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## Comparison of variations in sediment accumulation rates of the upper part of Zakeen Formation through cyclostratigraphic study in 2SK-1 and 2SKD-1 wells in Salman gas field

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### Abstract

The Zakeen Formation is one of the possible gas reservoirs in the Zagros sedimentary basin. In this paper, the cyclostratigraphic study of the upper part of the Zakeen Formation was performed by using evolutionary spectral analysis methods. The Multi-Tapper Method (MTM) periodogram is one of the evolutionary spectral analysis methods used in this study to identify and prove the frequency ratios of Milankovitch cycles in the studied sediment sequences. In this study, using the introduced methodology, the frequency ratios of the Milankovitch cycles in the upper part of the Zakeen Formation was identified for the first time, and their existence was confirmed. Besides, the spectral powers of spectral gamma-ray (SGR) and density (RHOB) series, in evolutionary Fast Fourier Transform (FFT) and Wavelet Transform (WT) Scalograms, in 2SK-1 and 2SKD-1 wells of Salman gas field show strong astronomical signals of the Milankovitch cycles (E, e, O, P). After investigating the cyclostratigraphy of the upper part of the Zakeen Formation in the studied wells, by using new methods of evolutionary correlation coefficient and evolutionary significance levels, comparison of sediment accumulation rate variations of the Zakeen Formation was performed in the studied wells.

**Keywords:** Cyclostratigraphy, Sediment accumulation rate, Milankovitch cycles, Zakeen Formation, Salman gas field

### Introduction

The Zakeen Formation is a clastic succession and in its type section at Faraghan Mountains, north Bandar-Abbas, has 285 m thickness. It is composed of sandstones, shales, and with several dolostones horizons (Ghavidel-Syooki 1999). The Zakeen Formation, based on palynological studies by Ghavidel-Syooki (1999 & 2003), is attributed to the early to late Devonian (Lochkuvian to Frasnian). In this study, only the Frasnian sequence of the upper part of the Zakeen Formation in 2SK-1 and 2SKD-1 wells of the Salman gas field was studied. Cyclostratigraphic studies were also focused primarily on proving the existence of Milankovitch cycles in sedimentary sequences, determining timelines, calculating sediment accumulation rates and stratigraphic classifications (Zheng & Luo 2004; Li et al. 2018a; Chen et al. 2019). To compare the sediment accumulation rates of the upper part of the Zakeen Formation in the studied wells, cyclostratigraphy study was first performed to show the existence of the Milankovitch cycles and the way they affect the upper part of the Zakeen Formation. The spectral analysis methods together with density and spectral gamma-ray logs data were used to study the cyclostratigraphy of the studied formation. Milankovitch (Serbian scientist) has calculated the

duration of the three main parameters of the Earth's orbit around the sun that affect global climate change, known as eccentricity, obliquity, and precession, and these are referred to Milankovitch cycles (Milankovitch 1941; Fletcher 2013). Cyclostratigraphy of the Devonian system in the different parts of Earth including southern China (Gong et al. 2001; Chen & Tucker 2003; De Vleeschouwer et al. 2017), France, Morocco (Ellwood et al. 2011), Canada (De Vleeschouwer et al. 2012; De Vleeschouwer et al. 2017), Poland (De Vleeschouwer et al. 2013, 2017), Belgium (De Vleeschouwer et al. 2014, 2017), USA (De Vleeschouwer et al. 2017; Pas et al. 2018) and varying frequencies of Milankovitch cycles from the deposits of these areas have been reported. The purpose of this study is to analyze cyclostratigraphy and compare the sediment accumulation rates of the upper part of the Zakeen Formation in 2SK-1 and 2SKD-1 wells of the Salman gas field.

### Material & Methods

In this paper, by using evolutionary spectral analysis techniques (FFT spectrogram and WT scalogram) and MTM periodogram in a series of digital signal processing methods in Acycle v2.0 software (Li et al. 2018a), time series were

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extracted from SGR and RHOB logs. Afterward, their spectral powers were used in the cyclostratigraphic analysis of the upper part of the Zakeen Formation.

Milankovitch cycles recorded in the upper part of Zakeen Formation were identified using a set of evolutionary spectral analysis methods for the desired logs including MTM and subsequently analyzed in the FFT Spectrogram (Kodama and Hinnov 2015). The influence of such cycles on sedimentation of the upper part of the Zakeen Formation and their abundance in this formation at different depths from the two studied wells were studied. The WT scalogram is then used to compare statistically significant zones between time series (Grinsted et al. 2004). The frequency ratio method (Mayer & Appel 1999) was used to establish the link between the cycles identified in the sedimentary signals and the theoretical astronomical parameters.

After identifying the Milankovitch cycles in MTM periodograms, they were then extracted from the SGR logs by filtering the cycles of 405 kyr (E), 100 kyr (e), 34.4 kyr (O) and 21.3 kyr (P).

Subsequently, confidence levels with median, 90, 95, 99% levels were plotted for each MTM periodogram and almost all cycles were sampled from the median confidence level and some above 90%.

Through performing MTM periodograms, Milankovitch cycles were detected. Also, by using FFT spectrograms (reviewed by Hinnov), their influence on deposition of the upper part of Zakeen Formation and their abundance were labeled. Through the extraction of WT scalograms, high statistical significance zones were compared (correlation against E, e, O, and P cycle filters) to find the main lithological changes, probabilistically.

Finally, cyclostratigraphic results in two studied wells were investigated. Moreover, sediment accumulation rates of the upper part of the Zakeen Formation in two studied wells (2SK-1 and 2SKD-1) were estimated. Through applying evolutionary correlation coefficients and evolutionary significance levels of spectral analysis methods for the SGR logs in both wells, estimates of sediment accumulation rates of the upper part of Zakeen Formation was precisely carried out.

### Discussion of Results & Conclusions

Through plotted MTM periodograms for each well logs, the cycles ratio were identified in well 2SK-1 based on SGR MTM periodogram as 18.03, 5.63, 3.6, 2.39, 2.08, 1.58, 1.2, while with refer to RHOB MTM periodogram they are 20.8, 7.11, 4.0, 2.33, 2.0, 1.48, 1.33. This is close to the ratio of 20:5:2:1 cycles (from left to right we have the component ratio of the cycles E, e, O, and P). In contrast, in the MTM periodogram plotted for the SGR log, the ratios are 18.24, 6.08, 3.78, 2.87, 2.38, 1.55, while in MTM periodogram plotted for the RHOB log, ratios of 19.38, 6.45, 4.43, 3.6, 2.62, 2.16, 1.83, 1.49 were obtained. All ratios in two wells, being approximately equal to 20:5:2:1 and thus the relative ratios, each based on their value, are interpreted as one of the Milankovitch cycles (E or e or O or P).

In this study, by evolutionary spectral analysis methods including MTM periodograms, FFT spectrograms, and WT scalograms, cyclostratigraphy study of the upper part of the Zakeen Formation were performed in 2SK-1 and 2SKD-1 wells of Salman gas field. Evaluation of sediment accumulation rates of the upper part of Zakeen Formation in

these two wells was performed with evolutionary correlation coefficients and evolutionary significance levels. This allows them to be observed in the stratigraphic domain alongside the well log data. Based on FFT spectrograms in 2SK-1 well, three cycles including E, e and O have more effect on the sedimentation rate of the upper part of the Zakeen Formation. In 2SKD-1 well such an effect is due to four cycles comprising of E, e, O and P.

Subsequent analyses by the evolutionary correlation coefficient spectrogram plotted for the SGR log in 2SK-1 well revealed that only the E cycle affected the deposition of the upper part of the Zakeen Formation. The evolutionary correlation coefficient plotted for SGR log in 2SKD-1 well also confirmed the effect of E and O cycles on the deposition of Zakeen Formation. Other cycles with low impact on cyclic sedimentation of the upper part of the Zakeen Formation have been involved in these two wells. Sediment accumulation rates of the upper part of Zakeen Formation were estimated by time columns from cyclostratigraphy and thickness of the upper part of the Zakeen Formation for both wells by approximately 0.8 cm per thousand years. Subsequently, through the analysis of evolutionary correlation coefficients plotted for SGR logs, it was determined that sediment accumulation rates of the upper part of the Zakeen Formation in 2SK-1 wells show ascending, constant and descending trends. In contrast, in the 2SKD-1 well, sediment accumulation rates have been almost constant. In general, the sediment accumulation rates of the upper part of Zakeen Formation in 2SK-1 well are estimated more compared to 2SKD-1 well. Also, large variations in sediment accumulation rates of the upper part of the Zakeen Formation were observed in the 2SK-1 well compared to the 2SKD-1 well, indicating the occurrence of hidden effective processes for these changes.