An MS Excel based approach to estimate the subsidence in Olpad Formation over Sanand Structure, Cambay Basin using Decompaction Process

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Sanand; Olpad; Decompaction; Subsidence; Drape Structure

Summary

The Sanand Field is located on the crest of Sanand Structure that trends roughly in NS direction and is known for accumulation of oil and gas in Kalol, Cambay Shale, and Olpad Formations. The field is present in the prolific Ahemdabad-Mehsana Tectonic Block. In the Sanand Area, deltaic sands in Kalol Formation of Eocene Age are main producer.

Sanand Structure evolved during Paleocene due to fault block tectonics related to rifting. As rifting continued, the size of structure grew with faulting; grabens formed were filled with syn-rift sedimentation. Kalol Formation was deposited post cessation of rift activity. It is likely that drape structure at Kalol level was formed due to differential compaction with underlying basement rock and Deccan Trap remained uncompact being more competent.

This study aims to understand the evolution of drape structure at Kalol Level formed by the process of differential compaction by estimating the subsidence in Olpad Formation.

The study well Sanand-78, drilled on a low present to the west of Sanand High, has encountered sufficient thickness of Olpad Formation. In an MS Excel base utility, the decompacted thickness was obtained using an iterative method based on the relationship on porosity with sediment burial depth. The decompacted thickness derived from the iteration is significantly higher than the compacted thickness, which implies that due to overburden the lower lying strata was compacted and this compaction caused the subsidence. Subsequently, a drape structure at Kalol Level was formed due to differential compaction. This study shows that the compaction of Olpad alone caused ~350m of subsidence.

Introduction

Cambay Basin located in the northwestern margin of the Indian Peninsula is an intra-cratonic rift graben between Saurashtra Uplift and Aravali Ranges. It extends in a roughly N-S alignment, as a long and narrow depression from North Gujarat to Gulf of Cambay.

Cambay Basin is further traversed by a number of transverse faults trending roughly E-W, which have divided the basin into five tectonic blocks. From north to south, they are Patan-Sanchor, Ahmedabad-Mehsana, Cambay-Tarapur, Jambusar-Broach and Narmada Blocks forming a number of uplifts and depressions within the basin.

The Sanand Field lies in the highly petroliferous Ahmedabad-Mehsana Tectonic Block of the Cambay Basin, which contains a number of oil and gas fields.

Deltaic sands of the Kalol Formation constitute the main reservoir rocks in the Ahmedabad-Mehsana Tectonic Block of the North Cambay Basin. Kalol Sands and Silts are the important reservoir rocks in most of the nearby oil fields, e.g., Kalol, Ahmedabad, Nandej, Wasana, Nawagam and many other smaller fields.

In Cambay Basin, the nuclei of most of the structures were formed during Paleocene as a result of faultblock tectonics (Mathur et al, 1968). The growth of the structures continued with repetitive fault movements and after fault activity ceased, drape structures formed by the process of differential compaction (Bhandari et al 1975).

Details of the Study Area

The study area (Figure. 1) covers the flanks of main Sanand Structure with major part of area covered by two lows present to east and west of main Sanand High as depicted by the time structure map at Kalol Level (Figure.2).

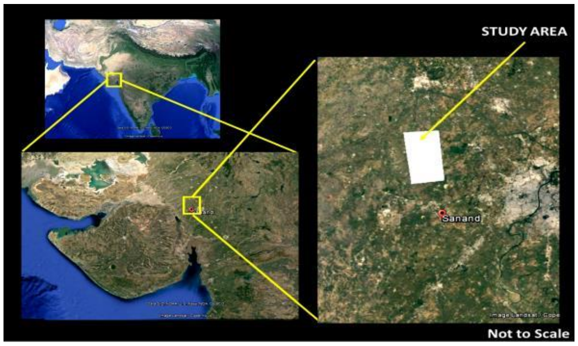

Figure.1: Study Area

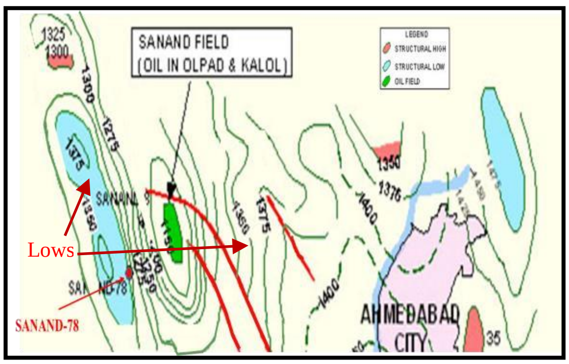

Figure.2: Sanand High as depicted by the Map at Kalol Level Time Structure

Available 3D seismic data covering the study area is of moderate to fair quality and has been utilized to interpret the Sanand Structure on seismic sections. The E-W section thru the area (Figure.3) shows a low present in the west however gives no distinct picture about the low present to the east.

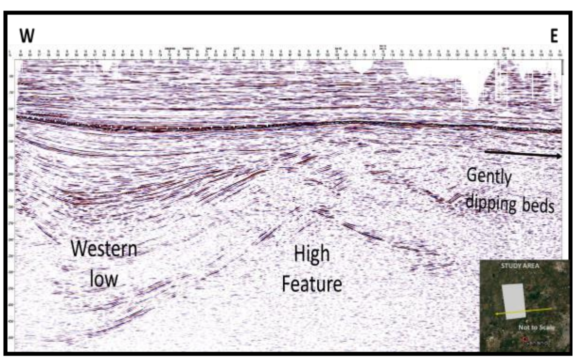

Figure.3: E-W section thru Sanand High Structure

However, the character of beds visible at shallower levels shows likely presence of a relatively wide low to the east of Sanand High.

No well in this area has penetrated Deccan Trap with few wells truncating within Olpad Formation. In lack of a Time-Depth relationship up to Deccan Trap, the last correlatable reflector is considered as the Deccan Trap Top (Figure.4a) and it is assumed that this reflector follows Basement's Relief.

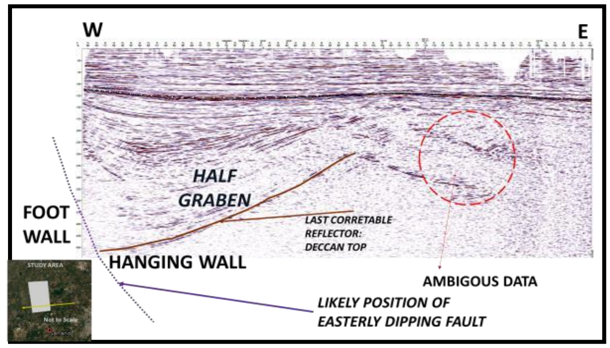

Figure.4a: EW section thru southern part of study area depicting last correletable reflector and half graben geometry

Data quality is ambiguous in the eastern part so a clear-cut 'last visible reflector' could not be recognized in the eastern part. The character of beds in the western low suggests a half-graben geometry with easterly dipping faults as shown in figures. 4a & b.

Basis these observations, the hanging wall block shown in figures. 4a & 4b on 3D seismic data, is interpreted as Sanand Structure formed by the rifting.

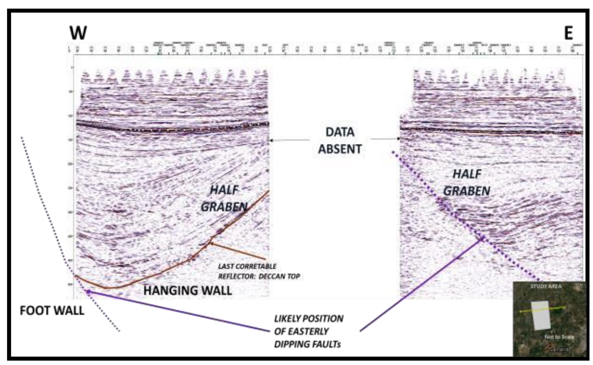

Figure.4b: EW section thru northern part of study area depicting last correletable reflector and half graben geometry

The rifting in Cambay Basin ceased at the end of Paleocene during the deposition of Cambay Shale Formation. Kalol Formation got deposited in post rift phase during Mid-Eocene. The syn-rift and post rift package are identified on seismic based on the time thickness of various sequences as shown in Figure.5.

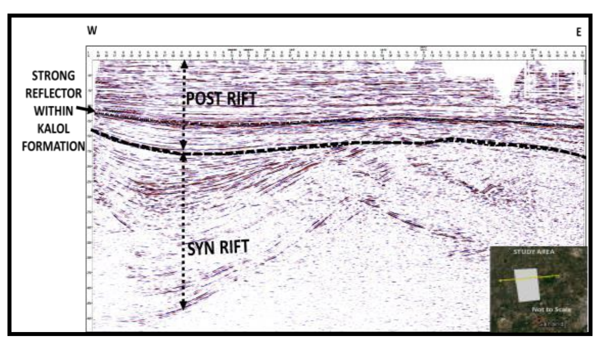

Figure.5: Syn rift and post rift package as identified on seismic

The strong reflector within Kalol Formation shows a subtle low in the western part of block and gently dipping beds on the eastern part forming a high feature in between. It is likely that the area might have attained peneplanation during deposition of post rift sequences and the high feature present was a result of a subsequent phenomenon.

Well Sanand-78, present in the western low (Figure.2) has encountered a total thickness of 1279m in Olpad Formation (Figure. 6a). The well has encountered slight thickness of Older & Younger Cambay Shale Formation(OCS/YCS) therefore the decompaction process approach couldn't be used for Cambay Shale Formation. The density log (Figure. 6b) recorded in well shows a gradual increase in density in Olpad with depth whereas no major change in lithology is reported. One inference derived from this conclusion is that the increase in density may be due to subsequent loss of porosity (density-porosity relation) which was caused by the compaction due to overloading of sediments.

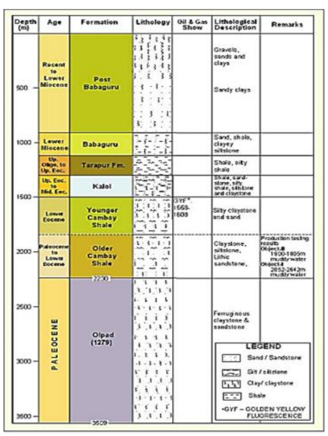

Figure.6a: Sanand-78 well litho- column

Methodology

An attempt has been made in this study to obtain the decompacted (original) thickness of Olpad Formation at the end of its deposition.

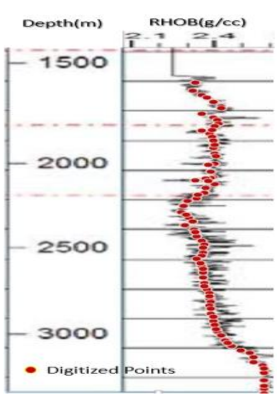

Figure.6b: Density Log thru Olpad section in well Sanand-78

Following equations governs the relations of porosity-depth and density-porosity (Allen & Allen):

$$\Phi = \Phi_o e^{-cy} \quad \text{..(1)}$$

$$\rho_b = \rho_m * (1-\Phi) + \rho_f * \Phi \quad \text{....................................(2)}$$

Where,

Φ = porosity at a given depth

Φ_o = initial porosity

C = constant

Y = depth in meters

ρ_b = bulk density

ρ_m =matrix density

ρ_f = fluid density

Density log in well Sanand-78 is not available in digital format, therefore the log has been scanned and digitized. The digitation is done taking the average values on log in order to remove the effects of spikes some of which might be present due to poor hole condition.

Subsequently porosity is derived using Eqn. 2. ρf value is taken as 1 gm/cc considering the formation to be water filled. Since the Olpad Formation consist of clay and sandstone, a range of value for ρm between 2.4-2.8 gm/cc is possible at different depth. Different values of ρm is used and the value at which maximum number of Φ values are positive is chosen to derive the Φ log from bulk density.

Φ_o and constant 'C' are derived by plotting the porosity log on a semi-log scale(Figure.7). The slope and intercept values of the best-fit line on data are the values of Φ_o and C.

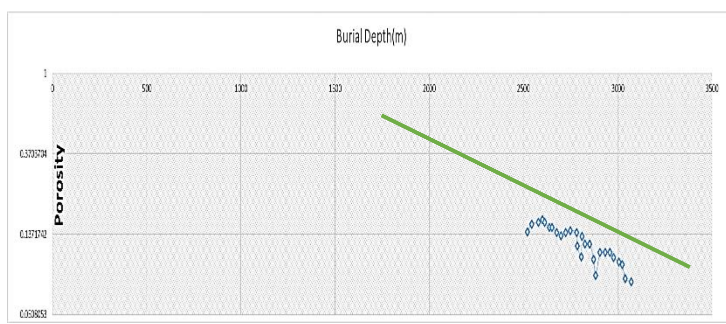

Figure.7: Porosity vs. Depth plot on a semi-log scale

In order to derive the decompacted thickness, a MS Excel based utility is used (Basin Analysis with a Spreadsheet, Theodore Lloyd Larrieu 1995). The process of decompaction is explained in Figure. 8.

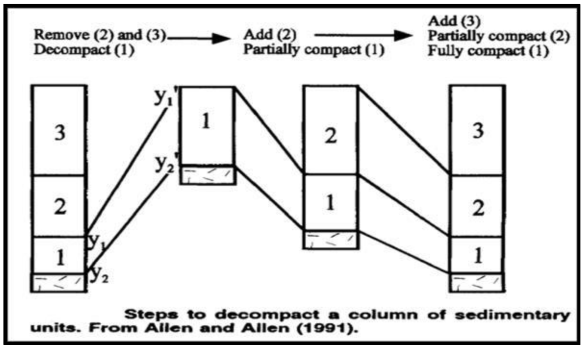

Figure.8: Decompaction Process (After Allen & Allen)

Eqn.1 is derived for a rock layer and can be written as (details of derivation are present in textbook, Basin Analysis: Principle and Application, Allen & Allen),

$$0 = y2–y1-(\Phi_o/C)(\exp(-cy1)–\exp(-cy2))+(\Phi_o/C)(\exp(cy2') -\exp(–cy1'))-y2'+y1' \quad \ldots\ldots\ldots\ldots(3)$$

Eqn. 3 is solved for y2', where y2' and y1' are the bottom and top burial depths (Figure. 8) of a unit at a given time interval, y2 and y1 are present-day lower and upper-burial depths , Φ_o is the initial porosity of the unit, and constant C is the compaction coefficient of the unit.

Eqn. 3 however does not have an algebraic solution; its solution must be approximated using a numerical technique such as Newton's Method. With an initial guess of y2' in one spreadsheet cell, and Eqn.3 in another cell, equation solver in MS Excel (Figure. 9) can be invoked to iteratively find a solution to Eqn. 3.

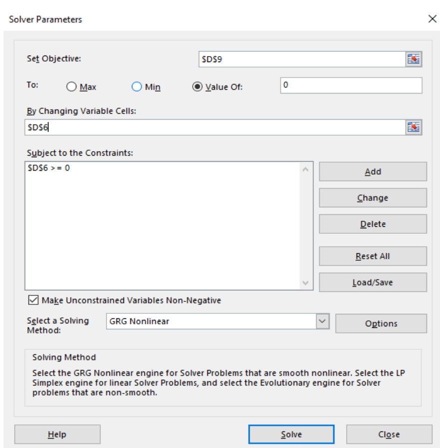

Figure.9: MS Excel equation solver

Results

Following table shows the iteration results for Olpad Formation at well Sanand-78:

	A	B	C	D		
1	Formation	y1	y2	thickness	c	Φ_o
2	Olpad	2230m	3509m	1279m	0.0001	0.534
3						(eqn. was solved for y2' iteratively using excel solver such that the value in cell *D9 = 0*)
4		Age	Olpad	OCS		value of y1' is 0
5		OCS		0		
6		Olpad	0	*1518.22m*	*y2'*	
7		Age	Olpad	OCS		
8		OCS				
9		Olpad		*-4.97E-04*		

Table.1: Iteration results for Olpad Formation at well Sanand-78

The results show that the decompacted thickness of Olpad Formation is 1518.22m against the thickness encountered in the well that is 1279m. This gives an indication that the due to overburden the lower lying strata was compacted and this compaction caused the subsidence. The estimate shows that compaction of Olpad alone caused ~350m of subsidence.

This compaction throughout the strata could not be uniform as the more competent rock (Deccan Trap) lying beneath will suffer negligible compaction. Therefore, a differential compaction has taken place, which has caused the formation of a drape structure at Kalol Level above the main Sanand Structure.

Conclusions

- Sanand structure evolved during Paleocene due to fault block tectonics related to rifting. As rifting continued, the size of structure grew with faulting.
- After the cessation of fault activity, the compaction of sediments of Olpad and Cambay Shale Formations caused the subsidence.
- Subsequently drape structure at Kalol Level was formed because of differential compaction with underlying basement rock and Deccan Trap remained uncompact due to overburden.
- The decompacted thickness of Olpad Formation derived by iterative process is 1518.22m against the original thickness encountered in the well, which is 1279m i.e. the compaction of Olpad alone caused ~350m of subsidence.

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