Possibility of Well Log Correlation Using Standard Deviation Trends in Neogene-Quaternary Sediments, Sava Depression, Pannonian Basin

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Working method for well log correlation in Neogene-Quaternary infill of the Croatian Pannonian Basin is based on visual identification on specific motifs that can be observed regionally through the Depression. Method is proven successful through exploration for petroleum accumulations in the aforementioned area but its application is limited outside of the interval of Upper Miocene sediments and is subjective. Standard deviation values of well log data from conventional well logs (spontaneous potential, shallow and deep resistivity) were calculated and observed in the entire well interval for defining new and correspondence with the old well log horizons. Traditionally determined horizons did not coincide with those defined by standard deviation technique. However, regional horizons were established in the youngest part of the infill, which made more detail correlation now possible.

Key words: standard deviation trends, well-log horizon, correlation, Sava Depression, Pannonian Basin

1. INTRODUCTION

Subsurface settings and stratigraphic relations of the Croatian part of the Pannonian Basin (CPBS) has traditionally been divided into formations and members based on
research that is ongoing from 1950’. These are divided by well log horizons which represent distinctive motifs that can be observed on well log curves, more specifically on the resistivity curves in thick-bedded marl (VRBANAC, 2002). This is a valid method when the sedimentary environments are large enough to support the forming of such layers that can be distinguishable regionally. In smaller and/or more dynamic environments, a different kind of approach has to be employed to be able to regionally correlate deposits in the subsurface. For this purpose, a mathematical approach using cumulative standard deviation curves was tested on well data from Neogene – Quaternary infill of the part of the Sava Depression, Pannonian Basin (Fig. 1). Testing was performed initially on the entire Neogene – Quaternary sediments and later focused on the youngest part – Pliocene, Pleistocene and Holocene.
Figure 1: Extent of the exploration area with pointed out well locations (from CVETKOVIĆ, 2016)

2. GENERAL SUBSURFACE GEOLOGY SETTINGS AND PREVIOUS RESEARCH

Stratigraphic subdivision of the Neogene-Quaternary infill of the CPBS has been performed from 1950’ when the first exploration for hydrocarbons started. This subdivision was based on a lithostratigraphical subdivision for each depression in the CPBS. The area of focus for this investigation is the sedimentary infill in the Sava Depression. Neogene-Quaternary succession in Sava Depression has been subdivided into six formations whose lithology has been described in detail in
PLETIKAPIĆ (1969), ŠIMON (1973, 1980), Velić et al. (2002); SAFTIĆ et al. (2003), VELIĆ (2007) and can be generally observed in Fig. 2.

Figure 2: Chernostratigraphic and lithostratigraphic units valid for Sava Depression
These formations (and members within) are separated by well log horizons that are traditionally treated as chronohorizons. Traditional approach for the determining the position of the well log horizon is the selection of the distinctive motifs on well log curves, which could be tracked on adjacent wells. Well log horizons can conformable, unconformable or have a dual character, e.g. conformable in the mid part of the depression while unconformable on the marginal areas. Conformable horizons are located within the thick marl layers and it is presumed that these characteristic motifs are a result of minute granulometry change in marls as a response to the environmental influence (VRBANAC, 2002). According to VRBANAC (2002) they do not only represent a border between a lithostratigraphic units but could also serve as chronohorizons as he presumed that the environmental influence should be simultaneous depression/basin wide. These kind of well log horizons are regionally confined to Late Miocene intervals which had a large accommodation area and a dominate source of clastic materials (VRBANAC, 2002, LUČIĆ et al., 2001, GRIZELJ, et al., 2017).

Generally, well log horizons should be as a minimum recognizable on a localized area (size of a Oil field) but ones most usable are those that can be tracked trough depression. Various set of well log curves can be used for but most common that are used for this purpose are the resistivity curves. These fall in the set of conventional electric well log curves that are acquired in the entire well interval unlike other more costly well logging applications that are acquired mostly in the limited well interval. As mentioned in the introduction, well log horizons In CPBS have been distinguished in the whole Neogene sequence of sediments with the emphasis on the Upper Miocene clastic infill. Regional well log horizons that are valid for Sava depression are:
Tg/Pt (unconformity) – boundary between Neogene infill and Cenozoic sedimentary rocks (Pt) or magmatic and metamorphic rocks of Mesozoic or Paleozoic age (Tg).
Rs7 (dual character) – approximate boundary between Middle and Upper Miocene sediments or border between Prečec and Prkos formations.
Rs5 (dual character) – border between Lower and Upper Pannonian according to VRBANAC (2002) or border between Prkos and Ivanić-Grad formations.
Z' (conformable) – border between Upper Pannonian and Lower Pontian (sensu lato as existence of Pontian as in Eastern Paratethys is Questionable, ĆORIĆ et al., 2009) according to VRBANAC (2002) or Ivanić-Grad and Kloštar Ivanić and Široko Polje formations.
Rϕ (conformable) – border between Lower and Upper Pontian (sensu lato) sediments or Kloštar Ivanić and Široko Polje formations.
α' (dual character) – border between Miocene and Pliocene sediments according to ŠIMON (1980), VELIĆ (2002), CVETKOVIĆ (2013) or border between Široko Polje and Lonja Formations.

Methodology for locating well horizons (visual determination) has been applied from earliest explorations and has proven to be successful as large number of fields and accumulations have been discovered by this approach. This principle is valid worldwide although there were some successful approaches to use geomathematics to determine well log horizons (LUTHI & BRYANT, 1997; LAPKOVSKY et al., 2015). Downside is that the method itself is quite subjective and is applicable in large sedimentary environments where similar conditions existed depression wide. This is a problem observed in a more dynamic environment (CVETKOVIĆ, 2013, MANDIC et al., 2015, GRIZELJ, et al., 2017, which existed prior, and after the Late Miocene.
For this reason, a relatively simple mathematical method was employed for establishing a working method to distinct horizons in wells in aforementioned problematic intervals – analysis of trends in curves of standard deviation (CSTDEV). These have been successfully tested on a limited dataset and on a single horizon (CVETKOVIĆ & MALVIĆ, 2013).

3. METHODS

Standard deviation (σ) is a measurement of the dispersion of data values in relation to the mean data value (Eq. 1)

\[
\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \mu)^2}
\]

whereas:

- \( n \) – number of cases in the observed dataset
- \( \mu \) – mean value of dataset
- \( x_i \) – \( i^{th} \) member of the dataset

The goal of calculating standard deviation is to determine the amount of change in the environment, which relates to the change in values that can be observed in well log curves.

The value of standard deviation is in this way dependent on two factors. Firstly, well log data dispersion, which directly relates to the lithological composition of the rocks. Second factor is the radius of the observed interval or resolution of standard deviation sampling. As the first factor is constant, influence of the radius interval was tested for three cases – one meter, two meter, and four meters. The center point interval is the data point for observation of standard deviation (STDEV, Fig. 3). All
conventional electric well log (E-log) curves were initially subjected to STDEV analysis (spontaneous potential, SPN; shallow resistivity, R16 and deep resistivity, R64). Resistivity curves in general, did not prove to be as appropriate for STDEV analysis in general (CVETKOVIĆ & MALVIĆ, 2013) so the focus was on the SPN values.

Figure 3: Representation of the interval used for calculated STDEV values in the case of 1, 2 and 4 meters

Numerically, when observing standard deviation, the values less than 1 represent homogenous impermeable intervals (eg. marls and shales) between 1 and 5 for dominantly sandstone intervals, and more than 4 for thin layered marl-sandstone succession. For further emphasizing the STDEV values for differentiating monotonous marl intervals from dynamic environments standard deviation value was squared. In that way numerical value of STDEV for marls being less than 1 was squared (STDEV_R2) and smaller in reference to STDEV values that were initially
greater than 1. Result of plotting this STDEV and STDEV_R2 values over a well interval shows the distribution of the data dispersion. The peak values can be used for defining lithological boundaries as they fall on the mid-point of the curve of inflexion. In this way, defining lithological boundaries is a less subjective process and can serve as a benchmark for training purposes as the correct procedure requires the border to be put on the mid-point of the inflexion of the curve (BASSIOUNI, 1994, BAKER et al., 2015).

Figure 4: STDEV and STDEV_R2 values plotted against thin-layered section (left) and thick-layered section (right)

Values of standard deviation on a specific point as shown in Fig. 4 represent only the dynamics of environment in a single point plotted over an entire well interval but little information is in this available about the general dynamics. Cumulative value curves of selected data have been previously used to depict trends in the subsurface, e.g.
cumulative dip values were plotted along the depth axis of a well from dipmeter values (BENGSTON, 1981; HURLEY, 1994; VELIĆ et al., 2009). In those instances they show a general trend in change of a dip incline which could be related to the prevailing tectonic regime. A similar approach was performed with STDEV values where plotted as a cumulative standard deviation curve (CSTDEV). Initial testing was performed for defining optimal resolution of STDEV value to be plotted on a CSTDEV curve. Testing was performed for one, two and four meter resolution. Applicability of each resolution was tested by comparing it with a well log horizon which should point out a great change in the sedimentary environment when large lake system was significantly reduced and marsh environments occurred on a larger scale (CVETKOVIĆ, 2013, MANDIC et al., 2015) – α’. Although curves of all three resolution showed a break pattern, one meter one was most precise when compared to the data acquired from the initial well log horizon database (CVETKOVIĆ & MALVIĆ, 2013).

As defining trends based on CSTDEV curves relies on visual determination, a square value of standard deviation was also plotted as a cumulative curve (CSTDEV_R2). In this way, curves represent a general environmental dynamics where low increment of cumulative data value increase represent a small change in the environment and a high increment a dynamic environment. Squared value emphasizes the low and high change in the environment to an even greater extent.

As a final step curves have to be normalized for the purpose of easier visualization. In opposition to plotting the CSTDEV and CSTDEV_R2 values on the axis, which can significantly differ from well to well, values were plotted as a percentage of the maximum value (Fig. 5). In this way, cross-correlation should prove more reliable as
values of spontaneous potential for lithology can differ from well to well based on well logging conditions.

Figure 5: Results of plotting cumulative standard deviation value curves of normal (CSTDEVN) and squared (CSTDEVN_R2) value of SP for entire interval of Well 1.
4. RESULTS

Analysis of CSTDEV and CSTDEV_R2 curves was performed on 43 wells in Sava Depression (Fig. 1). First part of the analysis concerned the entire Neogene-Quaternary infill where regional well log horizons were plotted against calculated curves. Several breaks in curve trends are were present but two distinctive ones can be correlated thought the Depression. Unfortunately, only one of these breaks can be related to existing well log horizons – \( \alpha' \) (boundary of 2\(^{nd}\) and 3\(^{rd}\) interval, Fig. 6).

![Graph showing well log horizons and CSTDEV curves](image)

**Figure 6:** Relation of well log horizons determined by traditional method and general trends by CSTDEV curves

1\(^{st}\) interval defined by this break generally represents Prečec and Prkos formations but can extend to even Kloštar Ivanić formation (Fig. 6, Well 6). In general, sandstone
layers are thicker in this interval or absent thus resulting in low STDEV values and a low increment CSTDEV trend.

2nd interval relates to a clastic infill of of Ivanić-Grad, Kloštar Ivanić and Široko Polje formations. Sandstones layers are generally thicker than 10 m. Several trends can be observed within this interval but do not follow any of the well log horizons that are traditionally in use. Unfortunately, seismic cross sections were not available for testing the possibility of correlation in this interval.

Uppermost boundary is marked by a break in the CSTDEV curve which coincides with regional well log horizon α’. 3rd interval belongs to thin layered (<5 m) clays and sands which are poorly sorted. Frequent lithology change resulted in steep gradient in CSTDEV curves.

Second part of the analysis focused only on sediments of Lonja formation (approximate age interval - Pliocene, Pleistocene and Holocene). Three distinctive trends were observed on CSTDEV curves in a confined interval (Fig.7).
Figure 7: Positioning well log horizons (J' and K') within Lonja formation and α’ based on trend line (green) intersections

These breaks could be tracked through the entire research area while CSTDEV_R2 curve showed too much sensitivity to change in SP values resulting in too many trends that could not be correlated on a larger scale. These trend breaks served as boundaries that define members in Lonja formation on which the infill of youngest formation in Sava Depression was subdivided and subsequently mapped (CVETKOVIĆ, 2013). Furthermore, the position of α’ horizon was adjusted on several positions based on CSTDEV curves to relate to the change in lithology.

5. CONCLUSIONS

Observation of standard deviation values and trends on a cumulative plot curve has proven of significant value. Plotting a STDEV value against E-log curves in the initial part of the lithologic analysis can help the interpretation in positioning the border between lithology as maximum values fall onto a mid-point of the curve inflexion. In this way, an objective parameter can be introduced in well log analysis rather than putting the approximate location based on experience or using a cut of values for lithology, which can differ due to the nature of acquiring the well log.

Observing trends and break points in CSTDEV and CSTDEV_R2 curves did not show relation with existing well log horizons, which makes their applicability in the Upper Miocene sediments questionable. In the base of Lonja formation on both curves, a distinctive break is present at α’ well log horizon. Furthermore, two distinctive breaks within the Lonja formation can be located on CSTDEV curve that can be tracked through depression. CSTDEV_R2 curve in this instance showed too
many breaks in trends and two, which could be clearly seen in previous case, were obscured.

Based on presented data, CSTDEV curves proved to be valuable for correlating the well logs in intervals within thin-layered succession in which single inflow of clastic material in the system is absent.

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