home volver al indice

Society of Petroleum Engineers

IADC/SPE 59212

First Multilateral Application in a Deep Devonic Gas Field In the North of Argentina

Luis E. Piasco and Hugo V. Eguia, Pluspetrol E&P, and Eduardo Perez Roca, Halliburton Energy Services

Abstract

The purpose of the paper is to show the first experience in drilling a multilateral well in a depleted, highly-fractured Devonian reservoir in the North of Argentina (Salta province). The well was drilled and a dual completion device was run successfully to produce one million cubic meter of gas from each one of the two branches of the well. The total cost of the well was $18.1 MM compared to the $14.5 MM for a single vertical well in the same field. The KOP for the first branch was at 2815 m with a length of 1001-m (TMD). For the second one the KOP was 2763 m with a length of 951 m (TMD). The well was completed as a MLT level 3 with the possibility to be changed to a level 5 in the future. A new whipstock technology was applied in the country for the first time. The paper will show casing design, application of the RWD technology, drilling operation sequence, Whipstock operations (difficulties and how they have been solved) time and total operation costs. Another interesting topic to be explained is the different behavior experimented in each branch regarding the fluid loss in the depleted zone. The results to be shown are the cost savings due to the replacement of two wells by one in a highly difficult logistic zone, the relatively new technology applied successfully in a deep highly deviated MLT well, and the improvement in casing design due to the RWD application in a highly tectonic zone

Ramos Field Overview

Ramos is a naturally fractured, gas and condensate field in Salta Province, northwestern Argentina. Field acreage is about 122 ha.

YPF discovered the field in 1976. They drilled three vertical wells prior to releasing the concession to Pluspetrol in 1981. From that time, Pluspetrol drilled nine development wells and completed one re-entry well. Four of these wells were horizontal, high angle wells. See **Fig. 1**.

The reservoir is composed of naturally fractured quartzitic sandstones in Huamampampa (Devonian), Icla and Santa Rosa formations (**Figs. 2 and 3**). An open fracture system provides effective porosity. The fracture system also controls fluid movement to the wellbore. Matrix porosity is less than 1%. The Huamampampa and Icla formations produce gas and condensate, mainly, whereas the Santa Rosa formation contains a volatile-oil ring. In June 1988, Pluspetrol decided to re-enter the Ramos 15 well (see **Fig. 4**). The Ramos 15 well, located on the north plunge of the structure, had the lowest production in the field. The plan to re-enter the well also included the first attempt to apply horizontal drilling technology in the Ramos Field. The re-entry met with limited success, however, inasmuch as only 147 m of the Huamampampa formation was penetrated. The maximum achievable inclination angle at that time was 52°. Nevertheless, the well experienced an increment in gas production of nearly 150M m^3/d, nearly three times its original production.

Developments in equipment and tools for re-entry drilling and support from new reservoir simulation analyses lead to a new plan to re-enter the Ramos 15 well. The plan resulted in a 350-meter-long openhole horizontal well that produced 1MM m^3/d of gas.

In 1997, the R1006 well was drilled with an 1100-meter horizontal reach. Geological analysis showed, however, that this well penetrated the objective lower than planned. In turn, therefore, a new 700-meter horizontal well was drilled using the same pilot well. It yielded better results. See **Fig. 5**.

During 1998, the R1008 (**Fig. 6**) well was drilled with 600 meter horizontal extension. This well was the first step in drilling a multilateral well from an initially-vertical well. The R1008 penetrated the Huamampampa formation vertically but due to poor reservoir characteristics, an extended horizontal branch was extended into the same Huamampampa formation. The well was viewed as partially successful because, as it was completed, it was impossible to enter the vertical branch to carry out workover jobs in the future.

Between 1998 and 1999, the R1010 well was drilled with two sub-horizontal branches, both into the Huamampampa formation. The well was drilled with the latest technology, and a wide variety of problems had to be solved during the operation. Its development is the focus of this paper.

Background

When a geological prognosis for the undeveloped portion of the Ramos field was completed, it was clear that two vertical wells spaced approximately 1500 m from each other should be completed in the Huamampampa formation. On-site inspection of the proposed well locations, however, showed that access and site-preparation requirements for both locations were serious liabilities to any drilling plan. The budget for site development alone was estimated at $1,500,000/each site.

Successful experience drilling horizontal wells into the Huamampampa formation indicated that a Multilateral ("MLT") well with two branches into the Huamampampa formation was feasible and would probably be more cost effective than a program of two separated wells placed on expensive drilling pads. Consequently, the operator working cooperatively with a Group of Service Companies made plans for the Ramos well—a two-branch, dual completion, state-of-the-art MLT well. The objective (see **Fig. 7** and **Fig. 8**) was to build only one site in an accessible location and, from there, drill two sub-horizontal branches into the Huamampampa formation. One branch was to have a 302° azimuth into the west side of the structure. The other was to have a 122° azimuth into the east side. A key requirement was to be able to service either one of the branches at will. The strategy for achieving the well construction objective was based on the following philosophical guidelines:

- Establish clear understanding of the Project's needs
- Perform all tasks efficiently, while maintaining the highest levels while working with safety and without harm to the environment
- Establish a Quality Assurance System for all participants that includes procedures that evaluate performance, institute continuous improvements, and assure that all objectives are compatible with each other as well as with the guidelines listed above
- Aim for excellence though good relations among the working parties and through a mutual desire for shared success
- Endeavor to generate the highest possible economic value from the effort, in keeping with the guidelines

The operator lead the project and set the standards. A formal Operational, Technical Team composed of staff from The Operator and from a Group of Service Companies was located in Tartagal (Salta). Key staff included a Project Coordinator (representing the Group of Service companies) and a Supervisory Drilling Engineer (an operator employee). Technical staff in Buenos Aires and Houston provided additional expertise regarding all aspects of drilling and MLT applications. All services and materials were directed through the Operational, Technical Team.

Preliminary Plans for Drilling R1010

The possibility of drilling a two branch well was known and deemed feasible at the time the R1010 well spudded. However, an unsuccessful attempt to recover a standard whipstock in R1006 well, drilled just prior to spudding the R1010, affected planning as explained in the following paragraphs.

The intended first step was to drill vertically a 12 ¼-in. main bore forty meters into the Huamampampa formation, run 9 5/8-in. casing and cement. It was conceivable that drilling deeper would not be possible thereafter because of inability to achieve the curvature required to follow the pay zone slope. Thus, the initial proposal called for setting a non-recoverable whipstock above the shoe, drill few meters of formation, leaving the hole ready to re-enter and drill this branch. After, set a second whipstock above and drill directionally the first leg. This option was considered low-risk: in a worse case scenario, if the second whipstock could not be recovered, it was better to abandon the first whipstock and the few meters of the formation drilled, rather than to lose the entire branch trying to recover the whipstock. The second leg would have been drilled through a portion of casing milled above the unrecoverbrable whipstock.

Because of availability and experience with 9 5/8-in. OD tools, the decision was made to run a tapered casing string. The plan called for a string composed of a top-portion of 2610 m of 10 ¾-in. casing and a bottom-portion of 205 m of 9 5/8-in. casing (see **Fig. 7**). The larger diameter pipe at the top of the string would allow running the dual completion device required by the production department. The smaller diameter casing at the bottom of the string was chosen to allow installation of the selected whipstock.

Operational Development

Common Procedures for All Development Wells and Variations for the R1010 Well. The first stage in development of all wells in the Ramos Field calls for drilling a 36-in. hole and run and cement a 26-in. casing. This stage provides a basis for installing the rotating head and the blooie line so that the next stage of the well can be drilled with foam. The casing shoe is placed 40 m below the rotary kelly bushing (RKB).

The second stage is drilled with stiff foam and a 24-in. bit to a depth of approximately 400-m. RKB. When this depth is reached, the hole is cased with 18 5/8-in. casing. Because the Ramos-field wells are known to have high-fluid-loss intervals, casing is cemented at the shoe and a check carried out to insure that the cement has been properly emplaced. Then, cement is added from the top down until the cement level can be sustained in the casing-borehole annulus at the wellhead.

The third stage is similar to the second. The hole is drilled with foam until water from the Tupambi formation makes the foam unstable. Then, the fluid system is switched to aerated mud composed mainly of PHPA and KCl. In the R1010 well, this switch was made at 1106 m. The top of Los Monos formation was reached at 1195 m. A 13 5/8-in. shoe was set at

1229 m. Overall, this stage of borehole development for the R1010 well was drilled as planned, without delays. Instead of the usual 13 3/8-in. casing a 13 5/8-in. casing is chosen as it provides a thicker wall for tolerating wear.

In general, wells in Bolivia and Argentina in the sub-Andean system drill their fourth stage, in the Los Monos formation, with oil base mud ("OBM"). In contrast, the fourth stage of the R1010 well was drilled with water base mud ("WBM"). In order to drill with WBM, mud from the previous drilling stage was conditioned with sufficient KCl to reach a concentration of 20,000 ppm. Shale stabilizers and shale sealants were also added to produce a drilling fluid with low API fluid loss value. For this stage of drilling, mud weight was increased as needed to control anticipated changes in formation pressure and also to provide borehole stability.

During the fourth stage of drilling, special attention had to be paid to the tendency for the borehole to deviate naturally. The Los Monos formation is characterized by zones with high dip angles and a tendency toward high deviations as well as by zones where there is little tendency for deviation. This mixture of tendencies can lead to severe doglegs that, in turn, can make running casing difficult.

In this stage of drilling the R1010 well, another factor that could affect deviation had to be dealt with: reaming-while-drilling ("RWD"). Bicentric 8 ½-in. by 14-in. bits and 8 ½-in. by 14-in.-reaming-while-drilling devices had never before been used in this field. These bits finished the interval within 10° of vertical.

Furthermore, the natural deviation was taken advantage of the geometry of this portion of the wellbore, it would be possible to enter the lower branch of the MLT using the force of gravity only. An awareness that tools fall to the low side of an MLT well lead to the attitude that the natural deviation would provide a kick-off point for the planned MLT.

The intermediate casing was also run successfully during the fourth stage of drilling.

The fifth stage of drilling in the Ramos field requires dealing with a below-hydrostatic pressure gradient in the gas-producing, Huamampampa formation. This condition makes drilling with OBM (0.84 Specific Gravity, SG) almost impossible because of leakage from the well into the formation. Normally, carbonate and fiber mixtures are used to stop leakage, but these mixtures were not enough. Also, the mixtures are known to produce at times undesirable formation damage, even though are acid solubles. As explained below, an unusual experience was observed while drilling each one of the branches in the same formation (Huamampampa).

Building the Main Bore. While drilling at the early stages of the R1010 well, new information required an immediate change in its design. The R15 well (**Fig. 4**), the first horizontal well in the Ramos field, had gas productivity decreasing at alarming rates. Gas production in the R15 comes from the Huamampampa formation, in which the well was completed but had no protection such as a perforated casing through the anticipated production interval. A workover rig was called in and confirmed that the production interval had totally collapsed. The upper zone of the Huamampampa formation, which is characterized by shales intercalation, was therefore cleaned and slotted casing run. The well then recovered production. A few weeks after this incident, the R1006 well collapsed in a similar fashion. It, too, was cleaned out and then cased with a slotted liner (see **Fig. 5**).

In view of the collapsed wells described above, the first well construction plan for the R1010 was abandoned. The completion program was changed to run slotted casing in the Huamampampa formation in both of its planned branches.

An MLT well with mechanical and hydraulic isolated junction had been decided on. However, after confirming the plan and estimating the time needed to get parts into the country, this alternative was put on hold. Attention was instead focused on the possibility of running casing in both branches of the well (level 3) with the option of switching the set-up to include a junction with hydraulic seal (level 5) at a later date when needed.

As soon as the Huamampampa formation was penetrated at 2798 m, the hole started to take fluid badly. Consequently, it was necessary to finish this interval by incorporating fluid loss material in the mud system and drilling without a downhole motor. The main bore reached a depth of 2826 m, and the final survey in this section indicated 9° inclination and 330° azimuth. In view of these values for inclination and azimuth, it was only necessary to build angle to start drilling the first branch immediately below the 9 5/8" in. casing.

RWD Performance. Plans to do reaming-while-drilling ("RWD") were based on the desire to save costs in pipe but still run a dual completion device. They were also based on concerns about well collapse. There had been successful experience running 10 ¾-in. casing in 12 ¼-in. hole in the well drilled prior to the Ramos 1010. Consequently, large differences in casing diameter versus borehole diameter were not considered a serious problem. Still, the Ramos 1010 was in an area affected by unusually high tectonic stresses. Hence, the more room between casing and hole in the event that the hole deformed after drilling but before casing is run, the better. Additional room could avoid stuck pipe. Even if casing with flush couplings were used, the greater the annular space would reduce torque and drag and the problems they cause when running casing in a deviated hole.

In view of these concerns, an RWD composed of an 8 ½-in. pilot bit with a 14-in. reamer was run in the Los Monos formation. Data shows that the rates of penetration with this drilling setup were similar to rates for conventional bits with average borehole diameter of 14 in. Because of the whirling characteristics of the pilot bit and the reamer position in the bottom hole assembly ("BHA"), the well developed a taper from the top to bottom of its run. The bottom of the drilled interval had a diameter of less than 14 in. Small diameter was not a problem because the casing string was designed with a taper. The last 200 m were ream with a 12 ¼ in. bit to ensure hole OD for the 9 5/8 in. casing

Building the Multi-Lateral. Drilling the first branch was a normal operation until the well started to take fluid. The mud weight was around 0.92 SG. Different sieve sizes of calcium carbonate ($CaCO_3$) and aragonite fibers were used to stop the losses. When the hole reached 3681 m, the drill string stuck owing to differential pressure. It was impossible to get the pipe free and recover the tool. Therefore, a sidetrack was initiated, but fluid losses were as severe as they were at the beginning. Many kinds of loss-control additives were tested and pumped to the well, unsuccessfully. During drilling of this portion of the branch, 800 cubic meters of OBM were lost. The final depth of the first branch was 3816 m. The well was logged. A casing collar log ("CCL") was also run to determine the locations of the collars and avoid them during the milling operation. The zone where the window was installed was worked with a casing scrapper and cleaned. The first Leg was completed with a 7-in. slotted liner with shoe at 3763 m (**Fig. 7**). The liner was hung in the 9 5/8-in. casing at 2785 m. The liner was not cemented because of extremely low formation pressures. Rather, the purpose of this pipe was to protect the hole from possible shale sections sloughing and plugging the well.

After the liner was set, the MLT hollow whipstock (HWS) and packer combination were run using a setting tool. The packer was dress with a liner tie back assembly to space it out. The tie back seals were removed to avoid drag during the process of orienting the HWS inside the polish bore receptacle (PBR). The whipstock was oriented to mill a window in the high side of the hole, so the azimuth for the first branch was opposite to the azimuth for the branch that would follow. Plans were to set a viscous K-max plug, to prevent cuttings from packing off around the whipstock but knowledge that high fluid losses would drain the pill away from the window level ruled out this idea. The concern was the K-max would migrate down hole with the fluid loss and not be in the window joint when we set the packer.

After everything was checked, the whipstock tool was run in and oriented with a gyro. The hydraulic packer was set and pressure-tested. Setting depth for the whipstock was 2770 m. Application of twenty-tons-weight sheared the (whipstock) setting tool pins. (18 tons over pull released the running tool). The string was pulled out of the hole, leaving everything ready to mill the window.

Three milling runs cut out the window. The drilling mud was conditioned to minimum yield-point values. The first run was made with the starter mill. During the first milling operation, the rate of penetration ("ROP") and advance were controlled, and sweep pills cleaned the well.

The second mill continued opening the window. The third mill insured that the window was cut all the way to the concave end of the whipstock to assure that drilling equipment could enter and leave the branch smoothly. A watermelon mill smoothed the edges of the window so that the well was ready to start operations with the mud motor. Magnets over the shakers recovered metal, and recovered metal was used to evaluate the progress of milling. Over 150 kg of metal debris was recovered from the R1010 well over the three mill runs.

Second Branch Building. A newly-formulated viscoelastic WBM drilling fluid was developed for the second branch. However, lab tests showed that the fluid would not prevent anticipated mud losses. Consequently, the second branch was drilled using the same OBM mud used in the first branch, However, its weight was lowered to 0.850 SG. From the beginning. The second branch was drilled to the east to 3714 m measured depth without problems. The unusual circumstance encounter was that this branch did not encounter any losses. There were no fluid losses, and there were good rates of penetration, particularly in the Huamampampa "limpio" formation. The selection of 8 1/2-in. bits used in the branches improved on the performances of similar bits used prior to the R1010.

The second branch was cased with a 7-in. slotted liner with shoe set at 3637.3 m (TVD). A liner with a PBR was installed to allow tying back the casing and sealing the junction in the future. No liner hanger was used. The top of the casing was left 20 m from the kick-off-point ("KOP") window at 2790 m.

After the second branch was drilled and casing run, communication was to set up between both branches and the main bore hole. The program was ready to run the final completion device.

Ordinarily, an MLT well system calls for milling out the center of a whipstock filled with a synthetic, easy-to-drill compound. However, the vendor reported problems in obtaining MLT reaming tools for this kind of whipstock when those are to be operated from the 9 5/8-in. casing. Therefore, the plan was changed to pull out the in-place whipstock and replace with the back-up run with the center pre - drilled.

A die collar with safety joint and jar was run to recover the whipstock. The first, 40-tonne-jar stroke set the whipstock free, and it was pulled out of hole. A cleaning run cleaned the zone at the site for the new whipstock. Finally, the new whipstock was run and oriented to the mule shoe, which put it in the same orientation as the original whipstock. A gyro checked its position and orientation. A slack off of 18 tons was used to set the whipstock and 18 tons pick up to release the running tool from the whipstock. When the shear pins were cut, the running tool was free to pull out of hole.

The last operation was to run the 6 1/8-in. milling tools to drill out the plug inside the packer and to clean inside the MLT system. As soon as the plug was milled, and opened, the well took fluid from the first branch just as had happened during the drilling phase. A 6 1/8-in. bit was run into the first branch to prepare to drift the hanger and casing in the zone where the production packer would be set. At this point, the drilling stage was finished, and completion operations were started.

Completion Operations. As soon as the first branch joined with the main borehole, it started to loose fluid. To control the well, a flux of 1500 to 1800 l/hr of mud was maintained because, to begin with the completion, the leak had to be stopped. To stop the leak, a wireline plug was set in the production packer run and set on wire line. It was known that debris collected on top of the wireline plug could make it difficult to recover the plug, consequently, a viscous gel pill was put there to protect the fishing neck from "dirt." The permanent packer was set with whirling at 2817 m on the second joint below the casing hanger. As soon as the packer was set, the leak stopped. This development left the well ready for the biggest job in the completion: running the dual completion string.

A 3 ½-in. tubing line with length programmed to handle the spacing of the packers was set up. The tubing line was equipped with a stinger for connection to the 7-in. packer. A 10 ¾-in. dual packer was connected with a 4-in. line screwed in from below. With the bottom installation ready, run-in started simultaneously with dual packer and 3 ½-in. and 4-in. tubing lines. The set up was pressure-tested with 3500 psi differential pressure every 1000 meters. A test plug was run above the circulation sleeve.

Before making final installation, subsurface safety valves were installed in both stingers along with one safety valve in each packer. The solid production block was also installed.

The next operation called for setting the dual completion packer by applying pressure in the 4-in. tubing line and recovering the tubing plug used in applying the setting pressure. After that, the tubing plug installed in the 3 ½-in. tubing line below the 7-in. packer was also recovered. next day, a nitrogen unit kicked off production. The well produced gas to the flare line while cleaning up the formation. The R1010 MLT well was a technical and economical success. (See **Fig. 10** for comparison costs between the R1010 MLT well and a single branch well -R1008-)

Conclusions

- The MLT application reduced considerable the costs when compared with two horizontal wells which would have the same productivity. (See **Fig. 9.** and **Fig. 10**.)
- The MLT system used tested the versatility of the tools as the hollow whipstock was swapped with a back with out any mechanical problems.
- The experiences in working as a Team between the Operating Company and a Group of Service Companies was effective, the well was completed on time with no accidents nor damage to the environment.
- The well R1010 will recover reserves more efficiently.
- The well produces independently from each branch and could be transformed to a Level 5 if so needed in the future.

Acknowledgements

Pluspetrol and Halliburton Argentina S.A. want to thank the staffs of both companies — especially members of the Operational Technical Team & the Group of Service Companies — for their effort in making the Ramos 1010 MLT well a success. Halliburton also specifically thanks Pluspetrol for the opportunity to implement the Halliburton Multilateral System technology in the R1010 well.

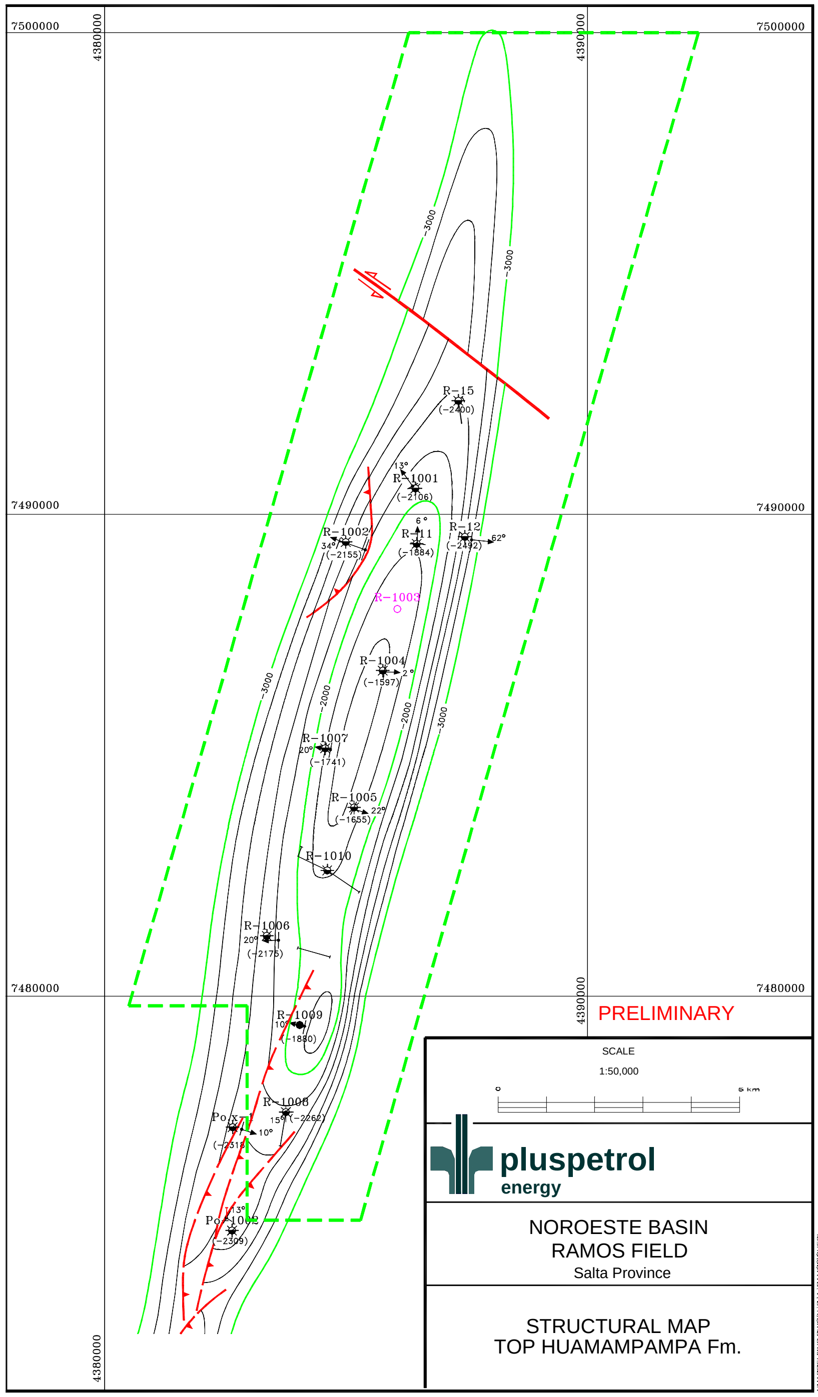

Fig.1.- Structure Contour map on the Huamampampa Formation, Ramos Field, Argentina.

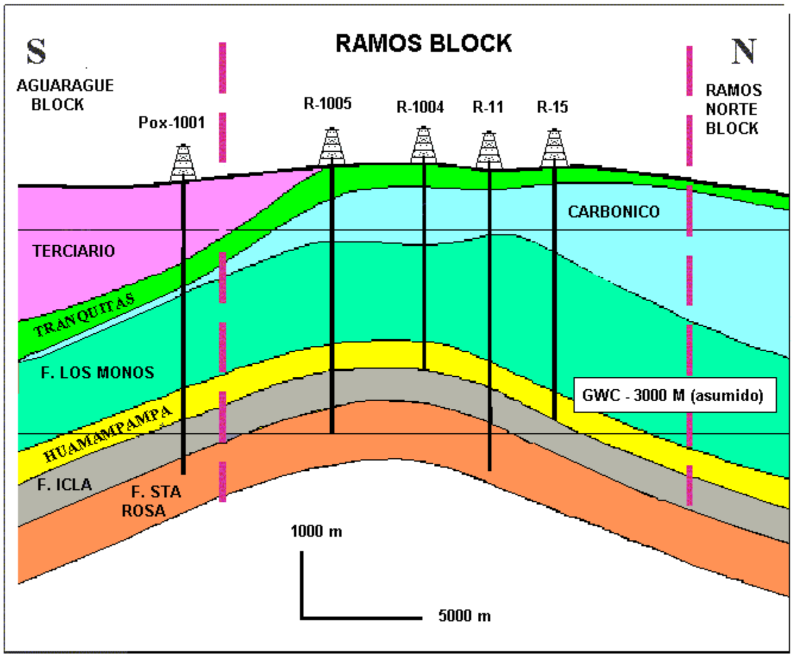

Fig.2.- North-South Cross-section Ramos Field.

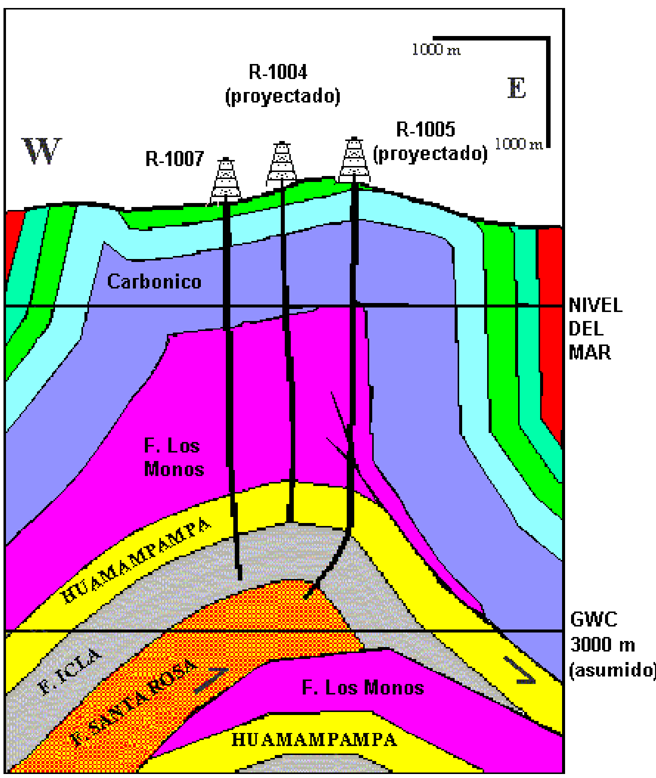

Fig.3.- West-East Cross- section, Ramos Field.

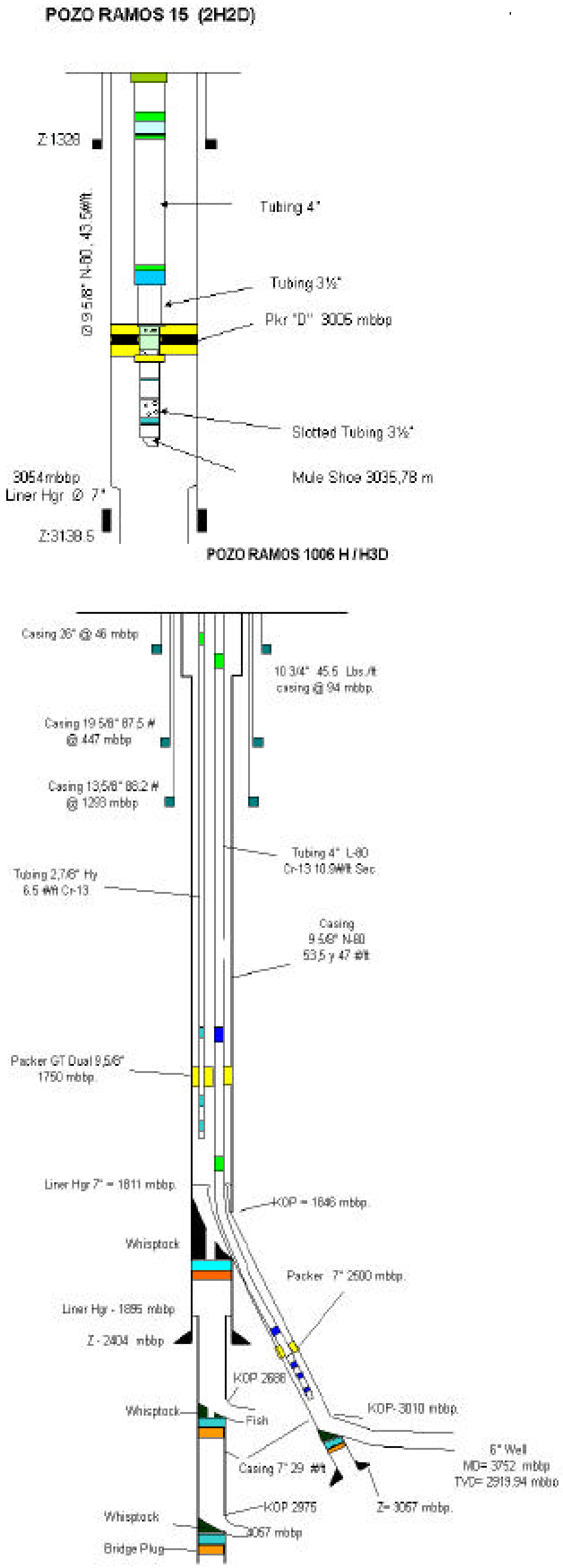

Fig.5.- Completion Program for the R1006 well.

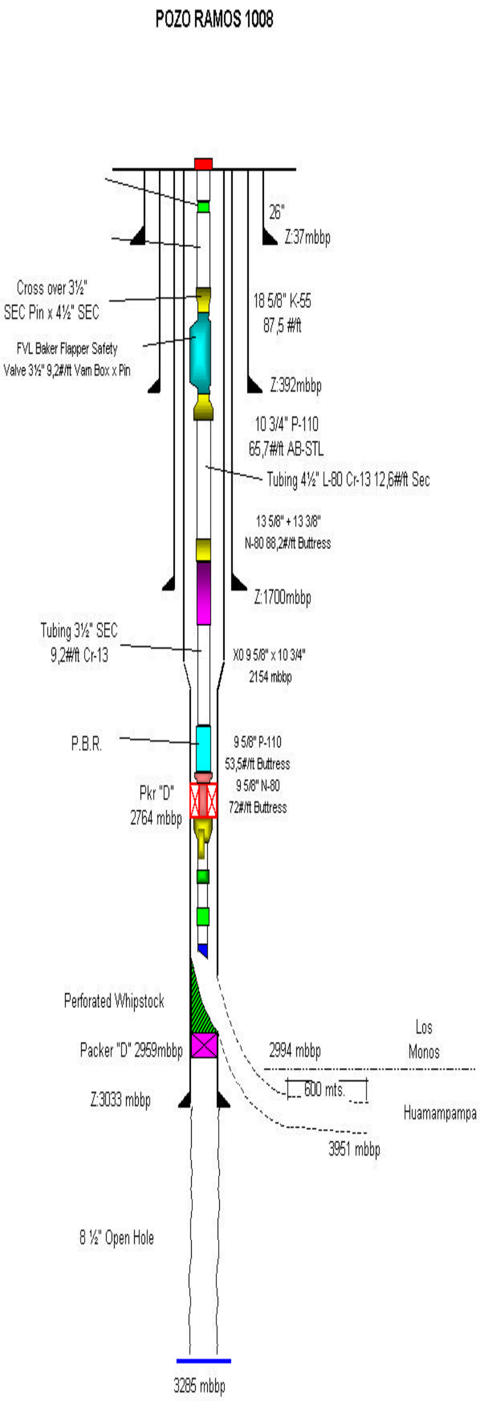

Fig.6.- Completion Program for the Ramos 1008 well.

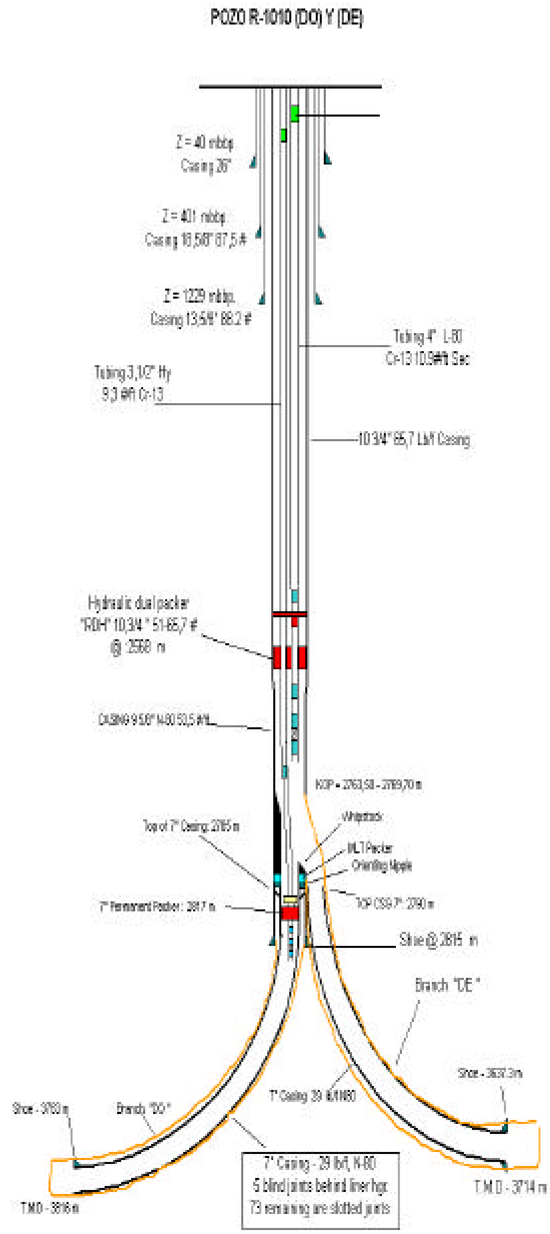

Fig.7.- Completion Program for the Ramos 1010 well. Note the arrangement of lateral sections from the main borehole. This design required only a single drillsite, a requirement that saved considerable expense.

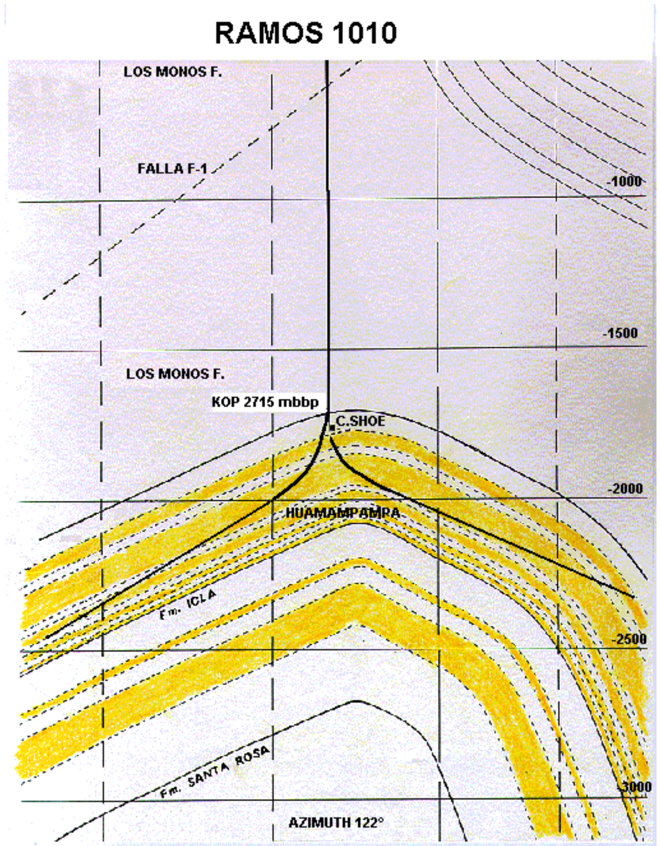

Fig.8.- East-West Cross-section through the MLT Ramos 1010 well. Note the trajectories of the proposed lateral sections of the main borehole.

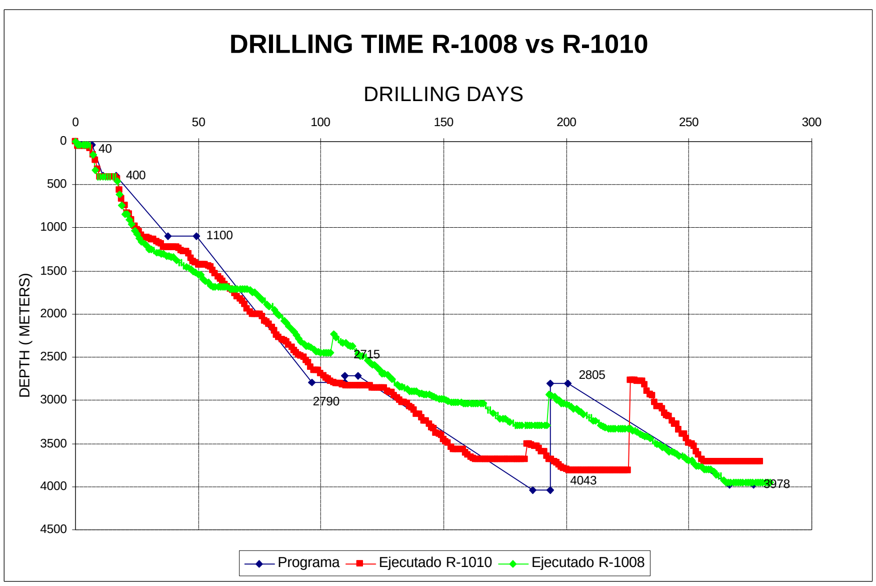

Fig.9.- R1010 vs. R1008 Drilling curve. Note the time consumption on R1010 well is more efficient considering that two branches have been drilled.

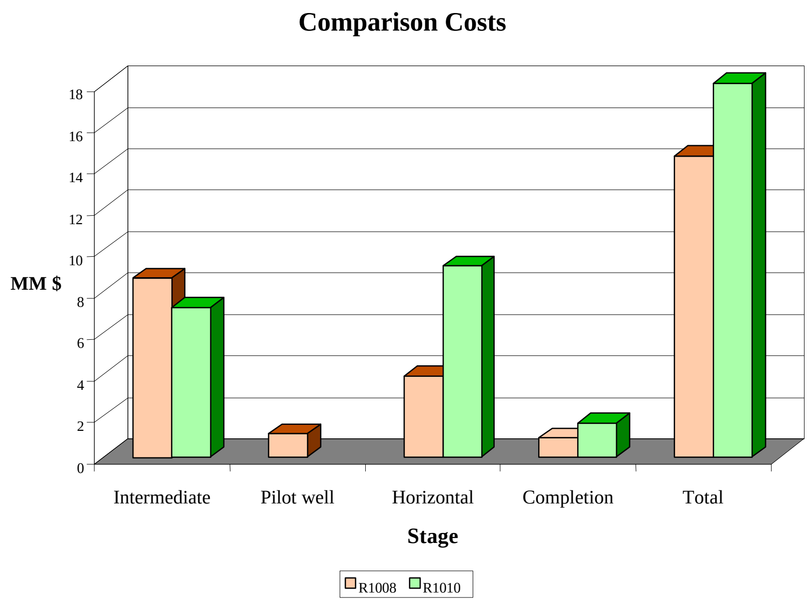

Fig.10.- Cost Comparison chart between R1010 and R1008 (one branch) wells. Note in the total cost the convenience in drilling the MLT well.