

Mineralogy and chemistry of the Ksour sandstones in the Aïn Sefra area (Western saharian atlas, Algeria)

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Abstract - The Ksour sandstones are well known on the whole western part of the Saharian Atlas and are even extended on the neighbouring areas. They are essentially formed by thick sandy beds alternating with clayed layers composed of illite. These sandy beds are hard and can be cemented by secondary silica, iron oxides or by carbonates. They are moderately sorted, rounded to subrounded and medium grained. The surface texture of the quartz grains, the detailed mineralogical study, the nature of the cementing material and the distribution of heavy minerals showed that the Ksour sandstones of Aïn-Séfra area are mature and polycyclic. They correspond to an orthoquartzite. These Ksour sandstones were most probably deposited in a fresh water environment and derived from a southern source far to south.

Key words - "Ksour Sandstones" - Upper Jurassic-Lower Cretaceous - Channel structures - Conglomerates - Sandstones - Clay - Mineralogy - Chemistry - Aïn Séfra - Western Saharian Atlas - Algeria.

Minéralogie et géochimie des grès des Ksour dans la région d'Aïn Séfra (Atlas saharien occidental, Algérie)

Résumé - Les grès des Ksour de la région d'Aïn-Séfra, appartenant à une épaisse série continentale d'âge jurassique supérieur-crétacé inférieur, présentent les caractères de grès matures, assez bien classés. Ces grès sont constitués essentiellement de grains de quartz auxquels sont associés d'autres minéraux tels que calcite, dolomite, feldspaths, minéraux argileux, oxydes de fer, barytine et glauconie. Ce sont des grès polycycliques dont les sources possibles seraient les formations antérieures remaniées et/ou les roches cristallines et cristallophylliennes qui forment les massifs sahariens au Sud et au Sud-Ouest.

Mots clés - "Grès des Ksour" - Jurassique supérieur - Crétacé inférieur - Chenaux - Conglomérats - Grès - Argiles pélitiques - Minéralogie - Géochimie - Aïn Séfra - Atlas saharien occidental - Algérie.

INTRODUCTION

The upper Jurassic-Lower Cretaceous Ksour sandstones cover large parts of the western Saharian Atlas (Fig. 1). Since Flammand's reconnaissance in 1911, these rocks have received little attention despite their association with the important copper deposit of the Aïn-

Sefra area. The first in depth study undertaken by A. Cornet (1952) was followed by the study of J. P. Bassoulet (1973). The latter described the broad lithological variation in the western Saharian Atlas and subdivided the sandstones informally into three formations. The terme «Ksour sandstones» was first introduced by J. Delfaud (1974, 1975) together with sedimentological data

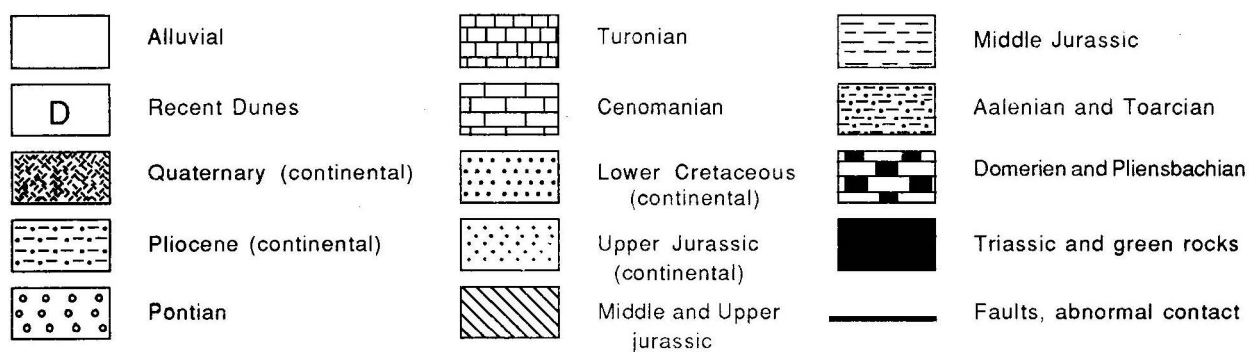
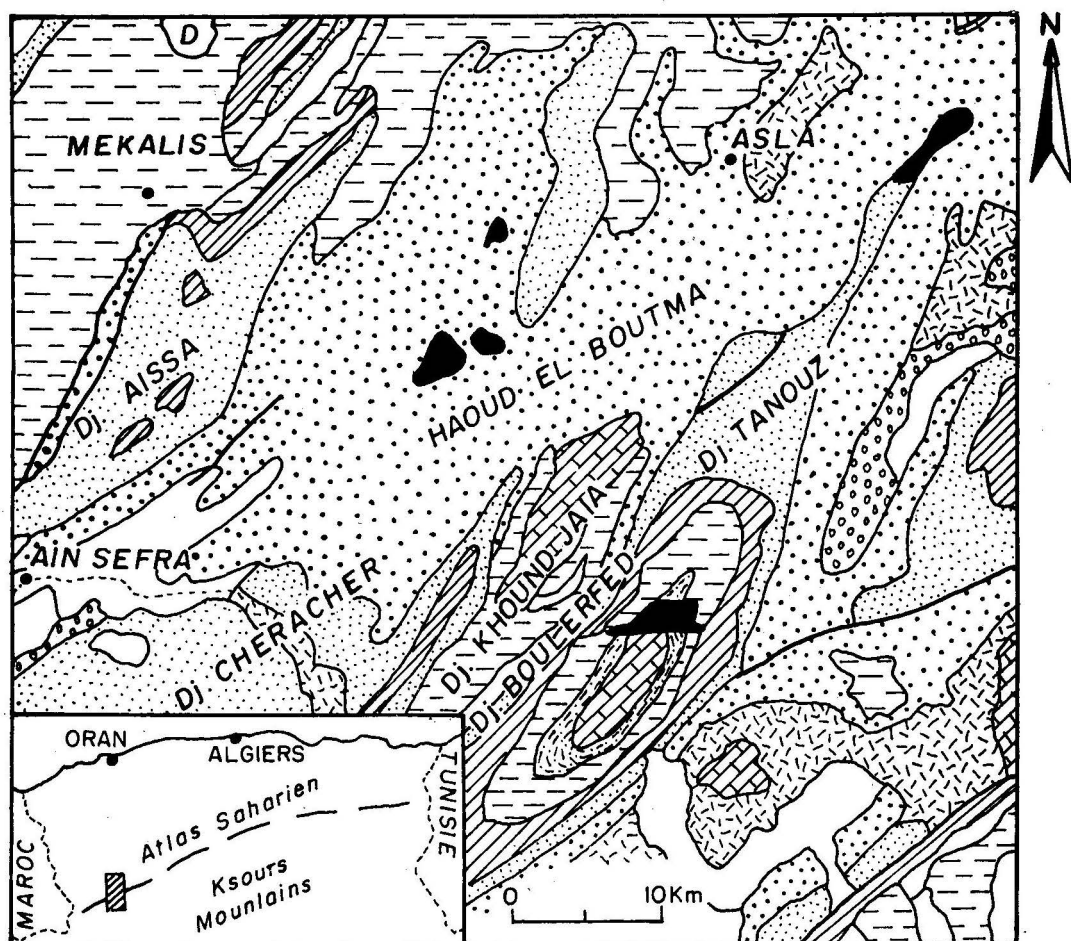


Fig. 1 - Generalized geological map of Aïn Sefra region (1/500 000);
from geological map of Algeria, 1952 with modification

*Carte géologique schématique de la région d'Aïn Séfra (1/500 000);
extrait de la carte géologique de l'Algérie, 1952, modifié*

on the depositional environment. He suggested a deltaic character for these sandstones and indicated a fluvial flow direction from SW to NE.

The total composite thickness of the group ranges from 2000m to 3000m with an average of about 2500m. The Ksour sandstones consist of

monotonous sequences of conglomerates, sandstones, siltstones, claystones and mudstones. Carbonates are very rare. Sandstones and conglomerates are emphasized by iron rich plant debris and pebbles of mudstone. Rootzones are common. Composition, size and internal feature of these sandstones characterize a deltaic facies (fig. 2).

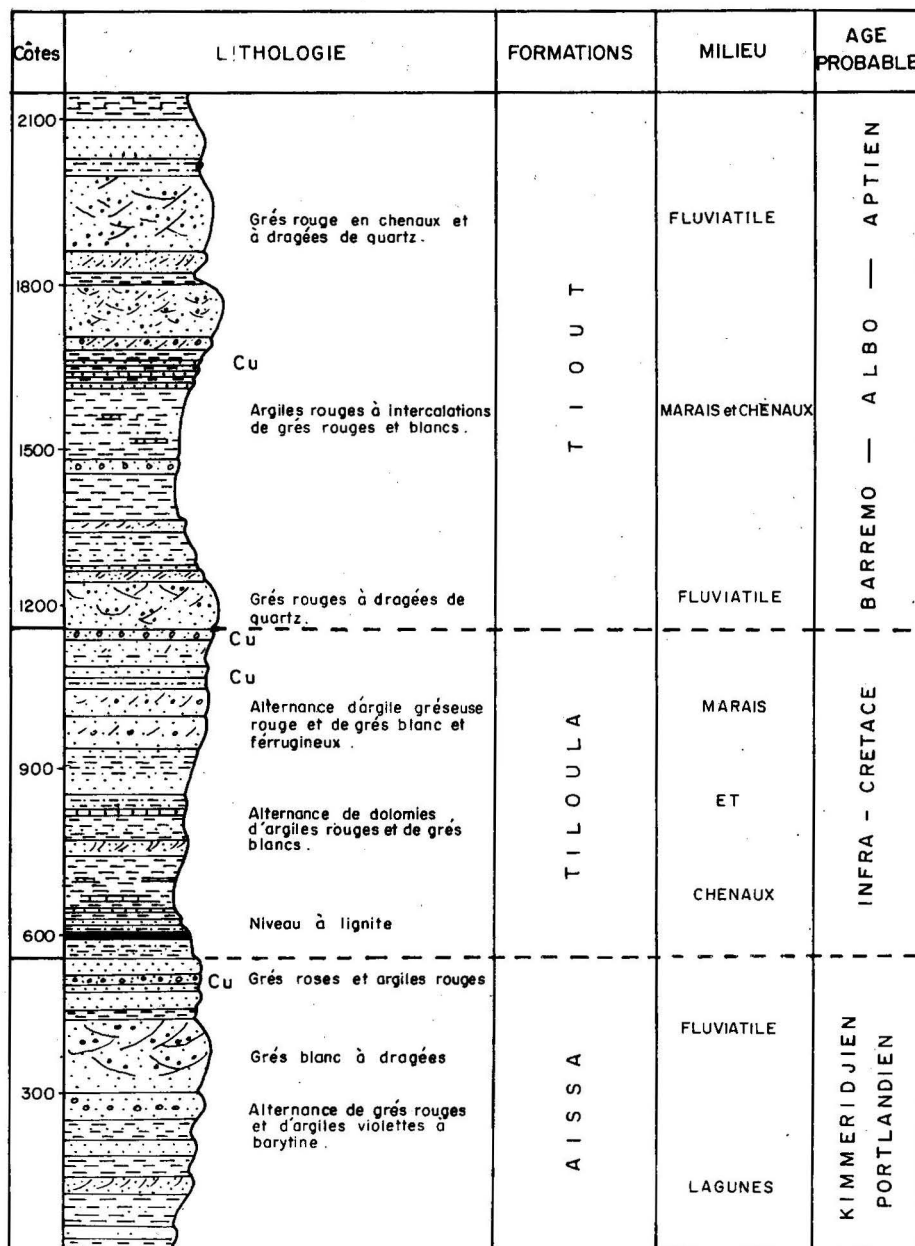


Fig. 2 - Diagrammatic columnar section of detrital formations of Aïn Sefra area.

Principales formations détritiques de la région d'Aïn Séfra.

The present paper describe in detail the mineralogy and chemistry in the outcrop region of Aïn-Sefra.

MINERALOGY OF THE KSOUR SANDSTONES

The Aïn-Sefra sandstones are essentially composed of quartz with an average of about 91%. Beside the quartz grains, rock-fragments, feldspars, carbonates, copper-minerals, baryte, iron oxides, micas, clay-minerals and heavy minerals are found. Illite ranges from 2 to 30 %. All other clay-minerals; kaolinite, chlorite and montmorillonite account together for 2,5 % of the samples.

Quartz

The roundness of the quartz grains varies from rounded to subangular. Well rounded grains are next in abundance, while angular grains are very subordinate. Generally quartz grains have a diameter between 0.1 and 1.5 mm. They seem to be of the «round-frosted» type. These sandstones are mostly composed of single quartz grains and to a lesser extent composite and polycrystalline (fig. 3). The detrital grains often present secondary overgrowths (fig. 4) in optical continuity with the original detrital quartz grains. The secondary quartz fills interstitial spaces and diminishes the roundness ratio of detrital grains. Various types of contact relation are possible: straight contact, point contact, interlocking contact and sutured contact. The first and third ones are the most frequently observed. The other types are more rarely observed.

Some quartz dissolution by calcite has been observed in many cases. This may prove that the diagenetic process took place in a silica poor environment. The quartz grains contain considerable amount of inclusions. These inclusions may be zircon or frequently acicular needles of rutile. G. M. After Friedmann (1978), the last one can be characteristic of quartz grains of granitic origin.



Fig. 3 - Photomicrograph showing typically strained polycrystalline quartz grains, each unit possessing its own distinct optical orientation. Note the occurrence of inclusions as continuous straight lines. Crossed nicols. Scale = 0.15 mm

Microphotographie montrant des grains de quartz polycristallins. Chaque grain montre sa propre orientation optique. Noter la présence d'inclusions sous forme de traînées rectilignes. Nicols croisés. Trait d'échelle = 0,15 mm

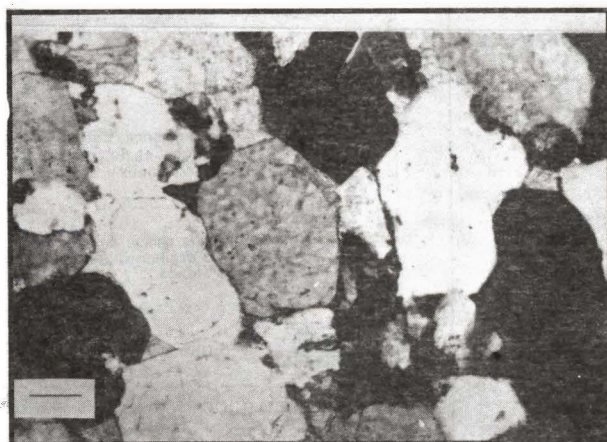


Fig. 4 - Photomicrograph showing a typically orthoquartzite. A truly quartzitic rock produced by thorough cementation of a quartz arenite. Note the well-preserved boundaries of highly detrital quartz separating detrital core from secondary quartz overgrowths. Crossed nicols. Scale = 0.35 mm

Microphotographie d'un orthoquartzite montrant un enrichissement en quartz secondaire autour des grains de quartz originaux dont les contours sont soulignés par des impuretés. Nicols croisés. Trait d'échelle = 0,35 mm

The present study showed also that these quartz grains are composed of two major types: (1) frosted-rounded quartz grains which can be edged in some cases and (2) pyramidal ended quartz grains. The grains of the first type are detrital quartz, covered by diagenetic quartz. The examination of this quartz with the scanning electron microscope (SEM) in the Geology Department of Orsay (Paris) revealed details on their mineralogical evolution. Many of the grains present internal dissolution phenomena. In fact, quartz grains show abundant mechanical «V» and half moon shaped percussion features and globular silica deposits. It appears here that these quartz grains have undergone two cycles in their transport and depositional history. The first cycle is apparent from the presence of «V» shaped impact pits and percussions which are similar to those on grains subjected to eolian mechanical abrasion. Associated with these mechanical features are fine spherulitic silica patterns that suggested a cycle in a relatively calm aqueous environment.

The second type shows pyramidal quartz overgrowths on monocrystalline or polycrystalline detrital quartz grains. Their size are variable and can reach a maximum of 100 μm , however the average falls between 30 and 40 μm . This can be interpreted by an «*in-situ*» overgrowing in a sedimentary environment where silica rich solutions circulated. L. Le Ribault (1975) pointed out that the process of this nature can be characteristic of an environment where mixture of fresh water and brines is present. This suggested a deltaic environment.

Clay minerals

Clay has been recorded in the matrix between quartz grains. It is usually associated with calcite, iron oxides and/or copper minerals.

Selective samples were examined using X-ray diffraction techniques as well as differential

thermal analysis. These investigations showed that illite is the only clay mineral encountered in all samples, while kaolinite, chlorite and montmorillonite are recorded only in few samples (fig. 5).

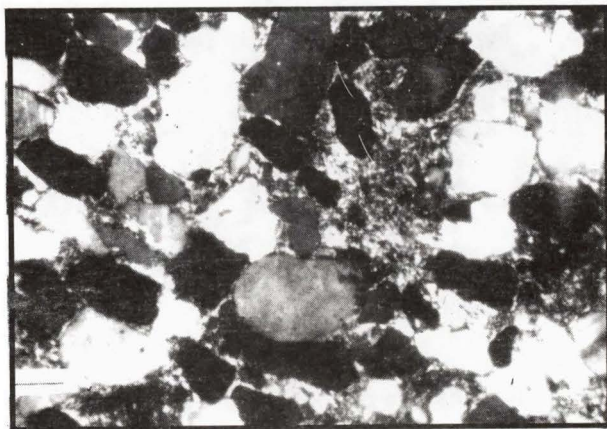


Fig. 5 - Photomicrograph showing detrital quartz grains cemented by clay matrix (illite). Crossed nicols. Scale = 0.35mm

Microphotographie montrant des grains de quartz détritiques de différente forme et de granulométrie variée dans une matrice argileuse principalement illitique. Nicols croisés. Trait d'échelle = 0,35mm

The X-ray diffraction study of illite shows that it presents more or less open sheets. This disordered character of illite can be explained by diagenetic alteration. Hence, one can suppose that illite is of detrital origin. In the same manner chlorite and kaolinite seem to be of detrital origin but the formation of montmorillonite is probably related to a diagenetic process (Kolli, 1984).

Iron minerals

The Ksour sandstones contain in average 0.2 to 3 % iron oxides with a maximum of 5 %. these fill interstitial pore space between quartz grains (fig. 6). Also, it is found that quartz grains are replaced to various degrees by the iron minerals. Observations by reflected light microscopy show the presence of hematite, goethite, hydrogoethite

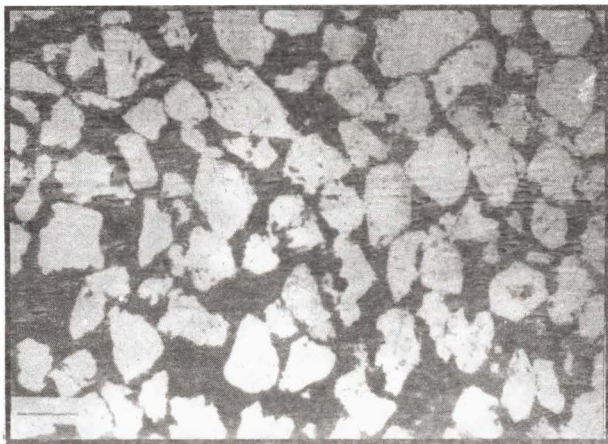


Fig. 6 - Photomicrograph showing quartz grains of different shapes and roundnesses, cemented by iron minerals (hematite and goethite). Note that the peripheries of some grains are corroded due to their replacement by iron minerals. Crossed nicols. Scale = 0.35 mm

Microphotographie montrant des grains de quartz détritiques cimentés par des oxydes et hydroxydes de fer (hématite et goéthite). Les contours des grains sont souvent corrodés. Nicols croisés. Trait d'échelle = 0,35 mm

and occasionally some martitized magnetite grains. These oxides and hydroxides are the cause of the red color of the sandstones and are characteristic of humid and hot climates.

Carbonates

The carbonates minerals, calcite and dolomite, occur as pore filling and replacement of detrital material (fig. 7). Calcite is predominant and can be found as a cement or as a mass of calcite cement deposited in optical continuity in these sandstones. Quartz grains may be engulfed in this calcite cement and are regarded as «floating» within the carbonates. Replacement of calcite by dolomite is also recorded. Dolomite occurs mostly within calcite and/or illitic matrix. It seems that dolomite has a strong tendency to replace clay in the sandstones. In fact, scattered dolomite rhombs are observed throughout the clay matrix.



Fig. 7 - Photomicrograph showing quartz grains cemented by calcite matrix. Dark and light grains are quartz in various positions of light extinction. Note that outline of quartz grains suggests replacement by calcite. Crossed nicols. Scale = 0.35 mm

Microphotographie montrant des grains de quartz détritiques dans une matrice carbonatée. Certains grains détritiques apparaissent flottant et d'autres sont franchement corrodés et remplacés par la calcite. Nicols croisés. Trait d'échelle = 0,35 mm

Feldspars

The Ksour sandstones contain from 0.1 to 5% of feldspars with an average of 2.8%. These detrital feldspars are mostly well rounded and comprise only orthoclase and microcline. They show evidence of alteration from weathering. Most detrital feldspars are monocristalline. Accordingly to M. T. Heald and G. F. Baker (1977), the presence of microcline can be put in relation with a plutonic source rock. Albite is very rare in the sandstones. In some cases, it seems to be of diagenetic origin.

Predominance of potash feldspars over plagioclase can be explained by an important remarkable selective process of weathering at the source area as pointed out by M. T. Heald and Baker (1977), where plagioclase is eliminated and potash feldspars are virtually unaltered.

HEAVY MINERALS

Heavy minerals in the Ksour sandstones are not very abundant and do not show a great variance in nature. The study of this fraction shows the ubiquitous presence of zircon, tourmaline, rutile, anatase and brookite. Beside these occur some metamorphic minerals like staurolite, corundum and titanite. Generally, all these heavy minerals are rounded and altered. Zircon crystals present variable morphologic features from completely rounded to euhedral grains which show some rounded corners. The zircon grains are colorless or pink in color.

Tourmaline, observed in all studied samples, which is the second important mineral of the heavy mineral fraction, appears to be rounded with an average diameter of 0.25 mm. The color of this mineral can be brown, brown to yellow and green (dravite). The schorlite and elbaite varieties are also observed.

Titaniferous minerals are also present in most samples and have an average size of 0.2 mm. Their roundness and corroded nature is proof of their detrital origin. Titaniferous minerals are varieties being frequently associated with sedimentary rocks in particular rutile which often occurs with zircon and tourmaline. These three minerals are characteristic for polycyclic sandstones.

Staurolite appears sporadically in Ksour sandstones. It has been identified in few samples. However, it is found as rounded grains of 0.2 to 0.5 mm with typical color and pleochroism. Corundum and titanite are recorded in some samples. They occur as subrounded grains.

CHEMISTRY OF THE KSOUR SANDSTONES

Ten representative Ksour sandstones samples from different varieties were crushed and split for analysis of trace elements which was performed

in the Department of Mineralogy of Ötvös Loránd, Budapest-Hungary.

Table 1 shows the chemical data of nine sandstone samples and one argillaceous sandstone from the Aïn-Sefra area. Together with average given by Pettijohn (1972). The most important chemical characteristics of the Ksour sandstones can be outlined as follows:

- silica varies from 84.14 to 96.73% with an average of 91.73%,
- the high content of silica and the low content of alumina (average content of 1.64%). Accordingly to Middleton (1960), sandstones with less than 5% alumina are considered as «clean quartzite». This is the case in the sandstones of Aïn-Sefra,
- the F_2O_3 (represents total iron) content has no genetic importance as its presence is not only controlled by its provenance, but also is largely affected by chemical conditions which prevailed in the basin of deposition and during diagenesis,
- the CaO content generally exceeds the MgO content, however in some samples the reverse is also observed. Petrographical studies revealed that calcite is the main carbonate cementing material while dolomite is very subordinate and found only as scattered rhombs within calcite. Therefore, the abundance of Mg in some samples is not only attributed to the presence of dolomite, but also largely to the alteration of ferromagnesian minerals present in these sandstones,
- the alkalis Na and K are mainly found in the feldspars; the Na_2O/K_2O ratio less than 1 means that during diagenesis no sodium rich solutions affected the investigated sandstones.
- titanium (TiO_2) is found with an average of 0.05 %. It is mainly found in claystones and in some recorded heavy minerals as rutile, anatase and brookite.

Table 1 - Chemical analysis of the studied sandstones

Analyses chimiques des grès étudiés

	AS1	AS2	AS3	AS4	AS5	AS6	AS7	AS8	AS9	AS10	Av. AS	A	B	C	D
SiO ₂	96.73	91.55	95.58	92.36	94.50	89.66	90.87	84.14	90.22	52.4	91.73	95.50	66.10	84.01	77.60
Al ₂ O ₃	0.83	1.25	1.56	0.88	0.50	3.02	1.77	2.00	1.36	13.01	1.46	1.10	8.10	2.57	7.10
Fe ₂ O ₃ *	1.31	0.52	0.23	1.03	1.48	0.94	1.31	0.65	0.35	2.59	1.15	0.6	5.20	0.43	3.20
MgO	0.05	0.06	0.09	0.10	0.10	0.21	0.41	1.53	1.28	1.53	0.42	0.10	2.40	0.67	1.20
CaO	0.08	1.23	0.10	0.18	0.04	0.13	0.26	2.63	2.45	0.23	0.78	1.60	6.20	5.41	3.10
Na ₂ O	0.11	0.05	0.05	0.06	0.04	0.25	0.35	0.07	0.05	0.13	0.11	0.10	.090	0.17	1.20
K ₂ O	0.49	0.53	0.77	0.46	0.36	0.74	1.03	0.56	0.52	3.26	0.60	0.20	1.30	0.86	1.30
H ₂ O ⁺	0.85	3.61	2.02	4.26	2.43	4.36	3.32	7.08	3.73	12.75	3.51	0.30	3.60	0.54	1.70
TiO ₂	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.37	0.05	0.20	0.30	0.05	0.30
MnO	0.01	0.01	0.01	0.02	0.03	0.04	0.03	0.02	0.02	0.03	0.02	n.d	0.1	0.04	0.10
P ₂ O ₅	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	n.d	0.1	0.04	0.10
CO ₂	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	1.1	5	4.65	2.5
Total	100.45	99.2	100.4	98.80	99.43	99.81	99.52	99.12	100.08	86,35	98.88	100.7	99.3	99.44	99.4

*Fe2O3: Represents total iron

AS1-AS9: Sandstones samples

AS10: Argillaceous sandstone

Av. AS: Represents the average chemical analyses of the sandstones of A-n-Sefra area.

n.d: not detected.

A: Represents the average chemical analyses of orthoquartzite (Pettijohn, 1963).

B: Represents the average chemical analyses of lithic arenite (Pettijohn, 1963).

C: Represents the average chemical analyses of protoquartzite «Sublithic arenite» (Pettijohn, 1963).

D: Represents the average chemical analyses of «sandstone» (Pettijohn, 1963).

Chemically speaking, these sandstones are generally homogeneous in chemical composition and they are related to the orthoquartzite group (Pettijohn *et al.*, 1972), after making some allowance for diagenetic effects.

To present more idea about chemical classification of Aïn-Sefra sandstones, the atomic percentages of Si-Al-Fe ratios were used (More and Dennen, 1970). Figure 8 illustrates the ternary plot of the atomic percentages of Si-Al-Fe ratios of sandstones of Aïn-Sefra. From this figure it is clear that these sandstones are mature and are of the «orthoquartzite» type.

TRACE ELEMENTS

Table 2 gives the abundance of trace elements (ppm) in the investigated sandstones. As a general rule, trace element data of Ksour sandstones are quite meagre. Almost trace elements show a weak anomaly. Their content is always below 100 ppm. The most frequent

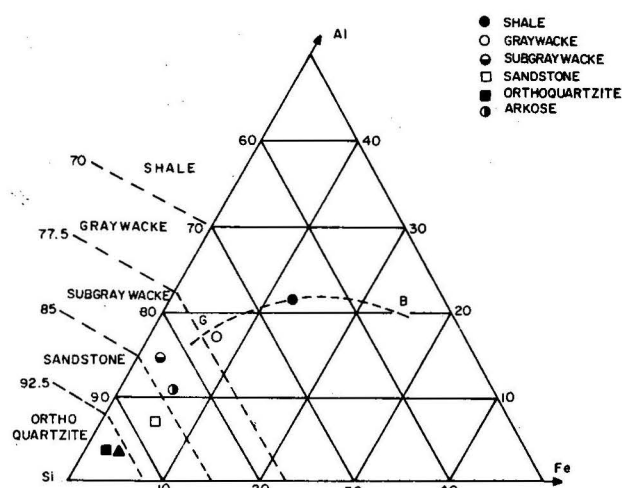


Fig. 8 - Ternary plot of Si-Al-Fe ratios of clastic sediments showing suggested silica ranges for various rocks types. The dashed line G-B gives the granite-basalt composition range (after Moore and Dennen, 1970). Black triangle represents average composition of Aïn Sefra sandstones

Position des grès de la région d'Aïn Séfra (triangle plein) dans le diagramme Si-Al-Fe relatif aux sédiments détritiques (d'après Moore et Dennen, 1970)

Table 2 - Trace elements analysis (ppm) of the studied sandstones (Garat Debba district)

Analyses des éléments en trace (en ppm) des grès étudiés (Secteur de Garat Debba)

Ech	Lithology	Cu	Pb	Zn	Ag	Mn	V	Co	Mo	Bi	Ba
G5	Red quartz sandstone	600	140	100	<1	tr	20	8	<4	<4	nd
G4	White sandstone	300	20	50	<1	50	50	60	<4	20	nd
G3	Copper mineralized white sandstone	3.75 %	20	40	3	300	80	30	15	200	200
G2	Argillaceous sandstone with copper mineralized wood fragments	4.75 %	20	50	6	100	150	150	<4	<4	nd
G1	Argillaceous conglomerate	1500	20	20	<1	100	40	20	<4	<4	nd
G0	Green pelitic clay	1700	20	100	<1	140	60	30	<4	<4	300
G	Red pelitic clay	900	50	100	<1	300	60	80	<4	<4	300

* nd = no detected

trace elements are: Cu, Pb, Zn and V. only Cu and Zn show high anomalies. It is possible to say that the studied sandstones are depleted with respect to many trace elements. The high content in Cu of the Ksour sandstones, compared to the other areas, can be explained by a primary enrichment and deposition. These sandstones were probably derived from a mineralized source area (O. Kolli. 1983).

CONCLUSION

In conclusion, the study of Ksour sandstones show that they are polycyclic sandstones comparable to the orthoquartzites described by F. G. Pettijohn *and al.*, (1972). The presence of inclusions of rutile in quartz grains and the color of zircon grains suggest a Precambrian age for the original material which may be partly derived from igneous rock. It is also interesting to indicate that these sandstones have a poor content in trace elements and this fact can be interpreted as an indication of a long transport and of a lagoonal and deltaic sedimentation. According to field observations and petrographical studies, these sandstones were most probably derived from a southern source far to the south. The possible source of these sandstones may be older sandstones or igneous and metamorphic rocks which were denudated, reworked and deposited.

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