VIRTUAL RESEARCH SYMPOSIUM
Latin America & Caribbean Region

PACIFIC BASINS
22-23 October 2020

# Exploring South America's Active Margin (Colombia, Ecuador, Peru and Chile)

## PRESENTATION ABSTRACTS

### DAY 1 – OCTOBER 22, 2020
### SESSION I: STRUCTURAL GEOLOGY & TECTONICS



### SESSION II: GEOPHYSICAL METHODS & INTERPRETATION

## DAY 2 – OCTOBER 23, 2020

## SESSION III: REGIONAL GEOLOGY AND BASIN ANALYSIS



## SESSION IV: STRATIGRAPHY & SEDIMENTOLOGY

## SPECIAL PRESENTATIONS



## BIOGRAPHICAL SKETCHES

# PRESENTATION ABSTRACTS

## DAY 1 – OCTOBER 22, 2020

## SESSION I: STRUCTURAL GEOLOGY & TECTONICS

**1.I Building an Andes Plate Tectonic Reconstruction Back to the Late Cretaceous ~80 Ma Using Unfolded Slabs from Seismic Tomography: Implications for Flat Slab Tectonics**

Yi-Wei Chen (presenter), Jonny Wu, John Suppe, University of Houston

The Andean margin has long been regarded as a classic example of long-lived, continuous oceanic lithosphere subduction beneath a continental margin. The current continuous subduction phase has apparently endured since the early Jurassic, or early Cenozoic, but uncertainty exists due to incomplete or missing geological records. Within a presumed context of continuous subduction, many studies have attributed episodic and localized changes in Andean deformation, magmatism and topography to repeated cycles of slab flattening and steepening or slab break-off (i.e. flat slabs). Here we present a slab-based, quantitative plate tectonic reconstruction that shows Andean subduction was not always continuous since the Mesozoic and has included episodic phases of strike-slip/transtension or divergence. Our results imply that plate tectonic-scale reorganizations and slab-mantle interactions – factors other than slab dip (i.e. flat slabs) – may have also played a crucial role in controlling the evolution of Andean geology.

In this study we mapped and unfolded (i.e. structurally restored) the Nazca slabs from global seismic tomography to produce a quantitative, slab-constrained plate reconstruction of the Andes back to the late Cretaceous ~80 Ma. Our reconstruction implies a subduction resumption at late Cretaceous following a 100 to 80 Ma regional plate tectonic reorganization. We suggest our predicted plate reorganization event corresponds geologically to the Andean margin-wide compressional event at mid-late Cretaceous. Our plate model also shows the Andes potentially experienced periods of strike-slip and even divergent tectonics until 55 Ma, which roughly fits the magmatic records.

Quantitative output of subducted slab lengths over time along the Andean margin from our model implies that at ~50 Ma the Andean margin had an anchored northern Nazca slab and a free southern slab in the upper mantle. We argue such a difference can explain the distinct geology north (compression) and south (extension) of 33 S at Andean margin between Eocene to Oligocene, a time period that almost all subduction conditions are equal along the margin. We will also compare other along-strike variations in Andean geology including magmatic patterns, and compressional/ extensional structures development to our slab-based plate model.

**1.II Tectonic-Structural Analysis of the Chilean Forearc (Offshore) Between 28.5° and 37.5°: Effects of Subduction in Submarine Morph-Structures**

Pablo Sebastian González Godoy (presenter) Cristian Rodrigo Ramirez. Universidad Andres Bello, Sede Viña del Mar, Chile

The behavior of the Chilean Fore arc in its offshore segment has been the subject of a large number of studies during the last 30 years. This work is based on a new interpretation of previously published geophysical antecedents together with an improvement of bathymetric grids in order to provide new imprints on the morpho - structural behavior of the ante arch in its offshore segment (28.5 ° S - 37.5 ° S).

The seismic lines and bathymetries analyzed in this work allow us to identify that the Fore arc basins are located mainly in the upper - middle slope area and are limited on their western edge by a raised outer arc high. This morphological feature is of primary interest since it represents the limit for the transport of sediments towards the trench, but also for the structural behavior of the slope (Figure 1), which presents structures with strike parallel to the trench (Figure 2) (deviations of up to 20 °) and dips with west direction for the occidental segment of the outer arc high and in the east direction for the oriental segment of the outer arc high. The seismic velocity profiles (Figure 4) demonstrate that the presence of the outer arc coincides with a contact between two layers of different velocities recognized as a paleo-accretionary prism and the rigid continental basement. This area in turn is home to the highest amount of seismicity that has occurred in the last 20 years. Evidence of strike-slip movements can be identified in the kinematics of two of the largest earthquakes in the past 60 years and also in the structural arrangements presented on the seismic lines south of the Valparaíso basin.

In this way, it is suggested that the presence of a sliver-type structure brings the paleo-accretionary prism and the continental basement into contact and may be an important factor in the morphological evolution of the fore arc, together with the accretion/ erosion processes that dominate the subduction of the Chilean margin.

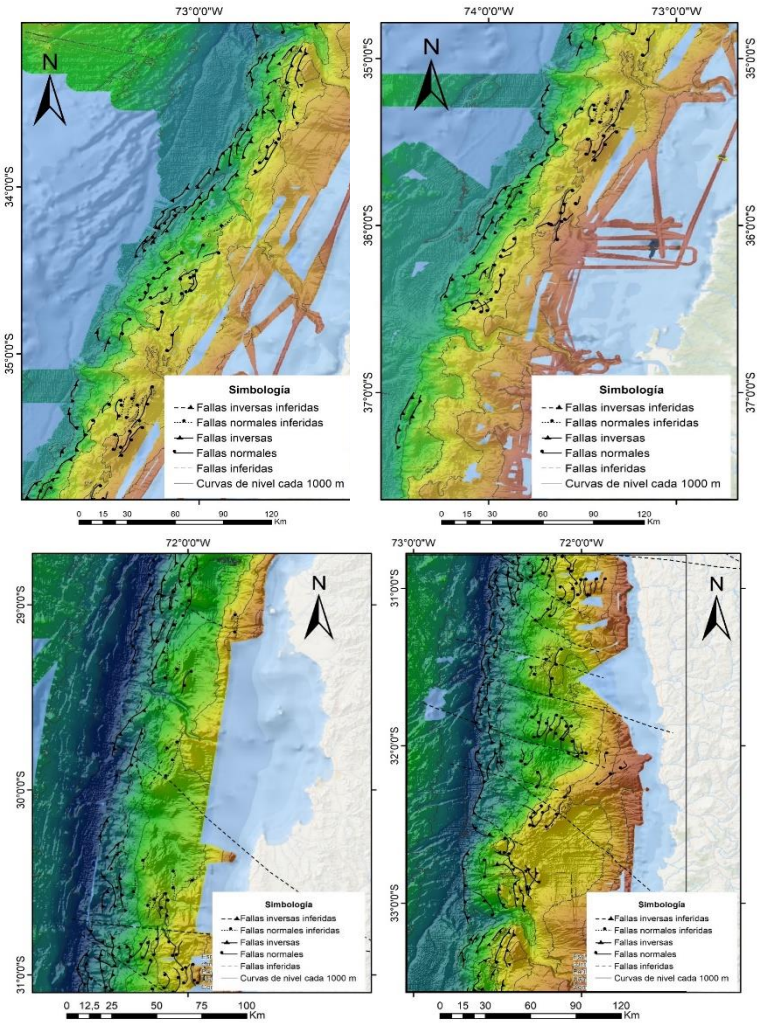


Figure 1. Structural features in the study zone

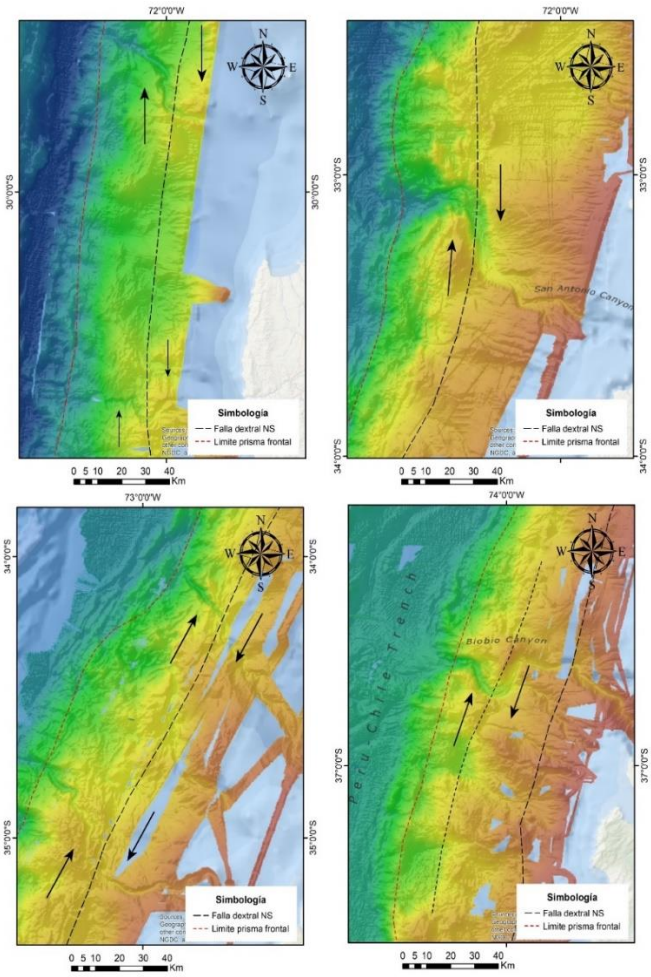


Figure 2. Strike-slip features in the study zone affecting underwater cannons.

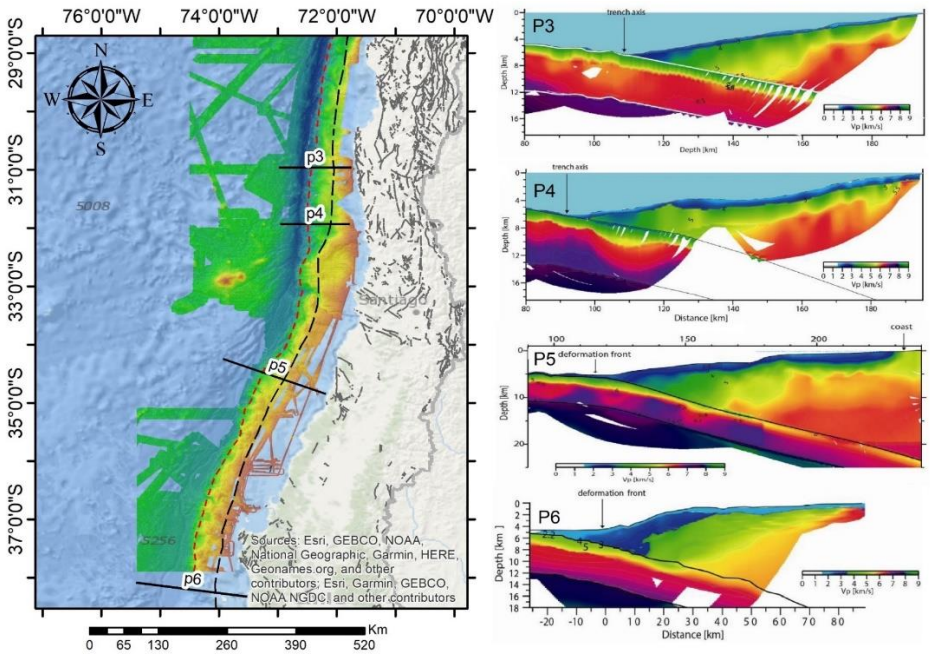


Figure 3. Velocity seismic profiles. P3 and P4 from (Contreras-Reyes et al., 2015), P5 from (Moscoso et al. 2011) and P6 from (Contreras-Reyes et al., 2008).

**1.III Cenozoic Structural Style and Tectonic Evolution of East Pisco Basin, Offshore Peru: Implications for an Active Petroleum System**

Daniel Peña[1] (presenter), Diego Timoteo[2], Pedro Alarcon[3]; [1]Repsol, [2]Hound Exploration, [3]Independent

The East Pisco basin belongs to the set of basins of the Peruvian forearc, which is bounded to the west by the Cordillera de la Costa Range (also known as Outer Shelf High in the offshore) and to the east by Olmos Marañón Continental block. This basin is characterized by its very complex and little-known tectonic history, although previous works evidenced extensional and compressional stages which controlled the basin throughout the Cenozoic. The present work integrates 2D/3D seismic interpretation with recent surface geological works carried out along the coast and applies structural analysis of faults and its associated deformation features. In this way, integrated seismic interpretation allowed mapping of key horizons: Pre-Cenozoic, Choros (Middle-Upper Eocene), Yumaque I-II (Upper Eocene - Lower Oligocene), Chilcatay (Upper Oligocene), Lower Pisco (Lower Miocene) and Upper Pisco (Upper Miocene). The structural maps from surfaces mentioned above delineate the main structural features in the basin: faults and fault-propagation folds. Accordingly, the analysis of sedimentary record and structural behavior suggest four main fault systems occur in the study area. The chronology of they define the structural styles and tectonic evolution model as follows: (i) development of grabens and halfgrabens with fault system SW-NE and dextral transfer faults SW-NE, related to extensional stage (N340 direction) during >40-30 Ma; (ii) development of fault-propagation folds due to compression related to a tectonic inversion stage (N50 direction) during 28-10 Ma; (iii) reactivation of the fault-related grabens SW-NE, which in turn coexists with the compressional stress component N50 during 10 Ma to the present. The oil seeps in the basin suggest at least one active petroleum system. Thus, this tectonic evolution model has strong impact in the hydrocarbon exploration: (1) the extensional stage (>40-30 Ma) allowed the deposition of the reservoirs and seals rocks recognized along the coast, as well as the burial for the potential Paleozoic and Cretaceous source rocks, and also extensional fault-related traps were generated. (2) During tectonic inversion stage (28-10 Ma), structural fold type and stratigraphic-structural traps were generated; (3) during reactivation of the extensional stage (<10 Ma) occurred the subsidence of the depocenters (grabens) and a possible late hydrocarbon generation event.

**1.IV Structural Analysis of the Talara Basin - E&P Implications**

Carlos Llerena (presenter), Diego Escobedo, Christopher Villafuerte, Savia Peru S.A.

Talara basin has been producing oil & gas for more than 120 years. However, there is still controversy in define its structural style. A recent Structural Analysis was performed integrating data from: bathymetry/topography, seismicity, interseismic coupling, gravimetry, 2D/3D seismic, thermometry/thermochronology, onshore/offshore wells and outcrops studies.High quality information from latest outcrops campaigns, show that 70% of the faults have strike-slip movement (wrench), supported by pitch measurements, structures related such as: en-échelon fractures/folds, stepovers, horsetail splays, push-up and pull-apart fractals, their kinematic solutions show a constant horizontal stress σ1 NW-SE direction ~N130° (similar to Induced fractures), different from the current subduction direction ~N80°, this is a result of the Mega Shear Dolores Guayaquil that affects and change the σ1 stress direction/magnitude in the basin; 25% correspond to normal faults (gravitational) and 5% to reverse faults (thrust).However, the main structural feature of Talara basin is the configuration of structural highs and lows, which are the product of a constant and diachronic uplift and subsidence process, the uplift origin is related first to the large transpression deformation related to the megathrust between 60-90 km from the

trench; and secondly related to abrupt uplift movements (+4mm/year) between 10-50 from the trench due to ridges subduction. It was estimated an erosion range between 2000 to 3500 meters in the structural highs.This complexity is exposed in the oil & gas fields productivity behavior and explain several issues in the reservoir/simulation modelling, besides open more opportunities in exploration through a better understanding of the Tectonostratigraphic frame in the basin

**1.V Forearc Basin Development Along the Southernmost Boundary of the Northern Andes**

Carlos Aizprua[1,2,] (presenter), Cesar Witt[2], Jean-Yves Reynaud[2], Diego Barba[3]; [1]Norwegian University of Science and Technology, [2]University of Lille, [3]PetroAmazonas

It has long been recognized that obliquity between convergent plates along active margins results in strain partitioning, both normal and parallel to the trench. Such active margins may develop large scale strike-slip faults that can be prolonged for hundreds of kilometers, bounding different forearc crustal slivers and where the accretion of allochthonous terranes may have played a great role in the observed deformation styles. However, less is known along the area linking the large strike-slip faults and the trench, and how this connection may have controlled the forearc tectonic-stratigraphic evolution. In the Northern Andes, a Late Cretaceous oceanic sliver underlies the forearc region of SW Ecuador, with its southern limit interacting with the continental basement of South America. Herein, we present a temporal paleogeographic reconstruction of the Gulf of Guayaquil-Tumbes basin, located across the inferred suture zone, providing us with an insight on the fault termination styles of large-scaled strike-slip faults, their associated tectonic elements and their influence on the stratigraphic record, and the current link to the trench. The geological record of a rapid shallowing of the forearc from deep marine deposits into fluvio-deltaic successions by Oligocene time, and the restricted conditions through the development of perched sub-basins, suggest more complex systems at the fault termination area. We suggest that the inherited configuration following the collision and accretion of an oceanic crustal sliver accompanied by the development of a local and thick accretionary wedge by Paleocene time, and the post-Oligocene transtensional regime along the southern boundary transform fault of the North Andean Sliver explain the basin configuration of this region.

**1.VI Crustal Structure of The Southernmost Northern Andes: A Trapped Oceanic Sliver**

Cesar Witt[1], (presenter); Carlos Aizprua[1,2], Marco Brøner[3], Diego Barba[4]; [1]University of Lille, [2]Norwegian University of Science and Technology, [3]Geological Survey of Norway, [4]PetroAmazonas

Along the Western Cordillera of Ecuador and Colombia, fault-bounded ophiolites derived from the Late Cretaceous Caribbean Large Igneous Province (CLIP) have provided key petro-tectonic indicators that outline the nature and the mechanism of continental growth in this region. However, most of the forearc basement across the southernmost Northern Andes is buried under sediments impairing its crustal structure understanding. Here we propose a crustal model throughout the spectral analysis of gravity and aeromagnetic data, constrained by observations made both at the surface and subsurface. Three main geophysical domains, within the southermost North Andean Sliver, have been defined based on spectral analysis and augmented by 2D forward models. An outer domain characterized by magnetic anomalies associated with mafic rocks that may coincide with evidence of a split intraoceanic arc system. An inner domain governed by long-wavelength mid to deep crust – sourced gravity and magnetic anomalies possibly evidencing the root of a paleo-island arc and the residuum of a partial melting event with subsequent associated serpentinization, the latest possibly associated to an obduction process during the middle Eocene – Oligocene. In addition, our model supports the presence of a

lithospheric vertical tear fault, herein the southern suture domain, inherited from an oblique arc-continent interaction. Our interpretation also brings new insights and constraints on the early geodynamic evolution at the southernmost Northern Andes and provides evidence on the structural style and preservation potential of the forearc basement, most likely the roots of a mature island arc built within an oceanic plateau.

## SESSION II: GEOPHYSICAL METHODS & INTERPRETATION

**2.I Data Reprocessing, Enhancement and Integration to Unlock Hydrocarbon Potential of the Peruvian Offshore. Examples from the Underexplored Salaverry and Trujillo Basins**
Eloi Carola (presenter), David Spofforth, Shona Culwick, Emmanuel Nformi, CGG GeoSpec

The Peruvian offshore margin is a classic example of a subduction zone with the typical structural domains where hydrocarbon exploration has been productive elsewhere. The structural evolution of the margin isolated several structural highs and sedimentary basins infilled with numerous potential source and reservoir rocks together with the intense fracturing of the basement. Despite the similarities in the evolution of the sedimentary basins, Peru is a story of two halves. The northern half, has production from several well-known oil and gas fields. In contrast, the southern half is underexplored, with only five wells drilled, but with evidence of a working hydrocarbon system. In spite of this duality, the whole margin is characterised by well-developed reservoirs spanning from Paleozoic fractured quartzites up to Cenozoic clastics. The presence of producing fields, wells with shows, and surface seeps is proof of a working petroleum system offshore Peru.

To unlock the offshore petroleum potential, Perupetro and CGG GeoSpec present an industry-leading reprocessing project designed to answer key questions on the petroleum system. Improved imaging is provided by 2D PSTM and PSDM reprocessing from field tapes together with a comprehensive and enhanced 2D and 3D seismic dataset. The data have been navigation corrected, amplitude & phase matched, zero phased and made workstation ready. Geological ground truthing is provided by enhanced well data, giving an overview of previous exploration and enabling lessons to be learnt from the past.

In this presentation we draw on examples from the Salaverry and Trujillo Basins to show how the integration of seismic and well data can illuminate the petroleum system and provide new insights into the petroleum potential of offshore Peru.

**2.II Hydrocarbon Prospectivity Implications of BSR-derived Geothermal Gradient Offshore Peru**
Karyna Rodriguez (presenter), Neil Hodgson, Searcher

Peru offshore southern basins are largely unexplored and therefore, source rock presence, distribution, quality and maturity remain as the key risks.The Trujillo and Salaverry Basins have good source indications as two of the four exploration wells encountered significant oil shows during drilling. In the Lima and Pisco strike slip basins, geological and geophysical studies carried out on just under 50 samples collected for geochemical analysis indicate that the Carboniferous Ambo Group may be one of the main source rocks. No wells have been drilled in the long, narrow Mollendo forearc basin, located mostly in the continental slope. However, asphalt layers encountered in Lower and Middle Jurassic formations, indicate the presence of potential source

rocks. However, the strongest evidence of a working hydrocarbon system in these basins, is observed in a large post-stack reprocessed seismic dataset covering all the offshore basins, in the form of Bottom Simulating Reflectors (BSRs) interpreted as the base of the gas hydrate stability zone.The thickness of gas hydrate zones mainly depends on sea floor temperature, pressure (directly related to depth) and existing geothermal gradient. BSR thickness, seafloor temperature and pressure are known, hence geothermal gradient can be calculated. The BSR- derived geothermal gradient was calculated and extrapolated throughout the basin which resulted in a better understanding of source rock presence, maturity, distribution and possible migration pathways. Offshore Peru has proven hydrocarbon systems and ample evidence of significant untapped hydrocarbon potential. The rectified seismic dataset provides a consistent regional dataset that hands a gift in understanding to the explorer beginning to unlock this potential

**2.III Developing an Interactive RockAVO Modelling Atlas for Improved Geological Understanding of Offshore Peru**

Roberto Ruiz (presenter), William Powell, Adriana Sola, Cyrille Reiser, PGS

A case study in which a robust petrophysics and rock physics workflow were implemented in eleven wells from the North-West Pacific region of Peru is presented here. Firstly, a full petrophysical evaluation was performed. Then, rock physics models (RPM) have been derived to predict the in-situ elastic response of the well logs, allowing us to initially perform a sophisticated QC and edition of well logs where needed, to predict shear information in wells that required so and explain the intrinsic relationship between geological mechanisms and the elastic response. In addition to this, the workflow enabled us to predict, in real time, how potential geological scenarios, such as changes in porosity, mineral volume and fluid properties, can affect the response in the elastic well logs and by extension in the seismic amplitudes. To this effect, regional post-stack merged seismic were integrated ensuring the agreement between the wells and the seismic.

Introduction

The geological provinces on the Pacific Coast of Peru have a long and complex geological history, the petroleum system has undergone more than a hundred years of exploration and exploitation[1], but still its full potential remains to be understood. Integration of seismic and well data has been made to build a consistent geological framework that can be used to explore its prospectivity.

The Talara and Progreso basins, which are the main focus of this study, are located in the North-West offshore Peru, and are in great part, the result of Late Cretaceous –early Tertiary tectonic activities that involved Paleozoic and Mesozoic strata. The Paleozoic fractured quartzites rest unconformably covered by Cretaceous sequences, which in turn are in unconformable contact with Tertiary rocks. In general terms, sediments deposited from the Upper Cretaceous to the Eocene are associated to fluvial to deltaic depositional environments, with the presence of some marine turbidites.[2]

Methodology

The first step was to perform a complete petrophysical analysis of well-log information to determine the volume of minerals and fluids present in the rock at in situ well-log conditions for each of the eleven wells. Then, a rock physics analysis was performed allowing to derive RPMs which describe relationships between the elastic response and the geological properties of the rock such as mineralogy, porosity, pore shape, permeability, fluid saturation, pore pressure,

laminations, fractures, etc. These calibrated RPM were also used to perform editions in the compressional and shear wave velocity logs and density where issues with the measured logs where found, and to fully predict shear wave velocity [3] in three wells where this log was not acquired. All this information was then delivered to a PGS interactive rock physics atlas (rockAVO™).

One key feature of this interactive rock physics well browser, is the real-time prediction of changes in the elastic and seismic response, as a function of changes in lithology, porosity and fluid properties, enabling to generate realistic geological scenarios, within the rock physics limits, that could explain observations in the elastic and seismic data.

## Results

Results indicated a strong relationship between the derived RPM and the geological setting:

- In the case of the post Paleozoic sequence:
  - The shales overall exhibited a response consistent with the soft sand model [4], i.e. a slow increase in the elastic logs (acoustic-wave and shear-wave velocities and density) with decreasing porosity. This can associate to porosity reduction through deposition of shale in the pore spaces or compaction.
  - The non-shale lithologies tended to exhibit a faster increase of the elastic logs with decreasing porosity, which could be related to cementation or changes in the cement type within the grain contacts, so an intermediate stiff sand model was implemented. The intermediate stiff model is a model that is halfway between the soft sand model and the stiff sand model [4] [5] [6].
- In the case of the Paleozoic sequence, results showed that fractured quarzites present a very stiff response in terms of elastic logs, and also very low porosities. Moreover, the porosity system in these rocks is quite complex: two types of porosities, primary porosity or porosity preserved from deposition through lithification and burial history, and secondary porosity, which is mainly associated to fractures. Based on this observation, an inclusion model and more specifically, a self-consistent approach (SCA) model [7] [8] [9] which allows to account not only for the presence of porous space but also for the different pore shapes present in the rock was required to accurately describe the elastic response of these rocks. In addition to this, this model allowed us to understand how changes in porosity could help us discriminate between brine and hydrocarbon sands.

## Conclusions

A comprehensive petrophysical and rock physics workflow was applied on eleven wells from the Talara-Progreso basin. Observations showed that changes in lithology, porosity and fluid properties in the area can be described using a soft sand model and an intermediate stiff sands model in the Post-Paleozoic sequences, and a self-consistent approximation model, that accounts for different aspect ratios of the pores, in the Paleozoic sequence. In addition to this, derived RPM from the present study allowed to perform a calibrated prediction of shear-wave velocity log in three wells, demonstrating that it's possible to implement this understanding and knowledge of the rock physics in other wells of the same region that share a similar geological history all of this integrated with the seismic providing an integrated product for screening opportunities.

References

[1] Paulo H. Gulelmo de Souza, Edwar Bustamante, and Jose Antonio Castillo. Seismic Interpretation in an Ultra-Mature Area: Talara Basin, Peru. SEG Technical Program Expanded Abstracts 2012, doi: https://doi.org/10.1190/segam2012-0814.1
[2] Higley, Debra. The Talara Basin Province of Northwestern Peru: Cretaceous-Tertiary Total Petroleum System. AAPG Bulletin, vol. 86, 2002, doi: 10.1306/61eeeb6a-173e-11d7-8645000102c1865d

[3] Greenberg, M. L., and Castagna, J. P., 1992, Shear-wave velocity estimation in porous rocks: Theoretical formulation, preliminary verification and applications: Geophysical Prospecting, 40, 195-209.
[4] Dvorkin, J., Mavko, G., and Nur, A., 1991, The effect of cementation on the elastic properties of granular material: Mechanics of Materials, 12, 207-217.
[5] Dvorkin, J., Nur, A., and Yin, H., 1994, Effective properties of cemented granular material: Mechanics of Materials, 18, 351-366.
[6] Dvorkin, J., and Nur, A., 1996, Elasticity of high-porosity sandstones: Theory for two North Sea datasets: Geophysics, 61, 1363-1370.
[7] Budiansky, B., 1965, On the elastic moduli of some heterogeneous materials: J. Mech. Phys. Solids, 13, 223-227.
[8] Hill, R., 1965, A self-consistent mechanics of composite materials: J. Mech. Phys. Solids, 13, 213-222.
[9] Wu, T. T., 1966, The effect of inclusion shape on the elastic moduli of a two-phase material: Int. J. Solids Struct., 2, 1-8.

## 2.IV 2D/3D Seismic Activity Along Offshore Peru and its Contribution to Increasing the Basins' Prospectivity

Edgar Borda[1] (presenter), Carlos Bianchi[2]; [1]Energy Resources Consulting, [2]SK Innovation

In the last 5 years, many oil companies have turned their attention towards the offshore Peruvian basins, where a lot of seismic information has been acquired, processed, re-processed, and interpreted as a part of the exploration campaigns of several former operating companies.

The purpose of this study is to illustrate the key role that 2D/3D seismic information has played in increasing the prospectivity of the offshore Peruvian basins, not only in areas where seismic information has been thought to be very bad quality but also in areas where its quality is considered from fair to very good.

Using a variety of methods and improvement techniques from the acquisition and processing of seismic information standpoint, positive impacts will be shown in the better understanding of the dynamics in the formation and evolution of offshore basins, not only from the structural point of view but also from the sedimentological in some cases, and thus managing to contribute to the reduction of the associated geological risks.

An adequate design of the seismic acquisition, as well as the use of the latest seismic processing improvement techniques, have improves the quality of the seismic information, even in areas where the structural complexity did not allow to see information from the subsurface.

This study confirms that the proper use of techniques both in processing and acquisition helps to better delineate the subsurface structures, along with the geological information that can help to improve the chances of success in a frontier exploration area. It is understood, that additional efforts are currently being made to update all the seismic information on the Peruvian offshore and this will have a positive impact on future companies that come for big bets in the offshore Peruvian basins.

## 2.V Direct Hydrocarbon Indicators Associated with Oligocene-Recent Folds of the Sandino Forearc Basin, Offshore Pacific Margin of Nicaragua

Lila Bishop (presenter), Paul Mann, The University of Houston

The Sandino Forearc Basin (SFB) is an active forearc basin located along the western edge of the Caribbean plate in Nicaragua and overlies the subducting Cocos plate. The available dataset includes 77 2D, time-migrated, newly acquired and reprocessed industry and academic seismic lines, angle stacks for AVA angle stacks, and migration velocities. These seismic lines are tied to published offshore and onshore well correlations. Using these data, I document an Oligocene-recent folding event marked by a regional, angular unconformity and are associated with a

200-km-long, a 30-km-wide, trench-parallel belt of fault propagation folds. Syn-folding, sandy deposits document abrupt shallowing across the unconformity from depths of 3000 m to shallower depths of ~250m as measured from clinoforms. Direct hydrocarbon indicators emanate from Eocene black shale intervals within the deepest "kitchen" area of the basin. Hydrocarbon indicators found in proximity to the Eocene shale and the overlying folds include: 1) bright spots over structure on full angle stacks along with brightening from near - far angle stacks when comparing AVA data, 2) phase reversal related to fluid contacts, and 3) velocity slow down over structure. Basin modeling using heat flow estimates from previous workers and from estimates from the depths of gas hydrates indicates the Eocene shale unit is mature for oil but underlying high TOC (avg 10%) late Cretaceous source rocks known from onland outcrops are overmature in the basin center.

## DAY 2 – OCTOBER 23, 2020

## SESSION III: REGIONAL GEOLOGY AND BASIN ANALYSIS

**3.I Mantle Impressions of Latin American Subduction History**
Douwe G. van der Meer, CNOOC International

A fundamental understanding of the tectono-stratigraphic framework of basins is crucial to predict prospectivity at greater distances from existing well penetrations and seismic constraints. Seismic wave tomography of the mantle reveals subducted lithosphere (slabs) as positive wave speed anomalies. Recently a global framework was published wherein slabs had been correlated with their geological record, accessible online at www.atlas-of-the-underworld.org. This compilation identifies slabs down to the core-mantle boundary, documenting subduction from ~300 Myr to Present. On their downward journey towards the core-mantle-boundary, slabs decelerate due to increased mantle viscosity. Generally deeper slabs are correlated to older geological records and younger slabs are stacked on top.

Along the Pacific Latin American margin, normal continental margin subduction occurred continuously since the Jurassic in two locations. This has resulted in the two longest continuous slabs on Earth, whereby the slabs reach depths of ~2500 km. These slabs are separated by a more complex Caribbean slab configuration. As the Americas were drifting westwards since at least the Jurassic, the Caribbean plate stayed relatively fixed in the paleo-Pacific, bounded by intra-oceanic subduction zones on both western and eastern ends. The arrival of spreading ridges along the continental margin subduction zone, resulted in slab windows in the upper mantle. Towards southern Patagonia, the Nazca-Aluk/Pacific ridge also resulted in a slab window. Southward migration of this ridge over time, resulted in a progressively shallowing slab. At greater depths, the earliest phase of continental margin subduction is connected to the Permo-Triassic Cape orogeny and associated flat-slab subduction along the southern Gondwanide margin.

With tomographic depth slices from core to crust, I will show a chronological overview of subduction across Latin America, which provides fundamental insights into the tectono-stratigraphic history of the Pacific Latin American margin.

**3.II The Overlooked Mollendo Basin in Offshore Southern Peru: Is There a Working Petroleum System?**

Alejandro Quispe[1] (presenter), Diego Timoteo[2], Fritz Palacios[2], Luis Pairazaman[2]; [1]Perupetro S.A., [2]Hound Exploration S.A.C.

The offshore exploratory activities in Peru have been focused on the central exploratory province for the last decade, overlooking the southern region. We herein assess for the petroleum system elements in the central-south portion of Mollendo Basin by the integration of regional 2D seismic data, stratigraphic sections, and geochemical data from onshore outcrops.

The sedimentary record of Mollendo Basin ranges from Paleozoic to Cenozoic; nevertheless, none of these units have been drilled in offshore. The potential source rocks in the basin consist of black shales and limestones of the Ambo Group and Socosani Formation, respectively. These rocks spread over coastal outcrops, showing 0.5-1.0 wt% of TOC values, and they could be preserved into the Pre-Cenozoic grabens.

The potential reservoirs rocks have been identified in the entire Cenozoic sequence, as sandstones related to channel systems filling submarine canyons. One best modern analogue corresponds to the deep-water submarine canyon system currently active in the basin. Mollendo basin preserves the geological history developed during two marked tectonic settings: (i) the pre-Andean domain and (ii) the Andean Orogeny domain, which have generated a variety structural, stratigraphic and mixed traps.

Based on these evidences, two new hypothetical petroleum systems are proposed: Carboniferous Ambo-Cenozoic (.), and Jurassic Socosani-Cenozoic (.).

This remote frontier basin needs a visionary exploratory effort nowadays because of the implementation of the southern gas pipeline in the next five years. These future surface facilities will connect the Ilo and Mollendo Ports, in front of the basin, turning the overlooked southern region into a new challenging area for hydrocarbon exploration in offshore of southern Peru.

**3.III Petroleum Systems Evidence and Exploration Opportunities in the Peruvian Offshore Frontier Areas (Salaverry and Pisco Basins)**

Kiko Valencia, Independent Consulting Geologist

The Cenozoic forearc sedimentary basins of the central Peruvian offshore have been defined along two NW-SE direction trends limited by two major structural elements. One corresponds to the offshore extension of the Coastal Range called Outer Shelf High and the other to a high located on the slope, called Upper Slope Ridge. These Cenozoic basins are overlapping, in a regional portion, on another Mesozoic-age basin, defined and called as the Peruvian Continental Margin basin that evolved in a tectonic context associated with the evolution of a volcanic arc of this continental margin, which is active at least since the Upper Jurassic.

The tectonic and sedimentary evolution of this area has been studied using structural sections from 2D / 3D seismic information and regional geology, which shows different events that, controlled the deposition, as well as the deformation and erosion of the sedimentary column; where the presence of more than one active Petroleum Systems have been evidenced, through the identification of several oil seeps on the sea surface and micro seeps data in piston cores from

the seabed, whose initial geochemical analyzes indicate the presence of potential Mesozoic source rocks.

Likewise, the interpretation of seismic acquired in the last decade shows the presence of several exploratory Plays, interesting from the point of view of hydrocarbons prospecting related to those source rocks, as a product of the geological processes that occurred throughout the Mesozoic and Cenozoic.

Some prospective traps, representative of several Plays identified, represent very interesting exploration opportunities to medium and even short term for exploratory drilling since they have interpretations based on 3D seismic, regional geology and the petroleum systems integrated analysis.

**3.IV Hunting for the First Play Opener in Salaverry Basin, Offshore Central Peru**

Diego Timoteo[1] (presenter), Fritz Palacios[1], Alejandro Quispe[2]; [1]Hound Exploration, S.A.C., [2]Perupetro S.A.

The forearc Talara, Sechura and Tumbes Basins constitute the northwest petroliferous province of Peru, which is one of the only three forearc regions with highest oil and gas production in the world. Exploration and production for over 150 years in this province have encouraged the exploration toward central Peru where the offshore Trujillo, Salaverry, Lima and Pisco Basins have been the focus of exploration efforts for the last 25 years, with no wells drilled since 1999.

We present herein a play assessment for Pre-Mesozoic, Mesozoic and Cenozoic sequences in an area of 12,000 km2 in the offshore Salaverry Basin. Well data and 2D/3D seismic surveys were the basis of our seismic stratigraphic and seismic geomorphological analysis to identify new plays and reduce the reservoir risk therein.

Nine exploratory plays have been identified in areas where analyzed oil seeps suggest at least one active petroleum system. Each play presents a variety potential clastic and naturally-fractured reservoirs with their correspondent seals. The plays also vary with the paleogeography and tectonics along the studied area forming structural, stratigraphic, and mixed traps. The most attractive targets contain stacked plays, increasing the chance of success in the basin.

Economic investment for offshore drilling in central Peru is high and requires extraordinary efforts to reduce the exploratory risk, so follow-up assessments are essential to mature prospects from the nine plays. In the future, one of them could become the first play opener in the offshore central Peru turning Salaverry Basin into a new energy hub for the region.

**3.V Tumaco Basin: Exploratory Insights from Basin Modeling and Sequence Stratigraphy**

Roberto Aguilera, RA Geologia E.U.

The Tumaco Basin is a frontier basin at the southern end of the Colombian Pacific Margin. In order to evaluate its prospectivity potential a regional study involving the existing seismic and wells data following a sequence stratigraphy scheme has been carried out, along with basin modeling of the known depocenters.Such analysis shows the development of two contrasting tectonic environments on both sides of the crest of the active margin accretionary prism, with the development of a forearc basin on the onshore part that are characterized by deep depocentres

filled with thick sequences of sediments, the product of a continuous subsidence since the Late Cretaceous, that gives rise to continuity and conformity of the seismic sequences, suggesting a balance between sedimentation and subsidence rates that have not allowed a rapid advance of progradational environments towards the west of the basin but in recent times (Late Miocene to the present).While the offshore tectonic accretionary environment in a shelf slope setting, in which progressive uplift due to the accretion of material on the margin, favors the cooling of the sedimentary succession, and its intense deformation affects the integrity of the prospective structures.Basin modeling of the onshore depocenters calibrated with the existing wells and seismic interpretation shows that in this depocenters its likely the generation of hydrocarbons and the low structural deformation and sedimentary environments, indicates that the most likely entrapment mechanisms might be associated to stratigraphic traps to the margins of the basin. In the offshore part of the basin the depocenters are more areally restricted, have a lower development and are continuously uplifted by the accretion along the margin.

**3.VI Chronostratigraphic Control and Evolution of the Southern East Pisco Basin (Peruvian Continental Margin from the Late Miocene to the Present**

Diana Ochoa[1], Thomas DeVries[2], Kelly Quispe[1], Rodolfo Salas-Gismondi[1,3], Matthieu Carré[1,4]; [1]Universidad Peruana Cayetano Heredia, [2]University of Washington, [3]Museo de Historia Natural-Universidad Nacional Mayor de San Marcos, [4]CNRS-IRD

Chronostratigraphic frameworks from forearc basins are key for understanding how basins react to eustasy and tectonics during plate convergence. Unfortunately, these sequences are often shorter and more fragmented than those from retroarc and foreland Andean basins, and so building reliable spatiotemporal frames can be challenging.

The East Pisco Basin (EPB) is a forearc basin located in the Peruvian continental shelf (12-15ºS), where it extends for more than 300 km. Towards the south, it gradually shallows as basement rocks from the Coastal Cordillera shoal, forcing the accumulation of disconnected and perched sequences. Herein, we review the uplifted and exposed record from the southern EPB (Sacaco sub-basin). We update the late Miocene-Pleistocene chronostratigraphic framework by integrating new radiometric ages and biostratigraphic data from the Pisco, Caracoles, and Pongo formations. Detrital-zircon populations show a major provenance change at ~6 Ma, likely linked to a paleogeographic shift. Three unconformities related to a tectonic event (4.5-2.7 Ma) and fourth-cycle order eustatic cycles (~6.3-6.0 Ma, ~1.8 Ma) were also identified. Sedimentary and stratigraphic architecture indicate the presence of, at least, two active depocenters in the EPB since the late Miocene (~11 Ma). The northern one corresponds with an extended accumulation zone where mid-grain sandstones and diatom-rich deposits were chiefly stored since the Eocene. The southern depocenter comprises a much smaller accumulation area receiving mainly sand-sized clastic sediments since the late Miocene. Development of this temporal frame allow us to place into context the most complete late Miocene-Pleistocene fossiliferous record existing from the Peruvian Pacific coast.

## SESSION IV: STRATIGRAPHY & SEDIMENTOLOGY

**4.I Stratigraphy and Tectonics Along Coastal Southernmost Peru (15.6°S–18.3°S)**

Thierry P.A. Sempere, Independent Consulting Geologist

A detailed knowledge of the geological record exposed along coastal southernmost Peru is crucial for the assessment and exploration of the adjacent offshore area (Figs. 1, 2, 3).

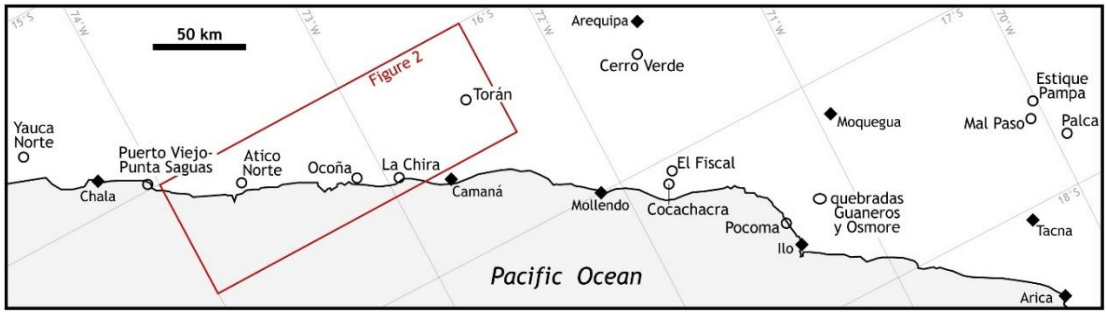


Figure 1. Location of the main localities relevant to the Yamayo Group in southernmost Peru (open circles). The red rectangle locates the area displayed in Figure 2. The La Mina locality in the Paracas peninsula lies ~310 km NW of Chala, outside this map.

The dominantly ~1 Ga-old metamorphic basement was exhumed as core complexes in several extensional steps, starting in the mid-Carboniferous. Low-angle detachments faults and related hangingwall and footwall deformation are well exposed (Fig. 4). These core complexes, traditionally referred to as the Arequipa "massif" as a whole, consist of high-grade metamorphites (mainly Grenvillian-age migmatites) and mid-Ordovician granites (Martignole & Martelat, 2003; Loewy et al., 2003, 2004; Casquet et al., 2010). They are overlain, generally through a detachment fault, by the Yamayo Group (Bellido & Guevara, 1963), a >2 km-thick sedimentary unit ranging from the mid-Carboniferous to the Late Triassic and representing forearc deposits that include potential source-rocks, reservoirs, and seals (Sempere et al., 2013; Figs. 1, 2, 3).

The Yamayo Group crops out in many areas along the forearc of southern Peru (Fig. 1). It consists of a mostly sedimentary unit that overlies the basement (the contact is generally a detachment) and is sharply to rapidly overlain by the dominantly volcanic Chocolate Formation (Fig. 3). Its thickness varies from 0 (near Cerro Verde; Fig. 1) to >2.5 km (in several coastal areas). The Yamayo includes continental and marine deposits, the latter apparently increasing in proportion toward the SW, where they dominantly consist of dark siltstones and shales (and locally include some bedded or massive chert). Marine deposits grade upward and NE-ward into shallow-marine and fine to locally very coarse alluvial clastics, which apparently prograded toward the SW.

U-Pb ages on detrital zircons (Boekhout et al., 2013) and a number of paleontological data (reviewed by Sempere et al., 2013) converge to indicate that the Yamayo Group was deposited at least from ~330 (mid-Carboniferous) to ~220 Ma (Late Triassic). Although it spans a ≥110 Myr-long interval, the Yamayo apparently displays no major internal unconformity or hiatus, at least in several sections. The Yamayo Group thus represents a time-equivalent of the large stratigraphic set formed by the Ambo, Tarma, Copacabana and Mitu 'groups' of central Peru. It displays however quite different facies, in particular due to the scarcity of carbonates and the existence of deeper-marine deposits (thick dark shales; stratified chert); south of Lima, the attractive source-rocks assigned by oil companies to the Ambo Formation/Group occur in the Carboniferous portion of the Yamayo Group.

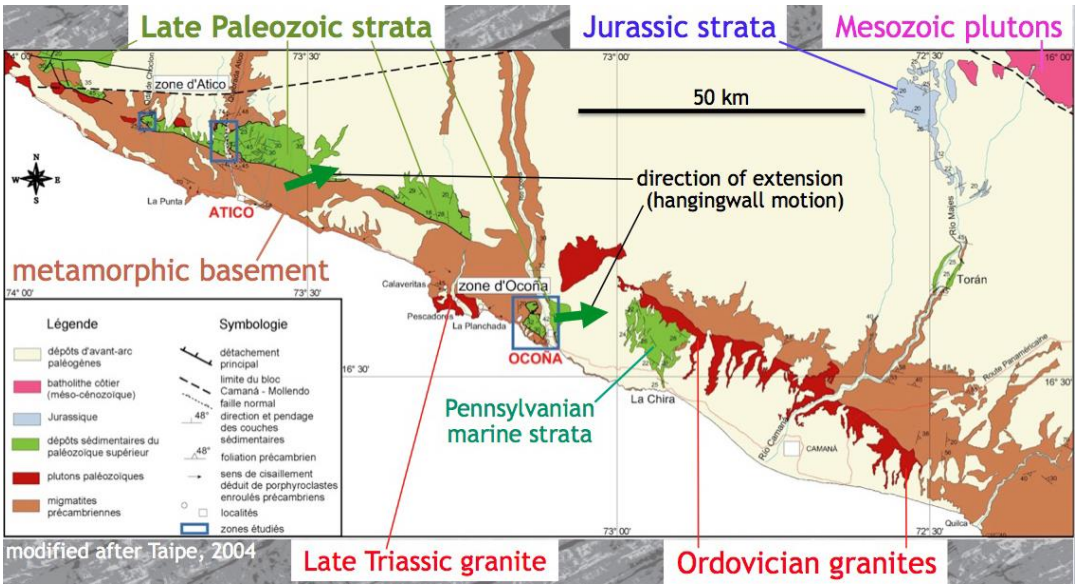


Figure 2. Simplified geological map of southern Peru between 16.0 and 16.7°S, and 72.3 and 74.0°W. See location in Figure 1.

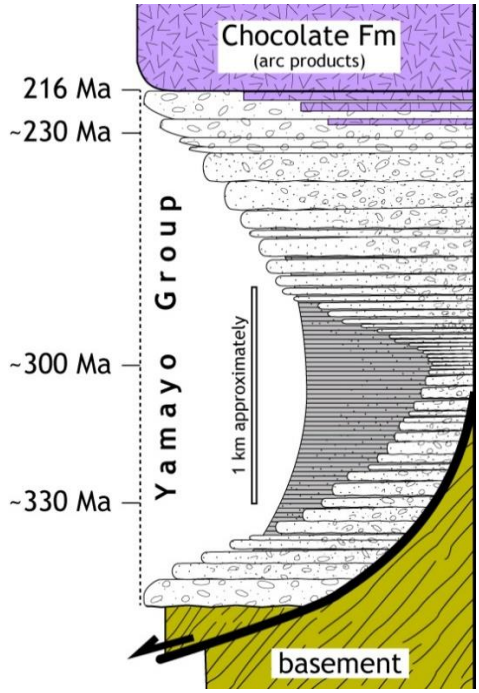


Figure 3. Schematic synthetic log integrating sedimentological observations and stratigraphic relationships relevant to the Yamayo Group over coastal southernmost Peru (Fig. 1). See Sempere et al. (2013) for details.

Regional considerations suggest that the Yamayo Group was deposited along the forearc basin of the coeval Andean arc (based on its reconstructed position by Mišković et al., 2009) while the margin was submitted to a protracted extensional evolution, as inferred from a number of compelling field observations (Taipe, 2004) and diverse geochronological data (e.g., Wipf, 2006; Noury et al., 2017; Sempere, unpublished). Consistent with the structural and stratigraphic data,

the latter indicate that large portions of the basement were cooled during a long interval ranging from the Late Carboniferous to the Late Triassic. This marked extensional tectonic evolution is reflected by the fact that the contact of the Yamayo Group with the basement is generally a low-angle detachment (Fig. 4), or at least a normal fault. Extensional structures have undergone no detectable tectonic inversion during the subsequent Andean evolution (a ~100 m-offset reverse motion of Miocene age is however documented in one case inland, a few km south of Torán [see Figure 1 for location]).


Figure 4. The spectacular Ocoña detachment (Fig. 2) dips 10-15° to the east and separates deformed Late Paleozoic sediments (above it) from the Grenvillian metamorphic basement (below it).

The Yamayo Group is overlain by the Chocolate Formation (Fig. 3), which consists of a variety of stratified arc products, ranging diachroneously from the Late Triassic to the Early Cretaceous. In the Late Jurassic the main arc migrated to the SW into the area now offshore but made a U-turn at some time between 150 and 110 Ma; the related plutons may be identified in seismic lines, allowing to estimate which areas are expected to have been heated by the arc activity.

A major unconformity must have developed between 60 and ~50 Ma when the arc underwent gravitational (extensional) collapse along the onshore Arequipa belt. However, no mid-Cretaceous to Eocene deposits are currently cropping out along the coastal strip considered here; the earliest known Cenozoic deposits seem to be of Late Oligocene age.

Significant coastal uplift started ~24 Ma ago due to the onset of major crustal thickening along the coeval arc, triggering the erosional shaping of the main coastal cliff, as well as the incision of the few rivers that were able to flow into the Pacific ocean (namely, the present-day Chala, Chaparra, Camaná, and Tambo rivers), which built deltas at their mouths during the Neogene. A wealth of multidisciplinary and regional data makes that the Neogene uplift/subsidence history is reasonably well understood along the area considered here.

The observed deformation is almost exclusively extensional (some local, recent effects of the Nazca Ridge subduction, and the minor case mentioned above near Torán, however exist). This widespread extension developed both parallel and perpendicular to the present-day trench (Noury et al., 2016, 2017).

Because dark shales and coarse sandstones of the Yamayo Group are inferred to extend offshore, as well as markedly extensional structures, the so-called Mollendo basin presents interest for hydrocarbon exploration. Furthermore, Mesozoic and Cenozoic sedimentary deposits are also expected to exist in offshore areas sufficiently away from the present-day coastline; however, their location and characteristics cannot be deduced from the geology cropping out onshore.

Acknowledgments
I thank Prof. Javier Jacay (Universidad Nacional Mayor de San Marcos, Lima) for early collaborations and fruitful discussions, as well as many colleagues and students from the years 2000–2015, who are however too numerous to be listed here.

References

Angiolini, L., Racheboeuf, P.R., Villarroel, C.A., Concha, A.E. 2003. Stratigraphy and brachiopod fauna of the Carboniferous El Imán Formation, Colombia. Revista Española de Paleontología, v. 18, p. 143–158.

Bellido, E., Guevara, C. 1963. Geología de los cuadrángulos de Punta de Bombón y Clemesí. Boletín de la Carta Geológica Nacional, v. 5.

Bellido, E., Narváez, S. 1960. Geología del cuadrángulo de Atico. Boletín de la Carta Geológica Nacional, v. 2.

Boekhout, F., Spikings, R., Sempere, T., Chiaradia, M., Ulianov, A., Schaltegger, U. 2012. Mesozoic arc magmatism along the southern Peruvian margin during Gondwana breakup and dispersal. Lithos, v. 146, p. 48–64.

Boekhout, F., Sempere, T., Spikings, R., Schaltegger, U. 2013. Late Paleozoic to Jurassic chronostratigraphy of coastal southern Peru: Temporal evolution of sedimentation along an active margin. Journal of South American Earth Sciences, v. 47, p. 179–200.

Boucot, A.J., Isaacson, P.E., Laubacher, G. 1980. An early Devonian, Eastern Americas realm faunule from the coast of southern Peru. Journal of Paleontology, v. 54, p. 359–365.

Casquet, C., Fanning, C.M., Galindo, C., Pankhurst, R.J., Rapela, C.W., Torres, P. 2010. The Arequipa Massif of Peru: New SHRIMP and isotope constraints on a Paleoproterozoic inlier in the Grenvillian orogen. Journal of South American Earth Sciences, v. 29, p. 128–142.

Chacaltana, C., Cerrón, F., Valencia, M. 2002. Nuevas evidencias devonianas en sedimentitas de la Cordillera Occidental (SO del Perú) con ocurrencia de Phacops (Trilobita) y Acrospirifer (Brachiopoda) y su implicancia en el análisis sedimentario y tectonoambiental. Boletín de la Sociedad Geológica del Perú, v. 94, p. 5-16.

Iannuzzi, R., Pfefferkorn, H.W. 2002. A pre-glacial, warm-temperate floral belt in Gondwana (Late Visean, Early Carboniferous). Palaios v. 17, p. 571-–590.

Jenks, W.F. 1948. Geología de la hoja de Arequipa al 200,000. Boletín del Instituto Geológico del Perú, v. 9.

Loewy, S.L., Connelly, J.N., Dalziel, I.W.D., Gower, C.F. 2003. Eastern Laurentia in Rodinia: constraints from whole-rock Pb and U/Pb geochronology. Tectonophysics, v. 375, p. 169–197.

Loewy, S.L., Connelly, J.N., Dalziel, I.W.D. 2004. An orphaned block: the Arequipa–Antofalla basement of the Central Andean margin of South America. Geological Society of America Bulletin, v. 116, p. 171–187.

Martignole, J., Martelat, J.-E. 2003. Regional-scale Grenvillian-age UHT metamorphism in the Mollendo-Camaná block (basement of the Peruvian Andes). Journal of Metamorphic Geology, v. 21, p. 99–120.

Mišković, A., Spikings, R.A., Chew, D.M., Kosler, J., Ulianov, A., Schaltegger, U. 2009. Tectonomagmatic evolution of Western Amazonia: Geochemical characterization and zircon U-Pb geochronologic contraints from the Peruvian Eastern Cordilleran granitoids. Geological Society of America Bulletin, v. 121, p. 1298–1324.

Morales, G. 1997. Nuevos datos geocronológicos y bioestratigráficos del macizo antiguo de Arequipa. Actas, IX Congreso Peruano de Geología, p. 365–369.

Murray, G.E., Furnish, W.M, Carrillo, J. 1960. Carboniferous goniatites from Caballeros Canyon, State of Tamaulipas, Mexico. Journal of Paleontology, v. 34, p. 731–737.

Narváez, S. 1964. Geología de los cuadrángulos de Ilo y Locumba. Boletín de la Carta Geológ. Nacional, v. 7.

Noury, M., Bernet, M., Schildgen, T.F., Simon-Labric, T., Philippon, M., Sempere, T. 2016. Crustal-scale block tilting during Andean trench-parallel extension: Structural and geo-thermochronological insights. Tectonics, v. 35 : doi:10.1002/2016TC004231.

Noury, M., Philippon, M., Bernet, M., Paquette, J.-L., Sempere, T. 2017. Geological record of flat slab–induced extension in the southern Peruvian forearc. Geology, v. 45, p. 723–726.

Olchauski, L.E. 1980. Geología de los cuadrángulos de Jaqui, Coracora, Chala y Chaparra. Boletín del INGEMMET, v. 34 (A).

Paredes, J. 1964. Estratigrafia del Paleozoico en la costa del Departamento de Arequipa. Arequipa, Universidad Nacional de San Agustín, tesis de grado, 110 p.

Pecho, V., Morales, G. 1969. Geología de los cuadrángulos de Camaná y La Yesera. Boletín de la Carta Geológica Nacional, v. 21.

Pino, A., Sempere, T., Jacay, J., Fornari, M. 2004. Estratigrafia, paleogeografia y paleotectónica del intervalo Paleozoico superior - Cretáceo inferior en el área de Mal Paso - Palca (Tacna). In: J. Jacay & T. Sempere (eds.), Nuevas contribuciones del IRD y sus contrapartes al conocimiento geologico del sur del Peru, Sociedad Geológica del Perú, Publicación especial nº 5, p. 15–44.

Reimann, C.R., Bahlburg, H., Kooijman, E., Berndt, J., Gerdes, A., Carlotto, V., López, S. 2010. Geodynamic evolution of the Early Paleozoic Western Gondwana margin 14°–17°S reflected by the detritus of the Devonian and Ordovician basins of southern Peru and northern Bolivia. Gondwana Research, v. 18, p. 370–384.

Salinas, E. 1985. Evolución paleogeográfica del sur del Perú a la luz de los métodos de análisis sedimentológicos de las series del departamento de Tacna. Arequipa, Universidad Nacional San Agustín, tesis de grado, 205 p.

Sempere, T., Boekhout, F., Noury, M., Taipe, E., García, F., Jacay, J., Spikings, R.A., Schaltegger, U. 2013. Reinstauración del Grupo Yamayo (Bellido y Guevara, 1963) y su significado en la evolución de la margen peruana del Carbonífero al Triásico. Boletín de la Sociedad Geológica del Perú, v. 108, p. 227-231.

Taipe, E. 2004. Détachements en extension et sédimentation: les bassins pennsylvaniens d´Atico et Ocoña (sud-Pérou). Toulouse, Université Paul-Sabatier, mémoire de DEA, 38 p.

Wilson, J.J., García, W. 1962. Geología de los cuadrángulos de Pachía y Palca. Boletín de la Carta Geológica Nacional, v. 4.

Wipf, M. 2006. Evolution of the Western Cordillera and coastal margin of Peru: Evidence from low-temperature thermochronology and geomorphology. ETH Zurich, Ph.D. dissertation n° 16383, 152 p.

## 4.II Effects of Local Basin Analysis Evolution on Anatomy of Sedimentological Morphology and Dynamics for the Delivery of Mud to Deep-Water Environments Characteristics- Pleistocene Gulf of Guayaquil (Ecuador)

Afsoon Kazerouni, Bemidji State University, Center for Sustainability Studies

Topographical and structural evolution of orogenic plateaus plays a significant role to study the impacts on atmospheric circulation patterns for evolution of the Gulf of Guayaquil (Ecuador), where the amount and distribution of rainfall, caused surface processes variations in sediment record.

The study area consists of various sediment accumulation of the Esperanza and Jambelí basins mainly composed of carbonate and clastic deposits, forming under consistent oceanographic and atmospheric conditions. Hence, by exploring a sediment type system, in which the boundary conditions and hydrodynamics contrast with many previously documented systems, this study aims to provide new insights into the fundamental controls on morphology and dynamics of the Pliocene-Pleistocene marine sequences (Lower and Upper Puná formations) that were deposited in an inner platform environment. The Jambelí detachment system (JDS) and the associated Jambelí basin documented here are characterized by a complex array of old (pre-Quaternary) and recent structures. The results suggested that the flux and deposition of carbonates in the periplatform environment are variable on a temporal and seasonal scale, where a relatively minor proportion of bank-derived components is deposited during calm, storm-free periods, with the

balance delivered during the channel of recurrent, low-amplitude seasonal storms and occasional hurricanes. With the Holocene rise of sea level, sediments have been flooded and tidal currents pass through, causing decrease of the coarse clastic supply, favouring the onset of a carbonate system.This proves that the decreased sedimentation rates of glacial intervals preserved during Holocene/ Pleistocene formed by reduction of sediment input during glacial low stands when banks are exposed to rainfall and produce lower amount of sediment.

**4.III Miocene Turbiditic Successions of the San Juan Sub-basin, Potential Reservoir and Seal Rocks in the Colombian Pacific Active Margin**

Carlos Rey[1], Juan Patiño[2], Jaime Reyes-Abril[2] (presenter), Freddy Corredor[3]; [1]ANH Colombia, [2]Servigecol, [3]GeoStrAp

The Chocó Basin of the Colombian Pacific active margin is divided into the Atrato and San Juan sub-basins. The stratigraphy of the San Juan Sub-basin has been extrapolated from stratigraphic reviews and geophysical interpretations of what is known as the Istmina-Condoto high that estimate at least 3,750 meters of Paleocene to Pliocene lithostratigraphic units with stratigraphic hiatuses between the Paleocene and the Eocene sequences, and Oligocene and Upper Miocene sequences. These general studies and regional geologic maps do not allow to evaluate in detail elements of the petroleum system in these sub-basins.

We present the results of a detailed field mapping campaign with emphasis in the sedimentological, stratigraphic and structural data descriptions of Miocene stratigraphic sections. The total thickness measured in five sections of the Condoto Formation and La Mojarra Conglomerates totals 2,735 m. The described facies and facies associations allow the interpretation of upper continental slope and submarine fans depositional environments. Micropaleontological analysis let to the interpretation of a Middle Miocene (Tortonian) to Late Miocene (Langhian to Middle Serravallian) age for the Condoto Formation, and Upper Middle Miocene to Late Miocene for the La Mojarra Conglomerates. The massive sands and conglomerate packages of these two stratigaphic units are interpreted to be good reservoirs, while the muddy sequences to be good seal rocks in this Sub-basin. The seismic interpretation of these sequences results in further understanding of the regional distribution and evolution of the Colombian Pacific basins.

**4.IV Zircon Geochronology and Morphology to Decode the Evolution of Arequipa-Tarapacá Basin During the Middle Jurassic To Lower Cretaceous**

Angel Carlos Salas Colca, Universidad Nacional Daniel Alcides Carrión

Afterwards of disaggregation of Pangaea in Mesozoic, in the western margin of Gondwanaland, the extensional Arequipa-Tarapacá basin took place; this basin registered the nearly beginning of the Andean Orogeny, the litostratigraphic unit: Yura Group, Jurassic – lower Cretacic, represents a transition from a shallow marine to continental environment. Zircon geochronology and morphology from sandstones in southern Peru give us a reliable tool to reconstructing the tectonic setting, sediment provenance and paleogeography. Kernel Density Estimation of zircon geochronology in Cachíos, Labra and Hualhuani Formations (Yura Group) have the same pattern of ages, they point out the first peak in the Pampean Orogeny (500 – 700 Ma), the second peak is in the Sunsas-Greenvilian Orogeny (900 – 1200 Ma) and the rest of the ages are older than 1200 Ma. Morphology of zircon was studied under petrographic microscope, most of zircons rounded forms (80 – 90%) and the remaining have prismatic habits. The ages between 500 and 700 Ma do not

have an obvious source, except in Sierras Pampeanas at Argentina (this ages are plenty in many sedimentary rocks of Peru mainly in the lower cretaceous, hence it is correlated with the Marañón Massif; the ages between the 900 and 1200 Ma come from two sources, the outcrops of Arequipa Massif and the recycling of Paleozoic sedimentary rocks, the ages older than 1200 Ma are also from recycling of sedimentary rocks, this recycling is checked with the morphology of zircon mostly rounded, and finally the absence of Andean ages point out that the volcanic arc was absent probably due to flat slab subduction.

**4.VI The Identification and Implications of Large-Scale Clinoforms in the Austral-Magallanes Basin Outcrop Belt, Southern Chile**

Stephen Hubbard (presenter), Ben Daniels, Tom Peploe, University of Calgary; Brian Romans, Virginia Tech; Lisa Stright, Colorado State; Erin Pemberton, ConocoPhillips

Clinoforms with >1000 m of relief that are at least 40 km long crop-out in the Magallanes Basin of southern Chile, recording the axial filling of a deep-water foreland during the Late Cretaceous. Fluvial- and wave-influenced deltaic deposits represent the upper, flat portions of the sigmoidal slope profiles (topset strata). Mudstone, siltstone, and a notable paucity of sandstone generally characterize upper- to lower-slope units (foreset to bottomset strata). However, punctuated delivery of coarse-grained sediment off the shelf edge is evident from channelized bodies composed of conglomerate lags and thick sandstone units. The clinoform-dominated stratigraphic architecture, scale and facies of the outcrop belt have been shown to share many analogous attributes with other deep-water foreland basins, as well as continental margin strata from around the world.

This presentation will focus on the results of more than a decade of research in the Chilean outcrop belt, including facies characteristics and their distributions, geometrical characterization of reservoir-scale bodies, auto- and allo-genic controls on clinoform development (e.g., sediment supply, antecedent topography), and synthetic seismic responses of various portions of the immense outcrop belt. Overall, the outcrop belt provides a unique opportunity to investigate the entirety of well-exposed shelf, slope to basin floor sediment routing systems.

## SPECIAL PRESENTATIONS

**SP.I Exploration Opportunities in Northwest and Offshore Peru**

Eris Gabriel, Exploration Manager, PeruPetro

No abstract provided

**SP.II Acquiring Information for Understanding Colombia's Pacific Basins**

Carlos Rodríguez Taborda, Technical Vice President, ANH Colombia

No abstract provided

# BIOGRAPHICAL SKETCHES

## SESSION I: STRUCTURAL GEOLOGY & TECTONICS

**Convener: Freddy Corredor, GeoStrAp, Colombia**
Freddy is a geologist, explorationist and entrepreneur with over 25 years of experience in the oil and gas industry. He holds a BSc in geology from the National University of Colombia, a MSc degree in geology from the University of Colorado at Boulder and a PhD candidacy in Earth and Planetary Sciences from Harvard University.

He started his career with Occidental Oil and Gas in Colombia where he led the discovery of the 100 MMBOE Gibraltar Field, now operated by the NOC Ecopetrol. In 1998 he moved to the U.S. and during that time he held internship positions with Oxy, Chevron, BP and Shell. In 2004 he joined Shell E&P Company in New Orleans as senior structural geologist for the GOM assets.

In 2006 he returned to Colombia where he has held various executive positions including Founder and Director at GeoStrAp SAS; Director of New Ventures Latin America at Casa Exploration LLC; Exploration Manager of Vetra E&P Colombia; and Executive VP Exploration at Amerisur Resources.

**Yi-Wei Chen, University of Houston**
Yi-Wei is a PhD candidate at the University of Houston.

**Pablo Sebastian González Godoy, Universidad Andres Bello**
Pablo earned a BSc from the Universidad Andres Bello at Quilpue, Chile.

**Daniel Peña, Repsol**
Daniel is a Geological Engineer with 14 years of experience in the industry. He currently works at Repsol Services Co. at The Woodlands, Texas, as Senior Exploration Geoscientist, working in Mexico projects (Burgos Basin and Mexican Ridges – Offshore Area).

Daniel is a member of AAPG and SGP.

**Carlos Llerena, Savia Peru S.A.**
Carlos is a Geological Engineer from the National University of San Agustin, with 10 years of experience in the industry. He currently works at Savia Peru, at Lima/Talara, Peru, as Senior Geologist, where he develops exploration and reservoir geology activities.

Carlos is a member of AAPG, SEPM and SPE.

**Carlos Aizprua, Norwegian University of Science and Technology, University of Lille**
Carlos earned a MSc and currently has 12 years of experience in the industry. He is Principal Geologist at Equinor, Norway, where is responsible for reservoir characterization of pre-salt carbonates in Brazil. Previously, he worked in companies as Total and BakerHughes.

Carlos is a member of AAPG.

## SESSION II: GEOPHYSICAL METHODS & INTERPRETATION

**Convener: Karyna Rodríguez, Searcher, United Kingdom**
Karyna earned a BS and a MSc in Geology from the Oxford University and a MSc in Stratigraphy from the University College London.

With 31 years of experience in the industry, Karyna is VP Global New Ventures at Searcher, UK, where she is responsible for developing and managing Searcher projects which support energy companies's ongoing and future energy exploration campaigns. She previously worked in companies as British Gas, PEMEX, Apache, Pioneer.

Her professional affiliations include AAPG, EAGE, PESGB, London Geological Society.

**Eloi Carola, CGG GeoSpec**
Eloi earned a PhD from the University of Barcelona.

With 6 years of experience in the industry, Eloi is Senior Geologist at CGG GeoSpec at Llandudno, UK, where he works as seismic interpreter. Previously, he was Exploration Geologist at Gas Natural Fenosa.

His professional affiliations include AAPG and AGGEP.

**Karyna Rodríguez, Searcher, United Kingdom**
Karyna earned a BS and a MSc in Geology from the Oxford University and a MSc in Stratigraphy from the University College London.

With 31 years of experience in the industry, Karyna is VP Global New Ventures at Searcher, UK, where she is responsible for developing and managing Searcher projects which support energy companies's ongoing and future energy exploration campaigns. She previously worked in companies as British Gas, PEMEX, Apache, Pioneer.

Her professional affiliations include AAPG, EAGE, PESGB, London Geological Society.

**Roberto Ruiz, PGS**
Roberto is a Geophysical Engineer from the Universidad Central de Venezuela.

With 10 years of experience in the industry, he works at PGS, UK as Project Geoscientist part of the Quantitative Interpretation team, where his main responsibilities are undertaking technical work related to the development and application of methodologies for comprehensive rock physics analysis and studies, reservoir characterization and rock properties prediction. He previously worked at PDVSA, ARK CLS and Rock Solid Images.

He is a member of EAGE and SEG.

**Edgar Borda, Energy Resources Consulting (Eresources)**
Edgar earned a MSc in Regional Geology and Tectonics from San Marcos National University (UNMSM) and a Micromaster in Project Management from Rochester Institute of Technology (RIT).

With 25 years of experience, he is General Manager at Energy Resources Consulting (Eresources) in Lima, Peru, where he conducts and develops exploration and development studies in the energy industry. His previous experience includes exploration and development of oil and gas assets with international reach for major and independent companies as Savia Peru, Fairways Offshore Exploration, Shell and Petro-Tech Peruana.

Edgar is a member of SEG and SGP.

**Lila Bishop, University of Houston**
Lila earned a MSc in Geology from the University of Houston. With 1 year of experience, she works as Research Assistant at the same university, where she interpretates seismic and structural 2D seismic data.

## SESSION III: REGIONAL GEOLOGY AND BASIN ANALYSIS

**Convener: Alejandro Chalco, Exploration Geologist, Peru**
Alejandro earned a MSc in Petroleum Geology form the University of Aberdeen.

With more than 30 years of experience, Alejandro is an oil explorer expert in designing and leading exploration programs and adding value to the exploration portfolio in Peru and Colombia. He has proven record discovering and delineating new fields. Former employee at Cepsa, Pluspetrol, Enterprise Oil and Occidental.

He is a member of AAPG and SGP.

**Douwe G. van der Meer, CNOOC International**
Douwe van der Meer is a geophysicist by background and a subject matter expert in plate tectonic processes and tectono-stratigraphic evolution of basins.

Following his graduation as MSc. at the tectonophysics group of Utrecht University in 2002, he continued research on mantle structure in parallel to his oil industry career. After a sabbatical at the geodynamics group at the Norwegian Geological Survey in Trondheim in 2009, publications followed on global subduction and causal effects on earth's climate and sea level, culminating in a PhD. cum laude in 2017.

Over the past 18 years he has worked in explorationist roles in Shell, Nexen and CNOOC, based in the Netherlands, U.K. and U.S.A. Throughout his career he has been leading New Ventures teams, analyzing basins, plays and prospects for their conventional and unconventional hydrocarbon potential. As an explorationist and Earth system-enthusiast his work and research has covered all continents and time-spans from the Archean to Cenozoic. Currently he is Sr. Manager New Ventures Latin America for CNOOC.

**Alejandro Quispe, Perupetro S.A.**
Alejandro earned a MSc in Tectonic and Regional Geology from the National University of Engineering, Peru.

With 10 years of experience in the industry, he is Specialist in Evaluation of Reserves and Resources at Perupetro S.A. in Lima, Peru, where develops geological studies to promote exploration and exploitation areas of the different hydrocarbon basins of the country.

Alejandro is a member of AAPG.

**Kiko Valencia, Independent Consulting Geologist**
Kiko earned a BSc in Geological Engineer from San Antonio Abad University, Cusco, Peru, and a MSc from San Marcos University, Lima, Peru.

With 23 years of experience in the industry, he worked for 11 years at Pluspetrol Perú Corporation and for 9 years at Savia Perú S.A. He currently is independent consulting geoscientist working on hydrocarbons exploration & production projects.

Kiko is a member of AAPG, SGP, and CIP.

**Diego Timoteo, Hound Exploration, S.A.C.**

**Roberto Carlos Aguilera Vaca, RA GEOLOGIA E.U.**
Roberto is a Geologist from the Universidad Nacional de Colombia, Bogota.

His 25 years of experience in the industry includes 2 years as exploration geologist in Geopozos S.A., 3 years as freelance consultant, IHS Markit Colombia Correspondent 2010 to date and 20 years at RA GEOLOGIA E.U., where he currently is CEO-Owner, responsible for management of seismic processing, exploration and production consultancy projects, research head of machine learning applications and business research focused in the Caribbean and Northern South America (focus on Colombia, Ecuador, Perú and Bolivia).

Roberto is a member of EAGE, SPWLA, SEPM (Gulf Coast Section) and IARP.

**Diana Ochoa, Universidad Peruana Cayetano Heredia**
Diana earned a PhD from the Universidad de Salamanca, and with 5 years of experience, she is a researcher at the Universidad Peruana Cayetano Heredia, where is on charge of teaching and research analysis of geochronological and (micro)paleontological data, to define a chronostratigraphic scheme for the East Pisco Basin.

Diana is a member of TMS.

## SESSION IV: STRATIGRAPHY AND SEDIMENTOLOGY

**Convener: Andrea Ortiz, Ecopetrol S.A, Colombia**
Andrea earned a BS in Geology from the Universidad Nacional de Colombia and a PhD in Deepwater Depositional Systems from the University of Leeds.

With 16 years of experience in the industry, she is Exploration Advisor in Ecopetrol S.A. at Bogotá, Colombia, where she is responsible for technical assurance, career planning, technical standardization. Before Ecopetrol, she worked at BP (2005-2012).

Andrea is a member of AAPG, SEPM and ACGGP.

**Thierry P.A. Sempere, Independent Consulting Geologist**
Thierry is a Doctor in Geology and Engineer from the Paris School of Mines. He has 38 years of experience, and worked as researcher at ORSTOM/IRD from 1982 to 2017. He currently is independent consulting geologist at Lima, Peru. Thierry is a member of AAPG.

**Afsoon Kazerouni, Bemidji State University**

**Jaime Reyes-Abril, Servigecol**
Lorena is a Geological Engineer from the Los Andes University, Venezuela and earned a MSc in Paleontology and a PhD in Earth Sciences from Zaragoza University, Spain.

Over the past 18 years he has taught stratigraphy, paleontology, clastic sedimentology, structural geology, petroleum geology, sedimentary environments, in Los Andes University (Venezuela), Universidad Nacional (Colombia) and Los Andes University (Colombia). He has also been stratigrapher in exploration Paleozoic rocks to PDVSA E&P with Los Andes University (employer); assessor in stratigraphical, cartographical and paleontological hydrocarbon exploration projects or cartographic national projects to REMORA, ADA, ECOPETROL, ANH and SGC with GRP Ltda (employer); stratigrapher and paleontologist in hydrocarbon and paleontological national projects for Colombian Geological Service (SGC).

Currently, he is Stratigraphical and Paleontological Assessor at Servigecol LTDA, Bogota, Colombia, where is responsible for stratigraphical, cartographical and paleontological analysis, and technical representation.

**Angel Carlos Salas Colca, Universidad Nacional Daniel Alcides Carrión**
Angel is a Geological Engineer from the Universidad Nacional Daniel Alcides Carrión.

With 2 years of experience in geochronology and petrography, he is Analyst Geologist at the same university, where he is responsible for microscopical sample description.

**Stephen Hubbard, University of Calgary**
Steve Hubbard joined the faculty in the Department of Geoscience at the University of Calgary in 2006, shortly after completing his PhD at Stanford University. Prior to his PhD he obtained BSc and MSc degrees at the University of Alberta and worked as a geologist at Shell Canada.

His research, teaching, and student mentorship is focused on topics in siliciclastic sedimentology and stratigraphy, as well as applications to petroleum geology. He specializes in the processes and products of channelized depositional systems.

## CLOSING PANEL DISCUSSION

**Moderator: Pedro Alarcón, Past-President, AAPG LACR, Independent E&P Consultant**

**Carlos Rodríguez, Technical Vice President, ANH Colombia**
Carlos is a geologist from Universidad Nacional de Colombia and earned a MSc from the University of New Orleans.

With 40 years of experience in the industry, he currently is Technical Vice President at the National Hydrocarbon Agency of Colombia (ANH), where he is on charge of the improvement of the knowledge and acquisition of information for mature, emergent and frontier basins; of the evaluation of areas to be promoted by the ANH for bidding process, and leads the update of the land map.

He previously has held managerial positions at Interoil, Mansarovar and Mohave; business development for Ecopetrol; and senior geophysicist for Lasmo, Exxon and Texaco.

Carlos is a member of AAPG and ACGGP.

**Johnny Rebaza, Senior Exploration Geologist, Perupetro**

**Federico Seminario, Geological Exploration Advisor, Pluspetrol**

**Freddy Corredor, GeoStrAp, Colombia**
Freddy is a geologist, explorationist and entrepreneur with over 25 years of experience in the oil and gas industry. He holds a BSc in geology from the National University of Colombia, a MSc degree in geology from the University of Colorado at Boulder and a PhD candidacy in Earth and Planetary Sciences from Harvard University.

He started his career with Occidental Oil and Gas in Colombia where he led the discovery of the 100 MMBOE Gibraltar Field, now operated by the NOC Ecopetrol. In 1998 he moved to the U.S. and during that time he held internship positions with Oxy, Chevron, BP and Shell. In 2004 he joined Shell E&P Company in New Orleans as senior structural geologist for the GOM assets.

In 2006 he returned to Colombia where he has held various executive positions including Founder and Director at GeoStrAp SAS; Director of New Ventures Latin America at Casa Exploration LLC; Exploration Manager of Vetra E&P Colombia; and Executive VP Exploration at Amerisur Resources.

**Kiko Valencia, Independent Consulting Geologist**
Kiko earned a BSc in Geological Engineer from San Antonio Abad University, Cusco, Peru, and a MSc from San Marcos University, Lima, Peru.

With 23 years of experience in the industry, he worked for 11 years at Pluspetrol Perú Corporation and for 9 years at Savia Perú S.A. He currently is independent consulting geoscientist working on hydrocarbons exploration & production projects.

Kiko is a member of AAPG, SGP, and CIP.