



SPE 107784

Correction Of Bound And Free Fluid Volumes In The Timur-Coates Permeability Equation For The Presence Of Heavy Oil - A Case Study From The Golfo San Jorge Basin, Argentina

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This paper was prepared for presentation at the 2007 SPE Latin American and Caribbean Petroleum Engineering Conference held in Buenos Aires, Argentina, 15–18 April 2007.

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Abstract

In the Golfo San Jorge basin, Argentina, the Timur-Coates permeability index obtained from the T2 distributions is considered as a good indicator of reservoir quality and has been used as a very important variable for production forecast. However, when heavy oil is present, having a relaxation time below the standard free fluid-bound fluid cut-off of 33 ms, it is conventionally counted as part of the bound fluid, independently of its mobility. For this reason, in case of movable heavy oil, the standard Timur-Coates permeability index using 33 ms tends to be always pessimistic, in eventual disagreement with other reservoir quality indicators as the SP curve, depositional environment, cuttings and production data.

In order to perform a correction of the permeability index for the presence of heavy oil, two layers of one well from the Diadema field, with a complete set of SP, Resistivity, MREX and production data was selected and evaluated using 2DNMR (T2intrinsic - Diffusion) maps, which uses the diffusivity contrast for discriminating between capillary bound water and heavy oil, within the bound fluid window (BVI). The clay bound water (CBW) cut off has been chosen to be 6 ms.

The results show that the corrected Timur-Coates permeability can increase by an order of magnitude in the tested zone of the reservoir layers, but can become even higher within the whole layers, which is a

reasonable estimation for the corresponding channel depositional environment. The production data also support the interpretation, indicating that the NMR rock quality estimation can be performed more accurately even in the presence of heavy oil. The corrected Timur-Coates permeability values can be used in a future update for forecasting well production.

Introduction

Golfo de San Jorge basin, Argentina, located in the heart of Patagonia, and extending from the Atlantic Ocean to the Andean foothills, the San Jorge basin accounts for around one third of the hydrocarbon production in Argentina (Fig. 1). The origin and subsequent geological evolution of the basin are caused by the rift process responsible for the opening of the Atlantic Ocean in early Jurassic times. Accumulation of terigenous sediments continued well into early Cretaceous times¹. Clastic deposition in the hydrocarbon-producing zone is characterized by thick shale laminations of lacustrine and flood-plain origin, interspersed with much thinner and laterally sparse sand units that today serve as hydrocarbon reservoirs. The relatively small concentration of sand units in the sedimentary column is explained by their ephemeral fluvial origin, which could only account for their effective clastic accumulations between 0.5 and 15 m (1.6 to 49.2 ft), but predominantly thinner than 4 m (13.1 ft). Starting in early Cretaceous times, Andean tectonic activity caused yet another significant perturbation of sedimentary column in the form of finely laminated deposits of tuffs of pyroclastic origin associated with intermittent pulses of volcanic eruptions. The presence of tuffs has altered significantly the original petrophysical properties of existing sand units. Subsequent structural deformation adversely modified the already marginal porosity and permeability of the sands and caused extensive fracture damage in the existing tuff units.

Challenges in petrophysical NMR evaluation

Within relatively short distances the petrophysical properties of these reservoirs are known to experience

changes that complicate their assessment by means of standard methods. As a consequence of that there is a lack of efficiency in well production. In order to overcome these difficulties the NMR logging for rock and fluid typing has been extensively used.

NMR variables, such as clay bound water (CBW), bound (BVI) and bulk volume movable (BVM) fluids, and the Timur-Coates Permeability Index (PERM) are normally used to provide rock quality characterization and even forecast the well production. However, the presence of movable heavy oil, with T2 relaxation times starting around 6ms up to the BVI T2 cut-off of 33 ms, affects the BVI values and hence the rock quality estimation, introducing a pessimistic bias.

Any heavy oil correction of the NMR rock quality variables has to rely on an adequate fluid typing method. One of the relatively new approaches for NMR fluid typing is the 2DNMR (T2intrinsic - Diffusion) map. The map represents in separated regions each of the fluid present in the reservoir, as water (clay- and capillary bound and movable), oil and gas. The maps can be generated due to the contrast in the Diffusivity constant and in the T2 intrinsic (not modified by the magnetic field gradient) of the fluids. The evaluation of the 2DNMR maps yields volumes, fluid saturations and a correlation based oil viscosity value. The fluid volumes can be used to correct the Timur-Coates Permeability.

In this case study of a well in the Diadema field, San Jorge basin, we present the evaluation of two layers for which the Timur-Coates permeability has been corrected. The layer A produced mostly viscous oil where the second layer B has produced more light oil. The respective conventional and basic NMR curves are shown in Fig. 2. The development of the SP curves shows a channel like geological depositional environmental characteristics for both layers.

The Timur-Coates Permeability Correction for Heavy Oil

In general, one the greatest strengths of NMR is to allow determining the movable and bound fluids. Hence the water can be found as clay bound (CBW), capillary bound (BVI) and movable water (BVMW). In the absence of laboratory generated values, we take 6 ms and 33 ms as lower and higher T2 limits for BVI.

The conventional Timur-Coates equation is given by:

$$k = \left(\frac{\text{MPHE}}{C} \right)^m \left(\frac{\text{MPHE} - \text{BVI}}{\text{BVI}} \right)^n, \quad (1)$$

where $C=10$, $m=4$, $n=2$ and MPHE is defined as effective porosity to:

$$\text{MPHE} = \text{BVI} + \text{BVM}, \quad (2)$$

Equation (2) is equivalent to

$$\text{MPHE} = \text{MPHS} - \text{CBW}, \quad (3)$$

With MPHS defined as total porosity.

In presence of movable heavy oil, with a minimum T2 value around 8 ms, setting a standard T2 cut-off of 33 ms leads to a pessimistic rock quality interpretation, because the BVI forced to be higher than it really is, as such a cut off which works very consistently for water does not necessarily apply for oil. Mathematically, the relationship between a correct and a standard Timur-Coates permeability can be expressed as follows:

With α defined as,

$$\alpha = \frac{\text{MPHE}}{\text{MBVI}} \quad (4)$$

The relationship between a permeability corrected for heavy oil, k_{HO} and a standard one is given by

$$\frac{k_{HO}}{k} = \left(\frac{\alpha_{HO} - 1}{\alpha - 1} \right)^n \quad (5)$$

The following example shows how significant the correction can be:

Given $\text{MPHE}=20$ pu, $\text{BVI}=5$ pu, Heavy Oil volume $V_{HO}=10$ and $n=2$ we obtain $\alpha_{HO} = 4$, and $\alpha = \frac{4}{3}$.

The permeability ratio is calculated to:

$$\frac{k_{HO}}{k} = \left(\frac{\frac{4-1}{\frac{4}{3}-1}}{\frac{4-1}{\frac{4}{3}-1}} \right)^2 = 9^2 = 81.$$

This is equivalent to a k_{HO} almost two orders of magnitude higher than k .

The NMR2D Diffusivity-T2int maps

The T2int-Diff maps take advantage of both T2 intrinsic and Diffusivity contrast for fluid typing purposes. It allows differentiating between CBW, BVI, BVWM, Oil and Gas and discriminating between BVI and heavy oil volumes, a necessary step for correcting the Timur-Coates permeability in the presence of movable heavy oil.

The basic principle beyond the T2int-Diffusivity maps is the fact that fluids can be differentiate not only due to their relaxation time T2, or T2int but also due to contrast in the diffusivity constant. Because of that water, oil or gas appear on different zones of the map. The maps overcome the drawback of overlapping of fluids contributions to one dimensional T2 or Diffusivity spectra, the 1D representation. The NMR logging has been acquired using the MREX logging tool in Poro-Perm Fast mode.

The Fig. 3 shows the general representation of the

reservoir fluids on a T2int-Diffusivity map.

Results

Layer A: x660m-x675m

Production

This layer has been reported to produce within the interval from x662.5 to -x664m 940 l/h oil and 10% water; the oil density was reported to 0.92 gr/cc and 22° API gravity.

T2int-Diffusivity maps

Fig. 4 shows the average Diffusivity-T2int map for this layer. The heavy oil volume corresponds to the area defined by the white rectangle on the map; its corresponding T2 intrinsic and Diffusivity windows are also highlighted on the numerical table and shown on the 1D representation of T2int and Diffusivity spectra respectively. Fig. 4 also shows the selected fluids: CBW, BVI and BVMW for water, and LOIL, MOIL and HOIL for light, medium and heavy oil. On this representation HI states for Hydrogen Index, T2(1) for the left and T2(2) for the right T2 Bin number, D(1) for the lower and D(2) for the upper Diffusivity limit bin number. PPOR is the fluid filled porosity in porosity units (pu).

The petrophysical evaluation in terms of filled porosity, saturation and viscosity based on the T2int-Diffusivity maps is shown in Fig. 5. Track 1 shows depth and tested interval between x662.5m and x664m. Track 2 shows the T2int and track 3 the Diffusivity distributions respectively. Track 4 shows the fluids filled porosities, which are later used for the Timur-Coates permeability correction. Track 5 shows the fluids saturations. Track 6 shows the viscosity of the light and heavy oils. Track 7 shows the Diffusivity – T2int maps.

In agreement with the production data, the results show that between x662.5m and x664m medium and heavy oils are present. The heavy oil viscosity is estimated to be around 100 cp and the light oil viscosity around 5 cP. The movable water spot on the up-right corner on the map is partially due to the presence of mud filtrate invasion, as NMR MREX tool reads in the flushed zone.

A more detail description of the Diffusivity-T2int map along the layer is shown in the Fig. 6. It shows the variation in depth of the map every 0.348 m, where the main heavy oil spots can be found between x662m and x664m, the tested zone.

Permeability Correction

Following equations (1)-(5) the permeability can be corrected. Fig. 7 shows BVI, BVM and PHE variables corrected for heavy oil (a) and standard one (b). Fig. 8 shows on the same track (a) the heavy oil corrected and standard permeabilities and the permeability ratio in (b). For the tested zone the heavy oil correction yields an increase of the permeability on a factor between 3 and 25, as the permeability varies from a range of 3 mD to 18 mD to a corrected range of 10 mD to 273 mD.

Layer B: x810m-x817 m

Production

The production report shows the following data: 3425l/h Oil, 6% water and gas traces; 0.89 gr/cc oil density at 27°C and 32° API gravity. Tested zone is from x811m to x813.

T2int-Diffusivity maps

Fig. 9 shows the average T2int-Diffusivity map for the zone between x810m-x813m, the rectangle indicates the heavy oil zone on the map.

The petrophysical evaluation in terms of filled porosity, saturation and viscosity from the T2int-Diffusivity maps is shown in Fig. 10, indicating that in the tested zone the amount medium and light oil is as much as heavy oil however the bright water spot indicates filtration from water based mud, which has, eventually, flushed preferably the medium to lighter oils.

Analog to the previous layer, a detailed, qualitatively description of the reservoir fluids on the T2int-Diffusivity maps is giving in Fig. 11. From this figure we can assume that below x813m, and down x814, oil can eventually be found; however, there is no production data available from this zone.

As the amount of heavy oil present in this layer B is not as significant as in the layer A, the bound fluid is basically water, see Fig. 12. The BVI shows a very little correction for heavy oil in the tested zone and a more pronounced correction below it (x814), where the SP tends to develop much more as it does in a channel depositional environment.

In Fig. 13 (a) see can see very little variation in the Timur-Coates permeability, hence the correction factor is close to the unit for the tested zone and below one order of magnitude below it, Fig. 13 (b).

Conclusions

In the present case study, the NMR derived Timur Coates permeability is estimated pessimistically in the presence of movable heavy oil, as it increases the amount of bound fluids, due to its relaxation time window located between 8ms and the standard T2 cut off of 33 ms.

By using T2intrinsic-Diffusivity maps the amount of amount of heavy oil and bound water can be quantify separately because of their Diffusivity contrast. These values can be used for correcting the permeability index, using only the BVI value corresponding to the capillary bound water.

From the two analyzed layers, the correction factor for the Timur Coates permeability was significant in the higher (up to 25) heavy oil producing zone than where medium to light oil production is reported (less than 10).

It is shown that the T2int-Diffusivity maps for fluid typing and quantification purposes perform very well in this case study of an oil well in the Diadema field, San Jorge Basin, Argentina.

Acknowledgements

The authors thank the Compañías Asociadas Petroleras, S.A. (C.A.P.S.A.) and Baker Hughes, Inc for the permission to public the results of this case study.

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Fig. 1 Location of the San Jorge Basin

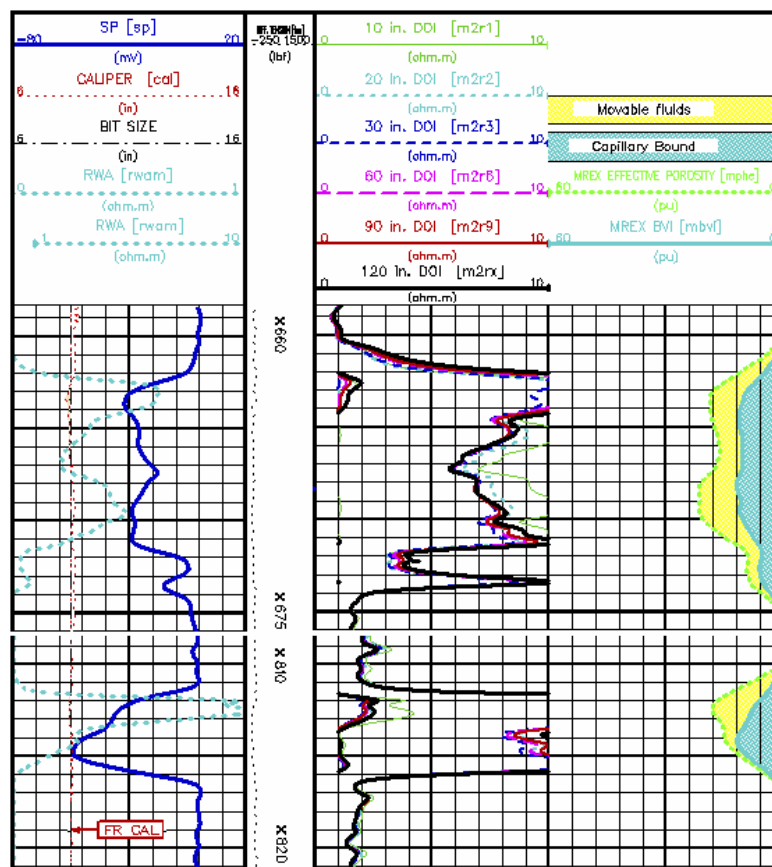


Fig. 2 Conventional logs and BVI and MPHE from MREX logging acquisition for the depth intervals x660m to x675 and x810m to x820m

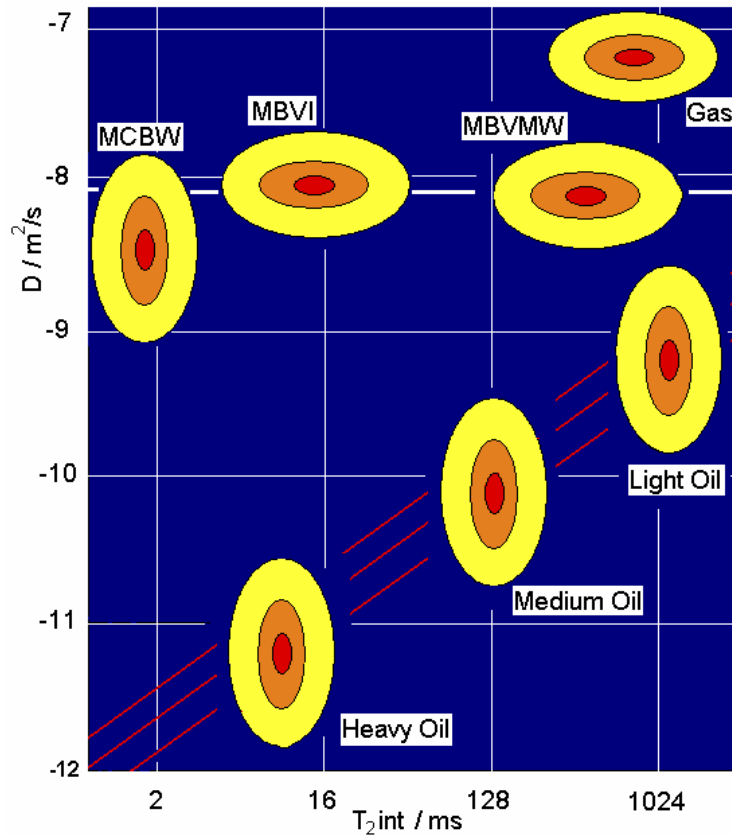


Fig. 3 Schematic representation of NMR T2int-Diffusivity map

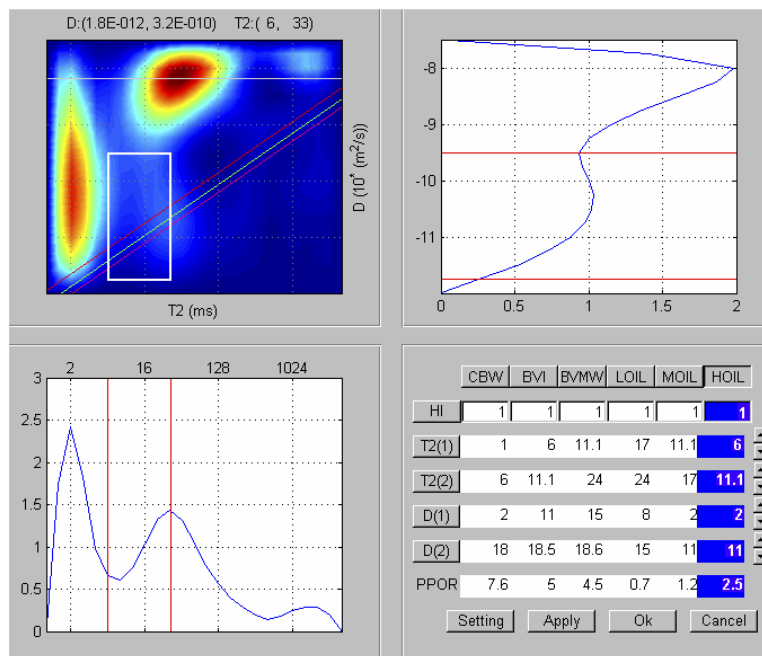


Fig. 4 T2int-Diffusivity average map for the depth interval between x660m to 675m

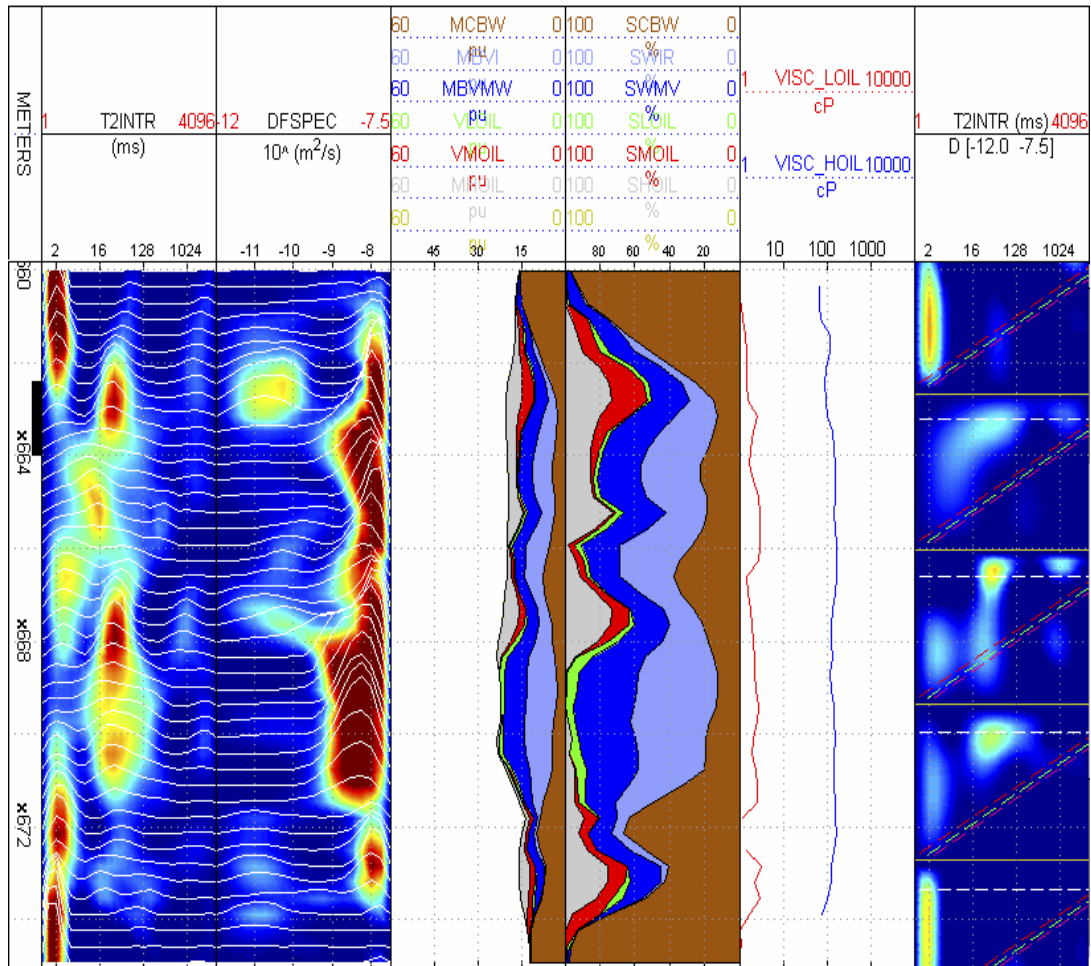


Fig. 5 Petrophysical evaluation of the layer between x660m and x675m. Tested zone between x662.5m and x664m appears in black on track 1

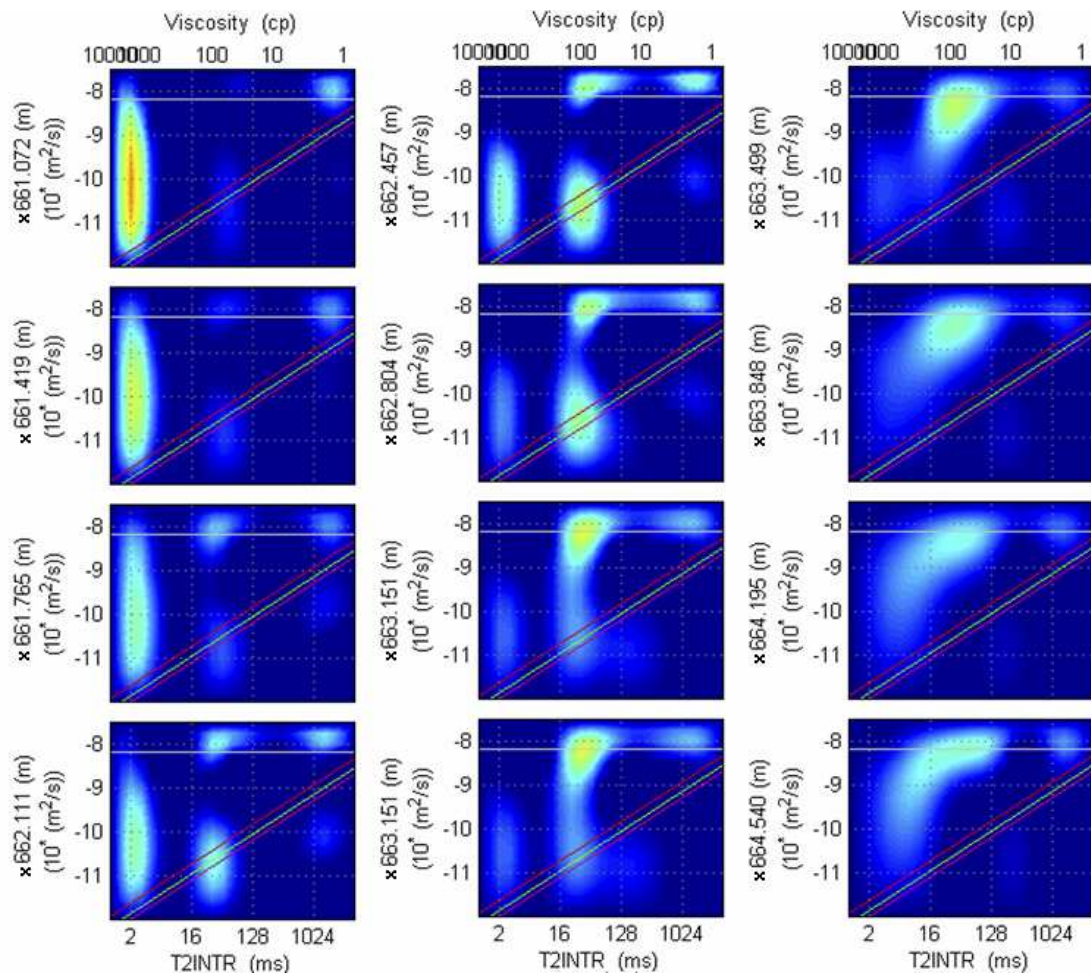


Fig. 6 Detailed T2int-Diffusivity maps for the tested zone x662m to x664.5m

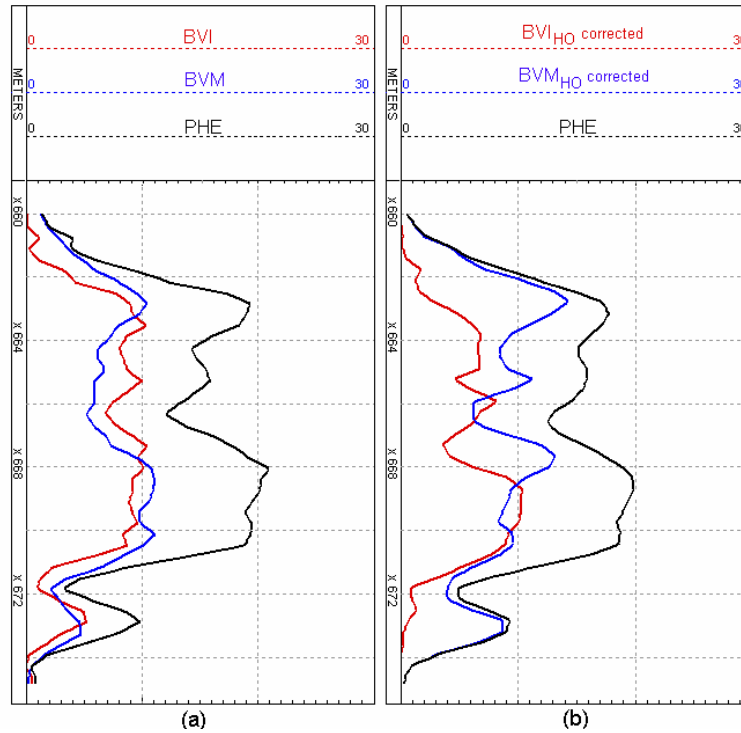


Fig. 7 BVI, BVMW, PHE (a) standard and (b) corrected for HO. Depth interval between x660m and x670m

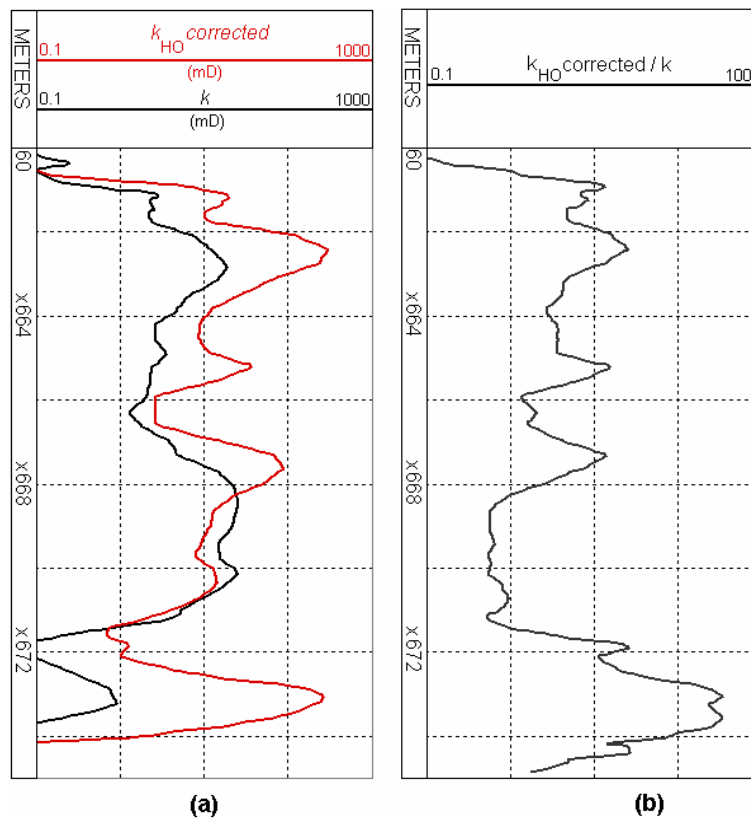
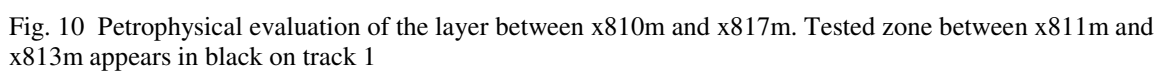
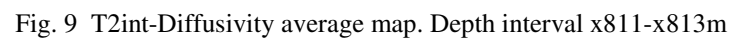


Fig. 8 Standard and corrected permeabilities (a) and permeability ratio (b). Depth interval between x660m and x670m



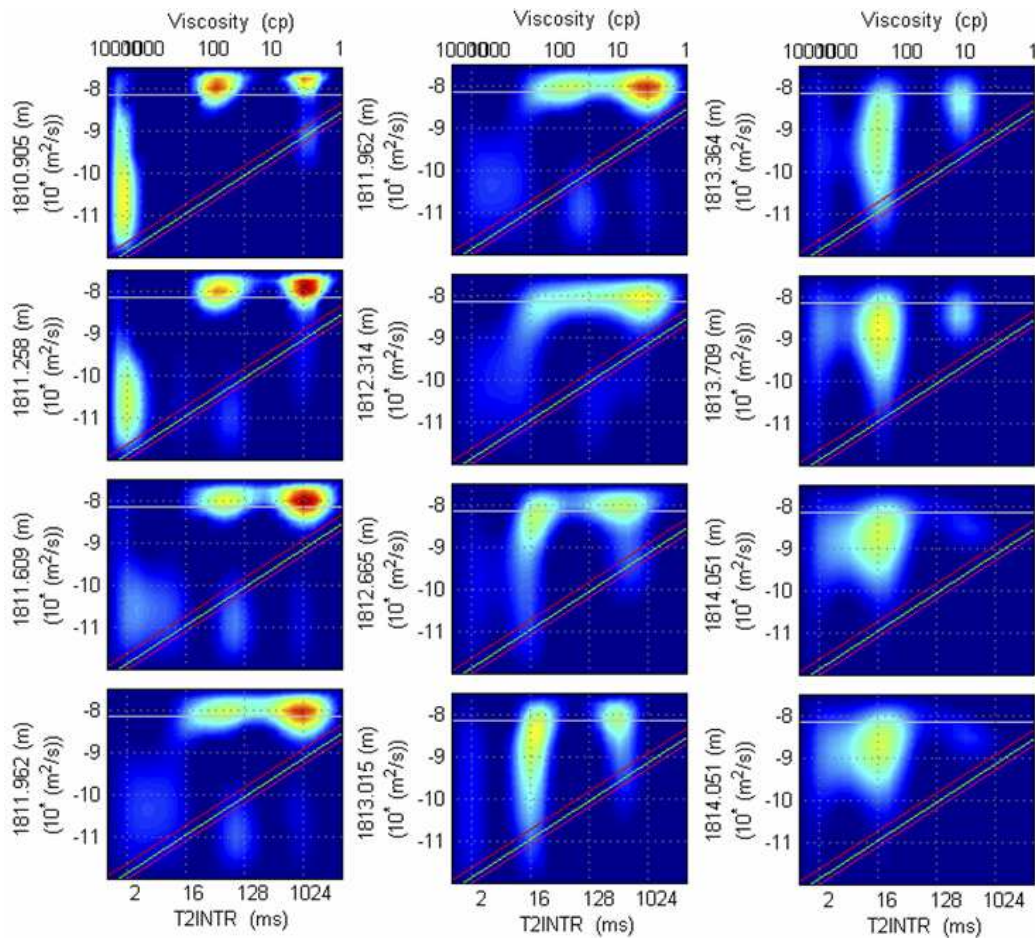


Fig. 11 Detailed T2int-Diffusivity maps from depth interval between x810.9m to x814m

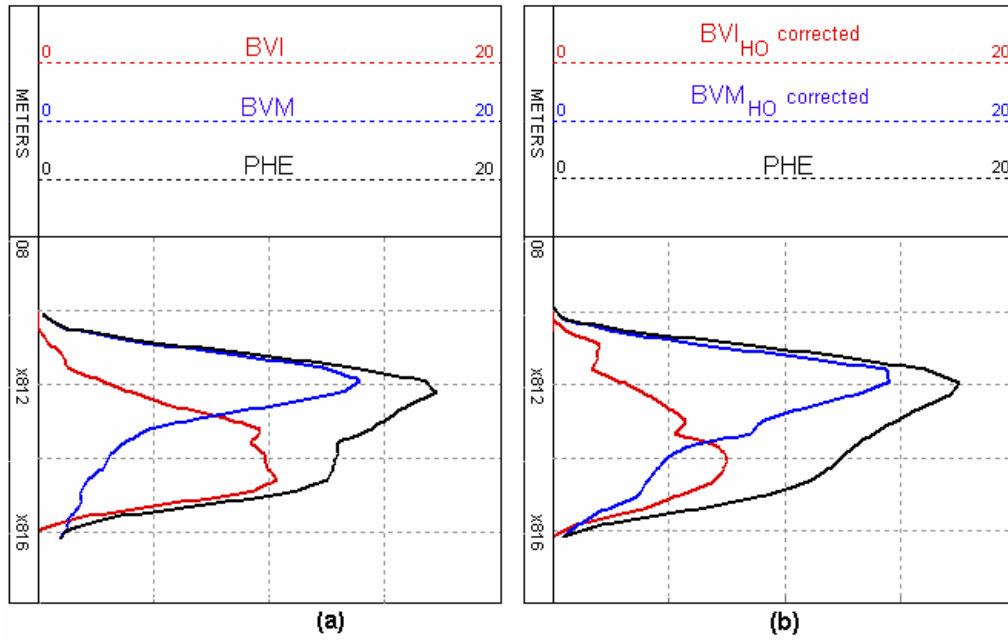


Fig. 12 BVI, BVMW, PHE (a) standard and (b) corrected for heavy oil. Depth interval between x810m and x817m

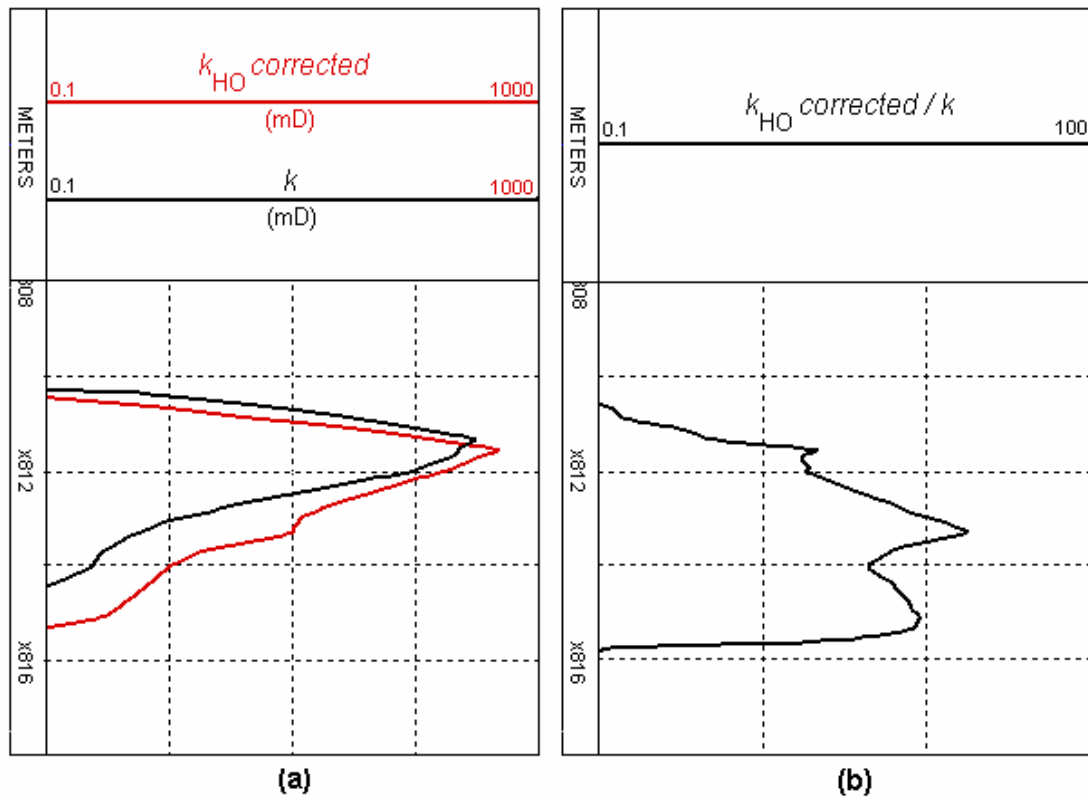


Fig. 13 Standard and corrected permeabilities (a) and permeability ratio (b). Depth interval between x810m and x817m