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Distribution of Overpressure and its Prediction in Saurashtra Dahanu block, Western Offshore Basin, India

ABSTRACT

Overpressured formations are encountered in the Saurashtra-Dahanu PEL Block, Western Offshore Basin, India. The block covers an area of 2500 sq. km. and six wells have been drilled so far for exploration of hydrocarbon to test prospectivity within Early Eocene to Early Miocene sequences. The thick basin fill of over 6000m is characterized by high geothermal gradient and overpressure. The drilled well data indicate that over-pressured formations occur at depths ranging from 1800m to 3600m within Early Eocene to Early Miocene strata. The overpressure was encountered in both limestone and shale sections in the area. Overpressure in Early Miocene limestone is confined in nature and overpressured pore fluid is developed probably due to fluctuating bathymetry and inability of pore fluid to escape. Since measured formation pressure data is scanty, the mud weight used while drilling is considered to be indicative of formation pressure where overpressure led to well activity. Normally it is assumed that mud weight used to control such well activity is higher than formation pressure. Drilling any high pressure and high temperature well is a costly affair in terms of well design and rig cost. We have used seismic interval velocity to predict overpressure in Saurashtra-Dahanu exploration block. Our analysis of plots of seismic interval velocity against time shows regression against zone of abnormal pressure. The well which did not show any regression in interval velocity vs. time plot did not encounter any high pressure while drilling. The acoustic well log analysis also show that travel time decreases within over-pressured zone. Our analysis can be used in the future locations to be drilled which may result in cost savings in terms of well design and rig cost and lead to smooth drilling of well.

INTRODUCTION

Overpressures are common in sedimentary basins all over the world and require careful pre-drill assessment and well planning for successful completion of any exploratory well. Overpressures, sometimes, called “geopressure” are common in subsurface rocks. A pore pressure fluid is overpressured if its pressure exceeds that of a hydrostatic pressure gradient at specific depth (Osborne, 1997). They have been studied in detail in geophysics (Bethke, 1986) and geodynamics (Turcotte and Schubert, 1982). Loading during burial can generate considerable overpressure due to disequilibrium compaction during rapid subsidence of low permeability sediments (Osborne, 1997)

The Saurashtra –Dahanu PEL block covering an area of 2500 sq. km. is situated in the north of Bombay Platform in Western Offshore Basin, India (Figure 1). The block is characterized by high pressure leading to well activity during drilling. Six wells have been drilled so far in this area out of which four have encountered high pressure in various proportions from different geological age strata. The well B-9-D (Figure 2) drilled in the western part up to Basaltic Basement did not show any abnormal well activity during drilling. Similarly, well B-9-B, was completed without any drilling

complication as the well was drilled immediately after completing the well B-9-1 which encountered well activity during drilling. The mud weights were suitably modified while drilling this well.
The interval velocity in the 3D seismic volume, acoustic travel time log data, MDT pressure data and mud weight data during drilling in drilled wells were analysed to configure the pressure distribution in the entire study area. The mud weights represent an upper limit close to formation pressure because the weight of the mud column in the well must be greater than formation pressure to avoid possibility of uncontrolled well activity leading to blow out (Lee and Deming, 2002). The present study attempts to address distribution of overpressure and its prediction in the block. Our analysis shows that seismic interval velocity may be used to predict overpressure in the un-drilled locations in Saurashtra-Dahanu block and nearby areas for better well design and cost effectiveness and successful completion of exploratory well.

GEOLOGICAL BACKGROUND

The Saurashtra-Dahanu block is situated to the north of Bombay Platform, south west of Tapti-Daman area and east of Saurashtra depression. It has an area of 2500 sq. km. with B-9 field in the north western part (Drilled wells B-9-A, B-9-B, B-9-C and B-9-D) and B-12-9 field in the south eastern part (Drilled wells B-12-9-A and B-12-9-B). The sedimentary fill in the drilled wells range from 3000 to 4400m. The deepest well, B-9-D, which encountered basaltic basement at a depth of 4250m. was terminated at 4433m. The basin consists of sediments from Paleocene to Recent and overpressures have been encountered within Eocene, Early Oligocene, Late Oligocene and Early Miocene respectively. The generalised stratigraphy is given in Figure 3.

The B-9 structure in the north west is a north east-southwest trending inversion structure formed due to reactivation of north east- south west trending fault. However the intensity of the structural strain is more pronounced in the eastern part, where wells B-9-A, B and C are drilled, as compared to western part, where B-9-D is drilled. The B-12-9 field in the south eastern part is located on a basement high and has been subjected to rotational movement. The strike slip movement has resulted in the structuring along B-12-9A and its north western corridor. The small structures formed are broadly east-west trending.

The Panna formation of Paleocene to Early Eocene with mainly Type- III and Type-II organic matter is the dominant source rock unit. Hydrocarbon accumulation is proved within sands of Daman Formation of Late Oligocene age and Mahuva limestones of Early Oligocene age. The migration is through deep seated faults where as shales provide effective top seals.

OVERPRESSURE DISTRIBUTION AND PREDICTION IN THE AREA

Six wells have been drilled in the area to explore Panna, Mahuva and Daman formations. Being a high pressure and high temperature area, the drilled wells witnessed drilling complications in terms of well activity in a number of wells. Only one well B-9-D has penetrated the entire sedimentary sequence in the area and terminated within basaltic basement. Daman Formation of Upper Oligocene age has produced hydrocarbon gas whereas Mahuva Formation of Lower Oligocene age flowed oil of high API. The overpressured sequences, as observed from well activity (Well completion reports) in the area are given in Table 1.

Table 1. Nature of well activity, mud weights used during drilling and mud weights used to control the well activity.

Sl. No.	Well	Depth (M.D.) in Meters	Formation	MW used (ppg)	Nature of well activity	MW used to control (ppg)
1	B-9-A	2759	Mahuva	12.7	While drilling at 2753m, drill break was observed followed by gas bubbling along with total gas of 19% in MLU	13.8
2	B-9-A	3042/ 3066/ 3090	Mahuva	14.0	Well activity with total gas of 8.9% - 9.9% in MLU besides self flow and gas bubbling at well mouth.	14.8
3	B-9-C	2390	Bombay	11.9	While pulling out string for coring, observed self flow and pit gain of 6 bbl/hour.	13.0
4.	B-9-C	3116/ 3130	Mahuva	14.4	While drilling at 3116m, pit gain of 3 bbl in 10 minutes was observed.	15.6
5	B-12-9-A	1880/ 1887/ 1930	Bombay	10.5	Observed self flow, pit gain and detected total gas in MLU unit.	12.1
6	B-12-9-A	2163	Daman	12.1	During pipe connection observed self flow of 100 bbl/hr, reduction in mud wt and drop in viscosity and total gas 8% in MLU.	12.5
7	B-12-9A	2698	Mahuva	13.4	Self flow and total recorded gas in MLU 52%.	14.0
8.	B-12-9A	2804	Mahuva	14.0	Heavy splashing of mud at well mouth, total gas 40%.	16.8
9	B-12-9B	2159	Bombay	11.5	During drilling self flow was observed.	12.7
10	B-12-9-B	3547	Panna	16.7	Observed 3% increase in flow rate during drilling but no self flow during static condition. Tried to kill with mud wt. of 17.3 ppg but observed mud loss. Terminated well at 3565m under mud loss and mud pit gain condition.	17.8

We have plotted two way PSTM time against interval velocity (Figure 4) and acoustic travel time against depth (Figure 5) for all the six drilled wells in the area to configure any relationship between occurrence of overpressure in the area with lowering of seismic interval velocity and/or deviation in trend line on acoustic travel time corresponding to overpressure. Our analysis shows that overpressures encountered in well B-9-A at 2759m and 3042/3066/3090m correspond to lowering of seismic interval velocity from 2500 to 2800 milliseconds two way travel time (Figure 4 and Figure 5). Lithologically, the intervals are characterized by limestone and shale alternations which were deposited in a fluctuating bathymetry (Kundu et al, 2007).

Similarly, in wells B-9-B and B-9-C also lowering of seismic interval velocity around 2500-2700 milliseconds two way travel time is attributed to overpressure. However, it may be noted that during drilling of well B-9-B, no well activity was observed which may be due to higher mud weight already used during drilling of this section with the drilling experience of well B-9-A. The mud weight used while drilling the overpressured section in well B-9-B was in the range of 13.6-13.9 ppg in the interval 2700 – 2800m (Note the equivalent overpressured section was controlled with mud weight of 13.8 ppg in well B-9-A at 2759m depth as given in Table-1).

In well B-9-C, another lowering of interval is observed around 1900 milli seconds which encountered water kick while drilling at 2390m. A thick 90 meter, mainly limestone strata with thin intercalations of shale were penetrated in this section. The MDT pressure of 5323 psi is calculated to be equivalent to 12.99 ppg mud weight. The Table 1 shows that mud weight which was required to control this kick was 13.0 ppg mud weight.

In well B-12-9 A, lowering of seismic interval velocity around 2000 milliseconds and 2450 to 2800 milliseconds is observed where splashing of mud at well mouth was observed during drilling. These two way travel times correspond to depths of 2163m, 2698m and 2804m respectively where well activity was observed. The recorded reservoir pressure around 2800m was measured to be around 16.4 ppg mud weight equivalent. The mud weight which was used to control the well activity at this depth was 16.8 ppg.

The well B-9-D was recently drilled to target depth of 4433 m and has penetrated the entire sedimentary sequence and terminated within weathered basaltic basement. In this well overpressure was not encountered while drilling the entire well. In well B-9-D, the equivalent section, where lowering of interval velocity is not seen (i.e. around 2500 milli seconds shown in rectangle in Figure 4) was drilled with mud weight of 13.1-13.5 ppg in the interval 2700 – 2900m).The seismic interval velocity curve shows no apparent lowering in this well and follows almost a straight line compared to other wells where overpressures have been encountered. Lithologically this well also exhibits limestone and shale alternations in the target section.

Based on our study, we have demarcated the likely overpressured and normal pressured areas (Figure 6) in the study area. The time structure map close to Early Oligocene top shows that the area lying to the west show normally pressured area (shown with black dotted lines over the faults). Incidentally, the normally pressured area is bound by the north east – south west inversion fault in the eastern area bounding the B-9 structure (encompassing wells B-9 A and B-9-B) whereas in the southern area the east – west trending strike slip fault limits the normally pressured area.

Our study, thus demonstrates, that seismic interval velocity as a tool can be used to predict overpressure in Saurashtra Dahanu exploration block. This will lead to reduced exploration cost in terms of rig design, casing design and lower mud weights. This study was not intended to address the mechanism of over-pressuring in this block for which more studies will have to be undertaken.

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(Unpublished ONGC reports)

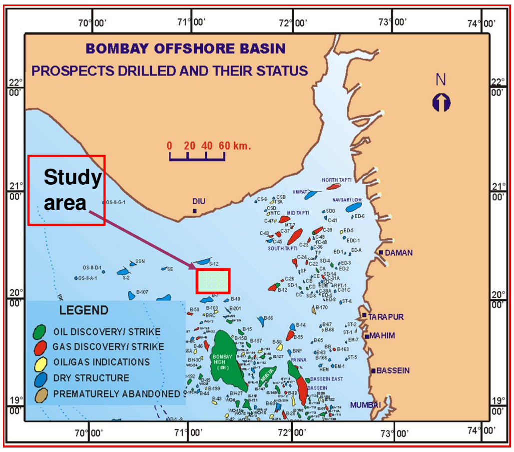

Figure 1. Map showing the study area.

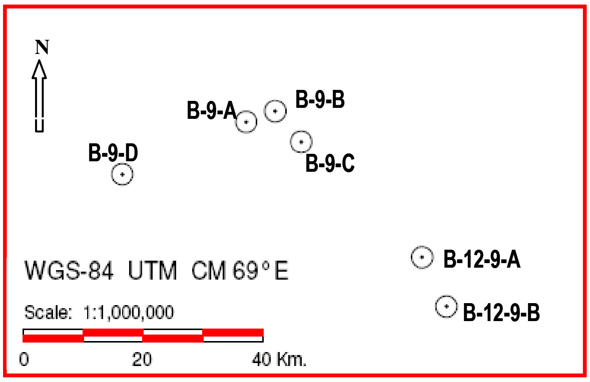

Figure 2. Location map showing position of wells drilled in the study area.

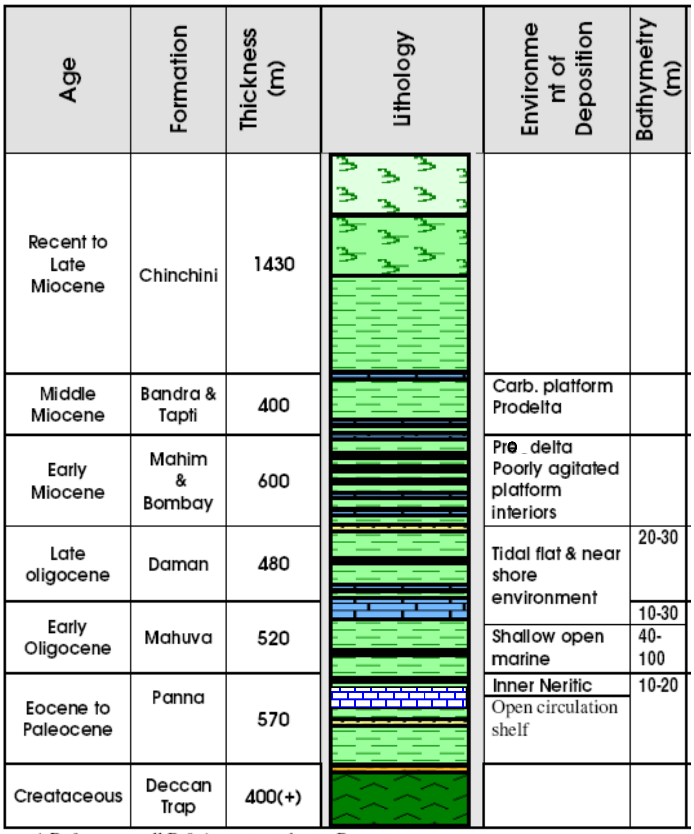

Figure 3. The generalised stratigraphy of the area.

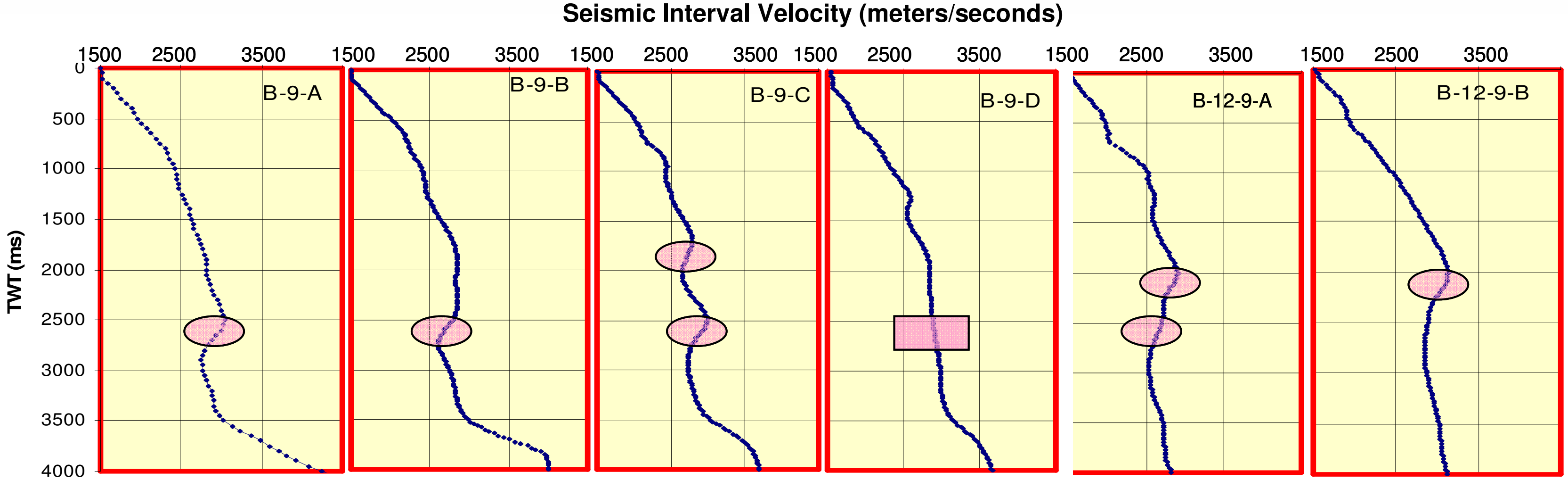

Figure 4. Plot of seismic interval velocity (in 'X' axis in meters/seconds) against Two Way Travel Time (in 'Y' axis in milliseconds) showing lowering of velocity in overpressured zones (marked in circle). Note that in B-9-D there is no deviation in the trend line (marked in rectangle)

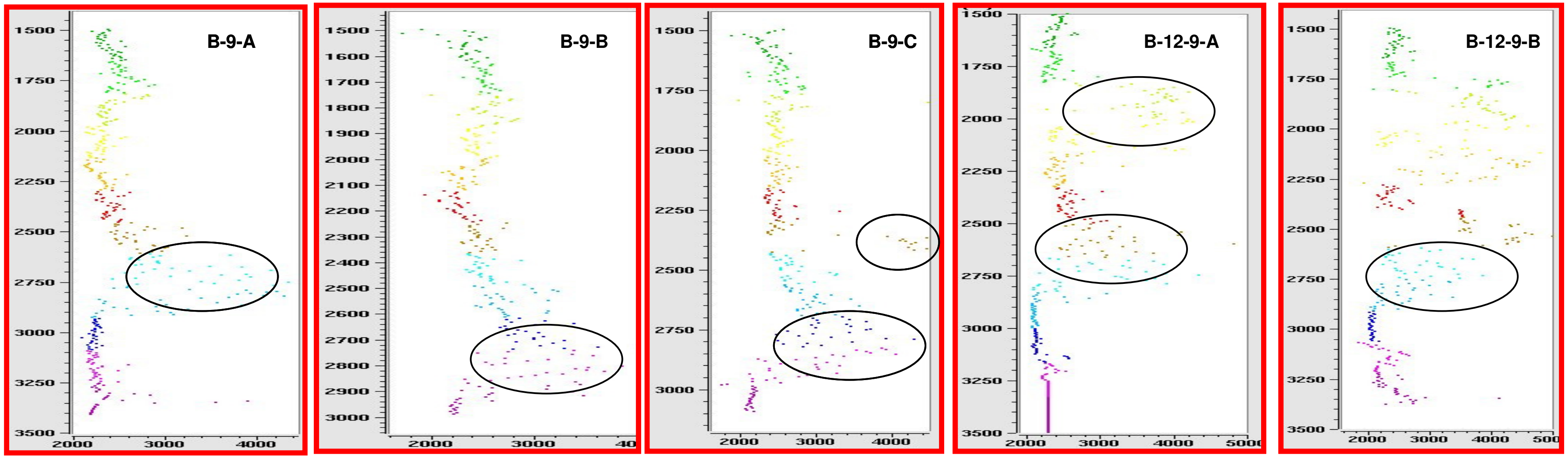

Figure 5. Plot of sonic travel time (in 'X' axis in meters/seconds) against depth (meters) showing lowering of velocity against overpressured zone (marked in circle).

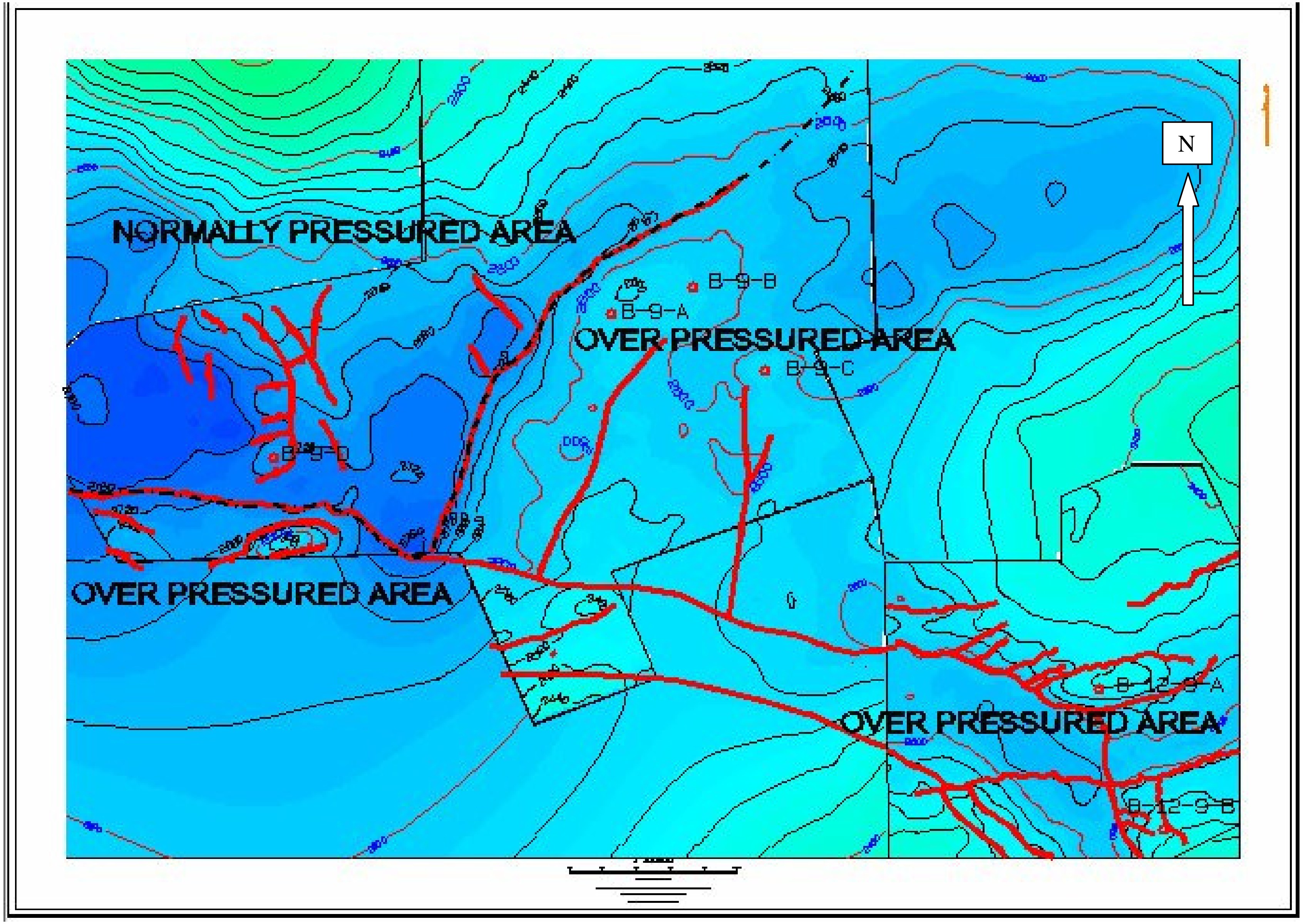

Figure 6. The time structure map close to top of Early Oligocene showing the normally pressured area and overpressured area in the study area. The area west of north east – south west inversion fault and north of east – west striking strike slip fault