3D Pore Pressure Prediction using Hybrid Velocity Modelling – Lakwa Area of A&AA Basin

Hymavathi Dharma Surya, Debashis Saha, Anuradha Tiwari, R K Dhasmana*
Oil and Natural Gas Corporation Ltd
Hymavathi_Royyuru@ongc.co.in

Keywords

Overpressure, Effective stress, Compaction Disequilibrium, Normal Compaction Trend, Hydrostatic Gradient, Overburden Gradient, Pore Pressure Gradient, Fracture Gradient, Mineral Transformation.

Summary

Pore pressure prediction is a key factor to reduce risk and ensure safe well engineering by planning wells with proper mud program and casing design in anticipated high overpressure zones and prevent a variety of drilling problems. Proper integration and careful calibration of traditional wireline logs, petrophysical logs, seismic velocity data, vertical seismic profile data and field test data is required in formation pressure analysis. The scope of our work is to derive a 3D pore pressure model in Lakwa area of North Assam shelf where various downhole complications were encountered in drilling thick Kopili formations. During the well data analysis, it was found that a high pressured shale within Kopili formation indicating a pronounced lowering in sonic velocities is consistent in all the wells of the area. The main objective of our study is to identify the causative mechanism of overpressure and to generate a pore pressure model to delineate high pressure locales in the area. This is accomplished by performing a fine grid seismic velocity analysis on inverse NMO corrected PSTM gathers and utilizing velocity to effective stress transforms for deriving 3D pore pressure and fracture gradient volumes. The predictive reliability of the model is determined by a blind test procedure using drilled well and the pore pressure output extracted from 3D volume fairly matches with the drilled results.

Introduction

Pore pressure or formation pressure is the pressure experienced by the pore fluids in pore spaces of subsurface formations. The main mechanisms responsible for generation of overpressures are ineffective volume reduction with increased overburden weight leading to compaction disequilibrium, fluid volume expansion due to mineral transformation, hydrocarbon generation, fluid migration & tectonics.

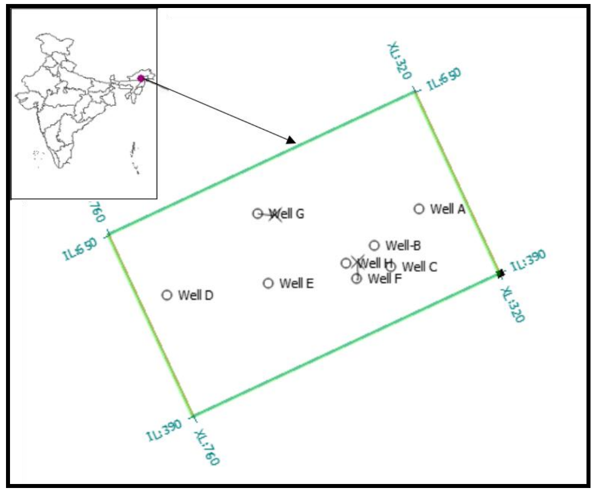

Fig.1 Basemap of study area

The principle mechanisms leading to large magnitude over pressures are found to be due to compaction disequilibrium & fluid volume expansion. Identifying overpressures in drilling is crucial as it narrows the available drilling mud window thereby increasing the possibility of either fracturing the formation or inviting blowouts. Lakwa area falls in North Assam Shelf Block of Assam & Assam Arakan Basin (Fig. 1). The general stratigraphy of Lakwa area is shown in Fig. 2 All the wells drilled through Kopili formation of the area encountered severe downhole complications including caving, held up, tight pull, mud loss & stuck up.

Procedure

The fundamental theory for pore pressure prediction is based on Terzaghi's and Biot's effective stress which states that total vertical stress (Sv) is equal to the sum of the effective vertical stress (**σ_e**) and the formation pore pressure (**P_f**)

$$S_v = \sigma_e + P_f$$

3D pore pressure prediction studies

AGE	FORMATION / SAND	LITHOLOG	GROSS LITHOLOGY
Recent	Alluvium		Poorly consolidated coarse sand with sandy clays and clay.
Pliocene - Pleistocene	Namsang		Dominantly loose medium to fine grained sand with little mottled dominantly red color clay/claystone.
	Nazira Sandstone		Predominantly grey, medium grained sand with minor grey to brownish grey clay and occasionally siltstone, coal.
Miocene - Pliocene	Girujan Clay		Mainly red, brown and greenish grey mottled clay with minor fine grained sand at the bottom.
	Lakwa Sst. TS-1		Dominantly fine to medium grained grey sandstones with minor light grey soft clay/ claystone.
	Lakwa Sst. TS-2		
	Lakwa Sst. TS-3		
	Galeki Sst. LCM+TS4		Dominantly clay/ claystone with occasional sand/ sandstones
	Galeki Sst. TS-5		Intercalation of sand /sandstone with clay /claystone and siltstone.
	Galeki Sst. TS-6		
Oligocene	Barails Rudrasagar (BCS)		Dominantly shale inter-bedded with coal and minor clay stone with Sand and siltstone
	Barails Demulgaon (BMS)		Dominantly fine to medium grained grey sandstones with some inter-bedded clay and shale.
Late Eocene	Kopili		Mainly shale (splintery) alternating with fine grained sandstone and siltstone.
Middle Eocene	Sylhet		Mainly fossiliferous limestone with shales and thin sandstone bands.
Early Eocene	Tura		Dominantly sandstone with minor shales.
Pre - Cambrian	Basement		Leucocratic granite (weathered) with essential minerals e.g. quartz and pink feldspar.

Fig. 2 General stratigraphy of Lakwa area

Shale compaction is generally controlled by difference between total applied stress & pore fluid pressure which is termed as effective stress. Under increasing effective stress, the sediments compact & their density, resistivity & sonic velocity asymptotically decreases depending on the properties of sediment grains. The geophysical signature of rebound is a depth interval in which shale sonic velocity & resistivity undergo larger reversals than bulk density measurements. If high pressures are developed during fluid expansion, it causes unloading resulting in a small amount of elastic rebound along a flatter effective stress path.

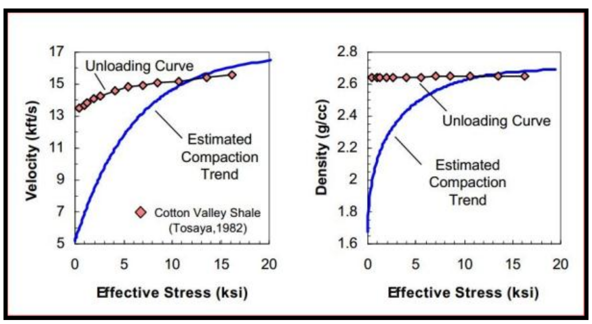

Fig. 3 Typical representation of unloading trend using velocity & effective stress crossplot (Courtesy., Glenn L. Bowers 1995)

Bulk properties like density & porosity depend only on net pore volume while transport properties like velocity & resistivity depends on pore size, geometry & interconnectivity.

One of the effective ways of identifying overpressure generating mechanism is by using cross plot between I) velocity & effective stress (Fig. 3) & II) velocity vs. density cross plotting (Fig. 4). Eaton method is one of the most commonly used techniques which provides a good prediction of pore pressures where compaction disequilibrium is the main overpressure generating mechanism. However, the major drawback of this method is that it underestimates the overpressure effect of secondary overpressure mechanisms. For determining pore pressures in such type of complex overpressure systems, a pore pressure prediction strategy that accounts for unloading phenomenon needs to be implemented.

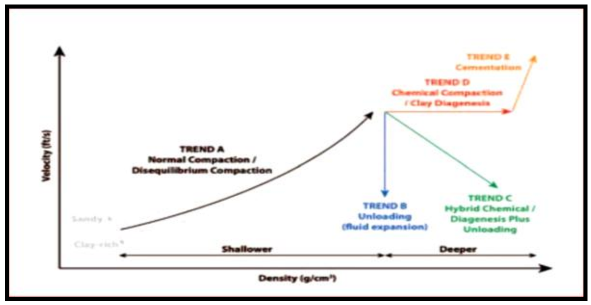

Fig. 4 Typical representation of overpressure mechanisms using Density & velocity crossplot (Courtesy., Hoesni, M.J., et al, 2007)

Pore pressure prediction is a two-step process that involves A) Well based pore pressure calculations from existing wells using the log data & B) Seismic based Pore pressure prediction which involves judicious estimation of seismic velocities which were further related to bulk properties & porosities of rock to obtain required effective stress, pore pressures & overburden pressures.

Well Based pore pressures:

Well based pore pressure calculations is the first step in pore pressure prediction. Using the log data recorded & hard data like MDT & LOT, one could get an idea of drilling related problems like mud-loss, kicks & stuck-ups, formations collapse resulting in cavings.

3D pore pressure prediction studies

Suitable algorithm of pore pressure prediction is deciphered from the cross plots. Thus, the pore pressure algorithm suitable for study area, parameters of Normal compaction Trend & calibration factors for pore pressure & fracture gradient can be finalised in this step.

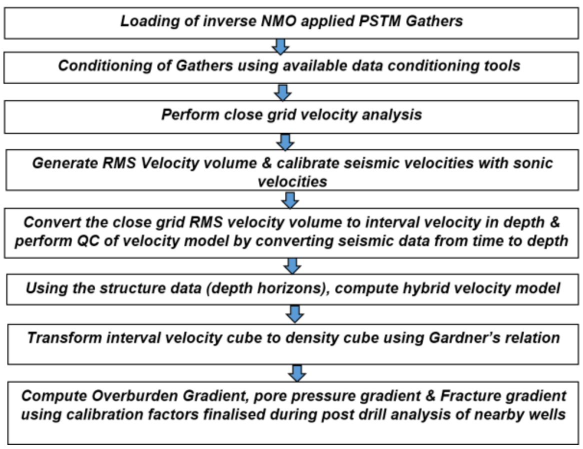

Fig. 5 Workflow for carrying out 3D pore pressure prediction studies

Seismic based pore pressure prediction:

Pre-drill estimates of pore pressure are derived from surface seismic data by estimating seismic velocities and then utilizing velocity-to-effective stress transforms appropriate for a given area combined with an estimated overburden stress.

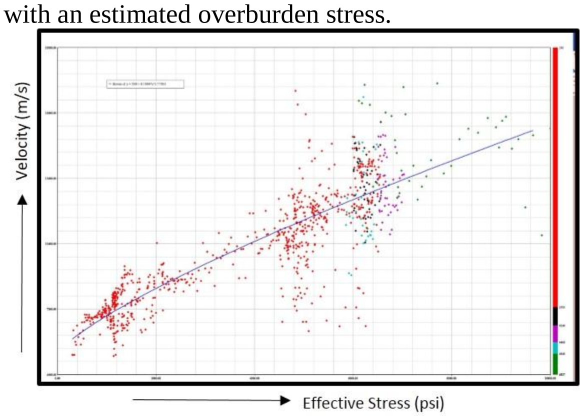

Fig. 6 Crossplot of representative well (Well E) of Lakwa area

So, the accuracy of seismic velocities used are of utmost importance. One of the valuable information that could be derived during processing of 3D seismic data is stacking velocities which are designed to optimize the stack/ migration process.

Pore pressure predictions derived only on the basis of nearby wells or the seismic velocity provided by processing centre may lead to unrealistic/ dramatic results. Local fluctuations frequently are smoothed out, the velocity pick interval is often coarse, making those velocities lack the resolution required for carrying out pore pressure analysis. Therefore, it was judiciously decided to carry out close grid velocity analysis on inverse NMO corrected PSTM gathers. As it is known that the seismic velocities are not always equal to the well velocities (seismic velocities are generally higher than that of the well velocities), it is very essential to derive a scalar to scale the seismic velocities to match with the sonic log velocities. This can be achieved by calibrating picked seismic velocity at gathers corresponding to well location with recorded sonic data.

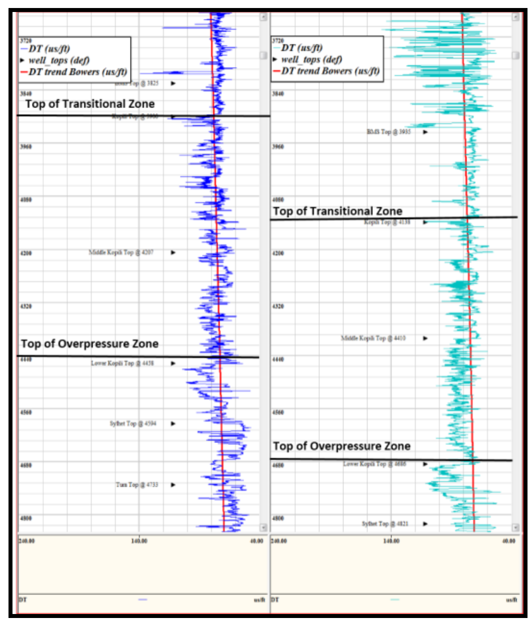

Fig. 7 Overlay of Sonic log & estimated Normal compaction trend depicting high pressure zones of wells A & Well G

Results & Discussions:

Using the velocity & effective stress cross plot in all the deep wells in the area it was found that majority of data points fall in the disequilibrium compaction zone although secondary mechanisms like fluid expansion & clay diagenesis may also play a minor role in overpressure generation as depicted in Fig. 6.

3D pore pressure prediction studies

The sonic, density, gamma ray logs of all the 8 deep wells available in the area (Fig. 5) are analyzed for quality and conditioned to remove erroneous spikes. Bulk density and sonic logs are checked for continuity and also for affected portions with respect to calliper log and lithology. If either sonic or density only is present at an interval, the other one is derived using Gardner's formula. Overburden gradient estimation is computed using composite bulk density. Gamma ray log is used for discriminating shale and sands and sonic log filtered only for shale sections is used for computation. A normal compaction trend (NCT) line is defined on the sonic log on the basis of the shale points.

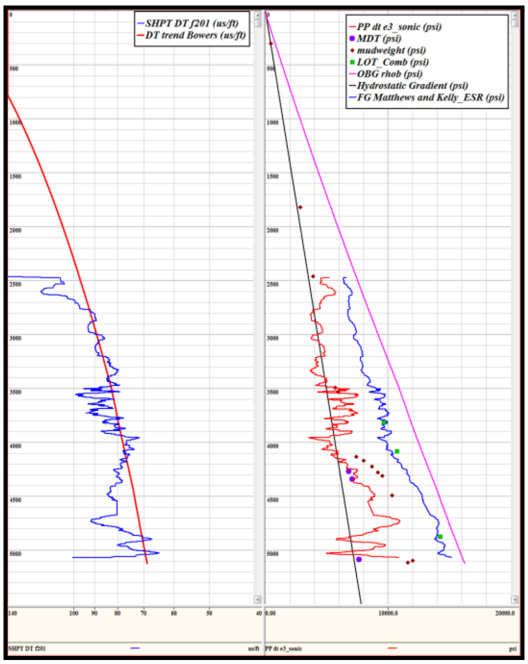

Fig. 8 1D pore pressure prediction results of representative well A

During the well data analysis, it was found that a high pressured shale indicating a pronounced lowering in sonic velocities in lower part of the Kopili formation (Fig. 7) is consistent in all the wells of the area. The sonic travel time (DT) of normally pressured shale fall on the NCT while that of the overpressure shale deviates from it. The depth of departure of DT from the NCT is considered as the top of overpressure. 1D pore pressures were predicted using log data, the parameters of Normal compaction trend are finalised using the Bower's algorithm.

Pore pressure gradient was calculated using Eaton's method for all the wells available in the area. The derived pore pressure gradient are calibrated with available MDT data & the fracture gradient is calibrated using the available LOT data (Fig. 8). Thus, the parameters of Normal Compaction trend, pore pressure gradient & Fracture Gradient are finalised during post drill analysis of nearby wells.

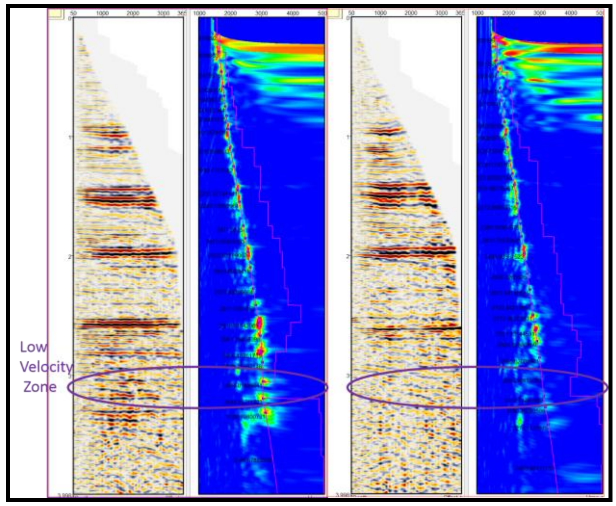

Fig. 9 Representative gathers depicting lowering in velocities

For velocity model building, the CMP gathers are first conditioned & Super gathers are formed to improve the signal to noise ratio by attenuating the random noise. Appropriate Automatic Gain Control (AGC) is applied to enhance the signal at deeper level, thereby providing a reasonably good semblance for velocity picking.

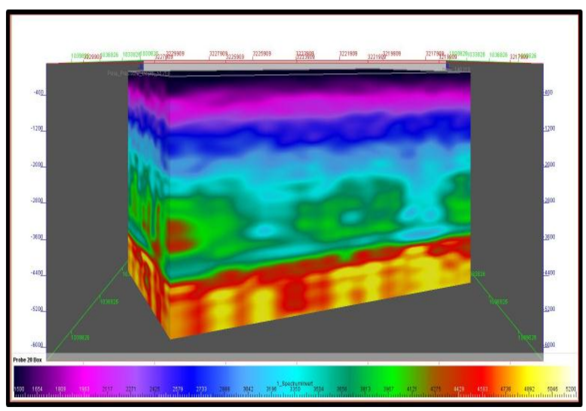

Fig. 10 Interval velocity volume derived using fine grid velocity analysis

3D pore pressure prediction studies

The velocity analysis parameters are also tuned to enhance the quality and standard of the semblance. During velocity analysis, it was observed that a pronounced lowering of velocities is evident in most of the gathers which corresponds to Kopili sequences followed by increase in velocity at top of Sylhet (Fig. 9). The seismic velocities are calibrated with sonic velocities & necessary calibration factor is derived and applied to the RMS velocity volume.

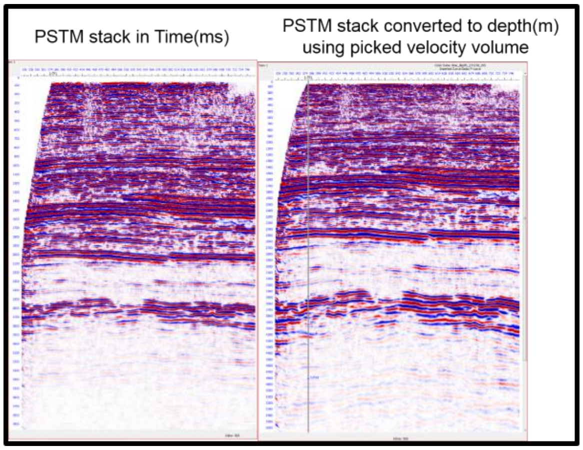

Fig. 11 PSTM stack converted from time to depth using interval velocity

The calibrated RMS velocity is converted to interval velocity in depth (Fig. 10). Using the interval velocity model, time migrated stack data is converted to depth (Fig. 11)

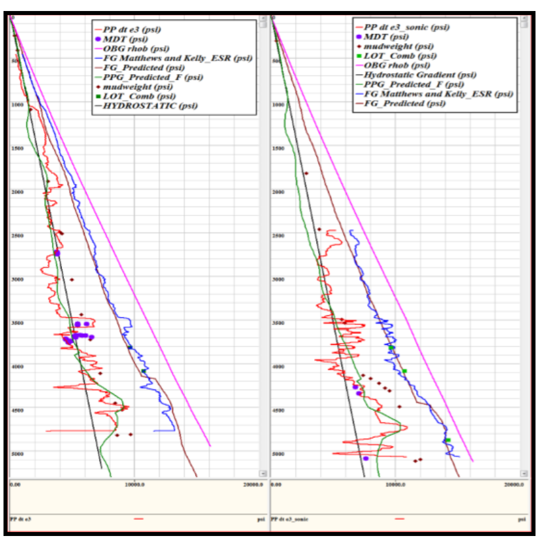

Fig.12 Overlay of well based & model derived pore pressure & fracture gradient

Using the workflow of 3D pore pressure prediction, (Fig 5), interval velocity volume is taken as input & Density, Overburden, Pore pressure & Fracture gradient volumes are generated (Fig. 13) utilizing the parameters finalized during post drill analysis of nearby wells. The predictive reliability of model is determined by a blind test procedure & the pore pressures extracted from 3D model fairly matches with the 1D pressures (Fig. 12).

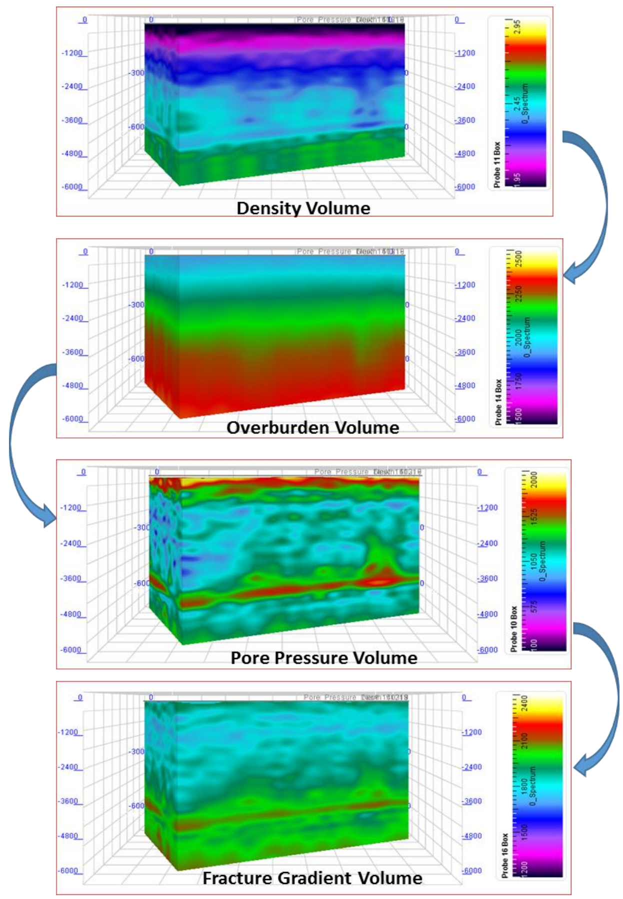

Fig. 13 Density, Overburden, Pore pressure & Fracture Gradient volumes derived from interval velocity model

From the 3D pore pressure analysis, it was found that the top of Kopili formation acts as transitional zone & shale dominant lower Kopili section acts as high pressure zone. In lower Kopili formation where dominantly shale were deposited in bathymetry of 10-20m, enhanced sediment influx of finer clastics in the shelf is evident in response to collision of Indian lithospheric plate during late Eocene.

The clastics, deposited during late Eocene preserves porosity & pore-fluids in shales resulting in under-compaction & generation of overpressures. A marked decrease in sonic velocity, or increase in sonic transit time as observed within Kopili formations, has conventionally been attributed to overpressure. This is evident from the pore pressure slices generated along horizons corresponding to Kopili, Middle Kopili & Lower Kopili (Fig. 14).

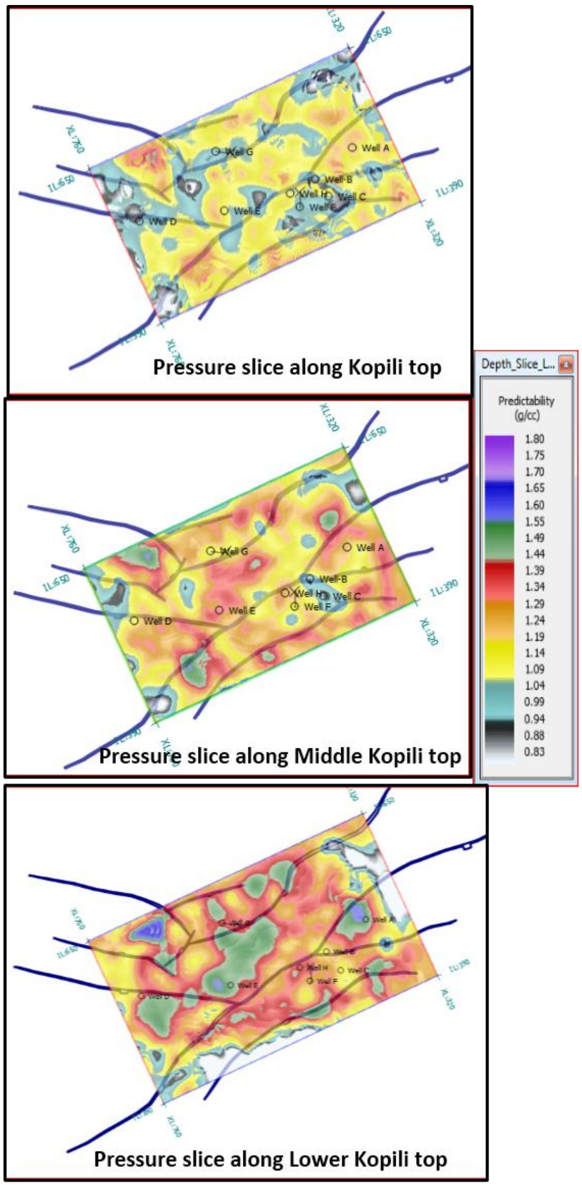

Fig. 14 Pore pressure slices generated along horizons corresponding to Kopili top, middle Kopili top & lower Kopili top

Conclusions:

A sophisticated approach utilizing hybrid velocity model integrated with structural framework has been adopted for 3D pore pressure prediction studies to delineate the high pressure locales of the area. The predictive reliability of model is determined by a blind test procedure & the pore pressures extracted from 3D model fairly matches with the 1D pressures. The predicted pore pressure & Fracture Gradient values suggests a higher mud window for preventing downhole complications in Kopili formation. As high pressure Kopili formation is underlain by Sylhet limestone & Tura formation which is a good reservoir, proper casing plan needs to be adopted for differentiating these zones.

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