# An Alternative Geodynamic Model for the Oriente-Northern Marañon Foreland Basin Petroleum System*

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## Abstract

The prolific Oriente-Northern Marañon Basin (~ 45 BBO estimated Oil in place) is part of the asymmetric foredeep portion of the present day sub-Andean foreland system. This supercharge basin is associated with the same petroleum system, the Cretaceous marine shales/limestones of the Napo-Chonta Formation. However, this source rock is either immature along the entire Oriente Basin (Ro ~ 0.3-0.6) or of poor TOC content (<1%) along the Marañon Basin. The accepted geological model associates the origin of this Cretaceous petroleum system to a hypothetical kitchen located west along the present-day Ecuadorian Interandean zone, named "Quito Kitchen", already exhumed/eroded or metamorphosed by Andean orogeny. However, this hypothesis is speculative and implies very efficient preservation and long remigration process.

A regional scale geodynamic framework combined with an extensive geochemical database, allows us to define an alternative model that can explain the origin of this rich Cretaceous petroleum system. The same proposes two major kitchens that generate oil during a distinctive stage of the Cretaceous-Cenozoic basin evolution: The first kitchen, it corresponds to a major depocenter along the south western portion of the basin, the present-day Santiago Basin, developed since upper Cretaceous time (-90 Ma) as a direct response of the late Cretaceous syn-depositional uplift of the northern Ecuadorian sub Andean zone. The generation and expulsion of hydrocarbons took place since late Paleocene-Eocene times, associated with the deposition of the early Tertiary section that records the most important subsidence event. NNE long distance migration from this paleo-basinal area was facilitated by the continuity of the late Cretaceous/early Tertiary tectonic fabric associated to the major transpressive driven inversion of NNE-SSW Triassic–Jurassic grabens which extend to the north in the Oriente Basin. The second kitchen, corresponds to the present day deepest portion of the foreland Basin. It was formed as a direct response of the Santiago Basin tectonic uplift and exhumation since late Miocene times (~10 Ma). New geochemical analysis confirms this kitchen responsible for the generation and expulsion of hydrocarbons since late Miocene, related to the deposition of the Mio-Pliocene section. The present day foreland geometry facilitated the migration of the new oils towards the east to the current forebulge position of the basin (Iquitos Arch).

## Introduction

The prolific Oriente-Northern Marañon Basin (ONMB) (~ 45 BBO estimated Oil in Place) is part of the asymmetric foredeep portion of the present day sub-Andean foreland system. Although the regional geology of the ONMB has been widely described (i.e. Tschopp, 1953; Faucher and Savoyat, 1973; Dashwood and Abbotts, 1990; Balkwill et al., 1995; White et al., 1995; Jaillard, 1995; 1997; Barragan, 1999; Christophoul, 1999; Baby et al., 2004; 2005), the origin of their oils is speculative and controversial, particularly since no regional geodynamic consideration has ever been widely taken into account, and even worse the basins and their oils have always been treated separately, as units corresponding only to their geopolitical limits.

Biomarker data along the ONMB supports multiple kitchens and pulses, and thus, several unproven hypothesis have been proposed in order to explain the origin of this rich petroleum system.

The aim of this study, therefore, is to define an alternative model that can explain its origin based on a regional-scale tectono-sedimentary and consolidate geodynamic framework that incorporates the major geological elements along the ONMB and their subandean zones, together with regional gravity information and updated geochemical data.

## Geological Setting

The ONMB consists of two physiographic-structural domains which have been independent from each other since Mio-Pliocene times (Baby et al., 2005). Its western subandean zone constitutes the wedge top depozone of the foreland basin system on the eastern edge of the Andean orogen and includes both the Santiago Basin in northern Peru, and the Napo highs in Ecuador (Figure 1). It is bounded to the east by the NNE-vergent deformation thrust front that restrained from the second domain, the vast Oriente-Marañon foredeep basin, which extends eastern to the current forebulge position of this foreland system, the Iquitos Arch.

The ONMB preserves a thick sedimentary infill ranging in age from Paleozoic to Quaternary (Tschopp, 1953; Fauchet and Savoyat, 1973; Pardo and Zúñiga, 1976; Dashwood and Abbotts, 1990) overlying a Precambrian cratonic basement. The stratigraphic column (Figure 2) can be subdivided into three main periods, each of them reflecting different sedimentary, tectonic, and magmatic characteristics, indicating distinctive geodynamic contexts:

The pre-Cretaceous series comprises Paleozoic marine sediments, Late Permian?-Triassic continental rift related deposits, early Jurassic carbonates, and Late Jurassic back-arc volcanoclastic sediments (Romeuf et al., 1997, Dashwood and Abbotts, 1990).

The Cretaceous sedimentary series was deposited. It comprises fluvial to shallow marine Aptian to Campanian deposits of the Hollin (Cushabatay) and Napo (Raya/Chonta/Vivian) Formations (White et al., 1995; Jaillard, 1994; 1997). It is characterized by cyclic sequences of limestones, shales, and sandstones deposited on a stable platform along a NW-SE depocentre and controlled by worldwide eustatic sea level fluctuations during Cretaceous time.

The Late Cretaceous -Cenozoic sedimentary series, represents the detrital section associated with the development of the true Andean foreland system (Christophoul et al., 2002).

Structurally, the Oriente-Maranon Basin is characterized by overprinted. Pre-Cretaceous compressional and extensional systems, inherited respectively from NW-SE late Paleozoic paleo-fold thrust structures and NNE-SSW Triassic paleo-rift structures have been tectonically inverted along the basin since late Cretaceous structures (Barragan et al., 2005). Nevertheless, the inverted extensional features are developed along three major oblique transpressive wrench–fault zones (Baby et al., 1999) which have deformed mainly the foreland system corresponding to the Oriente Basin and extend towards the Santiago Basin (Baby et al., 2005).

**Petroleum System**

The ONMB constitutes one of the most prolific petroleum systems of western South America. Primary reservoirs in the ONM Basin are the Cretaceous fluvio-deltaic and tide-dominated estuarine deposits of the Hollin/Cushabatay and Napo/Chonta Formations, and Basal Tena-M1/Vivian sandstones (White et al., 1995), trapped in low relief anticline structures of Cretaceous and Tertiary ages (Baby et al., 2004).

The Cretaceous Napo/Chonta-Raya shales and limestones are generally accepted to be the main source rocks for their oils. Organic matter is more marine-prone along the Oriente Basin and towards the northwestern-most part of Marañon and Santiago Basin (Type II - IIB; TOC commonly up to 3-4%) (PeruPetro, 2000; Navarro et al., 2005). It becomes terrestrial-prone and poor quality in the eastern part of the Oriente Basin and along the entire Marañon Basin (Type III, TOC of 0.5-1%) (PeruPetro, 2000).

Geohistory modeling for the Oriente-Northern Marañon Basin (1D and Pseudo-3D) was conducted regionally to determine the timing of oil generation with the ultimate goal of proving the possibility of generating kitchens within the present day foreland system. Maturity modeling was calibrated using the available geochemical data from several wells along the basin. Data from Santiago and Northern Marañon Basins is mainly from Navarro et al., (2005) and Barragan et al (1999). Geochemical data from the Oriente Basin, is mainly from Bernal (1998).

From north to southwest respectively, maturity indicators and models, suggest that this Cretaceous source rock is immature and have not reached the oil window along the present day foredeep zone of the Ecuadorian Oriente Basin (Figure 3a and Figure 3b). Nevertheless, it is evident that early mature stages in the southern part (i.e., Bobonaza, Amazonas wells) (Figure 3a) and peak of oil generation is reached in the present day deepest portion of the foredeep part of northern Marañon, the “Situche area” (Figure 3b), and in the Santiago Basin (Figure 3c). The latter is attained in two different stages according to the geodynamic history of the basins. Maturity modeling indicates that along the Santiago Basin the Napo/Chonta source rock reached oil generation maturity in the Paleocene-early Eocene. However, for the Situche area, northwestern Marañon, the Napo/Chonta shales reached oil generation since late Miocene times (8 Ma) after the uplift and exhumation of the Santiago Basin (Figure 3a and Figure 3b), during the deposition of the Mio-Pliocene Pebas and Pleistocene section that record the major pulse of subsidence along this new formed foredeep zone

## Geodynamic Implications:

The ONMB records drastic geodynamic changes since Turonian times (90 Ma). It shows the first phase of basin inversion of pre-Cretaceous structures (Baby et al., 1999) as contemporary to the deposition of the Upper Napo/Chonta Shales section (Barragan, 1999). Nevertheless, this tectonic event is more prominent along the Ecuadorian sub-Andean zone, where the Upper Napo Shales condense and/or absent as shown in the corresponding isopach map and in the E-W well correlation (Figure 4). This lack of sediments is related to a major uplift of the Ecuadorian subandean zone, western Oriented Basin (Jaillard et al., 1997; Barragan, 1999), forming a regional unconformity and sedimentary hiatus prior the deposition of the Tena Red Beds (Maastrichtian-Paleocene). Although it is the subject of some controversy, the mechanism that triggered this uplifted event and/or Turonian syntectonic sedimentary section could generally be attributed to either the onset of the Andean foreland system (Barragan, 1999; Baby et al., 2004) or simply to magmatic underplating. The latter could be a plausible explanation, as it is evident by the strong alkaline magmatic activity of asthenospheric mantle origin that has upwelled during Turonian to Campanian times (80-90 Ma) in the central and western part of the basin and contemporary with the upper Napo deposition (Barragan et al., 2005). In any case, a distinctive upper Cretaceous positive feature in the northern subandean zone it is evident, and it is different from its corresponding southern part, where, contrary to what occurs in Ecuador, the Upper Napo Section (Chonta) thickens forming an incipient foredeep zone located in the corresponding present day Santiago Basin. There, more marine and restricted conditions produced optimal oil prone source rock and a potential proto kitchen. On the other hand, the Tertiary deposits play a major role in the hydrocarbon generation history in this basin. The deposition of thicker Paleocene Yahuarango and Oligocene Chambira sections (Navarro et al., 2005) represent the most important subsidence events, triggering the generation and migration of hydrocarbons from this first western kitchen.

The change of basin configuration along the western side of the ONM since late Miocene, caused by the migration of Andean deformation toward the east (Baby et al., 2005), produced a second uplift of the entire subandean zone that allows the independence of several sub-basin from the Oriente and Marañon, and therefore the exhumation of the Santiago kitchen to the west (10 Ma; Baby et al., 2005; Alvarez-Calderon, 1999). This tectonic event triggered the development of a new foredeep zone along the east side of the new deformation front where its deepest part is located in the Situche area, the northwestern corner of the Marañon foreland Basin.

## Proposed Model

Two major kitchens that generated oil during distinctive stage of the Cretaceous-Cenozoic basin evolution are proposed here as responsible for the Oriente-northern Marañon ONM hydrocarbon system:

The **first**, it corresponds to a major depocenter along the south western portion of the Marañon Basin (present-day Santiago Basin), developed since upper Cretaceous time (90 Ma) as the direct response of the late Cretaceous syndepostional uplift of the northern Ecuadorian subandean zone (present day Napo high). The generation and expulsion of hydrocarbons took place since early Eocene times, associated with the deposition of the early Tertiary section that records the most important subsidence event. NNE long distance migration from this paleo-basinal area was facilitated by the continuity of the late Cretaceous/early Tertiary tectonic fabric associated to the major transpressive driven inversion of NNE-SSW Triassic–Jurassic grabens which extend to the north as major corridors in the Oriente Basin. Coincidentally or not, most of the giant and significant oil fields are located along these inverted features.

The **second** kitchen “the Situche kitchen” corresponds to the present day deepest portion of the foreland basin, the northwestern part of Marañon, as suggested by gravity data. It was formed as a direct response of the subandean uplift that exhumed the Santiago kitchen in late Miocene times (~10 Ma). New geochemical indicators confirm this active kitchen as responsible for the generation and expulsion of hydrocarbons since the late Miocene (8 Ma) and related to the deposition of the Mio-Pliocene section. The present day foreland geometry probably facilitated the migration of the new oils towards the eastern part in the current forebulge position of the basin (Iquitos Arch).

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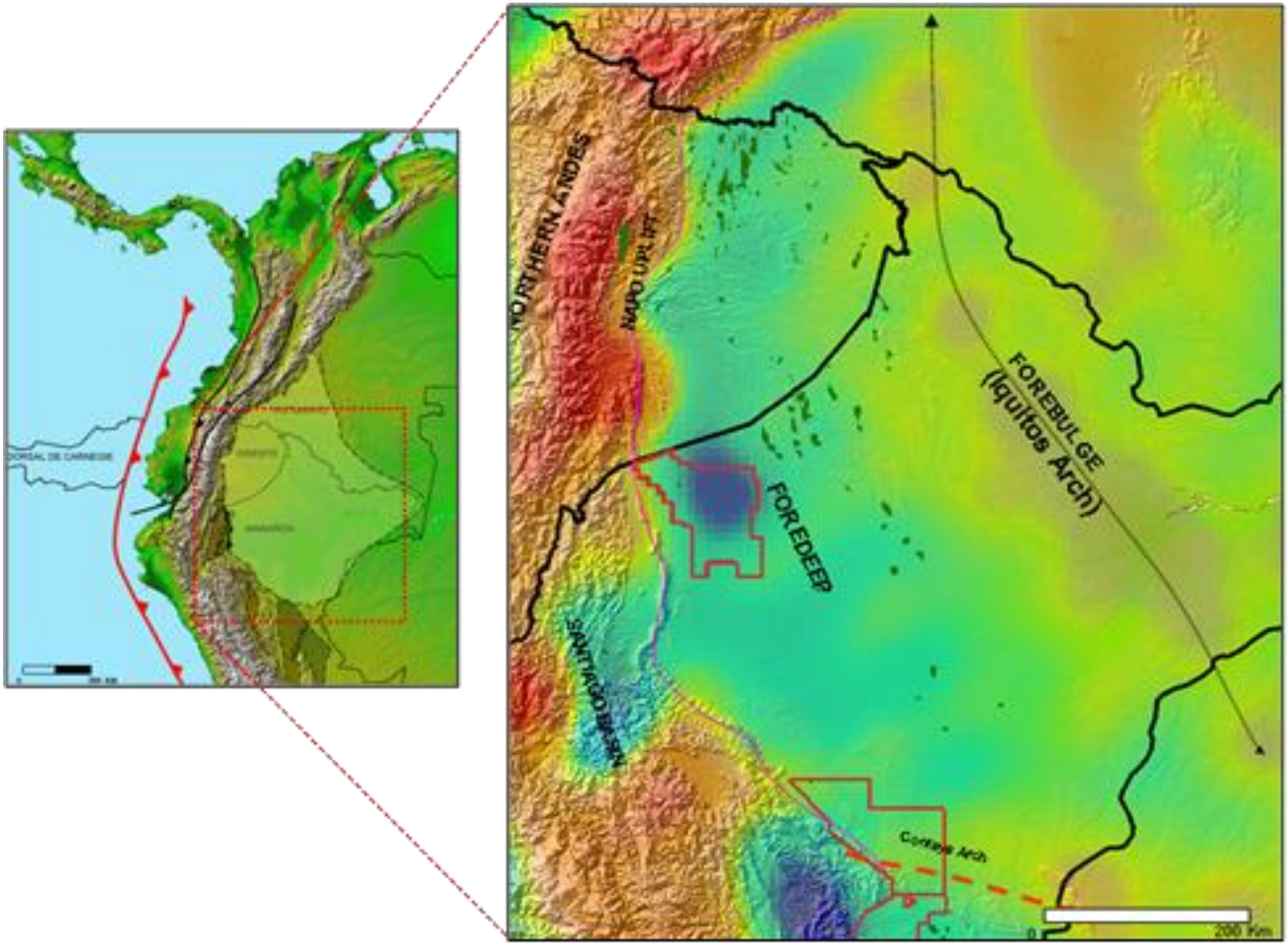


Figure 1. Location map of the ONM Basins, northwestern South America, showing the major elements and configuration of this sub Andean foreland system.

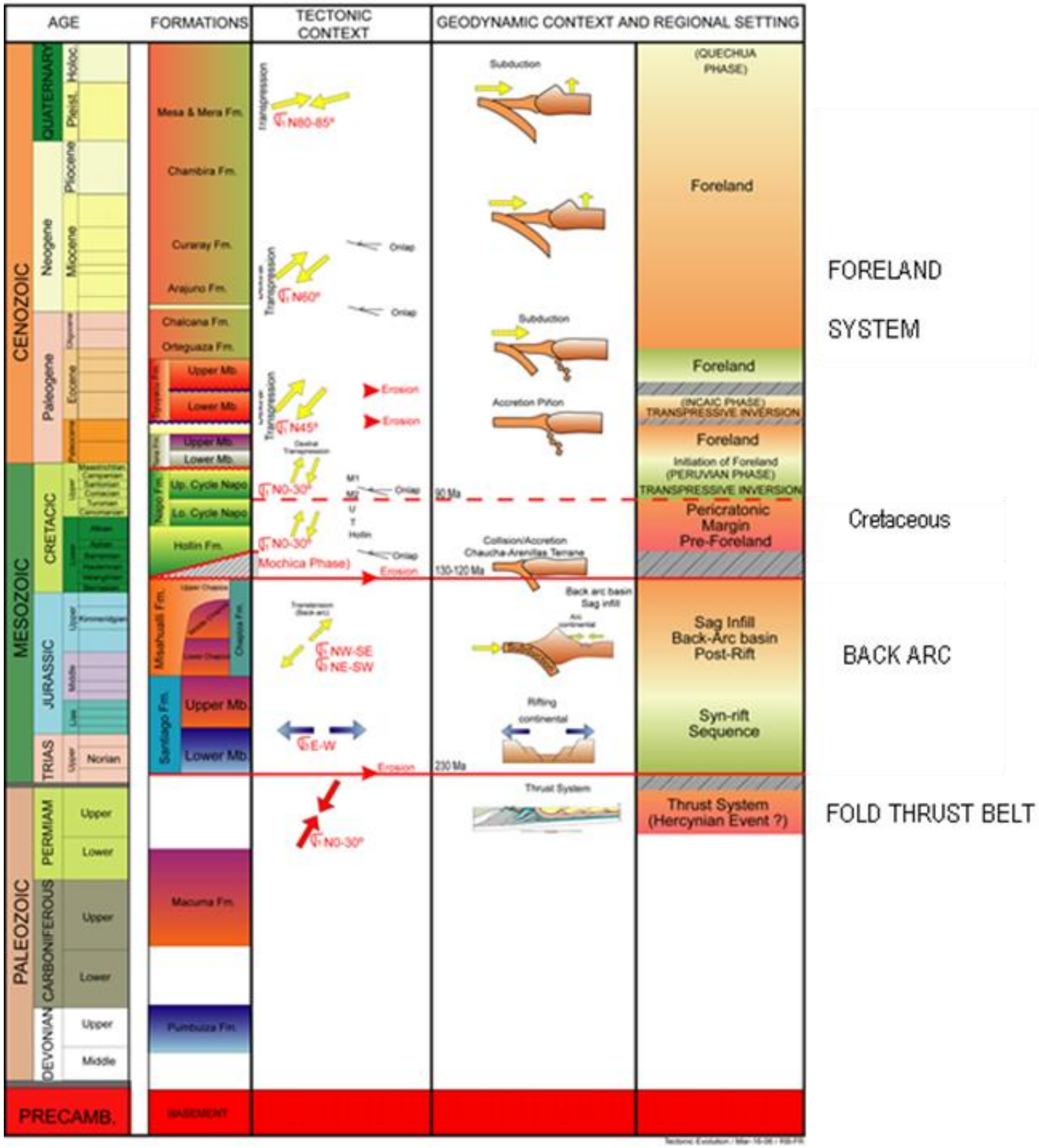


Figure 2. Tectono-sedimentary evolution of the ONM Foreland Basin.

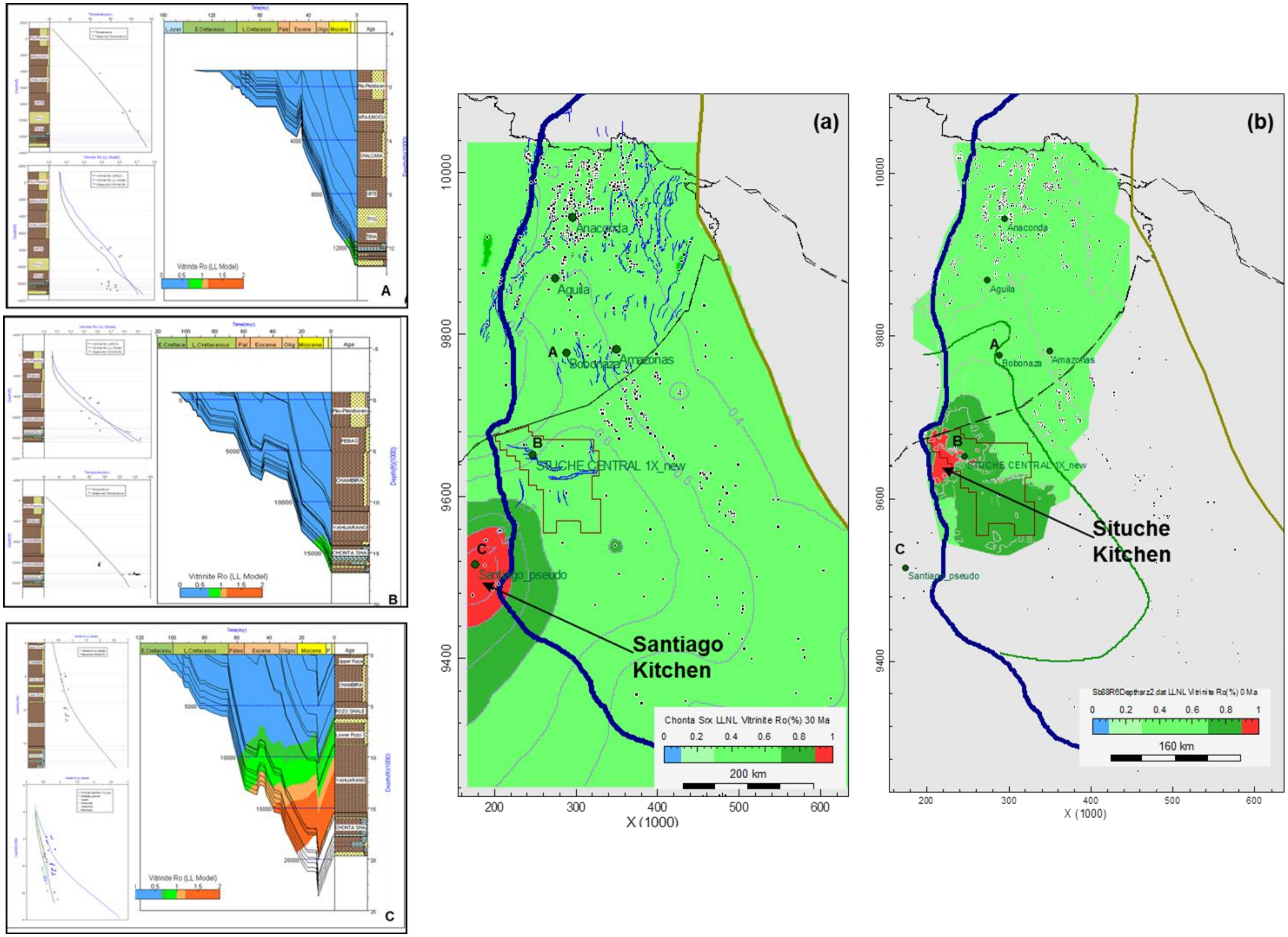


Figure 3. Left, 1D-Basin Modeling and Burial History for wells: A) Bobonaza-1, Oriente Basin; B) Situche C1, north western Marañon; C) Pseudo well, Santiago Basin. Right, interactive map-based petroleum systems modeling along the ONMB in order to explain the location of the Santiago Kitchen. (a) Oil Generation at 10 Ma just before the uplift and Santiago kitchen exhumation. (b) Oil generation present-day.

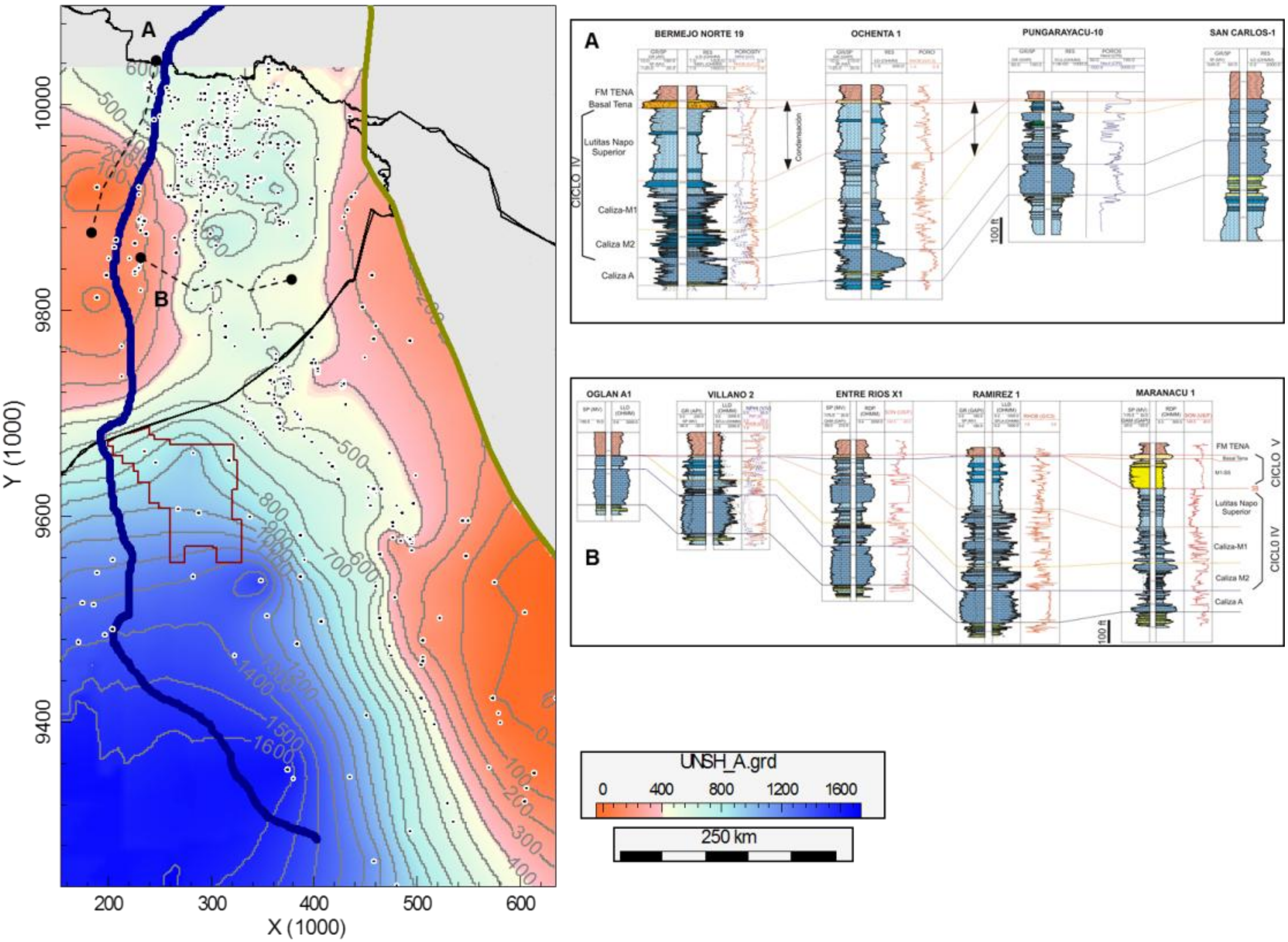


Figure 4. Isopach map of the Upper Napo/Chonta sections and well log correlation (modified from Barragan, 1999), suggesting an early uplift event of the western Oriente Basin (proto-Subandean zone) and the consequent synsedimentary deposition. It is also evident the development of the Santiago throat linked to this major Upper Cretaceous uplifted event.