

Application of Alpha mapping (α -mapping) of SP well-log Image, to obtain lithology and Correlate to evaluate the Reserves of Shan4 Depression of Shahejie formation China

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Abstract: Deducing geological parameters using SP curves is a very tedious, expensive, and error prone process such as obtaining formation water resistivity and the measurement of small negligible voltage potentials, mud filtrate resistivity and shale volume. This is due to the fact that there are many complex dependent variables surrounding data acquisition using Statistical method of data collection in an SP log image, these variables includes: borehole invasion, shale content, Bed resistivity and the ratio of salt water mud (R_{mf}) and fresh water mud (R_w). We have used Alpha (α) mapping method of SP-Log considering the shale content of the formation and the maximum possible deflection of Sp that a thick shale free porous and permeable formation can have at a given ratio of R_{mf} and R_w to obtain the lithology of Shan4 depression as well as limit error to the bearest minimum at a low cost of acquiring the petrophysical parameters. Based on the Structure map Shan4 depression in shahejie formation is composed of a complex depositional system of a prograded elongated delta, beach and bar formed under lower current energy of a shore-shallow lake. Hydrocarbon trap is created by an anticline pool separated by numerous oil layered complex faults, Oil and seeps in the depression are found in Tertiary sandstone reservoirs as well as underlying basement located at an approximate depth of 2020m below sea level (-2020m), including the Jurassic sandstone reservoirs and the carboniferous –Permian and Ordovician weathered zone.

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1. Introduction

An oil or gas prospect is developed by extensive and very expensive studies of regional geology, including subsurface geology and geophysics. Tile exploratory wells may cost several millions dollars to drill. It would be foolish to risk the loss of a prospect as a result of ignorance or carelessness on the part of the driller, the engineer, or the well-site geologist. Spontaneous potential (SP) is one of the earliest logs used and still in use the first was run in 1927 Spontaneous log records the electric potential set up between two electrodes in a sonde drawn up the borehole and fixed electrode at the earth's surface (Richard 1998), it is mostly used for the determination of lithology of a formation, to obtain a region that can be categorized as a reservoir and non reservoir. It is also mostly used in correlation, this article has grossly explored this advantage, the raw data (logs Image) are combined in a detail interpretation to obtain values of geological parameters.

The first commercial oil discovery was made in early 1960s. Since 1984 (S.Zhang et al 2004). Shan4 depression in shahejie formation is composed of a complex depositional system of a prograded elongated delta, beach and bar formed under lower current energy of a shore-shallow lake. Hydrocarbon trap is created by an anticline pool separated by numerous oil layered complex faults. No.1 fault.

Formation water geochemistry and overpressure transference also signify that the No. 1 fault was the main hydrocarbon migration pathway. Besides the long-term growth fault, early and late active faults also affect hydrocarbon migration and accumulation. The formation of the Shahejie oil pool is characterized as an autochthonous, hydrocarbon migration model controlled by overpressures, (C. Zhang et al., 2006). Source rocks of Shan4 are deep-water lacustrine shale of Eocene and Oligocene age that are draped over the buried hills. The secondary member is made up of sandstone, lithology for reservoir is silt-fine sandstone. It is up to 25%~30% for the porosity, and it is generally less than 120 mD for permeability of sandstone. It is about 10-15% for shale content. The thickness of the secondary member of the Shahejie Formation is approximately 1,000m in each sub-basin and its total organic carbon (TOC) values range from about 1 to 4.5. Oil-source rock correlations clearly demonstrate that oil in the buried hills was derived from adjoining lacustrine shale and mudstone (USGS 2000), its contact of oil and water is approximately located on 2160m in depth. The best reservoir rocks are shallow marine dolomite and limestone beds of Proterozoic, Cambrian, and Ordovician age that have been exposed to long periods of sub aerial weathering, erosion, and karst processes. Solution-enlarged fractures, vugs, and cavities are common features in

the better reservoirs. These dolomite and limestone reservoirs occupy the Proterozoic Wumishan Formation and numerous formations of Cambrian and Ordovician age. Local reservoirs consist of Archean crystalline basement, Proterozoic/lower Paleozoic sandstone beds, and Mesozoic volcanic rock and sandstone. The lower members consist of red mudstone interbedded with thin sandstones. There exist a localized unconformity at the top of the lower part of the member above which there is a bluish-grey mudstones siltone and sandstone with gypsum and halite horizons, near the top of the member there are also carbonates and oil shales. This member is typically 350-950m thick with the thickness in the northern part of Dongying Sag. (M.B. Allen et al., 1997).

Existing geophysics exploration methods (magnetic, gravity, seismic and electromagnetic) are based on the geophysical properties of the subsurface. However, these methods are limited in scope since each one of them is only applicable to one of these properties at a time. For example the seismic method is related to the thickness and density of a substance since it deals with the velocity of waves in a given material (S. Morris Cooper et al 2010), while well-log is all encompassing, it depends on the lithology of the formation, this paper hopes to describe the reservoir formed in shahejie formation by using hand correlation of the well-log on Corel draw software to obtain the data in the various wells as well as using a simple software surfer to create the grid based maps. We shall use the surfer software to create the sandstone thickness map, structure map, and the Oil saturation Map of the formation, the aim of this paper is to create a simple model of the overall architecture of the formation which will help predictions of the structure, stratigraphy and hydrocarbon potential of the formation.

2. Study Area

Shan4 depression is located within the giant Shengli petroleum province in east China, the source rock in the basin is mainly the lower part of the third member (E_s3) of the Eocene portion of the Shahejie Formation with other sags (smaller sub-basin) around it. Most basins in this formation lie in the Eocene portion except Bozhong sub-basin as narrated by F. Hao et al., (2009). The Shahejie Formation is subdivided into four members ; they are the first member (E_s1) , the second member E_s2 , the third member E_s3 , and the fourth member E_s4 from the upper to the lower . Delta , beach bar, and braided fan sediments develop in E_s4 member . The provenance comes from the northern , southwestern , and southern uplifts . The lithologic

associations are mainly siltstone , fine sandstone and medium sandstone (Zhang 2008). Tertiary anticline demarcated by faults formed the major hydrocarbon source and reservoir rocks, more reservoir rocks occur in the footwall crest of tertiary faults blocks. Existing descriptions of Shahejie formation tend to account for its structure in one of two ways: (1) orthogonal extension, creating NNE trending normal faults as the result of ESE-WSW extension (Hu Jianyi et al.,1989); (2) as a dextral pull-apart structure created at the fault-overstep of Tianhang Shan and Tan-Lu(Tan-cheng-Lujiang) faults systems at the western and eastern margins of the formation. Shahejie formation was deposited across a wide area of the Bohai Basin and for the first time in the Cenozoic, significant thickness of sediment accumulated in the Bozhong Depression and the northern part of the Huanghua, the formation reaches thickness over 3000m . (M.B. Allen et al., 1997). The main minerals are quartz, feldspar, and cuttings. Among these, quartz accounts for 25%–35%, averagely 26%; cutting 30%–45%, averagely 39%; feldspar 20%–45%, averagely 35%. Fillings are mainly calcite and clay. Generally, carbonate cement content is below 10%, locally up to 30%; and clay content is mostly between 3%–8%, highest up to 25% (ZHANG Wen-cai et al., 2008). The well location (geodetic coordinates) of 22 wells has been considered for this paper (figure 1).

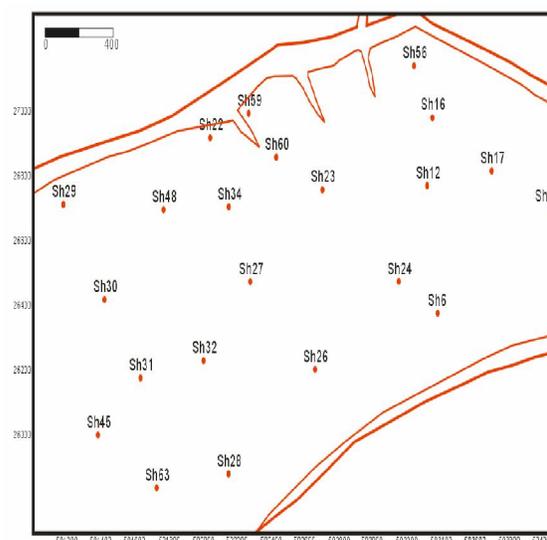


Figure 1: Base map of Study Area

3.0 Lithology of the formation interpreted by -mapping of SP Well-logs

A well log is a record of formation characteristics made by a tool as it rises in a wellbore. They provide a means to evaluate certain formation parameters and the hydrocarbon production potential

of a reservoir. The principal geological application of logs has been known to be used for the understanding and description of the subsurface stratigraphy and correlation. The SP log is a measurement of the natural potential differences or self potentials between an electrode in the borehole and a reference electrode at the surface. The response of the SP curve in front of fractured zones may exhibit either erratic behavior or a more systematic negative deflection due to a streaming potential (the flow of mud filtrate ions into the formation), however, streaming potentials can also occur near silt beds (Crary et al., 1987).

The method presented here takes advantage of shale content in the formation and the static Spontaneous Potential (SSP) curve, the maximum possible deflection of Sp that a thick shale free porous and permeable formation can have at a given ratio of R_{mf} and R_w . Here Alpha (α) mapping method of SP-Log was employed to limits the error to the lowest minimum.

Both the SP and Gamma Ray log can be used to map “clean” sediments, which generally have higher permeability and porosity, the SP response is depressed by shale, thin beds and hydrocarbons. SP alpha mapping is be used to determine clean zones (shale free), assuming a lower response is produced only by shale.

The first step is to compute the Static SP (SSP), which is the ideal SP response for clean, thick rocks, using the expression below:

$$SSP = (0.133 * T_f + 60) \log \left(\frac{R_{mf}}{R_w} \right)$$

Then we Pick the shale cutoff ($\alpha = 0\%$) of the SSP (can drift over long distances, of little consequences for single formations) and draw a line on the log then obtain two alpha values at $\alpha = 75\%$ and $\alpha = 50\%$ taken with relative to the shale base line (as shown in Figure 2 above), permeable zones are indicated where there is a deflection from the shale base line (this don't necessarily means that where there is no deflection are impermeable) (USGS 2000).

4.0 Well log correlation Using Corel Draw

Well correlation is used to establish and visualize the lateral Extent and the variation of reservoir parameters. In carrying out a correlation we subdivide the objective sequence into lithologic units and follow those units or their generic equivalent laterally through the area of interest. The scarcity of digital data, at a point of necessity poses a major threat to the application of computer methods for regional or field wide correlation. Previous methods

of automated correlation could handle very simple relative vertical displacement but often had limited success in accommodating missing sections and differential stretch of correlative intervals between wells, these features results from a normal geological history that includes multiple regime of erosion and non-deposition, which hamper periods of continuous varying rates of sedimentation (John et al.,1992). This papers hopes to take into cognizance the existence of these gaps and stretch problems, and thereby solving it by Alpha mapping of SP log by hand correlation. Though manual correlation is labor intensive, it gives a hope to the poor countries like Africa where geologist lack the funds to obtain the very expensive software program such as Petrel by Schlumberger, this make it very difficult for this geologist to study the petrophysics of the subsurface of their wildcat. This paper hopes to present the use of very common software in our desktop. Corel draw is graphic software we utilize for the purpose of correlation considering the lithology obtained from the α -mapping of SP well-logs.

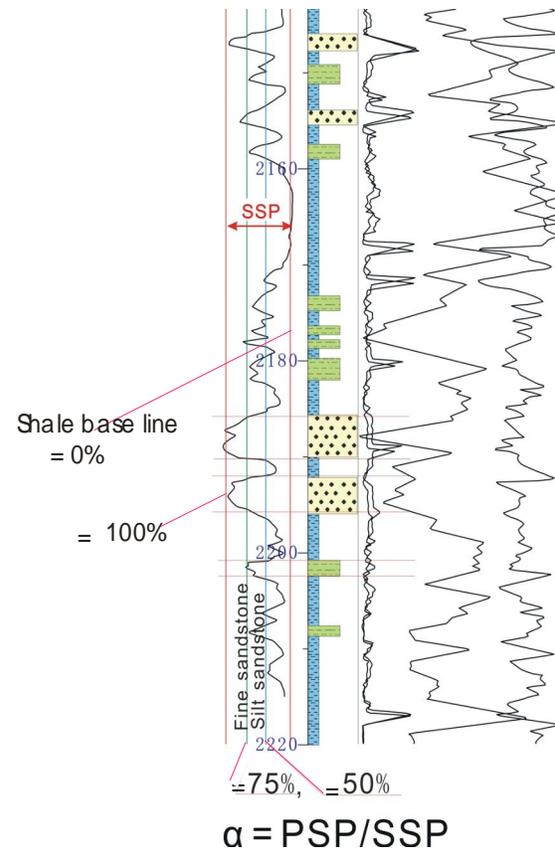


Figure2: Interpretation Techniques of α -mapping of SP Well-logs

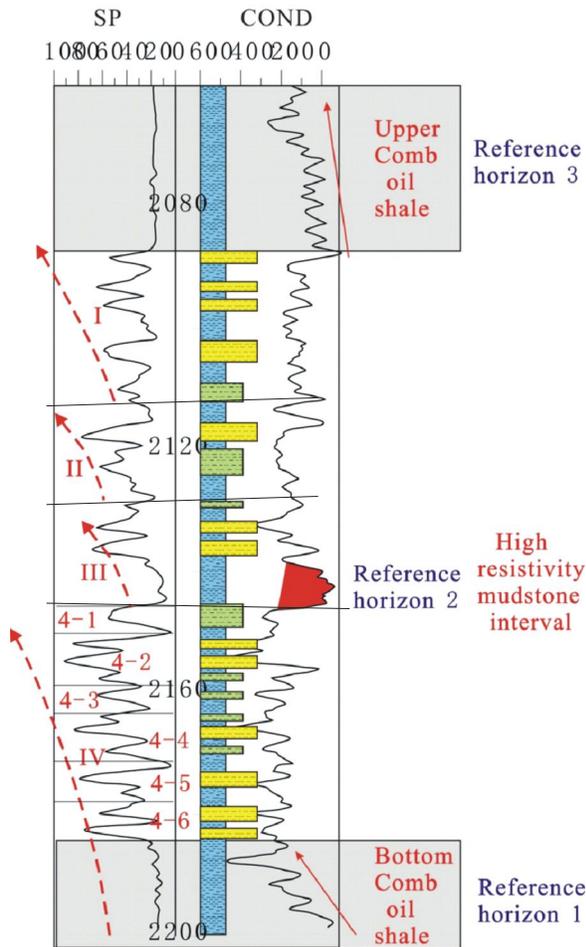


Figure 3: Well-log Profile showing division of the fourth package into six para-sequence

Correlation was done from near to far in the light of net sections, To start the correlation process we take the set of logs and select a datum plane (by comparing the log response. This is a marker which can be traced through all data points. A good datum plane would be a continuous shale because we assumed that it represents a “flooding surface” present over a wide area. Since shales are low energy deposits we may also assume that they have been deposited mostly horizontally, blanketing the underlying sediments thus “creating” a true datum plane, to align all logs at the datum plane this becomes a straight horizontal line. Note that by doing so we ignore all structural movements to which the sequence has been exposed (Figure 4). Six sections were chosen to form cross section net, the marks and cycle was determined. Six cycles with the scale of Para-sequence set and three marks was determined in the area. The six cycles constitute six sand packages

(from up to down it is the I/II/III/IV /V/VI for the code of four sand packages (figure 3). This is standard well for well of Sh29, Sh28, Sh34 and Sh12, Sh24, Sh11 the zonation has been done, it is important to divide packages 3 and 4 into six cycles with the scale of the para-sequence, though this paper will be limited to the fourth package and the first Para-sequence (figure 4), it is recommended that more research should be done on the other packages.

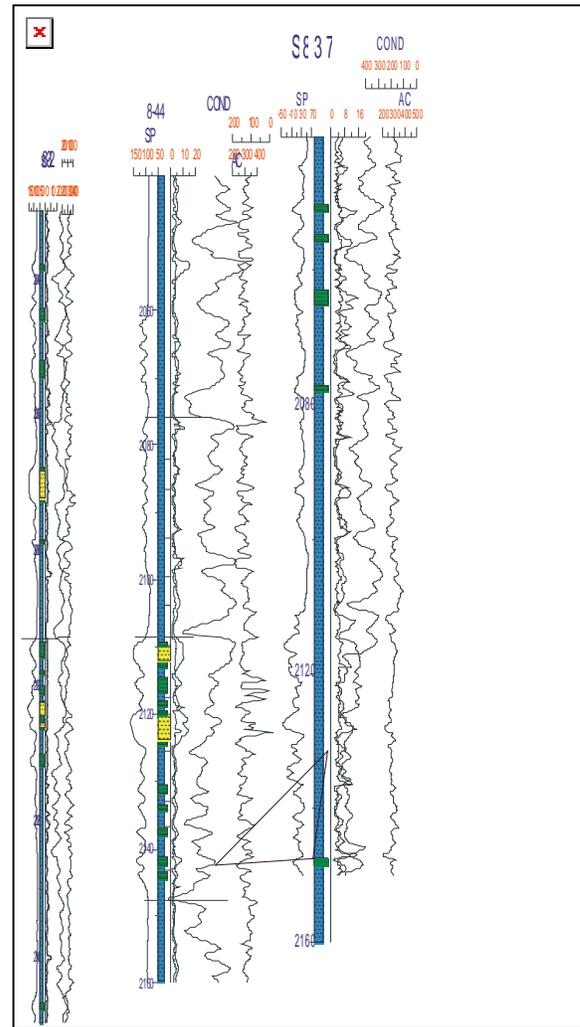


Figure 4: Correlated section

5.0 Parameter interpreted by logging

In the old days the calculation of R_w and S_w , Φ were made using company chart book and a calculator. Today, however, computer-processed interpretations, which give continuous readings of lithology, porosity and the percentages of various fluids. Although computer output looks very convincing the idea of baggage in baggage out should not be taken for granted. Here we take into consideration few petrophysical parameters, with

logs together with conventional logs it is possible to calculate essential reservoir parameters as well as identify and understand diagenetic phenomena within reservoirs, as researcher's belief that formation evaluation is now entering its third age, (Richard 1998). Reservoir management strategies are as realistic as the "image" of spatial distribution of rock properties. Permeability is the most difficult property to determine and predict, many investigators have attempted to capture the complexity of permeability function in models with general applicability. Empirical models are based on the correlation between permeability, porosity, and irreducible water saturation (Shahab 1997). The Parameters interpreted by logging includes:

- The top elevation of the fourth package and the first Para-sequence sandstone (datum elevation) = (Kelly bushing + surface elevation) – the depth of 4-1 sandstone.
- Sandstone thickness = bottom depth – top depth the fourth package and the first Para-sequence sandstone.
- Porosity, permeability, oil saturation determine by (Archie equation) and electric facies of the fourth package and the first Para-sequence sandstone was calculated by logging data which was read out from well profile.

Oil saturation was computed using the popular Archie equation of water saturation (S_w), then Oil saturation (S_o) = 1- S_w

$$S_w = \left(\frac{a * b * R_w}{\Phi^m * R_T} \right)^{\frac{1}{n}}$$

Where

a - tortuosity factor, a = 1;

b - lithologic factor, b = 1.

m - cementation exponent, m = 2;

n - saturation exponent, n = 2;

R_w - resistivity of formation water = 1.98

Porosity was obtained from the expression:

$$\Phi = 13.978 + 0.02632 AC$$

Where AC is the Acoustic log reading for a particular well

Permeability was obtained by the expression:

$$\ln K = 4.174 - 0.44 \ln \Phi + 0.125 \Phi$$

(USGS 2000).

In general, reservoirs in the deep horizons in Shan4 depression consist of medium-porosity Medium-permeability sandstones. The porosity is generally between 3%–22%, and the permeability is mostly between 0.1×10^{-3} – $250 \times 10^{-3} \mu m^2$. Nevertheless, in some intervals in the deep horizon sandstone, there are well developed reservoirs. For example, the porosity of well Sh16 in the interval from 2115 m to 2130 m is an average of 21%, and the highest permeability is up to $250 \times 10^{-3} \mu m^2$.

6.0 Contour map

Surfer is particularly utilized to create structure maps, Surfer is a software used to create a grid based map, the Kriging gridding method was considered, Kriging is a geostatistical gridding method that has proven useful and popular in many fields. This method produces visually appealing maps from irregularly spaced data. Kriging is a very flexible gridding method can be custom-fit to a data set by specifying the appropriate [variogram](#) model. Within Surfer, Kriging can be either an exact or a smoothing interpolator depending on the user-specified parameters. It incorporates anisotropy and underlying trends in an efficient and natural manner, and underlying trends in an efficient and natural manner.

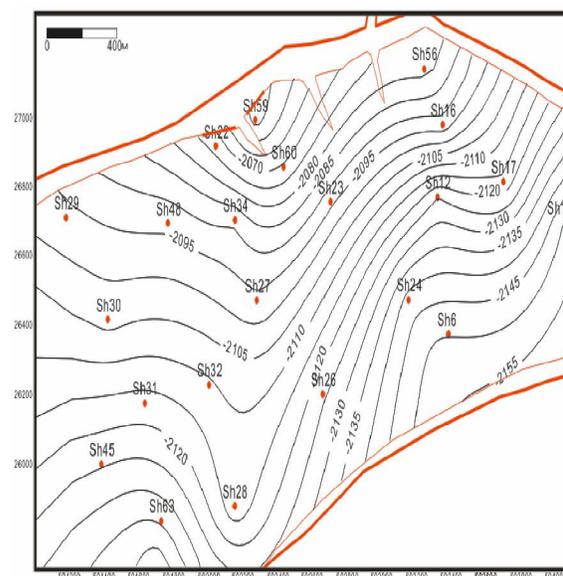


Figure 5: Structure Map

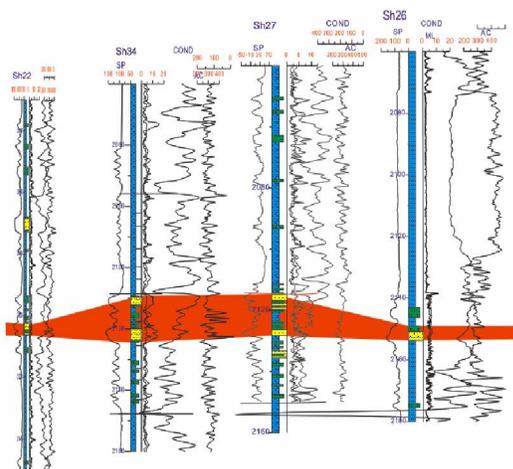


Figure 12: Cross Section of the pool in well Sh22, Sh34, Sh27 and Sh26.

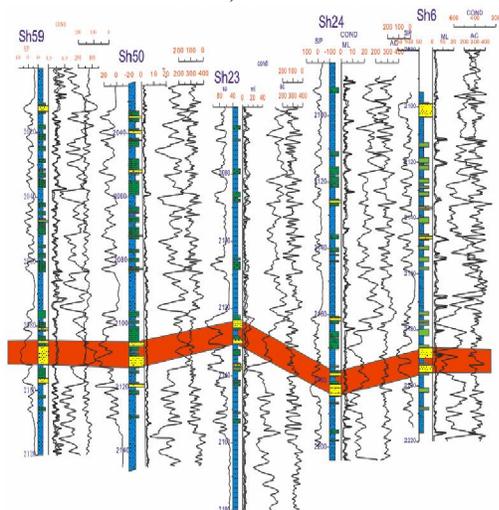


Figure 13: Cross Section of the pool in well Sh59, Sh50, Sh23, Sh24 and Sh6.

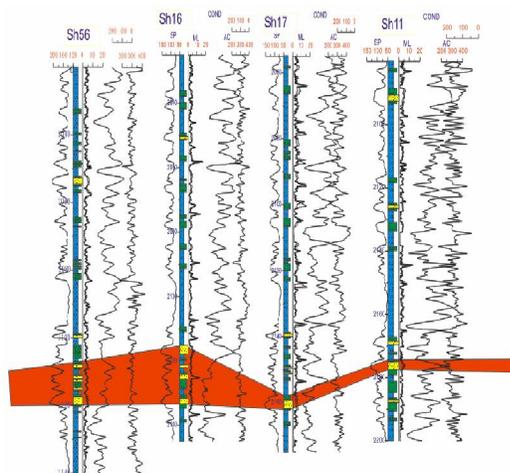


Figure 14: Cross Section of the pool in well Sh66, Sh26, Sh23, Sh24 and Sh6.

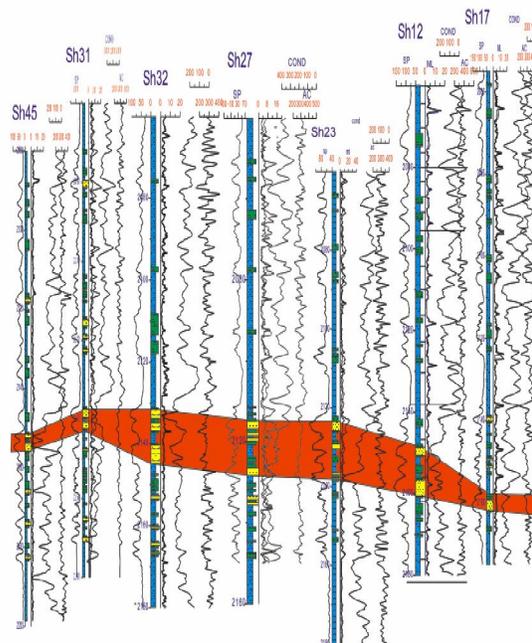


Figure 15: Cross Section of the pool in well Sh45, Sh316, Sh32, Sh27, Sh23, Sh12 and Sh17.

7.0 Conclusion

Nearly all anticlinal reservoirs are broken by faults. Usually they are at an angle of 70 degrees to the axis of the anticline, they are normally seals and break the reservoirs into individual units, each with its own pressure and oil-water contact. Obviously for efficient production each fault block must be considered a separate reservoir. Oil and seeps in the depression are found in Tertiary sandstone reservoirs as well as underlying basement, including the Jurassic sandstone reservoirs and the carboniferous – Permian and Ordovician weathered zone. Oil are produced from several faulted blocks shown in the structure map (figure 5), this result agrees with previous work in Shahejie formation particularly Fulin Basin by (Chen Jianyu et al., 1996). Based on the Structure map Shan4 depression in shahejie formation is composed of a complex depositional system of a prograded elongated delta, beach and bar formed under lower current energy of a shore-shallow lake. Wells for Tertiary reservoir failed because of inaccurate prediction of the oil-bearing height in the Jiyang Depression. (Zhao 2010). Hydrocarbon trap is created by an anticline pool separated by numerous oil layered complex faults, Oil and seeps in the depression are found in Tertiary sandstone reservoirs as well as underlying basement located at an approximate depth of 2020m, including the Jurassic sandstone reservoirs and the

carboniferous –Permian and Ordovician weathered zone. The oil-bearing height actually reflects the amount of hydrocarbon charging. While the charging amount of hydrocarbon mainly depends on the charging force of the hydrocarbon to the trap (Zhao et al., 2010). It is composed of organic-rich dark mudstone and oil shale of lacustrine origin and contains good quality Type I-II kerogen, all the oil in this member originated from Es3 source rock as extrapolated from biomarker similarity functions between oils and the source rock extracts. Assessment of the oil generation history indicates that oil generated is expelled from South slope of the Bohai Bay Basin east China. Though Xiongqi et al (2005) suggested that this suggest significant hydrocarbon expulsion from mature source rocks in the fourth (Es4) and third members (Es3) of the Oligocene-Eocene Shahejie Formation in the Niuzhuang Sag.

Shan4 faulted zone which could trap high quantity of oil pool are: Sh56, Sh50, Sh6, Sh16, Sh34, Sh27, Sh32, Sh27, Sh23 and Sh12 as the distance between the trap and the source rock is not too far. When the distance between source rock and trap and the altitude difference between source rock and trap increases, the actual migration distance of hydrocarbon will become longer, the dispersed rate of the source rock will increase, and the amount that can enter into the trap will decrease (Zhao Leqiang et al., 2010). A little amount of oil can also be gotten from well Sh59, Sh23, and Sh24. The high porosity distribution of Shan4 (figure7) indicate the wide variety of grain distribution, interstitial clays and secondary silica, size and shape of the pore. The analytical data (table 1) showing the porosity and permeability distribution shows that they are fairly good source rock. This results agrees with findings in other depressions in Shahejie formation Xiongqi et al., (2005) he discovered that most of the hydrocarbon are generated and expelled from Shahejie formation source rock in Niuzhuang Sag, and are made up of algae-rich Saline-brackish water lacustrine, Es4 oil Shales of the Shahejie formation. he also noted that all the oils in the formation share some common characteristics of brackish to saline lacustrine sourced oils, featuring high sterane and ammacerane contents, high C35/C34 homohopane ratios and low diasterane contents. Xiongqi et al (2003).

The findings agrees with (Richard 1998), (J. Zhang et al., 2008) that logs can also be used to determine the facies and depositional environment of a reservoir, the geometry and orientation of reservoir can be predicted.

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