ANDEAN FORELAND FOLD AND THRUST BELT DEVELOPMENT AND THE FATE OF GIANTS!

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SUMMARY

This paper is a product of graduate studies carried out from 1995 to 1998 by the first author at **Universidade Federal de Ouro Preto (UFOP),** Minas Gerais, in Brazil. The theme is the Andean *Cordillera*. We have been trying to figure out what should be an adequate geotectonic model for the South America subduction zone, as well as, the fundamental characteristics of the Andean orogen, the driving mechanisms of foreland fold and thrust belt development possible controlling factors the abundance of hydrocarbons along the entire western coast of the South America.

A new scenario for global Neoproterozoic/Paleozoic paleogeography began to emerge during the early 90's. This new concept recognizes the Proterozoic roots of the Andean orogen, represented by Grennville overprints on the distal western edges of the Amazônia Craton. Our starting point is an appreciation that the growth of the South American Platform and the Andes itself shall be adequatelly interpreted as a collage of Proterozoic/Paleozoic continental suspect terranes (Arequipa, Pampia, Precordillera, Colombia, Chiloe, North Patagonia and Deseado Terranes) during Neoproterozoic/Paleozoic along the western border of Amazônia, Rio de La Plata/Paranapanema and São Francisco Cratons and the Goias Massif. A subsequent period of suspect terranes-continent collisions during Mesozoic to Recent times is represented by the docking of the Mesozoic/Cenozoic accretionary/exotic terranes (Mejillones, Darwinia, Casma/Canta, Amaine, Celica, Pinon, Macuchi and Serrania del Baudó "Island Arcs") welded by juvenile magmatic additions to the South American plate. During this final stage, the Northern and Central Andes have been built by noticeable processes of crustal collisions between "island arcs" and the cratonic foreland of South America creating well-developed associated foreland fold and thrust belts. In the Southern Andes, the processes of mountain building were different. The southern margin of South America was composed by an en-echelon pattern of NW-SE oriented "volcanic arcs" separated by interarc/intra-arc basins which experienced a progressive clockwise rotation of the arc massifs through the Cretaceous time to virtually coallescing and forming a single and continuous volcanic line during Cenozoic to Recente. Such a process did not give rise to a well-developed associated foreland fold and thrust belt.

Empirical relationships suggest that accretion of terranes was responsible for wider foreland fold and thrust belt development in Northern and Central Andes and that there is a close relationship with well developed foldbelts and occurrence of giant oil & gas fields eg.Venezuela, Colombia, and Peru meanwhile, less developed foldbelts may be associated with much smaller oil & gas fields eg. Argentina and Ecuador.These relationships indicate that areas with well-developed foldbelts and low exploration levels might host several undiscovered giant oil & gas fields (Peru and Bolivia).

INTRODUCTION

This paper is a synthesis using graduate studies undertaken by the first author, from 1995 to 1998, at the UNIVERSIDADE FEDERAL DE OURO PRETO (UFOP) Campus in Minas Gerais, Brazil proprietary data acquired from 1973 to 1998 by BRASPETRO and an intense use of INTERNET based knowledge with focus on the tectonostratigraphic evolution of the Andean *Cordillera* and driving mechanisms of Foreland Fold and Thrust Belt (FFTB) development..An original assessment of plausible factors, if any, controlling the hydrocarbon occurence based on tectonic criteria, rather than any relationships with sedimentary basins petroleum systems as used by USGS World Energy Project was pursued (Klemme & Ulmishek,1998).

The knowledge of intracontinental orogens such as the Himalayas and Alps is fairly straightforward. However, the so-called *Cordilleran-type* Orogens, previously defined as the result of contractional deformation of a continental margin due to subcontinental subduction still needs to be further discussed, aiming at a better understanding. The Andean *Cordillera* a "classical cordilleran-type orogen", it is hereby defined, as a Continental Margin Orogenic System, product of a complex interplay between suspect/accretionary terranes/ridges-continent collisional events and juvenile magmatic additions to the crust.

Modern tools available for geotectonics as diverse as global topography, global bathymetric prediction, satellite gravity of the ocean floor, global seismicity and volcanism, and seafloor ages recently released througout the INTERNET by several USA Institutions and Universities (USGS, NASA, NOAA, JPL, IG-UTIG, CALTECH ...) considered as the best ever released and available data, provides an elaboreted approach for geotectonic context of the Earth. It emphasizes the power of Geomorphology in analysing the evolution of orogenic belts, through the study of tectonic landforms, where structure includes not only deformational features, but any characteristic of the rock bodies such as their mineralogy and fabric that govern their relative resistance to erosion. Tectonic landforms are structural features of regional extent. Landscapes developed on orogenic belts, uplifts, domes, basins and shields can all be thought of as tectonic landforms.

THE ANDEAN *CORDILLERA* : GEOTECTONIC DOMAINS, PHYSIOGRAPHIC PROVINCES, TECTONOSTRATIGRAPHIC UNITS AND TERRANES FRAMEWORK – A MODEL FOR THE ANDES

Figure 01 outlines the major tectonic features of the South American convergence zone related to the evolution of the Andean *Cordillera* such as the plate boundaries, the Precambrian shields, the cratonic foreland, the oceanic plates and associated fracture zones, transform faults, asseismic ridges, oceanic plateaus, spreading ridges, the subduction zone and the Andean orogen itself. We have introduced the Conceptual Elements of a Continental Margin Orogenic System, composed by Geotectonic Domains (Oceanic, Continental Interior and Orogenic). Our bottom line is based on the genetically related environments concept where we define the Domains. The Oceanic Domain embraces the oceanic plates and associated features.The Continental Interior Domain, which is composed by cratonic nuclei and parts of the cratonic foreland.The Orogenic Domain, which is genetically related to the interactions between the Oceanic and Continental Interior Domains, is limited to the west by the trench and extends eastwards to a diffuse transition zone with the Continental Interior Domain (Cavalcanti et al.,1999).

The Andean *Cordillera* stretches for nearly 9,000 km from the Caribbean coast to the southern tip of South America in *Tierra del Fuego*. The Andes show remarkable differences along its length with contrasting plate boundaries and diverse scenarios for each major segment. Tradittionally it has been divided into Northern Andes forming a transform/transpressional plate boundary between the Caribbe, Nazca, Cocos and South America plates down to the Peruvian-Ecuadorian border, where it is limited by the Huancabamba Deflection when the NE strikes of the northern sector changes abruptelly to a NW/NS structural fabric of the Central Andes which extends up to the RTT type Chile Triple Junction, which is the limit with the Southern Andes that continues untill the southern tip of *Tierra del Fuego*.

Figure 02 shall be considered as an adequate and robust model for the Andean Continental Margim Orogenic System (Cavalcanti et al., 1999). The Orogenic Domain is subdivided into Physiographic Provinces with respect to the volcanic arcs (forearc, arc and backarc regions), which are further subdivided into Tectonostratigraphic Units including the Trench, Outer Arc Bulge, “Forearc Basins”, the Volcanic Arc and related basins (intra-arc, interarc) and the Foreland Basin Systems which include the FFTB and related basins (Intermontannes, piggy backs and foreland basins). Moreover, the terranes framework is also depicted in the block diagram. These terminologies are largelly supported by well-constrained models previously published, and shall be considered as a derivative from models proposed by Coulbourn (1981) and Zalan (1996).

The Northern Andes is characterized by complex plates boundaries composing a sort of transform/dextral transpressional zone, where Caribbean and Pacific crusts have been obducted and subducted onto the South American crust. It shows a clear set of right-lateral en-echelon strike-slip/transform faults which accomodates much of the shortening and displacements between the plates. We should also notice that commom features present in other subduction zones are rare in this segment of the Andes. For instance, the accretionary prism has an uneven distribution along this border being present offshore Venezuela, where we should not expect it to be present due to plate boundary nature between the Caribbean and South American plates, and do not show clear signals of its presence where subduction is taking place in Colombia/Ecuador. We shall also notice that the outer arc bulge that is commonly interpreted as being part of the accretionary prisms in other subduction complexes are actualy formed by accreted oceanic terranes obducted and/or accreted onto the continental margin.

The subduction zone, entirelly associated with the Nazca plate, stretches over 5,000 km from Colombia to southern Chile. This subduction zone shows remarkable variability along its length, especially between central Peru and central Chile. Along Colombian and Ecuadorian coasts there is no well-developed trench and the subduction zone between plates actually represents an example of oblique convergence or subduction where stress partitioning gives rise to the obduction and right lateral transport of oceanic terranes from Colombia to Ecuador where it develops a horse-tail splay of strike-slip/transform faults responsible by the emplacement of terranes, forming important parts of the *Cordillera*, clearly showing that island arcs, active-spreading ridges and oceanic plateaus of the Nazca/Cocos crust have been obducted and laterally transported to NE, respective to the South America Plate At this point, we should also emphasize that we do not have forearc basins sensu strictu but rather a site of transtensional set of interarc/intra-arc basins developed along the Dolores Guayaquil Shear Zone and being represented by the Atrato/Manabi complex of basins.

The Nazca slab flattens both to the north and south of the "Bolivian orocline" and the Altiplano. The juxtaposition of the Altiplano and zones of flat subduction strongly suggests that they are dinamically related. The slab under Bolivia is being bent along axes, nearly paralell to the dip orientation, which is responsible for the 10% along-arc compression subjecting the long axis of the body of the *Cordillera* to the most intense shortening. In other words, the middle zone accommodates horizontal shortening along the entire length of the deep slab in one focused area. Hence, slip occurs on a near horizontal planes (Tinker, 1998) and, as will see later, much of this compressive stress is driven by the accretion of exotic terranes during Mesozoic and Cenozoic composing the Casma/Canta Terranes of Peru. We shall also notice that along Peru we have a quite well-developed accretionary prism but we do not notice the presence of an outer arc bulge. We can identify a coastal cordillera which represents ridges and/or island arcs accreted during Tertiary to the peruvian coast. There are no forearc basins sensu strictu, but rather, trench-slope basins and interarc/intra-arc basins of Tertiary ages eg. Trujillo, Talara, Salaverry basins. Further south the outer arc bulge is represented by the Arequipa Massif, an exotic terrane accreted during Paleozoic to the Coast. In Chile, the same pattern has also been observed with outer arc bulge composed by exotic terranes (Mejillones),and development of interarc/Intra-arc transtensional basins along the forearc region.

The Nazca/Antarctic plate boundary is comprised of the Chile-Ridge-Spreading Center, which intersects the Chile Trench at 46^0 12' S, forming a Ridge-Trench-Trench Triple Junction. It marks the boundary between Central and Southern Andes. Presently, it is a highly oblique ridge-trtench collision. The ridge subduction represents a huge change in the thermal structure of the continental margin. It has lasting effects on the structure of the crust where it has taken place. It is a superb example of ridge/trench collision, an event that occurred numerous times around the convergent margins of the Pacific Rim, more notabley along the California continental margin 24 Ma and the Present. It is an important plate phenomenum that gives insights into past processes that may influence plate reorganizations and help to clarify the understanding of the Scotia and Caribbean regions.

THE GROWTH OF THE SOUTH AMERICAN PLATFORM: ROOTS OF THE ANDES

Digital Elevation Models (DEM) are fundamental tolls to analyze modern orogens. It clearly shows the structural/tectonic framework and provides fundamental constraints to terranes delineation. A terrane is a crustal block or fragment that preserves a distinctive geologic history that is different from the surrounding areas and that is usually bounded by faults. Accretionary terranes are those that become attached to a continent as a result of tectonic processes and are considered to be diverse segments of crust, that often originated far from their present locations. They were transported on a moving plate that converged against another plate, eventually colliding with a continental margin and being obducted rather than incompletely subducted the other plate becoming accreted to that plate. The usual criteria for terrane recognition are centered on stratigraphic, structural, and paleomagnetic discontinuites between adjacent terranes. Continents themselves thus grow by progressive accretion of numerous plates over time onto early cratonic nuclei. A fascinating aspect, as a whole, is the recurrence of certain tectonic/geomorphologic motifs.Broadly speaking, different topographic expressions that, in turn, are controlled by structure hence,topographic events are superficial evidences of abrupt changes in underlying structures that result from accretion of suspect or exotic terranesFigure 03 contains the terranes framework taken from shaded relief, DEM maps from WEB sites of USA institutions (NOOA, JPL). These products are considered powerful tools which were used to delineate the terranes of South America.

At the close of the Proterozoic, the paleogeography of western Gondwanaland was composed by cratonic nuclei (Amazônia, São Francisco and Paranapanema Cratons) with an intervening shallow sea among them, known as Bazilides Seas. In such passive margin shelf and slope surrounding the western divergent margins of Gondwanaland were deposited up to 15 km of sediments. The docking of suspect terranes (Pampia, Altiplano/Puna and Colombia) can be possibly interpreted as rifted continental blocks with strong South American affinities, based on geochronology, Grenville ages of collision or thermal overprints on the distal western edges of Amazônia Craton shall be considered as the roots of the Andean Orogen.

During Late Cambrian to Ordovician, paleogeography was dominated by the progressive cratonization of the South American Platform and the retreat of the shallow seas and the docking of minor suspect continental terranes, represented by the Arequipa-Precordillera Complex. There appears to be the first signs of subduction of a Proto-Pacific crust related to the magmatic arc known as *La Faja Eruptiva de La Puna* present to the east of Precordillera. It has been proposed by several authors that the Precordillera was a piece detached from Laurentia marking the continuity of a Taconian-Famantinian Orogen. However, we follow the elegant proposal of Blakey (1998) which shows that Taconian subduction was to NW which would be in disagreement of a possible subduction to East represented by the Precordillera. We propose that there would not be physical connections between the two orogens but shall be consider ed that they are coevals, and group the Arequipa Massif and Precordillera as a single complex of suspect terranes, originated from western oceans which docked along the SW margin of Gondwanaland and would represent the early evidences of East directed subduction. Near the end of Ordovician the Arequipa/Precordillera Complex Terrane collided with the west side of Pampia.

During Carboniferous, it is found out the first conspicuous evidences of accretion of suspect terranes by the docking of North Patagonia and Deseado Terranes interpreted as volcanic arcs or crustal fragments which have been migrating from SW to NE, forming a double subduction complex to the NE. These terranes were progressively accreted during the Late Paleozoic contemporaneously with the assembly of Pangea during Permian which marks the consolidation of the Hercynian System untill Colombia and the Gondwanic Orogeny of southern South America. There are sparse evidences that subduction has taken place from the SW and that spreading ridges and oceanic plateaus or microplates with general NW-SE trends were approaching the margin. However the stability of the supercontinent of Pangea did not last long and already in the Late Permian, it can be noticed the beginning of Pangea breakup along its western margin and periods of regional rifting along the major lines of suturing. Underthrusting of the Proto Pacific plates started by Late Permian-Early Triassic recorded by calc-alkaline magmatism along the Northern Andes, the development of volcanic arc to the west of the Paleozoic continental shelf in Central Andes and the docking of the Chiloe Terrane, an accretionary wedge of late Paleozoic rocks along Southern Andes.

During Permian to Triassic, the paleogeographic elements of SW Andes were characterized by the arc massifs of Northern Patagonia and Deseado becoming welded to the margin and the establishment of the outboard jump of the subduction zone, coeval to the beginning of breakup of Pangea, forming a series of NW/SE en-echelon Intra-arc basins (Cuyo, Neuquen, San Jorge, and Austral) between the arc massifs where extension was driven by a series of NE/SW en-echelon right lateral regional strike slip fault zones.From mid Triassic to mid Jurassic, the breakup of Pangea was taking place through widespread extension along its major suture lines. From midJurassic to Late Jurassic (165-150 Ma), Pacific crust began to forming the Phoenix plate. During Early Cretaceous (142-119 Ma), the opening of a proto-Caribbean allowing connections between the Tethys and the Proto-Pacific Oceans. From Early Cretaceous to Late Cretaceous (119-85 Ma), began the breakup of Phoenix plate and development of a long NW-SE oriented spreading center which gave rise to the Pacific and Farallon plates which were continuously growing until Late Cretaceous (90-68 Ma). Farallon was moving to E, possibly transporting Pacific crust to the gap between the Americas.

Recently released new paleomagnetic poles, defining the northward motion of the Pacific plate relative to its present-day position, illustrate its growth and show that dominant motion has been northward with a small clockwise rotation betwen 57 and 43 Ma and a small counterclockwise rotation between 43 Ma and the present (Acton, 1994). The inception of the East Pacific Ridge collision whith North America Crust ocurred from Late Paleocene to Mid Eocene (60-40 Ma). From Eocene to Miocene, the South America plate started to move to NW and begining of the Bahamas subduction. Oligocene and Early Miocene (40-20 Ma) marks the climax of the EPR-North America collision which caused plate reorganizations and the breakup of Farallon into smaller crustal fragments (Caribbe, Cocos, Nazca, Antarctica and Scotia plates)during Miocene (20-10 Ma). Late Miocene to Recente is marked by the passage of Cocos/Nazca over Hot Spots (Galapagos, Easter and Salas) forming asseismic ridges and active spreading ridges (Galápagos and Chile Ridges).

FORELAND FOLD AND THRUST BELT DEVELOPMENT AND DRIVING MECHANISMS: LESSONS FROM THE ANDES *CORDILLERA*

In the previous topics we brought out to attention and emphasized the fact that the Andean orogen shall be adequatelly interpreted as a collage of Proterozoic/Paleozoic continental suspect terranes during Neoproterozoic/Paleozoic along the western border of South America, followed by a second period of accretionary terranes-continent collisions during Mesozoic to Recent. However, different segments of the Andean orogen have evolved differently, under diverse tectonic scenarios, which in summary may be outlined as follows: the Northern and Central Andes have been built by noticeable accretionary terranes-continental margin collisional events from Jurassic to Recent, with the collision of island arcs of Amaine, Casma/Canta, Macuchi, Celica until Late Cretaceous and a period of oceanic plateaus, island arcs and ridge-trench collision through oblique subduction which gave rises to obduction of oceanic terranes from Late Cretaceous to Recent. Meanwhile, the southern Andes is characterized by docking of accretionary terranes (Mejillones, Darwinia) during a restricted interval from Jurassic to Early Cretaceous and the oblique collision of an active spreading ridge with the continental margin promoting regional thermal events, represented by large magmatic activity which prevails with respect to the accretion processes, suggesting that magmatic loads were responsible for the FFTB development in Southern Andes, which in turn, gave rises to less well-developed FFTB.

Triassic and Jurassic were dominated by the formation of regional extension along the whole Andean Margin developing widespread intra-arc basins roughly oriented NE/SW in Northern Andes and NW/SE oriented in Central and Southern Andes. The Jurassic is marked by widespread period of accretion of terranes all over the Andean margin with the accretion of Amaine in Northern Andes , Casma/Canta in Central and the Complex Mejillones, Darwinia in Southern Andes marking the onset of what is generally considered as the Andean Orogenesis. This period actually spans the Jurassic and Early Cretaceous times with widespread development of calc-alkaline magmatism related to the subduction and the initial steps of the development of the FFTB. From Late Jurassic to Early Cretaceous (150 Ma) spreading direction in the pacific change and the Pacific and Farallon plates were moving to SE with well-developed subduction zones and microplates/plateaus were approaching the Andean margin from both the NW and SW sides (Fig. 04)

If someone highlights the foldbelts in northern Andes (Fig. 01), then it might suggest a first line of evidence between accretion of terranes and magnitude of FFTB development. Someone can easily realize that the Andean FFTB was mostly developed from Late Cretaceous to Recente and that there is a noticeable difference in driving mechanism between Northern/Central and the Southern Andes. The former was built by collisional events of oceanic plateaus and accretionary terranes giving rise to well-developed FFTB whereas the latter was governed by highly oblique collisions of spreading ridges which, in turn, promoted reheating and cooling and widespread magmatism. The importance of this termal transition to the strength of the lithosphere and, thus, to the style of compressive deformation where we would find thin crust and high elevations in Southern Andes. Gravity, together with topography analysis and lithospheric thickness provide understanding on the controls of large scale tectonic deformation suggesting that thick skinned shortening deformation included the whole lithosphere in Northern and Central Andes while in Southern Andes changes in crustal thickness should not be expected because the average elevation does not change significantly across the boundary, there is an isostatic balance between the two crustal sections because of the thermal expansion density reduction. High temperature in Southern Andes lithosphere causes the different results in a style of tectonics. Shortening is evident only in the overlying sedimentary rocks thrust sheets

Computer-generated shaded-relief map of South America, viewed from an altitude of two Earth radii, and rotated by 10^0 shows the structure of the continent along its western boundary, is strinkingly symmetric, particularlly the shape of the Andes and the simmilarity in shape and size of the Caribbean and Scotia Seas, suggesting that major variations in South America deformation, may be due to a single, large-scale process that is probably related to the absolute motion of the continent (Russo & Silver, 1996).After careful analysis of satellite gravity, crustal ages of seafloor and global topography, we envisage a scenario where Tertiary tectonics is quite well clear in those data, suggesting that tectonics were largely controlled by ridge push forces, plate reorganizations due to passage over hotspots and collision of oceanic plateaus (mostly spreading ridges), We can also notice that the Caribbean, Cocos and Scotia plates present a relatively uplifted bathymetry and that Scotia spreading ridge is contemporaneous with spreading at Cayman trough. We would have subduction and spreading ridges jump due to plate reorganization where spreading directions changes were caused by hotspots (Galápagos and Easter/Sala hotspots) caused, firstly, the collisions of the East Pacific Ridge with the coast of California and, later, the collision of The Chile Ridge with Southern Andes, which in turn promoted reheating and cooling thickening the crust of Caribbe and Scotia plates. In summary, we would identify the following steps: (a) from Latest Late Cretaceous to Eocene occur the gradual collision of the East Pacific Rise with North America marking th breakup Farallon which starts moving EW at 23 Ma creating Antarctica, Nazca and Cocos plates and the early emplacement of Caribbean crust (b) At 16 Ma moving directions changed to NE-SW; and (c) spreading ridge and subduction promoted large ridge jump and widespread deformation under continental crust may create the sliding of the triple junction along the trench/transform boundary, and would then justify the pattern for California and the the creation of Caribbean and Scotia Plates as absolute movement to West of South America and the effects of the ridge trench collision

In summary, we shall highlight that FFTB development were (1) initially formed by widespread terranes accretion until Late Cretaceous in Northern and Central Andes and by the progressive clockwise rotation of volcanic arcs to virtually coallesce and form a single line by Late Crtaceous in Southern Andes, (2) from Late Cretaceous to Eocene it was driven by terranes accretion in Northern and Central Andes and magmatic loads prevailing in Southern Andes; and (3) finally, from Oligocene to Present which was governed by the docking and NE/E transport of oceanic terranes in Northern/Central Andes driven by the passage of Nazca/Cocos plates over hotspots and by an active speading ridge-trench collision in Southern Andes which gave rise to widespread magmatism and less well-developed FFTB. Such tectonic environment would explain that magnitude of FFTB is larger in Northern/Central Andes than in Southern Andes.

PERCEPTIONS ON THE PETROLEUM OCCURRENCE: AN ANDEAN PERSPECTIVE

The outstanding analysis of Klemme & Ulmishek (1998), on the stratigraphic distribution and controlling depositional factors of effective Petroleum source rocks of the world, which is the basic geologic rationale of the USGS WEP (1974 to 1995) were published by a series of works lead by Masters (1997, 1998) and is deliberated centered on the Petroleum System concept. It is concluded that six stratigraphic intervals contains source rocks that have provided 90% of the World's discovered original reserves of hydrocarbons and that the stratigraphic distribution of source rocks given as a percentage of the World's original petroleum reserves generated by these rocks where they also conclude that there is no obvious cyclicity (Fig. 05).

An improved statistical approach to analyze these data would be possible by, highlighting that petroleum reserves are a cummulative process. Moreover, Klemme & Ulmishek "uneven distribution" may also be geologically interpreted.It is easily identified the presence of two populations with roughly lognormal shapes. One, related to the Paleozoic hydrocarbons, characterized by a very smooth tail from Proterozoic to Cambrian/Ordovician and higher peaks from Silurian to Lower Devonian, with a sharp cutoff to the end of the Paleozoic. The second, identified population, which extends from lowest values from Permian to Triassic and conspicuous higher values towards the Jurassic/Cretaceous/Cenozoic periods (Fig.05).

Geological interpretations can be further carried out with these curves. The assymptotic tail of the curves coincide with the presence of large landmasses (Gondwanaland and Pangea) creating unfavourable conditions to source generation and basin development. However, the peaks on the higher lobes correlate well with major tectonic events that occurred during Paleozoic and Mesozoic/Cenozoic actually suggesting that key factors controlling hydrocarbon distribution were time and tectonic episodes. We can further state that the petroleum life cycle was controlled by tectonic pulses related to the assembly of Pangea and latter tectonic episodes related to the dispersal of the supercontinente.

Areal distribution of source rocks were controlled by geologic age, paleolatitude of depositional areas, structural forms in which the deposition of source rocks occurred and the evolution of biota, where these orogenic development phases which represent the assembly and breakup of the Pangean. Landmasses have controlled paleolatitudes, and allowing extensive marine transgressions, initially at the border and progressivelly into the continents with clear controls on source rock deposition.

Maturation time of oil & gas is very young, about 70 % of the world oil has been generated since Coniacian and 50 % of petroleum was generated and trapped since Oligocene(Klemme&Ulmishek,1998). It is clear that generation, migration and entrapment is a late process during the evolution of sedimentary basins.The majority of oil was matured, migrated and entrapped from Late Cretaceous onwards showing that burial, migration routes and entrapment were caused by geodynamics processes, which provided the adequate stress field to accelerate those processes. Therefore, geodynamics shall be considered the key factors to understand the hydrocarbon abundance throughout the World. Major Mesozoic/Cenozoic Orogenesis might be related to the petroleum life cycle from Late Cretaceous to Recente. It is striking that 50 % of World's petroleum have been generated and trapped since Oligocene. Just synchronous to the development of our modern Orogens. At the bottom of figure 05 it is shown the changes in typical conditions of source rock deposition through the Phanerozoic, and major events of biologic evolution that affected these changes..In this diagram one can easily interpret that the evolution of conditions as governed by tectonics!

One could also speculate that the “missing” Neogene reserves, which would compose a lognormal-like distribution, may be suggestive that it represents late oil generated by Neogene tectonics yet to be found in Orogenic Domains (Fig. 05) Hence, we consider that the petroleum life cycle is a late process in the evolution of sedimentary basins and that the majority of sourced/trapped petroleum reserves distribution correlates extremelly well with the evolving modern orogenic systems from Late Cretaceous to Recent and, more specifically, with the Neogene tectonic evolution of such belts implying that large amounts of hydrocarbons shall be discovered in the less explored FFTB of the Neogene Orogenic Belts of the World(Andes, e.g.)

Analyzing the distribution of reserves and FFTB development along western South America (Fig.06) brought out to attention that empirical relationships suggest that accretion of terranes were responsible for wider FFTB development. Empirical relationships suggest that accretion of terranes was responsible for wider foreland fold and thrust belt development in Northern and Central Andes and that there is a close relationship with well-developed foldbelts and occurence of giant oil & gas fields (Venezuela, Colombia and Peru). Meanwhile, less developed foldbelts may be associated with much smaller oil & gas fields (Argentina, Equador). These relationships indicate that areas with well-developed foldbelts and low exploration levels might host several undiscovered giant oil & gas fields (FFTB of Peru and Bolivia and associated sedimentary basins: Santiago Huallaga, Maranon, Ucayaly and Tarija).

CONCLUSIONS

We have characterized the Andean *Cordillera* as an Accretionary Orogen and that the growth of the South America Platform shall be adequately interpreted as a collage of suspect continental terranes, from Neoproterozoic to Paleozoic, followed by a stage of accretionary/exotic terranes-continent collisions during Mesozoic to Recente. We have also compiled and produced a tectonic map of South America which integrates Precambrian Elements, a coherent and updated sedimentary basin classification of the whole continent, the Phanerozoic Volcanic arcs and a definitive approach to terranes framework of South America. Moreover, we have produced a generalized block diagram for the South America subduction zone with conceptual geotectonic domains, physiographic provinces, tectonostratigraphic units and terranes framework which represents an adequate and robust model for the Andes.

Empirical relationships, have brought out to attention, what might be an original assessment of factors controlling the HC occurrence based on tectonic criteria relating FFTB development with terranes accretion and abundance of HC, rather than any relatioships with sedimentary basins petroleum systems type as proposed by Klemme & Ulmishek (1998)) and USGS Staff (1991, 1994, 1997, 1998, 1999).

We have noticed that andean FFTB development is product of diverse paleotectonic environments along the length of the Andes. Northern/Central Andes evolved as a result of several episodes of emplacement of accretionary/exotic oceanic terranes-continental margin through collisional events almost continuosly from Jurassic to Present, giving rise to well-developed associated FFTB; whereas in Southern Andes the processes of collisional events were restricted in time to Jurassic/Early Cretaceous and by oblique collisions of an active spreading ridge from Late Cretaceous to Present causing widespread magmatism, which are the main loads to the development of a less well-developed FFTB. As a whole, the Andean Orogen shall be adequatelly interpreted as a collage of suspect terranes welded by magmatic additions to the crust.

TECHNICAL CONTRIBUTIONS

1 – The first published tectonic map of South America which integrates Precambrian elements, a coherent and updated sedimentary basin classification of the whole continent, the Phanerozoic volcanic arcs and a definitive approach to terranes framework of South America;

2 – The first generalized block diagram for the South American Subduction Zone with conceptual geotectonic domains, physiographic provinces, tectonostratigraphic units and terranes framework which represents a robust and adequate model for the Andean *Cordillera;*

3 - An original assessment of factors controlling the hydrocarbon occurrence based on tectonic criteria, relating FFTB development and abundance of hydrocarbons, rather than any relationship with sedimentary basins petroleum systems classifications as proposed by Klemme&Ulmishek (1991, 1998).

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ILUSTRATION CAPTIONS

Fig. 01 - Major tectonic features for the American Orogens (Cavalcanti, 1999). It is striking that both American Cordilleras evolved as a response to suspect terranes- ridge-trench collisions and the jumping of the spreading centers to the East (Cayman Trough and Scotia Sea Regions). Although processes may well be diachronous, it clearly suggest an origin with commom processes for the "Scotia/Caribbe Plates". It also shows that mountain building processes were driven by oblique subduction and the crustal collisions of oceanic terranes, giving rise to well-developed FFTB in Northern and Central Andes, while in Southern Andes oblique collision of the Chile ridge has promoted less well-developed FFTB and widespread magmatism.. The background image is a GIF from DEM of W. Smith&D. Dandwell from NOAA Satellite Altimetry Laboratory.

Fig. 02 - Conceptual Elements of a Continental Margin Orogenic System (Cavalcanti, 1999). It is radically different from previous published models for the Andes which were largelly "biased " by the Izu-Bonin-Marianas Arc System. Note that in the Andes the trench is not well developed, the accretionary wedge is not well developed as well and the outer arc bulge which is actually composed by terranes exposure accreted from Jurassic to Recente. The Andes Subduction Zone does not present forearc basins sensu strictu. They correspond to the Coastal plains and are rather better classified as a series of interarc/intra-arc transtensional/transpressional basins that occur at the forearc region (Manabi, Talara, Salaverry, Sechura etc,) between these basins and the Arc region occurs exotic terranes of Late Jurassic/Early Cretaceous (Amaine that occur as slivers at the Central Cordillera of Colombia; Cauca/Macuchi/Celica forming the western Cordillera of Colombia Equador and Peru; Casma/Canta in Coastal Peru and Mejjilonnes and Darwinia forming the Coastal Cordillera of Chile. The arc region itself is actually formed by a series of Mesozoic/Cenozoic transtensional intra-arc basins influenced by arc developmanent. The transition to the backarc region characterize what we call foreland basins systems, including the FFTB and associated basins (Intermontanne and Piggybackk basins) and foreland itself.

Fig. 03 - It shows the gross distribution of the South America Terranes, (Cavalcanti,1999) classified as follows: (a) Archean/Proterozoic Terranes (Amazônia, São Francisco, Paranapanema Cratons and the Goias Massif); (b) Neoproterozoic Continental Supect Terranes (Colombia, Altiplano/Puna and Pampia Terranes which we consider suspect because they have strong affinity with SouthAmerican Continental Margin, Eopaleozoic Accretionary/ Exotic Terranes (it is actually a group formed by Arequipa, Atacama and Precordillera as a single complex) it shall be considered the first lines of evidences of trully accretion tectonics along the western margin of South America; (d)Late Paleozoic Accretionary Terranes (Chiloe, North Patagonia, Deseado and Cuyania Terranes) they might well represent volcanic arcs, microplates or crustal fragments migrating from SW and forming a complex subduction system to the NE. After docking and accretion, occurred an outboard jumping of subduction system showing that basement foundation were quite different from Southern Andes to the others segments; (e) Late Jurassic-Early Cretaceous Accretionary Terranes (Darwinia, Mejjillones, Casma/Canta and Amaine), a generalized period of terranes accretion that marks the Inception of the so-called "Andean Orogenesis " deforming the previous intra-arc basins with the early development of the now Intra-arc foreland basins and the birth of the FFTB by terranes collisions and magmatic loads'(f) Late Cretaceous-Tertiary/Recent Accretionary Terranes (Pinon, Serrania del baudó etc) we shall notice that have occurred several episodes of terranes collisions in Northern and Central Andes while in the Southern Andes just the progressive clockwise rotation of volcanic arcs These two processes were responsible for diffetrent FFTB along the Andes.

Fig 04 – The Different Processes which prevailed in each major Andean sector (Cavalcanti,1999).. On the top of the figure the shaded relief map from NW South America is clearly defining several episodes of terranes accretion, oblique subduction with stress partitionimg causing obduction and lateral transport of island arc/oceanic ridges onto the South American crust giving rise to well-developed FFTB. At the bottom of figure we show the present tectonic outline of southern Andes where it can be highlighted the last terrane to collide-Mejjillones- and the Cretaceous /Tertiary collision of the Chile Ridge. it is also shown the Permian/Triassic tectonic setting of NW/SE oriented volcanic arcs which formed a double subduction system to NE just prior to docking and formation of an "Arc Massif" where the development of a series NW/SE oriented grabens/transtensional/transpressional intra-arc basins have ocurred. Extensional deformation were driven by a set of regional NE/SW oriented strike-slip faults brougting out to our attention that there are no rifts sensu strictu at early development of Andes but rather a series of en- echelon transtensional/transpressional/intra-arc basins. The bacground images are JPEG's from W. Smith & D. Sandwell fro NOAA Laboratory of Satellite Altimetry (1999).

Fig. 05 -- Figures from Klemme & Ulmishek (1998). On top figure, it is possible to carry out geological interpretations to the "statistical" distributions. A normalized cummulative plot would provide a "lognormal-like" distribution showing that we should not expect any cyclicity, but rather na envelope which shows that petroleum reserves should be treated as a cummulative and not a discrete process. Two populations can be depicted from the figure (one Paleozoic and other from Mesozoic/Cenozoic). On bottom figure i is shown the changes in typical conditions of source rock deposition. It also, cleraly shows, the increasing effects of time and tectonics on generation, migration and entrapment of hydrocarbons. We conclude from these figures that the evolution of our modern orogenic systems (Late Cretaceous to Recente) play a major role in hysrocarbons disstribution, more specifically the Neogene orogens (Andes, for instance.). One can further speculate that the missing interval in the Neogene on top figure, might

actually be correlated with late oil generated by late tectonic processes, yet to be find in the Neogene foldbelts with low exploration level.

Fig. 06 – Tectonic Map of South America(Cavalcanti etal., 1999). This map is an attempt to synthetisize the Precambrian Elements (Cratonic and suspect continental terranes and Phanerozoic elements: suspect terranes, accretionary terranes, the Mesozoic and Cenozoic Volcanic Arcs – distinguishing their plutonic and volcanic components – and a coherent and updated sedimentary basins classification of the whole continente. The Andean Realm is dominated by Paleozoic foreland basins, forming a once interconnected prism of sediments thichening to W, which included the Parana, NW. Chaco, PeruvianEcuadorian/Venezuelan and Solimões basins. From Late Permian-Triassic to Late Cretaceous the dispersal of Pangea it was developed a series of intra-arc basins (Austral, San Jorge, Neuquen, Cuyo NW, and the Peruvian/Ecuadorian/Colombian/Venezuelan basins). From Late Cretaceous to Recente the development of molasse-type sediments took place owing to a second pulse of foreland basins development along the entire Andean length, and a phase of of diverse types of sedimentary basins from Oligocene to Recente owing to development of Intra-arc/Foreland basins systems, Piggy back and Intra-arc basins (Falcon ,Maracaibo, Madalena Valley and the Peruvian Geanticline),. The map also suggest that where it is find larger foldbelts also there are correlations showing that there is a large amount of discovered Hydrocarbons, suggesting a empirical relationships: well-developed FFTB with presently low exploration level might host several untestead large hydrocarbon polls (Bolivia and Peru). **This is the fate of giants!.**

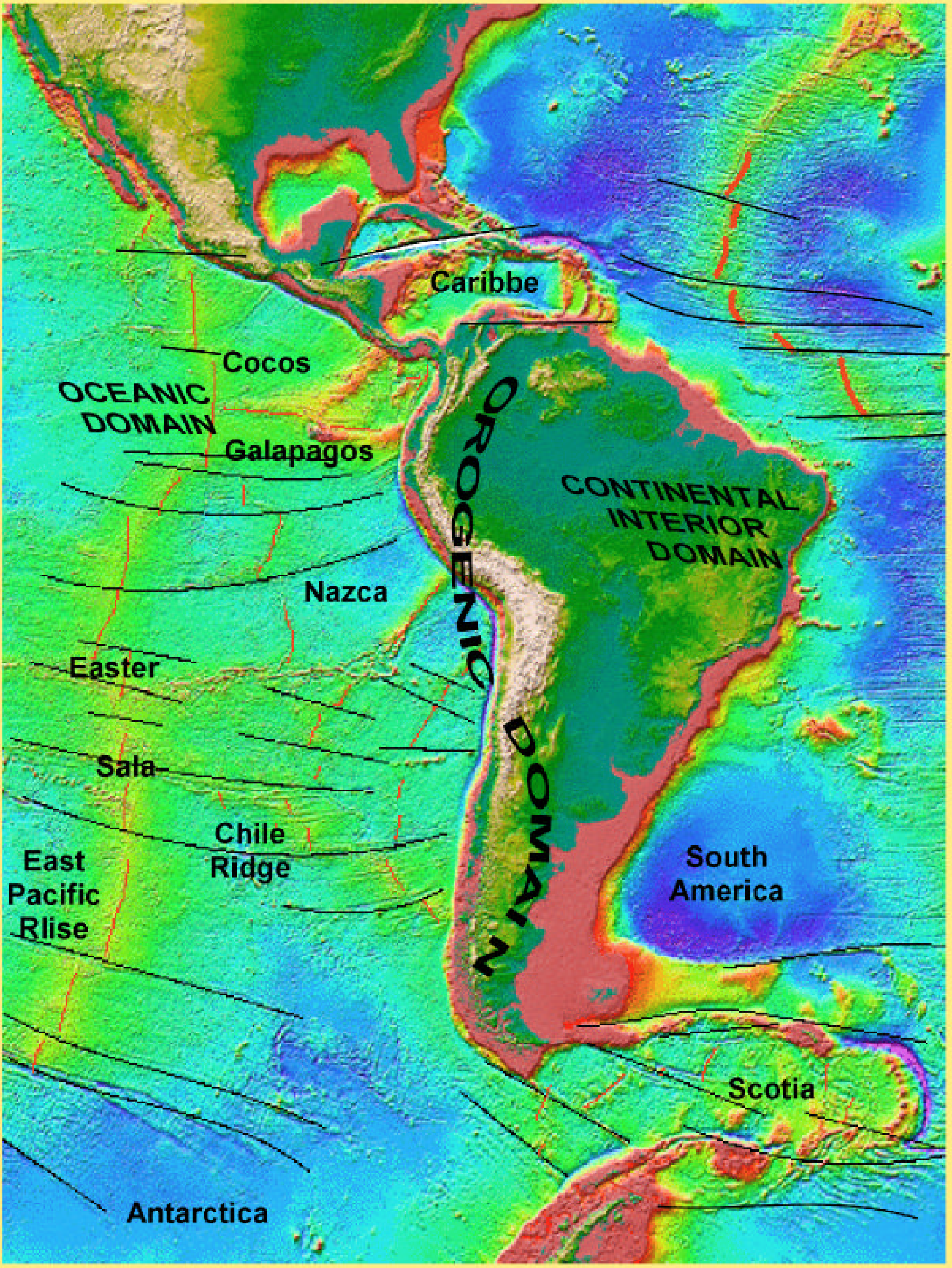
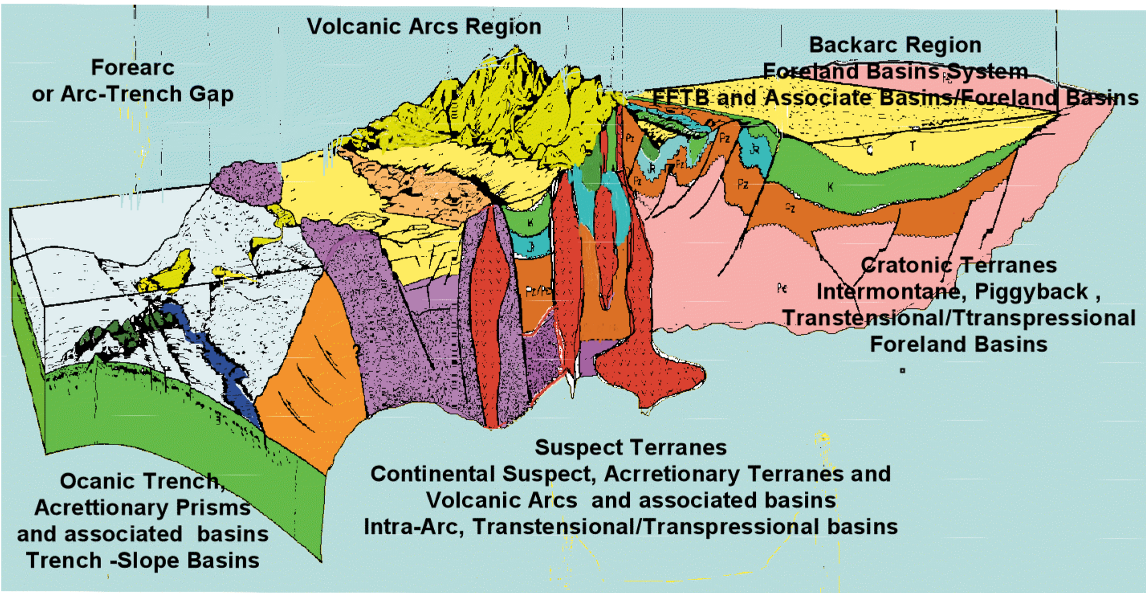

Caribbe
Cocos
OCEANIC DOMAIN
Galapagos
CONTINENTAL INTERIOR DOMAIN
OROGENIC DOMAIN
Nazca
Easter
Sala-
Chile Ridge
East Pacific Rlise
South America
Scotia
Antarctica

Figure 01

Conceptual Elements of a Continental Margin Orogenic System



Geotectonic Domains, Physiographic Provinces,
Tectonic Stratigraphic Units and Terranes Framework
A Model for the Andes

Figure 02

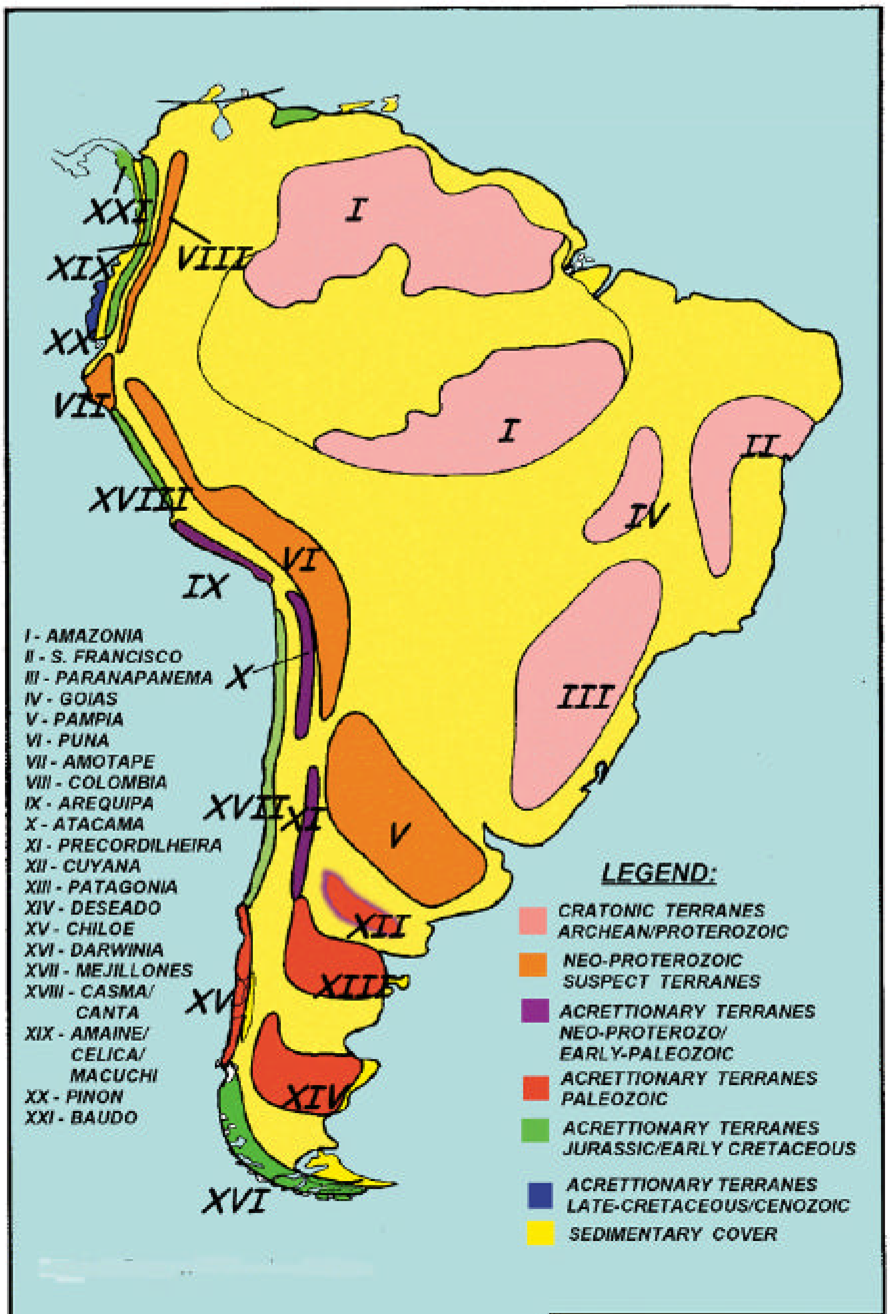

I
VIII
XXI
XIX
XX
VII
I
II
IV
XVIII
VI
IX
X
III
XVII
XI
V
XII
XIII
XV
XIV
XVI
I - AMAZONIA
II - S. FRANCISCO
III - PARANAPANEMA
IV - GOIAS
V - PAMPIA
VI - PUNA
VII - AMOTAPE
VIII - COLOMBIA
IX - AREQUIPA
X - ATACAMA
XI - PRECORDILHEIRA
XII - CUYANA
XIII - PATAGONIA
XIV - DESEADO
XV - CHILOE
XVI - DARWINIA
XVII - MEJILLONES
XVIII - CASMA/ CANTA
XIX - AMAINE/ CELICA/ MACUCHI
XX - PINON
XXI - BAUDO
LEGEND:
CRATONIC TERRANES ARCHEAN/PROTEROZOIC
NEO-PROTEROZOIC SUSPECT TERRANES
ACRETTIONARY TERRANES NEO-PROTEROZO/ EARLY-PALEOZOIC
ACRETTIONARY TERRANES PALEOZOIC
ACRETTIONARY TERRANES JURASSIC/EARLY CRETACEOUS
ACRETTIONARY TERRANES LATE-CRETACEOUS/CENOZOIC
SEDIMENTARY COVER

Figure 03

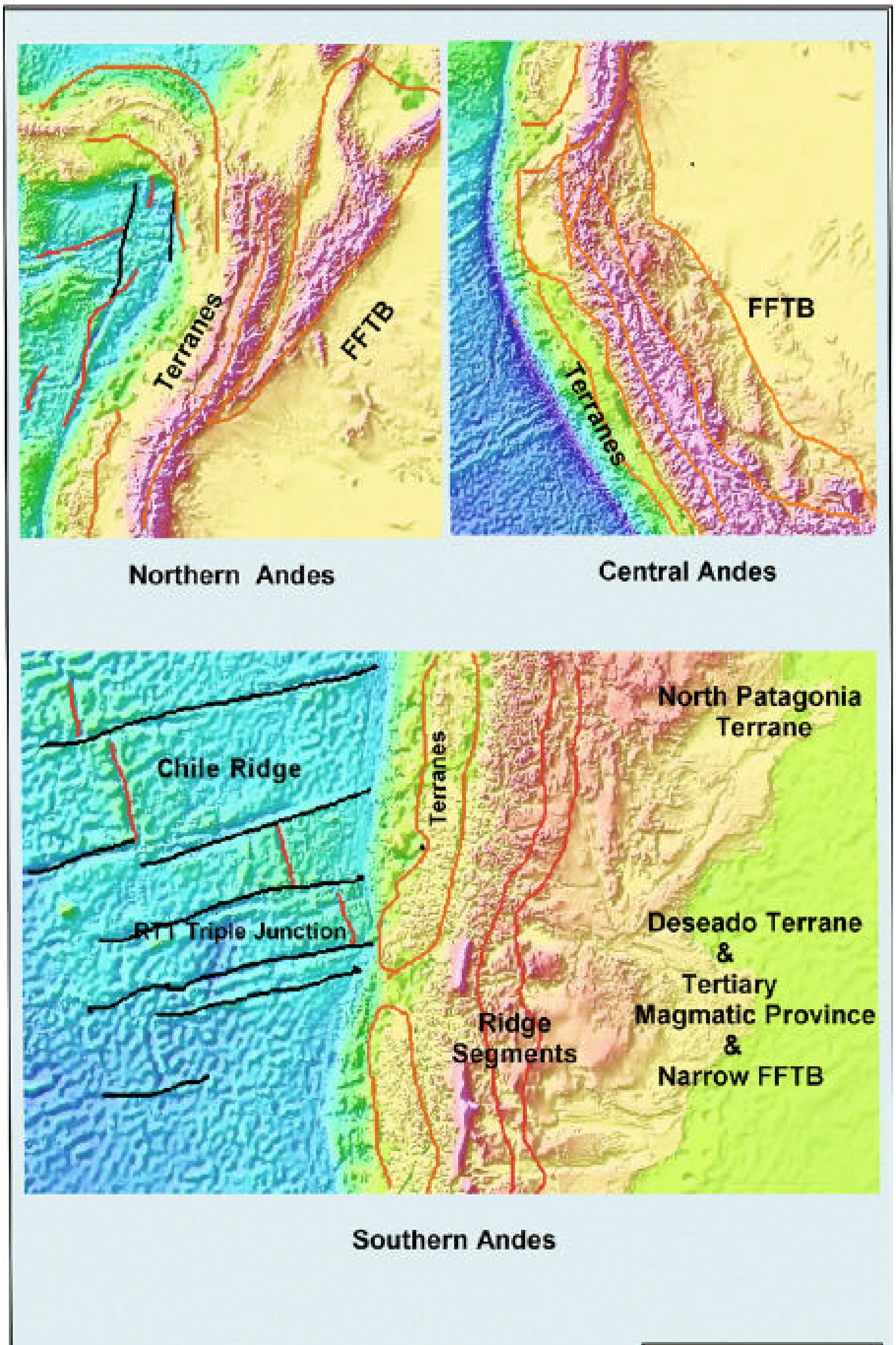
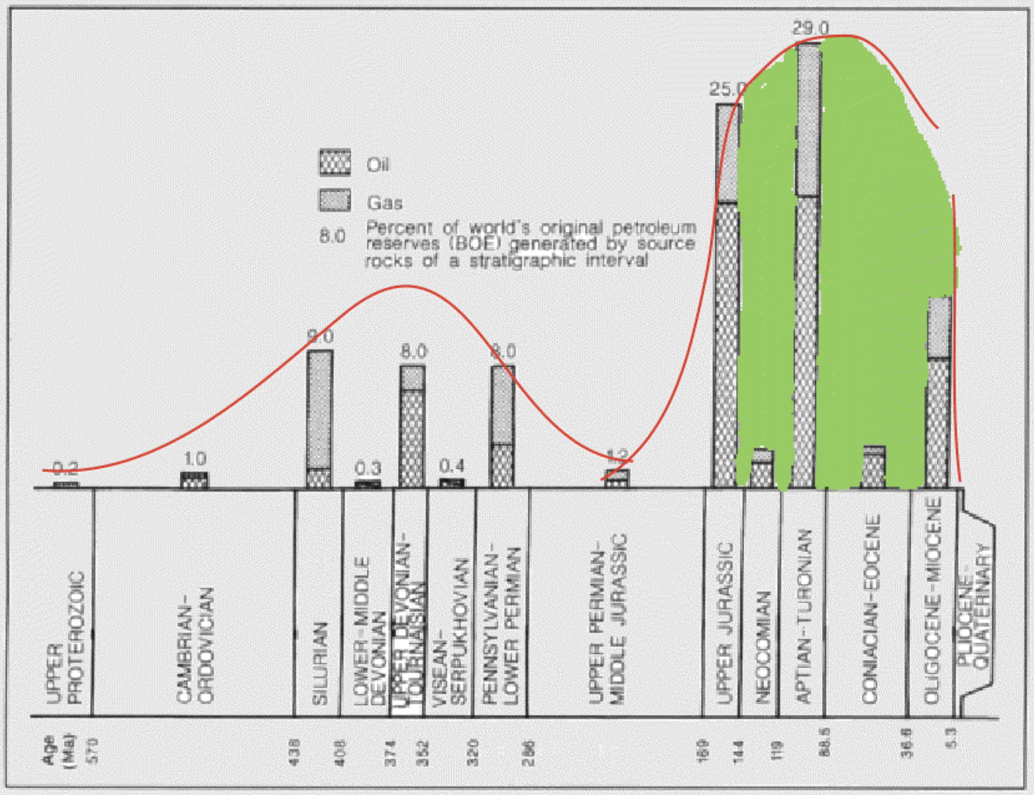
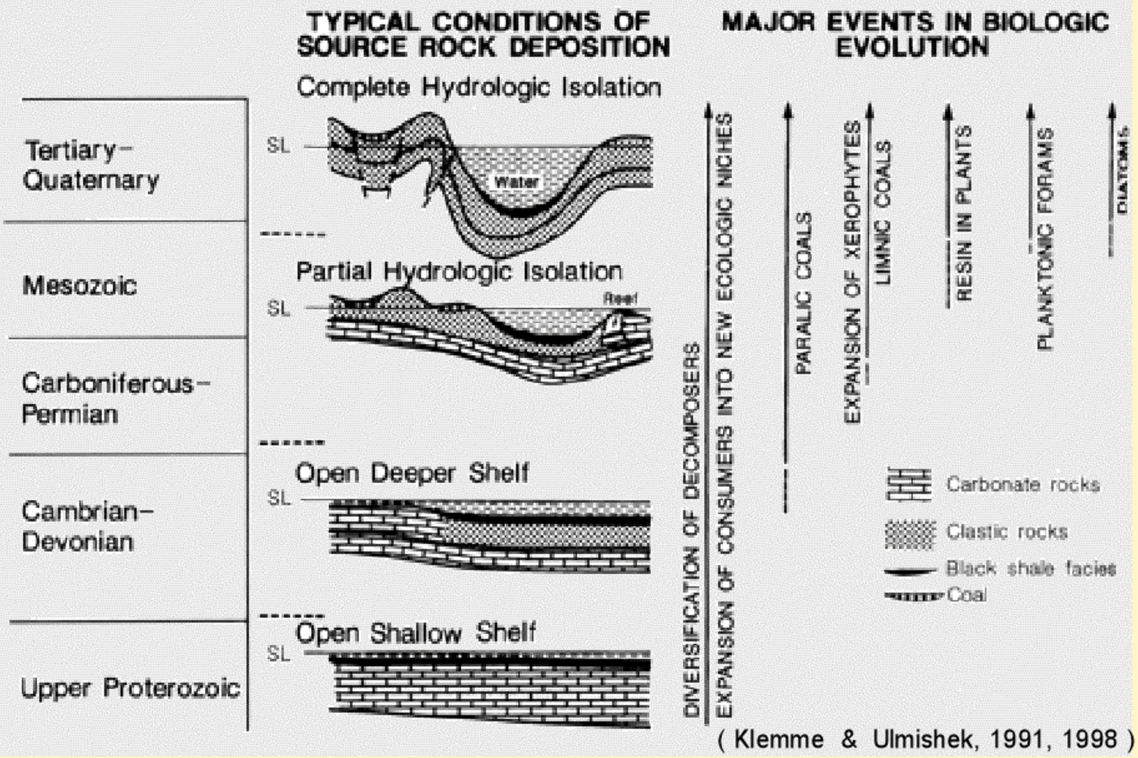

Terranes
FFTB
Northern Andes
FFTB
Terranes
Central Andes
North Patagonia Terrane
Chile Ridge
Terranes
RTT Triple Junction
Deseado Terrane & Tertiary Magmatic Province & Narrow FFTB
Ridge Segments
Southern Andes

Figure 04



(Klemme & Ulmishek, 1991, 1998)



(Klemme & Ulmishek, 1991, 1998)

Figure 05

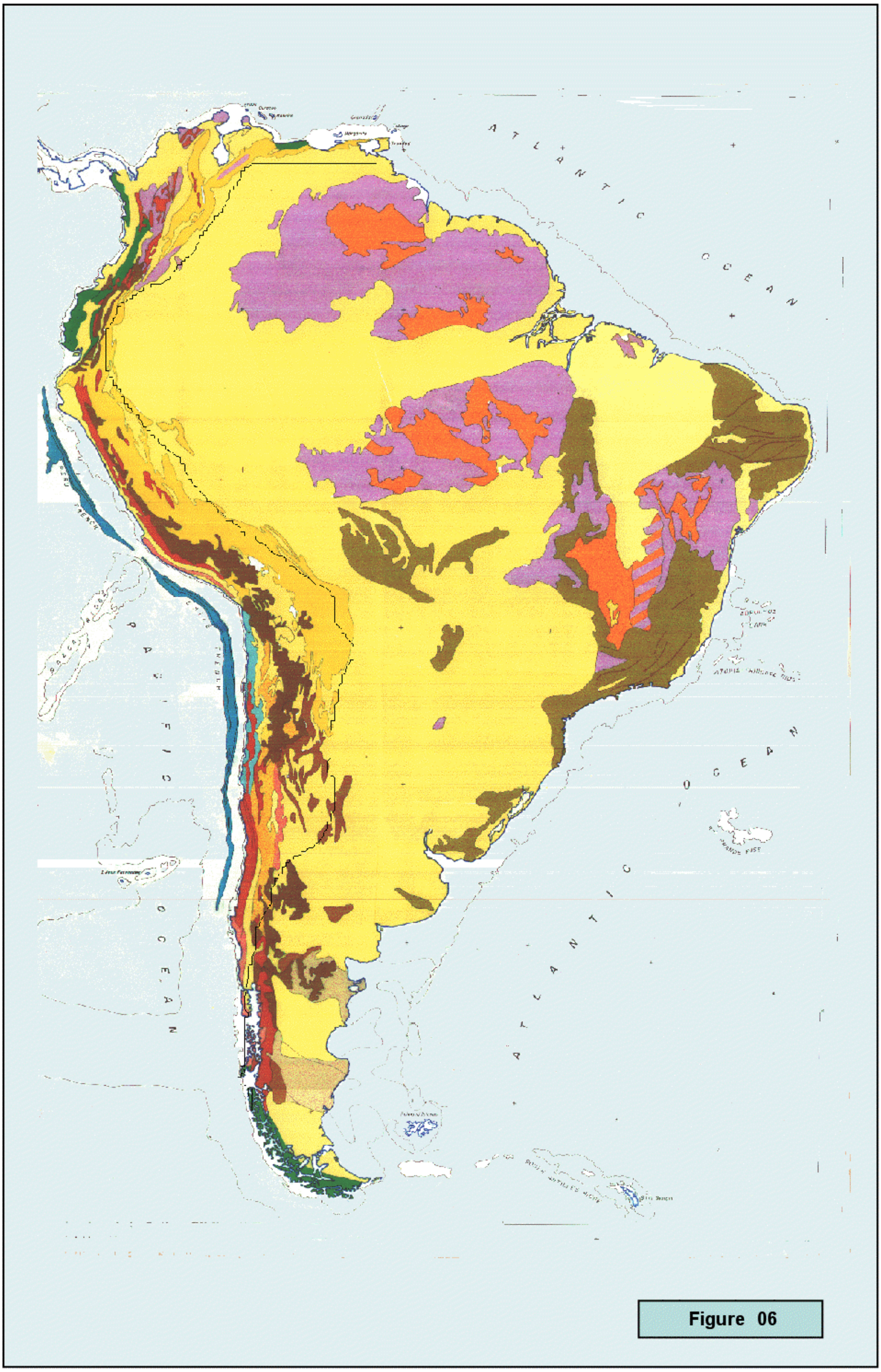


Figure 06