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Economic Development of Shallow Oil Sands in Trinidad, West Indies Using Electrical Conductivity Imaging

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This paper was prepared for presentation at the GSTT 2000 SPE held in Port-of-Spain, Trinidad, 10–13 July 2000. It was selected for presentation by a Technical Committee following review of information contained in an abstract submitted by the author(s). Contents of the paper, as presented, have not been reviewed by the Technical Committee and are subject to correction by the author(s). The material, as presented, does not necessarily reflect any position of the Technical Committee, Geological Society of Trinidad and Tobago, Society of Petroleum Engineers, its officers, or members. Copies of papers should contain conspicuous aknowledgement of where and by whom the paper was presented.

ABSTRACT

Middle Pliocene oil sands occur near surface in the Morne Diablo Field in Trinidad, W.I. Historically there has been little interest in developing these sands, as they have been considered too shallow to be economic. The economic potential of the shallow sands was re-evaluated using new technology and a new development strategy. Evaluation included geologic mapping based on electric logs, production history analysis, and surface Electrical Conductivity Imaging. For the first time in Trinidad, the technology of surface Electrical Conductivity Imaging (magnetotelluric, MT) geophysics was carried out to test for resistive geo-electric strata which may correlate with the shallow oil sands. The results of the MT data were integrated into the geologic maps already developed using existing well data. Evaluation of the resultant composite maps revealed potential oil bearing sand trends which were not previously identified using traditional well log data.

In order to test the trends, formation specific planning was developed for the drilling, completion, and production operations to minimize cost and reduce damage to the low pressure, unconsolidated formation and hence maximize production.

Thirteen wells were drilled on the basis of geologic mapping and the MT technology results. All wells were completed having encountered the target sands ranging from 8' to 380' from surface. The paper reviews the economically successful results of the shallow wells in proving up additional oil reserves in the Morne Diablo Field.

The paper concludes that the use of new geophysical tools like surface Electrical Conductivity Imaging may allow cost effective data collection to aid in development and recovery of additional shallow reserves in mature fields that would otherwise be bypassed.

INTRODUCTION

The Morne Diablo Oil Field, located in southern Trinidad, W.I. was first developed in 1937. Predominantly oil was produced from Middle Pliocene to Middle Miocene sands ranging in depths from 900 to 6000 feet. Several surface hole well logs showed the presence of shallow sands at depths less than 500 feet. Resistive shallow sands as indicated on well logs were concluded to be either fresh water or possibly oil bearing. Limited testing was carried out on some possible oil sands, however rapid decline of oil production due to water inflow proved the sands uneconomic.

In 1991 well MD 45 was perforated in resistive shallow sands and continues to produce oil to date. Investigation of the shallow sand potential in the area using electrical conductivity imaging, devising a economic development strategy and follow up drilling of 13 wells is discussed in this paper.

ELECTRICAL CONDUCTIVITY IMAGING

The method discussed in this paper incorporates the use of surface measurements of the earth’s magnetic and electrical fields from discrete stations along an arbitrary line. The signals measured are from two sources. First, the natural electromagnetic signals from the earth and second, man-made signals from a transmitter. The signals from the transmitter compliment the natural signals and fill in voids in the earth's signal spectrum.

Data acquisition involves the placement of two electrical dipoles and two magnetometers, orthogonal to each other, in the ground at each station along an arbitrary line. The receiver measures a band of frequencies from the earth and transmitter sources. Different frequencies are able to resolve features at varying depths. Low frequencies are required at depth and high frequencies near surface. The receiver simultaneously measures the electrical and magnetic fields and transforms them to an apparent resistivity profile.

The field data was acquired using 82 and 165-foot dipole spacing along lines from 330 feet to 1500 feet in length (Figure 1, Basemap). Measurements were made at each adjacent station, providing a continuous profile along the line.

The data shown represents field data and was not processed to remove any spurious responses or noise. Spurious data can be seen as discrete resistivity anomalies at single stations which do not continue to adjoining stations. Resistivity profiles were then generated, interpreted and results incorporated into geologic maps (Figure 2).

Figure 3 shows a resistivity profile along line MD 45. The resistive anomaly shows a thinning out or decreasing resistivity values to the southwest. These results correlate with expected shaliness to the south from geologic mapping. Of interest is the strong resistive anomaly at the northern end of the profile. Initial geologic mapping indicated that MD 45 well bore might represent the thickest oil sands, as oil sands at MD 55 thin considerably to the north. However, the resistivity profile shows that a thicker and more resistive anomaly (EM 4) extends northward past MD 45. The drilling of wells MD 65 and 75 on the anomaly confirm the thickened oil sand at this location. Resistivities of oil sands in MD 65 and 75 are greater than in MD 45. Furthermore very shallow resistors are apparent on the profile, which were not correlated with any sands in MD 45 well log. MD 65, 74, and 75 show resistive oil sands within 8 feet from surface and may be responsible for the anomalies.

Resistivity profile MD 44 (Figure 4) shows a resistive anomaly near MD 44 and extending in a northeast direction. Oil sands in new wells MD 64, and 68 appear to correlate with the resistive structure.

The profile line through MD 7 (figure 5) shows a resistive structure extending to the north of MD 7 for approximately 225 feet and then thinning considerably to a structure at a shallower depth above 100 feet and continuing northward. Southward (Figure 6) the resistive structure appears to decrease, however, a new anomaly (EM 2) appears from a depth of 250 feet to near surface. EM 2 extends southward to the end of the line, 650 feet from MD 7. The shallowing of the anomaly to the south may represent the actual dip to the north seen in the oil sands. EM 2 was not tested. MD 66 was drilled on the north extension of the MD 7 resistive structure. Oil sands encountered appear to correlate with the anomaly.

Line 800E(figure 7) is a continuous north-south profile extending 1,500 feet in length and located approximately 600 feet east of MD 7. A resistive structure (EM 1) occurs directly east of MD 7 and was interpreted to indicate the eastward extension of the oil sand trend. There were no other mapping controls, which would extend the trend in this direction other than extrapolation eastward from geologic maps. Quinam 52 was drilled to test the anomaly. Well logs showed a thick sand sequence, with a limited oil section. The well is producing 14 BOPD currently. A smaller and shallower anomaly (EM 3) occurs to the north of EM 1 and has not been tested.

The four resistivity profiles combined with the geologic maps showed that the resistive geo-electric bodies appear to correlate with resistive oil sands and indicate oil sand trends. Trends identified are thicker sands to the immediate north of MD 45, possible continuous oil sands from MD 45 to MD 7 and also sands extending eastward for 600 feet from MD 7.

GEOLOGY

Higgins and others have recorded surface oil shows in the map area since the 1930's. However, the oil shows or seeps have been attributed to oil migration along structural features, rather than sub-cropping shallow, oil-bearing sands.

In the map area the Forest Formation outcrops. The Forest Formation is Middle Pliocene deltaic and fluvial deposits of shales, sands and silts. To the west of the map area and still within the Morne Diablo field the Forest lies deeper. There it has produced over 2 MMSTB of 18-24 API gravity oil from lenticular sands.

Structurally the bedding dips to the northwest with dips increasing to the south as the NW-SE trending Los Bajos fault system is approached. Strike is approximately N70E with the trend along strike plunging to the southwest.

HISTORICAL WELL DATA

Drilling in the late 1930's and early 1940's showed possible shallow oil sands in wells MD 5, MD 7, MD 25, MD 44, MD 45, MD 55 and QUN 9. Well log resistivities of the potential oil sands vary from 5-40 ohms/m. In 1939 MD 5 was perforated over 3 intervals from 150-927 feet KB and tested 60 BOFD, 50% oil before watering out. MD 5 was again placed on pump in 1996 and produced 5,200 Barrels oil before watering out. MD 25 was also perforated at 348-352 feet KB at time of drilling and tested fresh water. Well reports at the time of drilling concluded it would not be economic to produce the shallow sands.

In 1991 MD 45 was perforated in 5 intervals between, 203-357 feet KB. Production commenced at 20 BOPD and is currently at 8 BOPD. Cumulative production totaling 22,000 barrels 18 API oil with no water. In 1997 MD 7 and QUN 33 were perforated through surface and production casing. Initial production was 20 BOPD per well and declining to a present production of 5 and 3.5 BOPD with 15,000 barrels cumulative combined. Significant drilling mud production preceded oil production in both wells. MD 55 was also perforated through 2 strings of casing with no fluid inflow.

ANALYSIS

Well log data and production data from tested wells indicated that initial production rates of 20 bopd could be achieved from the shallow sands with cumulatives in excess of 20, 000 barrels oil. Oil sand maps showed reserves in excess of 1 MMSTB oil to be recovered.

However, poor perforation results from well MD 55 showed there was mechanical risk in attempting to perforate through two strings of casing and cement to reach the oil sands in existing wells.

Thickness of total oil sands can exceed 200 feet per well. The individual sands can be thin with shale breaks in between. To gain access to all the potential oil sands behind casing would require a high density of shots. Additionally, the shots required must be powerful to penetrate two strings of casing and cement. These perforating requirements would be expensive. Also, the mud weight (70-80 pcf) used to drill the deeper wells surface hole and cement (108-112 pcf) used in cementing surface casing is excessive for the target shallow sands and may have caused formation damage which may affect the production potential.

With these risks in mind it appeared that drilling new wells to the target shallow sands and using pre-perforated casing would be required to achieve maximum production potential from the sands and still be cost effective.

DRILLING AND COMPLETION

To minimize environmental damage and cost, a small footprint drilling rig was utilized. Location size was kept to a minimum. 8 1/2" hole using 4 1/2" drill pipe on a top drive power swivel was bored to an average depth of 350 feet. Salt water with salt gel was used as the drilling fluid at mud weights between 66 and 69 pounds per cubic foot. Salt water was used to minimize any swelling reaction within the shales.

Circulating pump pressure was also kept to a minimum to avoid formation damage and well bore washout in the unconsolidated sands.

Gamma ray, spontaneous potential and resistivity logs were run in all wells, and porosity logs in only one well. The well logs allowed determination of the oil sand interval for the casing programme.

Shop perforated casing, 24 holes per foot, 90-degree phasing, 7/32-inch hole size, in either 7 inch or 5 1/2 inch casing size was used. Enough casing was shop perforated in advance such that the appropriate combination of blank and perforated casing joints could be selected and combined to make up the required casing string programme.

A single string of casing was run to surface with a bull plug on the bottom joint (Figure 8). Casing was landed on the bottom of the hole. A plug was pushed down around the outside of the casing and cement filled from the plug to surface on the outside of the casing. There was no cement between the oil sands and the shop-perforated casing in the 13 wells, in an effort to minimize formation damage and cost.

MD 66 was hand gravel packed between the casing and well bore. Slotted 0.012 inch, 5 1/2 inch, casing was run across from the oil sand. 20/40-mesh gravel was placed between the casing and well bore. A cement plug was set near the top of the casing to surface.

Production equipment consisted of a 300 series wellhead with 2-3/8 inch tubing to bottom. Progressive cavity pump, ¾ inch rods and a drive head were installed by the drilling rig.

The average time required to move the rig on location, drill, log and complete the well, and move off location was 2.7 days. This included various delays arising from rainy weather.

PRODUCTION RESULTS

From May through July of 1999, 13 shallow wells were drilled in the map area. Figure 9 summarizes the production history of the 13 wells. It shows the average initial production per well was approximately 17 BOPD peaking at 215 BOPD, and as of July 1, 2000 is 11 BOPD per well for a total of 145 BOPD. Cumulative oil produced to date from the 13 wells is in excess of 52,000 barrels. This brings the cumulative shallow sand oil production from all wells in the map area to over 90,000 barrels.

Sand production was expected to be a potential problem with no cement behind casing, however, this has not been the case. Incomplete removal of drilling fluid, as evidenced in drilling mud accumulation at the bottom of some wells has been encountered. The mud may prevent inflow from lower sands and requires removal.

CONCLUSION

The limited testing carried out with the electrical conductivity imaging shows the technology holds excellent potential for defining shallow oil sands. It is recommended that longer lines be surveyed with an emphasis on reducing spurious, noisy signals and determining background resistivity base levels. Further processing of the data in this regard should also be studied.

Shallow wells MD 65, MD 75, MD 66, MD 68 and QUN 52 were drilled based on interpreted correlation between resistive geo-electric anomalies and forest oil sands. All 5 wells proved successful and are oil producers. An additional 8 successful oil wells were drilled to test the continuity of the sand trends mapped from the combined geological and electrical conductivity imaging data.

Cost effective methods of drilling and completion, based on minimizing formation damage, were utilized to access new economic oil reserves, which had previously not been identified in the mature Morne Diablo field. Recoverable reserves are estimated in excess of 1 MMSTB and will require a significant number of additional new wells to be drilled in the follow-up programme.

ACKNOWLEDGEMENTS

The authors would like to thank Trincan Oil Limited and The Petroleum Company of Trinidad and Tobago Limited for providing technical data of the Morne Diablo Field for presentation in this paper. Douglas Groom and Jeff Johnson of Geometrics, Inc. have also been very helpful with respect to the electrical conductivity imaging instruments, theory and application.

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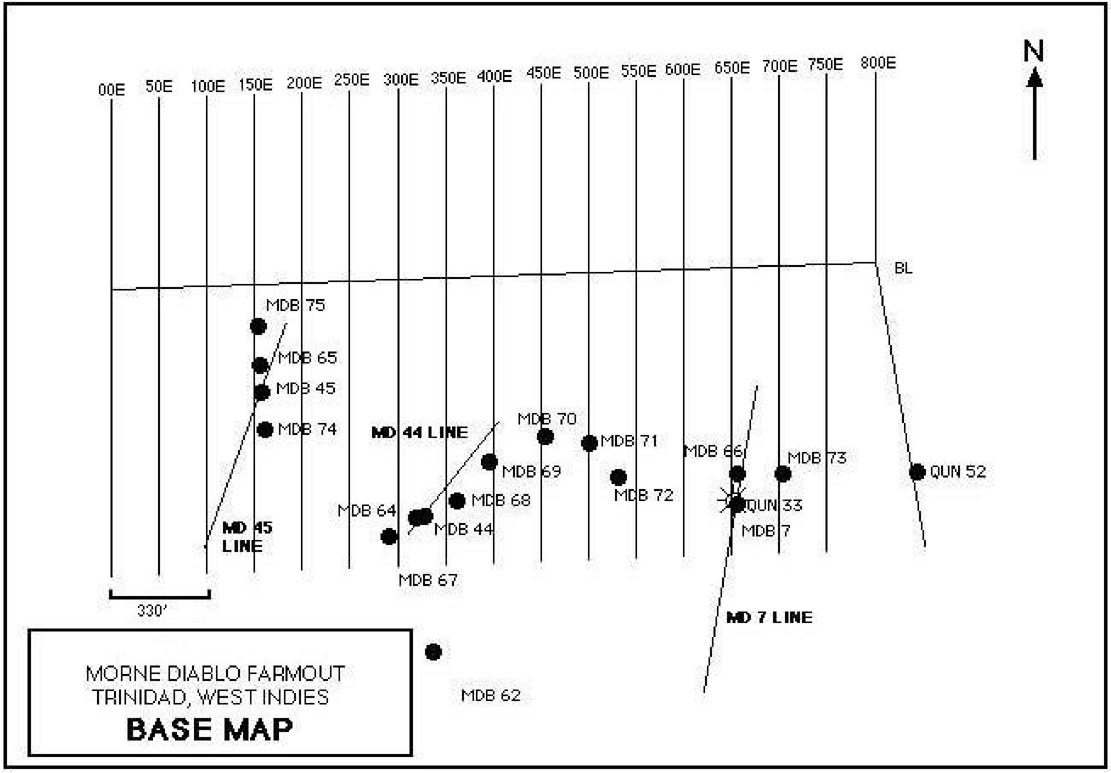
Figure 1



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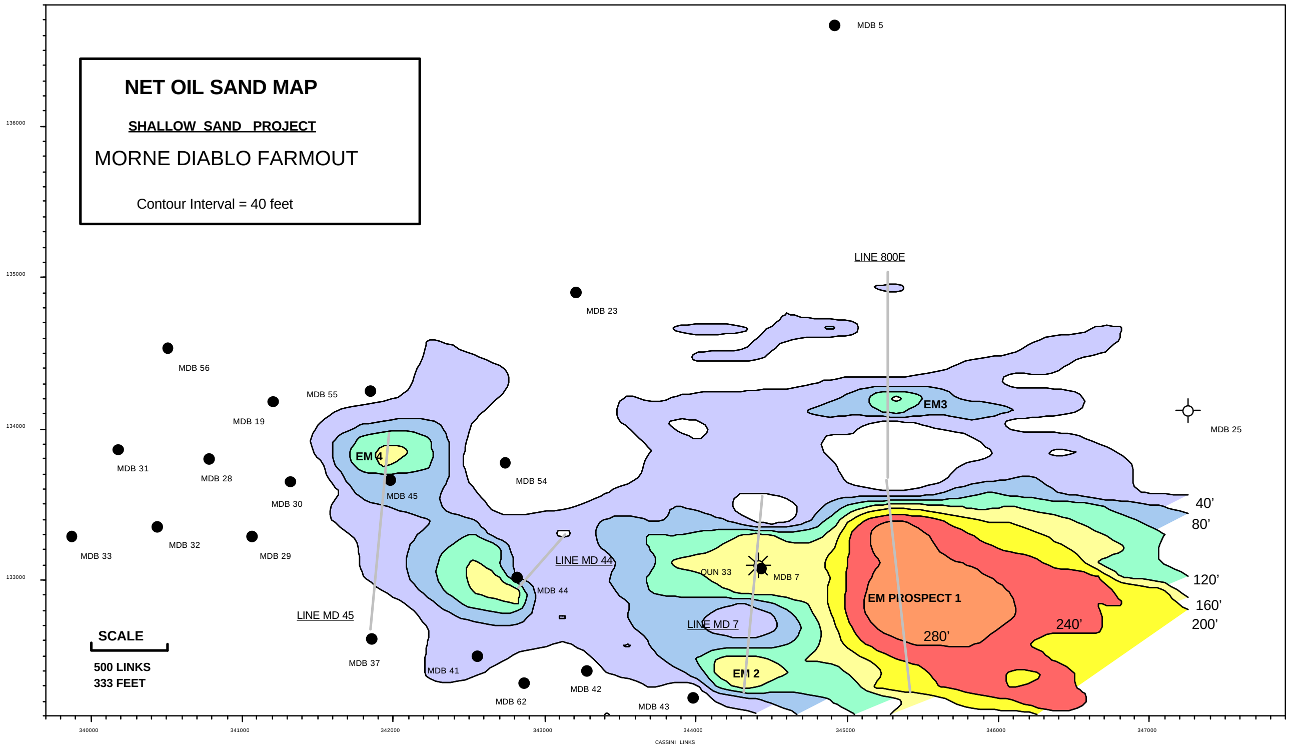

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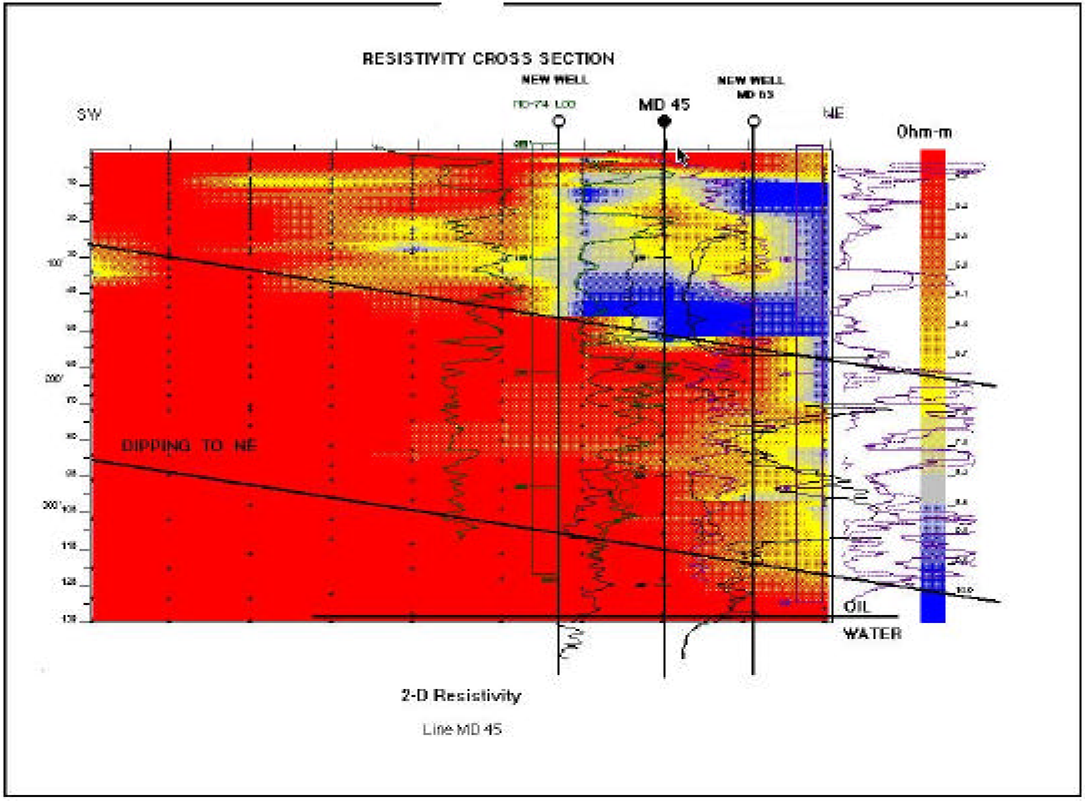

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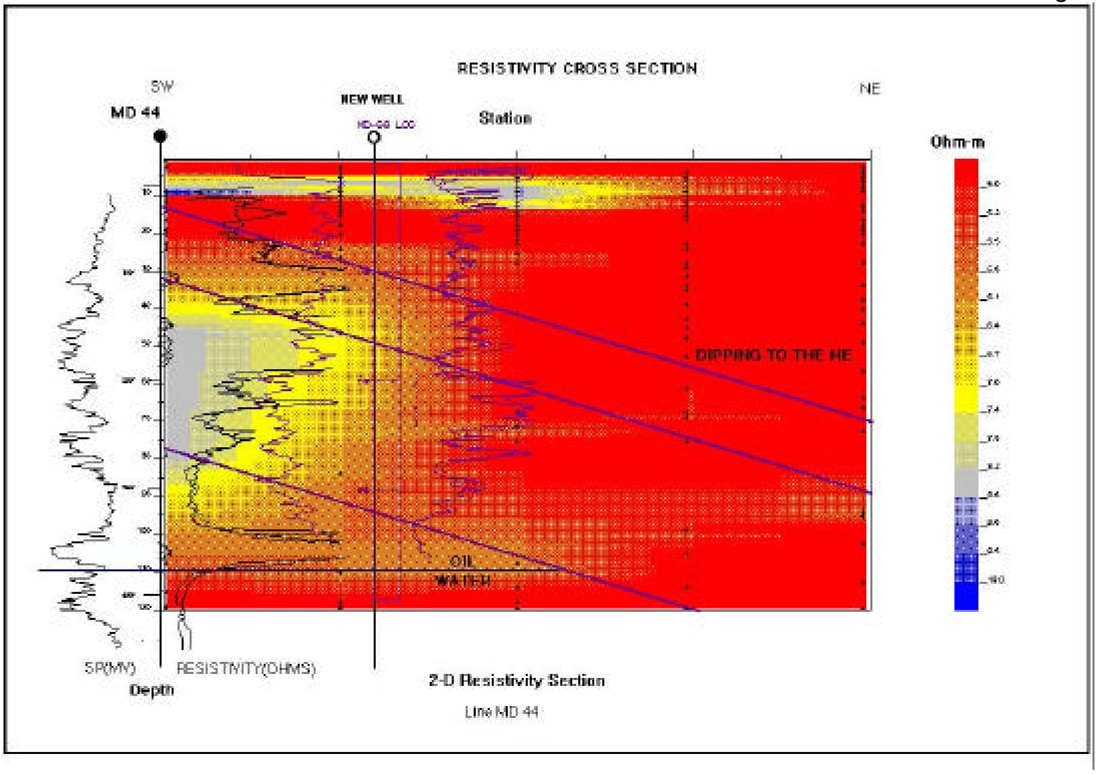

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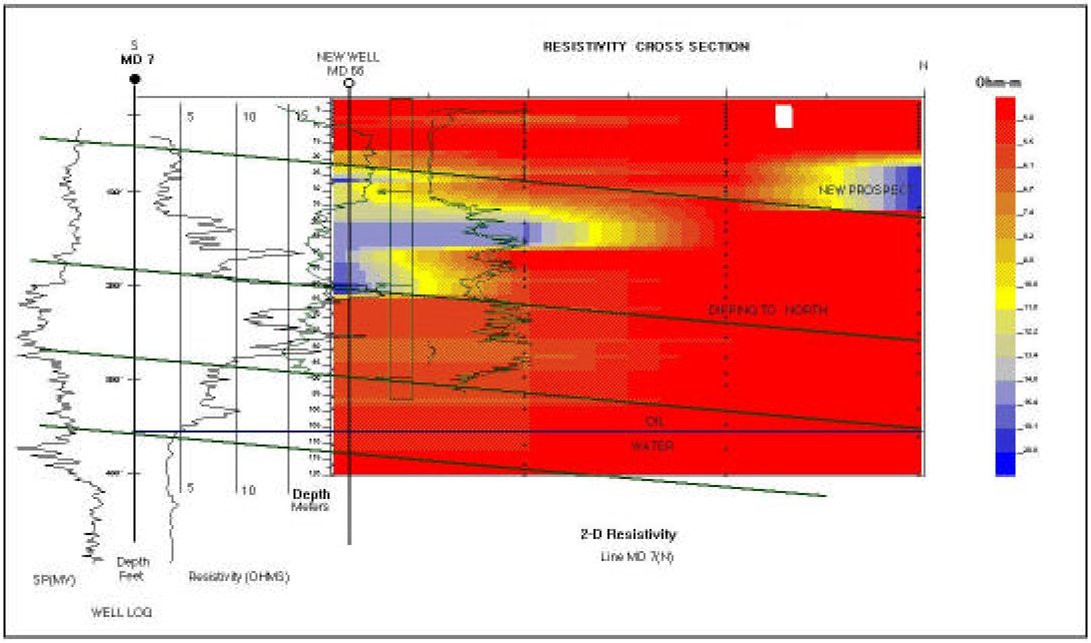

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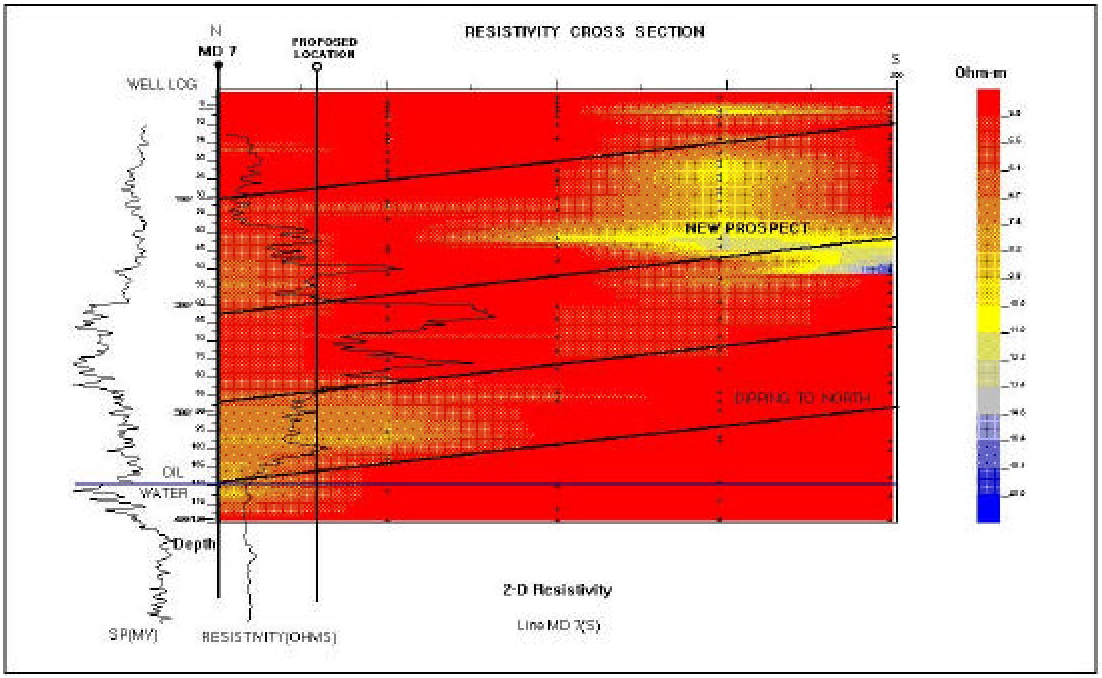


Figure 7

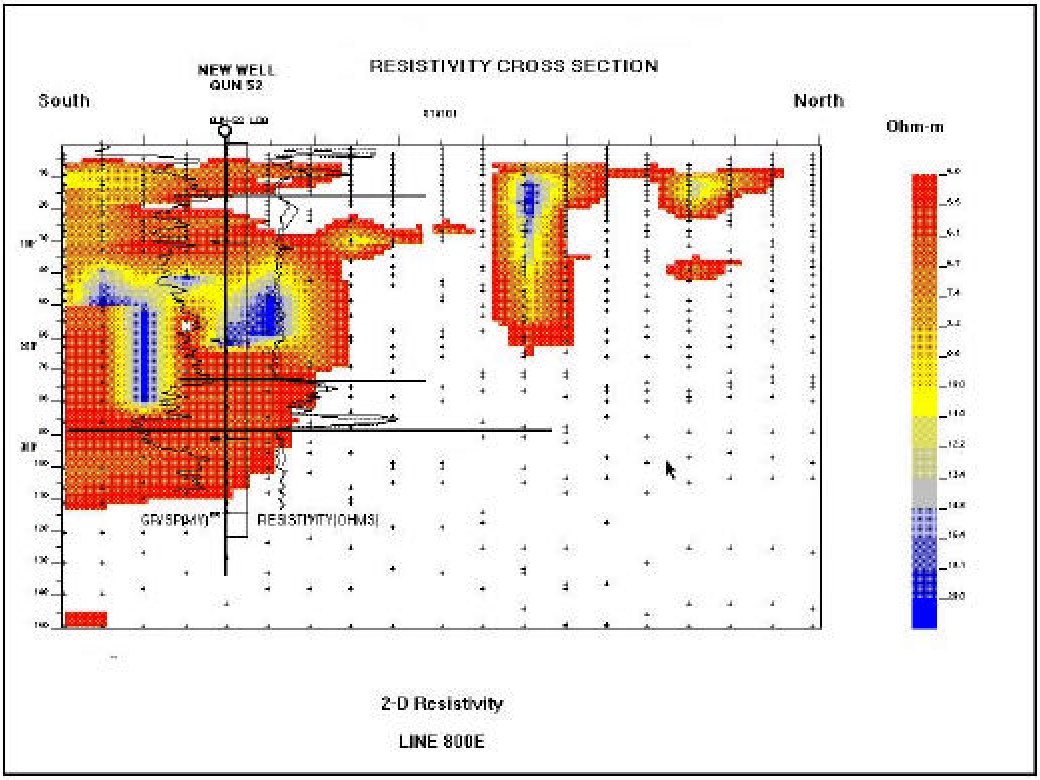
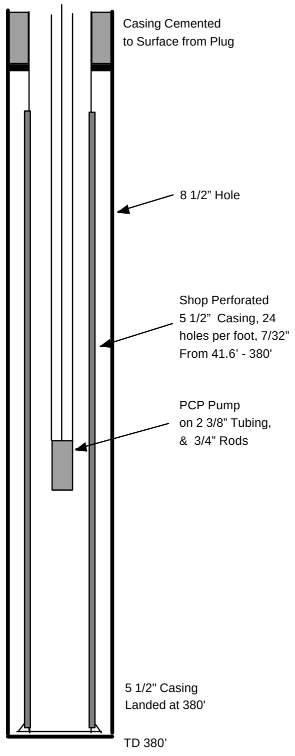

RESISTIVITY CROSS SECTION
NEW WELL
QUN 52
South
North
Ohm-m
GR/SP(MV)
RESISTIVITY(OHMS)
2-D Resistivity
LINE 800E

Figure 8



WELL COMPLETION DIAGRAM

MORNE DIABLO 75

Figure 9

PRODUCTION HISTORY - SHALLOW WELL PROJECT
Morne Diablo Field