Relation of the grain size, petrophysical parameters, and Fourier transform infrared analysis of Kusuri sandstones in the Zonguldak subbasin of the West Black Sea, Turkey

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The Zonguldak subbasin has recently attracted attention due to the identification of unexplored areas for hydrocarbon potential. Here, I present the first detailed reservoir investigation of Kusuri Formation sandstones in a well around Bartın, located in the Zonguldak subbasin of the West Black Sea. I employed an integrated approach that includes petrography, well logging, petrophysical analysis, and Fourier transform infrared analysis for reservoir characterization. The purpose of this study is to investigate the relation of the grain size, petrophysical parameters, and Fourier transform infrared analysis of Kusuri sandstones. The Kusuri Formation sandstones are divided into three groups based on their grain size using petrographic analyses. Group 1 is composed of 0.4-0.6 mm grains, group 2- of 0.3 mm grains, and group 3- of very fine grains (0.1-0.2 mm). Group 1 and group 2 sandstones of the Kusuri Formation exhibit medium-good petrophysical characteristics. The presence of hydrocarbons was determined using attenuated total reflection- Fourier transform infrared (ATR-FTIR) analysis. The results show that the Kusuri sandstone interval has medium-good reservoir properties and a high potential to produce hydrocarbons increasing the reserves in the study area.

Key words: Reservoir sandstone, well logs, grain size, petrophysical parameter, ATR-FTIR, hydrocarbon

INTRODUCTION

Zonguldak, Ulus, Devrek, Sinop, and Bolu subbasins, are parts of the West Black Sea Basin [1]. The Zonguldak subbasin extends between Ereğli and Amasra, parallel to the Black Sea. Currently, no studies have addressed the petroleum potential of the Zonguldak subbasin in the Western Black Sea region.

Hydrocarbons are produced from deltas in many parts of the world [2-7]. Kusuri Formation sandstones in the Zonguldak subbasin might have been deposited in a delta environment and the delta sandstones formed important oil reservoirs [8].

The Kusuri Formation is composed of dark gray shale and sandstone (Fig. 1). Well log data suggest that the thickness of the sediments in the Zonguldak subbasin is up to 8000 m. The thickness of the Kusuri Formation was measured as 3900 m in the Zonguldak subbasin [8]. The unit has reservoir rock features and contains porous sandstone.

This is the first study on a delta using well logs, petrographic, petrophysical properties, attenuated total reflectance-Fourier transform infrared (ATR-FTIR) spectroscopy analysis, and scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) analyses in the Kusuri Formation.

In this study, the reservoir characteristics of the Kusuri Formation sandstones in a well drilled in the Zonguldak subbasin (around Bartın), were investigated.

The aim of the study is to (1) determine the grain size of the Kusuri Formation sandstones, (2) evaluate the petrophysical parameters (porosity and permeability) of the sandstones, (3) well log interpretation, (4) determine the presence of organic matter (5) determine the clay minerals, and (6) determine the reservoir quality.

MATERIALS AND METHODS

Cores and logs from a well in the Zonguldak subbasin of the West Black Sea Basin were studied. Petrographic analysis was performed on 25 thin sections obtained from subsurface core samples. The grain size was measured using an optical microscope-ocular micrometer [9] from 20 thin sections by 300-point counts. Five core samples were analysed using a scanning electron microscope-energy dispersive spectrometer at the METU laboratories, Turkey. Porosity and permeability analyses to determine the reservoir rock quality of the Kusuri sandstones could not be performed using porosimeter and permeameter devices and cylindrical core samples due to the dispersive properties of the sandstones.

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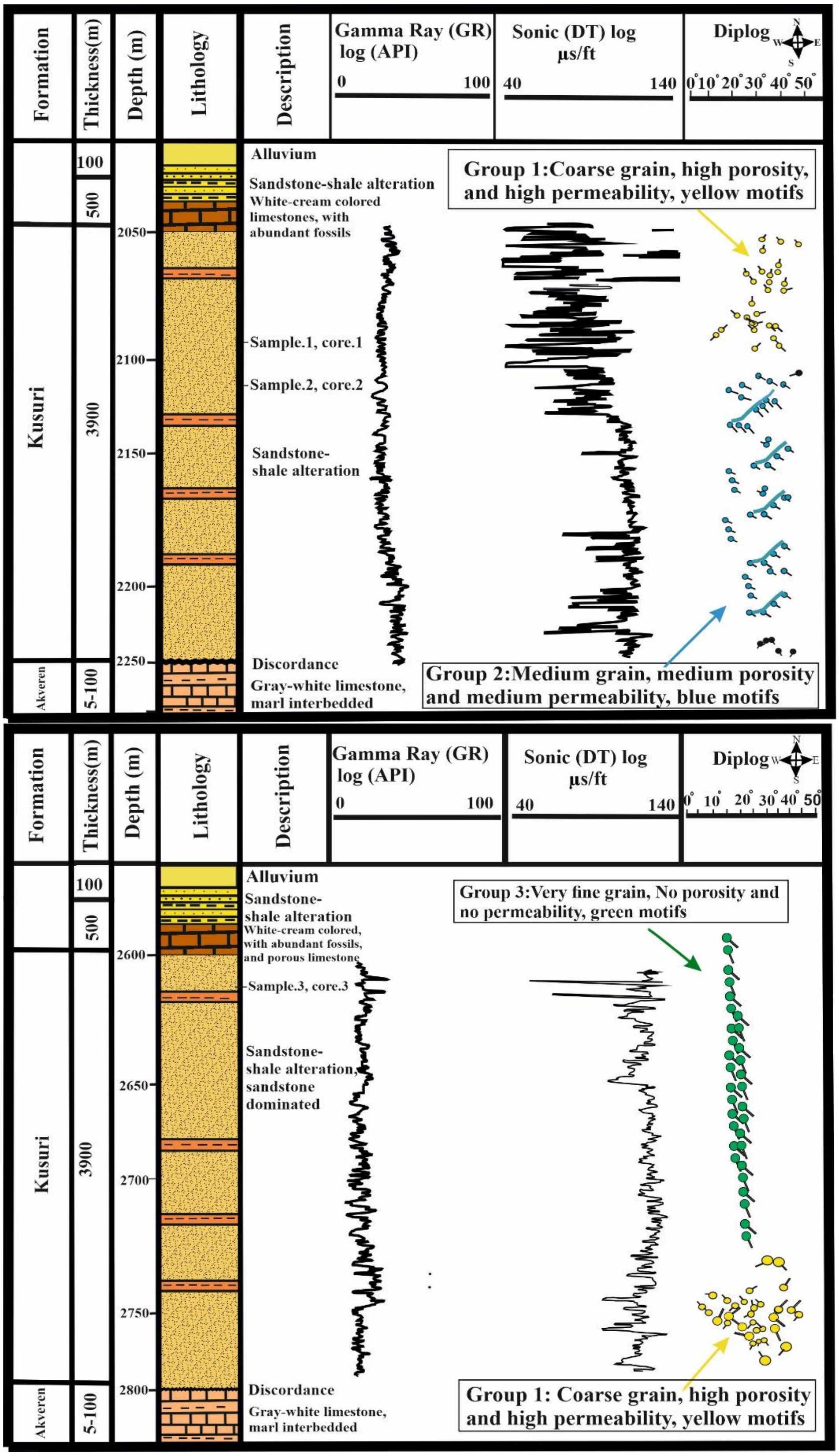


Fig. 1. Well logs (GR, DT, and Diplog) of the Kusuri Formation sandstones

Porosity and permeability were determined by Sonic logs only. The presence of hydrocarbons can be determined using FTIR analysis [10, 11]. The samples from the Zonguldak subbasin were analyzed using the ATR-FTIR method in this study for the first time. FTIR analysis was performed on core samples at the METU laboratories in Turkey.

Log measurements were performed in a well for the Kusuri sandstones in the studied basin (Fig. 1). Well logs were interpreted for a well of the West Black Sea, and the data were used to determine depositional characteristics, namely, laminations, grading, grain size, porosity, and permeability of the reservoir sandstones [8].

The reservoir properties of Kusuri sandstones were determined from gamma ray (GR), sonic (DT), and dipmeter (DIP) logs according to [12].

The shale (clay) volume V_{sh} in the Kusuri sandstones was calculated using the following equation [13]:

$$\mathrm{V_{sh}} = \frac{\mathrm{GR_{log}} - \mathrm{GR_{min}}}{\mathrm{GR_{max}} - \mathrm{GR_{min}}} \tag{1}$$

where GR_{log} is the average gamma ray log value, GR_{min} is the gamma ray minimum value, and GR_{max} is the gamma ray maximum value.

The effective porosity (ϕ_{ef}) of the Kusuri sandstones was calculated using the following equation [13]:

$$DT_{cor} = DT - \frac{V_{sh} * DT_{sh}}{(1 - V_{sh})} \tag{2}$$

where DT_{cor} is the corrected sonic log value for shaley sand, DT is the sonic log value, V_{sh} is the shale volume, DT_{sh} is the sonic maximum value for the shale sand zone, and $DT_{cor} = \phi_{ef}$.

The permeability (K) of the Kusuri sandstones was calculated using Timur's equation [14] at irreducible water saturation as follows:

$$K(mD) = \frac{0.136 * \emptyset_{ef}{}^{4.4}}{S_w{}^2} \tag{3}$$

where K is the permeability, ϕ_{ef} is the effective porosity, and S_w is the irreducible water.

Sandstone porosity was estimated using the sonic log of the well. Porosity can be determined using the sonic (DT interval transit time; microsec/ft) – porosity (ϕ_{ef}) crossplots [12].

In oil research, the sandstone grain size of rocks passing in a well can be determined by interpreting dipmeter logs [15]. These logs are indicated by pin-shaped symbols that vary depending on the depth in boreholes. The tip of the pin-shaped symbol indicates the direction of the dip, while the circular head of the pin gives the amount or angle of the dip. The displacement of the symbol to the right represents the magnitude of the dip angle.

In dipmeter logs, various symbols are named red, green, yellow or blue (Fig. 1). The amount of slope in the blue motif decreases depending on the depth and indicates the layers formed by medium grain sandstone. Mixed motifs inclined in all directions in the yellow motif indicate coarse grains such as conglomerate and sandstone. In green motifs, on the other hand, the amount of dip does not change, indicating a laminated low-energy environment such as very thin sandstones-shale according to [15] (Fig. 1).

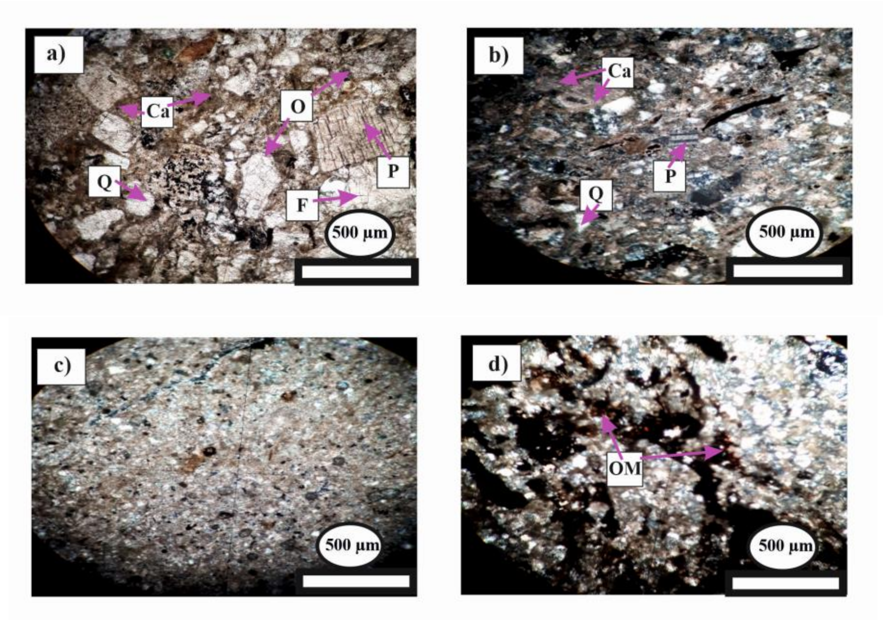
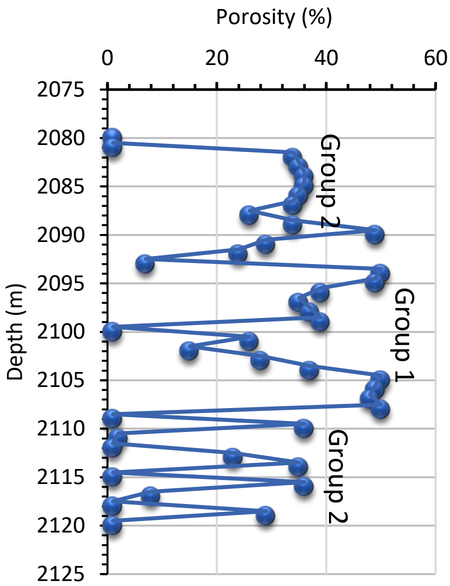


Fig. 2. Microphotographs of the Kusuri Formation sandstones. a) Group 1 sandstones Core number: 1. Depth: 2095.0 m b) Group 2 sandstones Core number: 2. Depth: 2115.0 m. c) Group 3 sandstones Core number: 3. Depth: 2610.0 m d) Organic matter smears (OM). Core number: 3. Depth: 2610.0 m. Double nicol.

RESULTS AND DISCUSSION

Petrographic analysis of the sandstones

Petrographic analysis of the Kusuri sandstones was performed on 25 thin sections obtained from core samples using optical microscopy. The Kusuri sandstones were divided into three groups based on their grain size using petrographic analyses. Group 1 contains medium-coarse grain sizes (0.4-0.6 mm) and medium well-sorted grains (Fig. 2a). Quartz (Q), orthoclase (O), plagioclase (P) minerals, fissure (F), carbonate cement (Ca, early calcite cement) are observed in the photograph. It is seen that the carbonate (Ca) mineral closes the pores (Fig. 2a).



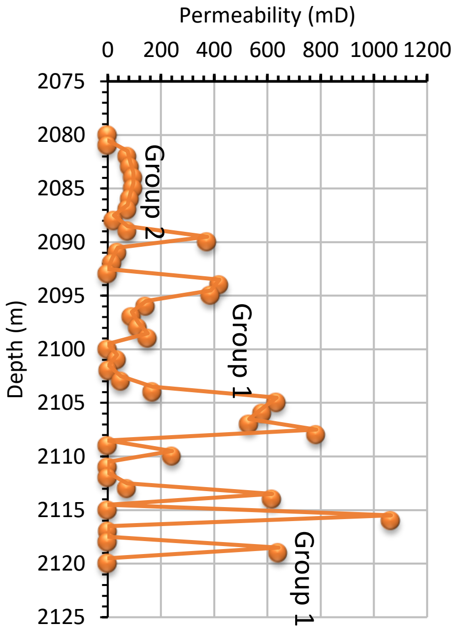


Fig. 3. Porosity and permeability *versus* depth for Kusuri Formation sandstones

Group 2 contains medium sized (0.3 mm) and medium-sorted grains (Fig. 2b). Quartz (Q) and plagioclase minerals (P) and carbonate cement (Ca, early calcite cement) are observed in the photograph (Fig. 2b).

Alternatively, group 3 has a very fine grain size (0.1-0.2 mm) (Fig. 2c) and does not exhibit reservoir features. In Fig. 2d, organic matter (OM) smears were observed.

Reservoir features of the sandstones

The porosity values of the Kusuri Formation sandstones are between 35% and 50% for Group 1 sandstones and 20-35% for Group 2 sandstones (Fig. 3). Similarly, permeability values range between 400-660 mD for Group 1 sandstones and 100-400 mD for Group 2 sandstones (Fig. 3).

Yellow motifs which show coarse grain in Dip logs have high porosity and high permeability. Blue motifs which denote medium grain in Dip logs have medium porosity and medium permeability. Green motifs which correspond to small grains show no porosity and no permeability (Fig. 1).

The Kusuri Formation Group 3 sandstones exhibit the worst reservoir characteristics, which is attributable to the very fine-grains, poorly sorted. In Group 1 and Group 2 sandstones, primary intergranular and mostly fractured crack porosities were dominant. Accordingly, it can be assumed that Group 1 and Group 2 have medium-good reservoir potential. Although the primary porosity decreases by closing the pores of early calcite cement and clay minerals (illite, kaolinite) (Fig. 4), fracturing of grains can be considered in positive terms of reservoir quality.

It can be said that the sandstones (Groups 1 and 2) of the Kusuri Formation are of medium to good quality, considering the grain size using petrographic properties, according to the porosity-permeability classification of Levorsen [16].

FTIR analyses

In this study, bituminous shale samples were analysed by FTIR spectroscopy using the ATR technique (Fig. 5). FTIR spectra were evaluated according to [17]. In the FTIR spectrum of the group 3 sample, structural hydroxyl peak at 3618 cm^{-1} was observed (Fig. 5a). The Si-O stretching of quartz was determined at 779 cm^{-1} and 798 cm^{-1}. Characteristic CO_3 peaks of calcite were observed at 712 cm^{-1} and 873 cm^{-1}. The peak at 462 cm^{-1} corresponds to Si-O-Si deformation. Aromatic C-H peaks were observed at 695 cm^{-1}, 984 cm^{-1}, and 1164 cm^{-1} (Fig. 5a).

The FTIR spectrum of the group 2 sample showed a structural hydroxyl peak at 3620 cm^{-1} (Fig.

5b). Si-O stretching of quartz minerals was observed at 779 cm^{-1} and 798 cm^{-1}. The CO_3 peaks at 712 cm^{-1} and 873 cm^{-1} showed the presence of calcite. The peak at 462 cm^{-1} corresponds to Si-O-Si deformation. Aromatic C-H peak was observed at 992 cm^{-1}. The $CH=CH_2$ peaks of alkenes were observed at 1418 cm^{-1} and 1634 cm^{-1} (Fig. 5b).

In the FTIR spectrum of the group 1 sample, a structural hydroxyl peak at 3627 cm^{-1} was observed (Fig. 5c). Si-O stretching of quartz minerals was determined at 779 cm^{-1} and 798 cm^{-1}. The CO_3 peaks of calcite mineral were observed at 712 cm^{-1} and 873 cm^{-1}. The peak at 460 cm^{-1} corresponds to Si-O-Si deformation. Aromatic C-H bonds were observed (695 and 992 cm^{-1}). In addition, the $CH=CH_2$ peak of alkenes was observed at 1418 cm^{-1}. (Fig. 5c).

Aromatic C-H bonds are the main hydrocarbon functional groups in the FTIR spectra of the samples (Fig. 5). The permeabilities of Group 1 sample, Group 2 sample, and Group 3 sample were 550 mD, 350 mD, and 0.1 mD, respectively. Samples with greater permeability displayed lower hydrocarbon peaks than those with lower permeability in the FTIR spectra, similar to that observed by Büyükutku *et al.* (2020) [8]. The aromatic C-H peaks and $CH=CH_2$ peaks of alkenes indicate the presence of unsaturated hydrocarbons. According to FTIR analysis, it was concluded that the shales of the Kusuri Formation contain organic matter and they are in the aromatic structure.

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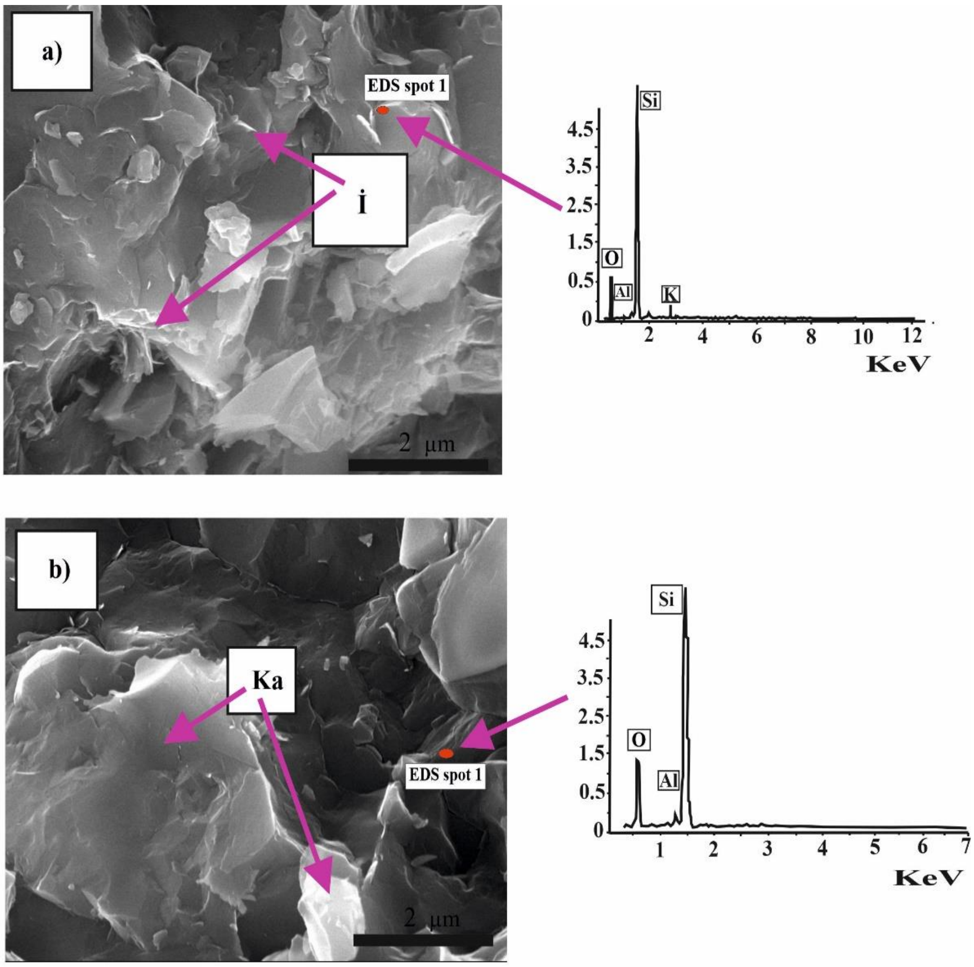

Fig. 4. SEM microphotographs of Kusuri formation. a) In the photograph, illite clay minerals (I) are observed in an acicular form. The K peak is dominant in the EDS graph. Core number: 2. Depth: 2115.0 m. b) Kaolinite clay minerals (Ka) are observed in the form of booklets. In the EDS graph, it is observed that Al, Si and O peaks are dominant. Core number: 2. Depth: 2115.0 m.

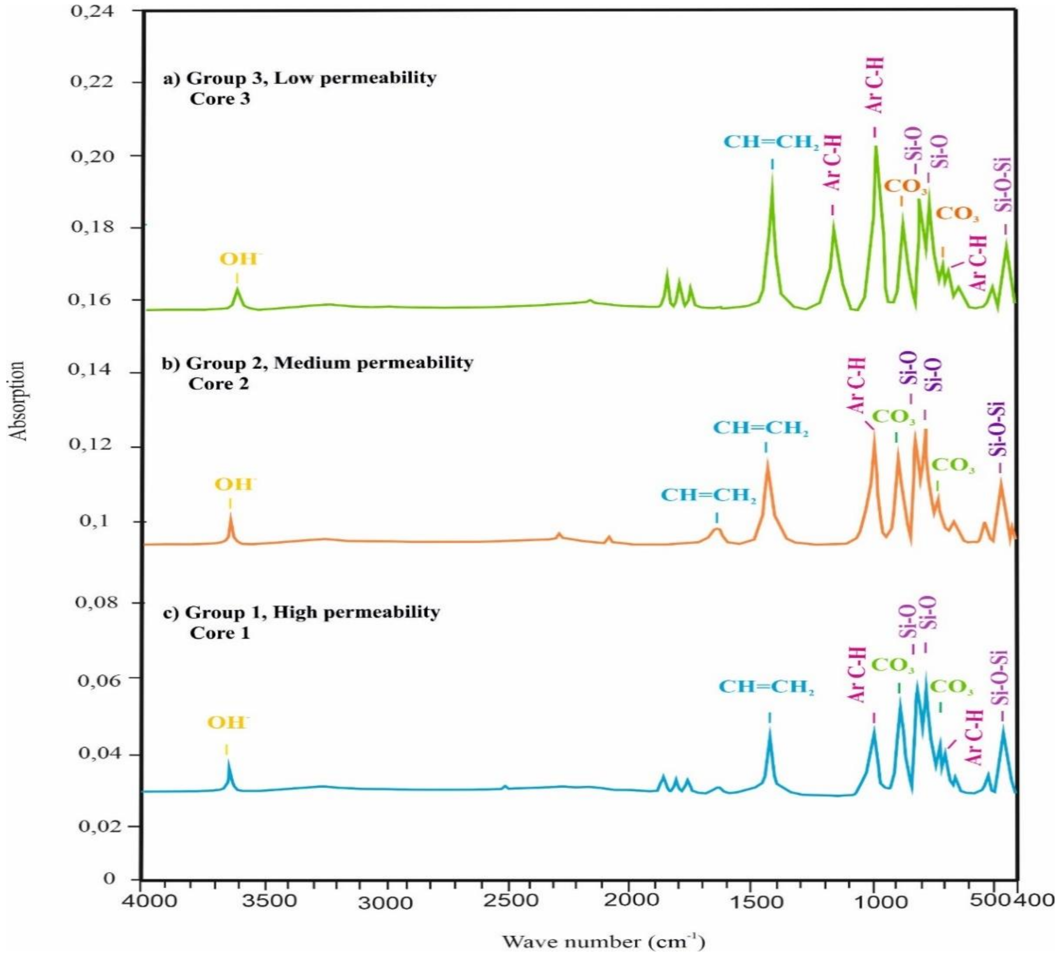

Fig. 5. FTIR spectra

CONCLUSIONS

In this study, Kusuri Formation sandstones with gas potential in the Zonguldak subbasin were investigated. A reservoir characterization was carried out by combining petrographic analysis and log-based petrophysical assessment (porosity and permeability values). According to the ATR FTIR analyses performed on the shale samples of the Kusuri Formation, the presence of organic matter and aromatic hydrocarbons was established.

The present study quantitatively analyses Kusuri sandstone sediments as regards their reservoir potential. Here, I present the first detailed reservoir investigation of Kusuri sandstones. This is the first-ever work from the studied field that presents a detailed petrographic and petrophysical investigation of different groups (Group 1, Group 2, and Group 3 sandstones) to imply the grain size, presence of organic matter, clay minerals, and reservoir quality. The porosity and permeability of the Kusuri sandstones are controlled by clay minerals and early calcite cement. It was observed that clay and early carbonate cement reduce the porosity and permeability. As fracture porosity was observed in the petrographic sections of the Kusuri sandstones, the reservoir rock porosity and reservoir quality increased. In the Kusuri Formation sandstones, Group 3 sandstones do not display a reservoir character, whereas Group 1 and 2 sandstones show moderate-good reservoir characteristics according to porosity and permeability values. According to FTIR analysis, it was determined that the Kusuri Formation shales contain organic matter that displays aromatic structure and gas formation.

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