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# Camisea Gas Fields, Peru. Uncertainties and Technologies Applied.


## ABSTRACT

The gas in Camisea was discovered in the 1980's, in two anticlines with three independent world class reservoirs, with intergranular porosity. GIIP ranges from 10 to 15 TCF with 600 to 900 MMB of associated liquids. The development of these fields was delayed 20 years, mainly due to uncertainties in the exploitation of hydrocarbons in the Peruvian Amazonian, a remote highly sensitive location.

Pluspetrol Peru Corporation took over the operations in December 2000, heading the Camisea Upstream Consortium. The type of development depends on a number of geological, operational and economical uncertainties. To solve the main geological issues several high-tech works were performed.

The first field operation related to G&G was the acquisition of 765 km2 of 3D seismic, with the objective to improve the structural image, identify the reservoir geometry and delineate the fluid distribution. A geomechanical model supported the drilling program of the high-angle extended reach wells. A real-time data acquisition system was successfully applied. The via web data transmission allowed an overseas multidisciplinary team to take quick decisions. An accurate welltest design permitted excellent wells performance with AOFs ranging from 0.5 to 1.0 BCFGD. A multi-compositional simulator helps in predicting reservoir behavior and anticipates production-injection rates.

The application of "state-of-the-art" technologies will ensure that the Gas of Camisea is exploited and managed in a rational and sustainable manner.


## INTRODUCTION

Camisea is one of the most important non-associated natural gas reserves ever discovered in Latin America. It was discovered in 1984 when drilling the well San Martin-1X. It consists of two fields: Cashiriari and San Martín that belong to the outer Subandean Thrust Belt of the Southern Ucayali basin, Eastern Perú. These fields are located approximately 500 kilometers east of Lima City, in the department of Cusco, in the rain forest region known as Bajo Urubamba.

The Camisea block is sited in a very sensitive area from the social and environmental standpoint. It is located between the Manu National Park and the Apurimac Reserved Zone, and close to the Machiguenga-Megatoni Sanctuary. The native communities that inhabit the region are both types: settled communities and nomadic tribes. The Bajo Urubamba valley is an area of natural biological diversity and species richness of extreme importance in the world.

The Urubamba river is the main communication via in the whole region and the base camp was located at a riverside plain named Las Malvinas which is 15 and 20 km far from San Martin and Cashiriari fields, respectively. One of the main challenges that the operator had to accomplish after took over the block was to have all materials in Malvinas in time and shape mainly using the *"river seasonal windows"*. From Malvinas the materials were heli-transported to the well site as in a typical remote area operation.

This first development step in Camisea was completed with a minimum operational risk due to the high performance of all personnel and technologies not only from the operator but from all the service companies involved in the project.

## SOCIAL AND ENVIRONMENTAL ASPECTS

The Gas from Camisea as a cheap energy will be conceived as a motor for the Peruvian growing in the meaning of competitivity with other countries, the life quality, commercial balance, new projects associated, etc. In order to minimize the environmental impact the concept for design covered the concentrated facilities in the existing locations, automated production, no road construction, no emissions and treatment of all effluents produced.

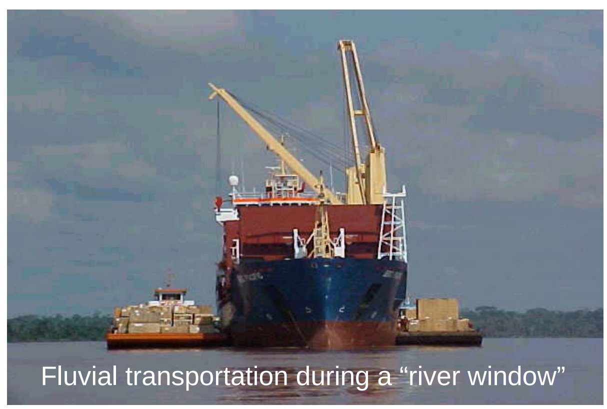
Also the protection to native communities throughout a sustainable development project was strongly considered. It was implemented a native communities program. The social assessment identified 8000 inhabitants where more than 50%

are under 15 years old, with a life expectancy of 49 years and average fertility of 7.3 children per woman. The average child mortality is of 126 per thousand (Peruvian national rate is 44 per thousand).

The implemented consultancy process has two main groups to work. The local communities inside the block and area of influence (Segakiato, Shivankoreni, Ticumpinia, Kirigueti, Cashiriari, and Camisea) integrate the primary interest group. On the other hand are the institutional interest groups, which are the public and governmental entities, related to native people, natural resources preservation, hydrocarbon and indigenous confederations.
A plan named "relationship with the communities" is a participative plan that contemplates, among other issues, a monetary compensation program for the use of the land. This generates a compensation fund with an investment plan coordinated by the communities, the NGO's and the local governmental authority.
There is a continuous monitoring of the biodiversity helped by the local people. This plan has a main objective of identifying the impacts and consequently designs a program to mitigate it, with the support of the Oxford University, La Plata University, The Peruvian Amazonia Institute and the Cusco University. Everything is oriented to obtain a standardized environmental management system based on ISO-14001 procedures.

**LOGISTICS**

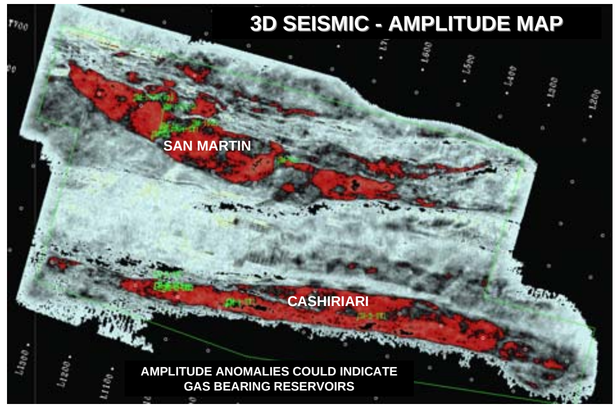
There are no roads in the region and the only means of transportation is by river from the north or direct access by air. Those situations condition all logistic and operational works done into the block. The river navigability along the year was main issue that the operator had to consider from the beginning of the project. And this is strongly related to the climate.
The rain forest jungle that characterizes the landscape at the Bajo Urubamba area is always suffering heavy thunderstorms and experiences distinct wet and dry seasons. The five months from November to March are rainy, with the drier season lasting from April to October. Consequently, high waters for goods transportation are known as "river windows" and are the only periods in the year when tools, plant parts, fuel, machinery, etc., can get into the Camisea block carried by big boats.
All transportation along the river was monitored by satellite controls. That permitted to know exactly where the boats were and in case of any accident or delay, it was easier to be solved. By the end of this first development stage a total of 120 thousands tons of material that occupied 260 thousands of cubic meters were introduced into the block through Malvinas Camp, mainly using the Urubamba River as transport way.


Fluvial transportation during a "river window"

**3D SEISMIC**

The available seismic information before the takeover consisted of ten 2D seismic lines acquired during the eighties. Eight 2D lines are oriented more or less perpendicular to the strike of the structures and two were shot along the crests of the Cashiriari and San Martin Anticlines.
After took over the area it was decided to perform a 3D seismic survey with the aim of improving the structural image and solve some major stratigraphical uncertainties as well as to give a better picture on the reservoir heterogeneities and fluid distribution. These two last goals are helped by the high quality in petrophysical properties that the reservoir rocks of Camisea fields showed in cores and other data gathered from new wells.

The initial program consisted in 787 square kilometers of 3D seismic acquisition that covered both the Cashiriari and the San Martin structures, with eastern and northern San Martin sub-structures included. At the end of the fieldwork the final coverage of the program was of 764 sq. km as consequence of avoiding enter the hunting and fishing area of some nomadic tribes.




The seismic survey last in 6 months and occupied almost seven millions of man hours where 2350 persons were involved in the payroll of the project having a maximum of 2000 people in the field simultaneously. Other numbers that can illustrate the job are the 4500 hours of helicopter, 63000 kilograms of explosives and half million of gallons of total fuel. Due to the landscape characteristics it was necessary to hire 81 mountaineers that used a total of 520 kilometers of rope in their job.

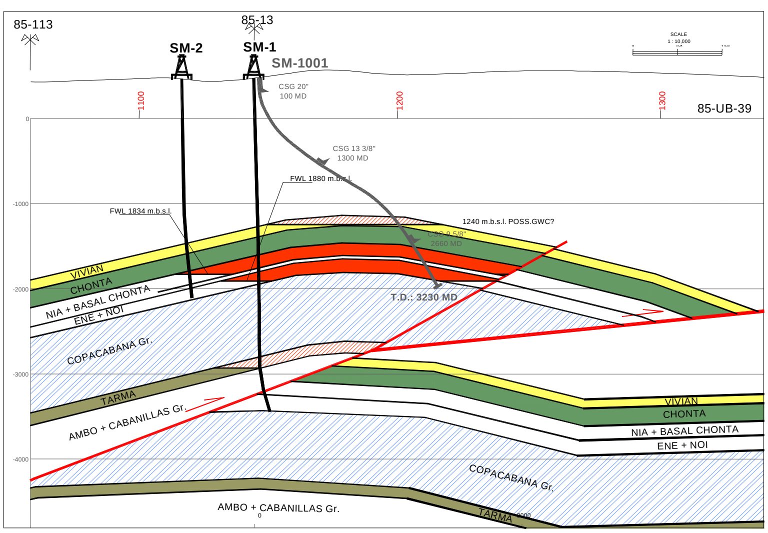
The fast track cube obtained by November 2002 was very helpful for the final drilling orientation of the well SM-1001. Also was very useful for the final drilling plan for the subsequent wells in San Martin structure previous to receive the final 3D cube by end of February.

The data quality was excellent and gave a very complete image of the structure as well as very interesting amplitude anomalies that could represent the fluid distribution inside the structure.

The reservoir characterization for the Camisea productive intervals is based in this high-quality 3D seismic and also the reliable well log data locally calibrated. To start with that study various processing methods, as acoustic impedance inversion, to determine lithologies, and amplitude versus offset, to identify fluid content, will be implemented.

## DRILLING

One of the great challenges that Camisea Project had was the drilling of development wells. In order to minimize the environmental impact on the field, it was decided to drill deviated wells from one same surface location applying a drilling system named *"offshore-in-land"*. As consequence the wells are extended-reach wells and also are *"slant-type"* in front the reservoirs.



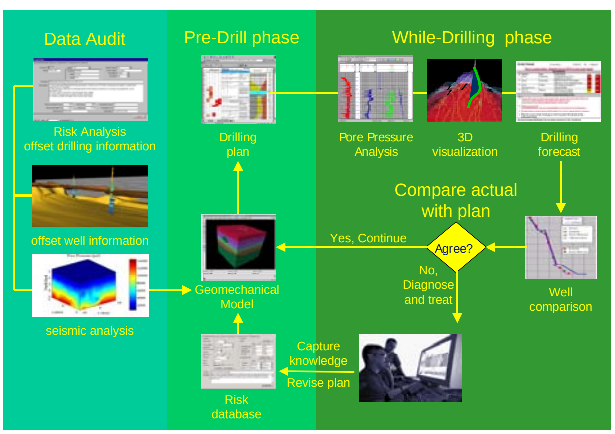

The Camisea production strategy has been conceived in order to obtain the maximum liquids recovery (Condensate and LPG) in accordance with the Plant capacity, satisfy the Peruvian Gas demand and re-inject the exceeding Gas back to the reservoirs. To achieve these objectives the development plan contemplates the drilling of four new wells and workover one existing well in the producer wellpad named SM-1X. On the other hand, the wellpad SM-3, located eight and half kilometers from SM-1X to the East, was selected as injector cluster and two new wells plus one sidetrack in the existing vertical hole were drilled. The location of the producing and injector wells was conceived locating the wellbores far enough in order to minimize any well interference during production avoiding an early lean gas production. This was obtained as consequence of several simulation runs.

The first well drilled in the block by the new operator was the San Martin 1001 that was the first challenge in this early development step. The well planning took many time and discussions before to be drilled. The direction of the well was selected following the N-S seismic line 85-UB-39 that cross the San Martin structure at the well SM-1X location and

was oriented to develop the northern flank of the structure. This decision was taken upon having only 2D seismic data for the times of drilling SM-1001.
All the wells drilled from both wellpads are slanted high-angle wells with an average deviation of 50 degrees that permitted to have longer sand intervals in the wellbore. The average total depth for the wells was 3500 meters (measured depth) with an average vertical separation of 2000 meters that were drilled in 70 days averaged per well with no big incidents.
In addition, a careful follow-up of operations was the outstanding tool for avoiding drilling problems. Real-time monitoring of all drilling parameters, good communication between key rig people and office personnel throughout an exclusive web page, and constant preventive equipment inspection, besides a safe work environment, helped to improve drilling performance as well as minimizing the probability of unplanned events.

## WELLBORE STABILITY & GEOMECHANICAL MODEL

The knowledge of rock mechanical properties such as compressibility, Poisson's ratio, internal friction angle, shear and compressive strengths, fracture and pressure gradient were of fundamental importance in the preparation of the drilling program.
Wellbore stability is an issue that was strongly considered during the planning of the San Martin wells. A Geomechanical Model was delineated to optimize mud weight and well trajectory and to select the best casing point to prevent wellbore failures and lost circulations. This was a powerful tool to verify and control wellbore conditions. Also logging while drilling that gave annular pressure, Gamma Ray, Resistivity and Neutron-Density data was a key downhole measurement for the diagnosis of the position and condition of the well and the drilling fluid.
For the first drilling operation the input came from the offset wells in the area but also all new data from new wells was introduced interactively in real time. Those new parameters were able to be modified, defining several mud parameter limits, or assessing effects of a change in drilling direction, mud weight or rock strength. A new quantitative risk assessment could be done to better analyze the success with changes in trajectory or mud weight and identified the variables with the greatest effects on reducing risk.




With reference to the mud system, it was used the state-of-the-art drilling fluids in order to avoid and/or mitigate any potential instability problem. To achieve that goal the on-site equipment to guarantee the optimum drilling fluid was implemented. This kind of extended-reach wells with complex trajectories is the economically and environmentally viable choice to exploit the field. That required low solids content and highly polymeric fluids to provide less formation damage and instability problems and, of course, the best cutting carrying capacity. The consequence of these new concepts and products is the high Gas production rate obtained in the wells already tested in San Martin Field.

## WELLTEST

The Well Deliverability Test was planned and delineated by the group of Geologists and Reservoir Engineers with the agreement of other specialized professionals such us Production Engineers, Drilling Engineers, Facilities Engineers and, of course, partners and Management. Also it was appreciated the collaboration of the service companies during the bidding step.
The team identified the most appropriate offset data from the previous wells to be used in the planning, and decided the test objectives, type of test, perforation technique, environmental considerations, equipment details and logistics.

It was decided to perform Flow-After-Flow tests that were preceded by a 12 hours clean up flow period followed by three drawdown periods of 4 hours each and one extended flow period of 8 hours. The test finished with a build-up period of 24 hours. The welltest design demonstrated to be a very confident tool to predict the well behavior. At the end of the tests there were no major differences among the pressures and rates predicted by the model and the values measured during the tests. The Production Log Tool gave very good information in identifying the relative participation of each sand body to the total Gas well rate.

Finally, it is important to note that the perforation system determined by the shot penetration analysis was vital to these excellent results in the well test operations. The guns used for these tests were high penetration 4 ½" HSD, 5 shots per foot, 72 degrees phase angle with an estimated penetration distance of 30 inches for this type of sandstone.

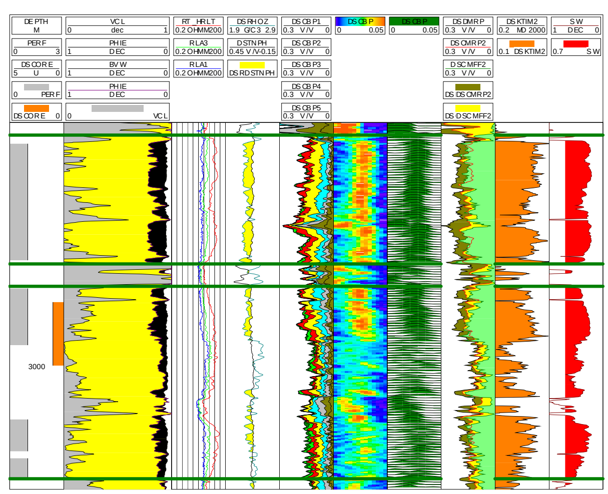
The well deliverability for the new wells showed lower pressure drop to produce the same gas rate than the former wells. This gives good confidence to the Production of the new wells. This uncertainty in well deliverability was eliminated thanks to this new technology applied in Camisea. The shown table gives some data on welltest results from the wells in San Martin Field, Producers: SM-1X, SM-1001, SM-1002, SM-1003 and SM-1004, and Injectors: SM-1005, SM-1006 and SM-3-ST1.

**CAMISEA - WELL TEST RESULTS - SUMMARY**

| Well | Choke (in) | Qg (MMscfd) | Qo (Bopd) | FWHP (psi) | FBHP (psi) | AOF (MMscfd) |
|---|---|---|---|---|---|---|
| SM - 1X | 64/64 | 51.1 | 1816 | 2451 | 3052 | 530 |
| SM - 1001 | 64/64 | 48.2 | 1692 | 2337 | 3015 | 470 |
| SM - 1002 | 64/64 | 49.1 | 1714 | 2350 | 3056 | 950 |
| SM - 1003 | 67/64 | 50.9 | 2021 | 2370 | 3042 | 531 |
| SM - 1004 | 64/64 | 48.8 | 1696 | 2329 | 3040 | 700 |
| SM-3-ST1 | 67/64 | 51.2 | | 2329 | 2983 | 337 |
| SM - 1005 | 64/64 | 46.7 | | 2320 | Injector w ell (clean-up period only) | |
| SM - 1006 | 64/64 | 48.2 | | 2400 | Injector w ell (clean-up period only) | |

*Note: Gas and Condensate rates constrained by separator's capacity*

## LOG ANALYSIS



Most of new generation tools known in the industry were run in the Camisea wells. The Logging While Drilling technology was successfully applied and demonstrated to be very helpful giving high-quality real-time data from the reservoir as well as downhole conditions. The application of Density and Neutron while drilling tool was of invaluable help in the recognition of good porosity gas bearing sandstones. That permitted to eliminate some wireline logs after drilling operations with the consequent saving of money.

The Nuclear Magnetic Resonance log was also run and gave improvement to the petrophysical reservoir properties evaluation helping in defining the intervals to be perforated for well testing. Once calibrated the T2 cutoff for the specific reservoir sandstone with core data, it is possible to read a quite accurate porosity and permeability values along the whole interval. Also the production log confirmed this certainty.

A neural network is also constructed in order to better predict the petrophysical distribution inside the reservoirs and helped in wellbore locations. The trainer wells needed long time analysis to get a good approach in the reservoir prediction mainly due to the heterogeneities observed in these continental sediments.

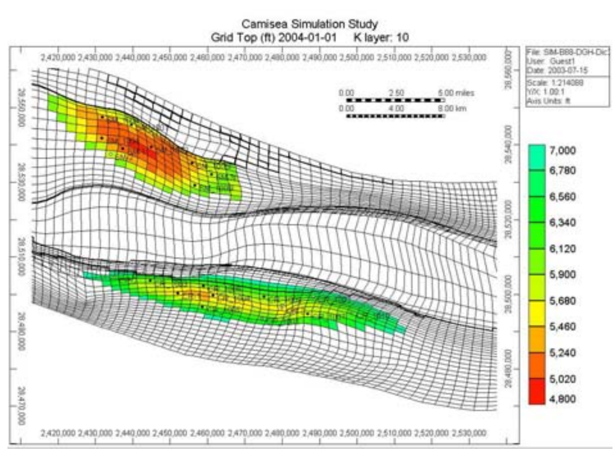
**CORE AND FLUID ANALYSIS**

The rock description in core samples is a very helpful tool to properly identify the depositional environment and also the petrophysical properties of the reservoir rock. The definition of the environment helps in prediction and delineation of the body geometry and distribution. Also that rock data allows calibrating the log information and 3D seismic attribute behavior. A total of 128 meters of core samples were recovered in all these new wells.


Core analyses consisted mainly in a complete set of petrophysical studies as porosity and permeability at reservoir conditions (NOBP) accompanied by a litho-facies analysis that helps a lot in the plug selection for any special core analysis.
Several reservoir facies were described by first time thanks to the core samples, otherwise it could be very difficult to be identified by logs. That is the case of some conglomerate in Upper Nia and eolian dune and interdune facies in Lower Nia and Lower Noi.
The permeability measures made in plugs are really very consistent with the K values estimated through magnetic resonance logs and also obtained in well test interpretation.
PVT analyses were performed in the recovered fluids from the new wells that confirmed the hydrocarbon composition for all the reservoirs previously considered.
All final results were input to the reservoir numerical simulator.

**RESERVOIR MODEL & SIMULATION**

Even having good data from the current wells already drilled in the fields it was considered that a simulation reservoir model will help in improve the fluid recoveries and at least anticipate production.
A three-dimensional visualization program was used to integrate the seismic and well data to build a 3D model and carry out volumetric calculations.
The interpreted seismic horizons were input to the geocellular model together with the fault planes. One of the most important steps in the modeling process was the creation of a fault framework based on seismic profiles and geological interpretations. There are major thrust-faults related to San Martin and Cashiriari structures, but secondary and minor faults as thrusts, back-thrusts and out-of-sequence faults are also present in the structural model.
During this process several balanced cross sections were constructed along the 2D seismic lines showing all the stratigraphic horizons. This gave confidence to the structural model.
The depth converted seismic data for all main intervals as Vivian, Chonta, Upper Nia, Lower Nia, Shinai, Noi and Ene, but also divided in several layers each, was gridded. The result is a 100 x 100 m grid geocellular model that was used to create the continuous structural surfaces in the 3D visualization software.
Besides the geological horizons, the location of the gas/water contacts (GWC) determined the boundaries of a reservoir. In the Camisea area different gas/water contacts between and within the two reservoirs occur. In Cashiriari Field, the GWC is encountered in the Lower Nia at a sub



sea depth of -2050 m. For Vivian reservoir the gas-down-to (GDT) was interpreted as being at –1698 m subsea from RFT data. In the San Martin structure, two GWC's are present. In the Nia reservoir the GWC is present at -1834 m and in the Noi/Ene reservoir is at -1873 m. The Shinai shale separates these GWC's.
The geological model of 40 layers of 100 x 100 m orthogonal grid was upscaled into the simulator model to 21 layers of 700 x 300 m corner point grid giving a total of 59000 cells. Four equations-of-state represent the fluid composition inside the reservoir. This composition was lumped into six pseudo-components. Net to gross and porosity values were upscaled using arithmetic averages.
The simulation model also represents the separation conditions at 1280 psia as plant inlet pressure at 86 degrees F, assuming a plant recovery of 98% of LPG (C3-C4) and 100% of Condensate. With the initialization of the simulation model the initial Hydrocarbon volume was calculated giving a Proven Original Gas In Place of 8.7 trillions of cubic feet with 600 millions of barrels of associated liquids (Condensate and LPG).
A number of simulation prediction runs were conducted in order to evaluate the liquid and gas recovery from both fields San Martin and Cashiriari. These runs generated gas and liquid production data for economic evaluation of the reservoirs. Also, it was considered gas cycling with the aim of having good liquid production when gas market demand could suffer a reduction.

**CONCLUSIONS**

The Environmental impact assessment was imperative to be the first action in the project in order to have an appropriate program to minimize the impact.
The logistic aspect of the Camisea Project was an issue by itself. No works, no materials, no constructions and no operations would be possible to be done in schedule if the planning on the river and air transportation were not done the way that the operator did it.
The drilling of high-angle extended-reach deviated wells using the *"offshore-in-land"* method was one of the most successful operations in the field development program.
The Geomechanical model was the best tool that permitted to predict in real time the wellbore stability behavior under any change in well trajectory or drilling mud condition.
The wireline and core data gathered from the new wells was the state-of-the-art technology that gave precise information on the reservoir quality and parameters. Logging while drilling technology was the star in this sense.
The implemented well test design resulted in a very precise tool to obtain the better performance of the well.
The implemented real time data transmission demonstrated to be a very useful way to know the well conditions and take a quick decision agreed among all interested people in the operation.
The geocellular model that integrates the seismic and geological data resulted in a reliable 3D model that was used as a basis for further studies and reservoir simulations.
The compositional numerical simulator helped in well location, predicting recoveries and anticipating production. Several conceptual models were run to perform sensitivity analyses to different parameters and designs, and later input the economical evaluations.

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