Hydrocarbon Potential of the Santiago Basin Peru

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Final Report on the

Santiago Basin

The Hydrocarbon Potential of NE Peru
Huallaga, Santiago and Marañón
Basins Study

by

PARSEP

Proyecto de Asistencia para La Reglamentación del Sector
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1.0 INTRODUCTION

The Santiago Basin Study is the second in a series of reports to be released by the PARSEP Group on the evaluation of the Hydrocarbon potential of NE Peru, which includes the Huallaga, Santiago and Marañón Basins (Figure 1). The first in this series of reports was on the Huallaga Basin. PARSEP is a joint venture between the governments of Peru and Canada and stands for “Proyecto de Asistencia para la Reglamentación del Sector Energético del Perú”. The parties comprising PARSEP are: the Canadian International Development Agency (CIDA), Canadian Petroleum Institute (CPI), Teknica Overseas Ltd. (TOL), and PERUPETRO. The technical work on this project is being done by personnel from TOL and PERUPETRO.

Figure 1: Areas of investigation of the PARSEP Group – Huallaga, Santiago and Marañón Basins, and intervening areas.

The data utilized in the project was supplied by PERUPETRO and consisted of 1566 km of SEGY format, 2D seismic data. This included data from four seismic surveys; Petroperu’s data set from the 1970’s and 80’s; Petromineros from the early 1990’s; and two data sets from Quintana Minerals (QMC) from 1995 and 1996. Seismic interpretation was done on a GeoQuest workstation. Additional geophysical data utilized by the study included a Carson Geophysical, 19,150 km² aerogravity/magnetic survey done for QMC, covering the entire Santiago Basin and surrounding area.
The principal well data used in this report consisted of digital and hardcopy (original) well curves from the seven exploratory wells drilled in the Santiago Basin and all the available accompanying data for each. This included such things as well proposals, final well reports, post-mortems, geochemical analyses, etc. Unfortunately, much of the Mobil well information from the 1960’s was missing and conclusions had to be reached utilizing summations of this data from later studies when available.

Numerous other reports on regional geology, geochemistry, stratigraphy, etc., of which there were many, were also utilized for this investigation. Of these, the earlier referenced works originated largely from Petroperu. The more recent in general, were industry generated reports of which, Quintana was the largest contributor. Of considerable importance to this report was the analysis made by the PARSEP Group (2000) on the Huallaga Basin area to the south. This allowed certain concepts on tectonics and stratigraphy developed there, to be brought northward into the Santiago Basin.

Finally, contributions by Dr. Tony Tankard on the tectonic reconstruction of the Santiago Basin were paramount in our understanding of this extremely complex area. The work by Tankard was done in conjunction with a much larger regional project focusing on Peruvian tectonics specifically for Perupetro and PARSEP.

2.0 SCOPE OF PROJECT

The primary objective of this PARSEP project, was to evaluate the remaining hydrocarbon potential of the Santiago Basin and pending favorable results, to assist Perupetro in the promotion of this area to Industry. This includes making recommendations to Perupetro concerning block size, configuration and location for tendering purposes. These recommendations have been presented to Perupetro in a memo separate from this technical evaluation.

In the process of such a study, many new concepts are often utilized and new conclusions reached that may ultimately change people’s perceptions on the geology of an area and it’s hydrocarbon potential. Through a rigorous evaluation of all the data, we believe this report introduces significant new ideas on the evolution of the Santiago basin, which helps in our belief, to make the Santiago Basin more attractive for hydrocarbon exploration.

The report begins with an overview section on regional geology and includes regional projections from the Huallaga Basin to the south and the Marañon Basin to the east. This was compiled primarily through regional work done to date by the PARSEP Group, published data, and Perupetro archived data.

The seven wells drilled in the basin were analyzed and it was concluded that all but two, Dominguza and Putuime, were valid structural tests. Both of these wells have
resulted in the development of prospects updip from the original well bore. In the course of this study, basin geochemical modeling was done on three of the seven wells, Tanguintza 1X, Putuime 1X, Piuntza 1X, and two pseudowells. The results indicate that various episodes of hydrocarbon generation and expulsion from the Pucara, Chonta and Pozo Shales had taken place in the Basin.

In the seismic interpretation of the Santiago Basin, three two-way time maps, 1) Top Lower Puca Formation, 2) Top Chonta Formation, and 3) Base Cretaceous; and two Isochron maps, 1) Lower Puca to Chonta, and 2) Chonta to Base Cretaceous, were constructed. In the process of the seismic interpretation, six prospects and one lead were ultimately defined. Potential reserve calculations were done for each of the prospects and are presented within the Prospect Summary section of this report.

Additionally, it was concluded through the integrated geophysical and geological evaluation of this area, that the tectonic evolution of the Santiago Basin was driven by wrench-related and not salt-related tectonics, the later of which, has been the historical interpretation of the area. Hopefully this new insight will enable others to view the Santiago Basin differently than they have before in the past.

One of the secondary objectives of this report was to compile a summary and synthesis of all data and technical reports relevant to the Santiago Basin. The purpose of this is to allow a third party evaluation team to make a meaningful interpretation of the Santiago Basin without having to go review all existing reports and literature. To further facilitate this process, a corrected and edited digital data set is included with this report consisting of well curve LAS (Enclosure 18) and seismic SEGY (Enclosure 19) files, which represents all the data that was used by the group for the study.
3.0 PREVIOUS WORK IN THE STUDY AREA

The Santiago Basin has experienced several periods of exploration and were initiated in the 1940's by Mobil Oil who began field studies there. This was followed up some time later in the 1960's by a Mobil Oil-Unocal consortium that undertook extensive geological-geophysical studies, which included 625 km of analog single fold seismic that targeted several anticlinal trends exposed on the surface. They drilled three unsuccessful exploratory wells in the Basin, Dominguza 1X, Piuntza 1X and Putuime 1X (Figure 2) after which they relinquished the area.

The Basin remained dormant for some time after and it wasn’t until the late 1970's and early 1980's that activity resumed. During this time, Petroperu carried out extensive geological field surveys and photo-geologic evaluations, which was done in combination with the acquisition of almost 1000 km of 6 and 12 fold seismic and approximately 100 km of gravity data.

Petromineros del Peru, an indigenous Peruvian company, entered the area in the early 1990’s and reprocessed approximately 2000 km of the Petroperu Santiago Basin seismic data and Superior Oil seismic data in the adjacent Marañon Basin. Additionally, they acquired 177 km of 120 fold seismic data in the Santiago Basin (Figure 2). Petromineros concluded their exploration program in the Santiago Basin shortly thereafter and left the area without drilling a well.

In 1995 QMC (Quintana Minerals Corporation) Sucursal Peruana signed an exploration contract with Perupetro for Block 50 (Figure 2) in the Santiago Basin. Block 50 includes most of the area under study in this report. QMC reprocessed 716 km of Petroperu seismic data in the Santiago basin, all 177 km of the Petromineros data and 381 km of data in the neighboring Marañon Basin. After the interpretation of this data QMC conducted several other geophysical work programs in the Block. The first program was a 309 km seismic survey with accompanying gravity data, done by Grant Geophysical. This was followed immediately by a 205 km seismic/gravity Digicon survey. Additionally, QMC ran a 19,150 km² aerogravity/magnetic survey completed for them by Carson Geophysical. This covered the entire Santiago Basin and surrounding area (Figure 3, and Enclosures 2, and 3).

QMC Sucursal Peruana and partners (YPF Sociedad Anonima, Sucursal del Peru, Elf Petroleum Peru BV, Sucursal del Peru, Enterprise Oil Exploration Ltd., Sucursal del Peru) drilled four exploratory wells, Caterpiza 1X, Pupuntas 1X, Manseriche 1X, and Tanguintza 1X, in Block 50 during 1996 to 1998. All four were completed as dry holes although the Tanguintza 1X tested substantial flow rates of gas/condensate from a thin upper Vivian sandstone. QMC et al relinquished the block in 1998 and since, there has been no activity in the Basin.
Figure 2: Location map of the QMC’s Block 50, seismic and wells by Company
4.0 REGIONAL FRAMEWORK - GEOLOGICAL OVERVIEW
SANTIAGO PROJECT AREA

4.1 BASIN DESCRIPTION

The Santiago Basin is an elongated NNE-SSW tectonic basin extending 200 km in length and 100 km in width in the northernmost Peruvian Andean Fold Thrust Belt (Figure 3). The basin is located at the western extremities of the Marañon Basin of which it was once part of until the two were separated during the Late Tertiary Andean Orogeny. Its borders are the N-S trending Manseriche/Campanquiz Mountains to the east forming a topographic feature and tectonic uplift separating the basin from the Marañon Basin, the pre-Cambrian/Igneous Condor Cordillera on the Ecuadorian border to the north and west and the E-W trending extension of the Huancabamba Deflection at Latitude 5° 15’ to the south (Figure 4).

From east to west, the basin includes the following NNE-SSW to N-S oriented features as displayed in Figure 4:

1. **The Campanquiz/Manseriche Anticlinal Belt** with outcrops of sediments of Cretaceous age along the core and of Tertiary age on the flanks, it forms the border with the Marañon Basin.
2. **The Santiago/Nieva Tectonic Depression** covered by sediments of Tertiary age. This elongated depression is 15-30 km wide and runs the entire length of the basin. All exploratory drilling, seismic and most geological data were acquired in the 150 km southern portion of this depression. The remaining northern 90 km close to the Ecuadorian border and the southernmost 10 km have neither seismic nor wells drilled. In most reports this Tertiary depression is referred to as the “Santiago Basin”, although it is only a portion of the major Santiago Basin as seen in Figure 3 and 4.
3. **The Huaracayo Hills** constitute an elongated anticline separating the two Tertiary depressions.
4. **The Kumpin/Ipururo Tectonic Depression** also covered by sediments of Tertiary age, is 150 km long and 20 km wide. Some surface geology data is found in the INGEMMET reports, but its subsurface nature and the presence of hydrocarbon seeps are unknown.
5. **The Comaina/Cenepa/Noraime Belt**, is an elongated less deformed belt extending over 160 km in length and 20-50 km in width, running parallel to the remote El Condor Cordillera. It outcrops with sediments of Cretaceous, Jurassic and Triassic age. Its name is taken from the major rivers basins located within the belt. Generalized surface geological data on this area has been summarized in the INGEMMET reports.
6. **The Condor Cordillera** represents the western border of the basin. It is composed of Precambrian rocks that have been intruded by Jurassic aged tonalities, diorites and granodiorites.
The Huancabamba Deflection, is an E-W mega shear and limits the southern border of the basin. To its south, the structural grain of the entire Andean Range is NW-SE and to its north, the orientation deflects to a N-S and NNE-SSW direction.

Figure 3: Topography Map of the Santiago Basin displayed from the Carson Geophysical Aerogravity/Magnetic survey data with overlay of seismic coverage
Figure 4: Surface Geology and structural features of the Santiago Basin.
4.2 REGIONAL GEOLOGY

The geological evolution of the study area is controlled by two regional tectonic systems recognized in the sub-Andean basins of Peru. The first, the pre-Andean System, encompasses three Marginal cycles of Ordovician, Devonian and Permo-Carboniferous ages overlying the Precambrian basement of the Guyana and Brazilian Shields. The second, the Andean System, was initiated with the beginning of subduction along the western margin of Peru. It encompasses several mega-stratigraphic sequences and numerous minor sedimentary cycles, ranging from late Permian to the Present. A stratigraphic column of NE Peru is presented in Figure 5. This Figure indicates that the presence of rocks older than Middle Permian have yet to be defined in the Santiago study area.

4.2.1 Pre-Andean System

The pre-Andean System begins with the Ordovician cycle and is represented by the siliciclastic Contaya Formation with a thickness of up to 150m in NE Peru, as found within the Marañon Basin. A maximum thickness of 4500m is reported for the cycle in the Eastern Range of southern Peru. The Contaya Formation outcrops in the Contaya Mountains of the northern Ucayali Basin and on the Shira Mountains. Close to and just south of the greater PARSEP study, the Contaya in the subsurface has been encountered in wells located on the Contaya Arch and in the Agua Caliente Dome, within in the subsurface.

Next in the succession is the Silurian, which is represented by argillites, flysch and tillites. They reach up to 1000m of thickness in southern Peru (Laubacher, 1978). This depositional cycle ends with an erosional episode in the Peruvian Oriente that is the result of tectonic movement during the Caledonian/Taconian Orogeny. The Silurian cycle merges with that of the Devonian, which is represented by sediments of the Cabanillas Group that have been deposited in the Madre de Dios, Ucayali and Marañon basins. In the south of Peru, Devonian sediments reach thickness of up to 2000m, while in northern Peru, the maximum thickness attained is 1000m. Rocks of Devonian age outcrop also in the Contaya High and in the Shira Mountains. No rocks of Silurian to Devonian age have been encountered within the study area nor are any inferred seismically.

The Permo-Carboniferous sequence rests unconformably over the Devonian Cycle and/or Ordovician sediments and Basement in the uplifted areas. It has a widespread distribution throughout the Andean Range, in the subsurface of the Peruvian eastern basins, and in the Brazilian Acre and Solimoes Basins. In the Peruvian basins the earliest Carboniferous sedimentation began with the Ambo Group, which was deposited as continental to shallow marine, fine-grained sandstones, with interbedded siltstones, gray shales, and occasional thin coal beds. These sediments are followed vertically by the thin transgressive, elastic-rich Tarma Formation, which is overlain, often unconformably, by the normally thick, massive shelf carbonates of the Copacabana Formation. The Tarma-Copacabana Group is widely distributed in most of the Andean basins. It is predominantly a marine carbonate sequence although the cycle begins with a basal fine- to coarse-grained sandstone, the Green Sandstone Unit. This is overlain by a thick sequence of dark gray, fossiliferous limestones (wackestones,
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**Figure 5:** Stratigraphic Column of the NE Peruvian basins. Highlighted in yellow is the nomenclature used in this report.
packstones and grainstones) and thin interbeds of dark gray shales. The unit contains several intervals with characteristic fusulinid forams of Permian age. The Copacabana limestones covered most of Sub-Andean Peru with the exception of the Contaya Arch where the Cretaceous overlies rocks of lower Palaeozoic age. The Copacabana Formation in turn was conformably overlain by the Ene Formation, a sequence containing black organic rich shales and dolomites with minor sandstones. A number of wells in NE Peru, have intersected thick sequences of the Copacabana Group. Tarma and Ene occurrences, however, are much rarer and restricted primarily to the Ucayali Basin and points south.

4.2.2 Andean System

The Andean System was initiated simultaneously with the beginning of the Andean subduction. A major change in the tectonic regime at the northwestern border of the South-American plate, promoted isostatic rearrangements. In a global scale, the initial phase of the Andean System developed during the Pangaea break up (M. Barros & E. Carneiro, 1991). The development of the Andean subduction zone during late Permian to early Triassic times is supported by geological information gathered by Audebaud, et. al. (1976) along the Peruvian Eastern Range, where they recognized a Permo-Triassic continental volcanic arc. The volcanic Lavasen Formation, which is seen in outcrops unconformably underlying the Mitu Group to the west of the Huallaga Basin (Serie A: Carta Geologica Nacional, INGEMMET Bulletin No. 56, 1995) could be a remnant of this arc. The Lavasen Formation is also found intruding older rocks such as the Ambo Formation. Its lower member is a volcanic-sedimentary sequence with interbedded red clastics. The upper member is comprised of thick lava flows and breccias.

The Paleozoic platform at Perm-Triassic time was now within a backarc setting and subject to extensional tectonics. This lead to the development of a series of horsts and grabens trending parallel to the Andean structural grain. We are interpreting the continental red beds of the Mitu Formation to represent the syn-rift depositional cycle associated with this extensional event. Others have referred to Mitu as a result of the Jurua Orogeny, which has been described (Mathalone and Montaya, 1993) as one of the more significant erosional events in the geological history of Sub-Andean Peru.

The Permo-Triassic initial rifting event and Mitu deposition was followed with subsidence and significant marine incursion, which resulted in the deposition of the Pucara Group of Triassic to Jurassic age. Deposition of this group occurred as a carbonate and evaporite dominated sequence over a broad depression that roughly coincides with the central to western Marañon and the westernmost Ucayali basins.

A regional supratidal sabkha environment developed at the end of Pucara which marks the beginning of the continental and shallow marine deposition of the Sarayaquillo Formation. An extensive deposit of evaporites mainly anhydrite, gypsum and minor salt interbedded with dolostones, limestones, mudstone and sandstones is found in outcrops and in subsurface. In the Peruvian Fold and Thrust Belt this evaporitic unit can be traced over a distance of at least 700 km. These deposits were intersected in subsurface by the Oxapampa 7-1 and Chio 1X wells in the Ucayali Basin and the Putuime 1X well in the Santiago Basin. The evaporites outcrop extensively in the Huallaga Basin, in the
Fold Thrust Belt of the Ucayali Basin, and in the Comaina/Cenepa/Noraime belt on the NW portion of the Santiago Basin as shown in Figure 4. It is interpreted that the evaporitic unit is an important gliding surface for the thin-skin tectonics of post-Pucara deposits.

In the area of the Santiago Basin, there was a rejuvenation of volcanic conditions on the western flank of the Comaina/Cenepa/Noraime belt (Figure 4) after deposition of the Pucara Group due to deep seated basement block faulting. The Oyotun volcanic lavas and volcanic breccias are found overlying the Upper Pucara Group and underlying the Sarayaquillo Formation. Similar post-Pucara faulting caused the formation of breccias and conglomerates with clasts of limestones and clastics of Pucara described as the Corontachaca Formation overlying the Pucara to the south of the Santiago Basin. This unit has not been identified in the Santiago Basin.

With the regression of the Jurassic sea, the Pucará and Oyotún Formations were conformably overlain by Middle to Late Jurassic continental red beds of the Sarayaquillo Formation. Termination of Sarayaquillo deposition coincides with the end of the Jurassic that is represented by the regional Nevadan unconformity over, which lie sediments of Cretaceous age. This is a boundary generally well recognized on seismic. Below this the Jurassic is seen to thicken westward and locally subcrops with considerable angularity. Cretaceous deposition was initiated in the greater Santiago/Marañon/Ucayali basin during Neocomian-Aptian times and was characterized by a westerly thickenings wedge of fluvial to marginal clastics occasionally punctuated by carbonate sedimentation.

The termination of the Cretaceous epeiric sea deposition was during Late Cretaceous with the arrival of the first pulses of the Andean orogeny (Peruvian and Inca Phases) at which time through to Middle Eocene time, molasse-styled deposition dominated the basin. This was punctuated during the Late Eocene to Early Oligocene by a marine transgression that resulted in the deposition of the Pozo Formation. Molasse deposition resumed in the Late Oligocene, which culminated during the Miocene Quechua deformation and has continued through to the present.

4.3 TECTONIC RECONSTRUCTION OF THE SANTIAGO BASIN

Exploration and prospect interpretation of the Santiago basin is extremely difficult because of the considerable structural deformation and lack of seismic coverage outside the lowlands of the Santiago River area. It is for these reasons that a detailed tectonic reconstruction was undertaken. Two maps were produced; first, a Late Cretaceous – Tertiary map (Figure 7) to show the essential framework of Andean deformation; second, a Late Jurassic – Early Cretaceous map (Figure 6) was interpreted based on regional considerations. Overall, these maps honor the topography (Enclosure 1), gravity (Enclosures 3 and 4), magnetic and seismic data.

Historically in the literature, the Santiago Basin has been considered to be a basin structurally controlled, largely by salt tectonics. In the course of this study very little support for this hypothesis was encountered. Seismic and gravity data indicated that the evolution of the Santiago Basin was driven largely by wrench tectonics.
Figure 6: Late Jurassic to Mid-Cretaceous tectonic reconstruction showing Santiago Basin to be a predominantly transtensional Basin
Figure 7: Tectonic reconstruction of the Santiago Basin during Late Cretaceous to Tertiary times
During the Late Jurassic – Early Cretaceous, the Santiago basin evolved as an extensional or transtensional basin, consisting of isolated rift segments that were offset across NW-trending, right-lateral accommodation zones. The orientation of basin-forming extensional faults is N to NNE. The seismic expression of this extensional basin is shown by flattening of E-W seismic lines at the level of the Chonta Formation. Unfortunately, the seismic is very restricted regionally, and offers only a partial insight into stratigraphic geometry, and is insufficient to distinguish between purely extensional versus transtensional geometries. Regional comparisons suggest a strong extensional component of subsidence. During this period, the Santiago basin was a complex of extensional depocenters that were, nevertheless, structural linked to the Marañon basin. In fact, the Santiago, Marañon and Huallaga basins were part of a continuous extensional tract.

Andean deformation in the Late Cretaceous – Tertiary resulted in massive structural inversion of the older extensional basins. Basin inversion was driven by left-lateral, NW-trending strike-slip faults (the principal displacement zones or PDZ), as well as a very prominent set of NNE-oriented, right-lateral antithetic strike-slip faults (conjugate Riedel structures) that are expressed in the transpressional inversion structures. These NW-trending and NNE-trending strike-slip faults combine to compartmentalize deformation. Interestingly, these structures also outline a series of structural blocks that appear to have rotated as a result of left-lateral displacement of the PDZs. Rotation of relatively cohesive blocks results in matching extensional and compressional areas. The compressional areas generally are associated with structural-trap formation, and hence have been targets for some exploration wells. The extensional areas are expected to reflect dilation and relative low pressure, and may possibly control migration pathways.
5.0 STRATIGRAPHY OF THE SANTIAGO BASIN

The Santiago Basin contains a Paleozoic, Mesozoic and Cenozoic stratigraphic sequence in excess of 12 km thick, deposited in more than three mega sequences overlying Precambrian metamorphic basement (Figure 5). Smaller scale depositional cycles are documented in the stratigraphic column. Most of the formations representing the mega sequences outcrop in the Santiago Basin and their subsurface presence is interpreted by seismic and through regional correlations. Pre-Permian rocks are interpreted to be present in the basin and are believed to be represented by deep seismic events.

A list of the sedimentary mega sequences, their major units and Basement is presented below. Included in the following discussion is a detailed description on each of the sequences and units regionally as well as a description when relevant, on their occurrence within the Santiago Basin.

1. Marañon Basement Complex
2. Permian-Jurassic (Mitu-Pucara-Sarayaquillo)
3. Cretaceous (Cushabatay-Chonta-Vivian-Cachiyacu)
4. Lower Tertiary and possibly an Upper Tertiary mega sequences

5.1 MARANON BASEMENT COMPLEX

The oldest rocks in the area are found in the Precambrian metamorphic Marañon Complex outcropping on the western/southwestern border of the Santiago Basin. These rocks are the northward continuation of the Marañon Geanticline, which forms the Eastern Andean Cordillera. They outcrop in essentially N-S oriented blocks made up of a highly metamorphosed sequences of phyllites, quartzites, schists and conglomerates with rounded to sub-rounded gneiss and granitic clasts. This suite of metamorphic rocks was later intruded by Late Jurassic igneous rocks and together these units form the Condor Cordillera (Figure 4).

5.2 PERMIAN TO JURASSIC MEGA SEQUENCE

The Permian to Jurassic mega sequence was deposited during a rift and basin sag episode that included a major transgressive-regressive cycle. Deposition within this sequence begins with that of the basal syn-rift continental red beds of the Mitu Group. This in turn is followed by the predominantly marine Pucara Group, then the continental to shallow marine deposits of the Sarayaquillo Formation. The regional maximum flooding surface for this mega sequence is localized at a mid-Pucara level within the Aramachay Formation.

5.2.1 Mitu Group

The Permo-Triassic Mitu Group of Paleozoic age is the oldest formation outcropping in the vicinity of the Santiago Basin, and is found to be overlying Precambrian Basement,
(Figure 4). The Mitu Group forms the basal section of the Permo-Jurassic mega sequence and is representative of a syn-rift deposit composed of red beds containing conglomerates with sandstone, shale and volcanic clasts, volcanic rocks and evaporites. The formation is interpreted to deepen eastward and to be present within the subsurface of the Santiago Basin. The Mitu Group is observed to grade upwards into the Pucara Group east of the Rentema Gorge, passing first through an evaporitic transitional unit (sabkha supratidal facies?). These evaporitic deposits at the end of the cycle are considered to be the principal fault gliding surfaces in subsurface of the Santiago Basin.

5.2.2 Pucara Group

The Pucara Group represents a carbonate, shale and evaporite sedimentary sequence deposited from upper Triassic to lower Jurassic time and is found overlying the Mitu Group. Generally, this contact is transitionally although locally it can be unconformable. Regionally, the Pucara Group is divided into three formations, which from oldest to youngest are the Chambara, Aramachay and Condorsinga. All three are recognized along the northern and central Andes of Peru in outcrops and in subsurface.

Generally, most of the studies done to date on the Pucara have been site specific with apparently little having been done on a regional scale. Additionally, most references in literature are focused largely on its economic importance as a host for ore deposits and with a fewer number referring to its sedimentological and paleontological characteristics. Recent focus in the last few years has recognized the Aramachay Formation as a major source rock for hydrocarbons in the Marañon and Ucayali Basins.

Regionally, the Pucara is represented by two stratigraphic cycles, a lower transgressive cycle formed by the Chambara and lower Aramachay Formations and an upper regressive cycle consisting of the upper part of Aramachay, the Condorsinga, and the Sarayaquillo Formations. The Condorsinga Formation is overlain conformably by the Sarayaquillo Formation, a red bed continental to shallow marine sequence laterally equivalent to the Pucara Formation. The westward progradation of this upper cycle and facies transitions between what we interpret to be the Condorsinga equivalent in the subsurface of the Ucayali basin and Sarayaquillo Formation, is clearly evident in the seismic line from the southern Marañon Basin displayed in Figure 8. The transition zone between these two formations is generally represented by a regionally extensive evaporitic unit related to sabkha supratidal deposition.

The Pucará shoreline was irregular in shape and had roughly a N–S trend to it with the hinterland being located to the east. As interpreted by some, the Pucará depression was a restricted basin partially isolated from the open sea by early positive movement on the NW–SE trending proto-Marañón high that acted as a subtle barrier during basin development. An alternative interpretation is that the basin was in part restricted due to the development of a volcanic arc system that began to develop in Permo-Triassic time. The Pucara Group extends in the subsurface throughout most of the Santiago Basin and progressively becomes shallower to the west until it outcrops in the Comaina/Cenepa/Noraiime belt (Figure 4). It has not been penetrated by exploratory drilling anywhere in the basin, although its presence in the subsurface is inferred by seismic and through regional correlations.
The Pucara described in the western Santiago Basin consists of a deep marine grey to dark grey limestone deposit. It’s micritic to sparritic, bituminous, thin to medium bedded, with minor sandy limestones and with thinly bedded dark grey to light green shales and siltstones. Within the Santiago area no detailed studies have been taken that divides the Pucara Group into units at a formational level. It is likely that the three formations of the Pucara Group, the Chambara, Aramachay and Condorsinga Formations, will eventually be identified since they are recognized east of the Rentema Gorge (Figure 4), south of the Santiago Basin.

**Chambara Formation**

The Chambara Formation is of Norian to Rhaetian age and in central Peru, is predominantly dolomitic, comprised of restricted to shallow marine, subtidal/ intertidal, and lagoonal facies. Marine shelf facies has also been found as crinoid bank deposits (Rosas & Fontboté, 1995). In northern Peru, the Chambara is comprised mainly of limestones, and is rich in shale and dolomite towards its base. The upper section contains well-stratified carbonate rocks, which include a siliciclastic-rich portion with a noticeable increase in shale and silt layers. A continuous transition to the overlying Aramachay Formation, is also observed (Prinz & Hillebrandt, 1994).

**Aramachay Formation**

The deep marine facies of Aramachay Formation of Hettangian to Sinemurian age represents the period of maximum flooding of the Permian to Jurassic mega sequence. The persistence of this 50 to 150m thick mix of fine-clastic and carbonate organic rich facies along the Andes would indicate that deposition was within a restricted marine
environment that occurred during a basinal transgressive event related to a rapid increase in sea level, followed by a relative slow sea level rise with the onset of the upper regressive cycle.

**Condorsinga Formation**

In central Peru the Condorsinga Formation is represented by a thick sequence of platform carbonates with restricted lagoonal and subtidal shallow marine facies with thin intercalations of supra/intertidal sediments (Rosas & Fontboté, 1995). In northern Peru, and just west of the Huallaga basin, the Condorsinga is predominantly comprised of limestones. Between the Huallaga and Marañon basins at the north end of the Cusabatay High in the Callanayacu “salt dome” area, the upper Pucara Group is exposed and found underlying an evaporitic sequence interbedded with thin black shales, sandstones, marl and limestone strata at the base of the outcrop. This passes gradually into limestone interbedded with thin sandstone and siltstone strata in the upper part (G. Diaz, 1999). In a proximal and similar outcrop around the dome, nearly 50m of anhydrites were found by PARSEP geologists overlying black bituminous shales and marl of the uppermost Pucara Group.

### 5.2.3 Evaporitic Unit (Pucara to Sarayaquillo Transitional Unit)

This unit in outcrop is usually found near crestal culminations of surface anticlines. Because of the occurrence of evaporites in such a structural position, the Ingemmet geological reports typically refer to these features as “salt domes” in the Huallaga area. These features extend northward into the Santiago Basin, although much less commonly. In the present study PARSEP interprets the occurrence of anhydrite that was intersected beneath the Cushabatay Formation near TD in the Santiago Basin well, Putuime 1X, to be of the same age.

Extensive outcrops of the same evaporitic unit were also found by PARSEP geologists earlier this year to conformably overly Pucara in the Rentema Gorge area and Huallaga Basin. An example of this occurrence is seen in the Callanayacu Dome in the Huallaga River, east of Chazuta (Figure 9). The name “Callanayacu Formation” is given to this evaporitic unit of predominant anhydrite and gypsum with minor salt and terrigenous clastics with a thickness of nearly 1000m at the “Callanayacu Dome” and over 500m in the “Tiraco Dome”, in a study undertaken for Advantage Resources (Advantage, 2001) in their evaluation of Block 86. In both instances this “Formation” is within the same stratigraphic position, and is found underlying the Sarayaquillo Formation, and overlying the Pucara Group.

In most instances, the ‘Evaporitic Unit’ is interpreted to be non-diapiric in occurrence and to be in its stratigraphical depositional position. It is believed to be representative of a supratidal sabkha facies and marks the beginning of the transition from marine to continental environments during Jurassic time. In other words, this unit represents the transition from the Pucara to Sarayaquillo. Based on our understanding of the depositional model for the two formations, this would be a time-transgressive boundary becoming progressively younger from east to west. From a petroleum exploration perspective, the significance of this relationship is, that an excellent regional seal exists immediately above potential carbonate source rocks and reservoirs of the Pucara Group.
Deep erosion to pre-Sarayaquillo levels over tectonically positive features has left these evaporites outcropping in cores of numerous structures in the Peruvian Fold Thrust Belt. As previously mentioned these features are often referred to as “salt domes” in the Huallaga and Ucayali Basins. Several of these occurrences are interesting in that they are interpreted by PARSEP to be representative of inverted Triassic rift basins. Examples of such are, the Tiraco Dome and Cushabatay High, which are located along the boundaries of the southwest Marañon Basin. These rift basins are believed to have been inverted in Late Cretaceous to Early Tertiary time.

In the case of the Putuime well, the anhydritic unit is found lying directly beneath the Cretaceous Cushabatay. The implications of this is that there was a pre-Cretaceous uplift (inversion?) and the Sarayaquillo Formation was completely eroded prior to the deposition of Cretaceous sediments. The cross-sections presented in Figures 10 through 13 demonstrate this concept. There is more discussion on the occurrence of the anhydrite in this well in several of the following sections.

Clearly, additional work needs to be completed in order to obtain a more comprehensive understanding of the evaporite deposition and occurrence within the Pucara Group in and around the Peruvian Fold Thrust Belt.
5.3 CRETACEOUS MEGA SEQUENCE

The Cretaceous succession in the Santiago and western Marañon Basins was deposited under more marine conditions than in the Marañon Basin to the east. The major change between the two areas occurs in the Oriente Group where the massive sandstone unit of the Agua Caliente Formation typical of the Marañon Basin, is characterized by a unit consisting of shales and minor thin sandstone interbeds in the Santiago Basin.

The lowermost Cretaceous is made up of the Oriente Group, which consists of three stratigraphic units. From oldest to youngest they are the, Cushabatay, Raya, and Agua Caliente Formations. Regionally, the Oriente Group represents the beginning of the Cretaceous mega sequence. Within the Group is a minor transgressive-regressive cycle, which is stratigraphically represented by the Raya Formation. After the Oriente Group, Cretaceous deposition continued with the transgressive/regressive, mostly neritic, marine Chonta Formation. This is one of the principal source rocks in the greater Marañon Basin. The Chonta Formation is overlain by the marginal marine Vivian and Cachiyacu Formations, which represents the culmination of Cretaceous deposition.

The cross-sections presented in Figures 10 and 11 show the correlation and continuity of the Cretaceous units from the western Marañon Basin into the Santiago Basin.

Unlike in other parts of NE Peru, Cretaceous sedimentation in the Santiago Basin is greatly influenced by pre- and syn-depositional tectonics. Thickness variations across many of the wrench faults identified in the basin is often quite dramatic, varying at times by more than 30%. The four cross-sections presented in Figures 10 to 13, demonstrate in varying degrees, the influence that tectonics have had on Cretaceous sedimentation. The impact of this with respect to hydrocarbon potential is covered in more detail in both the Well Summaries and Prospect Sections of this report.

5.3.1 Cushabatay Formation

The Cushabatay Formation of lowermost Cretaceous age, consists predominantly of fluvial, braided stream deltaic and shallow marine littoral sandstones interbedded with minor thin shale and siltstone beds. The sandstones are fine- to very coarse-grained and conglomeratic, and the shales are light grey to light brown and coaly. Generally, the Cushabatay Formation rests on a regional unconformity beneath which subcrops rocks of the Upper Jurassic Sarayaquillo Formation, and locally the Pucara Group and Paleozoic formations. The unit is overlain by the Raya Formation into which, it passes transitionally.

5.3.2 Raya Formation

The Raya Formation represents a regional marine transgression during Albian time, which resulted in the deposition of a shale-limestone-sand sequence. The unit grades transitionally upwards into the Agua Caliente Formation. A minor maximum flooding surface can be interpreted at mid-Raya level. This interval is referred to as the Esperanza Member, and consists of marine shales with some limestone intercalations. These shales have proven to be good seals for underlying oil and gas accumulations.
In the Santiago Basin the Raya Formation is represented by a thinly bedded shale-limestone unit as is found in the Caterpiza 1X and Pupuntas 1X wells.

5.3.3 Agua Caliente Formation

As originally defined in the greater Marañon Basin, the Agua Caliente Formation consists primarily of a white, fine- to medium-grained sandstone with a kaolinitic matrix, and contains few intercalations of thin, light grey to light brown coaly shales and occasionally light brown siltstones and mudstones. In the Santiago Basin this unit is represented by a shale with minor sandstone interbeds.

5.3.4 Chonta Formation

The Chonta Formation is a thick, marine transgressive-regressive sequence uniformly distributed throughout the sub-Andean basins and represents the major marine flooding event that occurred during Cretaceous time. The Chonta Formation is composed largely of light grey to greenish grey, glauconitic, fossiliferous shales with some intercalations of fine-grained, glauconitic sandstones and occasionally light grey, micaceous and coaly siltstones. Micritic limestones become common towards the western portion of the greater Marañon Basin and especially in the Santiago Basin.

The Chonta Formation is the principal source rock of hydrocarbons in the greater Marañon Basin and to date, almost all of the oil seeps and shows in the Santiago Basin have been typed back to the Chonta shales.

5.3.5 Vivian Formation

The Vivian Formation is a distinctive, dominantly quartz arenite sandstone with minor thin interbeds of dark grey shale, claystone and siltstone at its base and top. The sandstone is white to light grey, fine- to very coarse-grained and conglomeratic with a framework composed dominantly of hyaline, round to subangular quartz. These fine- and medium-grained sandstones are very well sorted, friable, generally porous and permeable, and are the principal hydrocarbon reservoirs in the NE Peru.

A thin Vivian sandstone, designated the “Bubble Sand” was found on top of the Vivian Formation in the Tanguintza 1X well separated from the principal Vivian sandstone by a 30+m shale interval. The “Bubble Sand” had large and interconnected pore space while the main blocky sandstone had reduced intergranular porosity which was a result of compaction and cementation. Porosity destruction by deep burial diagenesis has been typical within the Vivian section encountered in many of the Santiago Basin wells.

5.3.6 Cachiyacu Formation

This is a marginal marine sequence of medium grey shales and claystones with thin, very fine-grained sandstones and siltstone, occasionally with glauconite and coal fragments. It represents the last marine inundation, which occurred at the end of Cretaceous time.
Figure 10: Stratigraphic section flattened on top of the latest most Cretaceous Cachiyacu Formation showing the presence of an old structure at the Putuime location with an abnormally thin Cretaceous section, a deeply eroded Chonta section truncated by a pre-Vivian unconformity, and a pre-Cretaceous anhydritic unit which is believed to be representative of an inverted graben that was uplifted and eroded in pre-Cretaceous time.

Figure 11: Stratigraphic section flattened on top of the late Eocene Pozo Shale displaying continuity of correlations between the Santiago and western Marañon Basins. Note the; Paleocene-Cretaceous section thickening westward towards the Tanguintza area; the deeply eroded Chonta Formation; and the pre-Cretaceous anhydritic unit of possible lower Sarayaquillo to Pucara age in the Putuime well.

Figure 12: Stratigraphic section flattened on top of the latest most Cretaceous Cachiyacu Formation in the Santiago/Nieva Depression. Local inversion at Putuime is evidenced by the uplift and erosion of the Sarayaquillo in pre-Cretaceous times. The corresponding anomalously thin Cretaceous section above, is due to early Cretaceous thinning and a pre-Vivian uplift and erosion of the Chonta section. A similar situation is interpreted seismically north of the Caterpiza well, displayed in the Pseudowell North.

Figure 13: Stratigraphic section flattened on top of the late Eocene Pozo Shale in the Santiago/Nieva Depression. Note how local and regional tectonics continue controlling formation thicknesses of Lower Tertiary sediments as at Putuime and to the north of Caterpiza.

The figures 10, 11, 12 and 13 appear in the Annex I.
5.4 TERTIARY MEGA SEQUENCE

Deposition of Tertiary aged sediments was initiated with the Lower Puca Formation of Paleocene age. This is a molasses sequence consisting of a coarsening upward mainly terrigeneous clastic unit, which includes the Manseriche, Santiago Sandstone and Putushin Members. In this report the Santiago Sandstone name replaces the previously used Casablanca Sandstone to differentiate it from the Casablanca Formation of Cretaceous age found in the Marañón and Ucayali Basins.

Deposition of the Lower Puca Formation is characterized by small scale cycles of a few meters that result in the deposition of fine-grained, shallow marine sandstones and end with continental paleosoils in its lower section. The unit becomes more continental and coarser in its upper section.

The Pozo Formation also of Eocene age, overlies the Lower Puca Formation locally with angular unconformity. This formation was initiated during a period of transgression that begins with a thin tuffaceous and conglomeratic unit at its base and culminates with the deposition of a marine shale, the Pozo Shale. The Pozo Shale is considered to have excellent hydrocarbon source potential although in most areas it is immature.

At the end of Eocene time, regressive sedimentation resumed with the deposition of the Oligocene to Miocene aged, Upper Puca Formation. The Upper Puca Formation in this report includes the Pozo Regressive and the Upper Puca Formations together, which are described separately in literature elsewhere.

The Nieva Formation of Pliocene age unconformably overlies the Upper Puca Formation and is composed primarily of a quartzose fine-grained to occasionally conglomeratic unit in excess of 4750m in thickness in the SW portion of the Santiago Basin.

5.5 DISCUSSION OF THE PRE-CRETACEOUS TO EARLY TERTIARY FORMATIONS

Below is a summary on the current state of our investigations of the late pre-Cretaceous, Cretaceous and early Tertiary Formations in the Santiago Basin study area as interpreted from wells, seismic and regional geology. The four stratigraphic cross-sections included with this report, Figures 10, 11, 12 and 13, show the stratigraphic relationships of these formations within the Santiago Basin. Two of the sections, Figures 10 and 11 extend to the Chapuli 1X well in the western portion of the Marañón Basin. The points to emphasize related to these sections are listed below:

- The Cretaceous to early Tertiary section in the Marañón Basin continues to thicken westward into the Santiago Basin (Figures 10 and 11).
- The overall sand/shale ratio of the Cretaceous in the Chapuli 1X well is low and this ratio decrease further to the west, into the Santiago Basin. This change
is based on the following observations in the Manseriche 1X, Putuime 1X and Tanguintza 1X wells (Figures 10 and 11).

- The Agua Caliente is predominantly comprised of shale in the Santiago Basin. The base of this unit may be represented by the Chonta Sandstone Marker.

- The overall thickness of the Chonta and Raya formations have thickened and limestone has become a significant component to both formations. This would indicate a substantial decrease in siliciclastic material basinward in the western Marañon and Santiago basins.

- The stratigraphic interval between the Cushabatay and Vivian Formations in this report has all been designated as Chonta and this in turn, has been divided into three separate units:
  - An upper, mainly shale and limestone unit with a 50 meter-thick limestone near its base (Chonta Formation?). In the Tanguintza 1X well, this unit is present as a fine-grained shaley sandstone with good hydrocarbon shows (Figure 29) that may be representative of an additional upper Chonta unit or a facies change.
  - A middle unit (Agua Caliente Formation?) comprised primarily of shales with minor sandstone. This unit contains a 40m thick basal sandstone as demonstrated by the Pupuntas 1X and Manseriche 1X wells. The above mentioned limestone in the Upper Unit, and this sandstone correlate well with Chapuli 1X.
  - The lower unit is made up of shale and limestones (Raya Formation?), similar to the upper unit. The top of this unit is considered to be the “Chonta Sandstone” as shown in (Figures 10 and 11).
  - For simplification, the middle and lower units are considered as “Chonta-Agua Caliente-Raya Undifferentiated” in this report.

- A very abnormal pre-Cretaceous and a thin Cretaceous section was drilled by the Putuime 1X well. A similar scenario is seismically interpreted north of the Caterpiza 1X well and this interpretation has been projected into the cross-sections presented in Figures 12 and 13.

- The Putuime 1X well TD’d in a anhydrite unit (133+ m.), underlying the Cushabatay Formation. For the past 30 years this anhydrite has been interpreted, as being of Tertiary age. PARSEP, however, interprets this occurrence of anhydrite to be pre-Cretaceous in age and the same as the evaporite unit present in the Peruvian Fold Thrust Belt discussed previously in Section 5.2.3. Further reference to this in the Putuime well summary in Section 6.3
• The Cushabatay Formation in the well is only 600m thick versus an expected minimum of 800m, the Chonta Formation is only 138m thick versus 800m seen in the Campanquiz area to the west, and the Vivian Formation is 20m thick whereas over 100m of the same was drilled by the Piuntza 1X well just to the north. Thinning of the lower Cretaceous is interpreted to be the result of tectonic rejuvenation of the Putuime fault during the early Cretaceous. Further reactivation resulted in a pre-Vivian erosional episode that removed most of the Chonta section and resulted in a thinner section of early Tertiary sediments.
6.0 WELL SUMMARY

A total of seven wells have been drilled in the Santiago Basin (Figure 2 and Table 1). The first three Dominguza 1X, Piuntza 1X, and Putuime 1X, were drilled by Mobil Oil between 1968 and 1969. The Basin did not experience any further drilling until the 1990’s when QMC drilled four wells between 1996 and 1998.

Although all wells drilled to date in the basin have been completed as dry holes, a number have had hydrocarbon shows. The most significant of these was in the Tanguinta 1X well, which flowed 6.3 MMcfd gas and 478 bpd condensate from a test in the Upper Vivian Sandstone.

### Table 1: List of wells drilled in the Santiago Basin

<table>
<thead>
<tr>
<th>WELL</th>
<th>OPER</th>
<th>YR</th>
<th>TD</th>
<th>FMTD</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominguza 1X</td>
<td>Mobil</td>
<td>1968</td>
<td>3,091 m</td>
<td>Tertiary</td>
<td>D&amp;AOS</td>
</tr>
<tr>
<td>Piuntza 1X</td>
<td>Mobil</td>
<td>1968</td>
<td>4,020 m</td>
<td>U Chonta</td>
<td>D&amp;AOS</td>
</tr>
<tr>
<td>Putuime 1X</td>
<td>Mobil</td>
<td>1969</td>
<td>3,722 m</td>
<td>PreCretaceous</td>
<td>D&amp;A</td>
</tr>
<tr>
<td>Caterpiza 1X</td>
<td>QMC</td>
<td>1997</td>
<td>3,760 m</td>
<td>Vivian(#3)</td>
<td>D&amp;A</td>
</tr>
<tr>
<td>Pupuntas 1X</td>
<td>QMC</td>
<td>1997</td>
<td>2,255 m</td>
<td>Cushabatay</td>
<td>D&amp;A</td>
</tr>
<tr>
<td>Manseriche 1X</td>
<td>QMC</td>
<td>1997</td>
<td>716 m</td>
<td>Cushabatay</td>
<td>D&amp;A</td>
</tr>
<tr>
<td>Tanguinta 1X</td>
<td>QMC</td>
<td>1998</td>
<td>5,296 m</td>
<td>U Chonta</td>
<td>D&amp;AGS</td>
</tr>
</tbody>
</table>

Below in chronological order is a detailed description on each of the seven Santiago wells and a discussion on their results. A summary sheet for each of the wells is presented in Appendices 1a to 1-g. The Appendices 1a to 1g appear in the Annex III.

6.1 DOMINGUZA 1X

The first of three Mobil wells, Dominguza 1X, commenced drilling on January 16, 1968 and was completed as a dry hole on April 28, 1968 (Figure 2). The well was spudded in the Lower Pozo Formation and had a TD of 3,091m (10,142’) in the Tertiary Lower Puca Formation after apparently cutting four thrust faults within the Lower Puca section. The presence of a distorted and faulted section below 1819m (5970’) is supported by dipmeter data (QMC, 1998). The primary objective, the Cushabatay sands and the secondary objective, the Vivian sandstones were never penetrated.

The well was drilled as a deviated hole, but no well bore survey records could be found in the Perupetro archives and consequently it’s exact location in the subsurface is unknown. A map of the Dominguza structure is presented in Figure 14 and a seismic line through the well in Figure 15.

6.1.1 Reservoirs

The objective Cretaceous reservoirs were never reached.

The only reservoir encountered in the drilled section was the Tertiary aged Casa Blanca(?) sandstone, which had sonic porosities of 12% to 30%. Water saturations for the interval 894m (2935’) to 896m (2942’) range from 27% to 48%; however, "precise
Figure 14: TWT map on the Chonta Fm showing the structure tested by Dominguza 1X

Figure 15: Seismic Line GSI-50-270 through the Dominguza 1X well
saturation values are in doubt because the formation factor could not be determined reliably due to abnormally high, spiked delta- T values” (Mobil well report).

6.1.2 Hydrocarbon Shows:

From the Mobil well report on the well, the following shows were noted:

- **Tuff Mbr., Pozo Fm.** - Poor to fair oil shows from 37m to 52m (117-170’)
- **Putushim Mbr., Lower Puca Fm.** – Poor to fair oil shows from 52m to 888m (170-2,914’)
- **Casa Blanca(?) Sandstone** – Poor to fair oil shows from 888m to 920m (2,914-3,019’)
- **Manseriche(?) Mbr., Lower Puca Fm.** - Poor to fair oil shows from 920m to 1,442m (3,019-4,730’) and poor to very poor, questionable oil shows from 1442m to 2,533m (4,730-8,310’)
- Other oil shows occurred in the mud system while drilling from 229m to 945m (750-3,100’)
- Oil shows were found in 18 sidewall cores obtained from the interval 41m to 899m (136-2,950’)

The Corelab PD gas detector recorded gas shows while drilling from 156m to 2,242m (511-7,355’) with values ranging from 4 to 270 units, and on occasion, the detector was saturated (greater than 270 units). The frequency of shows was the highest and the recorded values the greatest, above 1,177m (3,867’). Below this depth gas shows occurred sporadically and usually were smaller than 20 units. Saturation of trip gas were common to 2961m (9,716’).

Based on log calculations and drilling shows (formation oil flowed over the shale shaker), a DST of a 5’ interval at 894m (2932’) to 895m (2937’) was run in what was interpreted to be the Casa Blanca(?). The test recovered 30’ of rat-hole mud, 2’ (1.17 gal) of oil-cut mud and a trace of free oil after being open for 17 hours. The Casa Blanca sandstone was concluded to be impermeable and having only fracture permeability, as indicated by the microlog (QMC, 1998).

6.1.3 Well Analysis

According to the PARSEP mapping, Dominguza 1X was drilled significantly off structure on the northeastern plunge of a narrow but lengthy northwest fault bounded structure (Figures 14 and 15). As a result the Dominguza structure despite it’s significant oil shows in the Tertiary, remains untested and as a result is in our current portfolio of Santiago prospects.

6.2 PIUNTZA 1X

The Mobil Piuntza 1X well was drilled after the Dominguza 1X at a location 32 km to its north (Figure 2). The Piuntza 1X well was proposed to test the crest of a nearly
symmetrical, north-south plunging anticline mapped by surface geology, photo-
geology, and good to phantom seismic (QMC, 1998). The primary objective was the
Vivian sandstone and the secondary objective was the Casa Blanca sandstone. The well
was spudded on May 13, 1968 in the upper Puca Formation and completed as a dry
hole on October 17, 1968 at a TD of 4,022 (13,194') in the Chonta Formation. The well
was deviated slightly and had a TVD 3,892m (12,772').

The map of the Piuntza structure (Figure 16) shows that the well was drilled within
structural closure in a near crestal position. A seismic line through the well is presented
in Figure 17.

6.2.1 Reservoir

The Vivian Formation was logged from 3,892m (12,771') to 4,002m (13,131'); its upper
part was conventionally cored. Just over nine feet were recovered from the 27' cored
interval at 3,894m (12,778') to 3,902m (12,805'). This is near the top of the formation
where logs show the sandstone to be shaley (tight). This was later verified by the core
porosity measurements carried out at the Mobil Field Research Laboratory (Dallas,
TX). For nine of the samples analyzed, porosities ranged between 3.7% and 7.2%. Seven of the samples also had permeability measured and values ranging from 0.07md
to 21.4md. The mean permeability is 7.4md, which indicates heterogeneous
permeability with a few "streaks" of fair to good permeability. Sonic log porosity for
the Vivian sandstone is found to range between 2% and 12% with an average of about
7.5%.

Ditch and junk basket samples, and a core from the Vivian, showed that the unit is
predominately a dense, hard quartzitic sandstone with only local zones or “streaks” of
relict porosity and permeability. Permeability has not been greatly enhanced by
fracturing.

The secondary objective, the Casa Blanca sandstone member of the Lower Puca
Formation was drilled from 2,523m (8,280') to 2,554m (8,380'). Log quality through
the interval is very poor due to caved-out hole. Its evaluation was based on induction
and sonic logs and good quality ditch samples. Sonic porosity ranged between 15%
and 18.5% and water saturation, between 38% and 100%. Logs indicate that not more
than 6m (20') of net porous sand are present and in intervals too thin to have
commercial value. Furthermore, the absence of separation between the short normal
and induction curves indicates very low permeability (QMC, 1998).

6.2.2 Hydrocarbon Shows

Sample shows described in Mobil well report are as follows:

- **Casa Blanca Mbr. Lower Puca Fm.** - Poor oil shows were found in the
ditch samples
- **Manseriche Mbr., Lower Puca Fm.** - Very poor oil shows were noted
from 2,554m to 2,905m (8,380-9,530)
- **Cachiyacu Formation** - Traces of oil (very poor shows) were found in
ditch samples of the sandstone from 3,780m to 3,886m (12,400-12,750')
- **Vivian Sandstone** - Fair oil shows were found from 3,893m to 3,916m (12,773-12,850’). Below 3,916m (12,850’) the percentage of “sandstone” with oil shows gradually decreased to a trace by 4,002m (13,130’).

The Corelab PD gas detector recorded the following gas shows while drilling at the following unlagged levels:

- **Shale Mbr., Pozo Fm** - 2,085m (6,842’) and 2,087m (6,848’)
- **Tuff Mbr., Pozo Fm.** - 2,107m (6,914’), 2,108m (6,916’) and 2,119m (6,951’)
- **Putushim Mbr., Lower Puca Fm.** - 2,182m (7,158’), 2,229m (7,314’), 2,487m (8,160’), 2,500m (8,202’), 2,511m (8,238’), and 2,513m (8,246’)
- **Casa Blanca Mbr. Lower Puca Fm.** - 2,530m (8,300’), 2,533m to 2,536m (8,312-8,320’), 2,547m (8,355’), 2,548m (8,359’), and 2,555m (8,382’)
- **Manseriche Mbr., Lower Puca Fm.** - 2,562m (8,407’), 2,586m (8,485’), 2,625m (8,611’), (8,635’), 2,658m (8,722’), 3,417m (11,211’)
- **Vivian Sandstone** - 3,931m (12,897’)

The gas detector reached values up to 100 units. The highest values were recorded in the Putushim and Casa Blanca Members of the Lower Puca Formation. A 2 unit gas kick occurred in the Vivian.

Five drill stem tests were run in the Vivian sandstone, after running 7” liner to evaluate the sample and log shows across this interval. These tests are presented below in Table 2.

<table>
<thead>
<tr>
<th>DST</th>
<th>Depth</th>
<th>Recovered</th>
<th>CI (ppm)</th>
<th>Time Tool Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3993m-3996m 13,101’-13,113’</td>
<td>9.4 bbl fm water</td>
<td>170,000</td>
<td>3 hours</td>
</tr>
<tr>
<td>2</td>
<td>3934m-3937m 12,908’-12,918’</td>
<td>80 bbl fm water</td>
<td>186,000</td>
<td>6 hours</td>
</tr>
<tr>
<td>3</td>
<td>3924m-3927m 12,876’-12,886’</td>
<td>23 bbl fm water</td>
<td>185,000</td>
<td>2 hours</td>
</tr>
<tr>
<td>4</td>
<td>3919m-3922m 12,858’-12,868’</td>
<td>22.5 bbl fm water 8.2 bbl water &amp; sli gas cut mud</td>
<td>175,000</td>
<td>2 hrs 15 min</td>
</tr>
<tr>
<td>5</td>
<td>3901m-3908m 12,800’-12,822’</td>
<td>0.34 bbl 37.9° API gravity oil</td>
<td></td>
<td>4 hours</td>
</tr>
</tbody>
</table>

*Table 2: DST results from Mobil Piuntza 1X Well*
Figure 16: TWT map on the Chonta Fm showing the structure tested by Piuntza IX

Figure 17: Seismic line GSI-50-205 through Piuntza IX
DST #4 is above an inferred oil/water contact at about 3922m (12,870') (Appendix 2c) suggesting that the rock is very tight, unable to produce any oil, and that the formation water entered from fractures (QMC, 1998). The Appendices “1a” to “1f” appear in the Annex III.

Across the DST No. 5 interval, a sonic log porosity of 8% to 12% was calculated by Mobil from three streaks totaling 7' of "good" porosity. Mobil concluded that the Vivian sandstone has very low permeability overall and was not capable of producing in commercial quantities. Of interest was the analysis of the DST #5 oil done by the Mobil Field Research Laboratory, Dallas for correlation to the seeps within Block 50. They concluded that “The crude oil is most similar to seep samples FRL 3439 and FRL 3442, both from the Pozo Formation, separated by about 40 km. The seeps are about 17 miles north (No.3439) and 7 miles south (No.3442) of the Piuntza 1X well. The oil samples from the DST's at the Piuntza-I and Dominguza-I are themselves quite similar in spectral character, overall composition, and C13 abundance indicating probable common or at least very similar sources’ (QMC, 1998). It should be noted that this is the only reference encountered in our review of the Santiago data that emphatically states that the oil encountered had been typed back to the Pozo Formation.

6.2.3 Well Analysis

The Piuntza 1X well was a valid test of the mapped structure intersecting the objective section in a near crestal position. The structure, however, is a young feature and consequently, no trap was present to receive an early hydrocarbon charge that would have preserved sandstone porosity and permeability against later burial diagenesis.

The presence of oil within the Vivian section does indicate the generative capacity of the Santiago basin and that even young Tertiary structures potentially can receive hydrocarbon charges. This is interesting in the fact that this is contrary to what is generally accepted in the Marañon Basin to the east, where young structures are typically found to be barren of hydrocarbons.

6.3 PUTUIME 1X

Putuime 1X was the last well of the Mobil drilling campaign. It was spudded on October 30, 1968, 13 km west of the Dominguza 1X well (Figure 2) and was completed as a D&A well on May 26, 1969. It was drilled to evaluate a highly faulted, northeast-southwest trending, asymmetrical anticline (Figures 18 and 19). that was defined by surface geology, photo-geology, and seismic interpretation. The primary objective was the Cushabatay sandstone at 3,526m (11,570') and the secondary objectives were the shallower sandstones of the Vivian and Lower Puca Formations. A sidetrack of the original well bore, which was drilled to 3,212m (10,539’), was made at 2,902m (9,523’) within the Chonta section and taken down to a final TD of 3,722m (12,212’).

In the final Mobil well report, the well was described as having cut a major thrust fault at 3,573m (11,725’) above which, is Cushabatay sandstone and below which, is a package of possibly Tertiary-aged anhydrites. The anhydrite is quite massive and very
much unlike anything encountered at shallower depths to date in the region. Additionally, it is difficult to interpret this proposed fault seismically and see no

Figure 18: TWT map on the Chonta Fm showing the structure tested by Putuime IX
Evidence that it exists (Figure 19). Without such a fault, it is virtually impossible to put the Cushabatay in fault contact with Tertiary evaporites as others have done in previous studies of the well. Consequently, we have elected to assign a pre-Cretaceous age to the anhydrite, and are suggesting that it represents the evaporitic transitional unit separating the Sarayaquillo and Pucara Formations. The Sarayaquillo, however, due to a pre-Cretaceous inversion, was uplifted and completed eroded putting the Cushabatay in contact with the anhydrite.

Additionally, the Putuime IX well has marked stratigraphic thinning over Cushabatay through to the Vivian and Lower Pucara section indicating that this area was also a structurally positive area from the Cretaceous through to the present. Seismically, it is interpreted that a significant unconformity separates the Vivian Formation from the Lower Chonta and that the Upper Chonta has been eroded due to a syn-Cretaceous uplift.

### 6.3.1 Hydrocarbon Shows

The following is a list of sample shows described in the Mobil well report for each of the formations:

- **At 1,720m (5,645‘) one fragment of tuffaceous sandstone had some faint brown specks of dead oil.**
- **Casa Blanca Sandstone** - Tar/dead oil specks were found in some 2-15% of the from 1,926m to 1,937m (6,321-6,358’).
- **Vivian Sandstone** - Poor Oil shows were found from 2,834m to 2,862m (9,299-9,390’)
- **Chonta Formation** - In the original hole, a few specks of dead oil were reported from sandstone at 2,970m to 2,972m (9,745-9,750’) and 2,988m to 2,992 (9,805-9,816’) and some wet chips of carbonaceous shale and coal had traces of gas at 2,969m to 2,970m (9,740-9,745’) and 2,972m to 2,974m (9,750-9,755’).
- **Cushabatay Sandstone** - In the original hole very poor oil shows were observed in shaley siltstones from 3,101m to 3,114m (10,175-10,215’) and traces of very fine-grained quartzose sandstone had specks of dead oil from 3,164m to 3,174m (10,380-10,415’). In the sidetracked hole, traces of sandstone at 3,004m to 3,007m (9,857-9,865’), 3,040m to 3,045m (9,974-9,991’), 3,123m to 3,126m (10,246-10,255’), 3,257m to 3,267m (10,687-10,717’), 3,508m to 3,522m (11,510-11,556’) and 3,552m to 3,564m (11,655-11,692’) had a few specks of dead/tar oil. At least some of the shows reported in the Cushabatay Sandstone may be due to contamination of “Stabil-hole”, a blown asphalt-tar mud additive.

The Corelab PD gas detector recorded gas shows while drilling at the following unlagged levels:

- **Vivian Sandstone** – 2,844m to 2,848m (9,337-9,344’), with reading up to 95 and 125 units recorded
• **Chonta Formation** – 2,926m (9,601’). The highest gas detector value, 250 units-saturation, was recorded in the Chonta Formation. Since this gas show cannot be assigned to any porous zone, it is assumed that it came from some shale and or coal bed.

An analysis done by Mobil of the log data and ditch samples of the Vivian sandstone, indicated that a gross oil column of 28m (91') with 17m (55') of clean, quartzose sandstone within the unit is present. Water saturations values were calculated ranging from 17 to 52%.

### 6.3.2 Reservoir

The primary objective Cushabatay sandstone is predominantly quartzose sandstone with intercalations of bedded tuff and shales. Sandstone porosity is mostly poor, ranging in sonic porosity from 6.4% to 13.5% with an average of 9.3%. The microlog indicates the presence of some mudcake and permeability - about 134m (440') of net porous sand. Three of seven attempted Formation Interval Tests across this zone were considered mechanically good, but no fluid was recovered, from which it was interpreted that the formation is too tight to produce.

The Vivian sandstone was drill stem tested after a 7" liner was set. Recovery was 130 bbl. of salt water (137,000 ppm Cl) after a 45 minute flow period. The strong salt water flow (calculated as 4,200 bbl/day) was interpreted to have come from underlying fractured Cushabatay. The Vivian section was concluded as too tight to produce, probably due to burial diagenetic alteration involving framework compaction and silicification as secondary quartz overgrowths. Fracturing of the Cushabatay is indicated by some cycle-skipping on the sonic log below 3,182m (10,440’) and the fact that 500 bbls of mud was lost in the hole while drilling at 3,219m (10,560’). Furthermore, the CBL shows no cement bond between the Vivian and the 7" liner and the recorded pressures indicate that flow was most probably from the Cushabatay sandstone (QMC, 1998)

### 6.3.3 Well Analysis

The Putuime 1X structure has been a positive structural feature through most of its geological history. Present closure is significant at all Cretaceous levels but is fault dependent. Oil shows in the Vivian and Cushabatay indicate hydrocarbons have at least migrated through the Cretaceous section in the Putuime structure.

The Putuime 1X well did not test the structure in a crestal position so there is still the possibility of an accumulation updip from the well in the Cushabatay over 700 ms structurally higher as seen on the map and seismic line presented in Figures 18 and 19. The presence of permeable fractured Cushabatay and oil shows in the Vivian make this an attractive lower risk prospect although closure southwest of the well is not well defined because of no seismic coverage.
6.4 CATERPIZA 1X

The Caterpiza 1X well was spudded on January 13, 1997 and was the first of four wells to be drilled by the QMC consortium and was proposed to test a structural closure related to thrust faulting. QMC acknowledged prior to the drilling of the well, that there was no evidence from the isochron mapping done over the location that would indicate the feature to have had any early structural growth, and consequently, that the destruction of reservoir quality due to deep burial diagenesis was a risk. Our interpretation has the structure as a well defined flower structure as depicted in Figures 21 and 22.

The well was abandoned on June 14, 1997 at a TD of 3,760m (12,335') after penetrating three repeats of the Vivian Sandstone, due to thrust faulting. All were encountered tight and wet. At that point QMC, considered that both; the Cushabatay was outside structural closure as a result of the complex faulting; and that the adverse effects of burial on reservoir quality (Vivian section) encountered to that point were sufficient reasons to terminate the well early. Consequently, the Cushabatay sandstone, the principal objective, was never penetrated.

6.4.1 Hydrocarbon Shows

Forty-two shows were logged during the drilling of the well, all of which were rated as poor to very poor oil shows. No significant drilling breaks were associated with the shows.

- **Casa Blanca Sandstone** - two sample shows were recorded.
- **Manseriche Mbr., Lower Puca** – had three sample shows of which one had the highest recorded gas show in the well at 178 units with C1 to C4’s.
- **Faulted Vivian Section** - thirteen shows were recorded in the first Vivian Sandstone which had the well’s second highest gas show at 43 units with C1 to C4’s; two shows were within the second Vivian Sandstone, two shows were within the Lower Puca and/or Cachiyacu, and eighteen were within the third Vivian Sandstone. Bitumen (tar) was noted as a common constituent in all the Vivian sandstones and found to partially occlude inter-granular pore space. It is an important contributor to the reduction of reservoir quality of the sandstone.

6.4.2 Reservoir

The Vivian Sandstone encountered in all three penetrations was hard, compact and with siliceous cement. The sandstones were tight with poor porosity having experienced extensive post-depositional alteration. Compaction and cementation had reduced porosity significantly so that now, the average porosity of the Vivian sandstones as calculated from core data, is around 9%. Well log data was less generous averaging the porosity at 7.3%. Average measured permeability for the Vivian was about 12md.
Within the Casa Blanca Sandstone the average porosity across the cleaner zones, as calculated by QMC (1998) was 14.7%.

Figure 20: TWT map on the Chonta Fm showing the structure tested by the Caterpiza IX well
6.4.3 Well Analysis

QMC concluded that the area of closure at Top 1st Vivian was very small and that the seals, the first being a lateral seal against salt(?) to the north, and the second, a fault seal to the east, were not effective. The low permeability and porosity encountered in the Lower Puca and Vivian sandstones was attributed to deep pre-uplift burial. A very thick Lower Puca stratigraphic section resulted in much deeper depths to the Cretaceous objectives than was originally predicted by QMC.

Our conclusions differ somewhat in that the Caterpiza well was drilled on a structure with significant fault dependent closure (Figure 7). No salt has been interpreted as being associated with the Caterpiza structure. Recurrent movement along the ‘sealing’ fault, breached any hydrocarbon accumulation that may have been there in the past. The sample shows and bitumen identified in the Vivian sandstone support the presence of a paleo-oil field or at least the evidence that migrated oil passed through the formation and up the non-sealing fault system at some point in time.

6.5 PUPUNTAS 1X

The Pupuntas 1X (Figure 2) spudded July 11, 1997 and was abandoned October 4, 1997 at a depth of 2255m (7397') in the Cushabatay Formation. The principal objectives of the Pupuntas 1X well were the Cretaceous Vivian and Cushabatay sandstones. The feature tested was a faulted anticlinal structure within the footwall section of the Japaima Thrust Fault (Figures 22 and 23). Closure was dependent upon a fault seal against an interpreted juxtaposed salt section (QMC, 1998) on the hanging wall of the fault. This study suggests that the juxtaposed section is Tertiary red beds and that the QMC interpreted salt does not exist.

6.5.1 Hydrocarbon Shows

The objective reservoirs were encountered being either wet or tight. Very few shows of any significance were noted in the objective Vivian and Cushabatay sandstones. Almost all recorded sample shows were from within the Chonta section. The highest reading on the gas detection unit of 83u was also from within the Chonta Formation.

6.5.2 Reservoir

The Vivian had fair to good measured porosity ranging from 11.5% to 17.9% with an average of 14.3%, and good to excellent permeability ranging from 504md to 1103md with an average of 504md. Although these sandstones are good reservoirs, they are fresh water wet. The Cushabatay and secondary objective sandstones of the Lower Puca and Chonta Formations on the other hand had poor porosity and permeability in addition to being wet. The Cushabatay had porosities ranging from 3.2 to 12.3% with an average of 9.3%, and permeabilities ranging from 0.002 to 113md with an average of 13.2md. The principal cement for the Vivian and Cushabatay sandstones is quartz, commonly as euhedral overgrowths, which resulted in loss of reservoir quality.
Figure 22: TWT map on the Chonta Fm showing the structure tested by the Pupuntas 1X well.
Figure 23: Seismic Line Q96-415 through the Pupuntas 1X well

Figure 24: Depth – Porosity plot of the Vivian Sandstone in the wells drilled in the Santiago Basin
Of all the wells drilled in the Santiago Basin the Pupuntas 1X well by far had the best porosity and permeability development within the Vivian sand section. A depth vs. porosity plot of the four Santiago wells that penetrated the Vivian Formation for comparison sake is presented in Figure 24.

6.5.3 Well Analysis

Success of the Pupuntas well was dependent upon fault closure. To enhance the possibility of fault closure, QMC suggested that the juxtaposed section on the hanging wall (sealing side of fault) was salt. We do not interpret any salt in this structure nor do we do so within any structure at shallow depths, within the Santiago Basin. This issue is described in somewhat more detail within Section 4.3 of this report. All that being said, the well was excellently located and drilled on a well defined, fault closed structure on the ‘downside block’ of a faulted anticline.

Pupuntas 1X is anomalous with respect to the other wells in the Santiago Basin in that it has good to very good porosity and permeability. This is the case despite the fact that the vitrinite reflectance data (QMC, 1998) indicates that the Vivian was buried to at least 5000m prior to uplift. Similar paleo-burial depths were derived by us through estimates utilizing seismic data, of eroded Tertiary section. At 5000m the Vivian should have experienced the same burial diagenesis history as the other wells.

Figure 25: Seismic line Q95-407 just north of the Pupuntas 1X well, demonstrates the thinning in the Cretaceous and Lower Tertiary sections (on the downthrown block) and which supports an early positive structural history to the Pupuntas feature
Obviously, this was not the case. Our explanation is that the Pupuntas location was once the site of a very significant hydrocarbon accumulation trapped within the Vivian Sandstone. The presence of hydrocarbons in the formation protected the reservoir from porosity destructive diagenesis as the basin was subsiding. During the most recent Andean uplift the seal was breached and the Vivian reservoir in turn was flushed with fresh water.

In support of the above, seismic line Q95-407 which is first line north of the Pupuntas 1X well (Figure 22), is presented in Figure 25. It shows that there is considerable thinning within the Cretaceous and Lower Puca section on the present day footwall block of the structure. At the onset of Chonta oil generation, the Pupuntas feature appears to have been a large structural high and probably the focal point for accumulation. A late Tertiary inversion reversed the sense of the blocks and gave the Pupuntas Structure it’s present configuration.

6.6 MANSERICHE 1X

Manseriche IX (Figure 2) spudded in the Chonta Formation on October 27, 1997 and was abandoned on November 21, 1997 at a depth of 716m (2348') in the Cushabatay Formation. The well tested the Cretaceous Chonta (Chonta Agua Caliente and Raya) and Cushabatay sandstones. The primary objective was the Cushabatay on the Campanquiz anticline (Figure 22), a regional structural feature found along the entire eastern border of the Santiago basin that separates the Marañon basin from the Santiago Basin. The Manseriche high is a segment of this trend that been compartmentalize from the main trend by significant several right lateral wrench faults. A seismic line over the well is presented in Figure 26.

No significant hydrocarbon shows were noted and the objective reservoirs were found to be tight and/or fresh water wet.

6.6.1 Hydrocarbon Shows

Eleven hydrocarbon shows were logged in the sandstones of the Chonta and Cushabatay Formations. All were rated as poor to very poor shows.
- **Chonta Formation** - Eight shows were logged and fluorescence across this section was typically described as “weak, dull gold/pale yellow; weak dull orange”. The maximum gas reading in the Chonta was 60 units with C1-C4’s. Very minor tar/asphaltic shows noted.
- **Cushabatay Formation** - Three shows were reported and the samples had weak dull gold/pale yellow/yellow white fluorescence. The highest gas reading recorded was 40 units with C1-C4’s. Very minor tar/asphaltic shows noted.

6.6.2 Reservoir

All of the objective sandstone reservoirs had poor porosity and permeability development. The Chonta sandstone porosities were all below 10% and typically they were in the 6 to 7% range. Measured permeabilities were all below 1md. The highest
recorded porosity for the Cushabatay was 11.5% and the highest permeability was 44.6md. More typically, however, the Cushabatay porosities were in the 7 to 8% range and permeabilities were below 1md.

6.6.3 Well Analysis

The principal reason for Manseriche’s lack of success was seal. The Cretaceous section is fresh water wet and consequently, is in communication with the surface, probably via faults. The presence of such poor reservoirs within the Manseriche structure indicate that sediments were at one time at a much greater depth and underwent extensive burial diagenesis.

![Seismic line Q95-405 through the Manseriche 1X well.](image)

When putting the Manseriche 1X into a somewhat more regional context to include the area of the Pupuntas 1X well, several interesting conclusions can be reached concerning the tectonic and oil generation/migration history of the area. This in part was addressed in Section 6.5.3, the Well Analysis section of the Pupuntas 1X well, concerning the evolution of the area.

1. During the Cretaceous and Early Tertiary, the present down thrown block of the Manseriche/Pupuntas Structure was the high block as evidenced by the Cretaceous and Early Tertiary thinning depicted by the seismic lines shown in Figures 25 and 26.

2. This Cretaceous/Early Tertiary high block was the focal point of accumulation for the first pulse of hydrocarbon generation from the Chonta Formation. As is
inferred by the Pupuntas well, the early entrapment of hydrocarbons preserved the porosity within the Vivian sandstone as the basin subsided.

3. The Cretaceous/Early Tertiary downthrown block, which was tested by the Manseriche well, was not within a favorable trapping position for migrating hydrocarbons and consequently there was no preservation of porosity and permeability as the basin further subsided.

4. The Manseriche/Pupuntas high was inverted during late Tertiary time. The previous high block tested by the Pupuntas well was now the structurally lower block, and previous low block tested by the Manseriche well was now the structurally higher block.

5. During the inversion process the Pupuntas ‘accumulation’ was breached and the hydrocarbons leaked off up the fault to the surface and/or the Manseriche Block.

6. The presence of hydrocarbon shows in the Manseriche well indicate at least the migration of hydrocarbons through the Chonta and Cushabatay reservoirs. Whether these shows are actually a result of re-migrated Pupuntas oil is unknown.

7. Sealing conditions never developed in the Manseriche Block or if they did, they also were ultimately breached, and the reservoirs are now fresh water wet.

6.7 TANGUINTZA IX

The Tanguintza IX well was the first of the QMC wells to spud on Block 50 (Figure 2), which it did on November 1, 1996 and on April 25, 1998, it was the last of the four wells to be abandoned. After four side tracts, the well had a final TD of 5295m (17,375’). Objectives were sandstone of the Cretaceous Cushabatay and Vivian Formations and Tertiary Casa Blanca Member of the Lower Puca Formation. The well was TD’d in the Upper Chonta and one of the original objectives, the Cushabatay Formation, was never reached.

The Tanguintza structure is a young feature and in comparison to the other structures drilled in the basin to date, it is one of the more tectonically simplest, and easily, the broadest, in width. A map of the Tanguintza structure is presented in Figure 27 and a representative seismic line across the structure in Figure 28.

Two Vivian Sandstone sequences were encountered. The uppermost is a thin 3m (12’) sand, designated the “Bubble Sand”, which tested gas from a stratigraphic trap of very limited size. The principal and lowermost Vivian sand, designated the “Blocky Sand” was tight and did not produce when perforated. The secondary targets in the Chonta and Early Tertiary (Casa Blanca) were also tight and/or wet.

The Vivian “Bubble Sand” has better porosity and permeability than the “Blocky Sand”. This is attributed to the “Bubble Sand” being a stratigraphic trap that was filled with hydrocarbons prior to the late Tertiary orogeny. The presence of hydrocarbons terminated the diagenetic processes within the reservoir and preserved the porosity and permeability during basin subsidence.
Figure 27: TWT map on the Chonta Fm showing the structure tested by the Tanguintza IX well

Figure 28: Seismic line PM-92-335 through the Manseriche IX well
6.7.1 Hydrocarbon Shows

In the drilling of the Tanguintza 1X well, twenty-one hydrocarbon shows were logged. These are presented below in Table 3. Refer to Figure 29 for a graphical presentation of the mud log shows within the Cretaceous section. All shows were rated by QMC to be poor to very poor oil shows with the exception of #2, which was considered to be a poor to fair oil show and #3, which was considered to be a very poor gas show. In our opinion, however, shows 13 through to 17 in the Chonta represent some of the better oil and gas shows encountered in the well (Figure 29) and in the basin.

<table>
<thead>
<tr>
<th>Show #</th>
<th>Formation</th>
<th>Depth</th>
<th>Max Gas</th>
<th>Gas Comp</th>
<th>Fluorescence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Pozo (Tuff)</td>
<td>2824-2827m</td>
<td>2u</td>
<td>C1</td>
<td>NA</td>
</tr>
<tr>
<td>2a</td>
<td>Lower Puca</td>
<td>2897-2899m</td>
<td>60u</td>
<td>C1-C4</td>
<td>NA</td>
</tr>
<tr>
<td>3a</td>
<td>Lower Puca</td>
<td>3561-3562m</td>
<td>43u</td>
<td>C1-C5</td>
<td>NA</td>
</tr>
<tr>
<td>1-2</td>
<td>Vivian</td>
<td>4983-4986m</td>
<td>115u</td>
<td>C1-C5</td>
<td>Weak pale yellow</td>
</tr>
<tr>
<td>3-7</td>
<td>Vivian</td>
<td>5003-5025m</td>
<td>32u</td>
<td>C1-C3</td>
<td>Pale to bright dull gold to yellowish white</td>
</tr>
<tr>
<td>8-9</td>
<td>Vivian</td>
<td>5035-5051m</td>
<td>42u</td>
<td>C1-C3</td>
<td>Pale dull gold to yellowish white</td>
</tr>
<tr>
<td>10-11</td>
<td>Vivian</td>
<td>5076-5082m</td>
<td>41u</td>
<td>C1-C3</td>
<td>Pale to bright yellowish white to dull gold</td>
</tr>
<tr>
<td>12</td>
<td>Vivian</td>
<td>5097-5101m</td>
<td>49u</td>
<td>C1-C3</td>
<td>Pale dull gold to yellowish white</td>
</tr>
<tr>
<td>13-15</td>
<td>Chonta</td>
<td>5128-5148m</td>
<td>225u</td>
<td>C1-C5</td>
<td>Weak dull gold</td>
</tr>
<tr>
<td>16-17</td>
<td>Chonta</td>
<td>5148-5157m</td>
<td>31u</td>
<td>C1-C2</td>
<td>Weak yellowish white to dull gold</td>
</tr>
<tr>
<td>18</td>
<td>Chonta</td>
<td>5163-5168m</td>
<td>29u</td>
<td>C1-C2</td>
<td>Weak dull gold</td>
</tr>
</tbody>
</table>

Table 3: Mud log and sample shows encountered during the drilling of the Tanguintza 1X well

Very little in terms of shows were noted in any of the Sidewall Cores taken in the well with only traces of bitumen being reported.

QMC’s petrophysical analysis from well logs (QMC, 1998) indicated that the Sw for the ‘Blocky Sand’ was on average 17% based on the dual water model they ran. They also noted over most of this massive Vivian sandstone that the Density porosity was reading 1 to 3 porosity units over the Neutron porosity and stated that this slight crossover was indicative of light hydrocarbons. As there is no indication of fluid contact or a water level within the Vivian, QMC concluded that the Vivian ‘Blocky Sand’ is full to the base with hydrocarbons but it is non-producible due to low permeability. However, subdued mud log gas shows across this zone (Figure 13) and a lack of significant shows in the SWC taken across this interval puts us somewhat in doubt of this interpretation. What is interesting, is the zone between 5125-5150m, which on the mud log (Figure 29), has perhaps the best gas and sample shows noted in the well. Sample descriptions across this zone indicate the presence of a dirty, fine-grained, white to light brownish white sandstone. Unfortunately, the hole condition is very rugose at this depth and consequently, the gas may be associated with an intensely fractured zone. This zone was neither tested nor cored by QMC.
Two DST’s were conducted in the Tanguintza 1X well with both being taken within the Vivian Formation.

- DST #1 tested the lower part of the ‘Blocky Sand’ across the gross interval of 5,034- 5,081m (16,518-16,670’) to determine if a gas/water contact existed in the sand. During the test, no formation fluid was recovered. An acid job was then attempted but this was unsuccessful because of the inability to inject the acid into the formation with approximately 6000 psi positive pressure differential downhole (QMC, 1998).
- DST #2 tested the ‘Bubble Sand’ across the following interval, 4985-4989m (16,356-16,370’). The test yield gas and condensate at a maximum rate of 6.3 MMscfd gas and 478 bbls/day condensate on a 24/64” choke with 1750 psi flowing tubing pressure. The initial reservoir pressure was 12,045 psi and the final was 9,355 psi. A 2690 psi drawdown between the initial and final shut in pressures indicates a
very rapid depletion of reservoir pressure (22.3%) during the test interval and that the reservoir probably is of very limited extent.

An analysis of the gas and fluid recovered from the DST #2 of Vivian indicated that the two show similar isotopic characteristics, indicating that both are cogenetic and of the same source which has been typed back to the Chonta Formation (QMC, 1998). Gas composition is 83.4% C1 with no H2S and little CO2 (0.94%).

6.7.2 Reservoir

The Casa Blanca Sandstone of the Lower Puca Formation was conventionally cored from 3,288m to 3,298m (10,789-10,820’) and “was found to be typical of fluvial channel deposits cutting through a marginal marine” sediments (QMC 1998). Across the cored interval, the average porosity and permeability is 7.5% and 5.5md, respectively.

The Vivian for purposes of analysis have been broken out into two distinctively different sand bodies (Figure 29 and Appendix 1g), the ‘Bubble Sand’ at 4,987m (16,363’) and the main ‘Blocky Sand’ at 5,015m (16,453’). The ‘Bubble Sand’ exhibits low to moderate compaction and the ‘Block Sand’ is highly compacted. Compaction and cementation are the primary factors controlling reservoir quality. Inter-granular pores dominate the pore systems. Inter-granular pores in the ‘Blocky Sand’ are severely reduced in size and poorly connected; i.e. poor reservoir quality. The ‘Bubble Sand’ contains somewhat larger and better interconnected pores. Porosity loss in the ‘Bubble’ Vivian is due primarily to cementation whereas in the deeper main Vivian sand body, compaction is the dominant factor causing loss of reservoir quality.

The ‘Bubble Sand’ has measured porosities and permeabilities up to 16.9% and 4.01md respectively, while the ‘Blocky Sand’ has porosity values that are less than 7.0% and permeabilities, less than 0.6md. Upon log analysis by QMC (1998) the ‘Blocky Sand’ was calculated to have 7.8% porosity. Porosity calculations in the ‘Bubble Sand’ were not possible due to rugose hole conditions.

6.7.3 Well Analysis

The Tanguintza 1X well was drilled on a large well defined fault dependent closure and was a valid structural test. Hydrocarbons (gas/condensate) were encountered within a thin upper Vivian sandstone of limited areal extent. The hydrocarbons are believed to have been stratigraphically trapped prior to extensive burial thereby preserving porosity. The presence of the QMC calculated hydrocarbon column in the Vivian ‘Blocky Sand’ has not been confirmed by test nor is there much supporting data from samples and the mud log. Of possible interest, however, is a potentially fractured shaley sand (?) sequence within the Chonta Formation that perhaps had some of the better gas and oil shows identified in the well. This zone was not tested.

Also worth commenting on is the vitrinite reflectance data of the Tanguintza 1X well displayed in Figure 30. This plot indicates that the Cachiyauc to Chonta section below 4,876m (16,000’) has an anomalous maturity in the range of 0.79% to 0.94% Ro, which is just past peak oil generation and significantly lower than would be expected from a
projection of the Tertiary maturation profile. The explanation to this given by QMC (1998) was the two groups of data are separated by a reverse fault of substantial throw. In our interpretation, however, no fault can be interpreted through this interval on seismic.

Figure 30: Measured vitrinite reflection (Ro) plot of the samples taken in the Tanguintza 1X well showing two very distinctively different data point trends.
7.0 GEOCHEMISTRY

7.1 SOURCE ROCKS AND MATURATION

Geochemical analyses to evaluate potential source rocks and their level of maturity in the Santiago Basin have been extensively carried out by Petroperu, UNOCAL, Mobil Oil, British Petroleum, Cities Service, Occidental International E&P, Petromineros del Peru and QMC. For most part these studies have documented the source potential of the Pucara, Cachiayacu(?), Vivian and Pozo Formations in and around the Santiago Basin and that they are sufficiently rich to have generated commercial amounts of hydrocarbons. Dependant on where one is in the Santiago Basin, levels of maturation have been reached at different times to generate oil and/or gas. This issue will be addressed in considerable more detail in the following section on Thermal Maturation and Hydrocarbon Generation Modeling.

Some 23 oil seeps have been documented from one end of the Santiago Basin to the other demonstrating that oil has been and is probably presently being generated. Seeps with known locations are plotted on Enclosures 2a and 2b. To date with the exception of some the earlier work done by Mobil, most if not all of the seeps and shows in the basin have been typed back to the Cretaceous Chonta Formation. This same formation has been attributed to sourcing much of the oil of the greater Marañon/Oriente Basin. Mobil in some of the earlier geochemical work done in the basin, typed the oil recovered from the Piantza and Dominguza wells as well as some nearby seeps to the Pozo Formation. Of all the sources, the Pozo Shale perhaps represents one of the better oil source rock in the Santiago Basin. TOC’s for the Formation vary considerably, but can reach values of up to 10% with frequent measurements in the 2-5% TOC range. Furthermore, the HI values of these mostly immature or marginally mature samples are exceptionally high between 500 to >800, indicating a Kerogen Type II-I. The Tertiary Pozo shale is an excellent potential source and probably in active stage of HC generation and expulsion in the deeper Neogene sub-basins such as the Santiago Basin, where this source facies may be preserved and deeply buried. Our source rock database indicates that the rich Pozo facies may be limited to the Santiago and Huallaga Basins (ChemTerra, 2000).

Our modeling indicates that the Pozo Formation is mature in various parts of the Basin and in the southern and deepest portion of the Basin, it is postulated to be within the gas window. Additionally, in areas of significant uplift, the vitrinite reflectance data on the Pozo samples indicates that the Formation was once in the oil window generating hydrocarbons prior to uplift.

7.2 THERMAL MATURITY AND HYDROCARBON GENERATION MODELING

The formations in the Santiago Basin, and the western portion of the Marañon Basin, have been deeply buried and consequently have the imprint of more mature conditions than the significantly shallower eastern Marañon Basin. Previous studies have
presumed that the Santiago Basin to be the hydrocarbon kitchen to a good percentage of the oil that has been found to date in the Marañon Basin. In the course of this study, basin modeling done on the Tanguintza 1X, Putuime 1X, Piuntza 1X, and two pseudowells (Figure 31), indicate various episodes of hydrocarbon generation and expulsion from the Pucara, Chonta and Pozo Shales. Tables 4 and 5 respectively, show the summaries of Basin Modeling by wells and formations. It is assumed that Cachiyacu and Cushabatay potential source rocks follow similar burial history as those in the Chonta Formation. Of the formations presented in this analysis, only the Pucara Formation has not been drilled nor is it found outcropping in the immediate study area. It’s presence is assumed through seismic and regional geological interpretations. Short and long distance migration, and trapping occurred in both the Marañon and Santiago Basins prior to the latest most Andean orogeny. The extent of long range migration is proven by the presence of significant reserves in Blocks 8, 1AB and 67 which are east of any significant documented mature source area. Block 67 for example, is around 300km in distance from the Santiago Basin.

![Figure 31: Location of Modeled Wells and Pseudowells](image-url)
Within the Santiago Basin, there is deeper burial and consequently more mature conditions in the area south of the Tanguintza well. This is known as the Nieva Depression. The basin becomes shallower and less influenced by thick Tertiary overburden north of the Tanguintza 1X well. In this southern area, Pozo Shales are deeply buried and modeling indicates that they have reached the top of the main gas generation window (Ro 1.3 %) at the Pseudowell South location (Figure 31) and the top of the mid-mature oil window (Ro 0.7 %) at Tanguintza 1X where they should be generating hydrocarbons at present time. In most other areas, the Pozo Shales had reached the early mature oil window (Ro 0.5 %) prior to the last uplift in latest Tertiary time. Additionally at this time, the Chonta Formation was in the mid-mature oil window at the Putuime 1X location and in the Pseudowell North, and in the late-mature oil window (Ro 1.0 %) at the Piuntza 1X location. The later removal of the uppermost Chonta sediments prevented passage of this formation into the gas stage in these areas. The Chonta source rocks, however, are presently in the main gas generation window at Tanguintza 1X and at the Pseudowell South.

The Pucara source rocks are in the main gas generation window throughout most of the Santiago Basin. Modeling indicates Pucara expelled oil before entering the gas window. In the westernmost part of the greater Santiago Basin, the Kumpin-Ipururo Depression (Figure 4) where overall burial depths are believed to be much less although very little work has been done in this area to support this, the Pucara may be less mature and in the oil window.

7.2.1 Introduction

PARSEP conducted thermal maturity and hydrocarbon generation modeling in the Santiago Basin for three wells and two pseudowells (Figure 31). The objectives of this modeling was to update:

1. The history of hydrocarbon generation
2. The timing of hydrocarbon generation and expulsion from the different source rocks.

The selected wells, Tanguintza 1X, Putuime 1X and Piuntza 1X all penetrated Cretaceous and/or Jurassic aged rocks and are located in the central portion of the basin. The two pseudowells are located in the northern and southernmost synclinal areas. These locations were picked as shot points on seismic lines GSI-50-105A (SP 1060) for the Pseudowell North and GSI-50-125 (SP 1964) for Pseudowell South. Tables 3 to 7 show the basic data used with 1-D Basin Analysis Modeling, Version 7.61, software package of Platte River Associates.
<table>
<thead>
<tr>
<th>PSEUDOWELL</th>
<th>Early Mature Oil Window 0.5-0.7 Ro %</th>
<th>Mid Mature Oil Window 0.7-1.0 Ro %</th>
<th>Late Mature Oil Window 1.0-1.3 Ro %</th>
<th>Main Gas Generation Window 1.3-2.6 Ro %</th>
<th>Bottom Main Gas Generation Window 2.6+ Ro %</th>
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<td>NORTH</td>
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<td>Mid Miocene (15-11 my)</td>
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<td>TANGUINTZA IX</td>
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<td>Pucara</td>
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<td>Aptian/Albian (94-70 my)</td>
<td>Late Paleocene to Early Eocene (57-52 my)</td>
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<td>Late Pliocene (3 my)</td>
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<td>Early to Middle Miocene (19-16 my)</td>
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<tr>
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<td>Mid Miocene (15-14 my)</td>
<td>Late Miocene (10-9 my)</td>
<td>Pliocene (5-3 my)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Basin Modeling Summary By Wells

The basic data used as input for modeling was gathered from Perupetro’s technical data archives and included such things as well reports and logs, geochemical and biostratigraphic reports to extract, BHT’s, age dating, and stratigraphic and lithologic information. Regional thickness, unconformities and the estimated eroded thickness at the unconformities were interpreted based on available data and on a report recently generated by PARSEP (2001) in the neighboring Huallaga Basin. Extrapolation from existing well control and depth conversions from seismic data was used to estimate unit thickness in undrilled areas of the basin where the pseudowell models were run.
### Table 5: Basin Modeling Summary By Formation

<table>
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<tr>
<th>Formation</th>
<th>PUCARA GP.</th>
<th>Early Mature Oil Window 0.5-0.7 Ro %</th>
<th>Mid Mature Oil Window 0.7-1.0 Ro %</th>
<th>Late Mature Oil Window 1.0-1.3 Ro %</th>
<th>Main Gas Generation Window 1.3-2.6 Ro %</th>
<th>Bottom Main Gas Generation Window 2.6 + Ro %</th>
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<tbody>
<tr>
<td></td>
<td>Pseudowell North</td>
<td>Cenomanian to Early Eocene (93-56 my)</td>
<td>Mid Eocene to Early Oligocene (49-33 my)</td>
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<td>Mid to Late Miocene (15-8 my)</td>
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<td></td>
<td>Piuntza 1X</td>
<td>Albion to Maastrichtian (101-72 my)</td>
<td>Late Paleocene to Mid Eocene (61-51 my)</td>
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<td>Putuime 1X</td>
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<td>Tanguintza 1X</td>
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<td>Aptian/Albian (94-70 my)</td>
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<td></td>
<td>Pseudowell South</td>
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### CHONTA FM.

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</table>

### POZO SH.

<table>
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<td>Putuime 1X</td>
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<td>Pliocene (5-3 my)</td>
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</table>

The modeling emphasized the presence of source rocks in the Pozo Shales, Chonta Formation and Pucara Group. The Pucara Group was the oldest formation considered to have any economic interest so the modeling did not expand beyond that.

Overall thickness combined for the Pucara and Sarayaquillo Formations is 2000m., the Cushabatay and Chonta Formations maintain an almost constant thickness of nearly

---

62
800m each. Locally these two formations show evidence of thinning that can be attributed to uplift and pre-Tertiary erosion, drape over older existing structures, or syn-depositional structural growth. Such features are important when trying to identify older structures that pre-date or are concurrent with hydrocarbon generation and migration.

The total thickness of Tertiary aged sediments is estimated to be in excess of 8,500m. This thickness is either partially preserved in the synclinal areas or it has been completely removed in Neogene and recent times off of the anticlines with Cretaceous rocks outcropping on the surface.

Modeling inputs used to best fit observed data were obtained using: the sediment mechanical compaction option of Baldwin and Butler; the permeability option of (Modified) Kozeny-Carmen; a Geothermal history based on gradient heat flow; a constant heat flow of 1.1 HFU; and, the Saturation Method for expulsion calculations.

Modeling outputs are presented in diagrams indicating burial history versus depth and Maturity versus Time. These figures show the geologic ages when the different source rocks entered:

- the early mature oil window (0.50 %Ro)
- the mid-mature oil window (0.70 %Ro),
- the late-mature oil window (1.0 %Ro),
- the main gas generating window (1.3 %Ro), and
- the present day maturity of the different formations acquired before final uplift.

### 7.2.2 Tanguintza 1X Well

The Tanguintza 1X was drilled in 1997 to a depth of 5,296m. The stratigraphic section penetrated and events are presented in Table 6. A minimum 2,000m of Tertiary aged sediments are interpreted to have been eroded at the well location.

The burial history diagram of the Tanguintza well is presented in Figure 32. The Pucara unit (bottom and top) entered the top of the early-mature oil window in early Cretaceous Barremian to Albian time (125-101 my), the mid-mature oil window in the Aptian/Albian (94-70 my), the late-mature oil window in the Late Paleocene to Early Eocene (57-52 my) and the main gas generation window between Mid to Late Eocene (47-39 my) time. At this later time, a thick section of rapidly deposited sediments of Tertiary age pushed the Pucara to the bottom of the main gas generation window.

The Chonta Formation (bottom and top) entered the top of the early-mature oil window in the Early Miocene (56-48 my), the mid-mature oil window in Late Eocene to Late Oligocene (40-26 my) time, the late-mature oil window in Late Oligocene to Middle Miocene (24-15 my) time, and the main gas generation window in Mid to Late Miocene (14-7 my) time, prior to the last uplift. A continuous and rapid subsidence caused the Pozo Shale (bottom and top) to enter the early-mature oil window in the Early Miocene (13-11 my). The bottom of the unit entered the mid-mature oil window in the Late Miocene (6 my) and the top was nearly at this level of maturity before it was uplifted in the latest Tertiary.
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<th>Well Top (m)</th>
<th>Present Thickness (m)</th>
<th>Missing Thickness (m)</th>
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Table 6: Tanguintza 1X Formations and Events

Figure 32: Maturity burial in Tanguintza 1X shows respectively Chonta Formation in the early and Pucara in the latest stages of the main gas generation window prior to latest Andean uplift. The Pozo Shale reached the mid mature oil window.
The maturity trend versus time presented in Figure 33, shows the Pucara unit reaching mature conditions and expelling oil during Late Cretaceous and Early Paleogene. It continuously reached a late-mature oil window during Early Paleogene and passed into the main gas generation window in Paleogene and Neogene time. The Chonta Formation follows this general trend having expelled oil in late Paleogene to early Neogene time, but it also entered the gas generation phase due to rapid subsidence in late Neogene time. The Pozo shales reached the mid-mature oil window in Neogene time with a 0.73 to 0.83 %Ro and possibly had began spelling oil before final uplift and erosion.

Most of the figures in the modeling are in accordance with measured data at the well. However, the Chonta Formation should have values higher than 1.38 %Ro, which is not in agreement with the observed values of 0.79 to 0.94 %Ro reported from samples of the Cachiyacu-Chonta interval. The testing of gas condensate from the 5 meter-thick Upper Vivian “Bubble Sand” (with C1-C5 gas and weak oil shows while drilling) supports the BasinMod modeling conclusion of the Upper Cretaceous being in the early main gas generation stage. A similar gas and oil show in a thicker 20 meter-thick ‘sandstone’ in the upper Chonta remains untested in the Tanguintza 1X (Figure 29) and could also be a gas-condensate accumulation if reservoir can be established. Oil was originally trapped in these sandstones but with deeper burial, it was cracked to gas/condensate.

Most of the figures in the modeling are in accordance with measured data at the well. However, the Chonta Formation should have values higher than 1.38 %Ro, which is not in agreement with the observed values of 0.79 to 0.94 %Ro reported from samples of the Cachiyacu-Chonta interval. The testing of gas condensate from the 5 meter-thick Upper Vivian “Bubble Sand” (with C1-C5 gas and weak oil shows while drilling) supports the BasinMod modeling conclusion of the Upper Cretaceous being in the early main gas generation stage. A similar gas and oil show in a thicker 20 meter-thick ‘sandstone’ in the upper Chonta remains untested in the Tanguintza 1X (Figure 29) and could also be a gas-condensate accumulation if reservoir can be established. Oil was originally trapped in these sandstones but with deeper burial, it was cracked to gas/condensate.

![Figure 33: Maturity versus time plot of the Tanguintza well](image)

7.2.3 Putuime 1X Well

The Putuime 1X was drilled in 1968/1969 to a depth of 3,722 m. The stratigraphic section penetrated by the well and events is presented in Table 7.
The burial history of the well is greatly affected by periods of erosions at the end of the Sarayaquillo and the Chonta (pre-Vivian), and at the end of Lower Puca deposition. These events include:

- The complete removal of Sarayaquillo Formation by tectonic inversion and the presence of an Anhydritic Unit with an estimated thickness of 500m underlying the Cretaceous.
- Some 800m of upper Chonta is missing through erosion at the well and seismic shows evidence for the erosion of approximately 1/3 of the uppermost Lower Puca section.
- An estimated 2,500m of young Tertiary aged sediment is interpreted to be have been removed by erosion at the well location.

As a consequence of these erosional events, the source rocks have been subjected to a lesser degree of maturation than in other areas where the stratigraphic section is fully preserved.

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*Table 7: Putuime 1x Formations and Events*

Figure 34 presents the burial history diagram of the well and shows the subsidence, uplift and erosion described above for all of the formations. The Pucara Group (bottom and top) entered the early-mature oil window in the Coniacian (87 my) but essentially this stage was not well established until Paleocene to Mid Eocene time (66 to 47 my).
Figure 34: Maturity burial in Putuime IX in the south central Santiago-Nieva tectonic depression shows, the Pucara Formation in the main gas generation window; the Chonta in the mid-mature oil window; and the Pozo in the early mature window prior to latest Andean uplift.

Figure 35: Maturity vs. Time plot in Putuime IX in the south central Santiago-Nieva tectonic depression.
when the section experienced rapid burial during the early Tertiary. The Pucara then entered the mid-mature oil window in the Early Oligocene to Early Miocene (36-22 my). During Paleogene times the area once again was buried deeper by rapid Tertiary sedimentation the Pucara continued through the mid-mature oil stage until the Early Miocene (17 my) when it entered the late-mature oil window. There it remained until the Mid Miocene (11 my) after which, it entered the late-mature oil window in Early to Mid Miocene (17-11 my). The bottom and nearly the top of the unit entered into the main gas generation window between Late Miocene and the period of latest most Tertiary uplift (10-5 my).

The Chonta Formation (bottom and top) entered the early-mature oil window in Early Miocene (19-18 my) time, the mid-mature oil window in the Late Miocene (10-9 my) where it stayed until final uplift. All other Cretaceous potential source rocks also reached the mid-mature oil window before final uplift. The Pozo Shales entered the early-mature oil window in Late Miocene (7 my) where it continued until final uplift.

Figure 35 shows how the above mentioned potential source rocks matured through time. The Pucara Group continuously passes from mid-mature in Late Paleogene, to late-mature, and to the main gas generation stage in Neogene time before final uplift. The Chonta and all the Cretaceous Formations follow this same general trend having expelled oil and reaching a mid-mature oil window in Neogene time before final uplift. The Pozo Shales reached the early-mature oil window before final uplift and were ‘suspended’.

7.2.4 Piuntza 1X Well

Well Piuntza 1X was drilled in 1968 to a depth of 4,022 m. Its stratigraphic section penetrated is presented in Table 8. Its burial history is interpreted to be similar to that of the Tanguintza well. Some 2,000m of uppermost Tertiary aged sediments are estimated to be eroded at the well location.

Figure 36 is the burial history diagram of the well. The Pucara Group (bottom and top) entered the early-mature oil window in Cretaceous Albian to Maastrichtian time (101-72 my), the mid-mature oil window between Late Paleocene to Mid Eocene time (61-51 my), and the late-mature oil window in Mid Eocene to Late Oligocene time (43-28 my). During the Late Oligocene to Early Miocene (26-20 my), a thick sedimentary section was deposited, which pushed the Pucara into the main gas generation window, and where it remains today. The Chonta Formation (bottom and top) entered the early-mature oil window between Mid Eocene and Late Oligocene time (41-24 my), the mid-mature oil window in the Early to Mid Miocene (23-15 my), and the late-mature oil window (bottom) in Mid Miocene time (12 my). The top of the formation was nearly reaching this late-mature oil window prior to final uplift. The Pozo Shale (bottom) entered the early-mature oil window in Late Miocene (6 my) before final uplift and erosion.

Maturity trend versus time in Figure 37 shows the Pucara unit reaching the mid-mature oil window and expelling oil during Early Paleogene time and the late-mature oil window in Mid Paleogene time. It reached the main gas generation window in Neogene time. The Chonta formation follows this same general trend having expelled oil while
in the mid-mature oil window in Early Neogene and in the late-mature oil window in Neogene time. It did not reach the main gas generation window before uplift. The Pozo shales reached the early mature oil window before final uplift and erosion.
Pseudowell North was selected on a syncline in the northernmost portion of the Santiago Basin, off of seismic data. It is located 24 km NNW of the Caterpiza 1X well on Seismic Line GSI-50-105, SP 1060 (Figure 38). The interpreted stratigraphic section is shown in Table 9, which is based on regional formation thickness and seismic events on the Top Lower Puca, Top Cachiyacu, Top Chonta, Base Cretaceous Unconformity and Top Pucara. In general, the modeling follows events similar to those seen in the Putuime 1X well. The exception to this is the erosion at the end of Paleocene within the Pseudowell North.

The burial history includes a Base Cretaceous and an intra-Cretaceous erosion events at the end of deposition of Sarayaquillo and Chonta Formations respectively. The latter is very likely pre-Vivian in age. The interpreted section concludes that 600m of Sarayaquillo, over 400m of Chonta and a minimum of 950m of young Tertiary age sediments, are missing by erosion.

The burial history diagram, displayed in Figure 39, show the interpreted subsidence, uplift and erosional events of the pseudo location. The Pucara Group (bottom and top) entered the early-mature oil window between Late Cretaceous Cenomanian to Early Eocene time (93-56 my), the mid-mature oil window between Mid Eocene to Early Oligocene (49-33 my), the late-mature oil window during the Late Oligocene and Early Miocene (25-17 my) and the main gas generation window between the Mid to Late Miocene (15-8 my).

The Chonta Formation (bottom and top) entered the early-mature oil window in the Late Oligocene to Early Miocene (26-21 my), the mid-mature oil window in Mid
Miocene time (15-11 my) and the bottom of the unit reached the late-mature oil window in Early Pliocene (5 my). At this later stage, the top of the formation, however, is still in the mid-mature oil window. The Pozo Shale reached the early-mature oil window during Late Miocene time (7 my) where it remains at present.

![Figure 38: Pseudowell North was picked up on Seismic line GSI-50-105, SP 1060.](image)

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*Table 9: Pseudowell North With Formations And Events*
Figure 39: Maturity burial curve of Pseudowell North in the northern central Santiago basin showing the Pucara Group to be in the main gas generation window, the Chonta in the mid- to late-mature window and the Pozo Shales in the early-mature stage.

Figure 40: Maturity Vs. Time plot of Pseudowell North in the northern central Santiago Basin
The maturity trend versus time in Figure 40 shows the Pucara Group to have expelled oil mainly between Mid Paleogene to Early Neogene and subsequently, entering into the main gas generation window in Neogene time. The Chonta and Cretaceous source rocks follow this same general trend although expelling oil in Neogene time. The Pozo shales reached the early-mature oil window in the Neogene.

7.2.6 Pseudowell South

Pseudowell South was selected on the deepest seismically defined syncline in the Santiago Basin area. It is located 22 km SSW of the Tanguintza 1X well on Seismic Line GSI-50-125, SP 1964 (Figure 41). The interpreted stratigraphic section is shown in Table 10, and is based on seismic events representing the Top Lower Puca, Top Chonta, Base Cretaceous unconformity and Top Pucara. Burial history and formation thickness used for this model are similar to those used for the Tanguintza 1X well. The one noticeable difference is the additional section of uppermost Tertiary that has been added to the Pseudowell.

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Table 10: Pseudowell South Formations and Events

The burial history diagram in Figure 42 shows that the Pucara Group (bottom and top) entered the early-mature oil window between the Early Cretaceous Barremian and Albian times (125-101 my), the mid-mature oil window in the Late Cretaceous Cenomanian and Maastrichtian (94-68 my), the late mature oil window in the very Late Paleocene to Early Eocene (57-52 my), the main gas generation window in Early Eocene times (47-40 my) and finally, the bottom of the main gas generation window in Mid Miocene time (12-10 my).

The Chonta Formation (bottom and top) entered the early-mature oil window in early to Mid Eocene time (55-49 my), the mid-mature oil window in Late Eocene to Late Oligocene time (39-28 my), the late-mature oil window in Late Oligocene to Early Miocene time (25-21 my), and the main gas generation window between the Early and
Middle Miocene (19-16 my). As this location has never been uplifted, it eventually reached the bottom of the main gas generation window in the Late Pliocene (2 my).

A continuous and rapid subsidence caused the Pozo Shale (bottom and top) to enter the early-mature oil window in the Early Miocene (19-18 my), the mid-mature oil window in the Mid Miocene (15-14 my), the late-mature oil window in the Late Miocene (10-9 my), and the main gas generation phase in Pliocene time (5-3 my). This is the only area in the greater Santiago Basin where the Pozo Share reaches these levels of maturity.

Figure 43 shows the Pucara Group reaching mature conditions and expelling oil during Late Cretaceous. It reached the late-mature oil window during Early Paleogene and passed into the main gas generation window from Mid Paleogene to Neogene time.

The Chonta formation expelled oil between late Paleogene and early Neogene time, and entered the main gas generation window due to rapid subsidence in early Neogene.

The Pozo shales rapidly reached the mid-mature oil window in Early Neogene, the late-mature oil window in Early Neogene and the main gas generation window in Neogene time.
Figure 42: Maturity model for Pseudowell South in the southern Santiago Basin shows Pozo Shale and Chonta Formation respectively in the early and in the late stages of the main gas generation window.

Figure 43: Maturity Vs. Time plot for Pseudowell South in the southern Santiago Basin
8.0 GEOPHYSICS

8.1 INTRODUCTION

The Santiago basin has seen several episodes of seismic acquisition starting from the early 1960’s when Mobil acquired 625 km of 1 fold analog data. Over a period of ten years, from the early 1970’s to the early 1980’s, Petroperu acquired 1000 km of 6 and 12 fold digital data. In the early 1990’s Petromineros del Peru acquired 177 km of 120 fold data. QMC conducted the last seismic programs in the Basin in 1995 and 1996, when a total of 514 km of 80 fold data were recorded.

The PARSEP project for the Santiago Basin was started in April, 2001 and included a total of 1,566 km in SEGY format. The data was loaded on a Geoquest workstation and interpreted using the IESX interpretation software. Considering the structural complexities of the subsurface and the difficult topographic logistics, all the various vintages of data have inherent problems. The most common problems are:

1) Processing datum and replacement velocity selection, which leads to misties varying up to 1000ms. Although QMC reprocessed 177 km of the Petromineros older data, large misties were still very evident due mainly to the position of the seismic lines.

2) Much more special care should be taken in the statics computation and migration steps of the seismic processing sequence. Considering the tectonic style of the Basin and the resulting steep dips of the formations, it is expected that two intersecting lines along these steep dips would not tie, simply due to the nature of the signal traveling through the earth.

3) In order to have full fold coverage over the crest and flanks of the structures, and therefore a proper migration of the data, the length of the dip lines must be calculated according to the assumed structural dips. In most cases, the dip lines are too short to properly image the structures.

4) In order to have proper horizon ties in such a complexly structured area, it is imperative that strike lines be acquired within the synclines on both sides of the structures. Many crestal strike lines were acquired. However, the seismic signal scatter was extreme, resulting in many strike lines not being interpreted with confidence.

5) Synthetic seismograms were made from the existing well logs at our disposal. Due to well deviations (whose parameters were not at our disposal) and many washout problems in the first 2000m, the velocities calculated from the sonic logs were, in many cases erroneous. A perfect time match with the seismic was impossible. Many of the formation ties are derived from the sonic curve character, and applied to the seismic data, looking for regional relative character consistencies.

Irrespective of these inherent inconsistencies, the main correlation problems were: difference in frequency, fold, acquisition and processing parameters, differences in seismic response due to rapidly varying lithology changes, no direct ties across fault zones, questionable jump correlations.
8.2 REGIONAL STRUCTURE

The regional seismic interpretation clearly shows the structural lineaments, generally running Northeast-Southwest, except for the extreme northern part, which runs north south and formed by two basic faulting styles. The Santiago Basin is the most easterly major effect of the Andean orogeny, limited to the east by the Campanquiz anticline. The second, and younger, faulting style is due to right lateral wrench tectonics, using previous zones of weakness to propagate upwards into the sedimentary section. It is this youngest reactivated tectonic event that controls the present day structural lineaments. In certain cases, the reactivation formed, what may be better described as ‘flower structures’. We have no evidence that any of these structures are salt cored, as indicated by previous interpreters.

Three velocity curves of Depth vs. TWT for all the Santiago Basin wells have been generated (Figure 44). The difference in the slope of the curves is due to the age of the sediments penetrated. The curve having the most complete sedimentary section includes wells Tanguintza, Putuime and Piuntza and shows a normally increasing seismic time with depth. No major deviations are noticed. This implies that the sediments penetrated are normally compacted. One curve is only for Pupuntas and another curve uses Caterpiza and Dominguza.

Composite seismic line GSI50-150, Q95-152 (Figure 45) running east-west across the center of the Santiago basin, is the best depiction of the dominant tectonic style of the basin. The western upward dipping sediments are controlled by the Andean surface expression. The eastern Campanquiz anticline is clearly a very young (Pleistocene to Quaternary) wrench-related uplift forming a symmetrical flower structure. The amount of uplift and erosion of the Campanquiz anticline, at this location, has been calculated to be in the order of 5100m. The central part of the basin, also involving wrench tectonics, show several episodes of compressional tectonics, the first pulse being in the Lower to Middle Cretaceous, with the last major reactivation occurring in the Pleistocene to Quaternary.

Composite seismic line Q92-295, GSII50-300, Q95-405 (Figure 46) is west-east in the southern part of the basin and ties wells Putuime in the west and Manseriche in the east. In general, the tectonic style is similar as previously described, with the exception being over the Campanquiz anticline. This is the first evidence of the structure being formed by a back thrust. Perhaps this structural difference is as a result of a pre-Cretaceous paleo-topographic high. The figures 45 and 46 appear in the Annex II.

This composite seismic line also shows a thinning Cretaceous section both to the east, against the Campanquiz high, and to the west. The Putuime well encountered a thin Chonta section of 120m. The seismic line clearly shows the section thickening eastwards towards the basin center and then thins again against the Campanquiz anticline. There is no evidence that the base Tertiary is an angular unconformity. Therefore, the erosion occurred because of a Cretaceous paleo-topographic. This variation in Cretaceous thickness is also seen on the north-south line GSI50-105 (Figure 48), with the thinning occurring northward. The flattened section on the Vivian
(Figure 49) clearly shows onlaps and erosional edges within the Chonta section. It appears that an erosional event occurred within the Upper Cretaceous, independent of the Base Tertiary unconformity. This is proven by the Putuime well where the encountered Chonta has been dated as Lower Chonta, while the Cachiyacu and Vivian were eroded to a minor degree. It is estimated that up to 800m of Chonta section may have been eroded over the Putuime high, prior to the deposition of the Vivian sands.

Figure 44: Time-Depth curves for the Santiago Basin wells.

8.3 HORIZON DESCRIPTIONS

A total of 6 seismic horizons were correlated throughout the Basin. However, only three are considered of importance to reconstruct the tectonic and sedimentary history. Three seismic structural map, top Lower Puca (Enclosure 5), Top Chonta (Enclosure 6), and Base Cretaceous (Enclosure 7) were constructed for this report as well as two isochron maps, Isochron Top Lower Puca to Top Chonta (Enclosure 8) and Top Chonta to Base Cretaceous (Enclosure 9).
Figure 45: Composite seismic line two (Figure 47), GSI50-150+Q95-152 showing the dominant tectonic style of the Santiago Basin.

Figure 46: East-West composite seismic three (Figure 47), lines Q92-295+GSI50-300+Q95-405, in the southern part of the Basin through wells Putuime and Manseriche.

The figures 45 and 46 appear in the Annex II.
8.3.1 Lower Puca (Enclosure 5)

The top of the Lower Puca is a regional continuous high amplitude reflector, immediately below a seismic transparent zone of about 150ms. The sonic curve of the wells, which encountered the complete Lower Puca section (Tanguintza, Putuime, Piuntza) show an increase in DT underlying a low velocity zone of about 200m. This low velocity zone is most probably the Pozo Shale. The correlation of this reflector across the structures is mainly by character since direct ties are often not available. Over the crest of the structures, the Lower Puca looses its character, which is most likely due to seismic signal scatter and poor surface-geophone coupling. Nevertheless, the reflector is identified with the help of surface geology and an extrapolation from the flanks of the structures.
Figure 48: North-south line GSI50-105 showing a northward thinning Cretaceous section.

Figure 49: Same seismic line as in Figure 4a flattened on the Vivian sands, showing onlaps and erosional edges within the Chonta section.
Regionally, the present day Lower Puca has its maximum depth in the southwest corner of the Santiago basin, with depths reaching 3.5 sec twt or 6000m. The seismic time structural map very clearly shows two directions of structural lineation. The most prominent, which is also seen on surface geology, is the north-south trending, partly symmetrical, Campanquiz anticline. This structure is the bounding feature between the Santiago and the Marañon basins. Several en-echelon strike slip fault zones break the structure into three components, which is further confirmed by the First Derivative Bouguer Gravity map (Enclosure 4).

The other, and also dominant, structural component is a series of northeast-southwest trending structures, terminating to the north against the Campanquiz anticline at an angle of about 45 deg. This anticlinal lineament abruptly dies to the southwest and is replaced by a significant graben. It is believed that an east-west wrench zone is responsible for this abrupt change in the structural component. In most cases, the entire Tertiary section has been eroded over the structured zones, leaving outcrops of Upper and Lower Cretaceous sediments. It is also worth mentioning that a series of depressions form parallel to the lineaments, except in the southern portion of the basin, where the Tertiary depression trends east-west.

The Lower Puca isochron map (Enclosure 8), when adjusted for the eroded sections, clearly shows that the center of the Santiago basin was a Tertiary depositional syncline between the Marañon Basin to the east and the Andean orogeny to the west. In general the thickness of the Lower Puca is in the order of 1000ms or 1500m. The east-west low, as seen on the present-day structure in the south of the Basin, persisted as the principal depocenter for the Tertiary.

8.3.2 Chonta (Enclosure 6)

Most of the wells drilled in the Santiago Basin either penetrated or TD’d in the Chonta formation. This formation lies immediately below the Vivian sands and is characterized on the sonic logs (Enclosure 17g) as the base of a high velocity zone. The high velocity zone often reflects the existence of the Vivian reservoir sands. Seismically, it generally is characterized as the base of a series of semi-continuous reflectors, whose time thickness is directly dependent on the thickness of the Vivian. As is the case with the Lower Puca, the correlation of this reflector across the structures is mainly by character, since direct ties are often not available. Furthermore, in highly structured areas, the Chonta loses its character and the identification is done with the help of surface geology and an extrapolation from the flanks of the structures.

The Chonta Formation outcrops or is eroded on most of the Campanquiz anticline and on the Cangaza anticline, a highly structured area in the middle of the basin. The Pupuntas and Manseriche wells both spudded in the Chonta Formation. Pupuntas was drilled on the southwestern flank of the Campanquiz anticline, encountered 986m, while the Manseriche well, drilled directly over the Campanquiz high found 612m, of Chonta aged sediments. The Putume well, although penetrating 2866m of Tertiary, found only 120m of the Chonta Formation. This is clear evidence for the existence of Cretaceous paleohighs with a subsequent erosive event. Although it has been assumed that the Base Tertiary unconformity was the main erosive event in the basin, the
Putuime well encountered partially eroded sections of Upper Cretaceous Cachiyacu and Vivian ages, albeit thinner than normal. It is believed that as much as 800m of Chonta Formation may have been eroded, implying that the main erosive event must have taken place within the Upper Cretaceous, towards the end of the Chonta deposition. North-south seismic line GSI 50-105 (Figure 48) clearly shows a northward thinning Chonta section, overlain by seismically identified Vivian sands. Onlaps and erosional edges within the Upper Chonta can be seen on the flattened version of the same line (Figure 49).

Regionally, the present day Chonta Formation has its maximum depth in the southwest corner of the Santiago basin, with depths reaching 4.5 sec twt or 9000 m. The seismic time structural map shows two main structural lineations, with the same geometry as described for the Lower Puca. The Campanquiz anticline is the most prominent.

8.3.3 Base Cretaceous (Enclosure 7)

None of the wells drilled in the Santiago Basin have ever penetrated the entire Cretaceous section. The main formations forming the Cretaceous are the Cachiyacu shales, Vivian sands, a Chonta shale-limestone-sand sequence and the Cushabatay massive sandstones. The seismic event for the Base Cretaceous was determined by summing the regional thickness of the Chonta and the Cushabatay Formations. The only wells to have encountered the Cushabatay were Putuime (630m?), Manseriche (103+m) and the Pupuntas (110+m). Putuime may be the only well to have penetrated the entire Cushabatay section. Theoretically, subjacent to the Cretaceous section, should be the Sarayaquillo formation. However, because of a complex tectonic history, existence of pre-Cretaceous paleo-highs, and lack of information on the regional thickness of the Sarayaquillo, the section subjacent to the Cretaceous could, in fact be, Sarayaquillo, Pucara or Mitu. The character of this seismic event changes across the Basin, mostly because of the ambiguity in identifying the nature of the underlying formations. This is complicated further by the lack of seismic ties across the structures. The eastern side of the Campanquiz anticline was tied to the Marañon interpretation but it is virtually impossible to directly tie the same event on the western side of this regional structural uplift.

Evidence of Cretaceous and pre-Cretaceous tectonics is seen throughout the basin. Composite seismic line GSI50-150 + Q95-152 (Figure 45) on the central northern part of the basin clearly shows that some faults were not reactivated during the Tertiary tectonic episode, penetrating upwards only to the Upper Cretaceous and lowermost Tertiary. This is also seen in the central and southern parts of the basin. Evidence of un-reactivated pre-Cretaceous faulting is seen on seismic lines GSI50-250 (Figure 18) and q95-405 (Figure 26).

Regionally, the present day Base Cretaceous has its maximum depth in the southwest corner of the Santiago basin, with depths over 5 sec twt or 10,000m. The seismic time structure map shows the same general geometry as the other maps previously described.
9.0 PROSPECTS

Through the evaluation of the hydrocarbon potential of the Santiago Basin, six prospects, Putuime Updip, Dominguza South, Chinganaza, Santiago, Cabo Reyes, and Tanguintza North, and one lead, Campanquiz, were defined and mapped. All are structural plays with the Cretaceous reservoirs, principally the Vivian and Cushabatay sandstones, being the primary targets. A map showing the location of the prospects is presented in Figure 50, and potential reserve estimates for each of the prospects, in Table 11.
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Table 11: Summary of potential reserve estimates for the six Santiago Basin Prospects

### 9.1 PUTUIME UPDIP PROSPECT (Enclosure 10b and 16a)

The Putuime Updip Prospect is a NE-SW trending three-way dip closed structure bounded to the northwest by a wrench/transpressional fault. Seismic and the Putuime 1X well indicate the presence of an updip structure (Figure 17 and 18) as mapped on Enclosures 10b and 16a where Cretaceous reservoir objectives will be some 450m structurally higher than at original Putuime 1X well.

The present structural configuration is due to a late Tertiary uplift or rejuvenation of an older structure. The Putuime Structure represents the most clear evidence of a pre-Cretaceous paleo-horst that experienced continued intermittent growth during Cretaceous and Early Tertiary time. A more detailed description on the Putuime 1X well can be found in the Well Summary Section 6.3.

Depth to the Vivian sandstone is calculated at 2400m while the Cushabatay sandstones should be at about 2550m. Maximum structural closure at the top Vivian Formation is about 12 km² whereas the structure is divided in two culminations with 4 km² closure each on top of Cushabatay.

The Cushabatay sandstone had an average porosity of 9.3%, however, three open hole FIT’s were conducted in the unit had no recoveries. A production test in the Vivian Formation flowed 4200 bwpd. The water, however, was most probably from fractures within the Cushabatay and due to a poor cement bond. Mobil interpreted the Vivian to be oil saturated. Poor to fair oil and gas shows were reported in Cushabatay and Vivian sandstones at the Putuime 1X well.

Basin modeling indicates that Cretaceous source rocks at the Putuime well area are in the mid-mature oil generation window. Erosional events removed overburden at various times and active tectonics created an old structure before oil generation and migration occurred during late Miocene time. Evidence of oil generation and migration is demonstrated by the three oil seeps along the bounding fault to the north of the old well (Enclosure 2b).
The risks to this prospect are reservoir quality, fault seal and closure on its SW nose is virtually undefined because of lack of seismic. The presence of permeable fractured Cushabatay and oil shows in the Vivian reduce the risks on this structure.

Reserve estimates for the Putuime Updip Prospect are presented below in Table 12.

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Table 12: Potential reserve estimates for the Putuime Prospect

9.2 DOMINGUZA SOUTH PROSPECT (Enclosure 13, Figures 51, 52, 53)

The Dominguza well was a Tertiary test, drilled in 1968 by Mobil Oil to a total depth of 3090m. The well spudded in Lower Pozo, and, after drilling 50m, entered the Lower Puca formation. Although oil was recovered from the mud pit, the primary Cretaceous reservoirs were never reached. The structure is very complexly faulted, resulting in a very steep eastern limb. This limb is a monocline dipping east and truncated to the west and north by a compressional fault with a strong wrench component. The well was drilled on the northern end of a linear high trend. Lack of dipmeter data and deviation survey prevents the proper definition of steepness of the beds and the trajectory of the well. However, it is suspected that the well crossed the fault into the downthrown side.

The prospect has not been evaluated for it’s Cretaceous potential, and a new location is proposed about 3 km southwest of the original well, on seismic line Q96-283. The structure is fault controlled in the west and north, and dip controlled in the south and east. However, data quality throughout the crest of the structure is very poor, preventing the proper definition of the geometry of the crestal position of the structure.

Evidence of oil generation and migration in and around this prospect is demonstrated by the presence of oil seeps (Encl. 2b) within the core of the prospect, as well as oil recovered in the drilling of the original well.

Depth to the Vivian is calculated at 2400m, while the Cushabatay should be encountered at about 4000m. Maximum structural closure at the top Chonta formation is 22 km².
Figure 51: Dominguza South Prospect TWT Structure Map - Top Chonta

Figure 52: Dominguza South Prospect 2WT Structure Map - Top Cushabatay
Figure 53: Dip line Q96-283 across Dominguza South Prospect

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Table 13: Potential reserve estimates of the Dominguza South Prospect

The risks to this prospect are reservoir quality, lateral and fault seal, timing of oil generation to trap formation, and structural integrity due to poor data.

Potential reserve estimates for the prospect are presented in Table 13.
9.3 CHINGANAZA PROSPECT (Enclosures 12, Figs 54, 55, 56)

Chinganaza Prospect is located about 12 km west of the Caterpiza well and about the same distance north of the Piuntza well. Although the structure is complexly faulted at the Tertiary level, forming a ‘flower’ structure, the Cretaceous is fairly simple, being affected only by a wrench fault with relatively small vertical displacement. It is believed that this fault is a reactivated pre-Cretaceous normal fault. Therefore, unlike Caterpiza structure, complex Upper Cretaceous structuring is not expected at this location. Seismic line Q96-161 shows a very thin Chonta section, about 100m, and a thinner than regional Cushabatay section. Reconstructing the structure at Cretaceous time by flattening at the Chonta level clearly shows the structure to have existed prior to the deposition of the Tertiary.

At the time of formation of this Late Cretaceous structure, the Chonta source rock was probably immature and consequently incapable of generating hydrocarbons into the reservoir prior to deep burial. Basin analysis, however, shows that the Pucara Formation generated and migrated its hydrocarbons towards the end of the Cretaceous instead. This would allow hydrocarbons to migrate into the reservoir prior to deep burial and preserve the reservoirs petrophysical characteristics necessary for the establishment of commercial production.

The main reservoirs are the sandstones of the Vivian, Chonta and Cushabatay Formations. The Vivian sandstone is expected at a depth of about 3300m while that of the Cushabatay, at about 3600m. Maximum structural closure at Chonta level is 21 km².

Figure 54: Chinganaza Prospect TWT Structure Map - Top Chonta
Figure 55: Chinganaza Prospect TWT Structure Map - Top Cushabatay

Figure 56: Dip line Q96-161 across Chinganaza Prospect
CHINGANAZA POTENTIAL RESERVE ESTIMATES

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Table 14: Potential reserve estimates for the Chinganaza Prospect

The risks to this prospect are, the effect on the trapping conditions at the time the main wrench fault was reactivated throughout the Tertiary, reservoir quality and fault seal.

Reserve estimates for the Chinganaza Prospect are presented in Table 14.

9.4 SANTIAGO PROSPECT (Enclosure 10, Figures 57, 58, 59)

The Santiago Prospect is located about 12 km northwest of Dominguza well and about 20 km south of the Piuntza well. It is a four-way dip closed structure at its crest and fault controlled at maximum closure. It is located west of the Cangaza uplift, with a local low area separating the two. Cangaza is the result of a late Tertiary uplift. The entire Tertiary section has been eroded, leaving Chonta aged sediments outcropping on the surface. The western flank of this prospect is bounded by a N-S compressional fault. The structure exists on the hanging wall for the Tertiary and Upper Cretaceous Chonta Formations, while the Cushabatay Formation has structural closure on the footwall.

The principle reservoir for this prospect is the Vivian sandstone. Seismic line Q95-253 clearly shows a series of parallel reflectors immediately above the Chonta horizon. This often is indicative of the existence of the Vivian sands. The secondary reservoir is the Cushabatay massive sandstone located in the footwall of the structure.

Evidence of oil generation and migration in and around this prospect is demonstrated by the oil seeps (Enclosure 2b) both to the north and to the southwest on the prospect. It is obvious that the oil comes to surface using major fault zones as conduits. No oils seeps are evident at the prospect location, indicating that the bounding faults most likely are sealing.
Figure 57: Dip line Q95-253 across Santiago Prospect

Depth to the Vivian target is calculated at 2900m while that in the Cushabatay, should be encountered at about 4200m. Maximum structural closure at the top Chonta formation is 10 km².

The risks to this prospect are reservoir quality, fault seal and timing of oil generation to trap formation.

Reserve estimates for the Santiago Prospect are presented in Table 15.
Table 15: Potential reserve estimates for the Santiago Prospect

9.5 CABO REYES PROSPECT (Enclosure 12, Figures 60, 61, 62)

Cabo Reyes Prospect is located 20 km northwest of the Caterpiza well and on trend northward from the Chinganaza Prospect. The structure is three-way dip closed, north-south trending, asymmetrical anticline, controlled to the west by a wrench fault. Cabo Reyes Prospect has many similar characteristics to the Putuime well, 60 km to the south, drilled in 1968 by Mobil Oil (Enclosure 16).

Although the data quality is very poor at the crest and the structure is complexly faulted at the Tertiary level, the Cretaceous is fairly simple, being affected only by a wrench fault. Seismic line GSI50-120 (Figure 62) shows the entire Cretaceous section thinning towards the western fault and thickening into the basin to the east. The Chonta section is calculated to be about 200m, while the Cushabatay sandstone is of the order of 300m.

Consequently, it is quite apparent that the Cabo Reyes structure existed at Cretaceous time. Early migration of hydrocarbons into the main Cretaceous reservoirs would have preserved the porosity against destructive burial diagenetic processes, which are so prevalent throughout the Santiago Basin.

The main reservoirs targets are the Vivian, Chonta and Cushabatay sandstones. The Vivian is expected at a depth of about 2500m with the Cushabatay being at about 2800m. Maximum structural closure at the Chonta level is 12 km².

The risks to this prospect are reservoir quality, timing of hydrocarbon migration to trap formation, the effect on the trapping conditions at the time the main wrench fault was reactivated at Tertiary time, reservoir quality and fault seal.

Reserve estimates for the Cabo Reyes Prospect are presented in Table 16.
Figure 60: Cabo Reyes Prospect TWT Structure Map - Top Chonta
Figure 61: Cabo Reyes Prospect TWT Structure Map - Top Cushabatay

Figure 62: Dip line GSI50-120 across Cabo Reyes Prospect

<table>
<thead>
<tr>
<th>CABO REYES POTENTIAL RESERVE ESTIMATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARAMETERS</td>
</tr>
<tr>
<td>Min</td>
</tr>
<tr>
<td>Depth (m)</td>
</tr>
<tr>
<td>Size Km2</td>
</tr>
<tr>
<td>Size Acres</td>
</tr>
<tr>
<td>Porosity</td>
</tr>
<tr>
<td>Sw</td>
</tr>
<tr>
<td>Net Pay (m)</td>
</tr>
<tr>
<td>Rec Factor</td>
</tr>
<tr>
<td>GOR</td>
</tr>
<tr>
<td>OIP MMbbls</td>
</tr>
<tr>
<td>Rec bbl/acre-ft</td>
</tr>
<tr>
<td>Rec Reserves MMbbls</td>
</tr>
</tbody>
</table>

| TOTALS | Min | ML | Max |
| OIP | 65 | 220 | 535 |
| RECOVERABLE | 10 | 38 | 107 |

Table 16: Potential reserve estimates for the Cabo Reyes Prospect
9.6 TANGUINTZA NORTH PROSPECT (Enclosure 14, Figures 63, 64)

Tanguintza North Prospect is a four-way dip closed gentle rollover situated 8 km north of the Tanguintza well. Tanguintza drilled to a depth of 5296m, 214m into the Upper Chonta Formation. Hydrocarbons were tested in the upper Vivian sands. Although these sands were almost 100m thick, only 4m were found to be porous and permeable, which, on test produced 6.3 mmcfd and 478 bpd condensate. The main body of the Vivian Formation has undergone severe digenesis and were tight and non-producible. Very good Gas shows (C1 to nC5) were also recorded while drilling within the Upper Chonta (Figure 29). This zone was never tested. For a more detailed account of this well, the reader is referred to a preceding section, 6.7 in Well Summaries.

The objective reservoir of this prospect is the Vivian sandstone, which is expected to be about 100m thick at a depth of 5100m. Based on the results of the Tanguintza well, and the varying quality of the reservoir, the only way to maintain good porosity/permeability in this prospect is for hydrocarbons to have migrated into the reservoir prior to the digenetic process.

Top of the Chonta is expected at 5200m, with a maximum structural closure of 24 km$^2$. The risks to this prospect are reservoir quality and timing of hydrocarbon migration to trap formation.

Estimated potential reserves for Tanguintza North, are presented in Table 17.
### Table 17: Potential reserve estimates for the Tanguintza North Prospect

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Vivian</th>
<th>Cushabatay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Min</strong></td>
<td><strong>ML</strong></td>
<td><strong>Max</strong></td>
</tr>
<tr>
<td>Depth (m)</td>
<td>5,100</td>
<td>5,100</td>
</tr>
<tr>
<td>Size Km2</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Size Acres</td>
<td>2,965</td>
<td>4,448</td>
</tr>
<tr>
<td>Porosity</td>
<td>10.0%</td>
<td>12.0%</td>
</tr>
<tr>
<td>Sw</td>
<td>35.0%</td>
<td>32.5%</td>
</tr>
<tr>
<td>Net Pay (m)</td>
<td>15.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Rec Factor</td>
<td>15.0%</td>
<td>17.5%</td>
</tr>
<tr>
<td>GOR</td>
<td>300.00</td>
<td>200.00</td>
</tr>
<tr>
<td>OIP MMBo</td>
<td>63</td>
<td>165</td>
</tr>
<tr>
<td>Rec bbl/acre-ft</td>
<td>64.6</td>
<td>98.7</td>
</tr>
<tr>
<td>Rec Reserves MMbbls</td>
<td>9</td>
<td>29</td>
</tr>
</tbody>
</table>

**TOTALS** | Min | ML | Max |
---|-----|----|-----|
OIP    | 63  | 165| 350 |
RECOVERABLE | 9  | 29 | 70  |

Figure 64: Dip line GSI50-320 across Tanguintza North Prospect
9.7 CAMPANQUIZ LEAD  (Enclosure 15, Figures 65, 66)

Campanquiz Lead is located on the central Campanquiz anticline, about 40 km north of the Manseriche well. The Manseriche well was drilled in 1997 to a depth of 716m to test the Cushabatay sandstone in a very high structural position. This structure is very young, of Upper Tertiary age and breached. Additionally the sands had undergone severe burial diagenesis, prior to uplift and as a result, they were tight and impermeable. For a more detailed account of this well, the reader is referred to a preceding section, 6.6 in Well Summaries.

At the Campanquiz Lead ‘location’, the surface geology map (Enclosure 2b) shows the Agua Caliente Formation to be outcropping. However, the rock sample descriptions are ambiguous, implying that Cushabatay may in fact be the Formation outcropping. If this were the case, no prospect would exist since the reservoir would have been breached.

The Campanquiz Prospect is different from the location tested by the Manseriche well for the following reasons:

- A classic flower structure in the Campanquiz Prospect is developed as opposed to the back thrust styled structure present at Manseriche.
- The Chonta source rocks are in direct lateral contact with the Cushabatay reservoir in Campanquiz Prospect, implying that hydrocarbon migration, using
faults as conduit is not necessary. The source section in the Manseriche structure laterally abuts against pre-Cretaceous section.

- Seismic line Q95-231 shows that the entire Lower Puca to Base Tertiary section on the western side of Campanquiz Prospect is less than 900 msec., implying that a paleohigh existed at this location prior to the late Tertiary uplift. This signifies that a previous hydrocarbon migration, and possible entrapment, from the Pucara source rocks may have occurred.

Assuming that the outcrops are of Agua Caliente age, then the depth to the Cushabatay Formation would be about 300m. Further fieldwork is required to ensure that the Cushabatay section is not outcropping. Based on only two seismic dip lines at 8 km apart, an approximate size to this Lead is 80 km$^2$.

Other than the risk of encountering an eroded Cushabatay section, additional risks are reservoir quality, top seal, timing of migration to structure formation, reservoir breaching and fresh water flushing.

![Figure 66: Dip seismic line Q96-231 across the Campanquiz Lead](image-url)
10.0 CONCLUSIONS

The Santiago Basin Project was conducted by PARSEP and took approximately five months to complete. During this time virtually all the available geological data, which included government, industry and academic reports, and well data, was utilized within the project area as well as regionally. Geophysically, all the available 2D seismic data provided in SEGY format, and an extensive aerogravity/magnetic survey was reviewed and interpreted. All this data was used to support the conclusions presented below.

10.1 BASIN TECTONICS

1. The Santiago Basin is an elongated NNE-SSW tectonic basin extending 200km in length and 100km in width in the northernmost Peruvian Andean Fold Thrust Belt. The basin is located at the western extremities of the Marañon Basin of which it was once part of until the two were separated during the Late Tertiary Andean Orogeny.

2. The geological evolution of the Basin is controlled by two regional tectonic systems, the Andean and pre-Andean.

3. Historically in the literature, the Santiago Basin has been considered to be a basin structurally controlled, largely by salt tectonics. In the course of this study very little support for this hypothesis was encountered. Seismic and gravity data indicated that the evolution of the Santiago Basin was driven largely by wrench tectonics.

4. During the Late Jurassic – Early Cretaceous, the Santiago basin evolved as an extensional or transtensional basin, consisting of isolated rift segments that were offset across NW-trending, right-lateral accommodation zones. The orientation of basin-forming extensional faults is N to NNE.

5. Andean deformation in the Late Cretaceous – Tertiary resulted from massive structural inversion of the older extensional basins. Basin inversion was driven by left-lateral, NW-trending strike-slip faults, as well as a very prominent set of NNE-oriented, right-lateral antithetic strike-slip faults (conjugate Riedel structures) that are expressed in the transpressional inversion structures.

6. Many of the major strike-slip faults in the basin have changed direction of vertical throw several times in their history, i.e. there is a repeated history of inversion structures.

10.2 STRATIGRAPHY

1. The Santiago Basin contains a Paleozoic, Mesozoic and Cenozoic stratigraphic sequence in excess of 12 km thick deposited in more than three mega sequences overlying Precambrian metamorphic basement.

2. The stratigraphy of the Santiago Basin correlates well with that the Marañon Basin to the east. The one noticeable difference is the significant decrease in the sand/shale ratio within the Agua Caliente Formation in the former.

3. The Putuime 1X well TD’d in an anhydrite unit (133+m thick), underlying the Cushabatay Formation. For the past 30 years, it has been interpreted that the well crossed a significant reverse fault and that the anhydrite was of Tertiary
age. We interpret this occurrence of anhydrite to be the same as the evaporite unit present throughout the Peruvian Fold Thrust Belt and to be Jurassic in age.

4. Significant thickness variations with the Cretaceous are seen throughout the Santiago Basin, which are the result of syn-depositional tectonics.

5. The presence of a ‘regional’ unconformity at the base of the Vivian Formation.

10.3 GEOCHEMISTRY

1. Some 23 oil seeps have been documented from one end of the Santiago Basin to the other demonstrating that oil has been and is probably presently being generated.

2. The source potential of the Pucara, Cachiacu(?), Vivian and Pozo Formations in and around the Santiago Basin are sufficiently rich to have generated commercial amounts of hydrocarbons. The level of maturation that has been reached at different times to have generated oil and/or gas is dependant on the location in the Santiago Basin.

3. The principal source rock for the Santiago Basin is within the Chonta Formation.

4. Our modeling indicates that the Tertiary Pozo Formation is mature in various parts of the Basin and in the southern and deepest portion of the Basin, it is postulated to be within the gas window. Additionally, in areas of significant uplift, the vitrinite reflectance data on the Pozo samples indicates that the Formation was once in the oil window generating hydrocarbons prior to uplift.

10.4 PROSPECTS

1. A total of six prospects and one lead were defined in the evaluation of Santiago Basin. All are structural plays with the Cretaceous reservoirs, principally the Vivian and Cushabatay sandstones, being the primary targets.

2. Two of the defined prospects are the result of wells with shows Putuime and Dominguza., that were drilled off structure. Considerable updip potential remains untested on these structures.

3. The estimated potential OOIP for the six prospects in a most likely scenario is 1477 Mmbo and of which, 254 Mmbo are recoverable.

10.5 HYDROCARBON POTENTIAL

1. Early structuration and/or entrapment of hydrocarbons is necessary to preserve the Cretaceous reservoirs from porosity destructive deep burial diagenesis. It is through this mechanism that the Vivian sandstones intersected in the Pupuntas well, were able to maintain their excellent petrophysical properties.

2. Numerous paleo-structural traps (pre-Early Tertiary) can be documented throughout the basin that would have been in place to trap an early pulse of Pucara and/or Chonta generated oils.

3. The numerous seeps and shows attest to the excellent generative capabilities of the Santiago Basin.
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