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Constrained Seismic Sequence Stratigraphy of Asmari - Kajhdumi interval with well-log Data

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Abstract

Sequence stratigraphy is a key step in interpretation of the seismic reflection data. It was originally developed by seismic specialists, and then the usage of high-resolution well logs and core data was taken into consideration in its implementation. The current paper aims in performing sequence stratigraphy using three-dimensional seismic data, well logs (gamma ray, sonic, porosity, density, water saturation and resistivity) on Hendijan oil field located in the northwest part of Persian Gulf. , Depth interval of the study that covered from Asmari formation to Kajhdumi formation was determined by using well markers. Based on the depositional sequence model that consists of four systems tracts and with the help of Wheeler diagram, observed patterns have been used in seismic reflection terminations to identify sequence boundaries, systems tracts and internal stratigraphic surfaces in the sequences. Additionally, well logs were interpreted for two objectives. Firstly, variation patterns of well logs were used to validate sequences, their components and internal sequence stratigraphic surfaces. Secondly, the well log data was used for characterization of systems tracts with the log values.

This paper addresses the constraints patterns for such stratigraphic problems in seismic interpretation with the aim of achieving better chrono-stratigraphic reasoning system with previous studies in Iran.

Keywords: sequence stratigraphy, depositional sequence, systems tracts, Wheeler diagram, and well log

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1 Introduction

The focus of hydrocarbon exploration has been mainly on structural traps for a long time. Therefore, most structural traps have been drilled or at least discovered. As a result of increasing the difficulty of exploring new hydrocarbon fields, increasing the oil price and Enhanced Oil Recovery (EOR) plans, searching for new hydrocarbon traps is more important, and hydrocarbon exploration has shifted toward stratigraphic traps detection more than the past. For this purpose, simultaneous use of well-logs and sequential stratigraphy is a powerful tool that reveals lithology, sedimentary environment and hydrocarbon reservoirs. Sequential stratigraphy analyzes the effect of sea level variation on sedimentation trend, which results in interactions between sediment supply rates and sedimentary accommodation space. However, sequence stratigraphy that initially developed by petroleum exploration experts, using mainly seismic data, has now been expanded using high-resolution data such as well-logs and cores. In this research, the goal is to carry out sequence stratigraphy analysis in a way that makes the highest possible use of all existing data we had from Hendijan oil field, including 3D seismic data and well-logs.

2 Case Study Area

Hendijan oilfield is one of the Iranian oil fields in the Persian Gulf basin, located in the Khuzestan province and is in west of the Bahargan region laid on the southern slope of Dezful embayment (Figure 1). The Bangestan Group, especially the Sarvak Formation (Cenomanian-Turonian), is considered as an oil-rich formation in this field. The upper boundary of Sarvak is the Turonian discontinuity. The combined study of thin sections, cores, petrophysics and reservoir dynamics shows that dolomitization, as one of the diagenetic processes, plays a major role in determining reservoir properties. The sedimentary environment model of Sarvak Formation in the study area determined as a ramp-type carbonate platform. Given the boundary of discontinuity at the top of Sarvak Formation, it can be expected that there are oil traps in the area that their exact identification requires detailed studies of the seismic data (including sequential stratigraphy as a main part of stratigraphic Interpretation).

Figure 1. Location of Hendijan oil field.

3 Seismic and Well Data

A part of the 3D seismic data of the oil field, which includes the coordinates of the largest number of wells, was selected for this study (Figure 2). This seismic data includes a length of 13.650 Km and a width of 9.9 Km. In depth, it covers the Asmari, Jahromi, Pabdeh, Gurpi, Sarvak, Kazhdumi, Burgan and Daryan formations (Inline range: 700-1240, Crossline range: 800-1198, Z range: 700-2848 milliseconds).

Different logs of wells 1 to 6 were used in several stages. The depth of the data taken by all the wells is at least up to the Kazhdumi Formation. Data of wells are checked and are correlated with seismic data before they are interpreted (Figure 3).

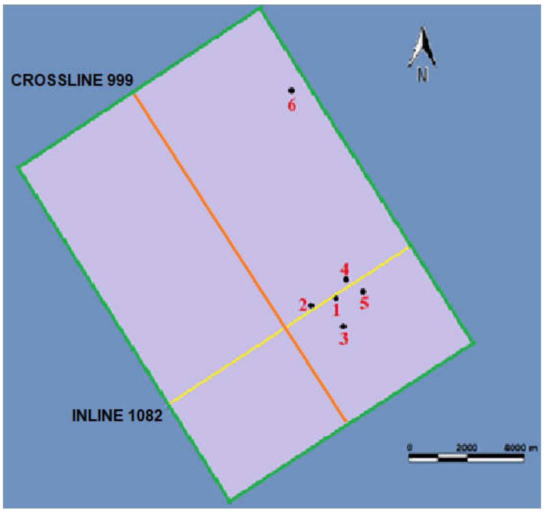


Figure 2. Map of the seismic layout and the location of the wells.

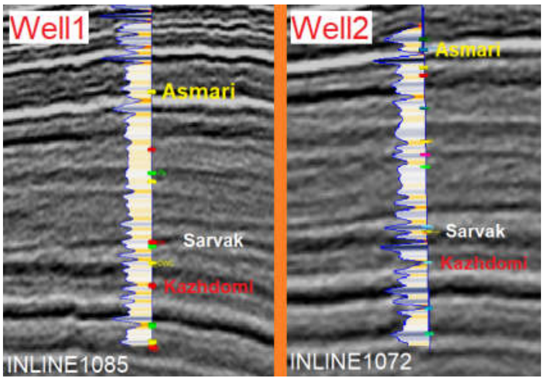


Figure 3. Synthetic seismograms (product of density and P-wave velocity) from well 1 (74% correlation with seismic trace) and well 2 (77% correlation with seismic trace).

4 Basic concepts

There are different terms for system tracks and their separator surfaces that are also used during this study. In the following these terms are explained briefly:

Systems tract: The sedimentary sequence components, which are sedimentary successions deposited during various stages of sea level changes, are called systems tracts (Figure 4). Each systems tract exhibits a characteristic log response, seismic signature and paleontologic fingerprint [1-6]. Four main types of system tract are recognized:

- **Highstand systems tract (HST):** Sediment deposited with progradational to aggradational stacking pattern during high sea level.
- **Early Lowstand or Falling-stage systems tract (early LST or FSST):** Sediment deposited as sea falls from high to low with progradational stacking pattern.
- **Late Lowstand or Lowstand or systems tract (late LST or LST):** Sediment deposited during low sea level and early rising sea level with retrogradational stacking pattern.
- **Transgressive systems tract (TST):** Sediment deposited with retrogradational to aggradational stacking pattern during rising sea level.

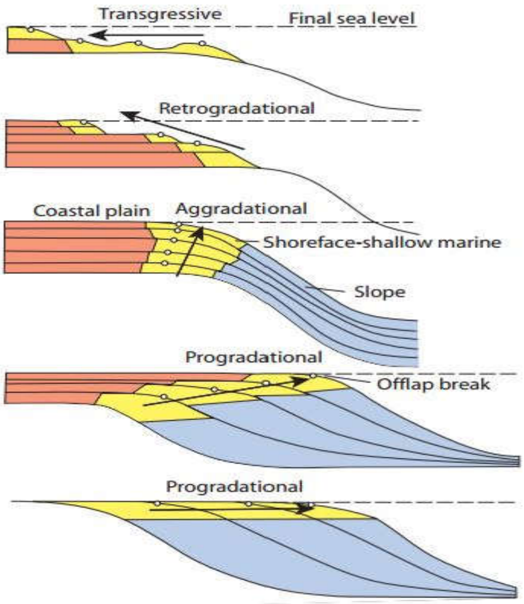


Figure 4. Sedimentation stacking patterns during sea level changes [16]

Sequence boundary (SB): The unconformity caused by deposits subject to erosion, forms sequence boundary.

Maximum flooding surface (MFS): The surface that indicates most landward extension of sea is called Maximum flooding surface (it is the separator of TST and HST).

Transgressive surface (TS) or maximum regressive surface: the horizon that indicates the beginning of retrogradational sedimentation (it is the separator of late LST and TST).

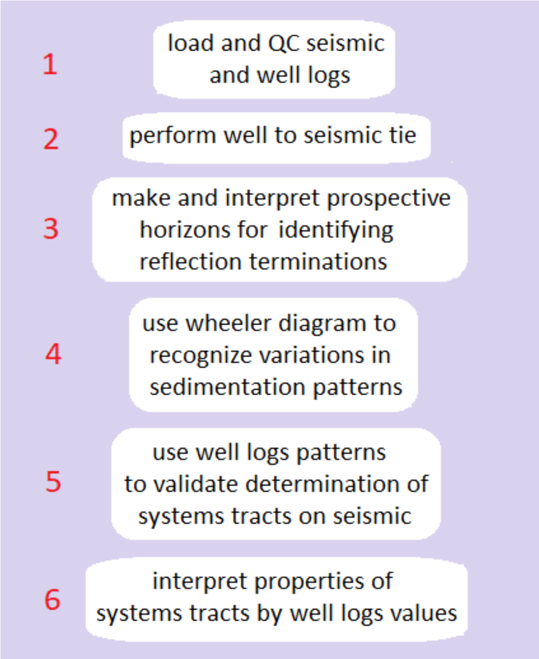


Figure 5. The workflow for sequence stratigraphy analysis in this study.

5 Methodolgy

To achieve the objectives of this study, a three-dimensional seismic data and six well-logs have been used and analyzed. First, a depth interval on seismic section is selected to perform sequential stratigraphy analysis, in the distance where well-log data is available. Then, in this area, t is tried to distinguish and highlight as more as possible sedimentary discontinuities and seismic reflection terminations. The next job is plotting a Wheeler diagram that represents the relative geological time in an offset. Identifying the discontinuities observed on this graph and considering discontinuities and seismic reflection terminations recognized on seismic section. Then, the separating surfaces of the systems tracts, which are the subset of the seismic stratigraphic sequence, are identified.

Now, we are going to use well data that will carry out in two steps. The first step is to examine the pattern of variation of the gamma ray log in order to confirm the subdivision of the sequences and the systems tracts on the seismic section, which is the most common and useful well-log for this purpose. After ensuring that the facies are recognized correctly on the seismic section, the second step is to determine their properties using available logs. The steps taken to carry out this research is shown in the workflow shown by a diagram in Figure 5.

6 The workflow for sequence stratigraphy analysis

6.1 The Steps Applied to Seismic Data

In this research, the steps which are carried out are shown below respectively.

6.1.1 Choice of the desired depth interval for applying sequential stratigraphy analysis

According to the area that well log data is available, a range was chosen that includes the distance from Asmari formation to Kazhdumi formation on seismic section (Figure 6).

Hereafter, all the analysis steps are done in this approximate area.

6.1.2 Determination of sedimentary discontinuities and seismic reflector endings on seismic section (Figure 7).

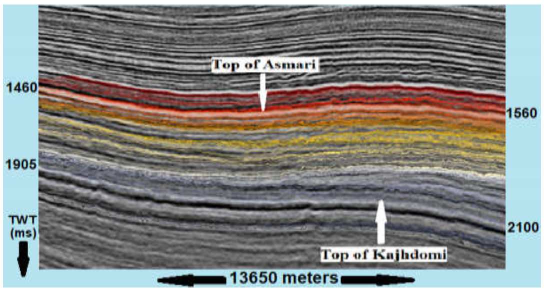


Figure 6. Depth interval considered for sequential stratigraphy analysis (from Asmari formation to Early Kajhdumi formation).

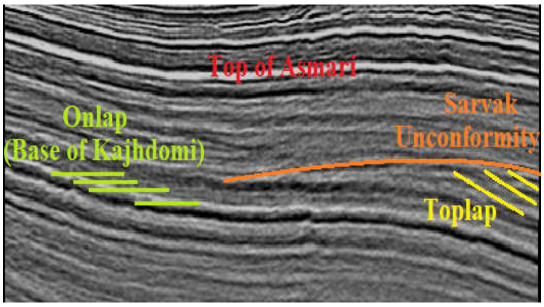
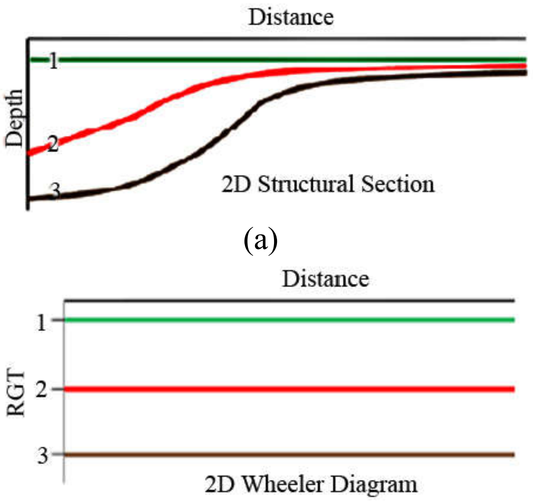


Figure 7. Sedimentary discontinuities and the reflection terminations are indicated on the seismic section

6.1.3 Application of Wheeler diagram

Wheeler diagrams (Figure 8), or chronostratigraphic charts, provide a useful way to look at stratigraphic temporal relationships, particularly with regards to understanding the location and timing of erosional and non-depositional events [7].



(a)

(b)

Figure 8. Wheeler diagrams are constructed by mapping surfaces in a structural view. (a) A schematic sketch of a structural cross-section containing three interpreted surfaces (namely 1, 2, 3). These surfaces are ordered stratigraphically by counting the surfaces, which helps to form an arbitrary RGT (Relative Geologic Time) scale. These surfaces are then flattened to construct a (b) Wheeler diagram [7].

In this step, seismic horizons are displayed in a way that is appropriate for detecting seismic reflector terminations (Figure 9).

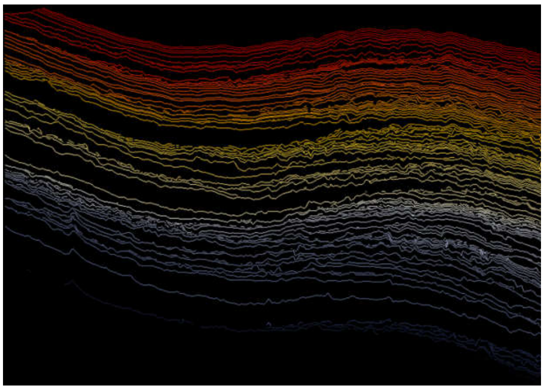


Figure 9. Seismic horizons in order to identify reflection terminations.

Then the Wheeler diagram is generated using the software (Figure 10).

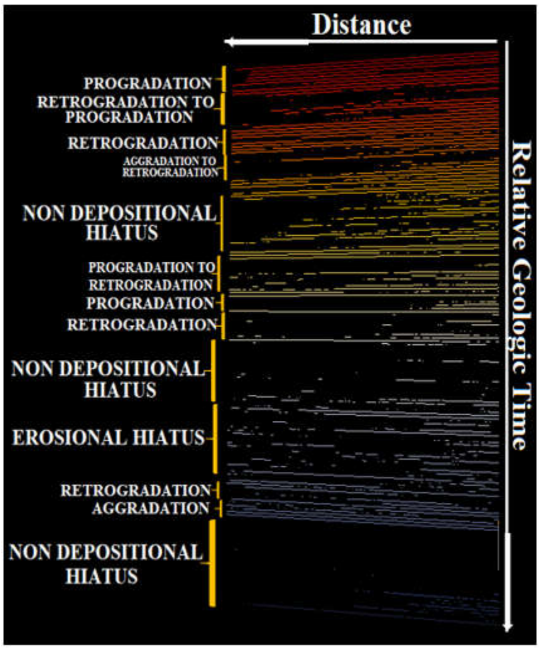


Figure 10. Wheeler diagram and interpretation of long period sedimentary trends.

Now, In comparison with Figure 9 and using the sedimentary discontinuities and sedimentation pattern variation observed on this diagram (Figure 10), we can interpret the long periods of paleo sedimentation, such as the progradation (sea ward) and retrogradation (land ward) of sediments, as well as the interruptions in the sedimentation (Figure 10) [7-10].

6.1.4 Subdivision of studied seismic cube into seismic sequences and the forming systems tracts

SSIS delivers Wheeler diagram in three dimensions. In addition, the details of seismic section including sedimentary discontinuities and seismic reflection terminations slightly change in the inlines close to inline 1082; therefore, the Wheeler diagram can be used to partition the entire seismic data volume into systems tracts (Figure 11). In this subdivision, the systems tracts are numbered from bottom to the top, and seismic sequences have been determined according to their definition in the studied area.

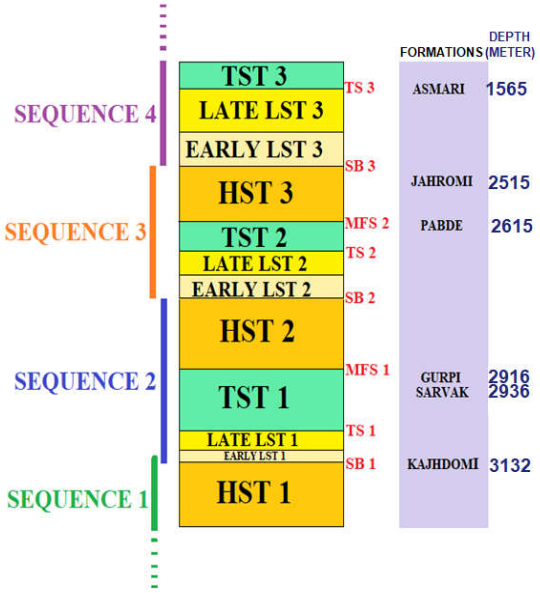


Figure 11. Division of the studied formations into seismic sequences and systems tracts along with the display of separating stratigraphic surfaces.

To display the thickness and continuity of each systems tracts in the entire volume, a figure is presented that includes an inline and a crossline containing the systems tracts (Figure 12).

6.2 The Steps Applied to Well-log Data

6.2.1 The use of gamma ray log pattern to validate systems tracts

In the previous step, we assigned systems tracts' limits to the entire volume of seismic cube with the help of Wheeler diagram. Now, in order to constrain prior results, the pattern of variations in gamma ray log pattern is used to confirm the division of seismic sequences, stratigraphic boundaries and systems tracts on the seismic data. Due to the formation of systems tracts in different periods of high or low sea level and in different depths, the sediments of shallow parts of the basin are overlaying deep part of the sediments of shallow parts of the basin (retrogradational stacking pattern) or vice versa (progradational stacking pattern). Therefore, there is a coarsening upward or fining upward trend in grain size of their sediment particles. These trends can be detected by gamma ray or spontaneous potential log patterns (Figure 13) [8 and 9].

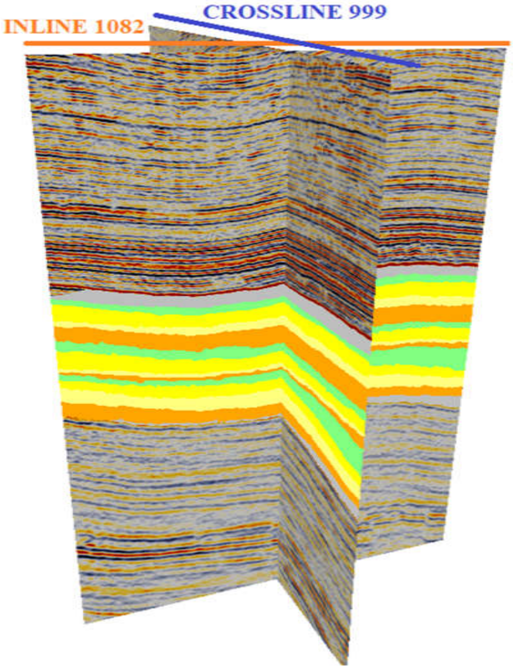


Figure 12. Three-dimensional view of the systems tracts on seismic sections (Total Two-way Travel time: 700-2848 milliseconds).

The pattern of gamma ray log along different systems tracts is shown below (Figure 14).

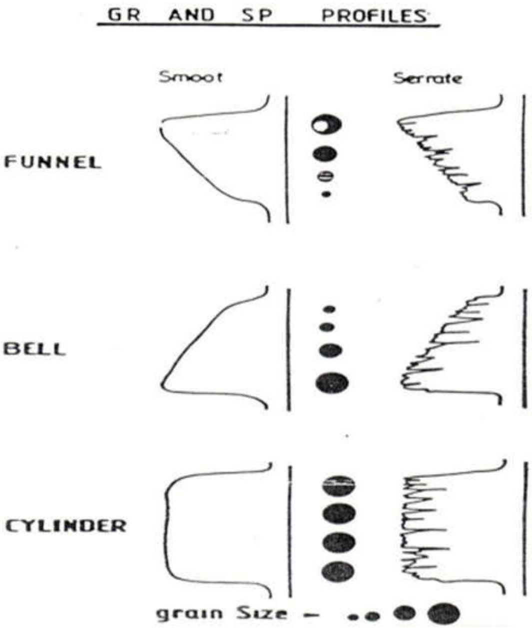


Figure 13. Different patterns created under the influence of the type of grain size change in gamma ray and spontaneous potential logs.

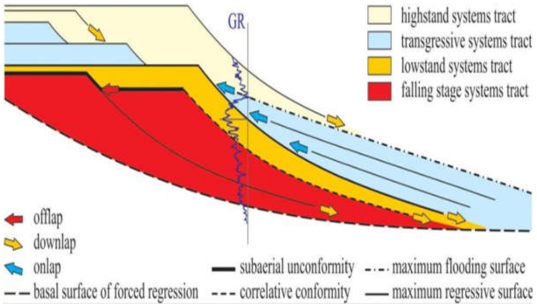


Figure 14. Gamma ray log along variations systems tracts [16]

Briefly, it can be said about the value of gamma ray log along systems tracts:

- HST: Increasing upward (coarsening grain size upward).
- TST: Decreasing upward (fining grain size upward).
- Early LST or FSST: Increasing upward (coarsening grain size upward).
- Late LST or LST: Increasing upward (coarsening grain size upward), but not until late.

Moreover, it is always possible to see a trend shifting from the increasing to the diminishing of the values of gamma ray log in MFS, and vice versa for TS.

Now, we look at the pattern of the Gamma ray log alongside the determined systems tracts (Figure 15). As it can be seen, this log along with the systems tracts and their stratal separating boundaries show up to the desired pattern.

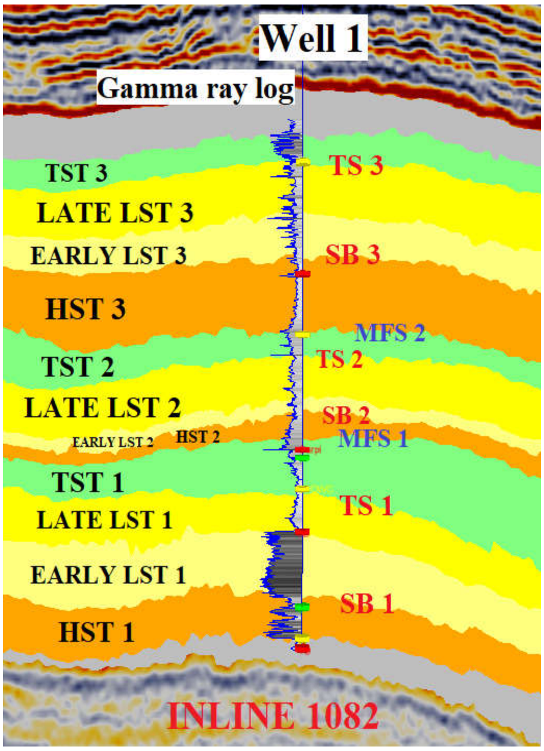


Figure 15. Displaying the adaptation of the gamma ray log variations pattern and the systems tracts identified on the seismic section. The gamma-ray log model has maximum relative droplet at the maximum drowning surface and is minimally relative at progressive levels.

Besides, this adaptation of the gamma ray variation pattern is investigated and compared with the systems tracts for all wells (Figure 16).

As it can be seen, the pattern of gamma ray log changes in all wells by crossing from the range of systems tracts and in different parts of the seismic data volume are highly similar.

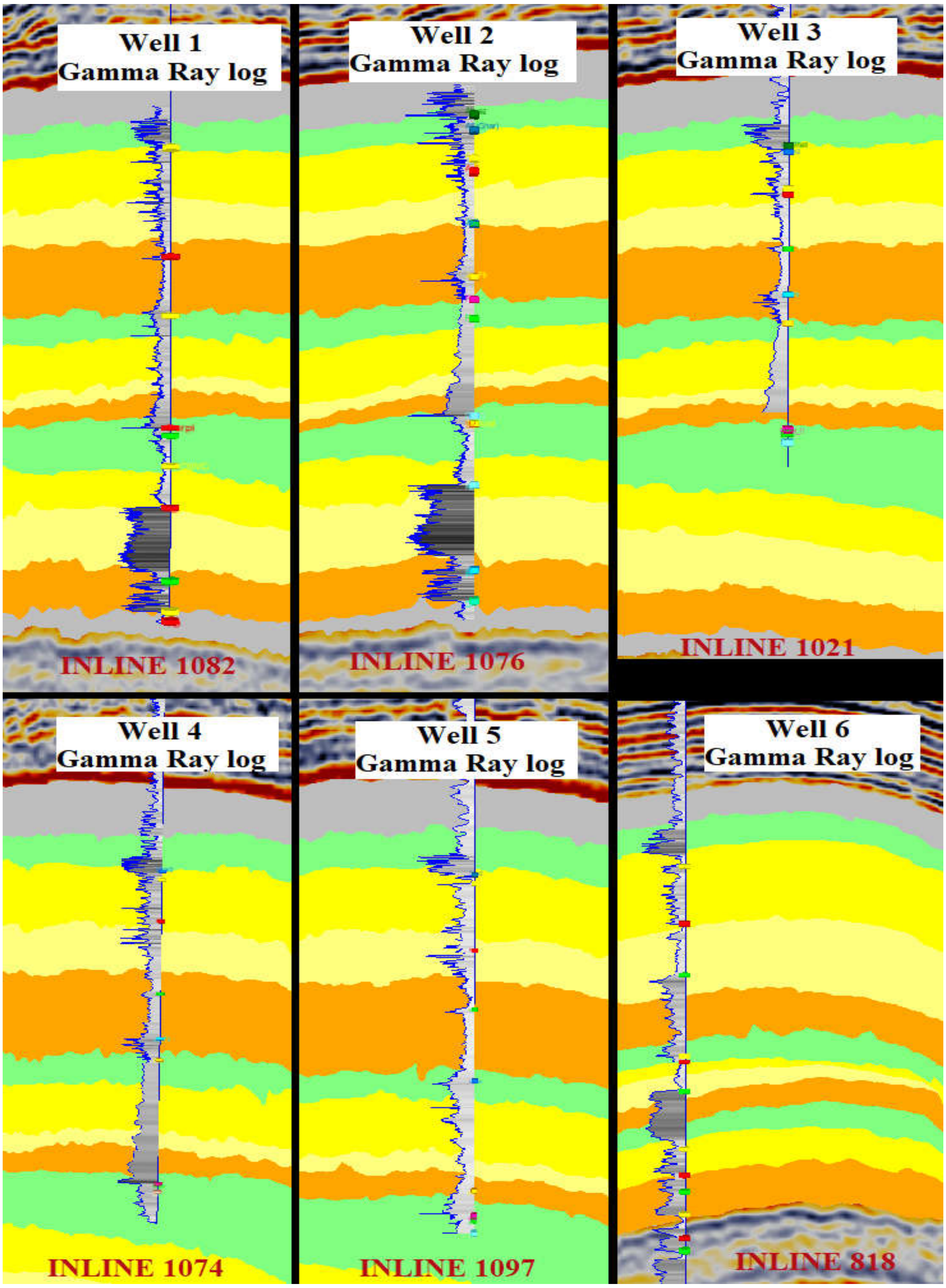


Figure 16. Similarity of gamma ray variations pattern in all wells near various seismic sections

As much as more logs from wells are concerned and the same pattern of variation of values is observed, we are confident in the correctness of the systems tracts recognition and the similarity of the properties of each of them in the entire seismic volume. In Figures 17, 18, 19 and 20, they are reviewed more.

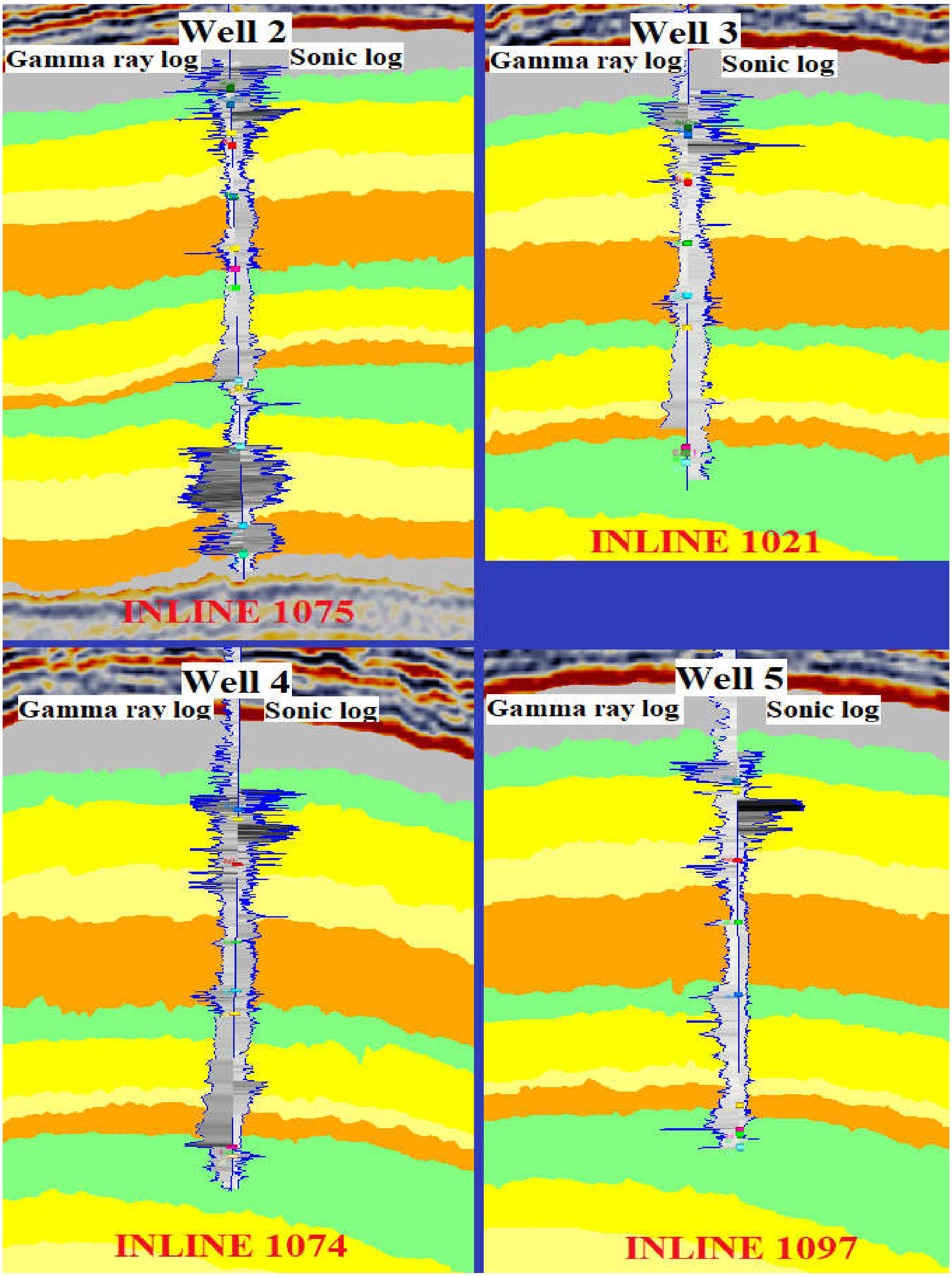


Figure 17. Adaptation of quantities and patterns of changes in sonic and gamma ray logs in different wells

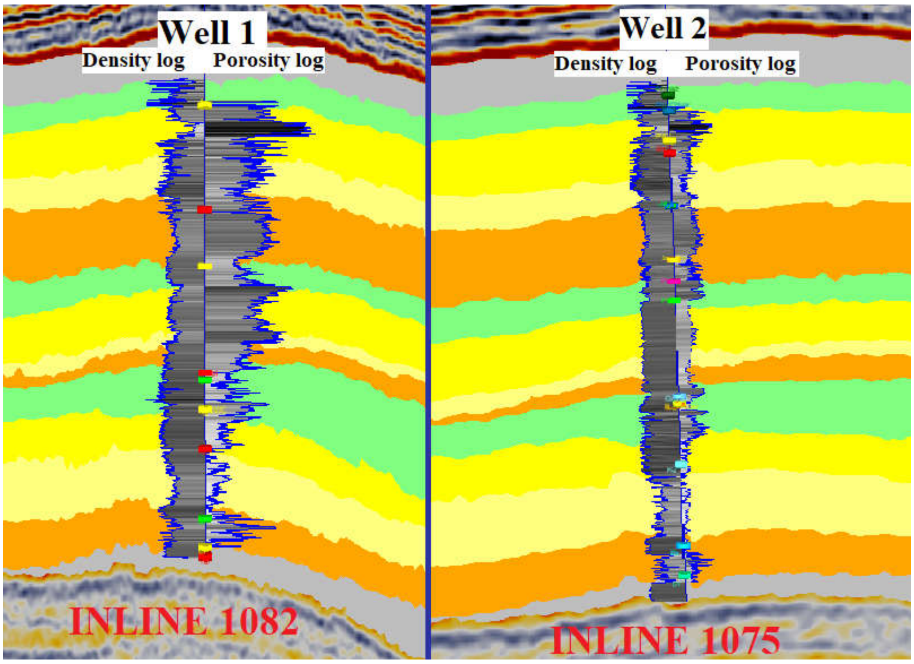


Figure 18. Adaptation of values and patterns of variation of density and porosity logs in different wells

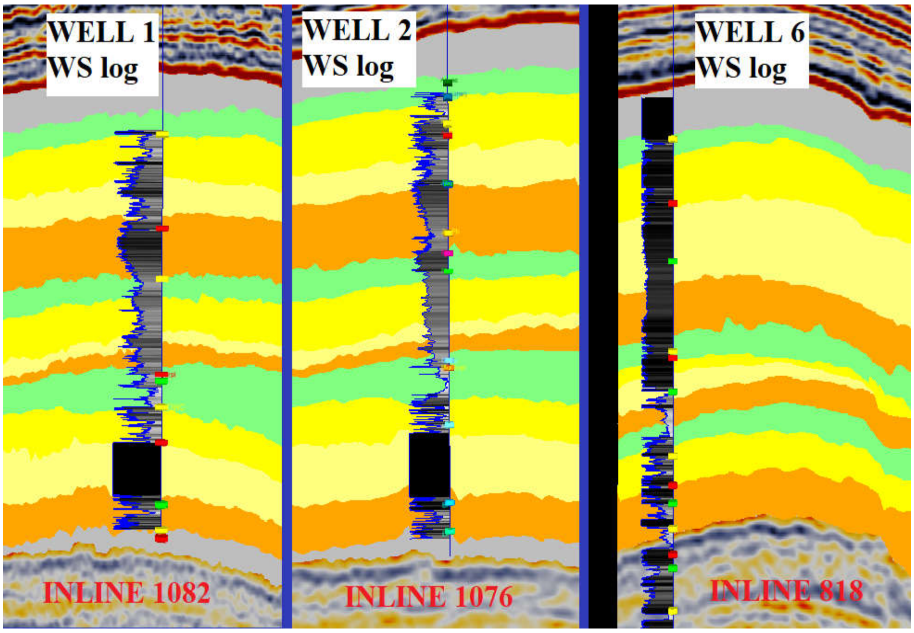


Figure 19. Water saturation logs in wells 1, 2 and 6.

6.3 Investigating the Properties of Systems tracts Using Well-logs

In the previous steps, we ensured the correctness of systems tracts determinations and the uniformity of their properties over the entire seismic data volume. At this stage, some characteristics of each systems tracts are determined using well-logs. The method for doing this is the step-by-step interpreting of the values of the existing logs in the systems tracts related intervals [11-15].

For this purpose and to find the systems tracts that are possible candidates for hydrocarbon bearing, we initially determined specified intervals with appropriate lithology such as sandstone or dolomite, by gamma ray, density, and sonic logs.

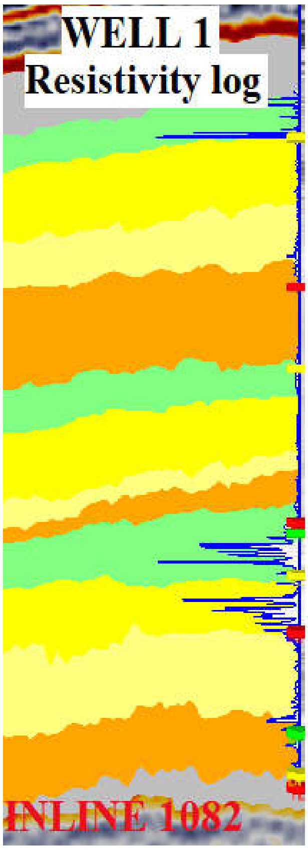


Figure 20. Resistivity log in Well 1

Therefore, the gamma ray log is used for lithology interpretation of the systems tracts. The systems tracts with values about 30-75 units of API are considered as the systems tracts with dominant sandstone lithology. On the other hand, values more than 75 units of API are considered as the systems tracts with dominant shale lithology.

Moreover, low water saturation and high resistivity logs values were used as hydrocarbon indicators. Some of the considered values are listed below.

- In the case of a density log, we consider the intervals with density about 2.3 gr/cm3 as shale, 2.64 gr/cm3 as sandstone and 2.87 gr/cm3 as Dolomite.
- In the case of porosity log, high values in the porosity log are proper for bearing hydrocarbon. We consider the intervals of 10 to 30 percent as shale, 20 to 35 percent as sandstone and for dolomite porosity is about 29 percent.
- In the case of sonic log, we consider intervals of 1790 to 5805 m/s as shale, 5100-5800 m/s as sandstone, 5490 – 5950 compact sandstone and 7010 – 7920 m/s as Dolomite.
- In the case of resistivity log, intervals with more than 10 ohm.m values can be hydrocarbon bearing zones. We consider intervals with 0.60-0.80 ohm.m as sandstone and 1.65 ohm.m as shaly sand intervals. Young shales have low resistivity (1 to 4 ohm.m), older shales have medium resistivity (5 to 25 ohm.m).

As already mentioned, the well-logs displayed close-fitting values in different wells for each systems tract. The average values of various well-logs we had in systems tracts' spans are shown in a table (Table1).

Table 1. The table of approximate values of well-logs in each systems tract's confine

Well-logs **Systems tracts**	Gamma Ray (API)	Density (gr/cm3)	Porosity (percentage)	Sonic (millisec/ft)	Water Saturation (percentage)	Resistivity (ohm.m)
TST 3	70	2.9	---	120	---	200
LATE LST3	35	2.2	20	90	45	30
EARLYLST3	30	2.4	16	27	80	30
HST3	20	2.3	18	50	90	30
TST2	33	2.35	14	50	40	30
LATE LST2	33	2.3	15	50	40	30
EARLYLST2	30	2.1	21	50	70	20
HST2	35	2.5	15	65	50	30
TST1	30	2.6	17	23	25	350
LATE LST1	30	2.5	14	120	35	300
LATE LST1	100	2.5	10	100	90	50
HST1	80	2.6	22	---	70	90

7 Discussion and Conclusion

It is a robust task to delineate new potential structural reservoirs, but Sequence Stratigraphy plays an important role in hydrocarbon exploration plans . By understanding global changes in sea level, the local arrangement of sand, shale and carbonate layers can be interpreted.

This research first used the known Wheeler diagram to detect changes in the sedimentation process, and consequently, the boundaries of the systems tracts are found. Then the validity of this determination was fully confirmed by gamma ray well-logs. In addition to that, other logs showed similar pattern for each systems tract in all the wells, which resulted in the same characteristics of each systems tract all over its volume. Therefore, the first conclusion of this work can be that, Wheeler diagram is a powerful and reliable tool to determine three-dimensional systems tracts with homogeneous properties throughout a high quality 3D seismic data, even if the well log data is not available or not enough.

Being sure of the accuracy in determining the systems tracts, the characteristics of each systems tract are studied. To do this, the values of well-logs are found. By examining the values of all logs in the wells and according to the values listed in section 5-3, the most likely systems tracts were identified for the hydrocarbon reservoirs respectively. Each of them in the seismic volume has a variation in the thicknesses, which the three-dimensional determination of the systems tracts is the most important advantage of sequential stratigraphy. Therefore, it is concluded that in the presence of 3D seismic data and sufficient well-log data, Sequence Stratigraphy can be considered as an independent tool for hydrocarbon exploration. Obviously, as more well-logs are available, further details of the characteristics of the systems tracts under consideration will be revealed.

The best candidate systems tracts for hydrocarbon bearing are respectively as follows:

1. Systems tract (TST 1): The depth range of this systems tract is from the top of the Sarvak formation to its middle part. Given the values of the gamma ray and sonic logs, the lithology of this systems tract is mainly found as sandstone and less as dolomite. Porosity logs in this systems tract show good values for having a good quality reservoir. Moreover, in the middle part of this systems tract, high values of resistivity and low level of water saturation were observed, which could be regarded as an indication of the presence of hydrocarbons.

2. Systems tract (LATE LST 3): The depth range of this systems tract begins at the top of the Asmari formation and includes about one third of top of this formation. Given the values of the gamma ray and sonic logs, the lithology of this systems tract is mainly estimated to be sandstone. Porosity logs in this systems tract show suitable values for having good quality reservoir. In addition, in the upper part of the systems tract, high values of resistivity and relatively low values of water saturation were behold, which could be considered as an indication of the existence of hydrocarbons.

3. Systems tracts (LATE LST 1): The depth range of this systems tract is from the mid-Sarvak formation to the top of the Kazhdumi formation. Compared to TST 1, the porosity logs show lower values and water saturation logs show higher values in this systems tract. However, the values of gamma ray and density logs are very similar to TST 1, and the high values of resistivity log make it possible to see hydrocarbon in the systems tract.

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