Zeitschrift: Bulletin der Vereinigung Schweiz. Petroleum-Geologen und -Ingenieure
Herausgeber: Vereinigung Schweizerischer Petroleum-Geologen und -Ingenieure
Band: 30 (1963-1964)
Heft: 79

Artikel: The productive and promising oil basins of Peru
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DOI: https://doi.org/10.5169/seals-192673

Bull. Ver. Schweiz. Petrol.-Geol. u. -Ing., Vol. 30, Nr. 79, März 1964, S. 8–25

The productive and promising oil basins of Peru

with 4 figures

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Abstract:

Peru is a land of severe contrasts. Within the variety of relief, climate and cover exist three very distinct zones: The Coastal Zone, the Andean Zone, and the Eastern Peru Zone. The different oil basin areas are : In the Coastal Zone, the Brea- and Pariñas basin and the Sechura basin; in the Andean Zone, some relatively small areas lying in the southern Andes chain, especially near Lake Titicaca; in the Eastern Peru Zone, the northern or upper Amazon basin, and the Madre de Dios basin. These areas vary in configuration, lithology, sequence, architecture and economic aspect. They are aligned in a general NW—SE trend paralleling the Cordillera strike.

An account is given of the composition, structural pattern, development through geologic history, and practical importance of each of the producing and the promising oil basins, and also of the areas of poor prospective resources. In appraising the oil potentialities, attention is particularly drawn to the all-controlling environments, the occurrence of unconformities, cause and extent of gaps, diastrophic pulses, magnitude and type of tectonic deformation, and degree of contact and dinamometamorphism.

By nothing the unique conditions prevailing in the southern Andes mountains and in eastern Peru, it is shown that the search for oil has rendered obsolete dependance on one man and one method. Further exploration must now rely on the close cooperation of a number of specialists to make skillful use of team effort and all applicable advancements in petroleum technology.

Résumé:

Le Pérou est un pays de contrastes accusés. Parmi la grande variété de reliefs, de climats et de couvertures, on peut y reconnaître trois grandes zones distinctes: La Côte, les Andes, et le Pérou Oriental. Les champs pétroliers se répartissent comme suit. Dans la Zone Cotière se trouvent les Bassins de la Brea-Pariñas et Sechura. La Zone Andine recéle quelques petites régions vers le Sud, principalment près du Lac Titicaca. On connait dans le Pérou Oriental le Bassin du Nord, ou Haut-Amazone, et celui de Madre de Dios. Ces bassins diffèrent par leur configuration, leur lithologie, leur séquence, leurs éléments tectoniques, ainsi que par leur intèret économique. Ils s'alignent suivant une direction générale NW—SE parallèle à la direction de la Cordillère.

Un aperçu précise les caractéristiques (série, structure, évolution géologique, importance économique) des bassins productifs et prometteurs, ainsi que de certaines zones de peu d'intèret. L'estimation des possibilités pétrolières met l'accent sur les milieux de formation, la présence de discordances angulaires, la cause et extension des lacunes, les pulsations diastrophiques, l'ampleur et le type des déformations tectoniques, ainsi que sur le degré de métamorphisme.

Les conditions exceptionelles sévissant dans les Andes Méridionales et le Pérou Oriental suffisent pour démontrer l'inactualité de la prospection pétrolière reposant sur un seul homme et sur une seule méthode. Les explorations futures exigent donc l'emploi des spécialistes travaillant en équipe et disposant des techniques les plus modernes.

The foundation of the present geological knowledge has been laid by the enthusiastic work of a small number of professionals and scientists, by the scattered pioneer exploratory efforts of very few petroleum firms, and by the more recent massive exploration assault of nearly a dozen oil companies. Notwithstanding, this knowledge is rather haphazard, at the most incomplete, and the shortcomings are considerable, especially in the Amazon jungle, which occupies almost half the area of Peru and is veritably the last frontier both from a literal as well as a figurative sense. Much attention needs to be given to basic research and thorough fieldwork, either by the government, by private organisations, or by universities. The following short description of the actual state of knowledge deals with the geology and general esconomic aspects of the productive and promising oil basins.

Crude output comes from both sides of the Andes Mountains – from the coastal zone of northwestern Peru, and the sub-Andean belt of eastern Peru –, and until recently crude oil was also produced in the high Andes chain, from traps of distinctly different types of rock, facies, and structure. Thus, there are three zones to be considered, the Coastal Zone, the Andean Zone, and the Eastern Peru Zone.

Coastal Zone, northwestern Peru

The principal Peruvian oil basin is the narrow strip of land between the Cordillera and the Pacific extending from northern Peru to southern Columbia, and which for the most part is made up of marine Tertiary deposits. The Peruvian sector of this large basin contains the oil fields of the Brea-Pariñas, Lobitos, El Alto, Los Organos districts, and the lesser important Mirador field in the south, and the Zorritos field in the north. Oil seeps are very common and have been known by the Indians ages before the conquest by the Spaniards. The Incas worked them for centuries and prepared the «copé» – the name given to asphalt or pitch – on a large scale for waterproofing their jars, baskets and skins, mummifying their dead, and spreading over their famous roads. At one time during the colonial period (1532–1821), the exploitation was a monopoly of the Spanish Crown, hence inciting keen interest in drilling in the very earliest days of oil industry.

The rocks of this basin range from Paleozoic to Recent (see Geological Map). A series of olive gray to dark violet blackish shales, slates, and quartzites of Pennsylvanian age or older, collectively named the Amotape formation, project above the surface in the Amotape Mountains, at Paita, at Illesca, and along the eastern periphery of the Sechura desert. The bottom portion of the series is not exposed and the top beds are badly worn down. Some sections are 1500 m thick. Post-Amotape granite intrusions caused widespread thermal metamorphism which formed rocks such as chiastolite schist, hornfels, and phyllite. Other pronounced alteration, however, is related to regional metamorphism. The Hercynic-Appalachian orogeny imparted high degree tilting and compression resulting in the extinction of the Paleozoic geosyncline and the emergence of a mountain range within and westward from the present coast line.

Bevelling and destruction of this uplifted landscape resulted in the accumulation, apparently under desert conditions, of more than 700 meters of greyish to pink Triassic (?) sandstones. They form towering ridges and exhibit marvelous dip-slopes in the neighbourhood of Olmos, bordering the Sechura basin. Followed by a small stratigraphic break occurs a thin section of blackish shales. The combined sequence shows authentic evidence of the old Cimmerian movement.

Unconformably overlying the sandstones and shales and spread over a wide area are 3000 meters of green to reddish purple andesitic ashes, tuffs, lavas, agglomerates, and polygenic breccia, with increasing occurrence of dark basalts higher up in the section. The effusives and pyroclasts were deposited in a shallow sea by submarine volcanoes of, as yet, unknown location. In Upper Triassic and Jurassic time these seas flooded

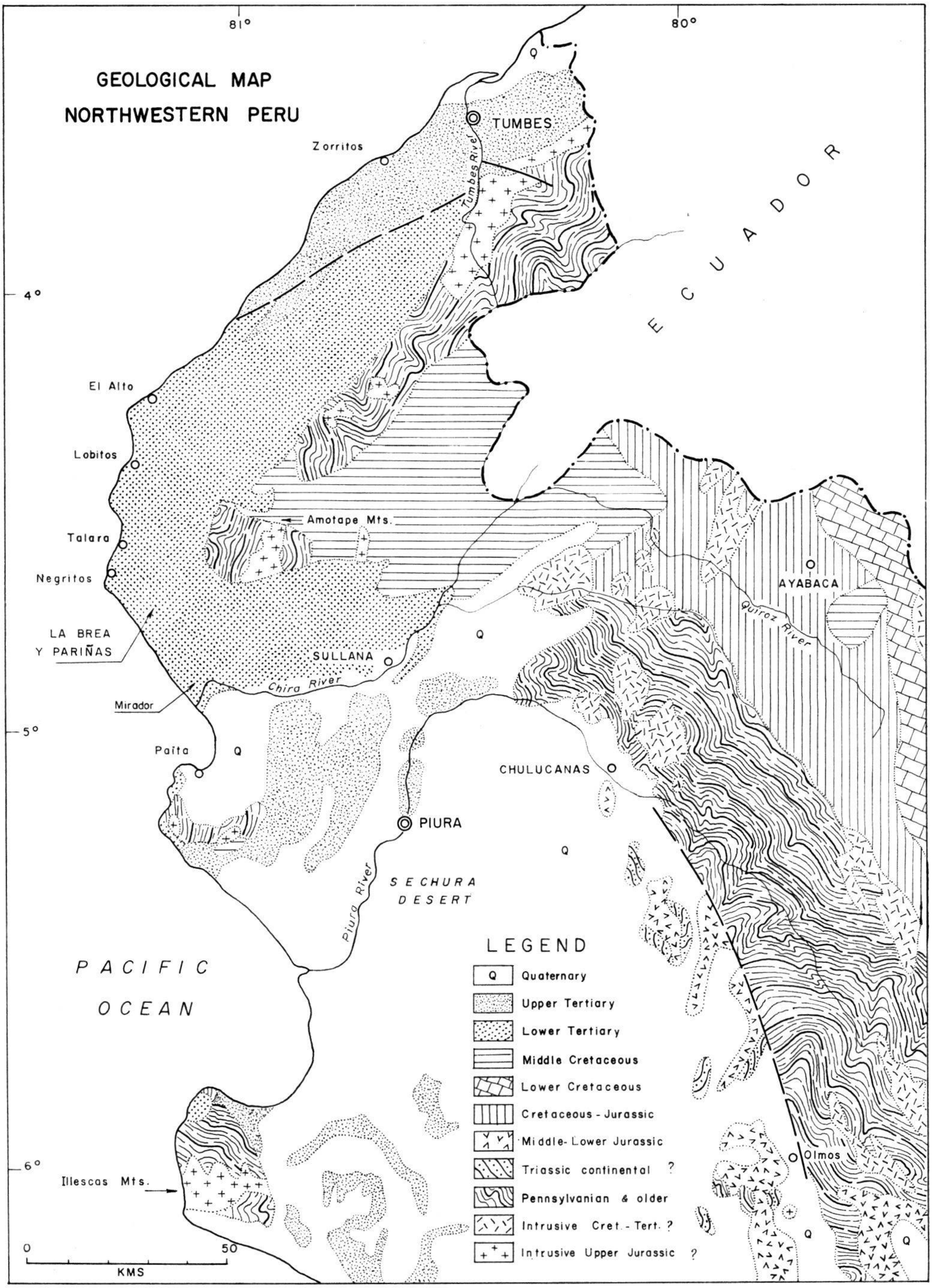
GEOLOGICAL MAP
NORTHWESTERN PERU
81°
80°
4°
5°
6°
TUMBES
Tumbes River
Zorritos
ECUADOR
El Alto
Lobitos
Talara
Negritos
LA BREA
Y PARIÑAS
Mirador
Amotape Mts.
SULLANA
Chira River
AYABACA
Quiroz River
Q
Paita
CHULUCANAS
PIURA
Piura River
SECHURA
DESERT
PACIFIC
OCEAN
Illescas Mts.
Olmos
0
50
KMS
LEGEND
Quaternary
Upper Tertiary
Lower Tertiary
Middle Cretaceous
Lower Cretaceous
Cretaceous - Jurassic
Middle- Lower Jurassic
Triassic continental ?
Pennsylvanian & older
Intrusive Cret. - Tert. ?
Intrusive Upper Jurassic ?

Fig. 1

the whole area, with the exception of an island arc situated near the present coastal region. Simultaneously, but in the deeper central and eastern part of this geosynclinal trough, there exists transition into non-volcanic facies, and limestones and pelitic materials were deposited. With the Nevadan or young Cimmerian folding at the close of the Jurassic occured wide scale uplift and warping of this depositional trough. Granitic plutonites encountered in Paleozoic slates and Triassic psammites are synorogenic accompaniments of this event.

There are but few records of the early Cretaceous period. A major sea advance took place in Aptian-Albian time, and at its climax covered the archipelago. It occupied, as did later Cretaceous seas, the old geosynclinal space. The products of these seaways is a 1600 to 3800 m thickness of different lithologic units of two distinct facies types. The first is comprised by the volcanics and siliceous shales from the western part of the basin, and the second, by the limestones and marls from the broader basin strip to the east. These rocks overlap truncated hills and blocks. They show unconformities as the result of pre-Senonian and pre-Danian mountain building. The archipelago just mentioned, heretofore a rather neutral and not very mobile element, broke up in a number of heaved blocks and sinking grabens. Fracture movement replaced alpine folding, resulting in the paratectonic type of mountain building wihch is paramount and classic in northewestern Peru after Laramide diastrophism.

The Tertiary basin oil deposits are by far the most important from an economic viewpoint. They are the source of nearly the entire production of Peru. The Tertiary column consists largely of alternating sands and sandstones, shales, lesser conglomerates, some diatomites, and many kinds of transitional variants. Limestones are practically absent. These clastics were laid down in water of moderate to shallow depth; transgressive beach accumulations are very conspicuous. Near the coast the sequence is nearly 100% marine, but inland it frequently grades into continental type deposits, especially near the bottom of the section. Marked thinning is visualized in local areas. The total thickness of all Tertiary rocks amounts to about 8500 m, but the greatest thickness exposed in any one area is that at La Brea-Pariñas, varying from 3150 to 5200 m, mostly of Eocene age.

The Tertiary group ranges from Eocene to Miocene-Pliocene. The formational units have been studied in minute detail, but nowhere is the sequence complete, representing the missing strata frequently long time gaps in the geologic record.

Sediments of the Pleistocene overlie more or less horizontally the planed-off surface of the highly faulted Tertiary beds. They are comprised of marine shell limestones, conglomerates, calcareous sandstones, and marly shales deposited on a series of three uplifted terraces, or «tablazos». Accumulations of recent age are profusely developed. They form alluvial plains, gravel fans, and extensive covers of eolian sands and evaporites.

As a whole, the Tertiary basin area depicts an ever changing succession of sedimentation, uplift, fracturing and truncation. The very irregular configuration of the individual depositional basins, and the contemporaneity of deformation with sedimentation have caused abrupt and almost unpredictable changes in lithology, thickness and distribution.

Chief factor in the structural picture of the northwestern Peru zone is the presence of two fundamentally different tectonic units, e. g. the Eocene Brea-Pariñas basin and neighbouring oil districts, originated in the later stages of the geosynelinal cycle between the island arc and the deep Ocean trough with its manifestly active peri-Pacific border phenomena in the north; and the Upper Tertiary Sechura basin or para-Andean depression lying between the highly folded and still rising Andes chain and the aforemen-

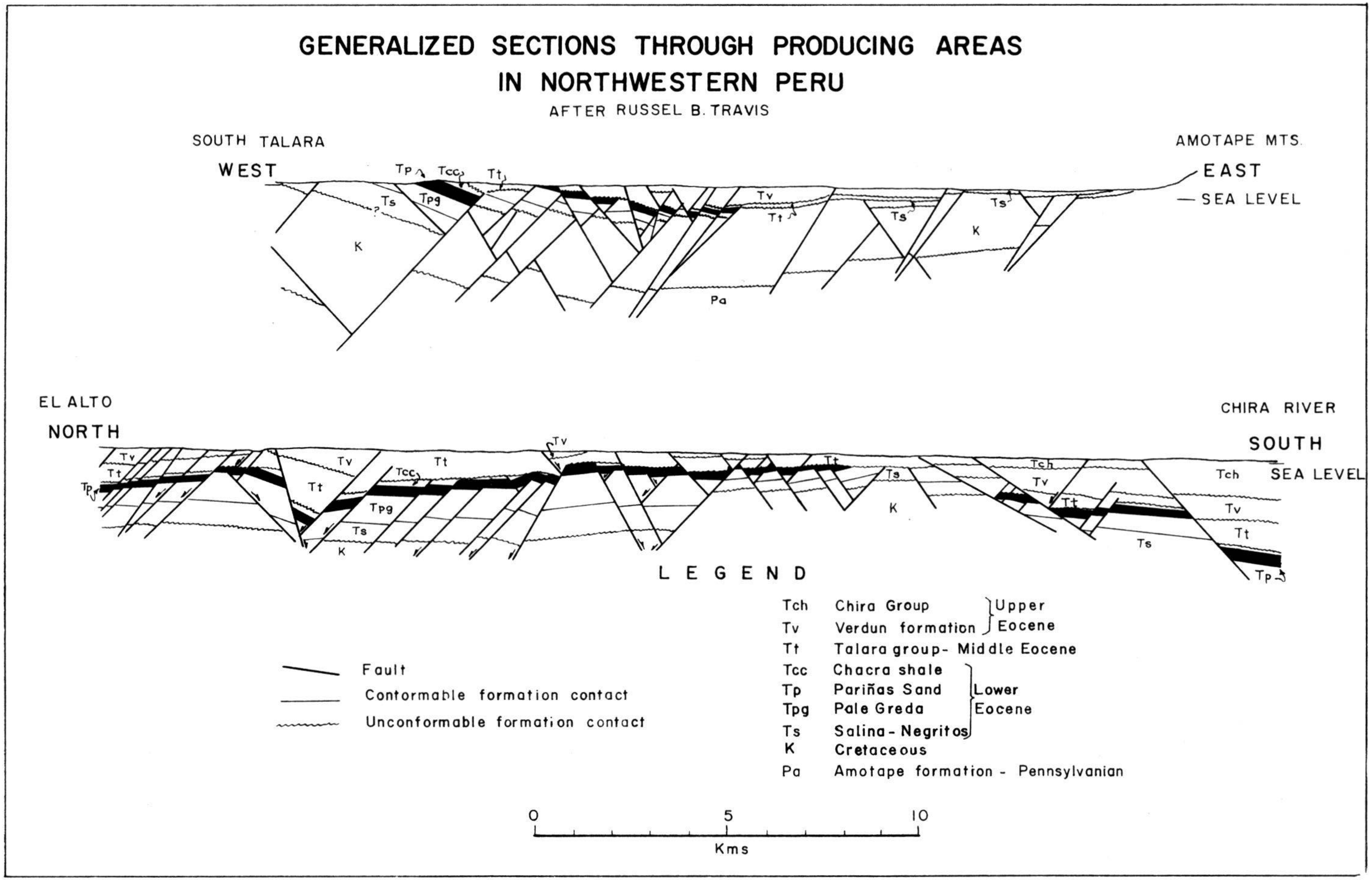
GENERALIZED SECTIONS THROUGH PRODUCING AREAS
IN NORTHWESTERN PERU
AFTER RUSSEL B. TRAVIS
SOUTH TALARA
WEST
AMOTAPE MTS.
EAST
SEA LEVEL
Tp
Tcc
Tt
Ts
Tpg
K
Tv
Pa
EL ALTO
NORTH
CHIRA RIVER
SOUTH
SEA LEVEL
Tch
LEGEND
Fault
Contormable formation contact
Unconformable formation contact
Tch Chira Group
Tv Verdun formation
Upper Eocene
Tt Talara group - Middle Eocene
Tcc Chacra shale
Tp Pariñas Sand
Tpg Pale Greda
Ts Salina - Negritos
Lower Eocene
K Cretaceous
Pa Amotape formation - Pennsylvanian
0
5
10
Kms

Fig. 2

tioned island arc in the south. This discrepant pattern and the ajustment of the involved pile of rocks is thus the logical behavior and outcome of the distinct structural elements, each one different in composition, architecture and mobility.

Reviewing the coastal belt, one is struck by the galaxy of intersecting faults, an intricate array which resulted in a chaotic mosaic of blocks fragmented seemingly in all directions. The faults fit no standard except that they are normal faults, are of different age, and intensively affect stratigraphy. In addition there occur readily perceptible major faults or zones of disruption trending north. It is clearly evident that faulting was contemporaneous with deposition, although there were events of intensified activity, which altogether led to six or seven unconformities within the Tertiary group. If all the faulting were the same age, migrating oil would have moved into the first updip trap and no farther. Although there exist structural highs and graben-like downfolds, which suggest domal and anticlinal structures, folding is poor or absent.

Oil accumulation appears to be related primarily to the main uplifts and a series of large stratigraphic and/or older fault traps showing low initial dips. These traps were later broken up and tilted into dozens of independent pools which may be composed of one, or of several fault blocks. The nearly complete lack of correlation between the accumulation and structural position remains one of the most intriguing problems in the area. Oil does not seem to be more abundant at the upper edges of a block, in the middle, or against faults. A sandstone that lenses out within a relatively small fault block may trap an appreciable amount of oil. Such distressing subsurface features as these give rise to oil fields of rather limited areal extent, which nevertheless yield good though spotty production but by the drilling of a large number of wells, with a proportionately high percentage of dry holes.

By far the bulk of the production in northwestern Peru is obtained from several different sands of Eocene formations. In the nearly exhausted Zorritos field, oil comes from Miocene sands. A very small production comes from the slightly bituminous Upper Cretaceous beds. Exploratory and development wells in the offshore fields produce oil from the Lower Eocene Salina and Pariñas sands at depths of less than 1000 and greater than 4000 feet. The daily production during the last few years is as follows (incl. the comparatively very small offshore production):

1959 bbls/d	*1960 bbls/d*	*1961 bbls/d*	*1962 bbls/d*	*1963 bbls/d*
46 210	49 830	50 360	54 176	55 153

The total proven reserve of the oil fields on Peru's northwestern coast is 650 million bbls.

Andean zone, southern Peru

In the Andes the only known petroleum manifestations in possible oil bearing structures with favorable reservoir and cap rocks are located in the south of Peru and near Lake Titicaca. These are the asphalt deposits at Chumpi-Coracora in Ayacucho Department, of Pallpata-Espinar in Cuzco Department, and the oil seepages of Pirín in Puno Department, all known for many years. Frequent attempts at exploitation by digging pits, drifts, tunnels, and drilling wells failed to find commercial quantities of either asphalt or petroleum. Prudential estimates of possibly exploitable asphalt accumulated at or near the surface at Chumpi arrive at 1.5 million metric tons, but as of 1962 there were no programs for further exploration or development. At Pirín, the world's highest oil field at 3900 m, on the border of Lake Titicaca, the holes have been drilled in completely adverse tectonic position, such as steep to nearly vertical beds occuring in a strongly disturbed and shattered area. The total output crude from this field is said to have been 300,000 bbls during seven decades of endeavors which extended up to 1946. The oil was produced from Cretaceous sandstone, but it is surmised the oil might have migrated from Jurassic or Lower Paleozoic source rocks, because the sequence of possible productive beds was never penetrated. The principal tectonic feature of the petroliferous region at Pirín are repeatedly faulted anticlinal and/or monoclinal structures, where drilling development is entirely inappropriate. Better results might be expected in the lesser disturbed and smoother folds and fault blocks located to the west.

The complete geologic section of this part of the Peruvian Andes embraces clastic and igneous series up to 20,000 m thickness. Quaternary and Tertiary effusives cover much of the area, particularly in the western portion. Cretaceous and Jurassic rocks crop out only at scattered localities. Paleozoic, especially Lower Paleozoic strata occur over far larger extensions north and northwest of Lake Titicaca than is currently shown on the maps, and plunge down into the deeply intrenched Andean border valleys of the foreland. The region is affected by at least four major folding events, is vigorously faulted and dissected. It shows small shearing and thrust zones with short over-riding limbs, but there are definitely no long distance overthrusts. Late characteristics of the Titicaca trough region is smooth warping, mild movements in connection with small faulting, and probable continued sinking of the basin or lake area. Strong vertical displacements, however, along enormous faults, as designed by some authors, are certainly not observed features.

As a whole southern Peru has not been explored for oil and will probably attract little or no interest as a petroliferous province for some years to come, because of the very uncertain results of present exploration techniques in areas extensively covered by volcanic aprons; and doubt is the enemy of investment.

Eastern Peru zone

The immense area which occupies the upper Amazon drainage basin east of the Andes is composed of three physiographical-geological units: 1) the high Cordillera on the west; 2) the craton, or old Brasilia, on the east, and 3) the sub-Andean trough lying between the two (see Geological Map). This remote country is known as the Peruvian «selva» (forest), or Peruvian «oriente» (east), and comprises two major basins: The northern, or upper Amazon basin, and the southern, or Madre de Dios basin. They will be dealt with separately.

Northern or upper Amazon basin:

This basin is part of the sub-Andean belt, an elongate depression which persists from eastern Venezuela south into northwestern Argentina. It occupies the spurs of the Cordillera, lower isolated ranges and hogbacks, and the floodplains of moderate, rolling topography, which stand above the surrounding swampy low land. A number of foreland folds lie as far east as the Peru-Brazil boundary and beyond, following the crest of one of the major uplifts, Contaya. Heavy jungle covers the whole region. Days are hot, sultry and humid, and nights rather cool. Travel is chiefly by air between the few larger settlements and by small boats or canoe over shorter distances. Despite the severe handicaps to exploration in the jungle, and the many failures in wildcatting carried out to date – lack of exploration and/or erroneous interpretation of field observation led to many inadequate location sites –, the insight obtained in appraisal of the oil

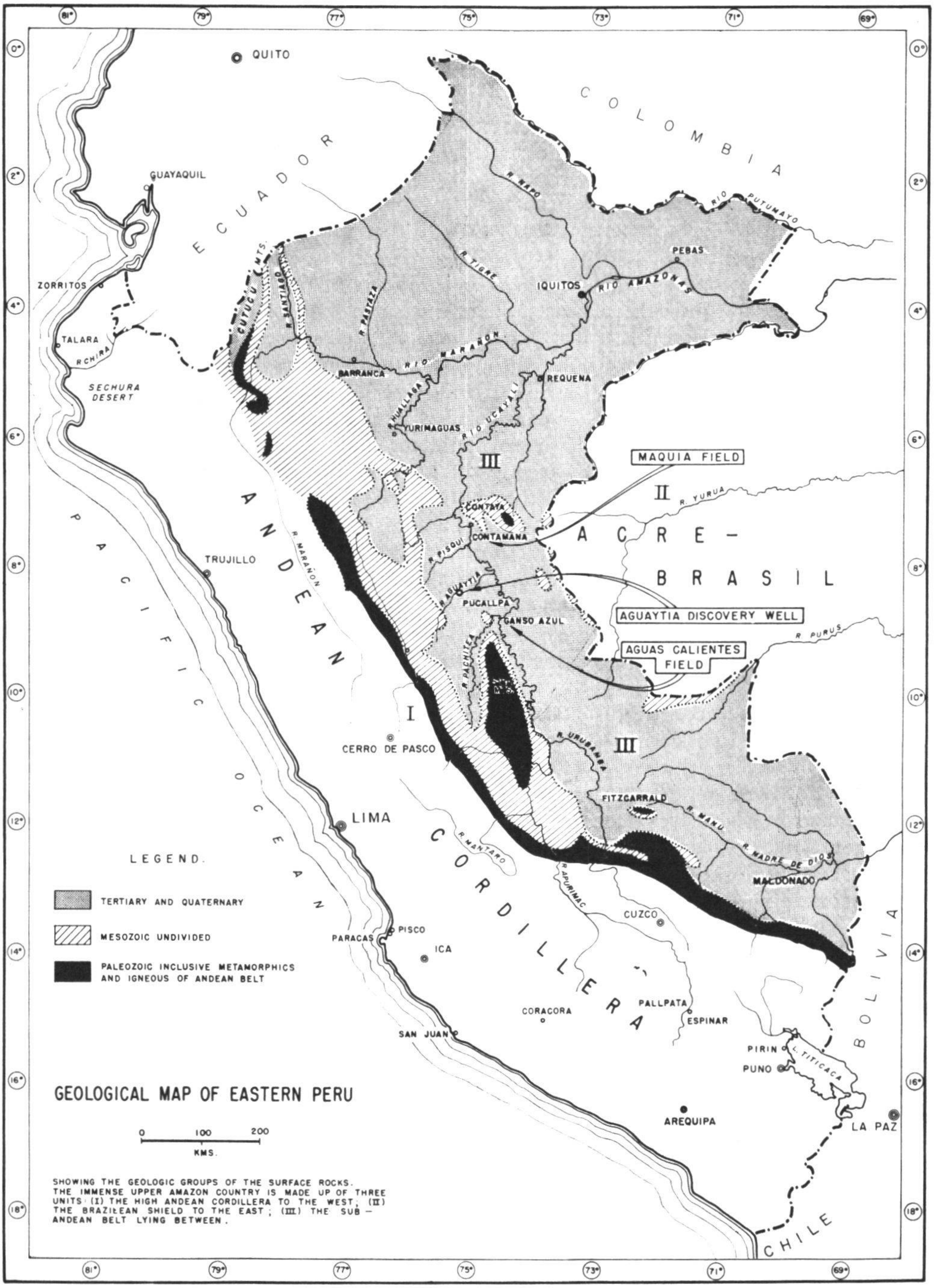
GEOLOGICAL MAP OF EASTERN PERU
LEGEND.
TERTIARY AND QUATERNARY
MESOZOIC UNDIVIDED
PALEOZOIC INCLUSIVE METAMORPHICS AND IGNEOUS OF ANDEAN BELT
0 100 200
KMS.
SHOWING THE GEOLOGIC GROUPS OF THE SURFACE ROCKS. THE IMMENSE UPPER AMAZON COUNTRY IS MADE UP OF THREE UNITS: (I) THE HIGH ANDEAN CORDILLERA TO THE WEST; (II) THE BRAZILEAN SHIELD TO THE EAST; (III) THE SUB-ANDEAN BELT LYING BETWEEN.
MAQUIA FIELD
AGUAYTIA DISCOVERY WELL
AGUAS CALIENTES FIELD
ECUADOR
COLOMBIA
ACRE-BRASIL
BOLIVIA
CHILE
PACIFIC OCEAN
ANDEAN CORDILLERA
SECHURA DESERT
QUITO
GUAYAQUIL
ZORRITOS
TALARA
IQUITOS
PEBAS
BARRANCA
REQUENA
YURIMAGUAS
CONTAYA
CONTAMANA
PUCALLPA
GANSO AZUL
TRUJILLO
CERRO DE PASCO
LIMA
FITZCARRALD
MALDONADO
CUZCO
PISCO
PARACAS
ICA
CORACORA
PALLPATA
ESPINAR
SAN JUAN
PIRIN
PUNO
AREQUIPA
LA PAZ
I
II
III
III

Fig. 3

possibilities of this large territory of promise is absolutely inconclusive as yet. Except for the excellent pioneer work of the first explorers, the principal interest and share of the exploration has been carried out almost 100 % by private enterprise. So far, however, surface and underground have only been scratched, and the geological information is highly incomplete over wide areas, leaving abundant room for theorizing and speculation.

The stratigraphic section of the upper Amazon basin includes rocks which range from pre-Ordovician Basement to Recent. The rare samples of basement rock obtained from exposures or cores are eruptives of gray to rose granites and greenish alkali-rich individuals of syenitic and dioritic types. They appear to belong to the pre-Cambrian Brazilian shield complex, but in part may be products of the Acadian, i. e. early-Hercynian orogeny and intrusive activity. There exist intrusives of probably younger age.

The Paleozoic rocks, both Upper and Lower, are well represented by outcrops and have been recognized in bore holes throughout the Amazon headwaters, such as in the Pachitea, Pisqui, Cachiyacu, Cashiboya and lower Marañón rivers.

The Lower Paleozoic consists of dark to black shales and slates, overlying a section of quartzites. They are identified by an abundant graptolitic and brachiopod fauna, which make them to begin somewhere in the lower Ordovician. In the Contaya High the rather soft shales yielded fossils of the Chazian. The Ordivician series evidently continues into slates and schists referred to as Devonian. This monotonous sequence is thickest in the Madre de Dios basin, thinning northwesterly. Silurian (Gothlandian) is not observed, on the contrary, a pronounced hiatus of regression and erosion separates Ordovician and/or lower-middle Devonian from Upper Paleozoic clastics, indicating that crustal movements were in progress in the sub-Andean belt. In spite of the absence of oil indications, the Ordovician shales are believed to be fair prospects for petroleum explorationists.

Upper Paleozoic beds are distributed on a generally moderate scale in the northern basin area. The Mississippian rocks, or Ambo group, well known in the Andes and on the Pacific coast, are missing in this part of the Amazon. Pennsylvanian and Lower Permian, however, represented by the Tarma and Copacabana groups, are important sedimentary products. It is plainly shown that the late Paleozoic seas constitute a major incursion which slowly flooded the dry lands in middle or late Pennsylvanian time, leaving certain elevated areas uncovered, and forming gray cristalline limestones in a clear neritic environment. Higher up in the section occur greyish black, fine grained carbonate rocks which are, in part, bituminous and deposited in water of poor circulation, and in part of the reef forming type. Separation of the two rock types is difficult, often feasible only by close identification of the organic material, especially the Wolfcampian fusulinids. The greatest thickness of these rocks, roughly 1000 m, is found in the Aguas Calientes-Pachitea area where the limestones are transgressive on Ordovician slates, which in turn encroach on pink granite. They show thinning toward the south in the Urubamba valley, and toward the north in the upper Pisqui region. In the latter area drilling penetrated a section of only 175 m Copacabana limestone, resting unconformably on Lower Paleozoic quartzitic sandstone and slates. The easternmost occurrence is struck in the Maquía field, where it directly underlies the Cretaceous Aguas Calientes formation. More eastward the carbonate rocks wedge out rapidly and are already absent in the Cashiboya well, where Ordovician pelites form the pre-Cretaceous land surface. The Permo-Carboniferous series offer favorable objectives as source beds and for storage, particularly the blackish facies, which may show good primary porosity and bioherm growth.

After the Gondwanic orogeny, the terrestrial and partially volcanic Mitu group was laid down. Its depositional area advanced very little into eastern Peru, fringing the outskirts of the Andean complex and fault scarp, as near Puente Durand-Tingo María – where it overlaps onto steep dipping gneiss – and in the upper reaches of the Pachitea, i. e. the Iscozazín and Palcazú rivers. It is assumed that the flows, lavic breccias, agglomerates and conglomerates resulted from subaerial volcanic activity rather than from fissure erruption. Intercalations of violet, reddish or variegated arkosic sandstones and slaty shales are common, and seemingly intertongue laterally with the volcanics. These products, Verrucano-like depositions, are mainly post-Leonardian, but they continue into the Triassic. It is likely that uppermost Permian and Triassic time also coincides with the precipitation of salt and anhydrite in small embayments or locked lagoons. The latter deposits are considered to be primary accumulations of the many later diapiric salt domes squeezed up during the main Tertiary folding in the Pachitea, Pisqui and Huallaga areas.

It was in upper Triassic and old Jurassic time, succeeding a major re-alignment of the geosynclinal basin in the eastern Andes, when seas spread over the Marañón and Huallaga districts, and probably also flooded a limited territory of the Andean foreland. A thick marine and mainly calcareous series was deposited, being the individual and sometimes alternating units readily noticeable: Gray marls, with preference in the lower portion; siliceous, dark blue limestones; lead gray carbonate rocks, locally sandy or marly; various types of yellow-white dolomite, nearly exclusively in the upper half. Interspersed are quartzitic sandstones and silty claystones. By noting the characteristic bivalved mollusks and cephalopods, this series is Triassic and Liassic in age. Its distribution is restricted to the western rim of the sub-Andean belt and, therefore, no vestiges of the formation have been found in the wells. In the Chinchao (Tingo María) valley, its thickness increases to a maximum of about 3000 meters. It is believed that the Triassic-Liassic sequence contains petroleum source beds. Moreover, some sections exhibit properties which could lead to advantageous reservoir conditions.

On the banks of the Callanayacu creek on the middle Huallaga, blocks and slabs of fossiliferous bluish dark gray limestone are exposed due to a big disturbance and to still active salt plug piercement, which is likewise responsible for the emanation of liquid oil in that place. This occurrence, together with much limestone boulders and pebbles in the nearby Chipaote river, showing a rich assemblage of Lias fauna, is thought correlative with the Ecuadorian Liassic Santiago formation, and doubtlessly is equivalent, in part, with the aforementioned carbonate sequence at Chinchao.

Resting against the foothill escarpments and covering strips between the Marañón-Huallaga region, Cushabatay Mts., Boquerón defile, Shira Mts., and the Tambo- and middle Urubamba river sectors, the Chapiza formation is the next younger unit of the stratigraphic prism occurring in the eastern Peru zone. It represents erosional products transported from the west where probable uplifts were happening in the adjacent Andes chain. The type sediment is made up of crossbedded to finely flaggy mainly chocolate to reddish brown, or purplish to violet sandstones and conglomerates, bedded gray yellowish limestones, and brightcolored or maroon sandy shales, siltstones, mudstones and marls. In many places it contains limy or sandy concretionary ledges, and salt and gypsum beds; occasional is the admixture of pyroclastic material. The bulk of the formation displays the characteristics of a continental redbed series.

The thickness of the Chapiza varies within wide limits, measuring between 650 to far over 2000 meters. Noteworthy is its thinning toward the east, northeast and southeast, but the series certainly underlies a great part of the middle and upper Ucayali district, and still has been encountered slightly east of the Ucayali river, in a section 57 m thick in well Rayo-1, north of Contamana. Since the exposed strata are completely barren of fossils, the age of the Chapiza is deduced from its relative stratigraphic position and paleogeographic considerations. Generally, the footwall of the sequence is formed by the unevenly capped Liassic (Santiago) limestone; its upper limit is a truncated pre-Cretaceous surface covered by the Aguas Calientes sandstone. The Chapiza is thus assigned an upper Jurassic age. Under proper conditions, some of its sections could offer suitable trapping and sealing accomodations.

For reasons of uniformity and the fact that no such formation is outcropping at all in the Sarayaquillo river, the name Sarayaquillo formation should be definitely dropped, and conveniently replaced by Chapiza formation, term of priority derived from the outcrop area along the Chapiza river in eastern Ecuador, where the stratigraphic relations and lithology of the series are excellently defined.

A considerable time space must be involved between the eroded topmost Chapiza layers and the superincumbent younger formations. The corresponding angular discordance marking the Nevadan cycle is sometimes clearly observed. Where wide marine transgressions were followed by only short withdrawals and readvances of the seas, the Cretaceous developed a nearly complete record of clastics which include the Aguas Calientes, Chonta, and Sugar Sandstone formations. The latter is overlain by the mainly terrestric Sol formation, so far only identified in the middle Ucayali region. It may be borne in mind that present drainage in the upper Amazon basin has reversed itself since Cretaceous time. The drainage formerly flowed westward into the Andean geosyncline.

The Aguas Calientes formation is composed of massive fine to conglomeratic, often slightly crossbedded sandstones of white, yellow and iron-stained buff tints. Interstratified are dark shales, siltstones, and sporadic limestone banks. The facies is fluvial in the lowermost portion, then deltaic-brackish and marine in its greater part. Distinct marine members, the Esperanza and Huayo, contain diagnostic fossil remains evolved in the middle and upper section of the series. They represent ingressions which are not constant in their easterly advances.

The thickness undergoes striking changes. It is smallest along the periphery east and west of the basin, e. g. 450 to about 700 meters in the eastern, and approximately 400 to 600 meters in the western border zone, while it is progressively greater down basin and greatest in the area of major subsidence, i. e. 1300 to 1800 meters in the middle Pachitea and upper Cushabatay rivers. The Aguas Calientes formation is a core builder «par excellence» of most known structures. The basal beds belong to the Neocomian and the variable upper portion ranges up to Turonian in age. As in the Cretaceous in general, there exist numerous oil and gas seeps and many hot springs, frequently sulfurous. Economic interest is warranted in the blackish marine shale members as a petroleum source, and also in the sands as convenient reservoir rocks. In the Ganso Azul field such sands produced an average of 65 000 bbls/month over the last three years.

Co-extensive with the concordantly underlying Aguas Calientes formation is the chiefly marine Chonta formation. It is easily distinguishable by dark gray to bluish laminated shales, pearl-gray massive or shaley siltstones, thinley bedded gray splintery limestones, and gray brown marls which turn greenish when bleached. Minor accessories are iron and lime concretions, and some thin sandstones, apparently slightly glauconitic. Throughout the outcrop area the Chonta is a rather non-resistent formation, but north and west of the Contamana region, where great increase occurs of calcareous siltstones and limestones, it also forms prominent ridges.

Greatest development is found in the Cutucú Mts., Marañón and Huallaga river areas, where the thickness is from 400 to 910 m. In the upper Pisqui, Boquerón, Ganso Azul and Contamana region, the sections vary greatly from less than 300 to 450 m. Of practical importance in some sectors is the interfingering facies change from marine to littoral-brackish (and to fresh-water) environment going eastward. The transition becomes palpable by the remarkable fading out of the highly fossiliferous marl-limestone strata and their balanced replacement by typical redbeds. Shrinkage and disappearance southeasterly and the complete absence of the Chonta in the Madre de Dios basin are other salient facts.

Determination of the age of the Chonta formation depends upon the age of the transgressive basal beds. It could vary from uppermost Albian to Coniacian, and an assemblage collected in the Pachitea district is said to yield the presence of lowermost Senonian. The deposits merge upwards into the Sugar Sandstone with conformable datum plane. In many sections the Chonta shows ideal sedimentary properties capable of having transformed prime material into hydrocarbons, and exposes conditions propitious to accumulation and trapping.

When the sea withdrew in upper Cretaceous time from its advanced foreland positions, the face of eastern Peru began to reverse itself, heralding greater changes in the Tertiary, and developping an epineritic platform in which the Sugar Sandstone or Arenisca de Azúcar was deposited. In its greater part, this formation is a yellowish white, medium grained to fine conglomeratic sandstone, showing strong delta structure and containing limonitic nodules and plant, bone and fossil wood fragments. Some sandstone members shale out westerly on the downslope of the shelf. There are, however, intercalated blackish shales in the lower half of the sequence, and a multicolored marly to limy, or silty shale section in the upper half. Pinching-out and lensing is frequent. In consequence, the differentiation of various units within the Sugar Sandstone has been registered, from intermittently continental-shoreline to marine facies development.

This formation occupies a zone from the Ecuadorian border through the Marañón, Huallaga and Ucayali rivers to the Pachitea, lower Urubamba and Mainique rapids. It constitutes a competent cliff and ridgebuilding unit. The isopachs show very considerable thickness variations, e. g. 185 m or far less east of the Ucayali; 250 to 400 m in the Ganso Azul district; and 260, 680 and more than 1000 m in the Pisqui, Cushabatay and Boquerón mountains, respectively. Hence, there exists a spectacular increase in thickness westward.

Very good porosity (18–25 %) and permeability (up to 1000 md), especially in the Lower Main Sand member, make the Sugar Sandstone an excellent recipient and trap for oil. The sequence is actually producing in the Maquía field where 10 wells are flowing with an overall potential of approximately 48 000 barrels per month. It is believed that the reserve potentialities of crude from both the Ganso Azul and the Maquía field are about 30 million barrels, primary recovery.

It became evident by recent exploration in the middle Ucayali district, that marker beds of great continuity exist conformably on top of the Sugar Sandstone. These constitute the Sol formation, uppermost Cretaceous redbeds of predominately continental origin and regional distribution. They are 100 m thick or slightly more east of the Ucayali, but accrue rapidly moving west, attaining certainly hundreds of meters on the actual Eastern Cordillera front, where the deepest part of this upper Cretaceous redbed-trough is to be expected. Over structures of identical north-south strike, the thickness is very consistent, but it increases notoriously toward synclinal areas, thus proving incipient anticlinal growth during sedimentation. The normal development of the Sol comprises three units: Variegated fresh-water marls, a few sandy limestones and shales at the base; gray-white tuffites and silty claystones in the middle; and bright-colored lacustrine marls and limestones in the top portion of the sequence.

Almost conformably, viz. with no major break except the presence of small erosional gaps and local mixture of different facies elements, the Tertiary redbeds or Capas Rojas overlie the Sol formation in a principally terrestrial basin extending throughout the Andean foreland belt. The sediments swept together in this milieu form an ubiquitious sheet over the greater part of eastern Peru, masking many of the older formations and underlying structures. Thorough fieldwork, aided by well-log studies and micropaleontologic research, especially on the Charophytes flora, carried out in the Contamana-middle Ucayali region, have just recently brought about the subdivision of this thick complex. The lowermost beds, the Capas Rojas-1, are composed of fine grained sandstones, siltstones and mudstones of reddish brown colors. There are also some coarser psammites, green claystones and gypsum beds present. Thickness is 600 to 800 m. Upwards, this unit changes into a tuffaceous, iron-stained bed, the 15 m thick Capas Rojas-2. This deposit is overlain by Capas Rojas-3, a conglomeratic sandstone which grades into intertonguing marls and sandstones, averaging 300 meters. Above lies a brackish-marine intercalation of about 50 m of sandy limestone with oyster shells, snails and foraminifera. C.R.-3 is considered to be equivalent to the marine Oligocene Pozo formation, mapped in the Yurimaguas-lower Huallaga district, where it is about 440 m thick, striking into eastern Ecuador. It is therefore of probable Oligocene age. On top of this marker horizon reappear continental clastics, i. e. marls, sandstones and mudstones building up Capas Rojas-4. This member is at least 400 meters thick. Its grain size is much coarser than in C.R.-1 and C.R.-3. The sands are arkosic, lime cemented, and include conglomeratic and brecciated layers. The mudstones in turn contain abundant bands of calcareous concretions. Higher up follow Capas Rojas-5, a section composed of clays, silts, sands, gravel and boulder beds, identified by light colors, friability, softness, little or no consolidation, and absence of carbonate rock. Thickness is 1000 meters and more. C.R.-4 and C.R.-5 may in part still belong to the Oligocene, but in its bulk they are obviously Miocene.

The total thickness of the Tertiary redbeds in the Contamana region is thus about 2500 meters. Measurements from other districts result in much higher figures. Most of the exposed sections are drastically reduced by erosion. The severe thickness reduction, however, may also be explained by syndepositional decrease or tectonic rise during sedimentation. Correlation, by using the new basic zoning or lithologic subdivision, with sequences lying hundred and more kilometers apart is not yet established. There are no oil shows in the Tertiary Capas Rojas, but salt water bubbles forth in many places.

An angular contact separates the Tertiary deposits from younger accumulations. The unconformity and, especially, the decisive transformations realized by folding, thrusting and salt intrusion are the result of the Quechua mountain building in probably upper Miocene time, which affected the Capas Rojas as well as part of the Mesozoic substratum. Apparently, the folding event was not simultaneous and did not equally compromise the immense territory. It might by supposed, for instance, that the flat lying or very moderately warped Iquitos-Pebas formation exposed along the bluffs of the upper Amazon river, still of debatable post-orogenic age, has escaped normal type Quechua folding and is therefore practically undisturbed. If that holds good, the deposits in question must be older than considered heretofore, viz. pre-orogenic and probably Miocene.

The new topography soon underwent denudation and peneplanation and alluvial piedmont fans and other accumulative clastics were spread far into the Brazilian shield area. Sections showing similar features are known from distant localities and most likely represent homotaxial time-equivalents. The sediments, judging from field and

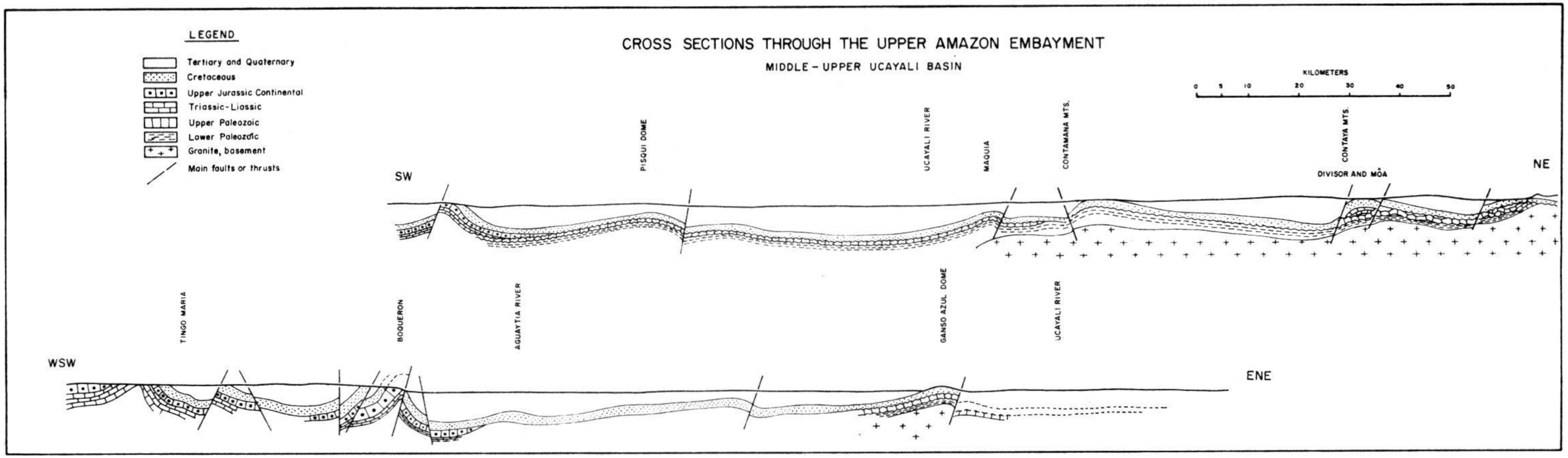
LEGEND
Tertiary and Quaternary
Cretaceous
Upper Jurassic Continental
Triassic-Liassic
Upper Paleozoic
Lower Paleozoic
Granite, basement
Main faults or thrusts
CROSS SECTIONS THROUGH THE UPPER AMAZON EMBAYMENT
MIDDLE - UPPER UCAYALI BASIN
KILOMETERS
0 5 10 20 30 40 50
SW
PISQUI DOME
UCAYALI RIVER
MAQUIA
CONTAMANA MTS.
CONTAYA MTS.
DIVISOR AND MÔA
NE
WSW
TINGO MARIA
BOQUERON
AGUAYTIA RIVER
GANSO AZUL DOME
UCAYALI RIVER
ENE

Fig. 4

photo-geologic evidence, involve different events and various terrace or Mesa levels which were brought about by periodic rejuvenation and gradational adjustment of the drainage. These deposits are definitely post-orogenic and range from Pliocene to the Present. They are flat or sub-horizontally disposed except for an almost indiscernible tilt obviously the result of posthumous movements. Attendant to radial uplift the greater part of the Peruvian Amazonian lands is actually undergoing renewed rejuvenation.

Structure

Among the main features worth noting, the structural geology of the northern Amazon basin is the least known. This portion of Peru reveals a multiple and vividly changing tectonic history which led to a widely folded, thrusted and faulted region. Chief among the orogenies were the Paleozoic and late Tertiary paroxysms which caused strong compressional tilting and also thrusting in the sector of the Andean cordillera border, and more gentle crumpling on mobile blocks in the easternmost spurs and foreland plains. The sub-Andean belt is built up by such units as the foothill zone, the Marañón basin and the Ucayali shelf.

The foothill zone culminates in several conspicuous highs. The structural pattern constitute elongated mostly narrow folds arranged in «en échelon» alignment. These show generally NW–SE bearing which overhelmed an apparently older primordial trend. The individual structures west of the middle and upper Ucayali are asymmetric anticlines with steep dips facing east, exhibiting frequent overturning (see sections Fig. 4). Thrusting transverse to the fold-axis, over-riding and also imbrication upon the foreland has occurred. Together with prevailing southwest–northeast cross-faulting and severe longitudinal rupture, the tectonic picture as a whole is a mosaic of all-dimensional intensively folded blocks.

A special entity developed immediately east of the northern foothill zone is the Marañón basin. It is a deep sink containing by far the greatest sedimentary thickness, being solely the Tertiary Redbed group nearly twice as thick as in the middle Ucayali district. The basin area strikes nearly parallel to the high Cordillera and to the frontal thrusts, and it seems to continue toward SE along the mountainous ranges across a rather narrow saddle seen to the west and northwest of Contamana. There are different size of structures; big, broad and gentle, smaller ones. Some of them are closed completely in Tertiary and/or Cretaceous beds; others are salt domes, classified by the depth of burial or type of upsurge. These diapires define a very special architecture which gives rise to primarily stratigraphic trap conditions along the salt edges. There are many ambiguous structures which only will be unraveled by geophysical work or by the drill.

Besides, the existence of a new regional arch, the Iquitos divide, located Amazonas down, i. e. over an extensive area near the Peru-Brazil boundary, has lately been postulated by the Petróleo Brasileiro S.A. The divide is shown as the major offshoot connecting the two great shields, the Guyana shield and the Brazilian shield, respectively. Its origin or uplift is traced back to the Paleozoic, representing a positive element since that time which acted as a border land to the western marine Cretaceous geosyncline. The clastic supply derived from this High lasted seemingly far into the Tertiary, being the Iquitos-Pebas formation eventually part of its erosional products.

Another outstanding structural element is the Ucayali shelf area. The west flank of this shelf constitutes a geologic feature of first importance in oil exploration because it marks the approximate line of facies change of much of the Mesozoic sequences from marine on the west to non-marine toward the east. The shelf is occupied by many folds and minor wrinkles which altogether belonged to the realm of the Cretaceous platform. The folds are generally slender and of attractive shape and size; some form anticlinoria and domes, followed alternately by stretched, mostly smooth synclines. On a series of anticlines occur flexures partially bound up with thrusts. These structures readily reveal the tendency evidenced on both sides of the Ucayali river, of a bilateral convergence toward the broad valley plain where no folding is observed. In the shelf area also, the strike is NW–SE, a disposition which shows cross-shifting of structural elements adopting a general east-west direction.

Detailed work may bring to light closed structures with relatively unmetamorphosed Paleozoic and Mesozoic objectives, as well as potential traps.*) The long costly experience established the importance of environment and facies as foremost requirements for the occurrence of oil. It became clear too, that the fundamental working in the field is not to concentrate on the Tertiary beds but to get acquainted with the Cretaceous and the suit of older rocks, to thoroughly investigate their structural behaviour and to search in the geohistorical past for the relation which strikingly exists between the diastrophic movements, the oil migration and its subsequent preservation.

Madre de Dios Basin

Separated from the northern Amazon Basin by the Fitzcarrald divide, and located in the southeasternmost portion of Peru is the Madre de Dios embayment. Its eastern part consists of extensive low lands riding on the outskirts of the Brazilian craton, while its narrower western half is formed by the rugged Andean foothills which stretch down from the steep sloping spurs of the high Cordillera. Mainly in this latter portion occur oil indications, rocks with sealing and storing properties, and also promising structural accommodations. These features advance in the foreland area where they disappear under younger drainage deposits. Rarely, if ever, is a true structure seen in this swampy, amazingly flat country.

Most of the territory is overlain by Cenozoic series, but older ones crop out as well. From bottom upwards, the sequence is composed of: Basement, being the leading types igneous rocks of the alkaline-atlantic tribe of the great Brazilian province, and metamorphics closely related to younger, large intrusions of batholitic expanse emplaced at the end of the Lower Paleozoic. Covering the old basement rocks is a nearly 1000 meter thickness of black Ordovician-Llanvirnian and probably much older shales and slates, sandstones and quartzites, reported from the Quince Mil- Tambopata- and Inambari region in the south, and from Alto Madre de Dios and Alto Manú rivers in the north. The dark hemipelagic pelites contain a rich graptolite fauna known time ago from different classic outcrop areas and certainly had a significant bearing on the origin of oil. Nevertheless, they are to a great extent intensely transformed, especially in its lower portion, by contact and dynamo-metamorphism, and oil they might have contained has been destroyed or else escaped into the concordantly overlying thick sandstones, greywackes, blackish shales and phyllitic silts of lower and middle Devonian age, in places crowded with brachiopods and crinoids and an occasional trilobite. It may be expected that similar sequences exist in the substratum of the wide foreland plains wedging toward the shield.

*) Of very recent date (January 1962) is the find of a huge natural gas field in the Lower Cretaceous section of a domal structure on the Aguaytía river, 40 km west of Pucallpa. Preliminary reserve estimates of the discovery well amount to a tremendous 2.5 trillion cubic feet of gas. The construction of a gas pipeline across the Andes to Lima has been planned providing great impetus to the industrial development, especially to the petrochemical industry.

A clear gap in the succession denoting regression, uprise and denudation is seen between the Ordovician and Lower/Middle Devonian clastics and the Upper Paleozoic beds. This break was brought about by the earliest orogenic movement observed in the Andes of eastern Peru, the Bretonic or Acadian phase of the Hercynian revolution, dated upper Devonian-lower Carboniferous. This and younger regional events established important highs or a «massif» with tectonic linearity outlining the backbone of the later Andes. Restricted to the actual cordillera front, there appears in the upper reaches of the Pantiacolla and Manú rivers a section of Mississippian (?) continental sandstones up to 700 m thick. On top of it, or encroaching on older rocks in the Alto Madre de Dios and aforementioned river areas are fossiliferous sediments of Carbo-Permian seaways. They are greyish black, compact or porous limestones, with possible development of reefs, often strongly bituminous or with pronounced odor of petroleum. Within this unit occur intercalations of reddish to dark shaley sandstones. The series increases from 300 to 650 m thickness northwesterly, and is a propitiously looking source and reservoir rock.

Further mountain building succeeded middle Permian when late Hercynian diastrophism created the Gondwanic arc, an event that was followed by a wide spread of intermediate to basic outpourings. What then happened in early Mesozoic history is obscure. With the prompt wearing down of the Gondwanides, a considerable sequence of coarse detritus was piled up. This apparently grades upwards without visible interruption into Cretaceous, or even Tertiary, as do comprehensive series. It is thus evident that some larger basins or smaller embayments of semi-continental habitat, remained undisturbed over very long periods, whereas deposits of other sedimentary troughs reveal strong discordance within the same type of section, doubtlessly produced by the Nevadan cycle. The present structural disposition, however, was achieved by warping, upthrust and dislocation during the Quechua folding act which affected the basin area and sedimentary groups, inclusive the Tertiary Redbed series, in their entire thickness. Subsequent erosion bit deeply into the tilted beds, and swept them from a large area down into the basin of the sinking shelf. For the present the lowering of the shelf (or shield edge) has apparently concluded.

As it also occurs in the northern Amazon basin, chief control on structures has been performed by the old basement pattern. So, the oldest Paleozoic basin is the proto-embryo of all later basin areas; and likewise, the young folding system is in part, or to at great extent, revived on the older structural lay-out. As a whole, the Madre de Dios basin is a twofold tectonic unit separated into a southwestern (or southern) zone and northeastern (or northern) zone. This designation is in harmony with the general strike of the structures which is frequently rather west–east than northwest–southeast.

The southwestern or southern zone, essentially spurs and foothills, shows strong to violent folding, and in places imbricate structure. There are sharply compressed narrow anticlines with steep flanks, but there exist also broader warps standing less steeply and pointing out fair to conspicuous saddle development. The girdle of folds is to a great part closed in Tertiary redbeds, but sometimes open in Mesozoic or upper Paleozoic rocks. The northeastern or northern zone commences abruptly along a considerable front of upturned scales or manifestly thrusted fault ledge. The fault planes are dipping southwest, and shears and thrusts of small magnitude are pushed and piled up against the border of upright folds. Away from this scarp the basin continues endlessly into the flatlands covered almost exclusively with Plio-Pleistocene to Recent beds which lie completely or nearly flat. They show no structure at all though attractive buried configuration may occur. This portion of the Madre de Dios basin is immense and by its remoteness, very poor accessibility and primitiveness of the area hardly known. Nevertheless it does not fail to look prospective, provided that the integration of geological concepts with intense geophysical techniques to achieve resolution will be the approach to be taken in the exploration of this vast territory.

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