Formation Evaluation of Unconventional Basaltic Deccan Trap Basement Reservoir of Gamij Field, Cambay Basin, India

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Summary

The Deecan Trap basaltic rocks form the technical basement of the Cambay Basin, India. The basaltic basement is proven hydrocarbon producer in some of the fields like Padra and Gamij located on the eastern margin of the Cambay basin. An earlier study in relation to Padra field showed moderately weathered basalt as the reservoir rock, and developed a suitable method for identification and evaluation of oil bearing zones in the basement section using well logs. The present study applies the same method to the analysis of basaltic basement in the Gamij field. After a brief account of the nature and characteristics of the basaltic reservoir and the methodology used for its evaluation, the results of the analysis of three wells are presented and discussed, and they are found to be in agreement with geological and production data. It further augments the reliability of the method for the analysis of basaltic section in other fields.

Introduction

The Deccan Trap basalt of Paleocene to Upper Cretaceous age forms the technical basement of Cambay Basin, located in western on land of India (Figure1). It is overlain by thick sedimentary succession of clastic reservoir rocks and shale barriers including Cambay shale – the major source rock and the coal beds. The sand-shale sequences provide entrapment of hydrocarbons in several formations in a number of fields in the basin. The basaltic basement itself is oil bearing and has emerged as the major oil producer in Padra field located in southern Cambay basin (Figure1). The nature of basaltic reservoir in Padra field and its delineation and evaluation by integration of core studies, log analysis and production data have been dealt with in detail earlier (Pendkar, Kumar, 1999; Kumar, Pendkar and Sangeeta, 2000). The Deccan Trap basement is oil bearing in Gamij field also which is located in the northern Cambay basin (Figure1). In a recent study on analysis of multiple reservoirs of Gamij field, the basement section has also been analyzed in some of the wells using the know-how obtained during the previous study on Padra field (Kumar, Narayan, Pabla, Mahanti and Lakhera, 2004). The analysis of basement in Gamij field is the subject matter of the present paper.

Both Gamij and Padra fields are located near the eastern margin of Cambay basin (Figure1), and both have beds dipping and thickening in the west towards the basin axis. In general, basement is deeper in Gamij than Padra field. In spite of depth difference, the log characteristics of the basement in the two fields are quite similar and, therefore, the methodology developed for the analysis of basement in Padra field is readily applicable to Gamij field.

Fig. 1.

The present paper first gives a brief account of the nature of the Deccan basaltic reservoir and methodology developed for its evaluation from well logs. Then, results of the three representative wells of the Gamij field are presented and discussed.

Nature and Characteristics of the Basaltic Reservoir

The reservoir development in basaltic rocks is somewhat uncommon and delicate due to their mineralogy and the way they are affected by weathering. The unstable mafic and calcic minerals in basalt are more susceptible to alteration as compared to the stable minerals present in the felsic (granite and gneiss) rocks. While a weathered granite and gneiss (grus) can have porosity and permeability similar to a sedimentary rock, the basalts are directly altered insitu to clay minerals. The fractures in basalts are likely to be filled up by precipitation released by leaching of mafic and Ca-rich plagioclase present in the basaltic rock. Thus, the development of reservoir in basaltic rocks can take place only under favourable conditions.

As per core studies, Deccan basalts can be classified into three categories – slightly altered to pristine (fresh) basalt, moderately altered basalt and highly altered basalt depending on the degree of alteration (Kumar et.al., 2002). The slightly altered basalt is massive and has no potential for being a reservoir rock. The highly altered basalts are dominantly made up of clay minerals – mostly smectite and have no effective porosity and permeability. The moderately altered basalts showing presence of spheroidal weathering host effective porosity and permeability, and are the probable reservoir rock. The pristine and the completely altered basalts may be acting as cap rock.

The Deccan Trap basalts were laid down by multiple lava flows which are recognizable on the well logs. Each flow starts with massive basalt at the bottom and gradually changes into weathered basalt towards the top. As a result, oil may be present at different levels in the basement section.

Methodology for Evaluation of Basaltic Reservoir

The fresh and weathered basalts can be identified with the help of well logs. In contrast to fresh basalt, weathered basalt is characterized by higher porosity (lesser density, and higher Δt and ϕ_N), lower resistivity, some SP development and generally lower GR values. It is observed that the clays formed by alteration of basalt are not reflected on the logs as clays normally do. The photo-electric absorption coefficient remains close to 5, and density and neutron porosity logs show uniform separation through out the basaltic section including highly altered basalt (Kumar et al 2002). So, from log analysis point of view, the basaltic section can be regarded as a single lithological unit. It permits the use of conventional empirical relations of porosity and water saturation for quantitative analysis of basaltic section. Thus, methodology developed for quantitative analysis of Deccan basement section is based on Pickett Cross Plot (log R_t – log ϕ cross plot) which is a graphical representation of Archie's basic relation: $(S_w)^n = a R_w / (\phi^m R_t)$. The porosity ϕ has been derived by using either of the following conventional empirical relations –

$$\phi = \phi_N - (\phi_N)_{ma} \quad \text{(From Neutron Log)}$$

$$= (\rho_{ma} - \rho_b) / (\rho_{ma} - \rho_f) \quad \text{(From Density Log)}$$

$$= (\Delta t - \Delta t_{ma}) / (\Delta t - \Delta t_f) \quad \text{(From Sonic Log)}$$

where $(\phi_N)_{ma}$, ρ_{ma} and Δt_{ma} are neutron porosity, density and transit time for matrix respectively. The matrix is fresh basalt with zero porosity. The values of the above matrix parameters have been found by observing the respective tool response against fresh basalt. Thèse are $(\phi_N)_{ma} = 0.12$ pu, $\rho_{ma} = 2.98$ gm/cc and $\Delta t_{ma} = 47$ µsec/ft. The above equations will give an estimate of total porosity; the effective porosity is expected to be much less than total porosity. The estimation of effective porosity is difficult due to unresponsive nature of logs to clay. The parameters m and aR_w required for water saturation calculation in Archie's relation are obtained by the Pickett Plot as discussed in the next section.

Results and Discussion

The results of analysis of basement section in three wells A, B and C of Gamij field are presented and discussed. The log R_t versus logϕ cross plots (Pickett plots) of the three wells against the basalt section are shown in Figure 2. In these plots, the least resistivity points for different porosities correspond to water bearing zones and show a linear trend that can be approximated by a straight line referred to as R_o line. The slope of the R_o line equals the cementation coefficient m while its cut off at $\phi = 1$ gives aR_w. The values of m and aR_w as obtained from these plots are1.72 and 0.25 Ωm for well A, 1.60 and 0.22 Ωm for well B and 1.51 and 0.21 Ωm for well C respectively. A comparison of these plots indicates that the respective hydrocarbon potential in basement section of wells A, B and C is in the decreasing order. The processed parameters R_o, R_t, ϕ, S_w and ϕS_w are shown along with open hole composite logs for the three wells A, B and C in Figures 3, 4 and 5 respectively. A brief well wise discussion is given below.

Well A

A number of fresh and weathered basalt intervals

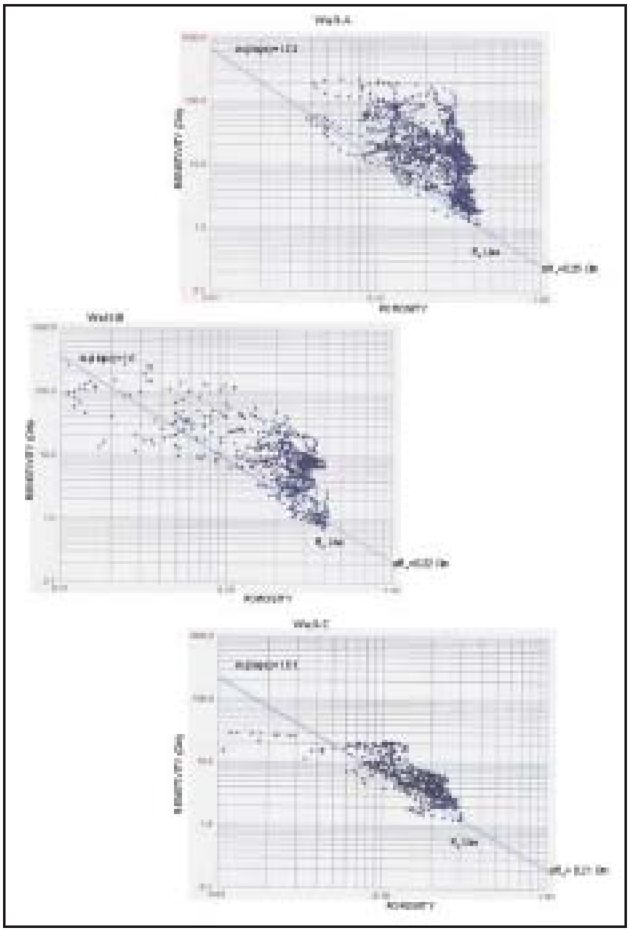

Fig. 2.

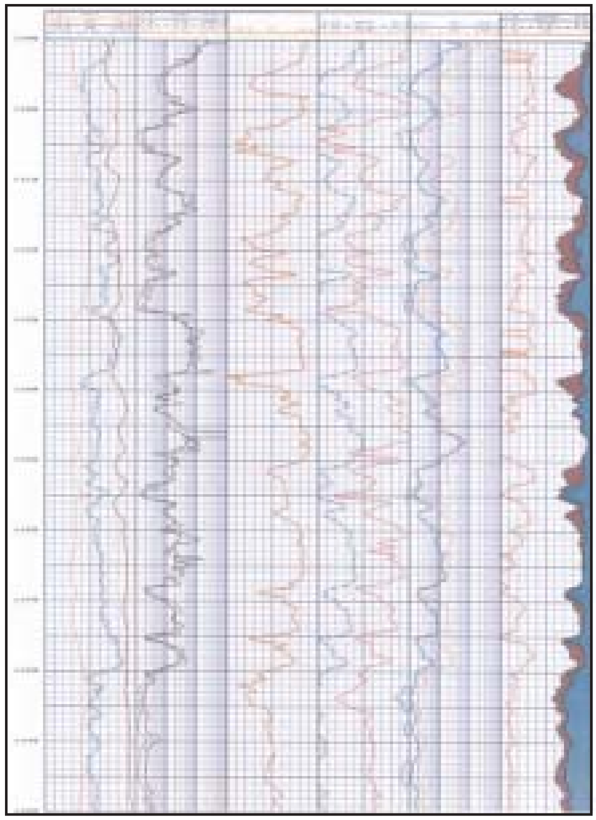

Fig. 3.

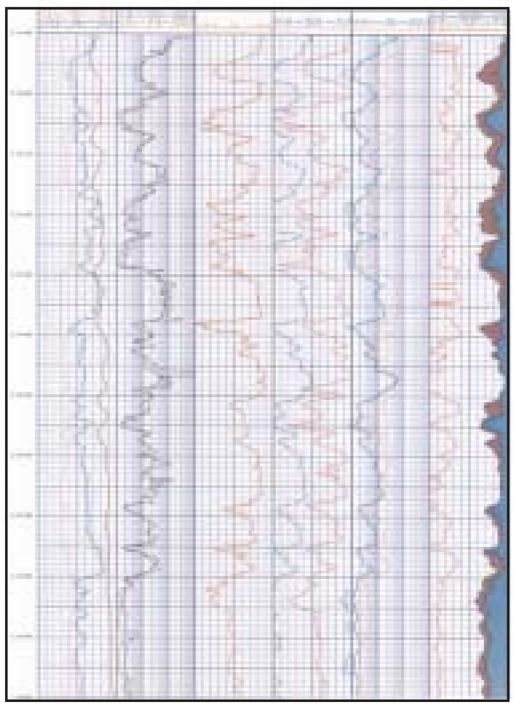

Fig. 3a.

are identified from well logs (Figure 3). A conventional core cut in the interval 1275-1281.4 m is mostly altered basalt with abundance of zeolite and quartz. The logs also show the above interval as moderately weathered basalt. The total porosity estimated from ϕ_N is displayed in the last track. In weathered basalt, it varies from 10 to 40%. The water saturation against oil bearing intervals is about 60%. The major oil bearing intervals are : 1206-1211m, 1214-1231m, 1240-1244m, 1251-1253.5m, 1255.5-1258m, 1264-1271m, 1275-1280m, 1284-1290m and 1294-1298 m. The bottom interval 1380-1400 m is water bearing.

Two objects were tested in the cased basement. The first object (1286-1290 m) was tested by cased hole DST. It produced gas with water. The second object (1206-1217 m) was tested conventionally and flowed oil @ 25 m^3 /d through 6 mm bean along with gas. It flowed on self flow for several years with a cumulative oil production 32854 m^3 and later ceased due to high GOR and water cut. The well was transferred to younger Kalol Formation. The basement section below 1240m to 1298m remains unexploited.

Well B

The composite logs and processed results are shown in Figure 4. The major hydrocarbon bearing intervals are 1280-1288 m, 1302-1306 m, 1311-1326 m, 1340-1365 m and 1382-1386 m with 30-35% total porosity and 60-65% water saturation. Three side wall cores recovered from the interval 1340-1365m are described as altered trap materials embedded in ferruginous red clayey material and have shown GYF, specky oil shows and moderate cut. The basement below 1367m is mostly water bearing. The interval 1289-1301m is fresh basalt.

The intervals 1341-1350m and 1358-1364m were perforated by Tubing Conveyed Perforation (TCP) and yielded poor influx of oil and water on testing.

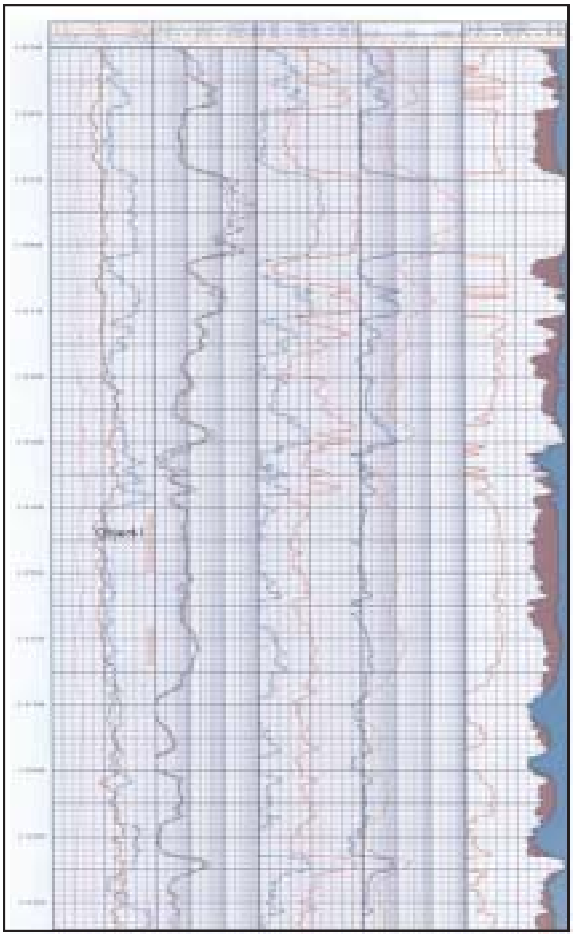

Fig.4.

Well C

In this well, both SP and GR logs are monotonous in the basement section (Figure 5). The porosity, generally 20% is much less as compared to wells A and B. The basement section is devoid of any significant oil bearing interval. Two side wall cores at 1179m and 1259m depths also did not indicate hydrocarbons. The testing of the barefoot basement section gave poor influx of water with traces of oil.

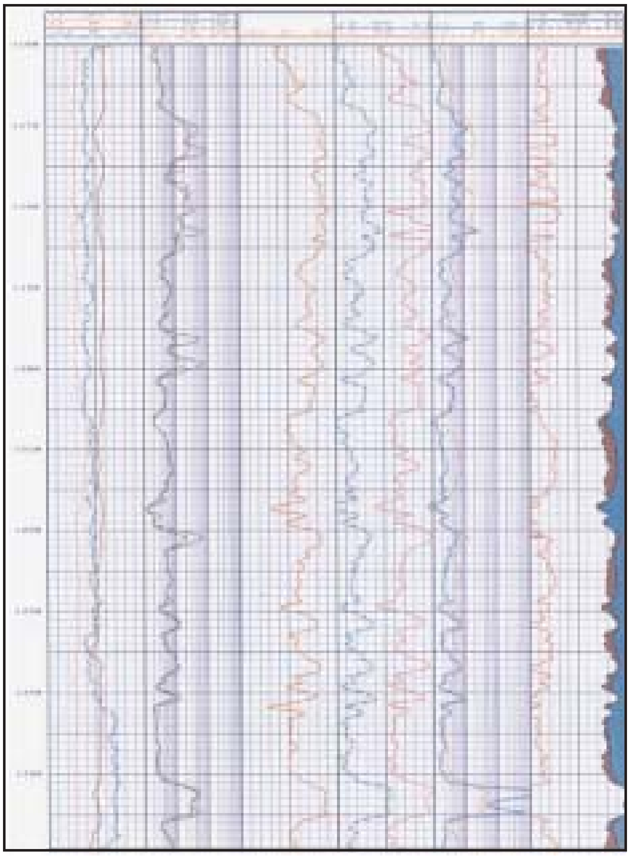

Fig.5.

Conclusions

The analysis of well logs of the basaltic basement section of Gamij field by a method based on Pickett cross plot first developed for Padra field has given results commensurate with geological and production data. There seems to be much oil left in the basement section of well A below 1240m which needs to be exploited. The matching of processed results with testing data has enhanced confidence in the method.

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