacian "Napo Formation" in Eastern Ecuador, the Albian to Turonian "Chonta Formation" in the Acre Territory, are representative of the Albian transgression in this area.

In the Late Cretaceous period the sea began to regress, and brackish to fresh water sediments were deposited. These form the "Tena Formation" in Eastern Ecuador, the Senonian "Vivian Formation" in the Acre Territory, as well as the Maestrichtian "Cachiyacu Formation" in the Contamana Region and the probable Danian "Rio Acre Formation" in Acre.

Indeed, the Cretaceous rocks of the Subandean Western Upper AmazonasArea are closely related on account of their transgressive and regressive position on the edge of the Cretaceous Geosyncline. The sea encroached upon some places of this area three or four times.

The "Gushabatay Member", the "Hollin Sandstone" and the "Môa Sandstone" show that the transgression of the Early Cretaceous sea began in this area with depositions of coarse sand originating from the West Brazilian Shield. These sediments were deposited over a peneplaned surface in a littoral fluvial environment.

Undoubtedly, during the antecedent late Jurassic period and the earliest Cretaceous, a strong orogenic movement took place. Due to this movement, an enormous subsequent denudation is to be assumed, because only thus one can explain how the Cretaceous "Oriente Formation" and the "Môa Formation" could overlap rocks of different ages, such as the Jurassic and Permian, in the Pachytéa Region, the Ordovician "Contaya Formation" in the Contaya Region, and the Carboniferous Pennsylvanian Rocks on the Môa Mountains in Acre.

The Aptian sea spread widely throughout the Cordilleras and reached east of the Cushabatay Mountains, depositing the "Esperanza Member" of the "Oriente Formation". A shore facies of this transgression is represented by the "Aguanuya Member" in the Cushabatay Mountains and the "Raya Member" in the Contamana Mountains. This eastward transgression of the Aptian sea may have extended into the Acre Territory through an embayment south of the Contamana and the Contaya Mountains.

In Northern Peru and Eastern Ecuador the Aptian sea deposited limestones and shales. Undoubtedly, the Eastern Geosyncline in Peru was connected with the Colombian Geosyncline through Eastern Ecuador during the Aptian and Turonian periods.

Probably in the late Aptian period the sea receded from the Contamana Region with the deposition of the upper "Raya Member" and the "Paco Member", which are followed by the deposition of the "Agua Caliente Sandstone".

The Albian sea transgressed into the Contamana Region, depositing marine shales and sandstones. A marine embayment may have existed south of the Contamana and Contaya Mountains, in Western Brazil (Territory Acre). In the north, the Albian sea spread over the area of Pongo do Manseriche and Eastern Ecuador.

At the close of the Albian period the sea regressed into the Contamana and Acre Region, depositing the "Huaya Sandstone and shale". At the same time, westward, in the axial zone of the Geosyncline, black bituminous "Carahuacra Shales" were deposited (see WEAVER 1942).

During the Aptian and Turonian ages, the sea transgressed again. The fossiliferous "Chonta Formation" consisting of calcareous siltstones and limestones, is developed along the Contamana Region, Contaya Mountains and Acre (The "Rio Azul Formation"), as well as in the Cushabatay, Pachiteia Regions and in Eastern Ecuador. (The "Napo Formation".)

The marine Coniacian spreads widely over Eastern Peru. In the Santa Clara Region it is represented by the "Chonta Formation", and it is equally developed in the Acre Territory by the upper sequence of the "Rio Azul Formation".

In Eastern Ecuador, on the contrary, the Coniacian is no longer developed, suggesting that during this period the Eastern Peruvian Geosyncline had become separated from the Colombian Geosyncline to the north.

At the close of the Coniacian the sea regressed from the Contamana Region northwest toward the Amotape Mountains, where Middle and Upper Senonian marine sediments were deposited. The receding Coniacian sea deposited the "Vivian Formation" in the Contamana Region, and the "Divisor Formation" in the West-Brazilian Acre, which may be considered a regressive littoral deposit.

In the Middle Senonian period, the sea encroached once more, spreading into the Contamana Region and into the Pachytéia and Perené Regions, depositing the "Cachiyacu Formation". In the Acre Territory occurs the Upper Cretaceous "Rio Acre Formation", which is equally a typical marine to brackish regressive sediment, correlative with the "Cachiyacu Formation". In El Oriente, in Ecuador, the lower section of the "Tena Formation" represents the regressive Upper Cretaceous.

The general emergence due to the advanced Laramic Orogeny in the Andes, caused the withdrawal of the Upper Cretaceous sea in this part of the Subandean Upper Amazonas Area.

The average thickness of the Cretaceous sequence in about 1100 *m* in Eastern Ecuador, about 2500 *m* in the Peruvian Contamana Region, and about 1350 *m* in the Acre Territory in West Brazil.

The transgression of the Lower Cretaceous sea and the advance of the Middle Cretaceous sea took place from the north, along the Preandean Geosyncline. Equally, the shortlived Middle Cretaceous retreat, and the Upper Cretaceous regression took place towards the north.

It is noteworthy that the fossil fauna of Cretaceous beds in the Subandean Geosyncline, in Colombia, Ecuador and Peru, generally show closer affinities to the European and North African fauna than to those of North America.

The Subandean Cretaceous Geosyncline was not a simple trough or embayment of sedimentation everywhere, but in some places was divided into smaller basins by ridges.

The important question of how far to the east the Cretaceous seas have spread into the cratonic part of the Upper Amazonas Basin, and where the eastern margin of the Geosyncline was, has still to be elucidated by drilling operations. It is possible that the epicontinental Cretaceous geosyncline extended also southward along the western margin of the Brazilian Shield, reaching as far as the Beni and Caupolican Region in northwestern Bolivia, where probably the light gray "Bala Sandstone" represents the Cretaceous.

Tertiary

During the Tertiary the whole Middle Amazonas, and the western part of the Lower Amazonas Trough was continuously uplifted. Only in the mouth and delta regions of the Amazonas River, in the Marajó Graben, Eocene, Oligocene and Miocene marine sediments were found in deep wells. Superficial Miocene and Pliocene marine sediments (Pirabas Formation) only occur along the Atlantic coast and in the States of Pará, Maranhão and Piaui.

The greatest part of the Amazonas Trough is covered entirely by the continental clastics of the "Barreiras Formation" which are generally horizontal or show only slight local displacements. The superficial outcrops of this formation appear to be largely from the Upper Miocene to Pliocene age. In the subsurface the Tertiary strata, found by drilling operations in the "Alter do Chão Formation" consist of coarse clastic fluvial deposits.

According to the conception of KATZER F. (1903), during the Tertiary, the rivers flowed towards the Pacific side producing a powerful erosion and depositing thick sediments in the western part of the Upper Amazonas Trough, where the "Pebas Formation" of mixed fresh water to brackish and marine facies, was deposited. As the Andes continued their ascent in the late Tertiary period, the dammed waters forced a drainage towards the Atlantic, reversing the course of the ancient Amazonas River system. However, KATZER's above conception has to be somewhat modified, considering that the former barrier, closing the exit to the Atlantic, did not exist any longer during the Tertiary period. The recent seismic and gravimetric surveys and several exploration wells have proved the existence of a submerged Graben on the Atlantic side, filled with Cretaceous, Eocene, Oligocene and Miocene brackish to marine sediments, over 4000 *m* thick, which indicate a very rapid sedimentation (Maraj Graben).

All these features give evidence that during the Cretaceous and Early Tertiary period a powerful erosion and drainage also took place towards the Atlantic side, taking into consideration the westward widening valley system and other morphological evidence.

Indeed, at the close of the Tertiary period, during the second Andean Orogeny due to the strong uplift of the Subandean Zone, the rivers reversed their course to the Atlantic leaving the former watershed (lying in the east) in the Amazonas Trough.

In the Subandean Upper Amazonas area a very thick, brackish to fresh water Tertiary sequence occurs over large areas.

The change from Cretaceous to Early Tertiary is marked in the Eastern Ecuadorian and Eastern Peruvian parts of the geosyncline by a distinct change from open sea environment to an estuarine and lacustrine one.

The Tertiary in Eastern Ecuador and Eastern Peru comprises a series of fine to coarse clastic sediments of brackish to fresh water facies about 4000 *m* thick. They consist chiefly of red shales with interbedded units of sandstone, siltstone and few limestones. These rocks, which have been previously referrred to as "Red Beds" or "Puca Formation", and recently as "Contamana Group", persist from the Upper Magdalena Valley through the Subandean Colombia and Ecuador to the Montana Region in Eastern Peru. These "Red Beds" also occur in Western Brazil, in the Acre Territory, where they are named "Cruzeiro Red Bed Formation" by OPPENHEIM V. They are, however, apparently very thin in this region.

The above-mentioned "Red Beds" including sediments of Paleocene-Middle Miocene age, are the following:

The Eocene-Oligocene "Tiyuyacu and Chalcana Formation" in the north-eastern part of Eastern Ecuador, and the contemporaneous "Cuzutca and Lower to Middle Pastaza Formation" which overlies with slight unconformity the Upper Cretaceous to Paleocene "Tena Formation".

The Eocene-Oligocene "Huchpayacu Formation" in northeastern Peru apparently overlies conformably the Upper Cretaceous "Cachiuacu Formation", while according to OPPENHEIM V. the Early Tertiary "Cruzeiro Red Beds" in the Acre Territory rest unconformably upon the Cretaceous "Rio Acre Formation".

Towards the close of the Miocene period the whole Subandean Geosyncline was affected by strong folding, faulting and uplift. This diastrophism took place during the "Incaic Orogeny", which has affected the whole Andes and Subandean area of Colombia, Ecuador, Peru and Bolivia.

The broad folding of the Contamana Region produced high anticlinal hills, extending well into the Serra de Môa and Serra de Divisor, in Acre (Western Brazil). The folding pressure came from the west and was directed against the Brazilian Shield.

The Late Miocene to Early Pliocene "Chambira Formation" in north-eastern Ecuador, as well as the correlative "Ucuyali Formation" in north-eastern Peru and the "Peba Formation" in the Acre Territory, the last two, both of similar late Tertiary age, overlie unconformably the older Miocene strata.

The Miocene "Incan Orogeny" was followed by the "Quichua Orogeny", which gave birth to the present structure of the Andes and of the Subandean Zone. During these orogenies, a renewed folding followed a period of extremely rapid denudation in the Subandean Amazonas area. In the Contamana Region, in some places, sediments about 5000 *m* thick must have been removed and the Ucuyali Peneplane was formed. This peneplane is overlain by the flat-lying Pliocene "Ucuyali Formation".

Equally, in the East Ecuadorian Subandean Upper Amazonas area, after the deposition of the Pliocene "Rotuno Formation", the whole region underwent rapid denudation and up to 4000 *m* of sediments were removed. Over the uneven surface, thick "Mesa fan deposits" were spread across the western half of Eastern Ecuador.

According to TSCHOPP, the assymetric ridges of the "Yasuni-Lorocachi Trend" in the northwestern Upper Amazonas area, have not been formed by tangential folding, but rather by faults which reach the Pre-Cretaceous basement.

In the Acre Territory, the undivided Pliocene "Barreiras Formation" apparently overlies with slight unconformity the older "Pebas Formation".

Quaternary

Due to the continued Subandean upheaval, caused by the "Quichua Orogeny" of the Andes during the Pliocene and early Quaternary, the Upper Amazonas Area was uplifted and tilted gradually to the east. This feature resulted in a forced reversal of the course of the Amazonas River towards the Atlantic. The Amazonas and its tributaries have accomplished immense erosion and deposition activity during the Quaternary.

The detritus from the newly uplifted areas was spread over the whole Basin, to form the blanket of fluvial and subaerial argillites, sands, sandstones, silts, and conglomerates, which constitute the Pleistocene "terra firme" and the recent "Varzeas".

The area of the Marajó Graben and the Amazonas Delta is covered by recent formations. Most of the islands of the region of the Amazonas mouth are formed by Alluvium terraces and are subject to constant erosion. In the exploration wells of the Marajó Graben the thickness of the Quaternary rocks was about 250 *m*.

In the Upper Amazonas area, in the subandean and foreland regions of Ecuador, thick volcanic and fluvial fan deposits spread from the eastern ranges of the Andes over Oriente, covering the older formations over wide areas. These fan deposits form various terrace levels.

The various Mesa levels between 1460 *m* and 450 *m* above sea level were brought about by periodic rejuvenation and subsequent changes of the drainage. It is probable, that the periodic epeirogenic tilt of the Andes was responsible for the various Mesa levels. The average thickness of the quaternary rocks is about 100 *m* in the eastern low-lands of Eastern Ecuador.

In the south, in the foreland regions of Eastern Peru and Western Brazil (Acre), the Quaternary deposits are also well developed. They consist mostly of essentially coarsely clastic continental sediments which form fans, terraces, mesas and cuestas.

The broad alluvial plains of the meandering Amazonas tributaries are covered by flat-lying Pleistocene and Recent rocks, consisting of argillaceous, sandy and conglomeratic sediments.

IV. Tectonic Evolution of the Amazonas Basin

IV/1. The Amazonas Trough in Brazil

The fundamental elements of structural events of the Amazonas Trough were determined by DERBY O., KATZER F., SMITH H., CHANDLESS F. E., MOURA P. de, OLIVEIRA I. A. de, and recently by MORALES L. G., who summarized the results of recent geological surveys carried out by Petrobrás from 1954 to 1959.

In general, the Amazonas Trough in Brazil was regarded as an ancient "Geosyncline" of long persistence, which was first submerged after the Early Cambrian, and secondly during the Upper Carboniferous. Nevertheless, in the strict sense of the word, from the tectonic point of view, this definition has to be modified, considering that this area represents a Cratogenic Intershield Trough, the sediments of which were never affected by any compressional folding. The whole area is characterized by faultings of different geologic age.

According to the author's conception, the Lower and Middle Amazonas Trough represents an extended Graben-Complex, which separates the formerly coherent Guyana and Brazilian Shields.

Since the central part of the lowlands is covered by flat-lying Cretaceous Tertiary and Quaternary deposits, the structural interpretation of the subsurface is revealed chiefly by geophysical surveys and drilling operations. Until the end of 1959, Petrobrás drilled about 98 deep wells in the Amazonas Area, which greatly contributed to its geological knowledge.

Based on seismic refraction work and drilling results, MORALES L. G. described three regional Arches indicating ridges which possibly joined the Guyana and Brazilian Shield.

1. The Iquitos Divide in the Upper Amazonas Trough is the westernmost N—S trending arch, evidenced by seismic refraction and gravity meter surveys.

2. The Purus Arch—The existence of this barrier has been proved by drilling operations at Coari, Labrea, Três Bocas and Tapana. No Silurian and Devonian rocks were found below the Upper Carboniferous limestones, which overlie directly the Pre-Silurian basement.

3. The Gurupa Arch is the easternmost regional barrier, which separates the Marajó Graben from the Middle Amazonas Trough. The eastern flank of this divide suffered a fault displacement of about 2000 *m*.

MORALES believed that all the three above mentioned arches had their genesis during the Lower Devonian uplift, which continued throughout the Paleozoic. He explains the formation of the Nova Olinda Evaporite sea closed on both sides to the East and West during the Upper Carboniferous by the further upsurgence of the Purus and Gurupa Arches.

The existence of Fault structures was proved by surface surveys carried out in the tributary valleys on the flanks of both shields, in the north and in the south, respectively. The Paleozoic rocks have a general west-east strike and dip 1° to 3° south or southwest at the northern border of the Guyana Shield. The regional structure seems to be simpler in the northern belt than in the southern belt, where irregular strikes and frequent faults with increased dips have been observed (Tapajós Valley).

However, the relatively simple tectonic structure shows some complications in some places. Stronger disturbance of the beds could be observed especially near the SW—NE trending faults, which are often associated with Diabase intrusions and basaltic extrusions.

One of the most interesting local structures is the "Monte Alegre Dome", described first by KATZER F., which was formed due to an uplift caused by a considerable igneous intrusion and extrusion. It is a typical Pierced Fault Block structure.

The reflexion seismic surveys indicate structural heights at several places in the subsurface of the trough's interior. One of such structural features is the Fault Block Structure at Nova Olinda 9 *km* long, 3 *km* wide trending N—S (having a closure of 60 *km*), in which the first oil well, the No. 1 Az, was drilled in 1954.

The dominating major faults trending SW—NE have been formed repeatedly since the early Paleozoic and have been renewed during the Mesozoic and Tertiary times.

The geomorphology of the northeast-flowing rivers such as the Purus, Madeira, Tapajós, allow us to suppose that the east—west trending trough has been complicated by several of such cross faults trending SW—NE, contributing probably to the formation of fault blocks.

According to the author's conception it is quite possible that also the above-mentioned major Arches are related to fault block systems.

During the Mesozoics, the elongated and revived faults trending SW—NE and S—N habe also probably created fault blocks which are often associated with diabase intrusions and basalt extrusions.

According to the older literature one can consider that there may exist three different principal fault trends in the Lower and Middle Amazonas Trough.

It is remarkable that the oldest major faults have a SW—NE trend, running parallel with the general strike direction of the Pre-Cambrian rocks of the Brazilian Shield.

The younger faults trending W—E are parallel to the axis of the present-day Amazonas Valley, while the faults trending SE—NW were probably formed during the Andean Orogeny in the Tertiary. The parallel NW—SE course of the northern tributaries of epigenetic character are indicative of the possible existence of the later fault-direction.

The easternmost part of the Lower Amazonas, the Marajó Graben, in the region of its mouth, represents a lowland belt, where the seismic and magnetic surveys have indicated the existence of a system of "Échélon-faults" generally trending in a SSW—NNE direction.

Several deep wells drilled by Petrobrás proved that the thickness of the Upper-Cretaceous and Tertiary sediments of the Marajó Graben exceed 4000 *m*. It is noteworthy that in the area of the Marajó Graben no Paleozoic rocks, such as Silurian, Devonian and Carboniferous sediments have been found.

The most important tectonic events of the Amazonas Trough in Brazil can be resumed as follows:

The primordial Amazonas Trough was formed at the end of the Cambrian due to a strong subsidence, which created a Rift Valley trending

SW—NE in the Pre-Cambrian Shield not yet divided. This first trough was probably running from the up-to-date NE Region of the Bolivian Rio Beni to the Atlantic side of the Amazonas Basin.

The absence of Devonian rocks in the northern part of the Upper Amazonas Trough, westward from the Purus Arch, can be explained by the epeirogenic uplift, beginning in the Devonian, caused by the "Acadian Disturbance". Later, the uplifted area became larger and larger due to the continued upheaval up to the Upper Carboniferous period (Pennsylvanian), so that at the end of Devonian land was formed by the withdrawal of the sea in the entire Amazonas Trough. The hiatus of the Lower Carboniferous Mississippian rocks is the most important evidence of this conception.

The second principal immersion of the Amazonas Trough occurred in the Upper Carboniferous along an axis line trending W—E, evidenced by the Middle Pennsylvanian marine transgression. The sea encroached from the Pacific, overflooding the major part of the Amazonas Trough to the Atlantic.

The late Paleozoic "Appalachian Disturbance" must have already begun at the close of the Middle Pennsylvanian. The thick evaporites of the "Nova Olinda Formation" suggest a quick withdrawal of the sea in the Middle Amazonas Trough. [1])

The absence of Permian, Triassic and Jurassic sediments, the formation of faults trending SW—NE, associated with diabase intrusions and the basaltic lava flows, as well as the manifestation of a strong erosion, are the

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[1]) Remark: It is still unknown whether the evaporites of Amazonas Trough form part of the normal stratigraphic sequence in the whole extension of the closed Upper Carboniferous Basin, or whether they are in some places already accumulated into masses.

Considering the enormous extension and the great thickness of the salt rocks it seems to be rather unlikely that salt domes should be totally missing in the whole Amazonas Trough.

According to the drilling results, the thickness of the evaporites show significant differences also over small distances. For instance the thickness of evaporites was found in the Wells Nova Olinda No. 1. 1213 *m*, in the Nova Olinda No. 2. 1448 *m*, in Cupari No. 1. 635 *m*, in Abacaxi No. 1. 1545 *m*.

It is well possible that the evaporites already have been mobilized beneath some places, where the pressure of overlying sediments was reduced due to erosion or to structural weakness, caused by faulting. Under such conditions, also in the Amazonas Trough salt could have been accumulated. Although piercement domes have not yet been formed, they may have given rise to buried elevated ridges along the major northeast trending post-Paleozoic faults.

The basic igneous rocks which overlie the evaporite-sequence, where extruded from similar fault systems, which resulted from tensional forces created by the uplift of the Guayana and Brasilian Shields.

The detection of probably existing salt-structures of the Amazonas Basin would be of great economic importance, not only for salt-mining, but also for petroleum-exploration.

The discovery of salt ridges or other salt structures could give new prospects to the oil-exploration. Large elevated fault-blocks could indicate, where the reservoirs of the Monte Alegre and Curua Formations might contain oil traps.

In any case, it is recommended to take into consideration the possibility of salt-structures and associated fault-block structures with view to the future petroleum prospection of Amazonas Basin.

best evidences that, due to the general emergence, the whole Amazonas Trough in Brazil became land at the close of the Carboniferous.

During the Cretaceous and Tertiary, new faults trending E—W and SE—NW originated, and old fault planes were reactivated due to the Andean Orogeny.

Conclusions regarding the Origin of the Amazonas Trough in Brazil

According to the above mentioned evidences, the present-day Amazonas Trough in Brazil was created by the formation of three different embayments of different geological age, namely:

1. Based on results of recent drilling operations performed by Petrobrás, one can assume the existence of an ancient primitiv Pre-Silurian Embayment, which extended only in the Upper Amazonas Area between the Andean Zone and the Purus Arch.

2. The presumable Early Paleozoic (Silurian & Devonian) primordial Trough trending southwest—northeast, parallel to Rio Madeira, running from the NE region of the Bolivian Rio Beni to the Atlantic side.

3. The Late Paleozoic (Pennsylvanian) embayment trending West—East, extending from the Maranhão and Andean Zone eastward into the major part of the whole Amazonas Trough, along the main axial trend of the present-day Amazonas Valley.

In the southern belt, at 58° W Longitude, the outcropping border of the Pre-Cambrian Shield begins to plunge southwestward parallel to the Valley of Rio Madeira, into the region of Rio Beni, near the Bolivian frontier; hereby, the sedimentary basin becomes assymetric, as the Pre-Cambrian border axis trending East—West runs southwestward.

However, the hypothetical Silurian-Devonian Trough appears to become narrow southwestward, and has not reached the Subandean Upper Amazonas Area to the west, considering that west of the Purus Arch the Silurian and Devonian rocks are absent, as far as Eastern Ecuador and the region of Contamana in East Peru.

According to evidences of both lithologic and biologic facies, the transgression of the typically "austral" Silurian and Devonian Sea probably advanced from the southwest, from Northeastern Bolivia, or from Southeastern Paraguay. Nevertheless, the supposed Silurian-Devonian Trough becomes much narrower in the South, because in the regions of Rio Beni and Madre de Dios, the West Brazilian Arch appears to extend also along the Eastern Cordillera, forming the eastern margin of the Subandean Geosynclinal belt. In general this West-Brazilian Arch is covered by Tertiary and also partly by Cretaceous sediments.

In the Middle Amazonas Trough the Silurian & Devonian basin becomes wider, but it extends only as far as the Gurupa Arch. It is notable that on the Atlantic side the Silurian-Devonian Trough becomes again very narrow, considering that in the Marajô Graben the deep wells drilled by Petrobrás did not find any more Silurian and Devonian rocks.

According to the discussed features the primordial Silurian-Devonian Amazonas Trough represents an elongated Rift Valley as compared to the Upper Carboniferous Amazonas Trough, which formed a wider basin.

IV/2. Tectonic events in the Subandean Amazonas Area

The long-drawn Subandean Geosyncline, which trends more or less parallel to the present-day Andes, seems to be somewhat older than the Middle and Lower Amazonas Trough, as it has been already established before the Ordovician period. The Middle Ordovician Graptolite Shales were deposited in a continuous seaway from Southern Bolivia to Northeastern Peru, and thence northward to Colombia.

The earliest orogeny belongs possibly to the Caledonian or Pre-Devonian folding period (Taconian or younger phase), which affected the Lower Paleozoic rocks of the Contaya area.

During the Silurian and Devonian periods, when the Middle Amazonas Trough was flooded by the sea, the Preandean seaway in the Upper Amazonas area was interrupted by land. The absence of known Silurian and Devonian marine rocks in the Montana Region (in Peru) and in Eastern Ecuador, suggests that a strong regional orogeny and uplift occurred here, during this period. The uplift of the Pre-Cambrian Shield in Northwestern Acre (Môa and Dividor Mts.), probably occurred simultaneously. This strong regional disturbance probably took place due to the "Acadian Orogeny".

The above-mentioned interruption of the Subandean sea due to this strong uplift during the Early Paleozoic period is also well manifested by the present morphological frame of the South American Continent, as the most prominent western part of the continent ranges in the latitude of a connecting line between the Guayaquil Gulf and the Amazonas axis.

A new submergence and transgression of the sea in this part of the Subandean sea first took place in the Middle Pennsylvanian period. The end of the Paleozoic period was marked by a strong orogeny and formation of land, as well as by a subsequent denudation during the Upper Permian and Early Triassic periods. The manifestations of this disturbance were observed especially in the Sira Mountains, and in the Region of the Rio Urubamba. It probably represents the "Young Paleozoic" or "Appalachian Revolution", most likely in the form of a block-faulting.

The Late Triassic sea extended only in the zone of the present Central Cordillera of Northern Peru.

The next new transgression in the Subandean Zone began only in the Early Jurassic period. However, in the Late Jurassic a new uplift and regression of the sea occurred again, with subsequent formation of land and a strong denudation.

There are many evidences which show that the Upper Jurassic strata were folded in the Region of the Rio Cushabatay, as the "Rayo Well No. 1", at the northern slope of the Contamana Hills showed unconformity between the Kimmeridgian-Portlandian and the Lower Cretaceous strata. The folding was probably caused due to the "Nevadian Disturbance".

In the Early Cretaceous period occurred a new strong submergence and subsequent transgression of the sea. Thick Cretaceous sediments were deposited in an epicontinental basin at the western margin of the Brazilian continent.

During the Late Cretaceous a general emergence began again, causing intense tectonic disturbance, which provoked the subsequent withdrawal of the sea.

According to STEINMANN, the "Peruvian Folding" which is well established in the Central Andes at the end of the Cretaceous period, as well as the "Incaic Paroxysm" in the Early Tertiary (equivalent to the "Laramide Revolution") were of minor importance in the Subandean Upper Amazonas Area.

It is probable that in the area which includes the Ganso Azul and Northern Sira structures, and part of the Rio Urubamba Region, there was little folding of the Paleozoic strata previous to the Pliocene orogenic movements. In general, no major displacements occurred in these regions until the late Tertiary.

In the Tertiary period a strong folding occurred and the definitive withdrawal of the inland sea took place. The eastern margin of the Cordillera was overfolded and partly overthrusted toward the east, to the newly emerged Brazilian Shield, especially in the northwestern part of the Acre.

Undoubtedly, the most decisive event in the tectogenesis of Eastern Peru is the surrounding active "Andean" or "Cuechua-Folding" lasting from the early to mid-pliocene period, which contributed greatly to the present morphological frame-work of the Subandean Upper Amazonas area. The final stage of this orogenic movement is probably still in progress.

In the Andes, during the same time, enormous masses were mobilized due to these orogenic movements. It is apparent that sedimentary groups all together moved over a deep-seated thrust plane, and were pushed up and overthrusted against the Upper Amazonas foreland; forming from west to east a series of symmetrical and partly recumbent folds. During this most recent revolution the renewed West Brazilian Shield served as a massive resisting block, which is no longer affected by the folding.

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Stratigraphic Correlation Chart of the Amazonas Basin

based on reference datas compiled by

Louis Loczy

Loczy—Table 1

Era	System	Series		Lower and Middle Amazonas Area in the States Para & Amazonas	Western Part of Upper Amazonas Territory Acre and State Amazonas	Southwestern Part of Upper Amazonas Rio Beni and Caupolican Region in Bolivia	Western Part of Upper Amazonas Area Contamana Region in Eastern Peru	Northwestern Part of Upper Amazonas Area El Oriente in Eastern Ecuador	Northwestern Part of Upper Amazonas Putomayo and Caqueta Basin in Colombia	Series		System
CENOZOIC	Quaternary	Alluvium Pleistocene	Recent Subrecent	Continental & fluviatile deposits. „Varzeas" "Terra firme"	Fluviatile and continental deposits.	Fluviatile and continental deposits	Fluviatile and continental deposits.	Fluviatile and continental deposits.	Fluviatile and continental deposits "Mesa Formation"	Recent Subrecent	Alluvium Pleistocene	Quaternary
	Tertiary	Neogene	Pliocene Miocene	"Barreiras Series" Sandstones and argillites along axis of Amazonas Basin (in surface outcrops) correlative with "Alter do Chao Formation" 310—350 *m* in borings. Sandstone, clay, siltstone and basis-conglomerate with plants. Both are fresh-water deposits. "Lower Section of Siltstones and Sandstones in the Marajo deep wells." Foraminiferes. Marine-brackish	"Barreiras Series" Plants and fresh-water fossils. Continental to fresh-water deposits "Pebas Formation" Sandstone, argillite, lignite. Brackish to fresh-water deposits with rich molluscan fauna. Slight Unconformity "Rio Branco Formation" Brown sandstone and argillites.	"Subandean Red Beds, Huachi Formation" terrestric beds, 2500 *m*	"Ucuyali Formation" Variegated clay and unconsolidated sandstone with fresh-water molluscs and plants. Unconformity "Contamana Group" 1500—3000 *m* Predominant shale sequence with evaporites. Brackish to fresh-water deposits, as the "Ipururo, Chambira, Yahuarango, Casa Blanca Formations"	„Rotuno Formation" 100 *m* Continental sandstone, clay and volcanic rocks; tuffaceous clay & conglomerate. Unconformity "Chambira Formation" & "Ushpa Formation" 1500 *m* Northern facies—Southern facies. Both are brackish to fresh-water deposits. Unconformity "Araujuno-Curaray- & Upper Pastaza Formations" 700 *m* Brackish to fres-water deposits.	"San Miguel Formation" clastic continental deposits.	Pliocene Miocene	Neogene	Tertiary
		Eogene	Oligocene Eocene Paleocene	Lower section of siltstones and sandstones in the Marajo deep wells. Foraminiferes. Marine-brackish	"Cruzeiro Red Beds" Red shales with sandstone, siltstone and limestone interbeddings. Brackish to fresh-water deposits. Unconformity	"Quendeque Clay" 1250 *m* exact geologic age undefined. Red beds, clay, sand, sandstones. Lacustrine facies.	"Huchpayacu Formation" 150 *m* (The lowest section of the Contamana Group) Red silty shale with siltstone. Brackish molluscs.	"Tivuyacu-Chalcana Formations" 500 *m* Northern facies. Brackish to fresh-water deposits. "Cuzutca- and Middle & Lower Pastaza Formations" Southern facies. Brackish to fresh-water deposits. Unconformity	"La Paloma Formation" Sandstones and shales. "Pepino and Mirador Formations" Green sandstones & shales with basal conglomerates.	Oligocene Eocene Paleocene	Eogene	
MESOZOIC	Cretaceous	Upper	Danian Maestrichtian Senonian	Probably Cretaceous shales and siltstones with Diabase-intrusions in the Marajo deep-wells. Foraminiferes and Algae. Marine-brackish	"Rio Acre Formation" Argillites with evaporites. Brackish to marine deposits "Divisor Formation" 150 *m* White sandstone with clay interbeddings. Bituminous brackish to marine deposits.	? ? ?	"Cachiyacu Formation" 150 *m* Black shales with Ammonites & Gastropodes. Brackish-marine deposits. "Vivian Formation" 140—400 *m* Crossbedded sandstone. Brackish to fresh-water sediments.	"Tena Formation" 240—800 *m* Eocene-Cretaceous Transition beds. Brackish to fresh-water deposits. Disconformity & Slight Erosion Granitic and Porphyritic intrusive rock. Disconformity	"Rumiyacu Formation" "Mocoa Formation"	Danian Maestrichtian Senonian	Upper	Cretaceous
		Middle	Coniacian Turonian Cenomanian Albian	"Sucunduri Formation" (continental:) sandstone-shale, conglomerate in drillings "Itaujari Formation" in Monte Alegre Region. (Exact geologic age undefined) Dark sandstone with conglomerate and few shales. Plants. Fresh-water to continental. Unconformity	"Rio Azul Formation" 800 *m* Bituminous shale and limestone. Brackish to marine deposits.	"Bala Sandstone" 600 *m* Light yellow, well bedded hard massive sandstones of undefined age, probably Cretaceous ?	"Chonta Formation" 150—650 *m* Dark shale with siltstone and limestone. With Ammonites, Pelecypods, Echinoids, Bryozoa. Marine deposits.	"Napo Formation" 240—800 *m* Richly fossiliferous black limestone with bituminous shale. Foraminiferes, Ammonites. Marine sediments. (Considered as oil source rocks)	"Caballos Formation"	Coniacian Turonian Cenomanian Albian	Middle	
		Lower	Aptian Neocomian	? ? ?	"Môa Formation" Sandstone sequence "Môa Member" 300 *m* Crossbedded conglomeratic sandstone "Capanuua Member" 100 *m* Pink sandstone with conglomerate. Fresh water sediments. Unconformity	? ? ?	"Oriente Formation" 400—1700 *m* Sandstone sequence with shale interbeddings "Huaya Member". Marine deposits "Agua Caliente Member". Fresh-water deposits. "Paco Member". Fresh-water deposits. "Esperanza Member". Fresh-water deposits. "Aguanuya Member". Fresh-water deposits. "Cushabatay Member". Fresh-water deposits. Unconformity	"Hollin Formation" 80—240 *m* Predominantly quartzitic sandstone with plants. Brackish to fresh-water deposits (Asphalt-oil seepages). Unconformity	"Misahualli Formation" Unconformity	Aptian Neocomian	Lower	
	Jurassic	Upper	Malm	Hiatus	Hiatus	Hiatus	"Sarayaquillo Formation" 100 *m* ? Considered as Upper to Middle Jurassic continental deposits, consisting of crossbedded sandstones. Unconformity ?	"Chapiza Formation" 600—4500 *m* Red sandstone with pink shale and evaporite intercalations. Plants. Brackish-continental deposits. Angular Unconformity	Upper section of "Giron Group" "Chapiza Formation"	Malm	Upper	Jurassic
		Middle	Dogger	Hiatus	Hiatus	Hiatus				Dogger	Middle	
		Lower	Lias	Hiatus (Basic Igneous Rocks)	Hiatus	Hiatus	? ? ?	"Santiago Formation" 2000 *m* Black marine limestone with shales, radiolarians, ammonites, Arietites. Unconformity		Liassic	Lower	
	Triassic			Hiatus (Basic Igneous Rocks)		"Beu Sandstone" 1200 *m* Red Permotriassic sandstone with conglomerate and tillite. continental-fluviatile deposits.	Hiatus	Hiatus	Lower section of "Giron Group" Siliceous limestone with tuffacious cherts. Marine deposits with Myophoria & Pseudomonotis			Triassic
PALEOZOIC	Permian			Hiatus	Hiatus	Gondwana-facies "Permocarboniferous marine sandstones, marls and limestones." 300 *m* with Spirifer and Productus (partly Pennsylvanian).	"Blue marine limestone" 480 *m* (Wolfcampian ?) Limestones with few shale interbeddings. Fossiliferous marine deposits. Schwagerina. In a well of Ganso Azul.	Hiatus	? ? ? "Permocarboniferous Beds" Not yet differentiated.			Permian
	Carboniferous	Upper	Pennsylvanian	"Nova Olinda Formation" 1200—1540 *m* Evaporites, thin limestones and black shales with Fusulines, Brachiopods. Brackish-marine facies "Itaituba Formation" 340—440 *m* Fossiliferous limestone with shale and sandstone interbeddings. Spirifer rockymontanus & Fusulinella silvai. Shallow marine deposits. "Monte Alegre Group" 75—110 *m* Crossbedded sandstone with some shale and conglomerate. Plants. Neriticmarine to continental. Unconformity	"Quartzitic Sandstone" with Productus cora ??? Neritic marine to continental deposits with Granitic intrusions. "Uncertain age determination" (In part it is possibly Ordovician, and correlative with the Quartzitic Sandstones of the lower part of "Chonta Formation") Unconformity		"Tarma Group" 350 *m* (Moscovian) Bluish silicious limestone with limy shale interbeddings. Fossiliferous Bryozoans. Productus, Fusulina. Shallow marine deposits. Disconformity	"Macuma Formation" 1400 *m* Blue silicious limestone alternating with black shale and quartzitic sandstone. Shallow marine deposits with Productus, Spirifer, Chonetes, Fenestella, Derbya, Fusulinella, Nummulostegina etc. Unconformity	Predominantly limestones, shales, sandstones and slates. Marine, fossiliferous, with Productus and Spirifer.	Pennsylvanian	Upper	Carboniferous
		Lower	Mississippian	Hiatus	Hiatus	Hiatus	Hiatus	Hiatus	? ? ?	Mississippian	Lower	
	Devonian	Upper		Hiatus	Hiatus	Hiatus	Hiatus	Hiatus	? ? ?		Upper	Devonian
		Middle		"Curua Series" 200—590 *m* Fossiliferous black slatey shale with sandstone. Plants, Trilobites Pteropods, Brachiopods, Gastropods. Shallow marine deposits.	Hiatus	"Caupolican Formation". 260 *m* Black bituminous shale and sandstones (in upper section) marine unfossiliferous deposits	Hiatus	Hiatus	"Devonian sandstones, quartzites and silty shales in the Cordillera Oriental, with Brachiopods and Bryozoas" not yet differentiated in the South.		Middle	
		Lower		"Maecuru Series" 70—400 *m* White fine sandstone with black slatey shale. Brachiopods, Trilobites, Pteropods, Bryozoans. Shallow marine deposits. Disconformity	Hiatus		Hiatus	Hiatus	? ? ?		Lower	
	Silurian			"Trombetas Series" 225—300 *m* Black slatey shale with fine sandstone. Graptolites, Sponges, Brachiopods. — Climacograptus innotatus var. brasiliensis. Shallow marine deposits. Unconformity	Hiatus	? ? ?	Hiatus	Hiatus	Hiatus			Silurian
	Ordovician			"Uatuma Series" 100 *m* Undefined geologic age, probably Ordovician. Compact arcosic sandstone. Unconformity	** See above, at Pennsylvanian **	"Cosincho Quartzite" 100 *m* with Scolithus (probably Ordovician) Unconformity	"Contaya Formation" 150 *m* Argillaceous shale, underlain by massive quartzite. Marine deposits with Graptolithes. Dydimograptus murchisoni. Unconformity	"Pumbuiza- and Margajites Formations" 1000 *m*. Undefined geologic age. Dark pyritic and graphitic slates with Lingula & Unidentified Pelecypods. Also Quartzitic sandstone intercalations. Unconformity	"Graptolithes Shales" with Dydimograptus extensus. Unconformity			Ordovician
	Cambrian			? ? ?		? ? ?			? ? ?			Cambrian
	Pre-Cambrian			"Crystalline basement" Metamorphic rocks and Porphyries	"Crystalline Basement" Gneiss, Amphibolite, Pegmatite.	"Crystalline Basement"	"Crystalline Basement"	"Crystalline Basement" Granite, gneiss	"Crystalline Basement"			Pre-cambrian


GEOLOGICAL MAP
of
AMAZONAS BASIN AND SURROUNDINGS
Compiled by Louis de Loczy 1962
MOST IMPORTANT REFERENCES:
"Mapa Geologico de Bolivia" AHLFELD F. La Plata, 1946, "Geological Map of South America" STOSE G.W. Geol. Soc. America, 1950,
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"Mapa do Brasil" Scale 1:5.000.000 Conselho Nacional de Geografia. Rio, 1960, was used for planimetrical basis.
SCALE 1:5,000.000
0
500 km
LEGENDE
Q Quaternary, Holocene and Pleistocene
Q+Tc Quaternary and Late Tertiary continental
Tc Tertiary continental undivided. Predominant Plio-Miocene
T1 Early Tertiary, Oligocene-Eocene. (brackish-marine)
T Tertiary in general. (continental-brackish)
Tcf Tertiary undivided, folded during Andean Orogeny
TpE Tertiary continental underlain by Pre-Cambrian Shield
K2 Upper Cretaceous (brackish-marine)
K1 Lower Cretaceous (brackish-marine)
Kc Cretaceous continental undivided
K Cretaceous in general
JTr Lower Jurassic (Lias) and Upper Triassic (predominant marine)
Trc Triassic continental
Trp Permo-Triassic continental (Gondwana facies)
PCc Permo-Carboniferous continental (Gondwana facies)
PC Permo Carboniferous marine
C3 Upper Carboniferous Pennsylvanian (marine)
C3c Upper Carboniferous continental (Gondwana facies)
D Middle and Lower Devonian (marine)
S Silurian, marine
SO Silurian-Ordovician, not divided (marine)
EO Cambrian-Ordovician, not divided (marine)
Pal Paleozoic undivided in geral
pE Pre-Cambrian not divided (Shield)
IGNEOUS ROCKS IN THE ANDEAN ZONE
Qv Quaternary-Miocene volcanics, undivided
Ki Cretaceous intrusive
pKi Pre-Cretaceous intrusive
pKv Pre-Cretaceous volcanics (Jurassic and Triassic)
Pai Paleozoic intrusive
i Intrusive in geral
IGNEOUS ROCKS IN THE SHIELD
+ + β Basic Igneous Rocks, basalt-diabase
+ + + α Acidic Igneous Rocks, Rhyolites, Dazites (Paleozoic)
x x x γ Granite
VENEZUELA
GUIANA BRITANICA
SURINAME
GUIANA FRANCESA
RIO BRANCO
AMAPA
AMAZONAS
PARA
ACRE
RONDONEA
MATO GROSSO
BOLIVIA
SERRA PACARAIMA
SERRA ACARAI
BOA VISTA
MACAPA
BELEM
MANAUS
SANTAREM
IQUITOS
CRUZEIRO DO SUL
RIO BRANCO
CERRO AZUL
GANSO AZUL
PONGO DE MAINIQUE
LAGO TITICACA
LA PAZ
GOIABA
CORUMBA
SERRA DOS PARECIS

PALEOGEOGRAPHIC DEVELOPEMENT
of the
AMAZONAS BASIN SOUTH AMERICA

Compiled by L. de Loczy 1962

Fig. 1

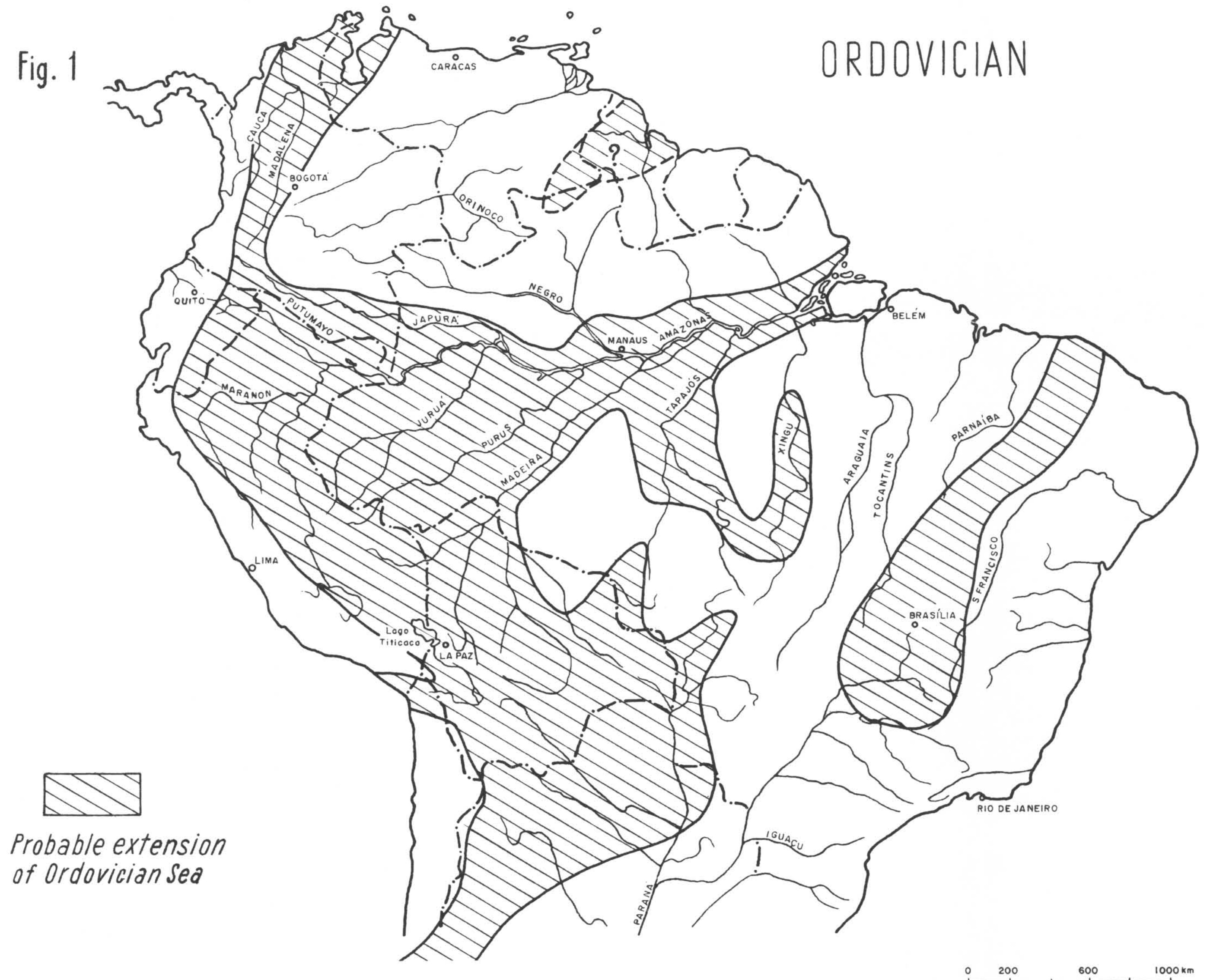

Fig. 2

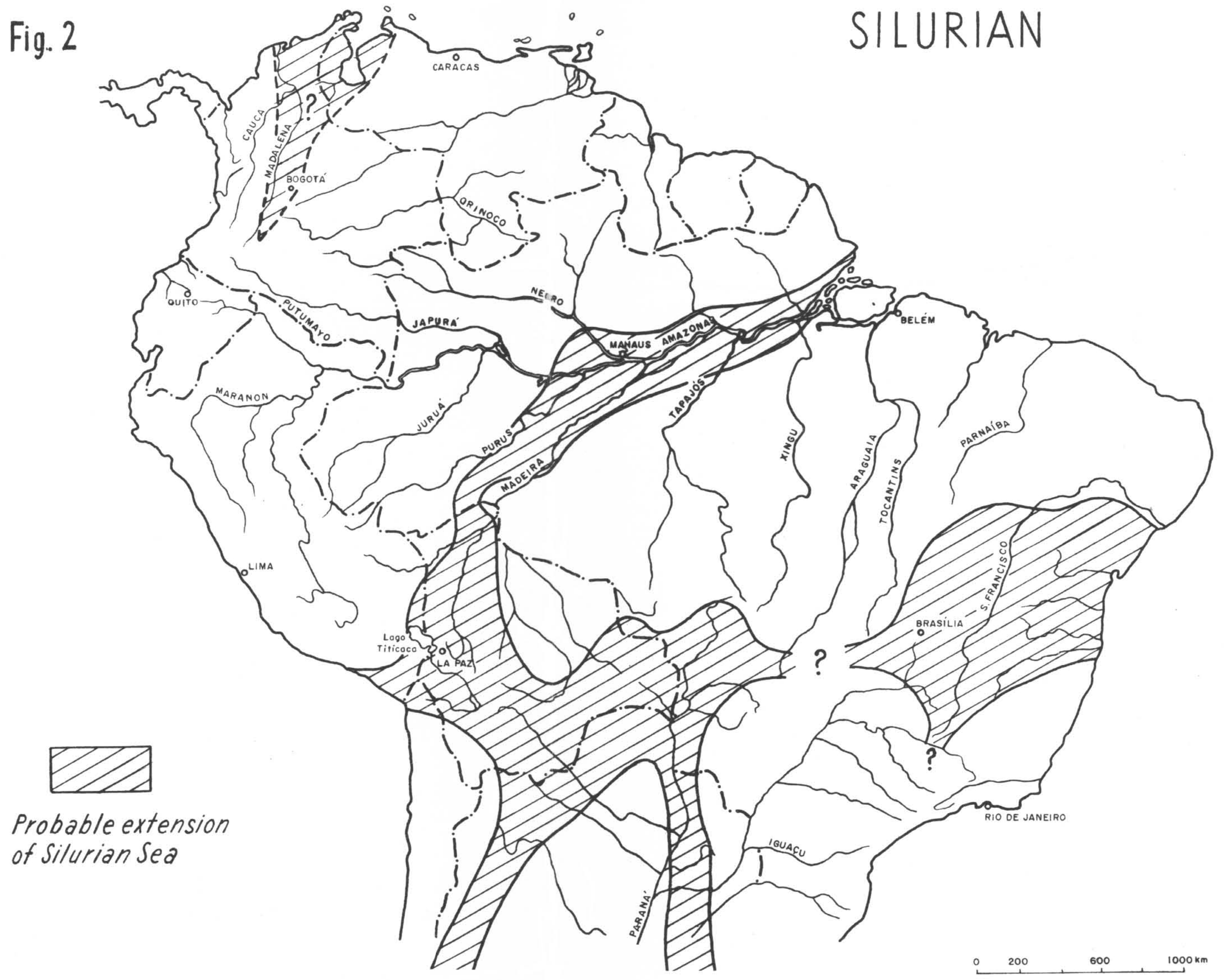

Fig. 3

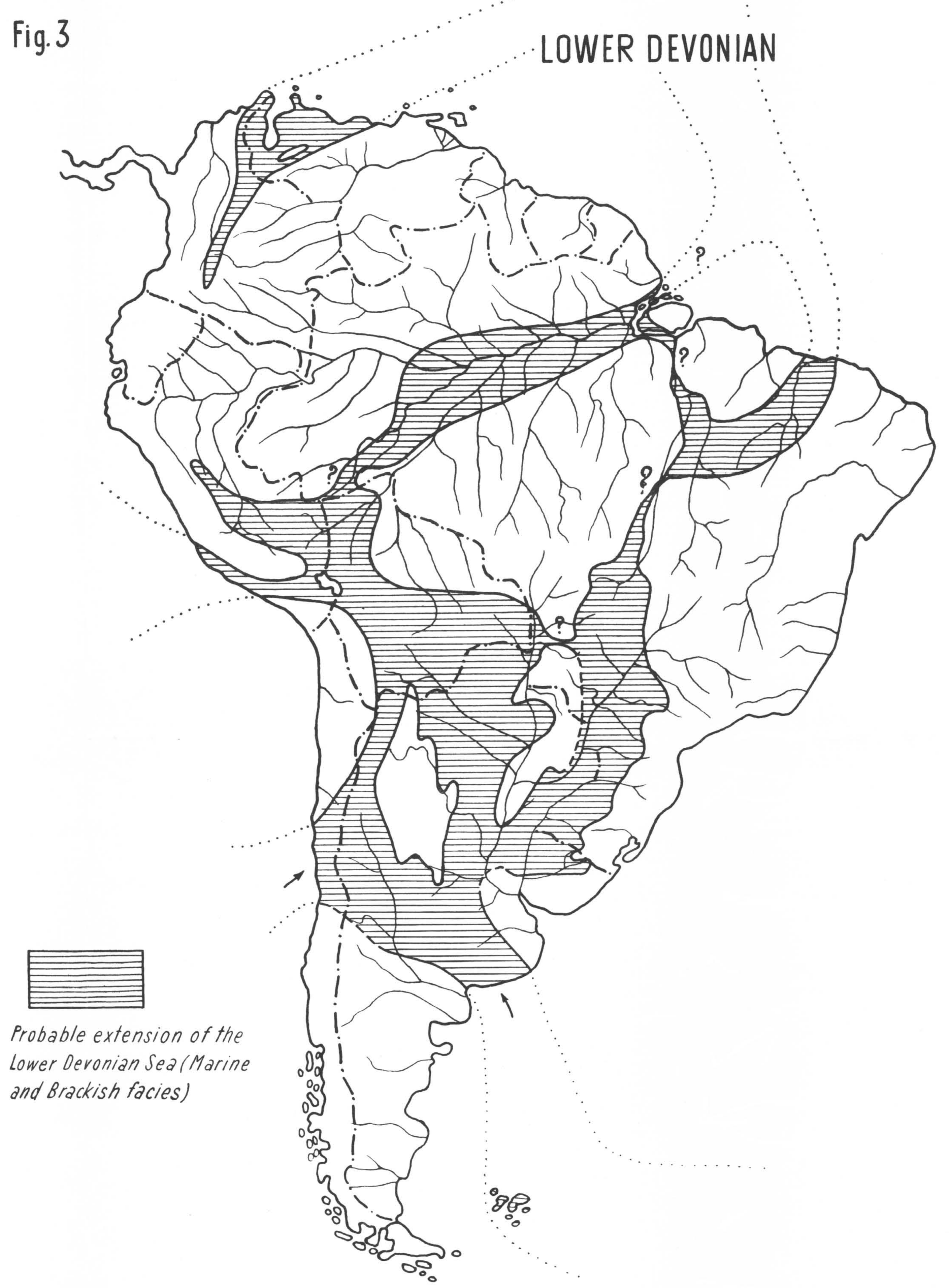

Fig. 4

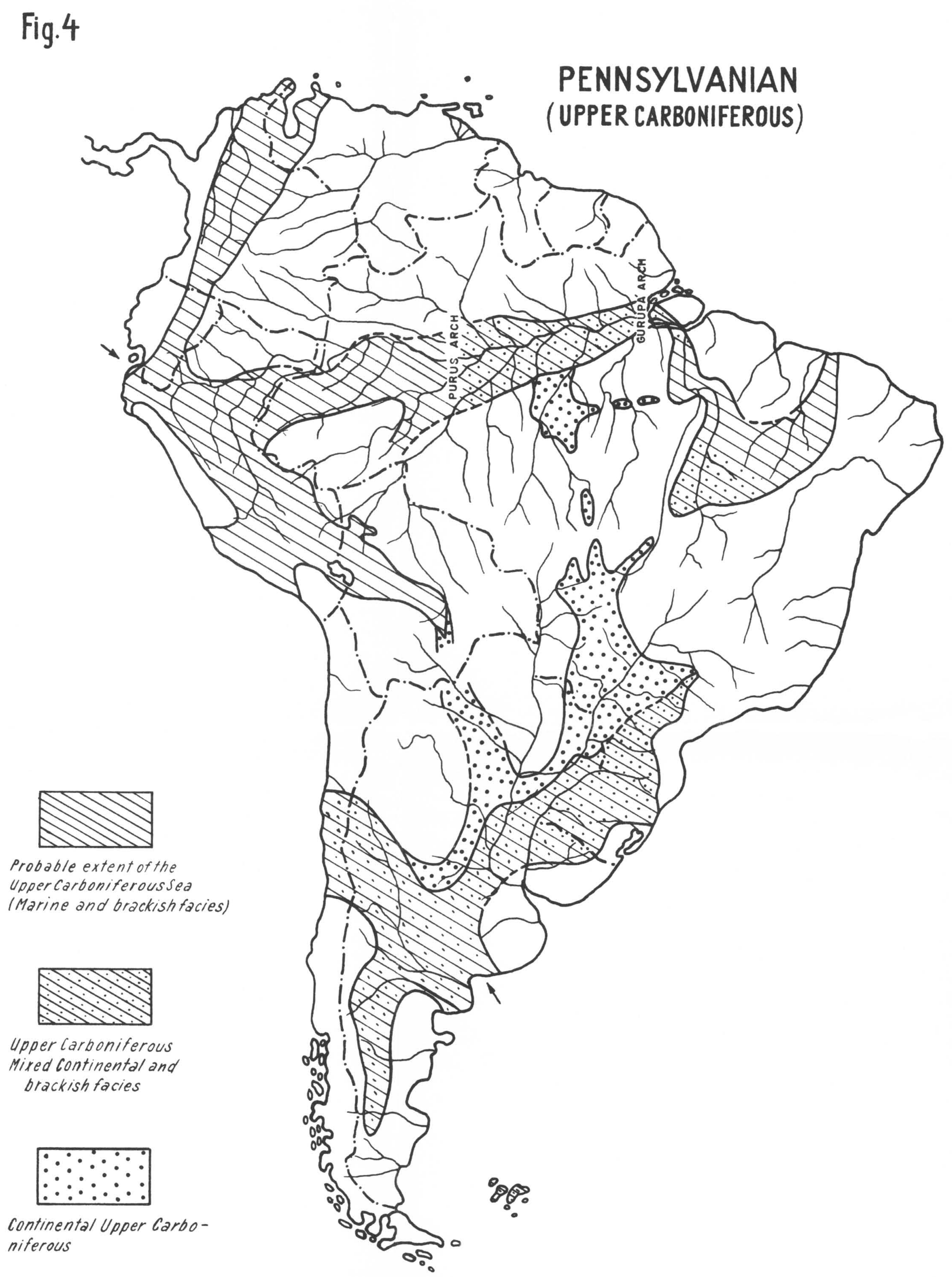

Fig5

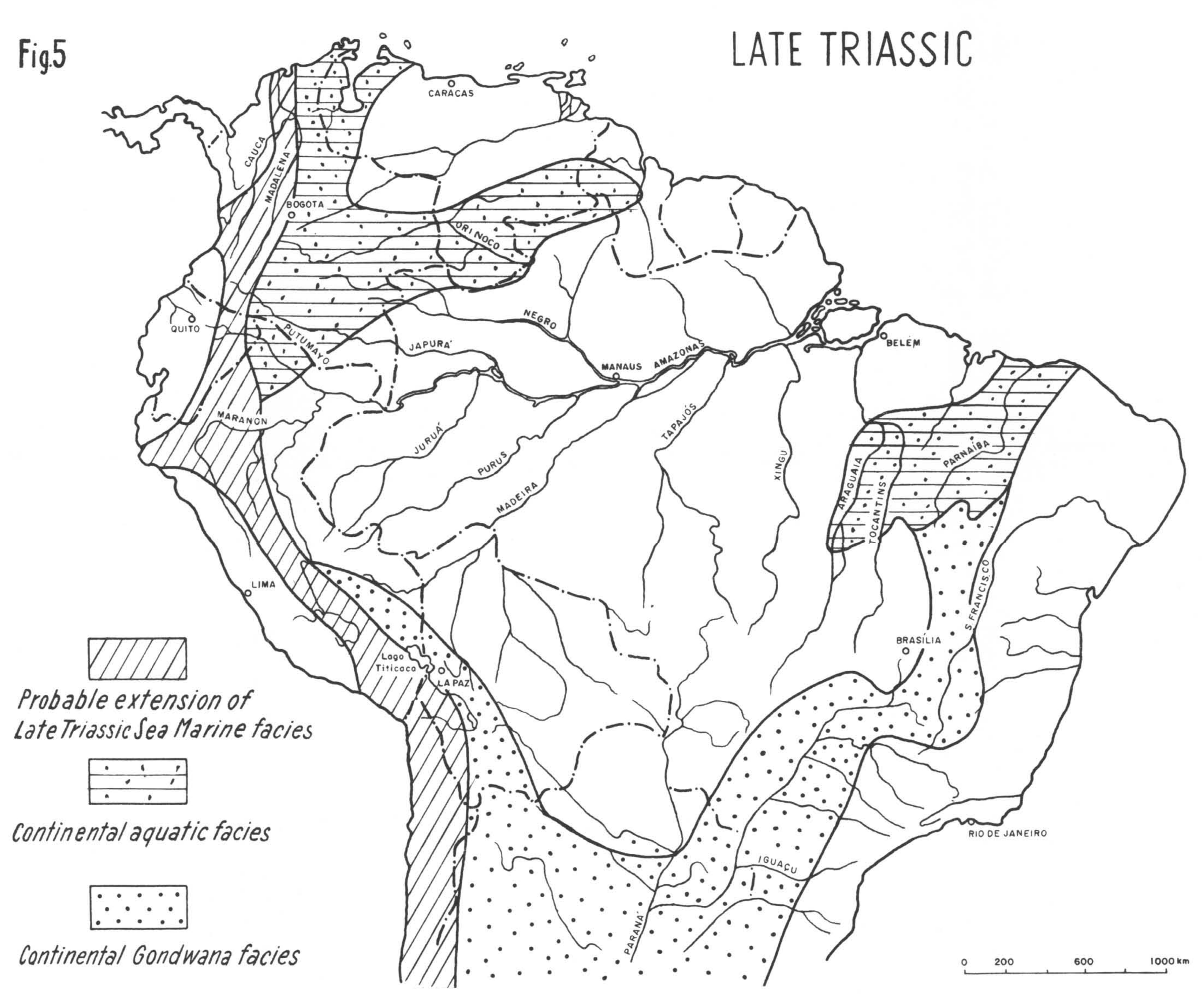

Fig. 6

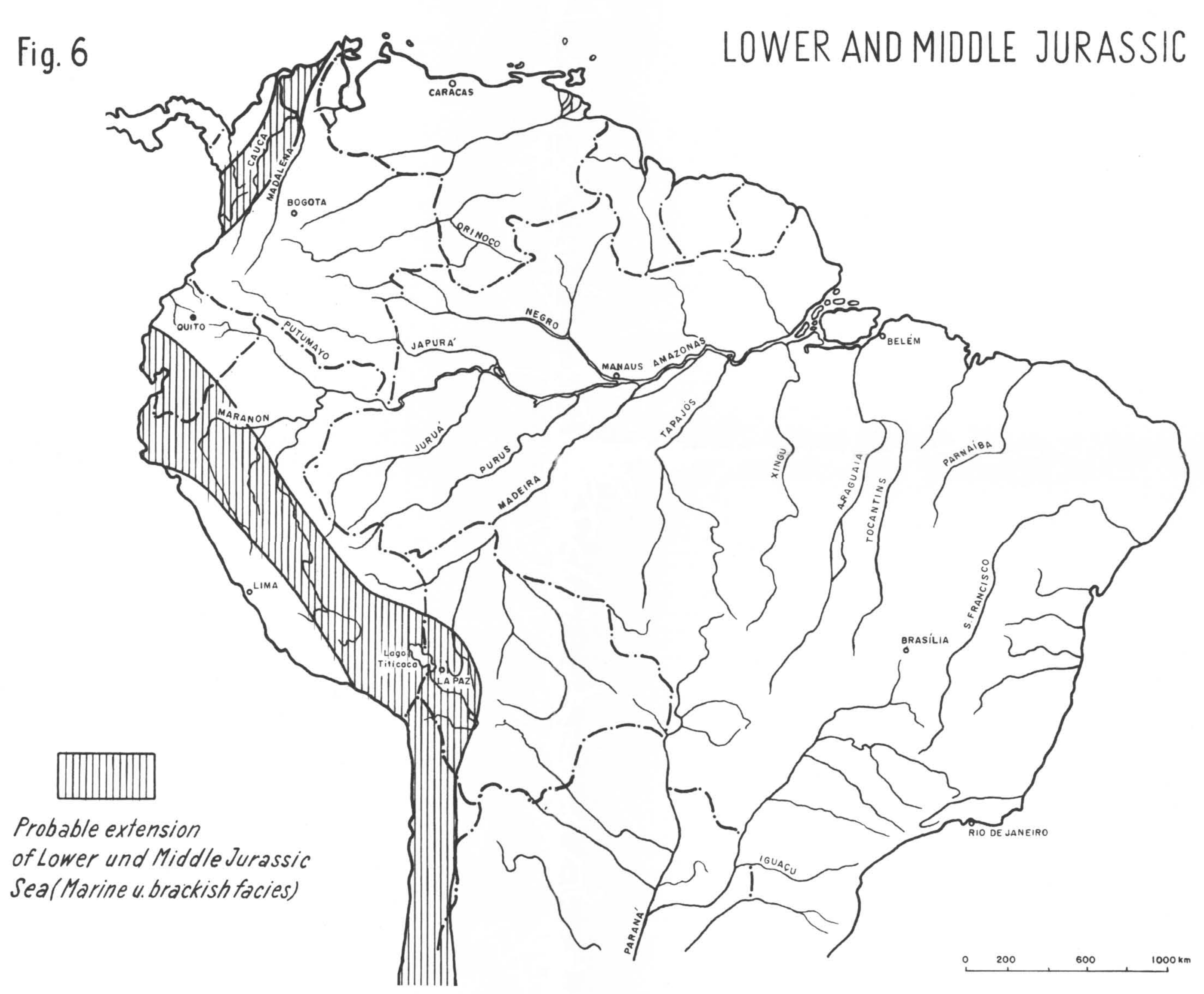

Fig. 7

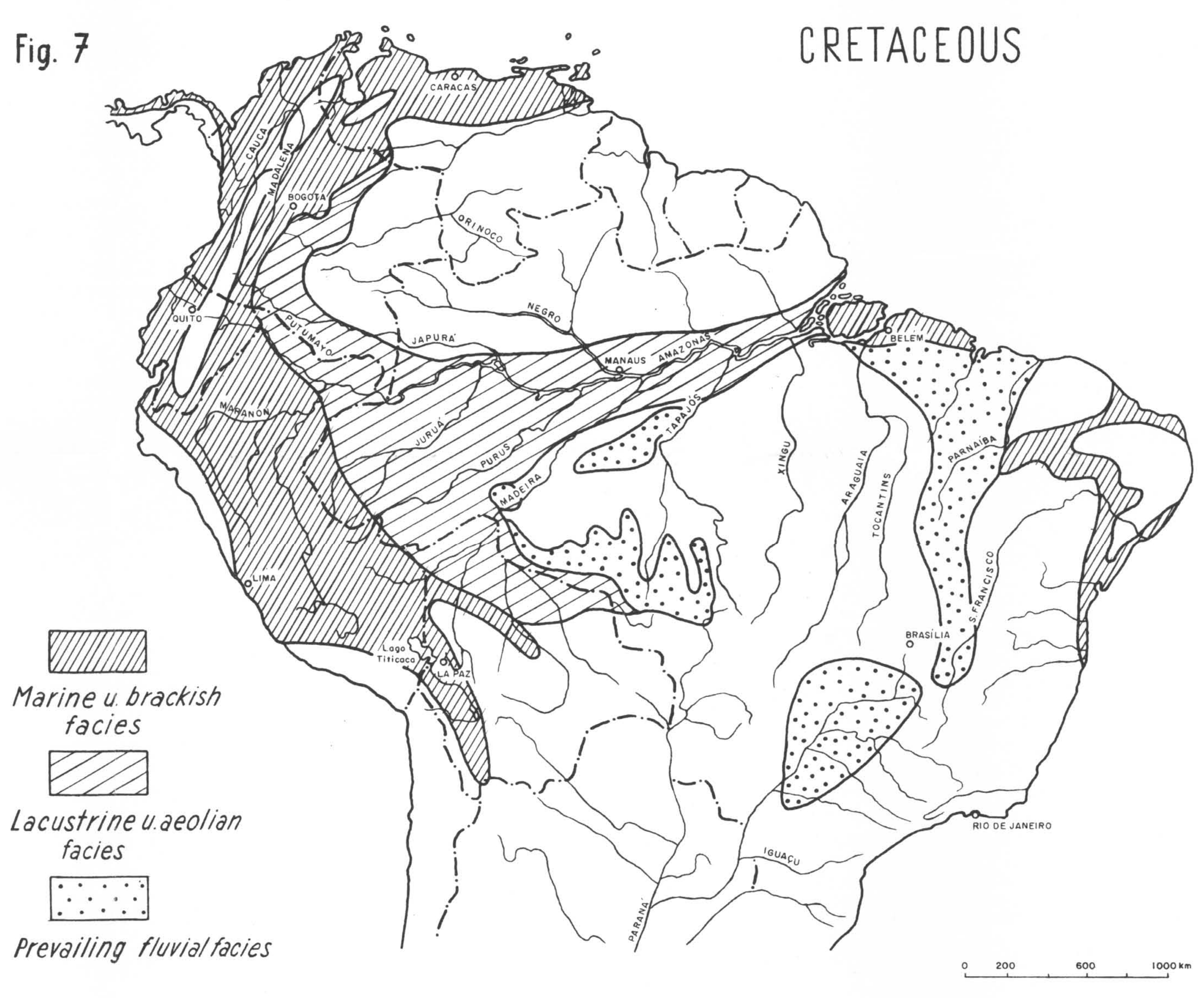

Fig. 8