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Oil Production from Low Resistivity, Thinly Bedded Middle Sands of Lower Goru, Lower Indus Basin, Pakistan

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ABSTRACT

The Lower Goru sandstone of Cretaceous age has long been contributing considerable volumes of hydrocarbons towards Pakistan's Oil and Gas production from the Indus Basin. The work included in this paper, demonstrates the oil discovery from thin bedded, low resistivity sands which apparently did not indicate presence of hydrocarbon from quick look evaluation of open hole logs. Moreover, there were no hydrocarbon shows during drilling. RFT (Repeat Formation Tester) also indicated water.

Detailed interpretation of logs response (porosity from the true resistivity Rt) indicated the presence of hydrocarbon. RFT was repeated but similar results were obtained. This was attributed to the limitation of RFT in thin beds reservoirs. Considering the RFT data as misleading, it was decided to trust the results of detailed open hole logs. On perforation, these sands produced 600 BOPD (barrel oil per day).

This work concludes that the RFT data may be misleading due to limitation of gauge and depth imprecision in thin beds. A detailed open hole logs interpretation and careful analyses of RFT data are required in low resistivity, thinly bedded reservoirs. It is suggested that Wire line formation testers having pump out facilities and optical fluid analyzer may provide better results in such environments.

INTRODUCTION

The discovery of Khaskheli Oil Field in the Lower Indus Basin in 1981 boosted the exploration activity in Pakistan. Till 1988, main target in this context, was the upper sands of Lower Goru Formation of Cretaceous age. Extensional tectonics during Cretaceous period created normal faulting (horsts and grabons) which happened to be the major oil traps. The Lower Goru Formation is composed of sand and shale, deposited in wave-dominated delta, representing a complete pattern of sea level rise (Kemal, 1991). This formation is subdivided into three zones (Upper, Middle, and Basal) which are hydrocarbon bearing. Initially Upper Sands were considered productive.

The discovery of Bobi Oil Condensate Field in 1988 was another landmark in the exploration history of Lower Indus Basin, when hydrocarbons were discovered in the Middle and Basal Sands of the Lower Goru Formation which are thinly bedded and has low resistivity. This discovery shows multiple reservoirs accumulations of condensate and volatile oil. The drilled sands were radioactive containing heavy and conductive minerals. The discovery of Bobi Field established a new trend to explore the Middle and lower sands of the Goru Formation

During the course of such exploration activity Palli Oil Field was also discovered in 1996 (Figure 1), which is the subject of this paper. This field is a unique example, that produced 38 degree API oil from fair to good quality, low resistivity reservoir sands with low clay contents, equivalent to the sands of Bobi Field (Basal sand).

RESERVOIR DESCRIPTION

Palli reservoir is a horst block bounded by eastern and western faults having normal dip closure on north and south directions. Palli structure was delineated as a result of seismic work carried out in the Sanghar Block. In terms of aerial extent, at basal sands level, trapping fault block is approximately 5 Km long and 2 KM wide. The Palli field is analogous to Bobi field, both in stratigraphy and structure.

The sands encountered in Palli-1 have 14% average porosity, 37% water saturation and 18 meters of gross thickness. The lowest known oil (LKO) was taken as the oil limit for this reservoir, which may be considered as 2875 meter subsea depth.

Petrographic studies of Bobi sands reveal that Chlorite (clay) rims are very common around quartz grains. The clay coating occurs as platelets perpendicular to the grain surface (Putnam, 1991). This coating is responsible for low resistivity sand beds. In thin sections of these sands, Ankerite(Ca.(Mg.Fe) $(CO_3)_2$), and Limonite were also observed. The presence of these minerals could also be another reason for low resistivity in these sands.

PETROPHYSICAL EVALUATION

A conventional logging suit was acquired in Palli-1, including BHC-GR (Borehole Compensated Sonic - Gamma Ray logs), LDL-CNL-GR Litho Density Logs - Compensated Neutron Logs - Gamma Ray Logs), and DLL-MSFL-SP-GR (Dual Later Logs - Micropherical Focused Logs - Spotoneous Potential - Gammay Ray Logs) logs. A quick look evaluation of open hole logs was carried out as faxed copies were received from the well site. Raw open hole log data as presented in figure 2. On quick look evaluation, this Formation was evaluated as water bearing because neutron and density logs did not show any gas separations. It can

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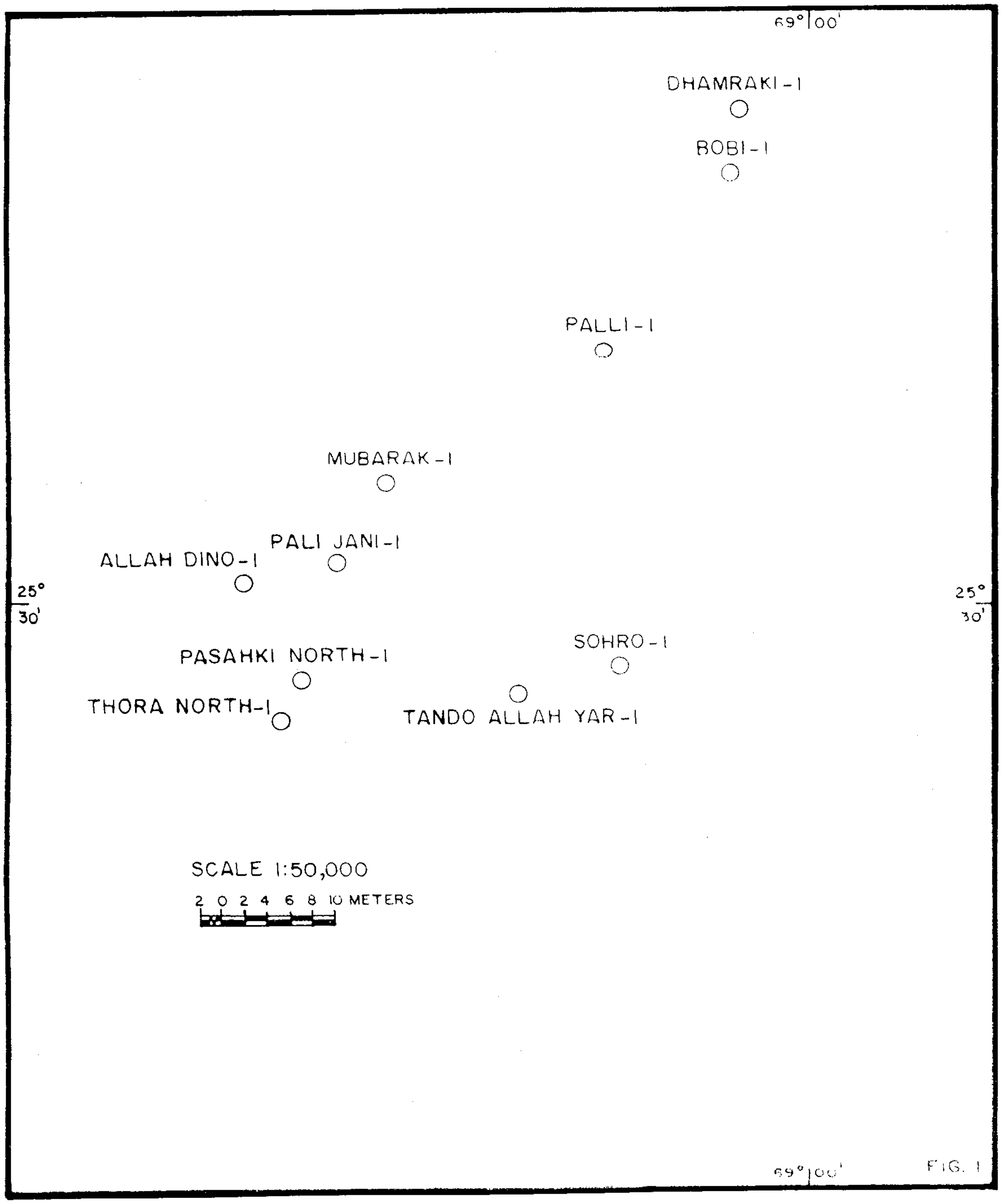

Figure 1- Map showing location of Palli-01 well.

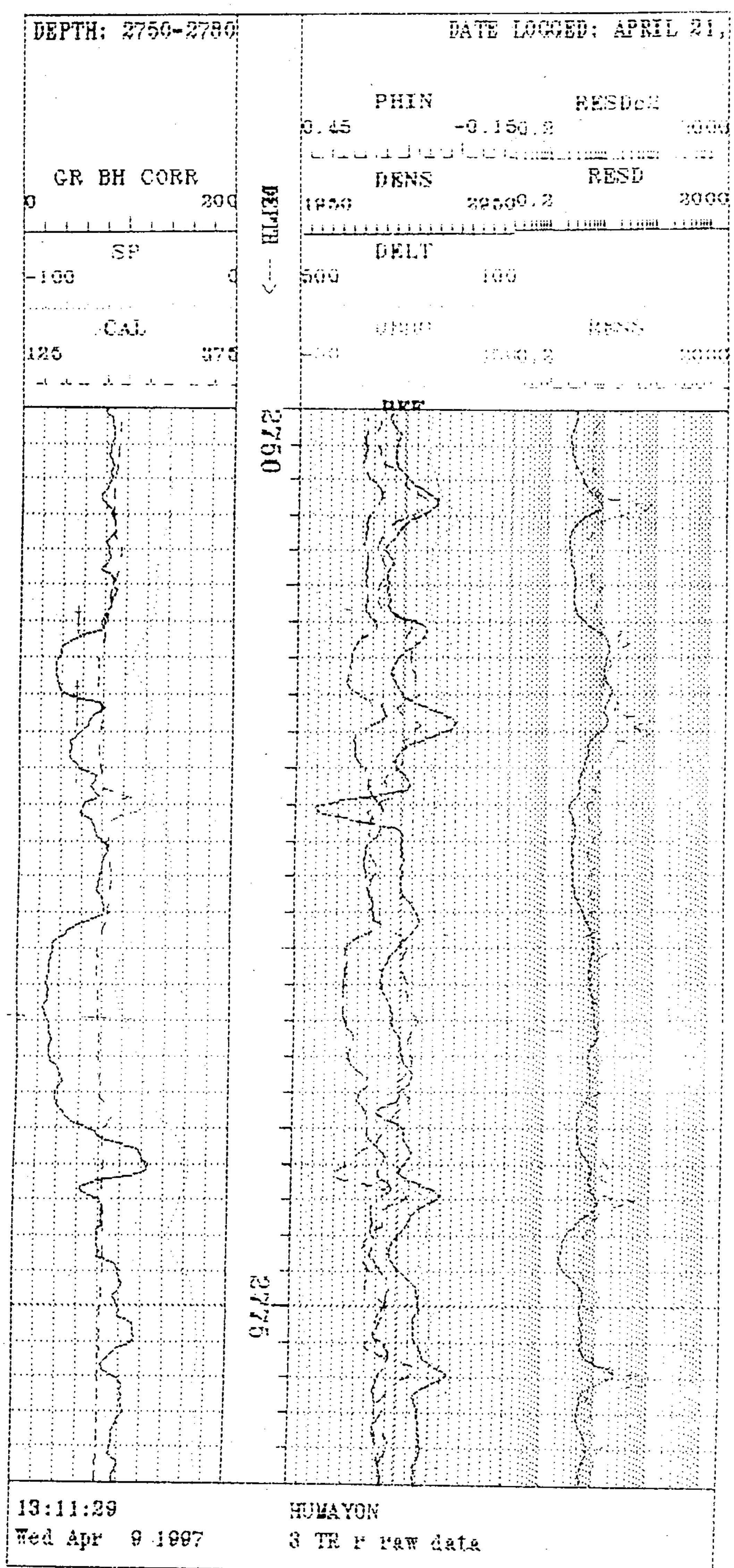

Figure 2- Raw curves of LDL-CNL-GR, DLL-MSFL-SP and BHC logs.

be seen that the maximum separation of neutron-density logs is around 7 porosity unit in the zone of interest. Typically, wet sands would have a neutron density separation of around 8 porosity units. Hydrocarbons profiles in fresh water-based mud on the resistivity logs were also absent. RESD was reading less than MSFL and RESM (Medium Resistivity). As in a typical hydrocarbon profile, where RESD (Deep Resistivity) reads the higher value, RESM reads middle value and RESS (Shallow Resistivity) reads shallow value, was not present on raw logs (Figure 3). Such readings were contrary to the log's signatures of Bobi wells, where although similar resistivity profile is present but gas separation is clear. First RFT was conducted and two pressure points were taken in this bed. The pressure gradient and derived fluid density from RFT data also indicated water. One of the vital factor which misled, was the absence of gas shows and fluorescence during drilling.

During detail interpretations, after applying all borehole correction, porosity was computed with six different methods such as neutron porosity, density porosity, sonic (wyllis) porosity, sonic-neutron porosity neutron density porosity and Rt (Deep Resistivity) derived porosity. In good hole conditions, all these porosity curves matched within an allowable limit in shaly zones as well as in clean zones. As RESD readings are sensitive to hydrocarbon zones, so its readings are adversely affected in hydrocarbon zones, therefore, Rt derived porosity would always be less than other computed porosities.

As good match of the porosity was attained in clean and shaly zones, except for interval from 2756-2271 m (Figure 4). This match of the porosity was excellent (except the above interval), validating the selection of interpretation parameters. This behavior of LLD derived porosity in the above zones indicates a fluid other than water in this zone . Considering the detail log analyses, RFT was carried out again. A discussion of the RFT data is mentioned in the following paragraphs.

RFT ANALYSIS

From the open hole logs, two zones of interest were identified. As depicted in Figure 5, the upper bed was about 1.5 meters thick referred to as Zone-A and the lower

Table 1. RFT Data for Palli-1 well.

Depth (meters)	Pressure (psi)	Mobility md-ft/cp	Remarks
2756.56	dry test		
2757.10	4121.12	66.2	Normal
2757.52	4121.72	62.0	Normal
2758.04	dry test		
2757.84	4123.52	0.70	S/charge
2765.03	4130.22	30.10	Normal
2765.57	4130.76	122.1	Normal
2766.57	4132.15	71.6	Normal
2768.10	dry test		
2769.57	lost seal		
2769.27	4167.3	0.10	S/charge

beds was about 5 meter thick referred to as Zone-B. Total of 11 pressure measurements were made in these two zones. Of these measurements, five were made in Zone-A and the remaining six were made in Zone-B. A detail of these measurements is presented in Table-1.

As evident from the above table that there are two dry tests and one super charged measurement in zone-A. This leaves us with only two points to include in the RFT analysis of this zone. Similarly, for zone B, one seal failure, one dry test, and one super charged measurements also makes us to consider only 3 normal points for RFT analysis of this zone

The analysis of RFT data contained in the above table can be seen in figure 5 through 8. For the ease of analysis, such a peculiar RFT data has been grouped in the form of 5 cases depicting different combinations of this data.

Figure 6 compares case-1 and case-2 of the said analysis. In these cases, fluid gradients of upper two points in zone-A are compared with the lower two points in zone-B. As clear from this figure, both gradients are indicating the presence of water in both zones. If one had considered to believe on this part of RFT analysis, then this well would have been abandoned long ago. But situations like these urge one to dig deeper into the analysis in order to attain any meaningful conclusion.

Figure 7 shows the above mentioned drive, by comparing case-2 and case-3 of the analysis. The pressure measurements used in this analysis are marked with arrows.

The fluid gradient of these points, are evident enough in indicating the presence of oil in zone B. Obviously, the OWC indicated from these gradient does not compare with the LKO (lowest known oil) derived from the logs. For reasons, i.e., the perforations in zone-B, the LKO appears to be considered as the most reliable OWC. It is also noteworthy here that only half a meter above, the formation appears to be oil bearing which can originally be thought of as water bearing.

Figure 8 presents another view of the RFT data. In this case, all of the pressure points in zone B have been used in the analysis. A trend line through these points reveals a gradient of 0.39 psi/ft., which itself is not clearly an oil gradient, the possibility of considering the above mentioned gradient as that of a dead oil cannot be ruled out. Whatever may be the case, in this case of RFT analysis one cannot rule out the possibility of oil presence in this zone. Figure 9 shows the gradient of 0.346 PSI/ft (case 5), which was the supporting evidence of hydrocarbon indication. In this case all the valid points were joined with a best fit line. The points marked with arrows were measured in the beds showing hydrocarbon on the open hole logs.

RFT IN THIN BEDS

RFT is widely accepted technique by oil industry for defining the type of reservoir fluid using pressure gradients. The restrictions imposed by strain gauge and depth imprecision, nearly limit the applications of RFT to thick reservoirs. A high precision quartz gauge would theoretically allow gradient measurement in thick beds, but

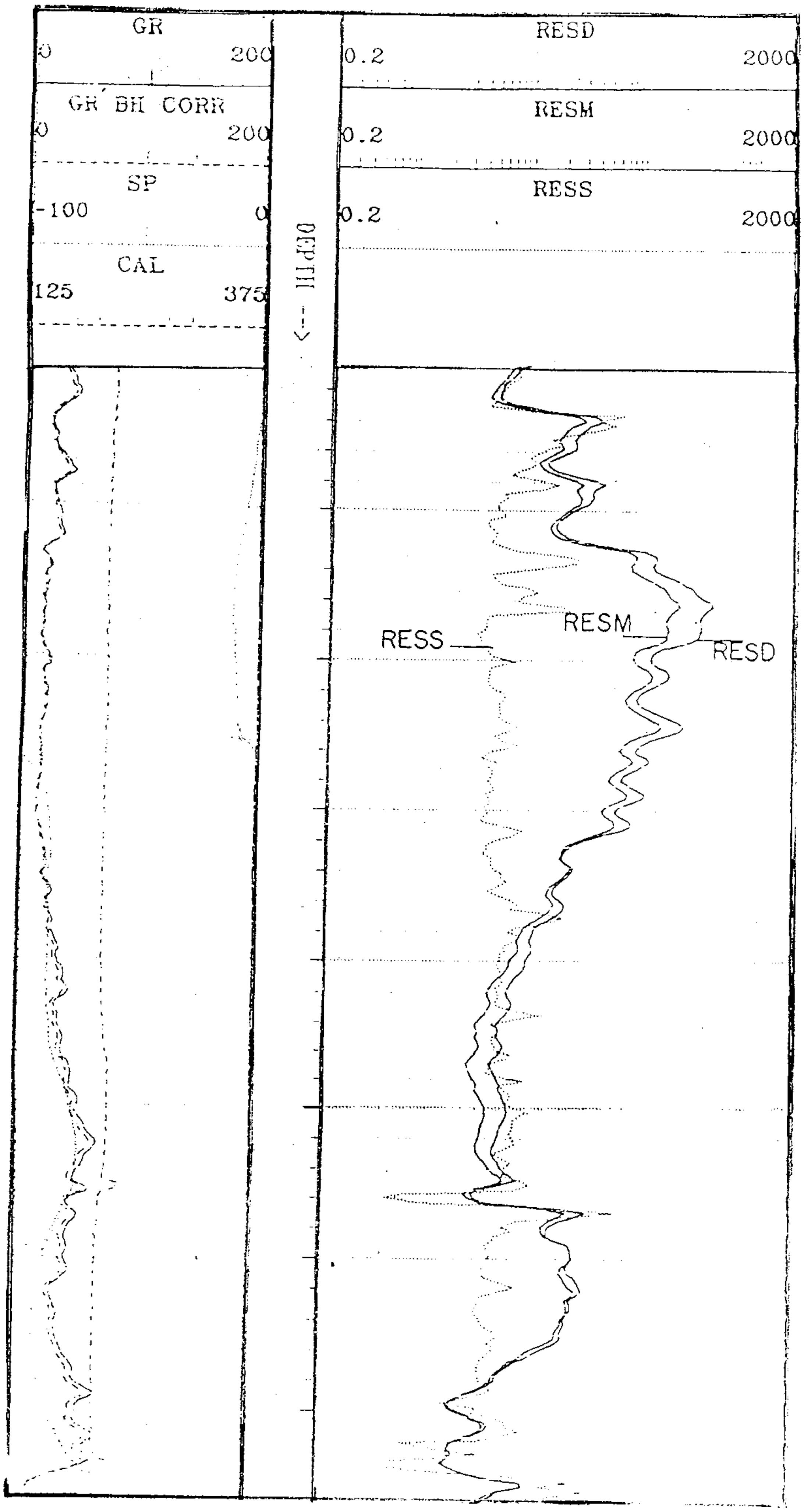

Figure 3- Typical hydrocarbon profile on the resistivity logs in the equivalent hydrocarbon bearing zones.

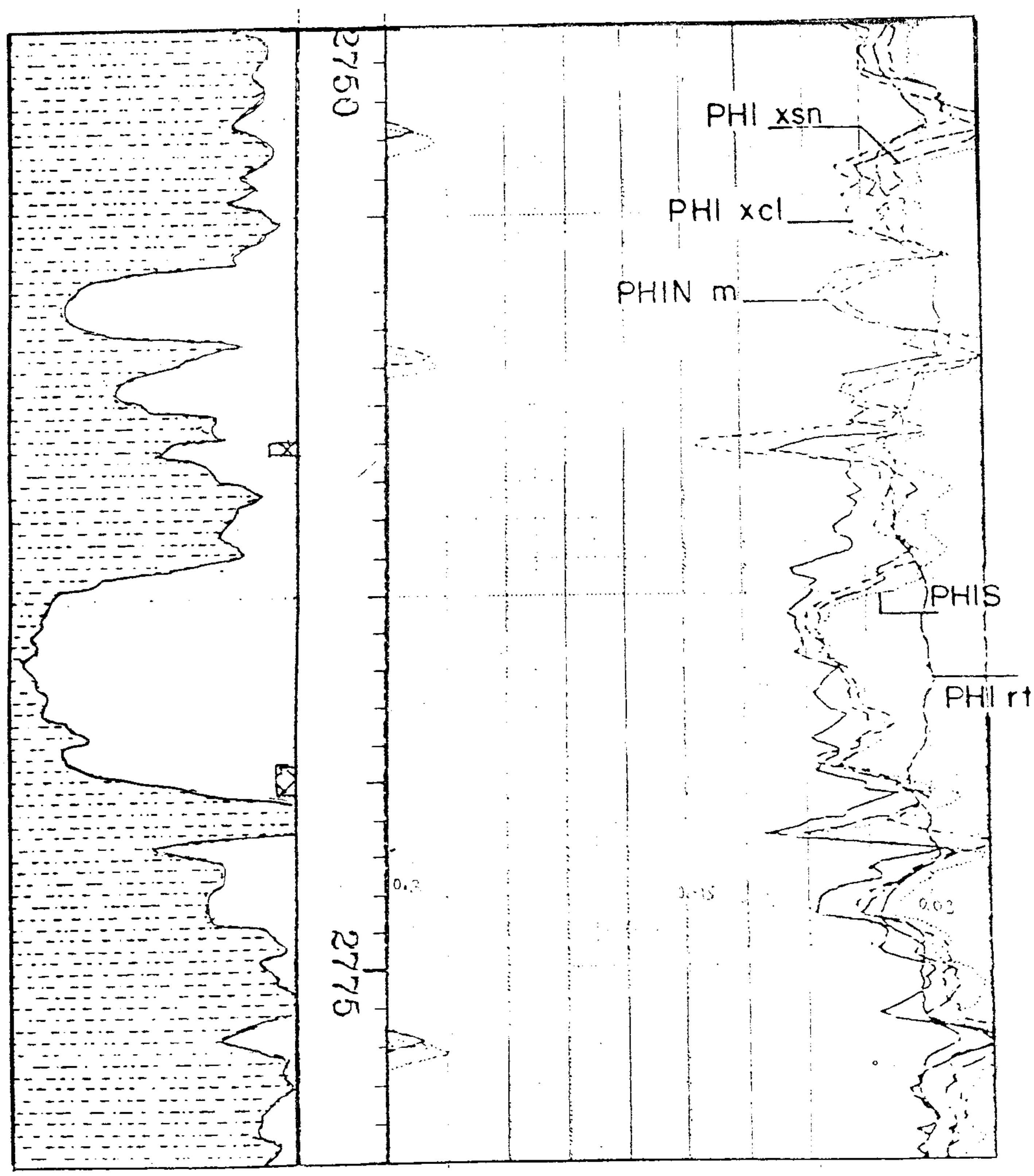

Figure 4- Porosity derived from different curves show and allowable match.

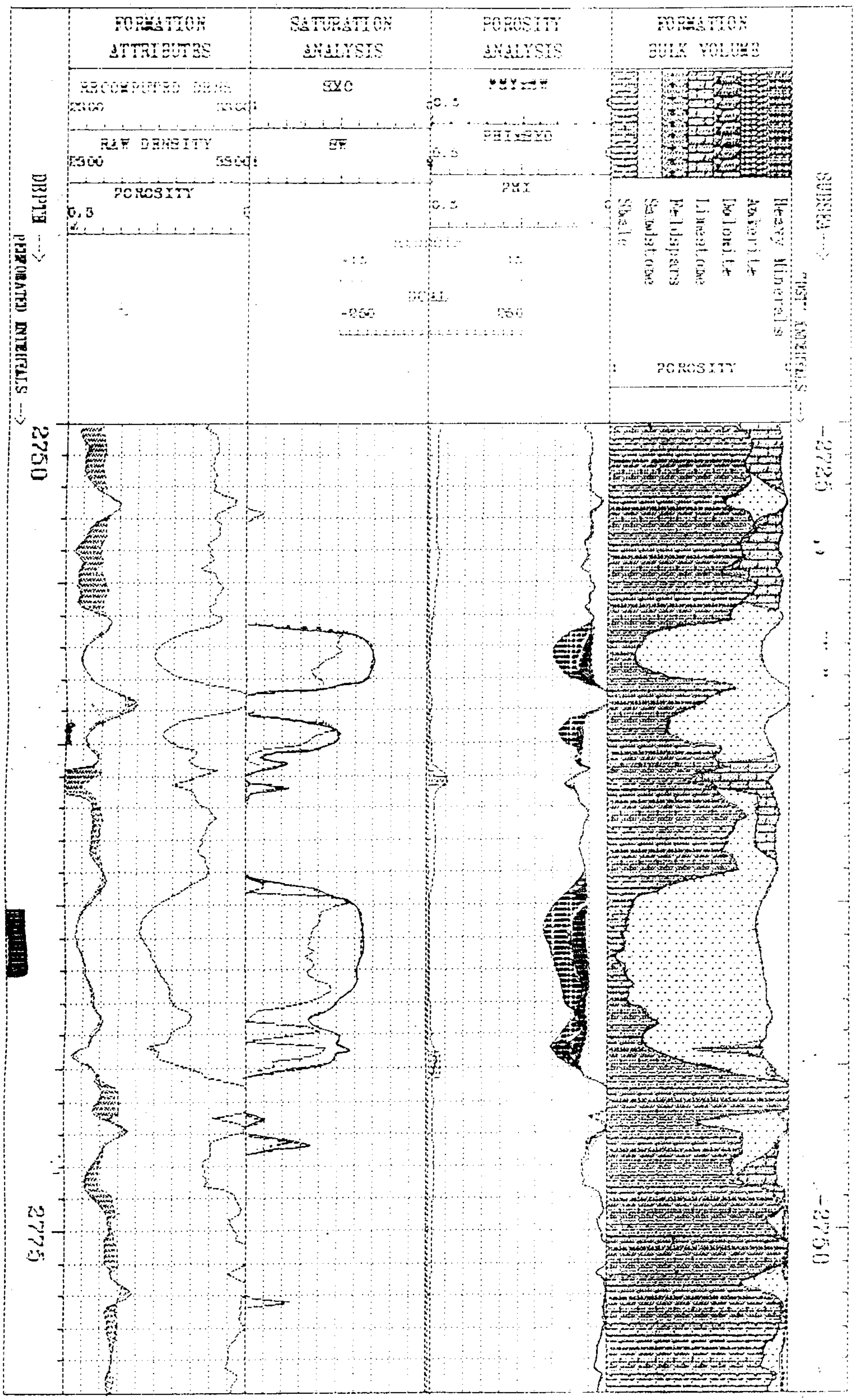

Figure 5- Answer logs of Palli-01 for the under discussion interval.

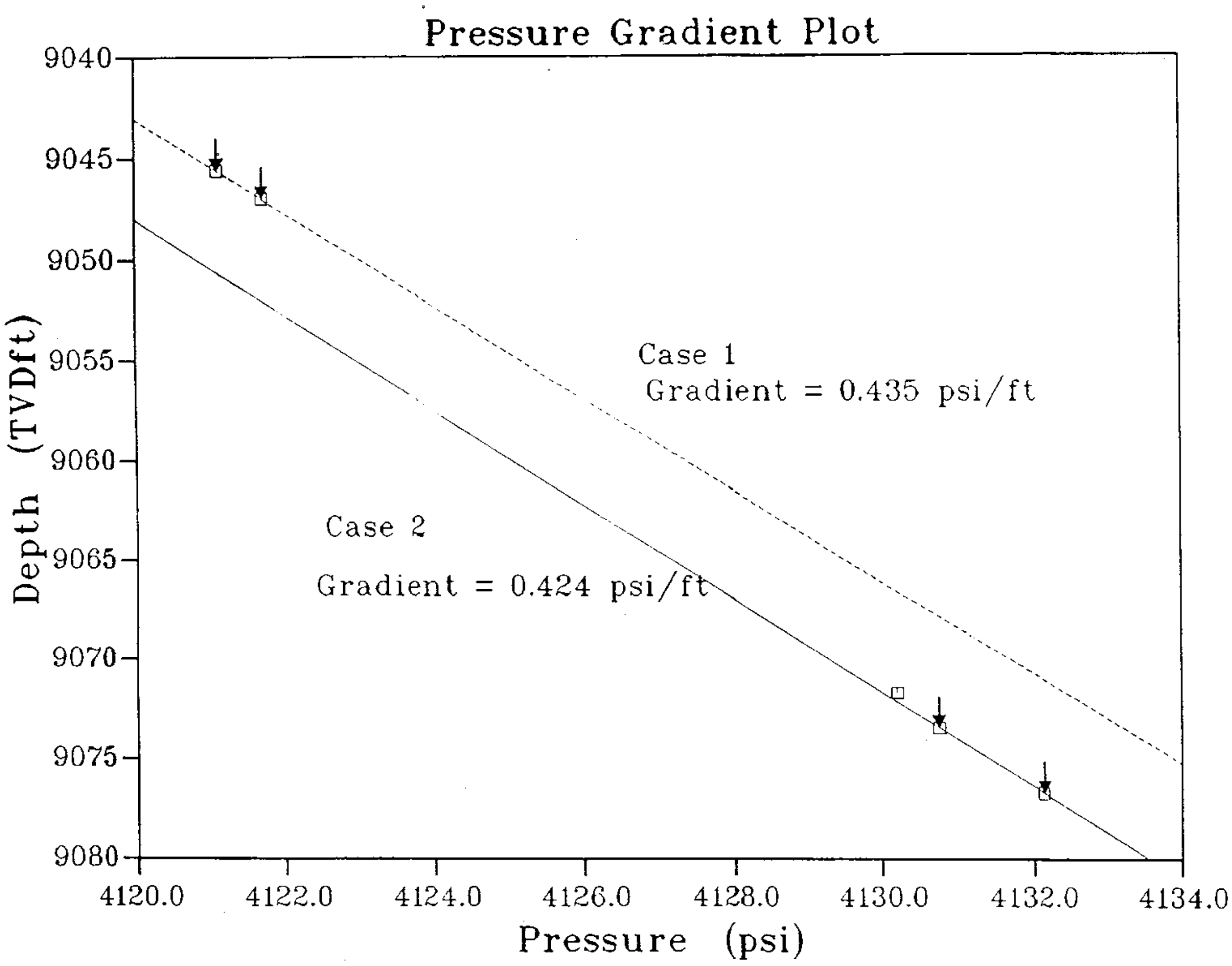

Figure 6- Pressure gradient plot (Case 1 & 2).

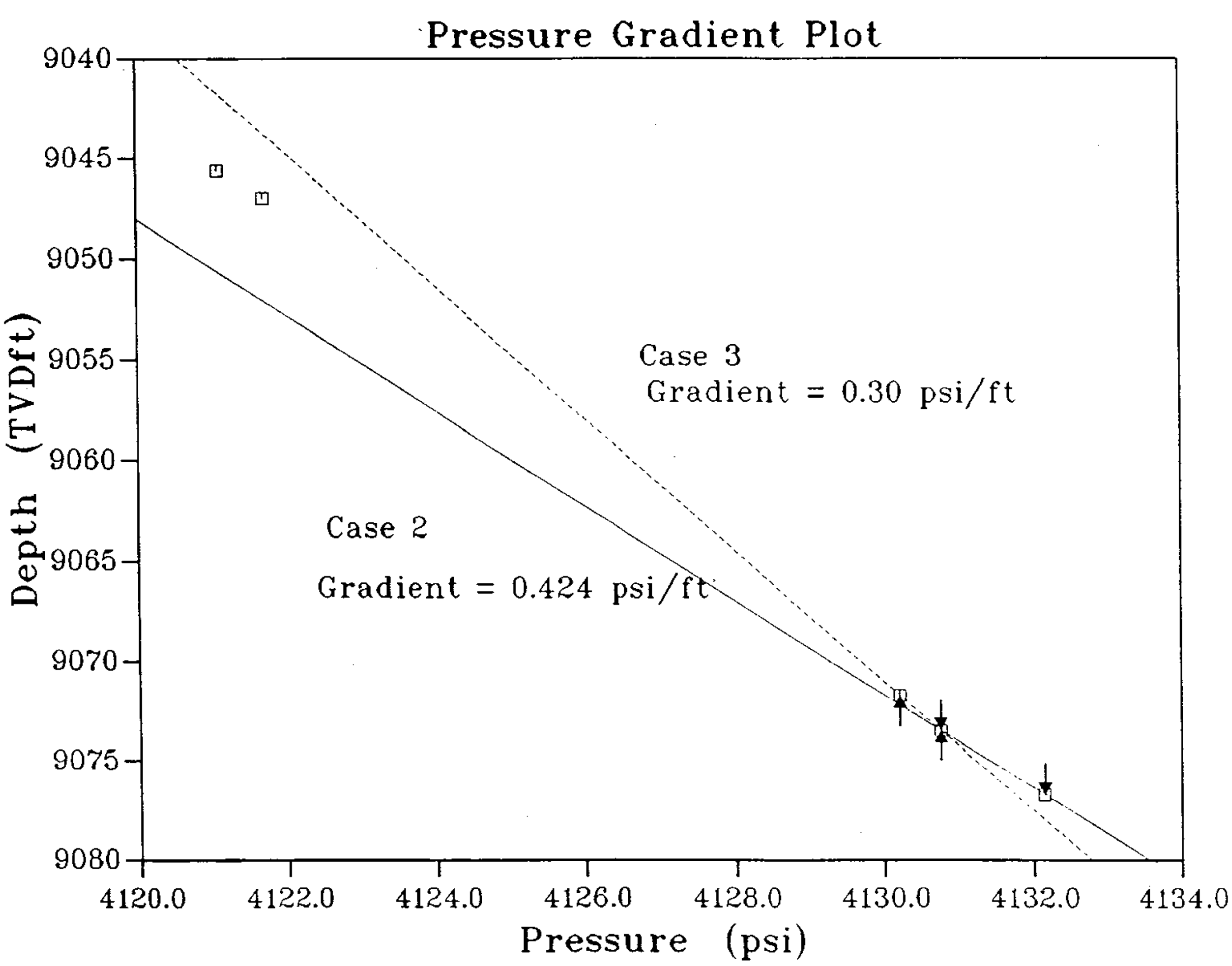

Figure 7- Pressure gradient plot (Case 2 & 3).

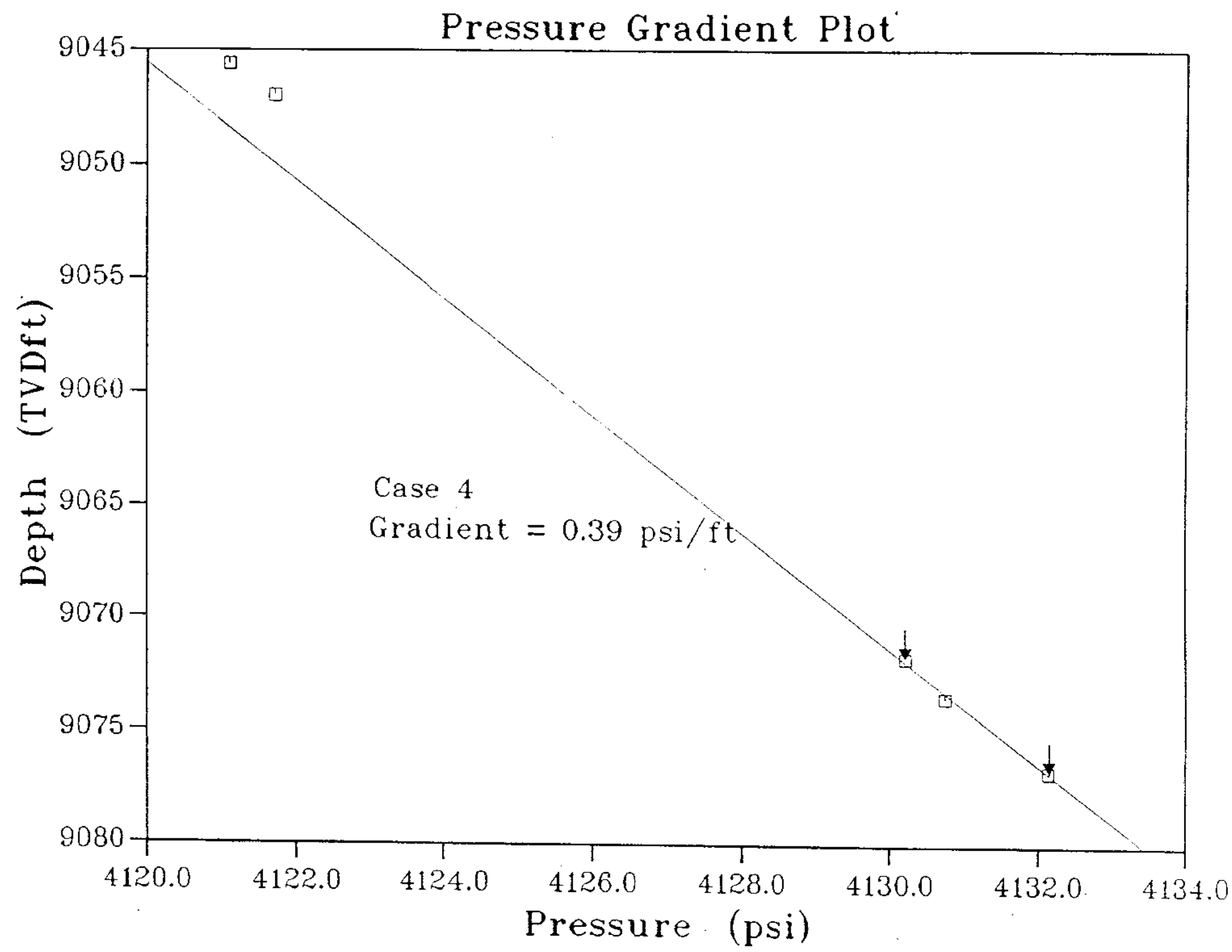

Figure 8- Pressure gradient plot (Case 4).

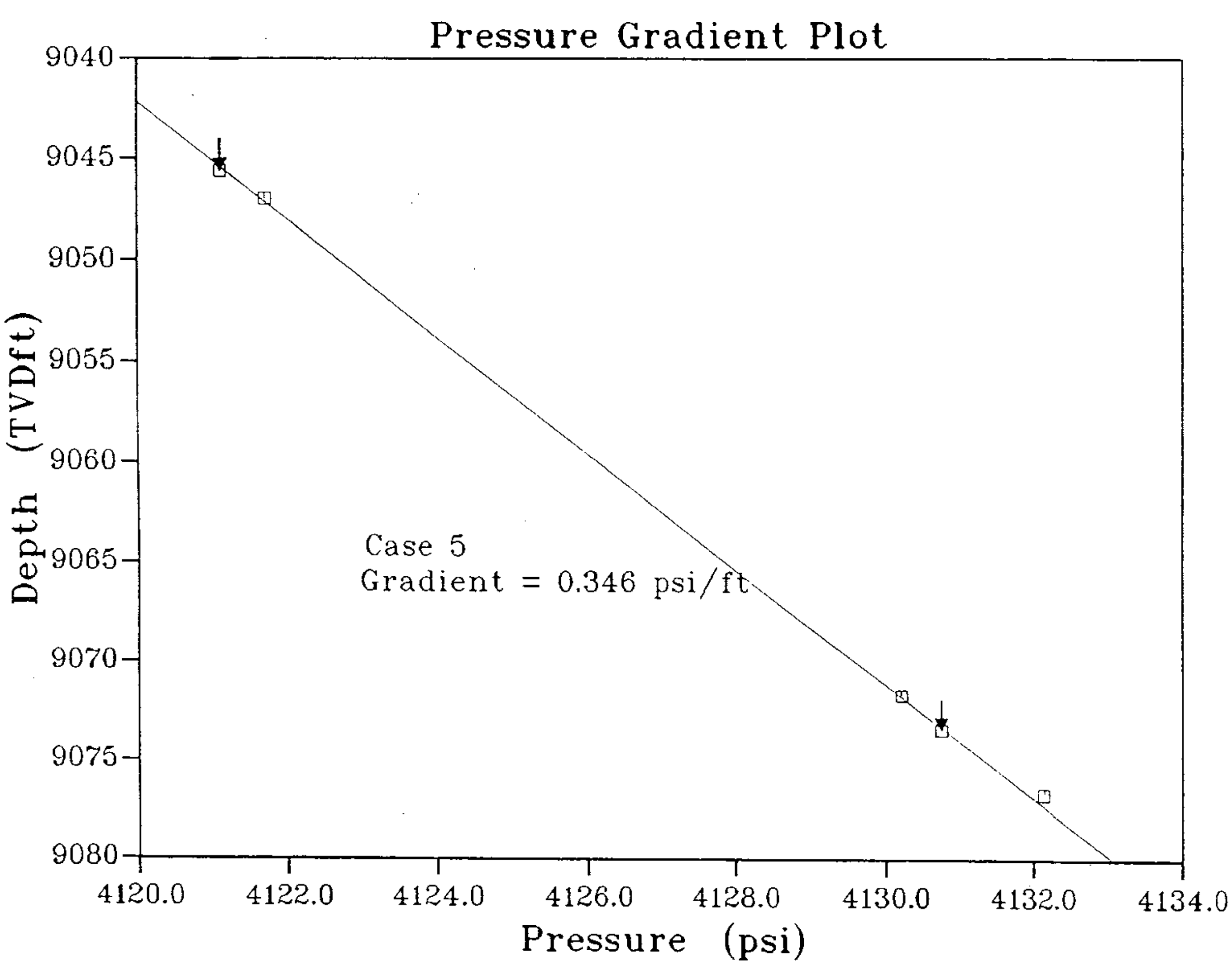

Figure 9- Pressure gradient plot (Case 5).

its practical use has been restricted by depth placement and stabilization uncertainty.

In general the best depth precision which can be obtained when positioning a tool downhole is 1 ft. A depth correlation depth device with high resolution would not completely remove the depth uncertainty. To establish the pressure gradient in relatively thin beds with a few points, we need to know the depth difference between stations with great precision. Each time, the tool is placed on station, there is an uncertainty caused by friction and cable creep.

Based on the detailed interpretations of the logs, this well was cased and tested. Three meters were perforated which produced 600 barrels of 36 degree API oil with minor quantity of gas. DST (Drill Stem Test) results are given in table-2.

RATIONALE FOR PERFORATION

Keeping in view the limitation of RFT in thin beds, prior experience in Bobi field, and the detailed analysis of open hole logs made us to perforate the lower zone(Zone B) which successfully produced oil. The results of initial testing are given Table-2.

Table 2. Initial testing results of Palli-1 well.

Choke Size	36	32	28	24
FWHP(psi)	50-60	60-70	80-90	100
Qo (B/D)	618	598	538	463
Qg(MMCFD)	0.026	0.024	0.019	0.017
GOR(Scf/B)	196	165	135	138
Qw(B/D)	Nil	Nil	Nil	Nil

Having successfully tested, this well was put on extended production testing. But the pressure in this well started to decline along with the production. An obvious reason for such a behavior of the well was very low volume of associated gas and no evident pressure support.

Owing to this situation, as a consequence of more careful evaluation of the logs, the thin beds above the declining zone were considered to be perforated. The major problem in making such an attempt was the fact that RFT was showing water gradient in these beds (Zone A), but the oil production from Zone B was encouraging at the same time.

Therefore considering the possibility that RFT may be deceptive in thin beds, these thin beds (Zone A) were perforated which eventually enhanced the declining production from 70 BOPD to about 300 BOPD.

SENSITIVITY ANALYSIS OF RFT GRADIENT

A sensitivity analysis of the gradient was done on the data points in Zone A with respect to the depth imprecision. In this analysis, repeatability, stabilization and other factors were ignored. It was found that the gradient in Zone A would change from water to oil gradient by changing the depth by only 0.2 meters. Also the gradient between upper and lower beds indicated oil presence. Hence, with this analysis in mind , it was decided to perforate the upper zone (Zone A), which has also produced oil.

CONCLUSIONS

1. RFT can be misleading due to limitation of gauge supercharging and depth imprecision in thin beds. Therefore, more care is required in interpreting such data.
2. Plug and abandon decision should be based on detailed and careful analysis of the data available and not only on quick look interpretation.
3. In testing thin beds, wire line formation testers having pump out facilities and optical fluid analyzer may provide better results.

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