CHARACTERISTICS OF UPPER TRIASIC SANDSTONE RESERVOIRS IN SYRIA USING ANALYSIS OF LABORATORY METHODS

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Abstract. The Upper Triassic sandstones of gas-oil reservoirs of Euphrates Graben in Syria are characterized by certain mineralogical characteristics, conditioned by the processes of sedimentogenesis and diagenesis. In the course of the analytical work, it was possible to establish the nature of minerals composing sandstones and their impact on the porosity of rocks. So, for example, a good sorting of detrital grains and their substantial quartz composition is an important factor determining the increased values of porosity. On the other hand, the increased content of clay and authigenic minerals (more than 10-15%) reduces the porosity of rocks studied.

Methods of optical microscopy, X-ray diffraction, electron microscopy and chemical analysis were used when describing sandstone. It is shown that the studied sandstones are quartz. Clay minerals, authigenic quartz and carbonates with a small fraction of amorphous material serve as cementitious material of detrital grains.

Studies with a scanning electron microscope in conjunction with dispersive X-ray spectroscopy have shown that quartz is clastic and amounts to an average of 70%, and up to 10% of authigenic quartz is also present in the samples. The same studies show differences in the morphology of quartz, which are found in all samples.

Key words: sandstone, research methods, Euphrates Graben, Upper Triassic, Syria

DOI: https://doi.org/10.18599/grs.19.4.8

For citation: Yousef I.M., Morozov V.P. Characteristics of Upper Triasic Sandstone Reservoirs in Syria Using Analysis of Laboratory Methods. *Georesursy = Georesources*. 2017. V. 19. No. 4. Part 2. Pp. 356-363. DOI: https://doi.org/10.18599/grs.19.4.8

1. Introduction

The purpose of the study was to assess the mineral composition of sandstones and its effect on the porosity of the Upper Triassic gas-oil reservoir, called the Mulussa F Reservoir (MUF). It serves as an important hydrocarbon exploration site in the Middle East in Syria. The discovered gas-oil fields in the Euphrates Graben are an important source of hydrocarbons (De Ruiter, 1995). The MUF reservoir has a thickness of 450 m (Figure 1). It is composed mainly of medium- and coarse-grained fluvial gas- and oil-saturated sandstones, interbedded with floodplain mudstones, lagoon and shallow marine dolomite shales and dolomites, which are most developed in the lower and upper parts of the reservoir. Due to the large gas and oil saturation of the Upper Triassic sandstones, they serve in the region as the main object of hydrocarbon exploration in the Euphrates Graben, as well as their production.

2. Research methods

The data of core material research are used in the work. 55 samples of sandstones were selected from 11 wells that penetrated Upper Triassic Euphrates Graben deposits in the depth range from 1.6 to 4 km. Samples were characterized using, in our opinion, optimal methods of investigation: optical, X-ray, spectrometric and X-ray fluorescence analyzes (Shmyrina, Morozov, 2013). Optical-microscopic analysis served to determine the main rock-forming minerals and the structure of sandstones. X-ray analysis was used to determine the qualitative and quantitative mineral composition of the samples, which is important for the reconstruction of diagenetic rock changes and the assessment of hydrocarbon reservoir (Ferrell, 1998). Scanning electron microscopy, coupled with microprobe analysis, provided a wide range of information on the structure, morphology, chemical composition of grains, allowed estimating the spatial distribution of grains in the rock and paragenesis of authigenic minerals.

3. Results and discussion

3.1. Quartz sandstones and cementing material

Optical microscopic observations together with X-ray analysis showed that sandstone fragments take on average 80% of the rock volume, and authigenic minerals such as kaolinite, illite, chlorite, siderite, dolomite and anhydrite occupy on average of 20% of the rock volume. Most clastic grains are represented by quartz (from 50 to 90%), less frequently by debris.

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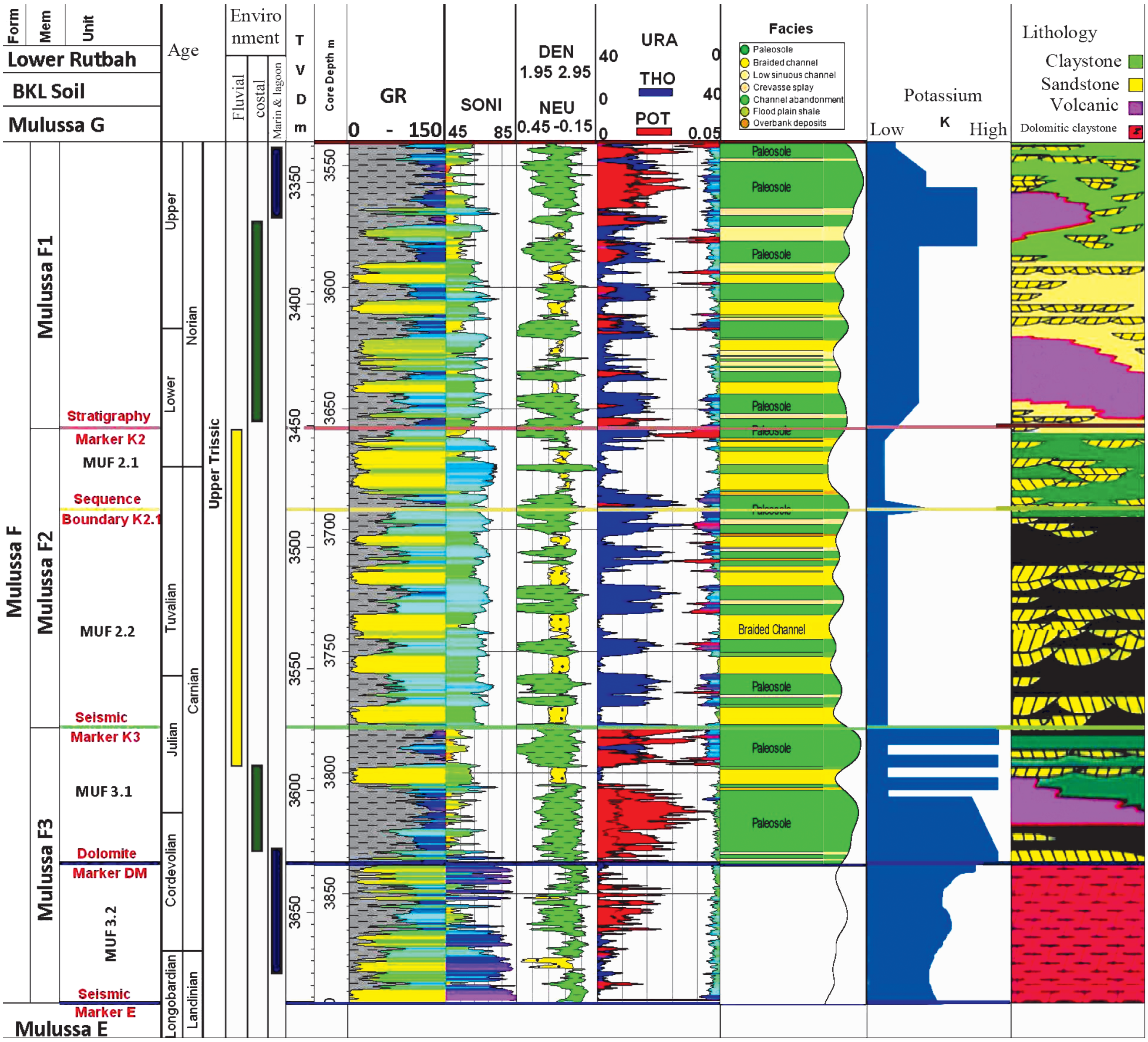

Figure 1. Lithology section of the upper Triassic deposits in the Euphrates Graben, Syria (Yousef, Morozov, 2017)

Clay material is also found in the form of separate spots and layers. It is most widely distributed in fine-grained sandstones and averages 10%. A detailed description of quartz sandstones is given in the Figure 2.

Cementing material can be quite small in them (Figure 2, a), some samples contain up to 20% of clay material (Figure 2, b) and do not refer to reservoir rocks. In other sandstones that are reservoir rocks – carbonate quartz sandstones – the content of dolomite can reach 10% (Figure 2, c), and the siderite content is also up to 10% (Figure 2, d). In the third isolated type of sandstones, the kaolinite content can also reach values of 10% (Figure 2, e).

Most clastic grains of sandstone are rounded or sub-rounded, they have a medium and coarse-grained structure and various sorting. The degree of sorting of detrital material deteriorates from fine-grained to coarse-grained sandstones.

Most clastic grains of sandstones with a low content of cement are compacted – contacts between debris are flat, concave-convex. Often regeneration is observed on the fragments of quartz. Judging by optical-microscopic observations, quartz cement is the earliest in comparison with carbonates. Most quartz grains in sandstones with a relatively high content of cement have spot contacts. The size of fragments varies from 250 to 500 μm and less often reaches 2 mm (Figure 2, f).

One of the features of most coarse-grained sandstones is the presence of clastic grains of quartz with small cracks, which are more developed in the marginal parts of grains (Figure 2, a). Among the fragments of quartz, mono-grains predominate (70%), and fragments of polycrystalline quartz-aggregates (20%) are less common. Both are characterized by corrosion of their surfaces, and for the latter, corrosion along the grain boundaries in the joints (Figure 2, f).

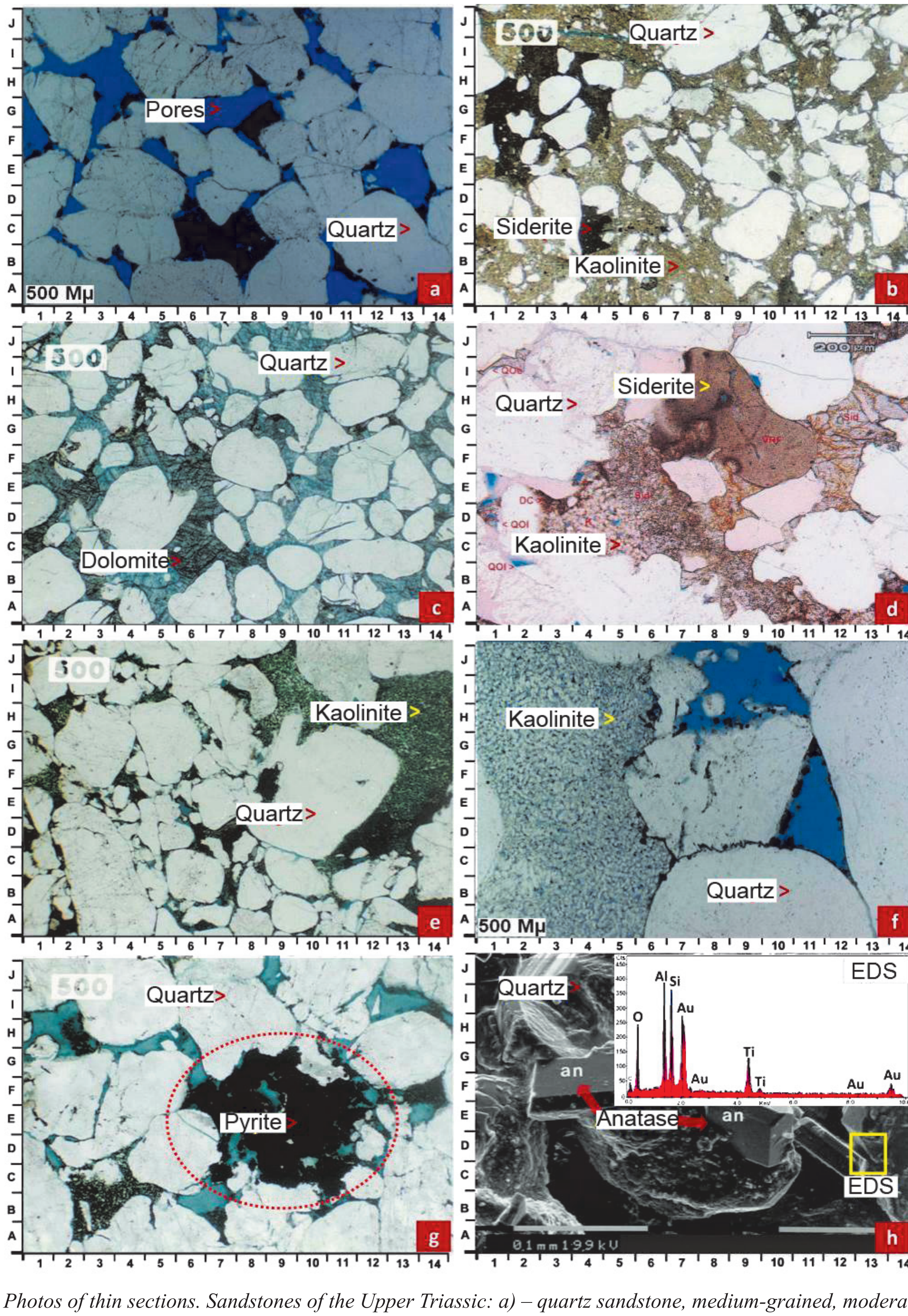

Figure 2. Photos of thin sections. Sandstones of the Upper Triassic: a) – quartz sandstone, medium-grained, moderately sorted; b) – quartz greywacke, medium-fine-grained; cement – clay material, partially replaced by siderite; c) quartz sandstone with poikillite dolomite; d) – quartz sandstone, clastic grains cement the hyppidiomorphic siderite; e) – quartz sandstone, clastic grains are cemented with vermiculite-like kaolinite; f) – dissolution (corrosion) of grains of quartz, feldspars replaced with kaolinite; g) – micro-concretion of pyrite, possibly replacing clay material; h) an electron microscopic photograph, the grains of authigenic anatase are growing on the corroded surface of clastic grains of quartz, the EDS data are given

Feldspars in sandstones are rare, mainly represented by potassium feldspar. Many grains of feldspar are fringed with chlorite and illite. During katagenesis, the feldspar grains become unstable and partially transformed into kaolinite (Figure 2, f, grain on the left). In some samples, the feldspar grains are dissolved and replaced by pyrite (Figure 2, g) or kaolinite (Figure 2, e).

Metamorphic formations are the source of quartz grains, judging by their structure. Some of the quartz grains collapsed during compaction, which can be seen from the formation of cracks in them and corrosion of the surface (Figure 2, f).

Heavy minerals are found among the accessory grains, represented by tourmaline and zircon, less often epidote and monazite. Opaque accessory minerals are clastic magnetite and/or ilmenite, less often authigenic anatase (Figure 2, h).

Clastic grains of sandstone are often cemented with clay material, the content of which can reach 10%. Clay material in some sections forms filling cement, in other sections composes bunch (spotted) cement. The sandstone voidness is formed by granular porosity; the pores are fairly well connected by channels. Some of the pores are filled with clay material, and some remain unfilled. There are pores of sedimentogenic and secondary origin, formed by the dissolution of feldspars.

3.2. Authigenic quartz and other authigenic minerals of sandstones

Authigenic quartz, occupying 1 to 13% of the volume of sandstones, is found in all samples except for those classified as quartz greywackes. Such quartz is easily detected and is represented by microcrystalline elongated pyramidal idiomorphic crystals having a dimension of about 50 μm.

They grow on grains of detrital quartz, forming in the porous space of sandstones (Figure 3, a). Often grains of such authigenic quartz form aggregates of parallel arranged grains (Figure 3, b). It can be considered that authigenic quartz as well as kaolinite and siderite plays the role of cement and clogs the pores, thereby reducing the porosity of sandstones and the connectivity of pores (Figure 3, c). Authigenic quartz in some of the samples studied has the appearance of polycrystalline intergrowths, which tend to slightly increase the surface area of host grain (Figure 3, d, e, f).

Such quartz forms radial syntactic cement, which results from dissolution and growth around detrital grains (Figure 4, a). This radial syntactic quartz form of cement connects the clastic grains and blocks the pores or fills them (Figure 4, b). In the samples under the electron microscope authigenic quartz has a size from 50 to 100 μm (Figure 4, c). This mineral is associated with hematite, which forms thin arcs around detrital grains, indicating that authigenic quartz is formed later on hematite (Figure 4, d). In some intervals of the section, sandstones contain up to 2-7% of anhydrite (Figure 4, e), which forms poikillite cement and is distributed randomly in the pore space. Sandsite is sometimes found in sandstones, the content of which can vary from 1 to 23%. Its grains are found in the pores and have sizes from a few microns to 150 μm. They form spherical aggregates <2.5 mm in size (Figure 4, f). Siderite can also be found in the form of poikillite cement or in the form of concretions filling the voids. The relationship between sideritic cement with authigenic quartz shows that siderite is a later mineral (Figure 4, g) (Worden, 2003).

3.3. X-ray analysis

X-ray analysis was performed for many samples of sandstones. Diffractograms (Figure 5, 1-5, Table 1) shows the mineral composition of sandstone samples. Analysis of diffractograms showed that quartz is the main mineral present in all the samples studied. Its content is from 42 to 80%. The content of other minerals is less: potassium feldspar, mica, albite, kaolinite. Dolomite, siderite, barite, pyrite, halite are also found.

The content of kaolinite can reach 25%. The high content of kaolinite in sandstones most likely indicates intensive chemical weathering in a warm, moist climate during sedimentogenesis (Ketzer, 2003). According to sedimentological data, we believe that kaolinite has a detrital origin, mainly inherited from the original rocks, subject to intensive chemical weathering in a humid warm climate. It was transported and deposited in river surroundings (Burley, 1993).

Limited occurrences of chlorite and illite may indicate the interruption of humid sedimentation by short periods of drought, which contribute to limiting chemical weathering (Bellon, 1994). Some samples contained siderite, dolomite, anhydrite, calcite and pyrite in different proportions (Table 1). We assume that the named minerals were formed during sedimentogenesis (calcite) and diagenesis (siderite, anhydrite, dolomite and pyrite).

In addition, scanning electron microscopy associated with the EDS analysis of elements (EDS graphs) showed the essential presence of Si, Al, Ti, Fe, Ca, S, Mg and O that composes quartz, layered silicates, anatase, siderite, pyrite, dolomite, kaolinite, anhydrite.

3.4. X-ray fluorescence analysis

The analysis showed that in the sandstones the greatest content is of SiO_2 (mainly quartz) with an average value of about 62.52% (Table 2). The analysis also confirmed the electron microscopy data, i.e. presence of iron oxide in the samples. The results of analysis carried out for different samples show that

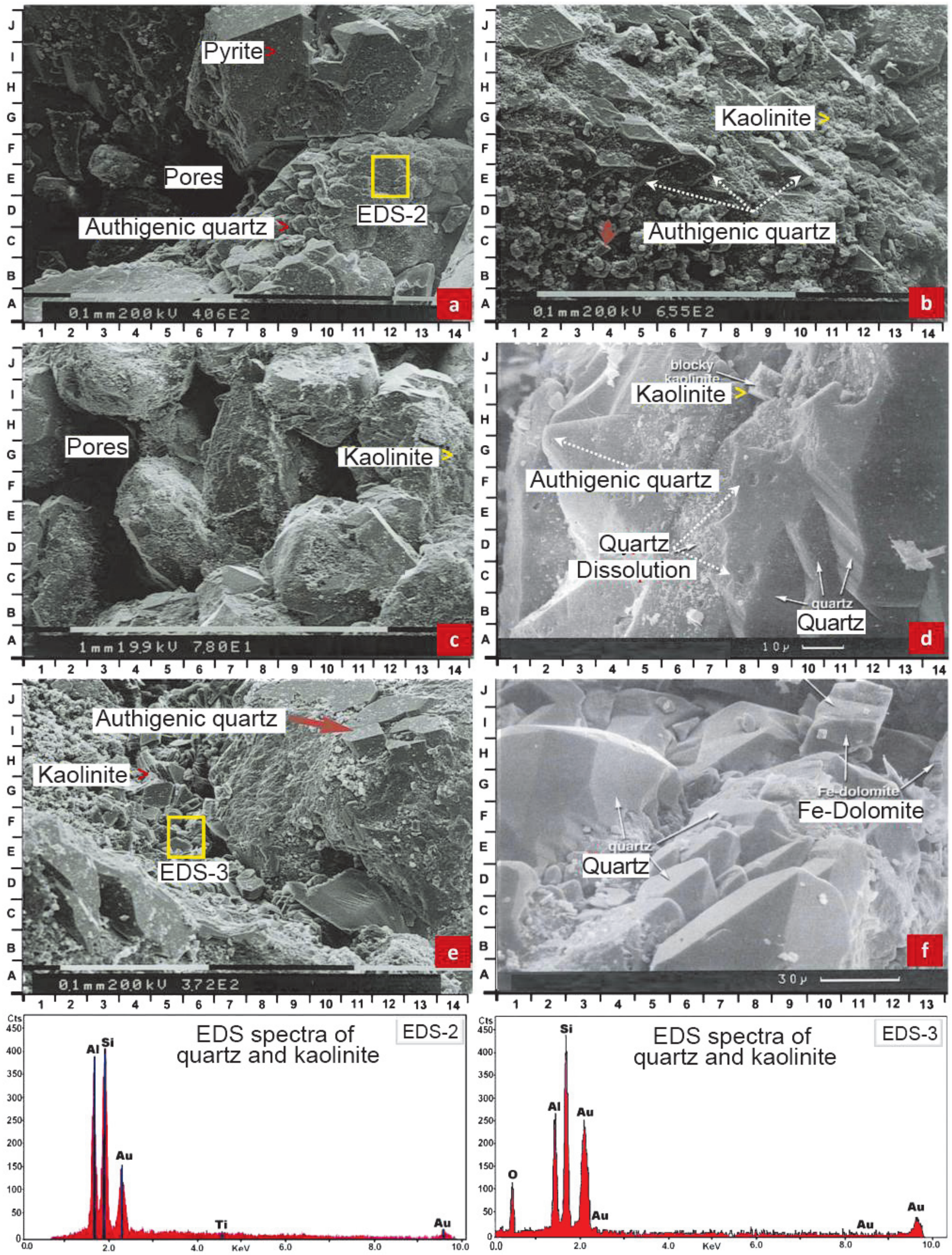

Figure 3. Electron microscopic photographs of sandstones and EDS spectra (below): a) – columnar growths of authigenic quartz crystals covering the pores; b) elongated pyramidal quartz growths growing on detrital grains; c) intergranular porosity, partially overgrown with quartz cement; d) – tabular crystals of authigenic quartz, growing on fragments; e) tabular, leafy growth of authigenic quartz; f) idiomorphic grains of authigenic quartz filling the void space

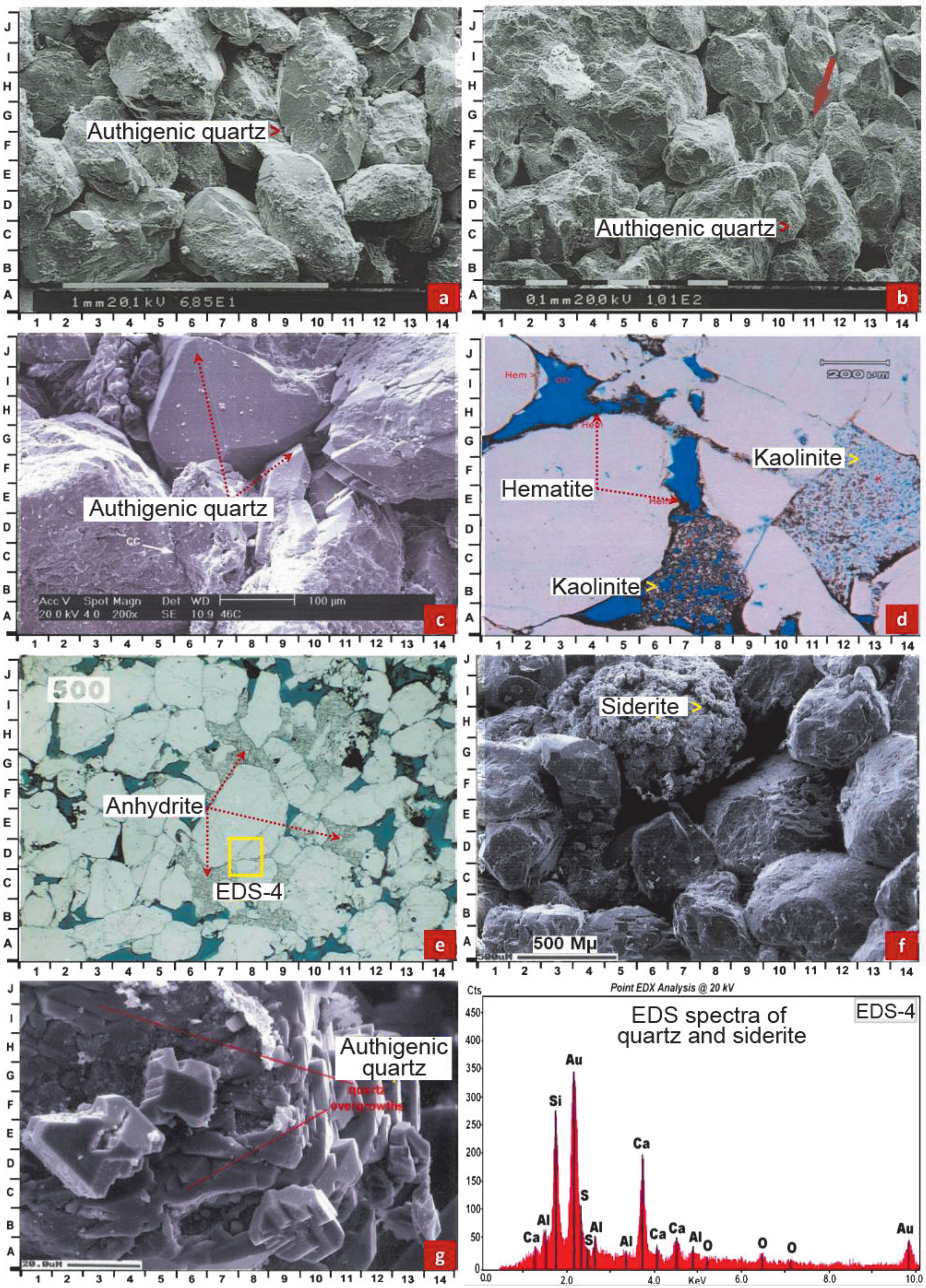

Figure 4. Photos of thin sections, electron microscopy and EDS spectrum. Sandstones: a, b) – accretion of quartz, clogging pores; c) – prismatic hyppidiomorphic crystals of authigenic quartz; d) pores partially filled with hematite and kaolinite; e) – poikillite anhydrite cement; f) – concretion of siderite; g) – grains of clastic quartz, covered with authigenic quartz and siderite crystals

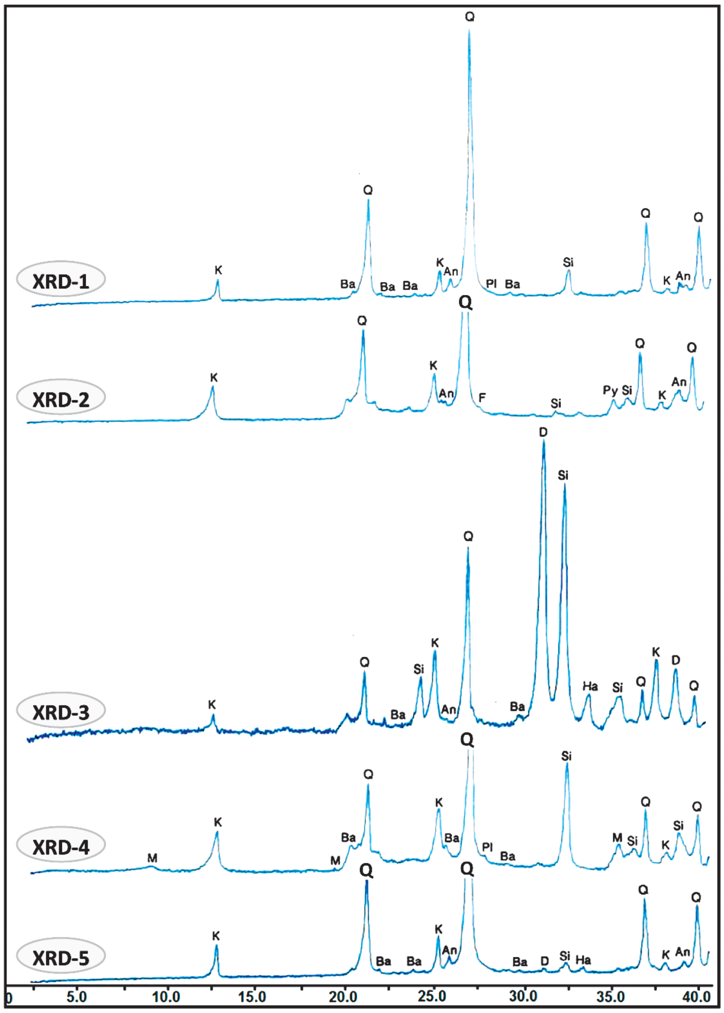

Figure 5. Diffractograms of sandstones and their quantitative mineral composition

Sandstone, analysis of rocks						
Symbol / Sample		XRD-1	XRD-2	XRD-3	XRD-4	XRD-5
M	Mica	(-)	(-)	(-)	4.21	(-)
K	Kaolinite	7.40	14.14	7.66	8.14	11.20
Q	Quarz	81.20	77.49	43.24	67.65	81.18
F	Fieldspar	(-)	1.18	(-)	(-)	(-)
D	Dolomite	(-)	(-)	26.15	0.00	1.66
Si	Siderite	3.53	2.14	17.64	16.69	1.22
An	Anhydrite	2.11	1.22	1.00	(-)	1.33
Ba	Barites	3.14	2.54	2.12	3.01	2.23
Py	Pyrite	(-)	0.84	(-)	(-)	(-)
Pl	Plagioclase	2.30	(-)	(-)	(-)	(-)
H	Halite	(-)	(-)	2.01	(-)	1.02

Table 1. Mineral composition of sandstone samples

sandstones contain up to 5% Fe_2O_3. In single cases, its content exceeds 5%.

In all samples, the proportion of SiO_2 and Al_2O_3 is quite significant, which indicates the presence of quartz and clay minerals in them.

On the other hand, the increased values of Fe_2O_3, MgO, CaO are probably related to the presence of hematite, siderite, dolomite and calcite.

4. Conclusion

The work shows the mineral composition of the Upper Triassic sandstones (Euphrates Graben, East Syria). In the course of the analytical work, it was possible to establish the nature of minerals composing sandstones and their impact on the

Sample	Si02	Al203	Fe203	MgO	CaO	MnO	MgO	CaO	K20	Ti02	MnO	P205	LOI	Total
S 1	69.93	16.22	2.09	1.24	0.18	0.003	1.24	0.18	4.62	1.42	0.003	0.009	2.01	99.145
S 2	68.85	14.22	3.22	1.79	1.68	0.033	1.79	1.68	3.64	1.22	0.033	0.008	1.02	99.184
S 3	79.01	14.32	2.23	0.2	0.08	0.002	0.2	0.08	0.21	2.06	0.002	0.055	1.36	99.809
S 4	58.65	28.13	7.77	0.36	0.16	0.013	0.36	0.16	0.96	1.63	0.013	0.136	1.24	99.582
S 5	66.91	13.61	1.31	1.05	0.15	0.121	1.05	0.15	2.2	0.78	0.121	0.057	1.65	89.159
S 6	74.73	13.3	0.62	0.4	0.09	0.023	0.4	0.09	1.11	1.1	0.023	0.015	1.48	93.381
S 7	78.02	15.12	2.58	0.09	0.05	0.001	0.09	0.05	0.26	1.92	0.001	0.032	1.39	99.604
S 8	68.81	21.24	1.99	0.49	0.09	0.001	0.49	0.09	2.03	2.31	0.001	0.026	1.58	99.148
S 9	70.88	22.18	1.19	0.29	0.09	0.001	0.29	0.09	0.78	1.92	0.001	0.014	1.78	99.506
S 10	75.69	12.78	2.48	0.96	0.09	0.001	0.96	0.09	3.1	1.17	0.001	0.043	2.15	99.515
S 11	74.41	13.16	3.37	1.04	0.12	0.002	1.04	0.12	3.37	1.19	0.002	0.024	2.01	99.858
S 12	68.98	15.77	4.18	1.47	0.15	0.002	1.47	0.15	4.4	1.28	0.002	0.002	1.65	99.506
S 13	68.27	15.24	4.71	1.48	0.17	0.002	1.48	0.17	4.41	1.28	0.002	0.009	1.89	99.113
S 14	70.76	14.47	5.89	1.06	0.14	0.003	1.06	0.14	3.41	1.36	0.003	0.018	1.67	99.984
S 15	82.9	11.46	1.23	0.35	0.05	0.002	0.35	0.05	1.02	1.19	0.002	0.018	1.25	99.872
S 16	78.74	15.29	0.94	0.11	0.07	0.004	0.11	0.07	0.08	1.93	0.004	0.067	1.89	99.305
S 17	65.69	23.71	2.77	0.64	0.19	0.003	0.64	0.19	1.9	1.87	0.003	0.02	1.68	99.306
S 18	71.88	15.98	2.77	0.84	0.21	0.002	0.84	0.21	2.93	1.51	0.002	0.012	2.33	99.516
S 19	63.71	17.9	2.73	2.26	0.72	0.006	2.26	0.72	5.42	1.41	0.006	0.002	2.14	99.284
S 20	70.51	14.05	1.87	2.18	0.93	0.042	2.18	0.93	3.95	1.08	0.042	0.08	2.15	99.994
S 21	64.51	13.56	2.86	3.12	3.53	0.087	3.12	3.53	3.4	1.11	0.087	0.06	0.6	99.574
S 22	74.89	13.96	2.59	0.93	0.12	0.001	0.93	0.12	3.19	1.35	0.001	0.023	0.99	99.095
S 23	59.34	13.95	3.96	3.15	4.021	0.065	3.15	4.02	4.04	1.01	0.065	0.01	0.12	96.901
S 24	77.75	12.93	2.21	0.71	0.14	0.002	0.71	0.14	2.37	1.29	0.002	0.024	0.99	99.268
S 25	65.61	21.35	0.97	0.15	0.04	0.001	0.15	0.04	0.32	2.33	0.001	0.134	1.87	92.966
S 26	76.13	18.24	0.58	0.12	0.05	0.001	0.11	0.05	0.33	2.13	0.001	0.081	2.15	99.973
S 27	70.95	20.69	1.92	0.36	0.07	0.002	0.36	0.07	1.25	2.14	0.002	0.122	1.36	99.296
S 28	72.56	19.72	0.74	0.07	0.07	0.002	0.07	0.07	0.04	3.64	0.002	0.039	1.99	99.013

*Table 2: X-ray fluorescence analysis (XRF) of samples of the Triassic upper sandstone. * LOI = Loss during ignition at 1050°C*

porosity of rocks. So, for example, a good sorting of detrital grains and their substantial quartz composition is an important factor determining the increased values of porosity. On the other hand, the increased content of clay and authigenic minerals (more than 10-15%) reduces the porosity of rocks studied. The main clay mineral is kaolinite, formed during sedimentogenesis. This role is played also by other layered silicates – chlorite and mica. However, another type of kaolinite – authigenic – on the contrary, increases porosity, because it is formed due to the hydrolysis of feldspars. Other authigenic minerals – calcite, dolomite, siderite, pyrite, found between clastic grains – lead to a decrease in porosity. The complex of analytical methods used in the study made it possible to obtain information supplementing and non-contradicting each other.

Acknowledgments

The work was carried out at the expense of the subsidy allocated within the framework of the state support of the Kazan (Volga region) Federal University in order to increase its competitiveness among the world's leading scientific and educational centers.

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Manuscript received 12 May 2017;
Accepted 25 August 2017;
Published 30 November 2017