PERUVIAN FOOTHILLS: EXPLORATION IN A FRONTIER AREA

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ABSTRACT

Within the general context of South America, the recent discoveries of giant fields, within the Andean Overthrust Belt e.g. El Furial complex in the eastern Venezuela Basin, The Cusiana-Cupiagua trend in Colombia or the large Camisea Field in the southern Ucayali Basin of Peru, have increased the interest of companies for exploring the foothills in Latin America.

As of today, less than 20 significant exploration wells (including the 8 wells drilled over the Camisea general area) have been drilled along the 1700 km Peruvian Fold and thrust Belt. However, the results of recent exploration efforts, including the large volume of geological and geophysical work performed, have greatly enhanced our comprehension of the area.

The Peruvian Fold and Thrust Belt (ie sub-andean zone) classically shows from East to West an underformed platform, a subsiding flexural basin and a deformed belt of deformation, partitioned into different segments from North to South, reflecting the influence of pre Andean (primarily Paleozoic and Triassico-Jurassic) sedimentary records and structural episodes of deformation. Within this context, each segment shows different structural and petroleum characteristics.

In the northern part, the western margin of the Marañon foredeep shows a deformed belt of Paleozoic through Cenozoic sediments within the Santiago Basin. This area records a long and polyphased history of deformation, which predates the Andean Orogeny. Within the basin, the first Andean phase (Paleocene through Late Eocene/Early Oligocene - Incaic-) has produced significant structural relief along with synflexural Paleogene foredeeps. Late on, the Mio-Pliocene Quechua phase induced various levels of inversion, along with the formation of second order piggy back sub basins, limited by “en echelon” faults, formed within the general pattern of a dextral wrench zone.

Along trend, The Huallaga Basin, with similar pre Andean structural and sedimentary evolution appears controlled by the inherited Hercynian structural framework of the basement, showing NW-SE and ENE-WSW orientations. Mesozoic evaporites (Jurassic?) have locally produced halokinetic structures, largely involved into the Tertiary deformations and locally recognized along the edges of the different thrusts. Furthermore, evaporites acting as major decollement level have allowed fairly important thrusting motion, the development of large hanging wall anticlines, as well as imbrications along the leading edges of the different thrusts.

Further to the south, the Pachitea sub basin has also preserved remnants of hallokinetic structures, and displays thick skinned tectonics of Mio-Pliocene age. Along the same trend, pre existing NS and WNW-ENE trends, controlling Paleozoic and Jurassic facies distributions, have guided the andean deformations within the Ene Basin, where typical thin skinned ramp-flat geometries interact to the East with the basement core structure of the Shira High.

Along the southern part of the Ucayali Basin, in trend with the major transverse Tambo Fault oriented WNW-ENE, thin s skinned deformation affects the sedimentary cover over a basal decollement which ramps up from Base Paleozoic into the Tertiary, resulting in the formation of the Cashiriari ramp anticline and San Martin through Mipaya leading edge anticlines, which form the traps at Camisea. Here again, deformations have most likely started as early as Paleogene times, although the actual geometries of structures were acquired during the most recent Quechua phases.

East of Camisea, similar tectonic events are recorded along the southern margin of the Madre de Dios Basin, where however, the inherited Madidi Arch has most likely acted as a butress zone during the Paleozoic and Cretaceous thrust slices along the southern limit of the external Tertiary detached syncline. Thus, this structural setting is the result of both, piggy back and overstep sequences of deformation with superimposed neotectonic events.

In this context, from the northern Peruvian Fold Belt where Mesozoic source rocks are predominant, to the southern part where Paleozoic source rocks constitute the base for the petroleum systems, parameters such as structural geometries, kinematics of deformation as well as sequence and velocities of thrusting, syntectonic sedimentation and erosional processes, flexural subsidence and uplifts have strongly influenced the maturation history as well as the evolution of the reservoirs. The understanding of these parameters for the different segments defined within the Peruvian foothills is key for evaluating the petroleum potential of this large and complex frontier area.

INTRODUCTION

Within South America, the recent discoveries of giant fields, within the Andean Overthrust Belt (i.e. El Furial complex in the Eastern Venezuela Basin, the Cusiana/Cupiagua/Pauto/Florena trend in Colombia, the Giant Camisea Field in the southern Ucayali Basin of Peru and most recently the San Alberto/San Antonio anticlinal trend in the Southern Chaco Basin of Bolivia) have increased the interest of companies for exploring the foothills in Latin America.

Applied to the Overthrust Belt of Peru, the results of recent exploration efforts including primarily large volumes of geophysical and geological work, performed during the last 3 years have greatly enhanced our comprehension of the area. However, as of today, less than 20 significant exploration/appraisal wells (including the 8 wells over Camisea) have been drilled along the 1700 km Peruvian fold and thrust Belt. Thus this extensive area, which extends from the Ecuadorian border to the North, to the Bolivian Border to the South East, remains largely underexplored. The limited exploration work performed have nevertheless led to the discovery of the Giant Camisea field (over10 Tcf of gas - $\cong$300 10^9 m^3-).

By now, taking into account the foothills/foreland complex at the scale of Peru, two distinct hydrocarbon fairways are recognized. The southern predominantly gas trend is associated with the external fold and Thrust Belt along the southern Ucayali and Madre de Dios Basins. The northern oil trend is tied to the eastern margin of the Marañon Basin where total reserves in excess of 1000 MMBls of oil have been discovered. Although this later trend potentially extends southward through the Ucayali and Madre de Dios foreland basins, no economical discoveries have come to support this assumption at present.

REGIONAL GEOLOGY

The evolution of the Andean Cordillera is associated to the subduction of the Pacific plate underneath the American continent. The evolution of the Cordillera as well as of the different provinces which can be identified (fig. 1) are therefore associated to the different phases of subduction from the Paleozoic through Present. Within this context, the Peruvian Overthrust Belt (ie the subandean zone), classically shows from East to West an underformed platform (the Brazilian shield) a subsiding flexual basin and a deformed belt (fig. 1 & 2). The entire chain is partitioned into different segments, which reflect the critical role of pre-Andean sedimentary records and structural episodes of deformation. In this respect, the structural framework of the basement, inherited from the Paleozoic Hercynian orogenies appear to have played a particularly important role.

The structuration of the Precambrian and Paleozoic basement was primarily acquired during the Late Devonian/Early Carboniferous Early Hercynian Orogeny, and was later on, reactivated during the Late Permian Late Hercynian phase. Two major sets of basement faults characterize these early deformations; these faults strike at N 110° (Contaya Arch, Tambo Fault ….) and N 160° Shira High, Seshea High, Eastern segment of the Contaya Arch ….) and are associated with conjugate systems oriented at N 20° to N 40° and N 50° to N70° (fig. 1 & 2). These fault trends represent important basement discontinuities, which were reactivated by the later episodes of deformation. As a result, the Paleozoic, Mesozoic and Cenozoic paleogeographies, as well as the corresponding tectono-sedimentary units are largely controlled by these basement fault systems (fig. 3).

Although much more complex in detail; on general terms and from North to South, the Sub-Andean foothills of Peru can be subdivided into two main "segments" (fig. 1 & 2):

1. From the Santiago Basin (North Peru) to the Ene Basin (Central Peru), the Cordillera strikes at N 160°, and is characterized by east verging thrusting in relation with the dominant, East-West direction of shortening. Decollement levels ramp up form the Lower Paleozoic (Ordovician through Devonian) shales into the Upper Cretaceous shales of the Chonta Fm and finally through the Tertiary at the leading edge of the different units. Shortening related to thrusting reaches on average over 100 km.

2. From Camisea to the Bolivian Border (fig. 1 & 2), the Cordillera strikes at N 110° to N 120°, reflecting a significant obliquity (most likely related to the Hercynian structural inheritance) of the deformed Andean belt, as compared to the East-West direction of the Andean compressive stress. As a result, deformations at this level include a significant senestral strike slip motion, although, the most apparent deformations are related to North East verging thin skinned deformations.

THE MAIN GEOLOGICAL PROVINCES OF THE PERUVIAN FOOTHILLS

- **To the North, the western margin of the Marañon Foredeep** shows a deformed Belt of Paleozoic through Cenozoic sediments **within the Santiago Basin** (fig. 1, 2 & 5). The area shows a moderately complete stratigraphic sequence which rests unconformably over the Precambrian basement (fig 3 & 4). Overlying the late Permian sands, shales and evaporites, the sedimentary section is very thick and consists in:

  - 1000 to 2000 meters of Liassic carbonates and evaporites, unconformably overlain by thick Upper Jurassic comglomerates, volcanoclastics and poorly sorted sandstones of the Sarayaquilo Fm. Within the sequence, the Liassic shaly carbonates which locally reach 1000 m in thickness represent an excellent type II source rock. Although source rock to oil correlations indicate that the Liassic sediments have contribued to the sourcing of some fields within the southern part of the Marañon Basin, its contribution appears relatively limited. This is most likely linked to its important paleoburial under thick Upper Jurassic, Cretaceous and Early Tertiary sediments. It is therefore most likely that generation of hydrocarbons from this source rock occurred as early as during the Cretaceous, prior to the formation of traps during the Tertiary Andean compressive episodes;

  - Over 1000 meters of Cretaceous dominantly margino littoral to shallow marine shales and sandstones, Neocomian through Late Maastrichtian in age. The Cretaceous represents the key to the petroleum system within the Santiago/Marañon, Huallaga, Pachitea and Northern Ene Basins as both the reservoirs (Early Cretaceous Cushabatay sandstones, and Late Cretaceous Chonta sands and Vivian sandstones) and the source rocks (Early Cretaceous Raya and Late Cretaceous Chonta shales) are present within this sequence (Fig 3). Source rock to oil correlations demonstrate that within the Oriente Basin sensu largo (Oriente Basin of Ecuador and Marañon Basin) the bulk of the oil discovered (Huerta 1991, Mathalone and Montoya 1995) were generated from these type II/III Cretaceous shales;

  - And, finally 4000 to 6000 meters of Tertiary synorogenic sediments, Paleocene through Pliocene in age (fig. 5). Maturation of The Cretaceous source rocks is acquired during the deposition of these syntetonic sediments.

Thus the area shows a long and polyphased history of deformation (fig. 3 & 4), including Hercynian basement faulting, Jurassic through Early Tertiary halokinetics followed by various phases of compressive events, from Mid Jurassic (Nevadian Orogeny) to the presently active Quechua phases of the Andean Orogeny.

Within the basin, the Incaic phases (Paleocene through Late Eocene/Early Oligocene) have produced significant structural relief, along with synflexural foredeeps (over 3000 m of Paleogene sediments). Later on the Mio-Pliocene Quechua phase induced various levels of inversion (from 1000 m, up to 6000 m), along with the formation of second order “piggy back” sub basins (fig, 5).

In this context, where the potential petroleum traps are linked to recent Quechua structurations and/or to earlier formed Incaic age structures (fig. 5), modeling indicate that despite important paleoburials, the Chonta (Cenomano Turonian to Santonian) type II/III source rocks remain in the oil window at present, over most of the basin. Preservation of good petrophysical properties of the potential reservoirs (Early Cretaceous and Campano - Maastrichtian sandstones) along with adequate timing of generation of hydrocarbons and formation of traps appear therefore to be key for a successful petroleum exploration in this complex area, where very important paleoburials and significant inversions appear predominant.

- **Along trend, the Huallaga Basin**, with similar pre Andean and sedimentary evolution (fig. 1, 2, & 3) appears controlled by the inherited Hercynian structural framework of the basement, showing N 110° and N 160° orientations. Here again, the Cretaceous source rocks and reservoirs appear to have supported important paleoburials, most likely within the paleo-Paleogene foredeep, associated with the Incaic deformation. Most recently (during the Mio-Pliocene Quechua phases) the entire basin was inverted (5000/6000 m of inversion are recorded locally) and thrusted in relation with the regional extension of Jurassic (?) evaporites, which have acted as a regional decollement level at the scale of the Basin (fig. 6). In light of the above the reconnaissance of tectono-sedimentary units which might have been submitted to lesser paleoburials and/or the identification of preserved Incaic age structures (which might have been sourced early on) appear again to be key for a successful exploration within this Basin.

- Further to the south, **the Pachitea sub basin** and the **northern Ene Basin** (fig. 1 & 2) show a similar stratigraphic section and have also preserved remnants of hallokinetic structures (fig. 7). Along trend, the preexisting Shira High and Tambo Fault appear to have controlled Jurassic and Cretaceous facies distributions (On general terms, to the south of the Tambo fault, the Upper Cretaceous Chonta Fm uncomformably overlies the Upper Permian shales and sandstones - see fig. 3 & 7). Within this area, the basement cored structure of the Shira High - Fig. 8 - (uplifted through the different andean phases) limits the propagation of thin skinned deformations eastward, resulting in the “stacking” of the different thrusted units along the eastern flank of the Shira High.

- **Along the southern edges of the Ucayali and Madre de Dios Basins**, in trend with the N 110° oriented Tambo Fault, the Peruvian Overthrust Belt displays a major deflection which is initiated at the level of Camisea (fig. 1 & 2). This segment of the Cordillera shows a very different stratigraphic sequence (fig. 3 & 7), characterized by the absence of Jurassic and Early Cretaceous formations (result of erosion during the regionally documented Neoconian inversion?). As a result the Late Cretaceous Chonta Formation lies unconformably over a moderately complete Paleozoic section. This sedimentary section which extends from the southern Ene Basin (South of the Tambo Fault) eastward through Camisea and the Madre de Dios Basin shows, overlying the Early Paleozoic Ordovician to Late Silurian fluvio deltaic sediments (fig. 3 & 7):

- 1000 to 2000 m of Devonian marine shales. These sediments deposited along the entire subandean zone of Peru during the Devonian regional transgression reach, on average over 1000 meters in thickness. Although, the average T.O.C (0,5 to 1,5%) appear relatively low, the important thickness of sediments, the importance of the source rock facies within the section (50 to 90% of the sequence depending on the stratigraphic intervalls), and their regional extent, the Devonian represents a major type II/III source rock (oil and gas prone) over the entire area;

- 500 to 1500 m of Early to Mid Carboniferous sediments. Following the Devonian regional transgression, which ended during Late Devonian times in relation with the Early Hercynian Orogeny, the Carboniferous corresponds to a regressive period. As a result the Carboniferous deposits lie uncorformably over the Devonian sediments and seal the Early Hercynian deformations and resulting paleogeographies (fig. 3). The corresponding formations are characterized by an important continental influence and were deposited in shallow marine (Laubacher, 1978), delta front to moderately wave exposed shorefore environments at the base of the sequence (Ambo Group) while the upper section (Tarma limestones) reflect inner to mid ramp environments of deposition. The important clastic content of these sediments is related to the erosion of the Proto Cordillera (Benavides, 1991, Gohrbandt, 1993) or in more general terms to the erosion of the releifs formed during the Early Hercynian Orogeny. Through out the section, the shaly facies appear admixed in small amounts and contain various coal seems. As a result the carboniferous sediments correspond to a predominantly type III source rock, primarily gas prone;

- 300 to 500 m of Early Permian mixed carbonate siliciclastric sediments. At the scale of southern Peru, the depositional environment of the Copacabana Group corresponds to a wide intracratonic sea with an overall ramp type basin setting of sedimentation. The lithostratigraphic unit is composed of mixed carbonate siliciclastic sediments. In detail, facies cycles evolve considerably due to high frequency glacio-eustatic sea level fluctuations. Lowsand tracts are composed of siliciclastic coastal plain deposits, while the trangressive and highstand intervals are respectively represented by bioclastic carbonates and oolitic limestones. As a result the Early Permian Copacabana Group appears to have an overall poor petroleum potential in Southern Peru, only the minor shaly intervals, present in the section, could reveal some source potential;

- 200 to 400 m of Late Permian to Early Triassic sandstones and shales. The Late Permian Late Hercynian Orogeny reactivated the Early Hercynian releifs, produced regional uplift and was responsible for a general recess of the sea from the continental margin. Thus the Ene, Noi, and Nia formations consists primarily in continental sediments deposited within shallow marine, fluvial and lacustrine environments. The Late Permian sedimentation consists of interbedded shales sands, dolomites and local anhidritic deposits. The Ene, Noi, Nia formations of Southern Peru, are likely lateral equivalents to the volcanoclastic sediments of the Mitu Group Within Southern Peru the Late Permian black shales deposited in restricted shallow marine and lacustrine environments correspond to an excellent type II-I to type I oil prone source rock, with average TOC of 2 to 3% (up to 8%), hydrogen indices of 400 to 600 mg H/g TOC (up to 900 mg H/ g TOC) and S2 averages of 10 to 15 kg HC/Trock (up to 36 kg HC/Trock). Despite these excellent source rock parameters, as of to date and to the contrary of what has been reported by various authors (Salas, 1991, Mathalone and Montoya, 1995, Fisher et al, 1996), none of the hydrocarbons accumulations or seeps identified, can be clearly associated to these Permian shales. The specific kinetic parameters of this predominantly type I source (late yield and short time of generation) vs timing of traps formation, could explain this fact (Advocate, 1999);

• 300 to 500 m of Late Cretaceous interbedded shales and sands of the Chonta Fm (Coniacian to Santonian) and of the Vivian/Huchpayacu and Casablanca formations (Campano-Maastrichtian). Therefore the area is characterized by the absence of the Jurassic and Early Cretaceous formations which reach 3000 to 4000 m in thickness westward and northward and up to 500 m immediately to the south in Bolivia (eolian sandstones of the Beu Fm. tentatively assigned to the Jurassic). The inversion linked to the compressive events of the Jurassic Jurua and Nevadian orogenies and of the Neocomian Mochica andean phase appear to be responsible for the erosion of the Early Mesozoic sediments over the area (fig. 3). On a petroleum point of view, the Cretaceous sandstones of the Lower Chonta, Vivian and Casablanca sandstones represent the main reservoirs (ie Camisea). On the other hand the Cretaceous marine shales of the Chonta Formation (main source rock northward within the Oriente Basin) loses its source rock potential southward, in relation with the heavy terrigeneous content of the sediments to the south of the Contaya Arch (fig. 3).

• Over 5000 m of Tertiary sediments were deposited along the proximal edge of the Thrust belt within the foredeeps associated to the Incaic and Quechua phases of deformation. Thus the present maturities of the Paleozoic source rocks were acquired during the Tertiary.

Therefore, in southern Peru the Devonian marine shales (type II to II/III), the predominantly terrigeneous shales and coal seems (Type III to III/II) of Carboniferous age and the Late Permian lacustrine black shales (type I to I-II) represent the main source rocks, while the reservoirs correspond to the Late Permian/Early Triassic sands and Upper Cretaceous Lower Chonta and Vivian/Casablanca sandstones. It has to be pointed out that if the Devonian sources display maturities reflecting "end of oil window" to "gas window" over the entire area (Vro $\geq$ 1), maturities of Carboniferous and Permian sources vary to a large extent along strike, reflecting the diversity in the structural evolutions (different timing for the formation of traps, various degrees and timing of uplifts and paleoburials …) from the Ene Basin to the West, to the Madre de Dios Basin to the East. This diversity in maturity gradients associated with the diversity of the types of sources (gas prone and oil prone) reflect the complexity in evaluating the petroleum potential associated to the Overthrust Belt of Southern Peru.

- In the Camisea area, thin skinned deformations affect the sedimentary cover over a basal decollement which ramps up from Base Paleozoic, northward into the Tertiary formation, resulting in the formations of the San Martin, Pagoreni and Mipaya leading edge anticlines and the Cashiriari ramp anticline (fig. 2) along the most external front of deformation, while a syntectonic "piggy back basin" develops southward. Preservation of good petrophysical characteristics of the reservoirs at Camisea imply that uplifts along the frontal zones must have started as early as Paleogene times, although the actual geometries of structures were acquired during the Mio-Pliocene Quechua phases of deformation. In the meantime "the piggy back" Basin located to south kept subsiding. This important subsidence has allowed the deposition of over 5000 m of Tertiary syntectonic sediments. The "kitchen" for the mature fluids discovered at Camisea is therefore, most likely located at the level this "piggy back" basin. Source rocks to oil correlations indicate that both, Devonian and Carboniferous source rocks are the main contributors for Camisea's hydrocarbons (fig. 3).

- **East of Camisea, along the southern edge of the Madre de Dios Basin** similar tectonic events are recorded (fig. 3 & 9). However, the butress zone associated to the East West trending Madidi Arch (where the Cretaceous rests unconformably over the Precambrian basement) stops the propagation of thin skinned deformation northward (fig. 10). The resulting tectonic style shows a "stacking" of thrusted units along the southern flank of the Arch, while the southern flank of the Tertiary foreland basin is uplifted, at the level of a back thrust in front of the formed tectonic wedge (fig. 10). Thus in this area, the present structural configuration is the result of both piggy back and overstep sequences of deformation, complicated by superimposed neotectonic events. Therefore and although the petroleum systems appear overall similar to those evidenced within the Camisea area, key factors here, are represented by the good understanding of timing of generation of hydrocarbons from the Paleozoic source rocks versus formation, preservation and potential reactivation of the Tertiary traps.

CONCLUSIONS

The geology of the Peruvian fold and thrust Belt is very complex; its structural style appears controlled to a large extent by inherited trends which were repeatedly reactivated during younger tectonic pulses. The understanding of trap evolution in time, and paleoburrials of both source rocks and reservoirs during the Andean tectonic phases appear essential steps for successful exploration.

Diversity of structural styles and structural evolutions, along with varying petroleum systems characterize the area. Mesozoic source rocks are predominant along the north western part; while Paleozoic source rocks constitute the base of the petroleum system along the southern Overthrust Belt of Peru. The different source rocks identified but also the specific evolution of each segment of the mountain chain, where structural geometries, kinematics of deformation, sequence and velocities of thrusting, syntectonic sedimentation and/or erosional processes vary considerably from one segment to another, imply in depth regional understanding and detailed characterization of the potentially attractive areas and structures, which are considered essential steps before proceeding further.

Work conducted so far, demonstrate that all key parameters necessary for hydrocarbon generation entrapment and preservation are present over most of this largely underexplored domain. Although challenging, this gives reasons for an optimistic outlook for future exploration.

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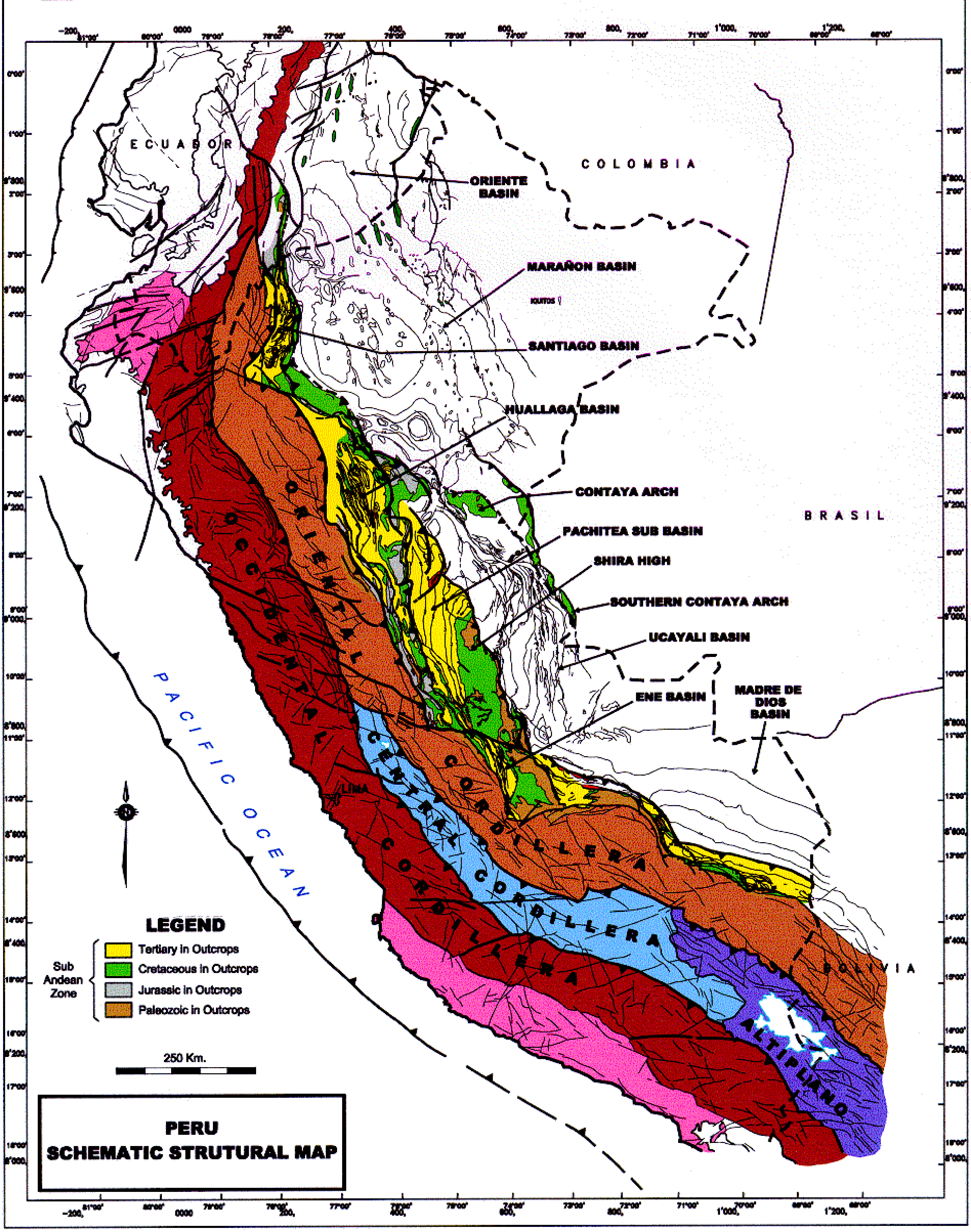
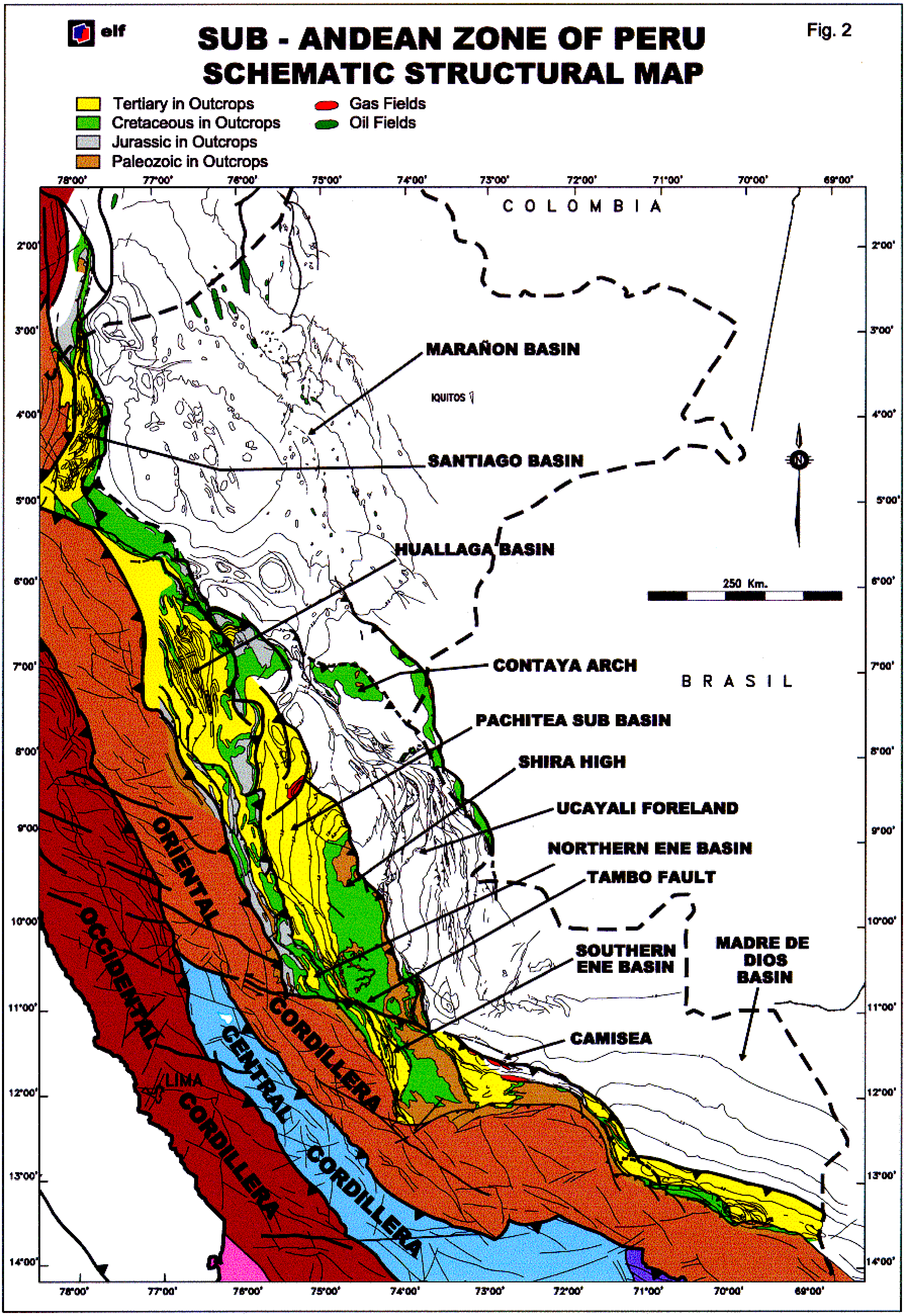
Fig. 1



PERU
SCHEMATIC STRUTURAL MAP

Fig. 2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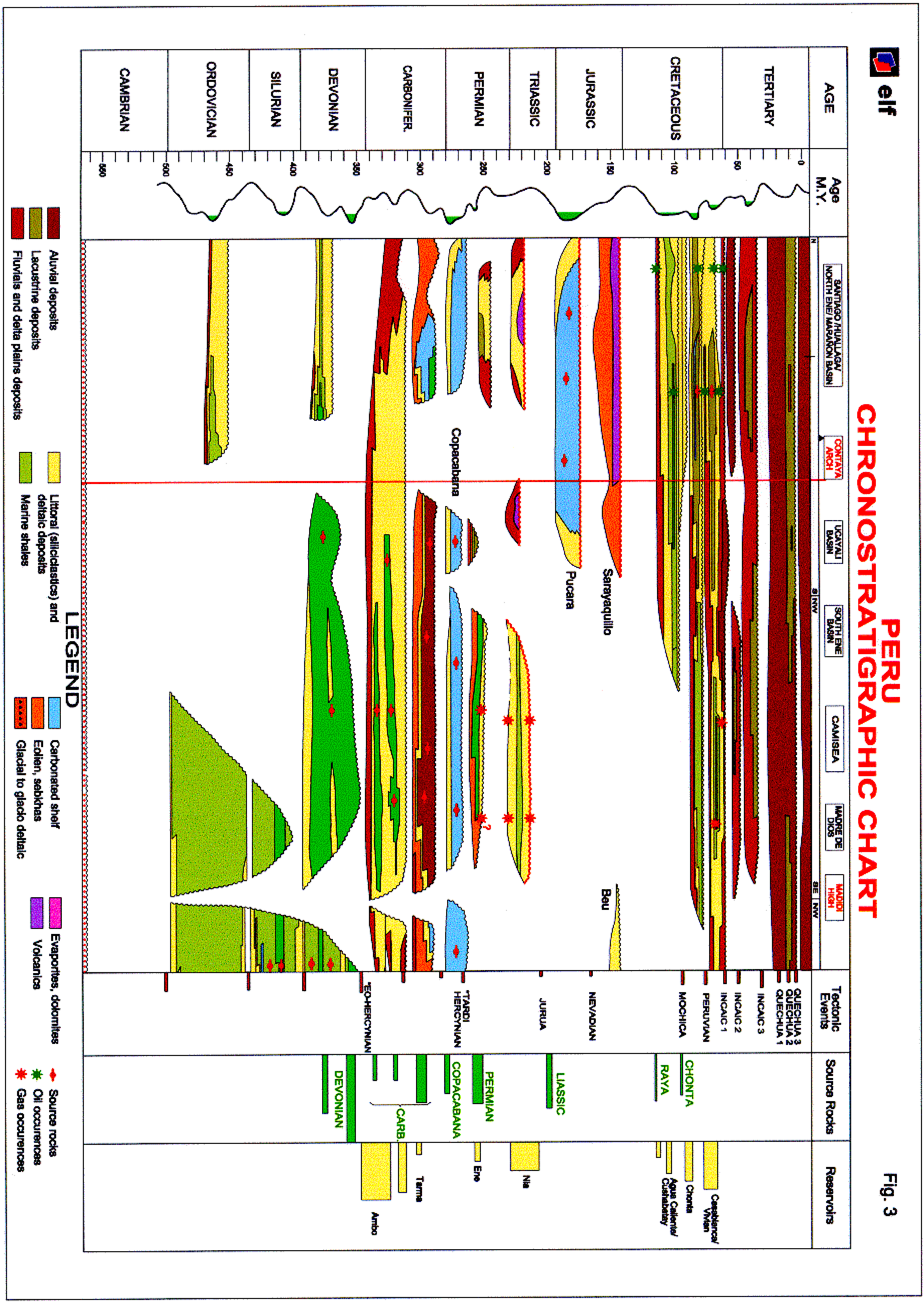
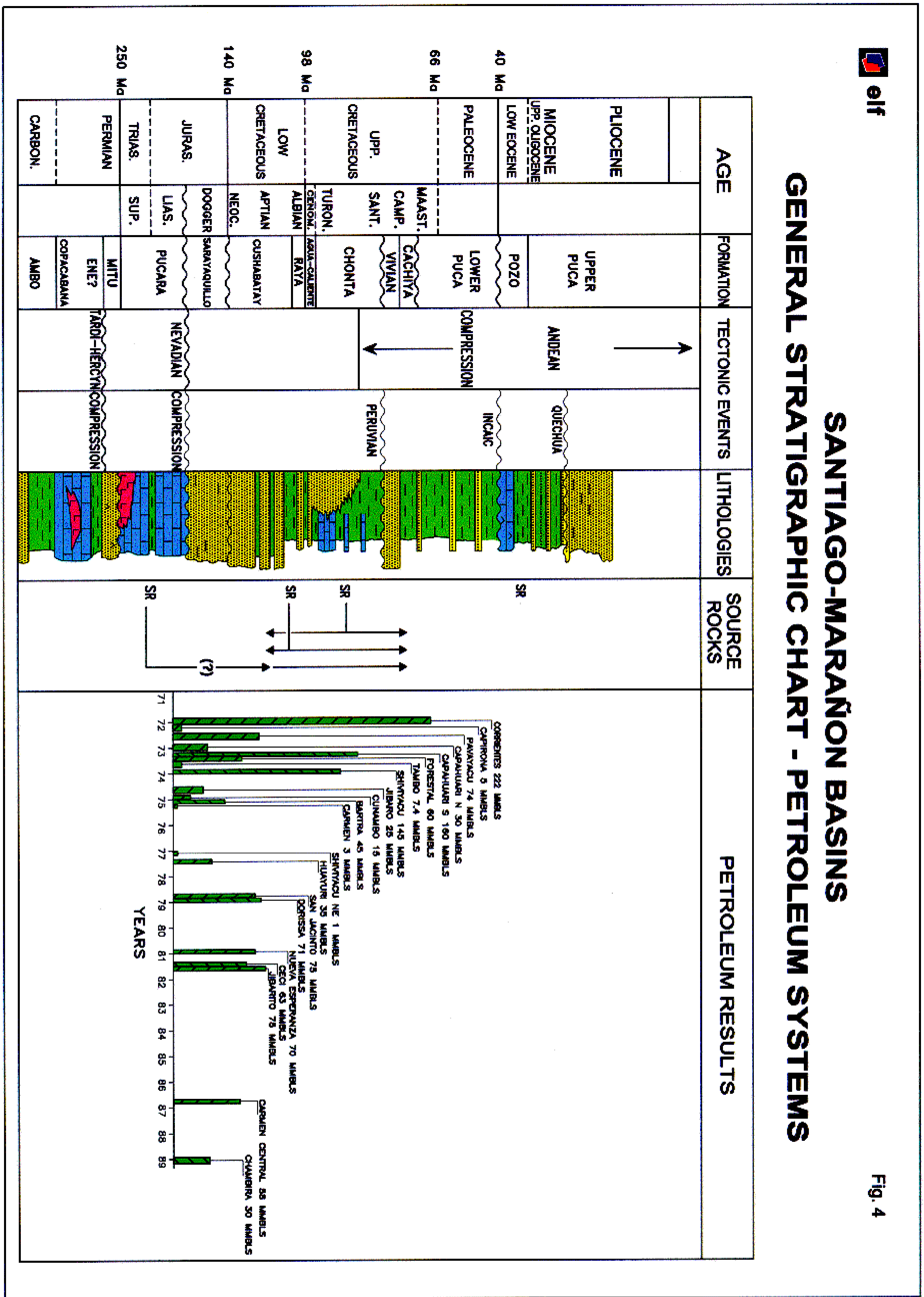
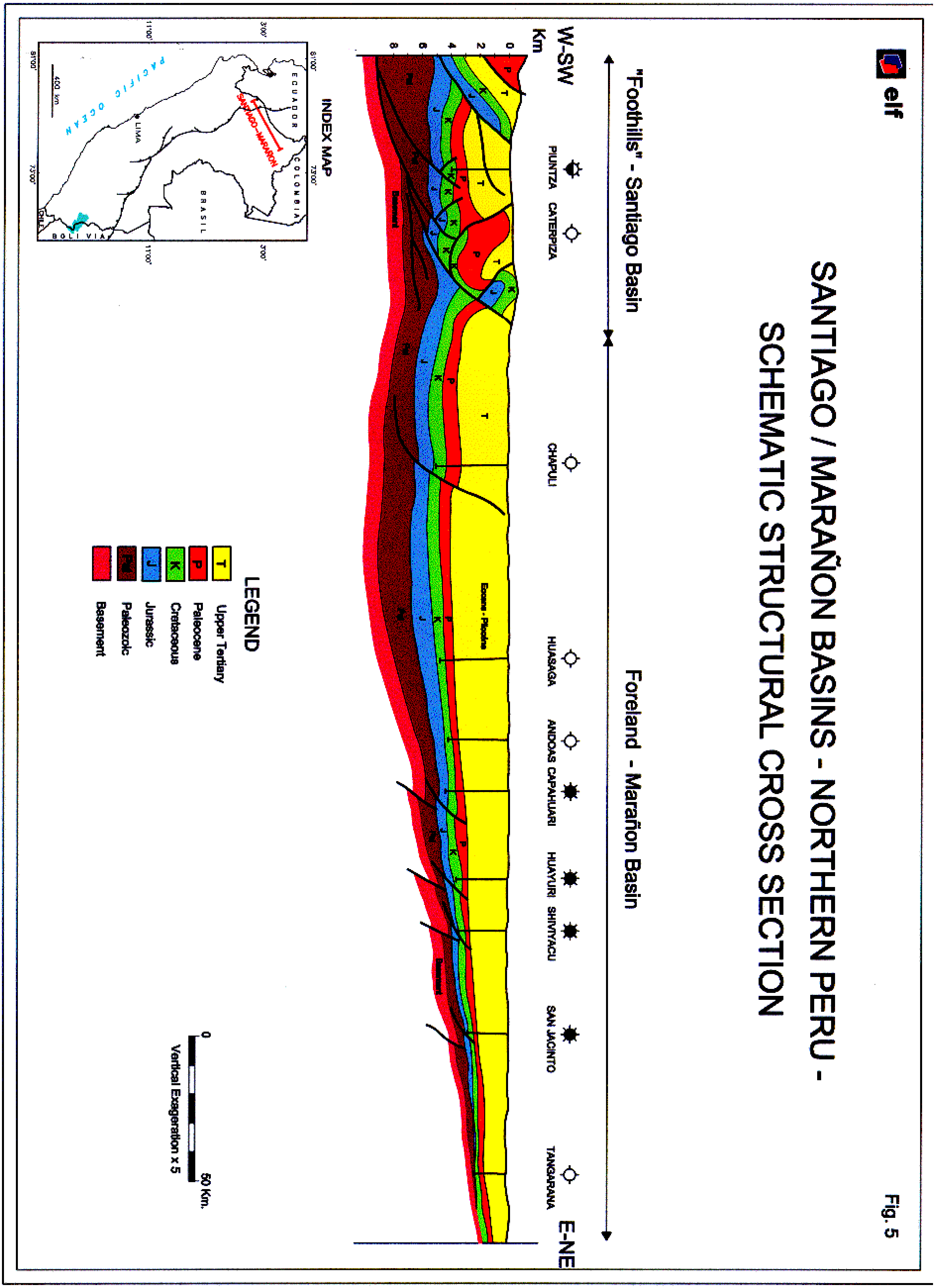
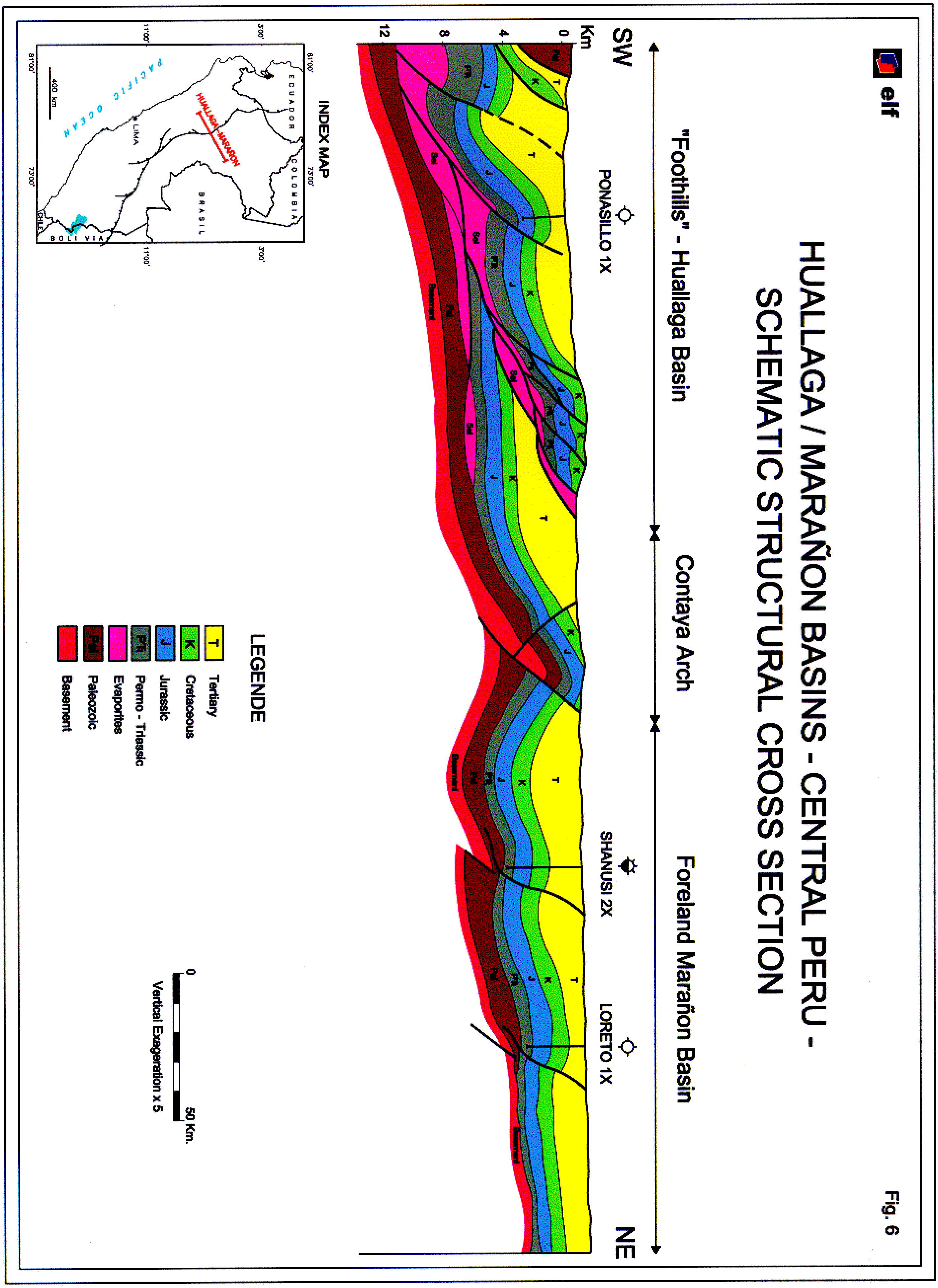
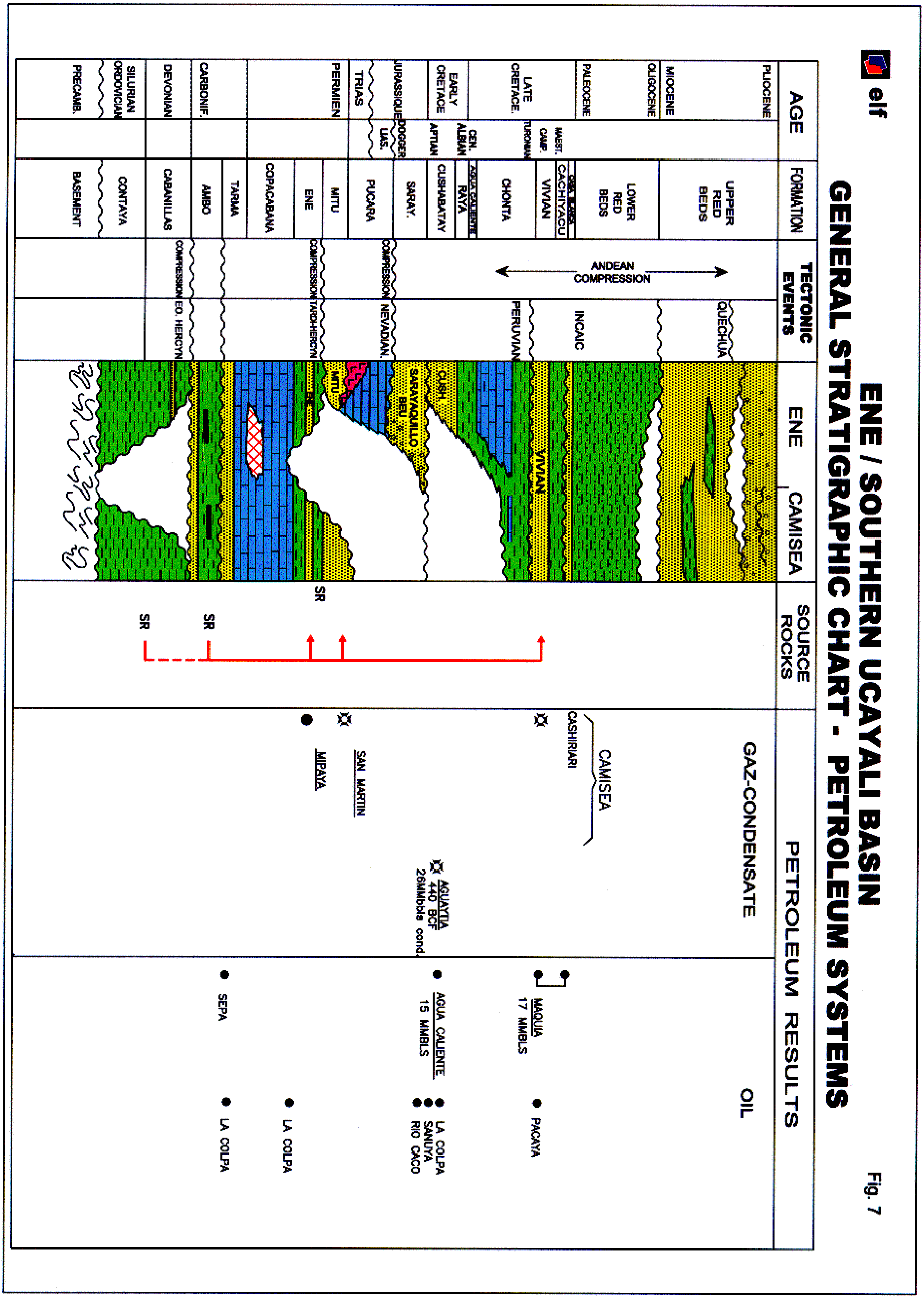
SUB - ANDEAN ZONE OF PERU
SCHEMATIC STRUCTURAL MAP
Tertiary in Outcrops
Cretaceous in Outcrops
Jurassic in Outcrops
Paleozoic in Outcrops
Gas Fields
Oil Fields
COLOMBIA
BRASIL
MARAÑON BASIN
IQUITOS
SANTIAGO BASIN
HUALLAGA BASIN
250 Km.
CONTAYA ARCH
PACHITEA SUB BASIN
SHIRA HIGH
UCAYALI FORELAND
NORTHERN ENE BASIN
TAMBO FAULT
SOUTHERN ENE BASIN
MADRE DE DIOS BASIN
CAMISEA
LIMA
CORDILLERA ORIENTAL
CORDILLERA OCCIDENTAL
CORDILLERA CENTRAL

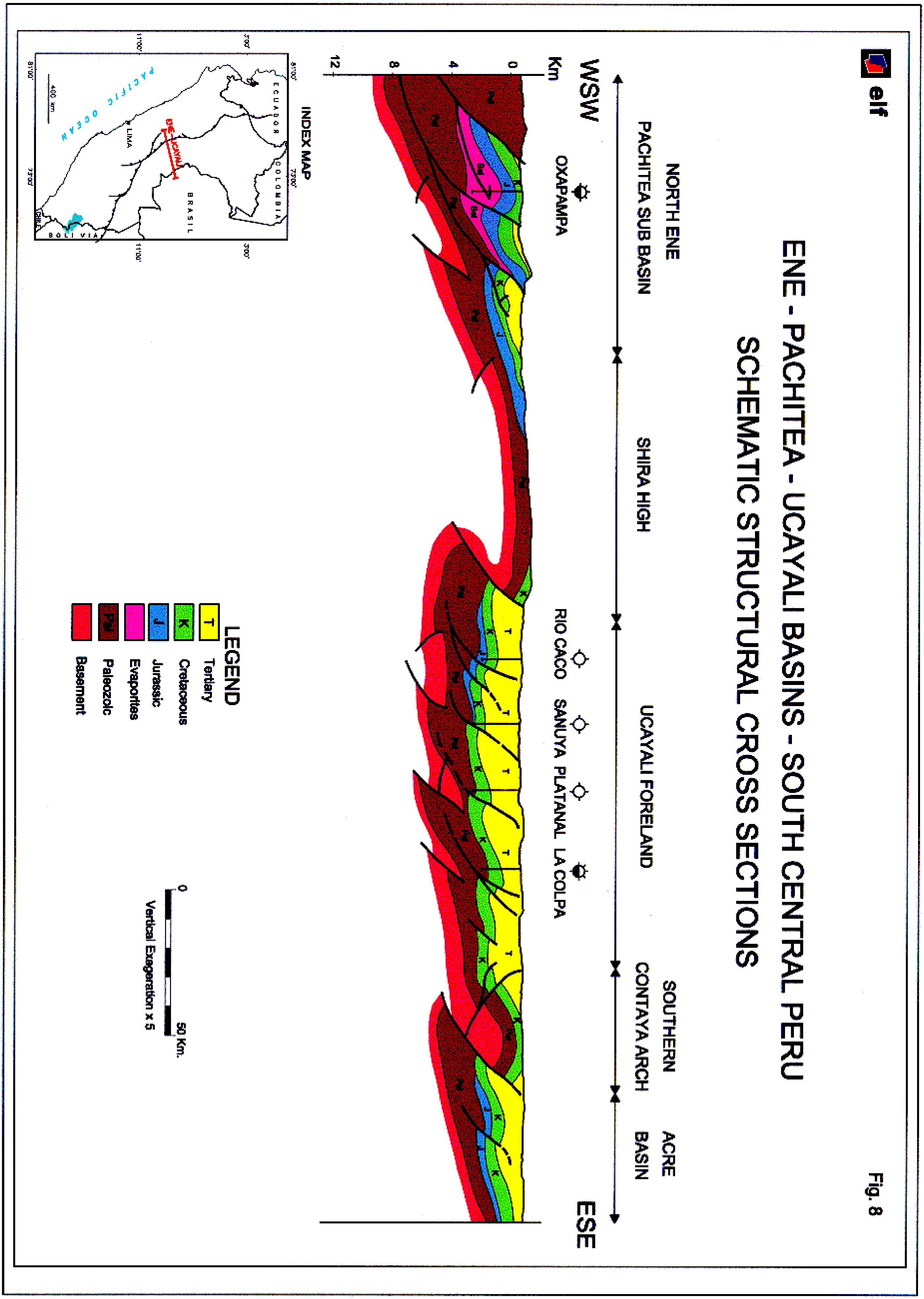

elf
PERU
CHRONOSTRATIGRAPHIC CHART
AGE
Age M.Y.
TERTIARY
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
CARBONIFER.
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
SANTIAGO /HUALLAGA/ NORTH ENE/ MARAÑON BASIN
CONTAYA ARCH
UCAYALI BASIN
SOUTH ENE BASIN
CAMISEA
MADRE DE DIOS
MADIDI HIGH
Sarayaquillo
Pucara
Copacabana
Beu
Tectonic Events
QUECHUA 3
QUECHUA 2
QUECHUA 1
INCAIC 3
INCAIC 2
INCAIC 1
PERUVIAN
MOCHICA
NEVADIAN
JURUA
TARDI HERCYNIAN
ECHERCYNIAN
Source Rocks
CHONTA
RAYA
LIASSIC
PERMIAN
COPACABANA
CARB.
DEVONIAN
Reservoirs
Cashiyacu/ Vivian
Chonta
Agua Caliente/ Cushabatay
Nia
Ene
Tarma
Ambo
LEGEND
Aluvial deposits
Lacustrine deposits
Fluvials and delta plains deposits
Littoral (siliciclastics) and deltaic deposits
Marine shales
Carbonated shelf
Eolien, sabkhas
Glacial to glacio deltaic
Evaporites, dolomites
Volcanics
Source rocks
Oil occurrences
Gas occurences
Fig. 3


elf
SANTIAGO-MARAÑON BASINS
GENERAL STRATIGRAPHIC CHART - PETROLEUM SYSTEMS
AGE
FORMATION
TECTONIC EVENTS
LITHOLOGIES
SOURCE ROCKS
PETROLEUM RESULTS
40 Ma
66 Ma
98 Ma
140 Ma
250 Ma
PLIOCENE
MIOCENE
UPP. OLIGOCENE
LOW EOCENE
PALEOCENE
UPP. CRETACEOUS
LOW CRETACEOUS
JURAS.
TRIAS.
PERMIAN
CARBON.
MAAST.
CAMP.
SANT.
TURON.
CENOM.
ALBIAN
APTIAN
NEOC.
DOGGER
LIAS.
SUP.
UPPER PUCA
POZO
LOWER PUCA
CACHIYACU
VIVIAN
CHONTA
AGUA-CALIENTE
RAYA
CUSHABATAY
SARAYAQUILLO
PUCARA
MITU
ENE?
COPACABANA
AMBO
ANDEAN COMPRESSION
NEVADIAN COMPRESSION
TARDI-HERCYN COMPRESSION
QUECHUA
INCAIC
PERUVIAN
SR
SR
SR
SR
(?)
CORRIENTES 222 MMBLS
CAPIRONA 5 MMBLS
PAVAYACU 74 MMBLS
CAPAHUARI N 30 MMBLS
CAPAHUARI S 160 MMBLS
FORESTAL 60 MMBLS
TAMBO 7.4 MMBLS
SHIVIYACU 145 MMBLS
JIBARO 25 MMBLS
CUINAMBO 15 MMBLS
BARTRA 45 MMBLS
CARMEN 3 MMBLS
SHIVIYACU NE 1 MMBLS
HUAYURI 35 MMBLS
SAN JACINTO 73 MMBLS
DORISSA 71 MMBLS
NUEVA ESPERANZA 70 MMBLS
CECI 63 MMBLS
JIBARITO 78 MMBLS
CARMEN CENTRAL 88 MMBLS
CHAMBIRA 30 MMBLS
71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89
YEARS
Fig. 4


elf
Fig. 5
SANTIAGO / MARAÑON BASINS - NORTHERN PERU -
SCHEMATIC STRUCTURAL CROSS SECTION
"Foothills" - Santiago Basin
Foreland - Marañon Basin
W-SW
E-NE
Km
PIUNTZA
CATERPIZA
CHAPULI
HUASAGA
ANDOAS
CAPAHUARI
HUAYURI
SHIVIYACU
SAN JACINTO
TANGARANA
Eocene - Pliocene
Basement
INDEX MAP
ECUADOR
COLOMBIA
BRASIL
BOLIVIA
CHILE
PACIFIC OCEAN
LIMA
SANTIAGO-MARAÑON
400 Km
LEGEND
T Upper Tertiary
P Paleocene
K Cretaceous
J Jurassic
Pz Paleozoic
Basement
0
50 Km.
Vertical Exageration x 5


elf
HUALLAGA / MARAÑON BASINS - CENTRAL PERU -
SCHEMATIC STRUCTURAL CROSS SECTION
Fig. 6
SW
NE
"Foothills" - Huallaga Basin
Contaya Arch
Foreland Marañon Basin
PONASILLO 1X
SHANUSI 2X
LORETO 1X
Km
0
4
8
12
Basement
INDEX MAP
ECUADOR
COLOMBIA
BRASIL
BOLIVIA
CHILE
PACIFIC OCEAN
LIMA
HUALLAGA-MARAÑON
400 km
LEGENDE
T Tertiary
K Cretaceous
J Jurassic
PTR Permo - Triassic
Evaporites
Pal Paleozoic
Basement
0
50 Km.
Vertical Exageration x 5


elf
ENE / SOUTHERN UCAYALI BASIN
GENERAL STRATIGRAPHIC CHART - PETROLEUM SYSTEMS
Fig. 7
AGE
FORMATION
TECTONIC EVENTS
ENE
CAMISEA
SOURCE ROCKS
PETROLEUM RESULTS
GAZ-CONDENSATE
OIL
PLIOCENE
MIOCENE
OLIGOCENE
PALEOCENE
LATE CRETACE.
MAEST.
CAMP.
TURONIAN
CEN.
ALBIAN
EARLY CRETACE
APTIAN
JURASSIQUE
DOGGER
LIAS.
TRIAS
PERMIEN
CARBONIF.
DEVONIAN
SILURIAN ORDOVICIAN
PRECAMB.
UPPER RED BEDS
LOWER RED BEDS
CACHIYACU
VIVIAN
CHONTA
AGUA CALIENTE
RAYA
CUSHABATAY
SARAY.
PUCARA
MITU
ENE
COPACABANA
TARMA
AMBO
CABANILLAS
CONTAYA
BASEMENT
ANDEAN COMPRESSION
QUECHUA
INCAIC
PERUVIAN
COMPRESSION NEVADIAN.
COMPRESSION TARDI-HERCYN
COMPRESSION EO. HERCYN
VIVIAN
CUSH.
SARAYAQUILLO
BEU
MITU
SR
SR
SR
CAMISEA
CASHIRIARI
SAN MARTIN
MIPAYA
AGUAYTIA 440 BCF 26MMbbls cond.
MAQUIA 17 MMBLS
AGUA CALIENTE 15 MMBLS
SEPA
PACAYA
LA COLPA SANUYA RIO CACO
LA COLPA
LA COLPA


elf
Fig. 8
ENE - PACHITEA - UCAYALI BASINS - SOUTH CENTRAL PERU
SCHEMATIC STRUCTURAL CROSS SECTIONS
NORTH ENE
PACHITEA SUB BASIN
SHIRA HIGH
UCAYALI FORELAND
SOUTHERN
CONTAYA ARCH
ACRE
BASIN
WSW
ESE
Km
0
4
8
12
OXAPAMPA
RIO CACO
SANUYA
PLATANAL
LA COLPA
INDEX MAP
ECUADOR
COLOMBIA
BRASIL
BOLIVIA
PACIFIC OCEAN
LIMA
400 km
LEGEND
T Tertiary
K Cretaceous
J Jurassic
Evaporites
Pal Paleozoic
Basement
0
50 Km.
Vertical Exageration x 5

MADRE DE DIOS BASIN - SOUTH EAST PERU -
GENERAL STRATIGRAPHIC CHART - PETROLEUM SYSTEMS -

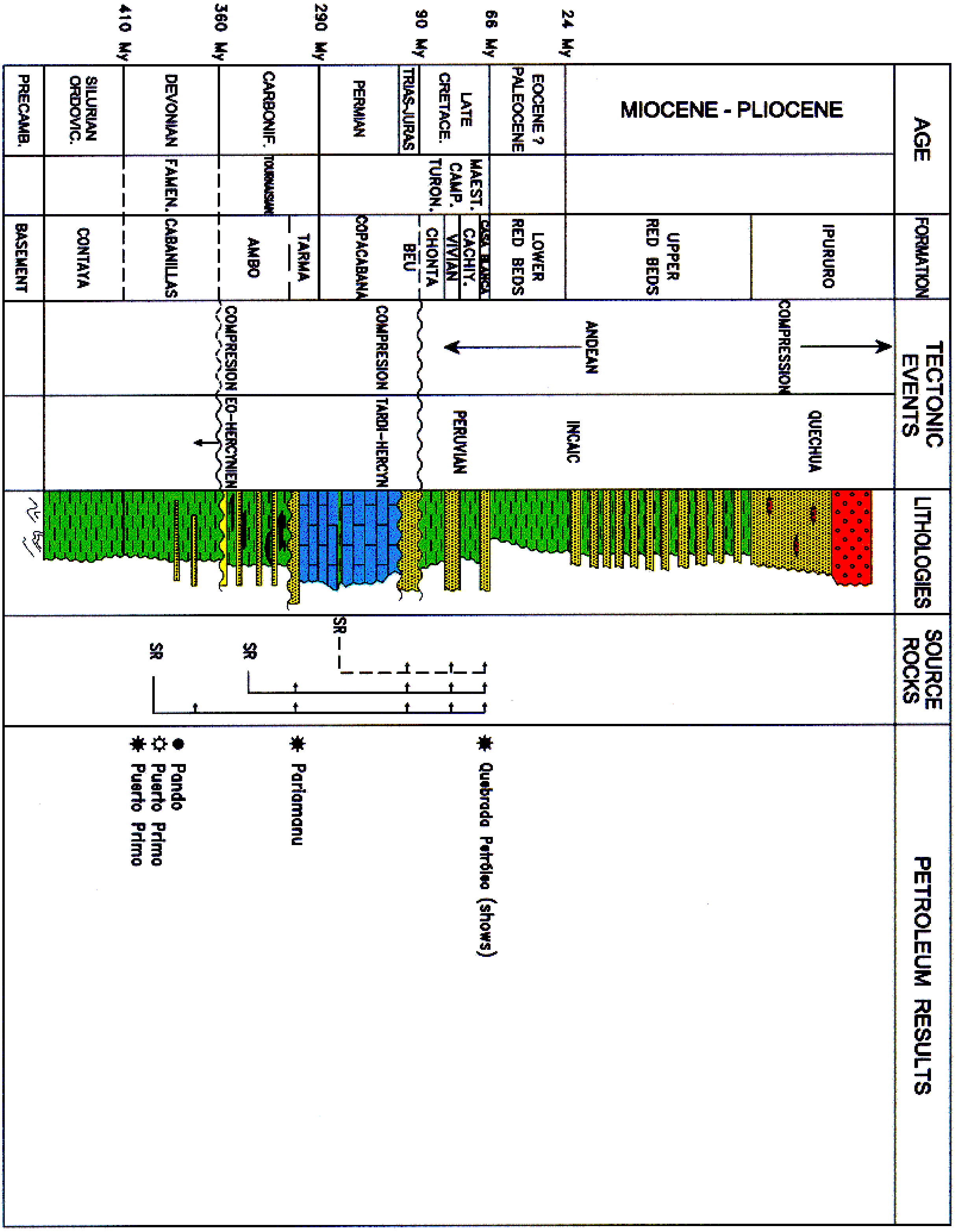
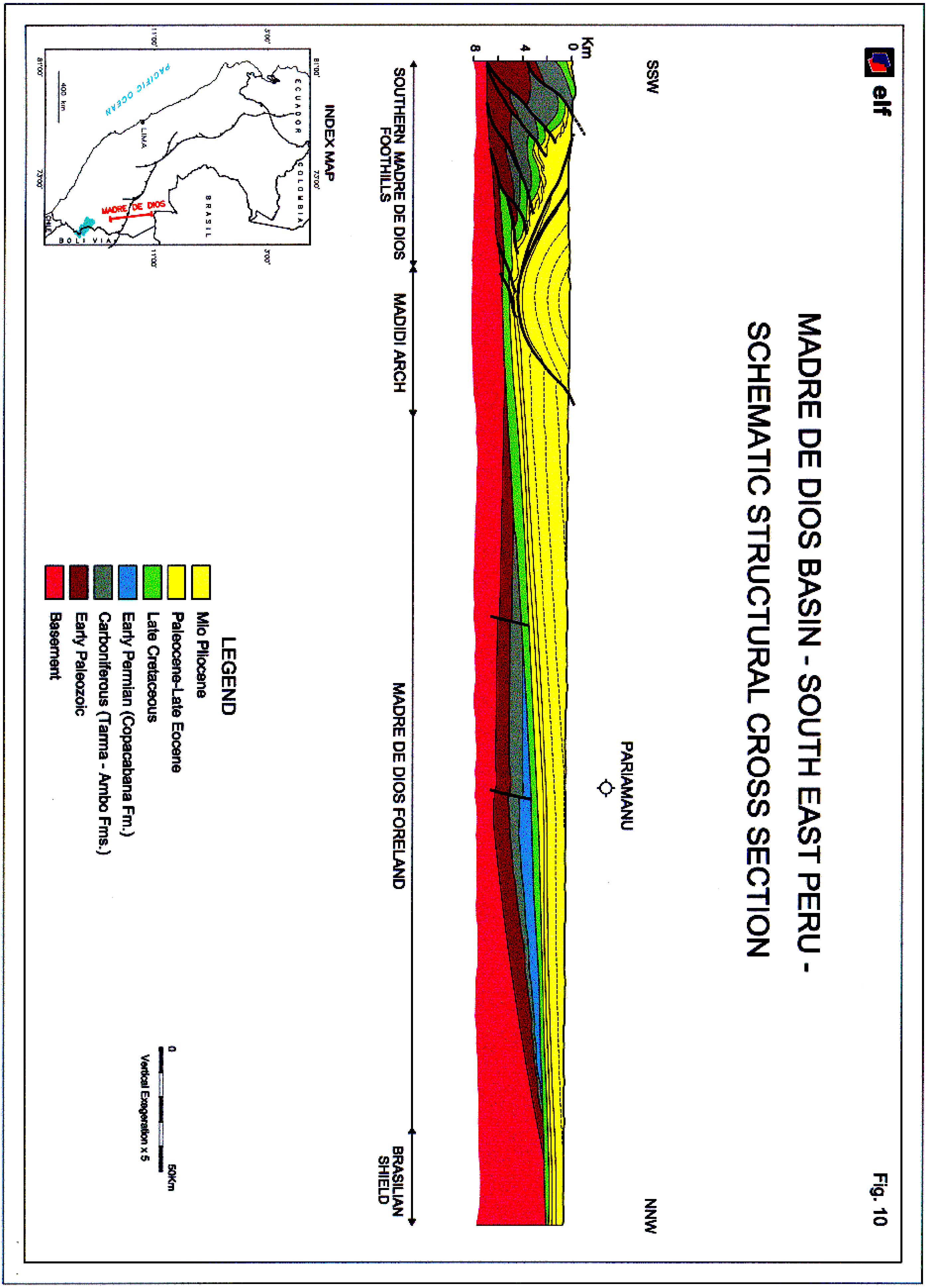


Fig. 9


elf
Fig. 10
MADRE DE DIOS BASIN - SOUTH EAST PERU -
SCHEMATIC STRUCTURAL CROSS SECTION
SSW
NNW
PARIAMANU
Km
0
4
8
SOUTHERN MADRE DE DIOS FOOTHILLS
MADIDI ARCH
MADRE DE DIOS FORELAND
BRASILIAN SHIELD
INDEX MAP
ECUADOR
COLOMBIA
BRASIL
PACIFIC OCEAN
LIMA
MADRE DE DIOS
BOLIVIA
CHILE
400 km
LEGEND
Mio Pliocene
Paleocene-Late Eocene
Late Cretaceous
Early Permian (Copacabana Fm.)
Carboniferous (Tarma - Ambo Fms.)
Early Paleozoic
Basement
0
50Km
Vertical Exageration x 5