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Determining the cause of overpressure using well logs: A case study from B-12 field of Bombay Offshore Basin, ONGCL

Abstract

Understanding the reason of overpressure generation is of utmost importance for its accurate estimation. Whereas some of the sources like compaction disequilibrium, centroid effects, buoyancy effects are well understood and can be effectively modelled, others like fluid expansion and tectonic reasons, although well recognised, are yet to be suitably modelled for overpressure prediction. Non-recognition of generation mechanism may lead to wide variations in pore pressure prediction and at times may be the main reason for the failure of mechanical earth models.

The variation in effective stress with different types of pore pressure is one of the ways to know the generation mechanics and if that is properly captured through the loading and unloading curves, it can provide the vital information about its source. Incidentally most of the logging tools respond to the effective stress as opposed to total stress, and therefore it can be inferred that crossplots of some of the log measurements may indicate the possible source.

The work presented in this paper has been done to investigate and understand the cause of overpressure by analysing such crossplots which essentially respond to loading and unloading paths. We have chosen three nearby wells of B-12 field of Tapti-Daman block of Mumbai offshore basin, where overpressure have been reported from moderate to extremely high in different reservoir sections. In one of the wells we have made an attempt to explain the high pore pressure in Daman section by bringing in the concept of quartz cementation, which otherwise is not visible on logs.

Introduction

Tapti-Daman block (Surat Depression), part of Mumbai Offshore Basin is a mixed siliclastic-carbonate system. Tapti-Daman area has witnessed two distinct tectonic regimes in geological time. The older basin formed during Mumbai-Cambay rifting represents extensional regime characterized by half-grabens /tilted fault blocks configuration and the younger Miocene tectonics resulted in basin scale inversion due to transtensional and transpressional movements. Thus, A package consisting of sand bodies deposited in various environments (distributary channels, coastal bars, tidal deltas and other transitional environments) encased in Daman shale overlying over-pressured prodelta clay stone of Early Oligocene (Mahuva) was formed. Reservoirs in these (Daman and Mahuva) formations are the most prolific producers in this area.

Besides high stresses, the formations in these fields are observed to be overpressured and encounter of unpredictable high pressured zones during drilling is a common phenomenon in this area. Hence pore pressure prediction in this field is a challenging task.

Pore pressure is the pressure exerted on the rock containing the pores (storage + connecting) by the fluids present in those pores. During burial under normal pressure conditions, the effective stress continually increases with depth. Consequently, the rock porosity decreases (exponentially) with depth and in turn increases the formation velocity. Because pore pressures affect compaction, changes in velocity can be calibrated to changes in pore pressure. The accuracy of this method depends on the validity of the relationship between pressure and velocity. However, it is crucial to understand that there can be more than one cause of pressure and that present-day pressure regimes are the result of the complete loading path that a rock has undergone since its deposition.

Theory

The origin or cause of overpressure can be broadly divided into 3 categories as discussed below:

1. Due to increase of compressive stress:

Disequilibrium compaction/Undercompaction: Where large loading rates are applied to rocks such as shales with relatively low vertical permeability, the confined fluids in the rock mass cannot escape abruptly enough to maintain a hydrostatic fluid pressure gradient and give rise to abnormal pressures. This type of abnormal pressure is observed in many young Tertiary basins worldwide and is commonly recognized in velocity data by the slow decrease in the velocity gradient with depth.

Horizontal stress change: Due to tectonic activities in an area, the effective horizontal stresses within the Earth increases giving rise to abnormally high pressures.

2. Changes in pore fluid volume or rock matrix:

Increase in fluid volume within a confined pore space or decrease in pore space can lead to high pressures. This can happen because of aquathermal expansion (needs perfect sealing for significant pressure), Clay dehydration (needs perfect sealing for significant pressure), Hydrocarbon generation & cracking to gas or Cementation or quartz precipitation in clastic reservoirs. Pore-pressure evaluations that incorporate the effects of unloading have been discussed by Bowers (1995) and Ward et al. (1995).

3. fluid movement or buoyancy:

Due to hydraulic head in shallow reservoirs (significant), HC buoyancy & osmosis (small amounts), high pressures are observed at the top of the reservoirs.

To investigate and know the cause of high pressure, certain crossplots can be used as discussed below:

Porosity vs. Depth Plot:

The different type of pore pressures impact the porosity trends differently as depicted in the figure below. Normally Porosity decreases exponentially with depth but in case of Undercompaction, fluids get trapped in the formation and there is negligible change in the porosity. Porosity remains constant, hence the pattern. However in case of unloading or fluid expansion, pore volume increases enormously, showing the deviation from the trend.

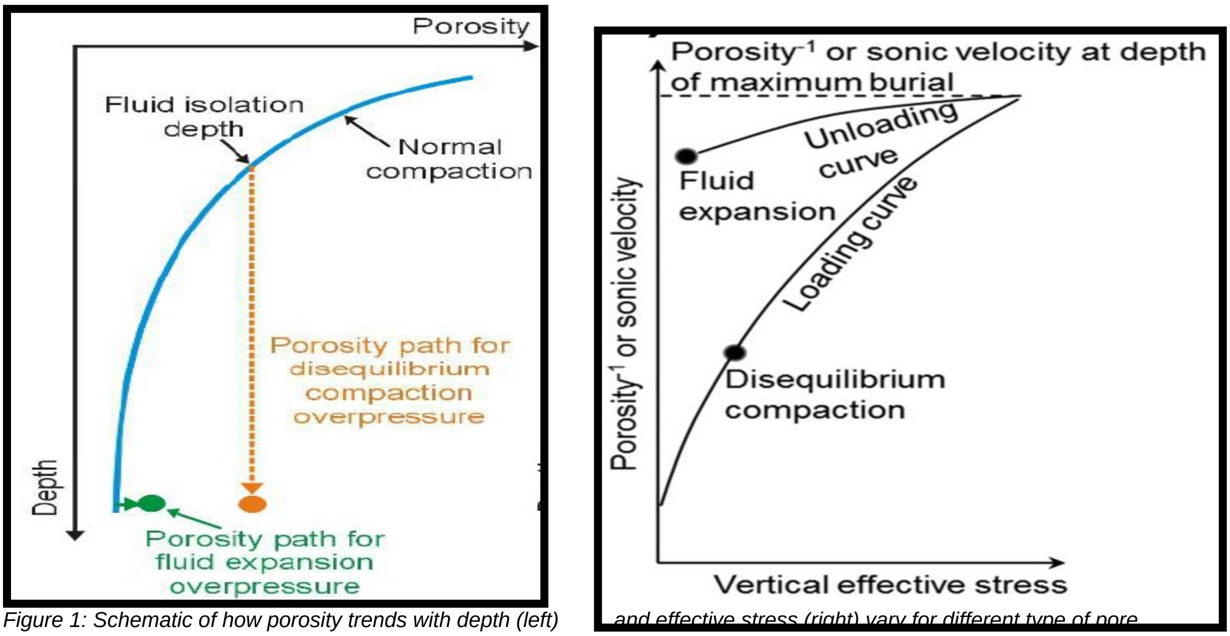

Figure 1: Schematic of how porosity trends with depth (left) and effective stress (right) vary for different type of pore pressure, Courtesy: Reference-1

Compressional velocity vs. effective stress plot:

As suggested by “Pore Pressure Estimation from Velocity Data: Accounting for overpressure mechanisms besides Undercompaction, Glenn L. Bowers,* Exxon Production Research Co.”, the loading and unloading mechanism follow the different path. In case of unloading, the effective stress decreases with depth whereas in case of normal compaction or Undercompaction the effective stress increases with depth.

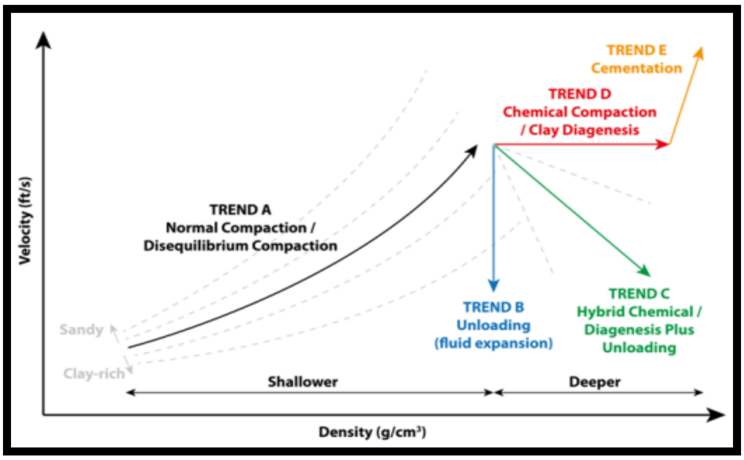

Figure 2(left): Schematic showing how trends on velocity-density crossplot varies for various type of overpressure generation mechanisms

Compressional velocity vs. Bulk Density Crossplot:

The sonic velocity versus bulk density crossplot shows different trend for different pore pressure generation mechanism (indicated in the figure below) depending on their impact on formation velocity and bulk density.

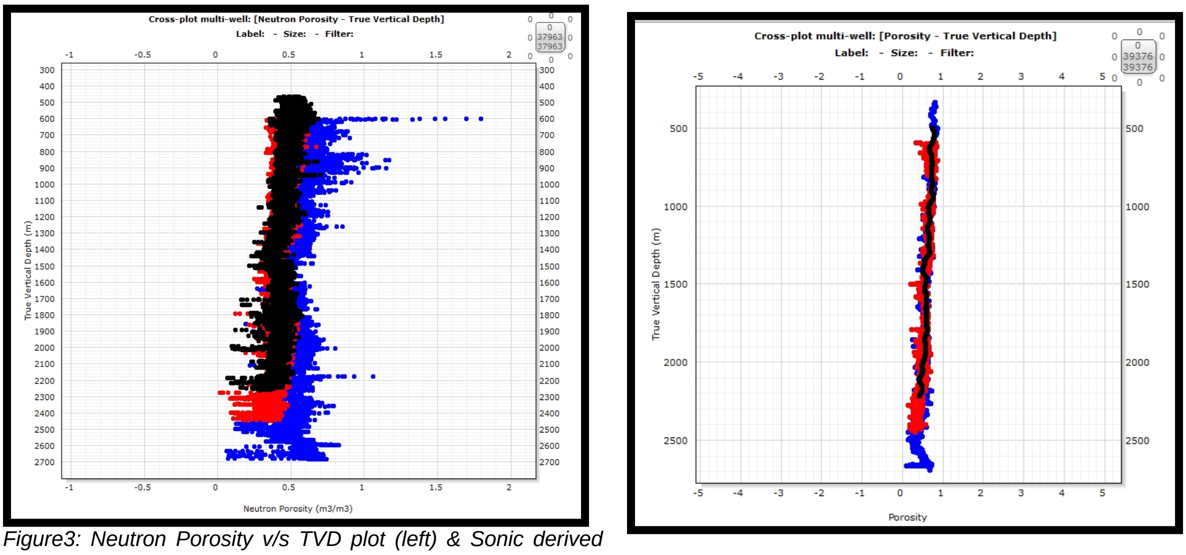

Figure3: Neutron Porosity v/s TVD plot (left) & Sonic derived Porosity versus TVD (right), ***Well: A (Blue), B (Black), C (Red)***

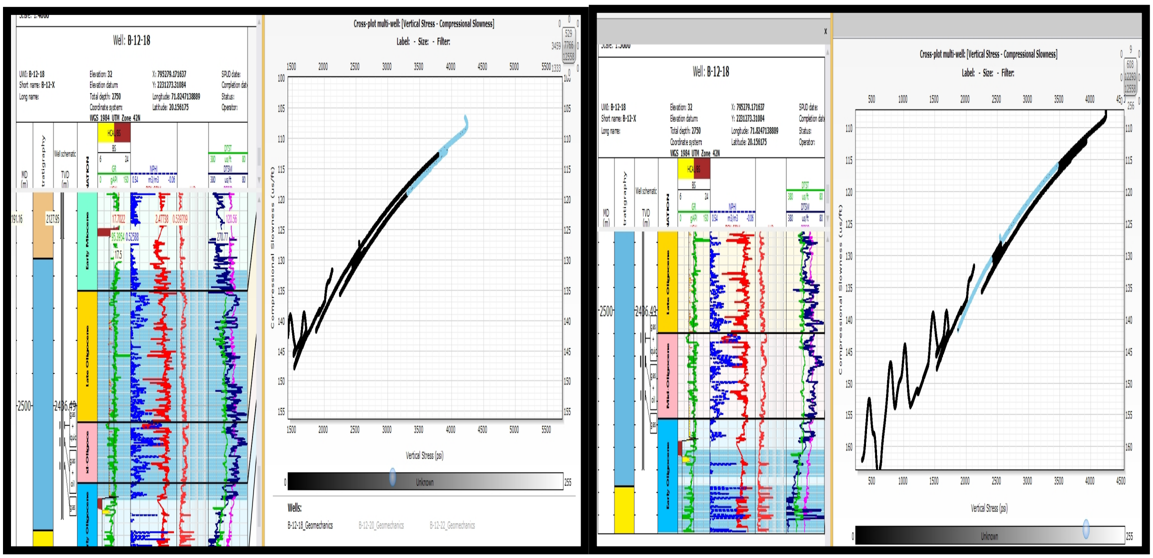

Figure 4: Compressional slowness v/s Effective vertical stress crossplot, well-A, Daman formation (left), Mahuva (right)

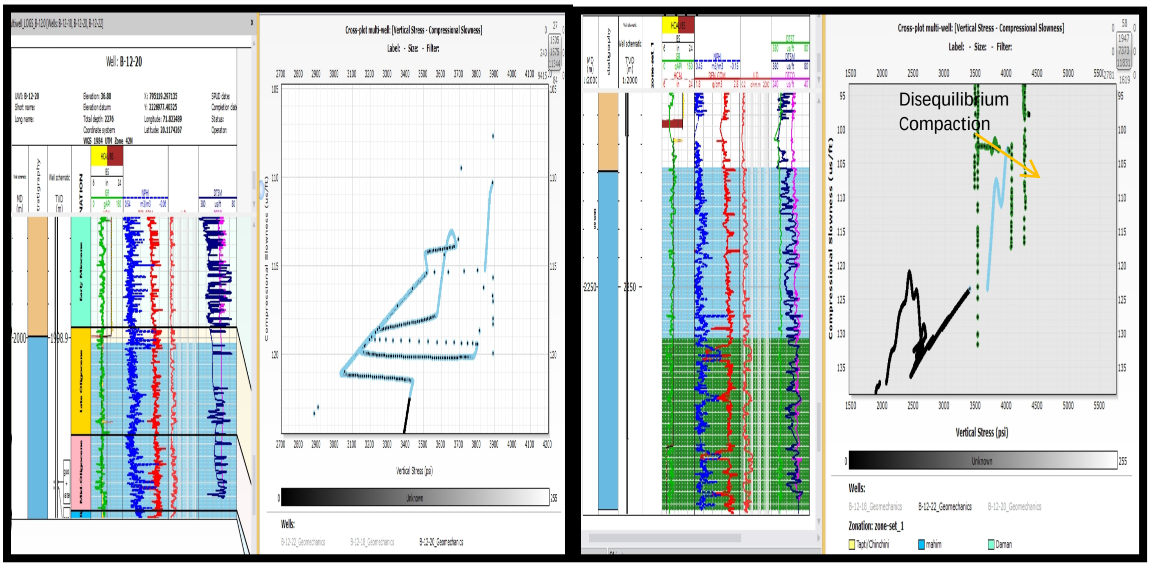

Figure 5: Compressional slowness v/s Effective vertical stress crossplot, well-B(Daman)(left) well-C (Daman)(right)

Observations/Analysis of crossplots:

The porosity versus depth plot (figure 3), show a normal compaction trend for all the wells with a change in trend after the depth of 1500m. Bottom of well- A i.e., Mahuva formation shows a rampant increase in porosity. This is indicative of fluid expansion in this formation. Sonic porosity also shows similar trend.

The velocity versus effective stress plot (figure 5) shows additional pore pressure due to Fluid expansion in bottom most part of Daman formation and Mahuva formation in well A. Whereas in well B & well C it shows normal compaction only. However, the normal compaction trends are different for different formation (Tapti & Chinchini, Mahim & Daman).

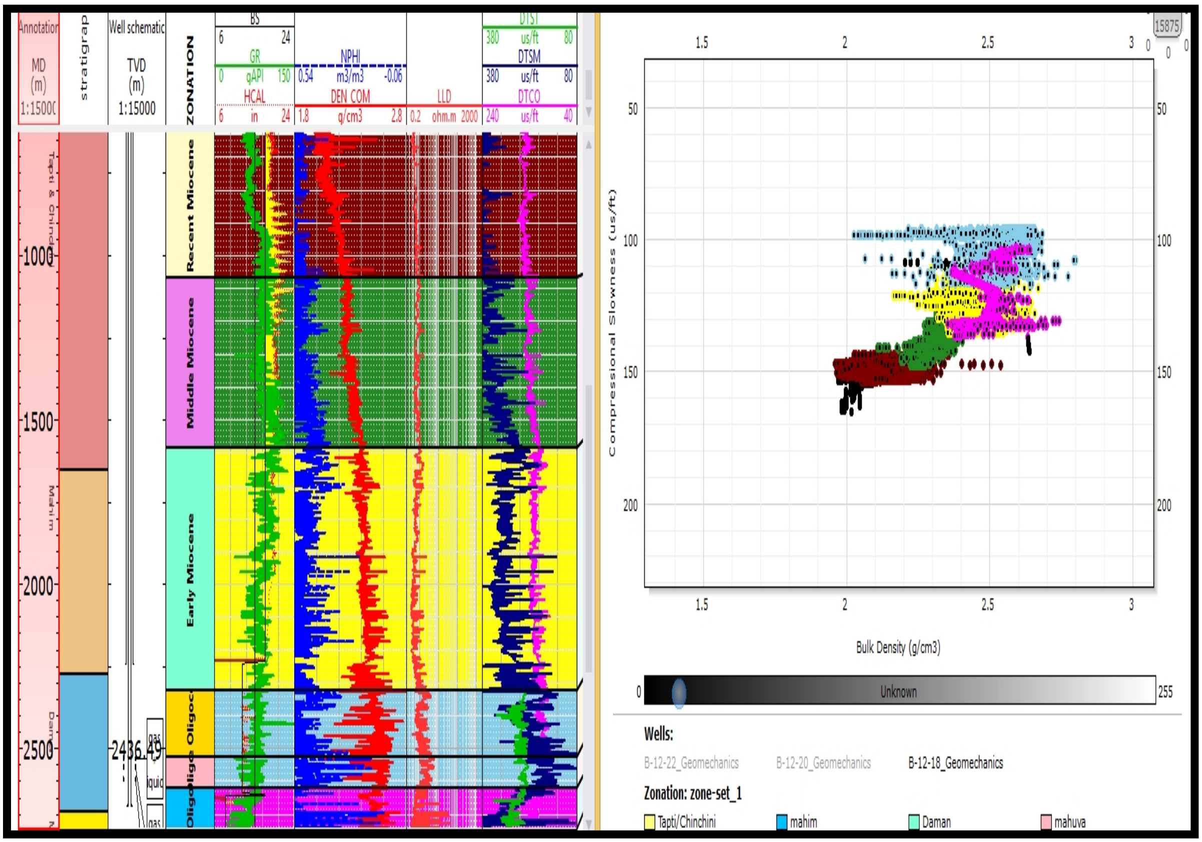

Figure 6: DTCO/Vp versus Density, well-A

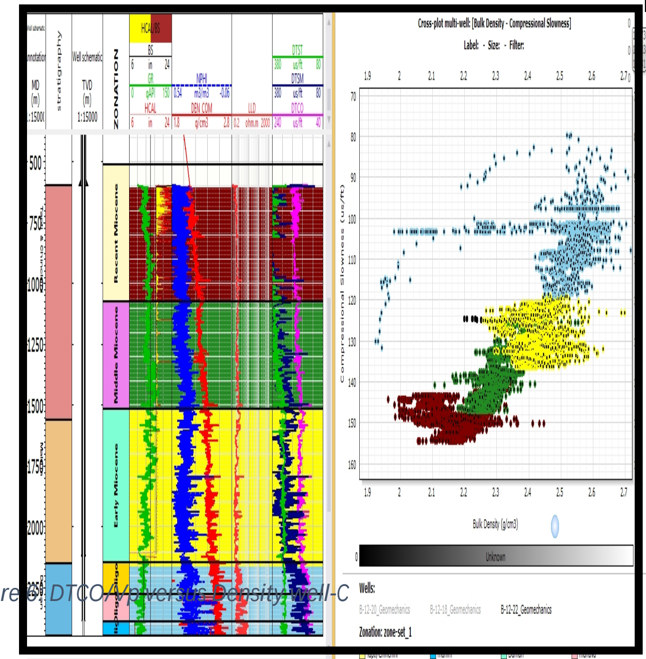

Figure 6: DTCO/Vp versus Density, well-C

From the velocity versus density crossplot, in Well A, the Tapti & Chinchini formations show normal compaction (Trend A) whereas Mahim ormation shows chemical compaction/ clay digenesis (Trend D) along with normal compaction. The part of Daman formation and Mahuva formation show unloading due to fluid expansion (Trend B). This can also explain the extreme high pressures observed in Mahuva.

n Well C, Normal compaction trend is seen in all the formations except the Mahim section where it's also indicating some clay Digenesis/ chemical compaction.

n Well B, the trend shows Chemical compaction/ clay digenesis in Mahim section and quartz cementation (discussed in next section) in Daman formation, unlike the trends in well-A and well-C

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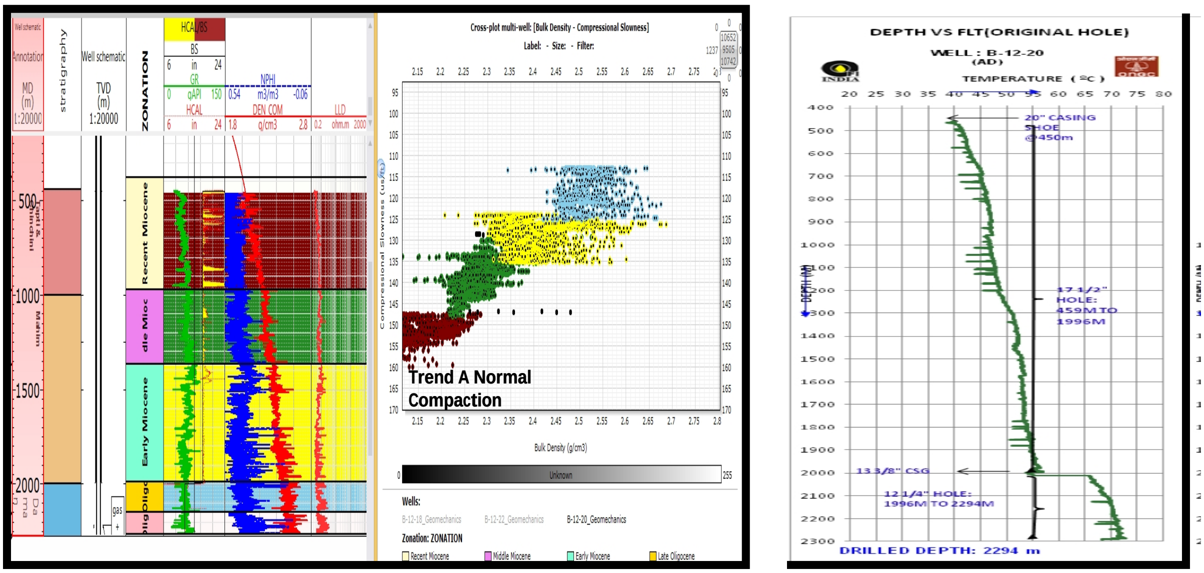

Figure 7: DTCO/Vp versus Density, well-B(left), Depth versus Temperature plot for original and side tracked hole of well B(right)

Discussion on Quartz Cementation in Daman formation of well B

Though pore pressure computed using Eaton's trend line method from sonic log shows normal pressures in well B, but activities encountered during drilling show that the sands in Daman formations in well B are over-pressured. The probable explanation given so far is that Daman might have hydraulic connections and is getting charged by the underlying Mahuva formation which is overpressured due to unloading/ fluid expansion (figure 3, 4 & 5). That would mean unloading in Daman as well. But referring to "velocity v/s effective stress" crossplot (figure 5) pore pressure generation due to unloading is not seen in this well, unlike in well A. Therefore another school of thought can be brought which would explain this overpressure by loss of primary porosity. Compaction & Cementation are the two mechanisms whereby primary porosity is lost in sandstones. For further considerations, on the "velocity versus density" crossplot, we can see that along with normal compaction, chemical compaction/clay digenesis in Mahim formation and quartz cementation in Daman have also contributed significantly. It is well known that the digenetic processes have the potential to control on the timing and magnitude of overpressuring. From 25% and up to 80% of the present-day overpressure may be caused by pore volume loss resulting from digenetic reactions.

For quartz cementation, high temperatures (>60^0C) and presence of feldspar are required. Conversion of K-feldspar into Kaolinite or Illite leads to silica release and thus the potential for quartz cementation. These reactions in sandstones may be accompanied by the co-precipitation of carbonate cement.

The quartz cementation process leads to reduction in porosity & permeability of the formation. Loss of permeability eventually forms local seals and inhibits further fluid expulsion with burial. As a result, overpressure builds up in such cases.

The observation made in velocity-density crossplot (figure 7(left)) is also supported by the change in temperature gradient seen against Daman formation, observed during flow line temperature measurements (figure 7(right)), as quartz precipitation rates are likely to increase with increase in temperature. Such a change in temperature gradient has not been observed in other two wells. Also presence of Kaolinite clay in high percentage (90-100%) in nearby wells can be indicative of such a digenetic alteration.

Conclusion

Shales are mostly over-pressured in this area, primarily because of compaction disequilibrium. However the pressure ramp observed at Mahuva top cannot be solely attributed to compaction disequilibrium and some unloading event is also responsible for this rapid pore pressure increase. The various crossplots generated show “fluid expansion” as the reason for such a high formation pressure in this interval (figure-3& 4).

In some part of Mahim formation “clay digenesis/ chemical compaction” (figure-6 & 7) is suspected. This is also supported by the various lab results which confirm the presence of altered clay minerals. Mostly, the sands are at hydrostatic pressures (confirmed with MDT pressures), but reservoirs in bottom part of Daman show hydrocarbon buoyancy effect.

In well B, reason for activity encountered during drilling in Daman can be attributed to quartz cementation in Daman (Figure 7) besides the usual explanation of hydraulic connectivity between overpressured Mahuva formation and Daman formation through some active fault. Change in temperature gradient in Daman formation further corroborates this fact. Although the plausible reason for isolated high temperature zone is yet to be investigated.

Hence, from this study it is evident that log data can be used to understand the generation mechanism(s) of pore pressure to some extent.

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