

## МІНЕРАЛОГІЯ, ГЕОХІМІЯ ТА ПЕТРОГРАФІЯ

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## PETROGRAPHIC CHARACTERIZATION OF THE URANIUM ORE OF TAHAGGART (EL-HOGGAR, SE ALGERIA)

(Представлено членом редакційної колегії д-ром геол. наук, проф. В.А. Михайловим)

**B a c k g r o u n d .** Algeria has long sought to exploit its uranium deposits in the Hoggar region, whose objective is to market the ore, and use part of the production exclusively in the civil field, especially in electricity generation. The exploitation and valorisation of this ore; require a very specific process of exploitation, characterization and treatment.

The main objective of this work is to establish a detailed and complete technical data sheet for the Tahaggart deposit, enabling the implementation of a uranium ore mining and beneficiation technique to obtain a marketable product known as "yellow cake".

**M e t h o d s .** To achieve this objective, samples were taken from the site under study, followed by microscopic and macroscopic analyses non-thin sections to obtain petrographic, mineralogical and geochemical identifications.

**R e s u l t s .** The analyses confirmed the sandstone character of the ore and the predominance of quartz, clays, oxides and iron hydroxides as well as uranium and rutile minerals. The uranium contents in the mineralized altered levels varied from 0.90 to 1.32 % and from 0.34 to 0.74 % in the mineralized conglomeratic sandstones. Uranium occurred either in the high-grade uranium minerals or in low-grade apatite, zircon, rutile, and in traces in monazite.

**C o n c l u s i o n s .** Different studies carried out on the Tahaggart region have proven the presence of Uranium ores with remarkable quantities, varying between 0.90 to 1.32 % in the mineralized altered levels and 0.34 to 0.74 % in the mineralized conglomeratic sandstones, however, despite this, and in view of the strategic value that uranium enjoys at the international level; to date, there is no exploitation of this mine by the state. The best treatment method in this case is heap leaching; the recovery rate by this method can reach 70 % in uranium as "yellow cake".

**K e y w o r d s :** Uranium, Tahaggart, Petrographic characterization, Mineralogy and geochemistry, Leaching, "yellow cake".

### Background

The element uranium was discovered in 1789 by the German chemist Martin-Heinrich Klaproth (Graubünden and Souidi, 2020). More than a century later, in 1896, Henri Becquerel discovered radioactivity from fluorescent uranium salts and at the same time demonstrated the radioactive properties of this element (Giry, 2017). Originally, uranium was only used as a chemical agent, notably in the ceramics and mirror-making industry (glass coloring), then in the manufacture of high-strength steel (Nilson and al., 2019). In the early 20th century, following Pierre and Marie Curie's work on radioactivity, its ores were an essential source of radium, used to treat cancerous tumors (Rentetzi, 2022).

The discovery of nuclear fission by Otto Hahn and Fritz Strassmann in 1938 marked the baptism of nuclear energy

and the use of uranium as a fuel element (Reed, 2020). Uranium in metallic form, can also be found as a structural element (counterweight) in aircraft and marine construction, as well as in the military field, for tank armouring and shell manufacture (Lourenco and al., 2016; Carvalho and al., 2023). It can also serve as shielding to protect against ionizing radiation, just like lead (Lourenco et al., 2016). Uranium is the main element used for the manufacture of fuel elements for nuclear reactors (Zerbib, 2024). However, its use goes through several stages of preparation called the nuclear fuel cycle. The first step in this cycle is the exploration, exploitation and valorization of uranium ores. The latter requires a specific treatment process, taking into account the technical sheet of the uranium ore. Algeria has significant mineral reserves, in particular, gold and uranium

are the main metals present in Hoggar. Tin, tungsten and tantalum, niobium, and copper indices are also present.

There are several uranium deposits identified and not exploited to date: Timgaouine, Abankor, Tinef and Tahaggart. Exploitation of a deposit requires a perfect understanding of its geographical environment, geology and geometry, and for profitable extraction of the raw material and valorization of this resource, in our case uranium in the Tahaggart deposit, it is imperative to establish a detailed and complete technical data sheet for the uranium ore. The first geological studies were carried out by Joulia (1959), Lessard (1961) and Claret et Tempère (1968), Legrand (1970), Fabre (1971) and Beuf et al (1971), who studied the Paleozoic history of the Saharan platform in the Tassili region or at N'Ahaggar de In Debirène in the southwest and in the Tin-Eggole region in the northeast. Mokadem carried out a study on the uranium mineralization of the Tin Séririne sedimentary basin (Tahaggart deposit and the Tamert-N-Iblis region) in 1980, followed by a study of the alteration of the Precambrian base on the periphery of the basin. In addition, the associated uranium and thoriferous mineralization (Hallalouche, 1995), and a structural study of the Tin Séririne basin were made using geophysical methods (Bournas, 1998).

A contribution to the geological and gītological study of the uranium mineralization of Tahaggart (Southeast of Hoggar): mineralogy and geochemistry of mineralization linked to alterations of the base and to the basic conglomerate of the detrital series was the subject of a magister thesis by Chahdane in 2009. Algeria began the first prospecting work in the Tin-Séririne basin around the 1970s. The aim of this work was to search for uranium in the northern district of the Algerian-Nigerian uranium province. The Romanian group GEOMIN (1969–1975) working on behalf of SONAREM (Société Nationale de Recherche et d'Exploitation Minière) highlighted the Tahaggart uranium deposit and the Timouzeline and Tamert-N-Iblis uranium indices. These mineralized zones were discovered by ground verification of the radiometric anomalies highlighted

by the aero-magneto-spectrometric survey at 1/200,000, carried out by the American firm Aéroservice (1971).

A reserve estimate has been made for the Tahaggart deposit. A SONAREM team (1976–1977) carried out hydrogeological research work in the Tin Séririne basin. From 1986 to 2005, uranium exploration work was carried out on the eastern and western flanks (Timouzeline and Tamert-N-Iblis) of the Tin-Séririne Basin (CREM, 1986–1991); on its northern and north-western periphery (CREM, 1991–1992), and its southern part (CREM, 1996–1997), as well as evaluation and extension work on the Tahaggart deposit (COMENA (2001–2005). Appreciable results were obtained in the Tin-Séririne basin, notably the identification and confirmation of uranium indices and anomalies. The present work represents a contribution to the enrichment of the Tahaggart uranium ore datasheet, through the petrographic (macro and microscopic), mineralogical and geochemical characterization of the main horizons, represented by the conglomeratic sandstones and alteration facies of which they are composed.

**Site description.** The Tahaggart uranium deposit is located 350 km southeast of Tamanrasset in the Tin Séririne basin in extreme southeastern Algeria; close to the Niger border (Rabia-Zaourar, 1978; Badahmaoui et al., 2020) (fig. 1). This desert region is characterized by very low human density, with altitudes ranging from 1,000 m in the north, to 400 m in the south on the Algerian-Nigerian border. Temperatures ranging from 40–45 °C (April to July) and from 13 to 11 °C (January to February), very little rainfall, vegetation limited to wadi beds, and fauna specific to desert zones (Chahdane, 2009; Khaldi et al., 2018). It is located at the crystalline basement-Paleozoic sedimentary cover contact, with global uranium reserves estimated at 8,105t of ore grading 0.215 % U, or 1,700 tonnes of U metal (Allek et al., 2013). It occurs as subhorizontal mineralized lenses 1 to 8 m thick hosted in altered Precambrian basement gneisses and Cambro-Ordovician basal conglomerates (Baadi, 2018; Gherbi et al., 2015).

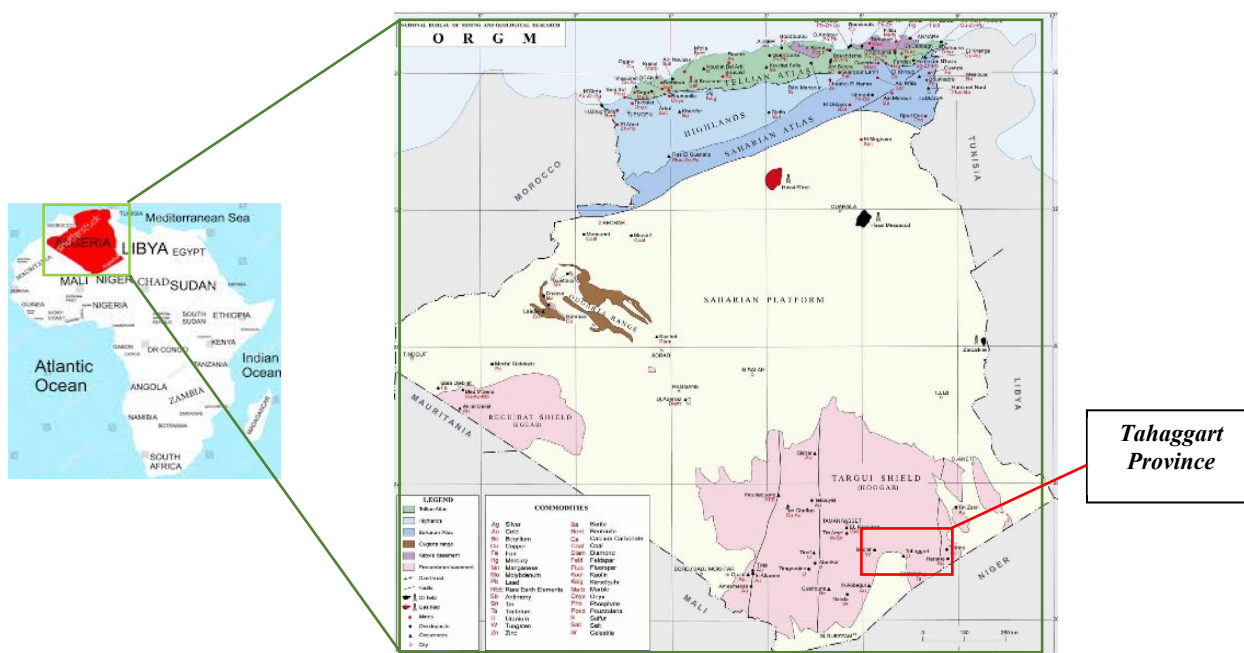


Fig. 1. Location map of study area

Uranium mineralization, is known at surface and sub-surface depths of 0 to 8 m, and occurs in more or less

discontinuous patches (Sanguinetti et al., 2018; Smirnov et al., 2018). The uranium ore essentially contains secondary

uranium minerals (utunite, torbernite), associated with iron oxides (hematite, goethite) and a clay matrix (Hatert et al., 2018). Significant thorium and rare-earth mineralization associated with conglomerates (Bonhoure, 2010; Boni et al., 2023); is related to primary and secondary minerals (monazite) and aluminophosphates (grandallite, florencite, brockite). Other secondary uraniumiferous minerals include carnotite, sabugalite and uranophane (Chahdane, 2009).

**Methods**

The samples were taken to cover most of the region studied. The diameter of the collected pieces varies from 0 to 250 mm; they are taken from conglomeratic sandstone ores and altered facies, then the diameter of the pieces of rocks was reduced using a hammer to sizes which do not exceed 90 mm. The pieces obtained from conglomeratic sandstone ore are intended for macroscopic observation with the naked eye, while microscopic observation was carried out using a Leica binocular optical microscope. Samples were selected to prepare thin sections of uranium ore.

To determine the chemical composition of the rocks, 19 samples were taken, 9 from conglomeratic sandstones and 10 from mineralized alteration rock, each sample was crushed using a Model HERZOG disc crusher, then mixed

and divided by quartering technique, to obtain a representative sample. Prior to FRX analysis, all samples were pulverized using a Model SIEBTECHNIK pulverizer. Preparation of the thin section for microscopic and petrographic study involved the following stages: the ore rock was cut by a BROTLAB diamond disk saw, then the samples were ground in a BROTLAB automatic diamond-grinding machine, followed by manual polishing, and finally GBS1 resin was used to bond the resulting section to special glass chips. The prepared thin sections were placed on the stage of a polarizing optical microscope (Leitz PoL 12 in PLNA in APL). The chemical composition was determined by X-ray fluorescence analysis, using a portable X-ray fluorescence spectrometer (Thermo Fisher-Niton xl3t Goldt+). This analysis made it possible to obtain results for each type of sample, its chemical composition and the content of each chemical element.

**Macroscopic study of uranium ore associated with conglomeratic sandstones.** Macroscopic observation of conglomeratic sandstones reveals the presence of 06 arenas (Fig. 2). The first facies, Uranium-mineralized alteration arena, has a ferruginous clay-quartz matrix.

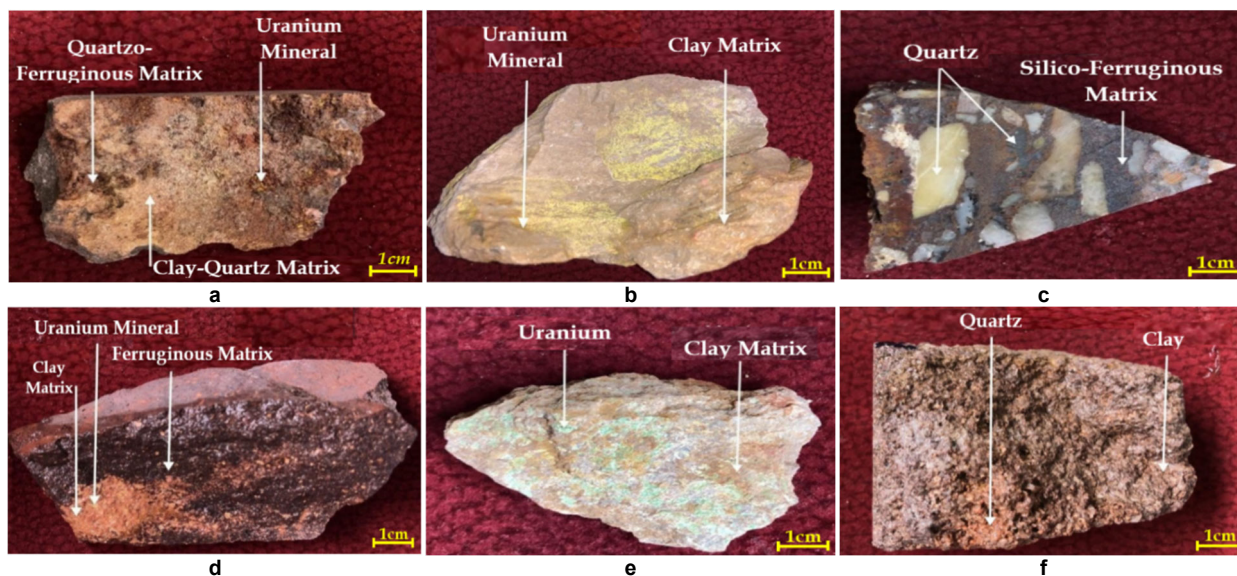


Fig. 2. Macroscopic observation of conglomeratic sandstones

This matrix is composed of clays and quartz grains of size varying between 1 mm and a few microns, impregnated with reddish iron oxides. Within this matrix there appear yellowish uranium minerals (Fig. 2a). The second arena is mineralized clay, essentially composed of a whitish-gray clay matrix containing 1–2 mm thick quartz beds and yellow uranium minerals. The latter appear as coatings plated onto the matrix (Fig. 2b). In the mineralized microconglomerate arena within a silico-ferruginous matrix, centimetric to millimetric quartz grains appear, whitish to grayish in color. These quartz grains are generally xenomorphic and angular, and sometimes sub-rounded. A few yellowish uranium minerals appear in the ferruginous matrix (Fig. 2c). In addition to a ferruginous-clay matrix, the mineralized ferruginous arena is also composed of clay pockets containing a few disseminated grains of uranium (Fig. 2d). The fifth arena is the mineralized ferruginous-clay arena. Green uranium films of millimetric to centimetric dimensions appear within this clay matrix. The clay matrix is

grayish and whitish-gray in color, with several planes of schistosity. Greenish uranium minerals sometimes permeate these schistose planes (Fig. 2e). The last arena is the quartz-clay arena. Within this whitish clay matrix, there are agglomerations and sheaves of whitish to grayish quartz grains (Fig. 2f). Under Leica binocular microscope in direct light, the different observed matrices of the samples studied are:

- A quarto-ferruginous matrix with small fine millimeter to micrometer quartz grains (Fig. 3a).
- A clay-ferruginous matrix with green uranium films (Fig. 3b);
- A quartz-ferruginous matrix with uranium grains scattered everywhere and sometimes iron oxides coated with clays (Fig. 3c);
- A clay-iron matrix, with clay particles in the form of microveins intercalated between quartz and iron oxide (Fig. 3d).

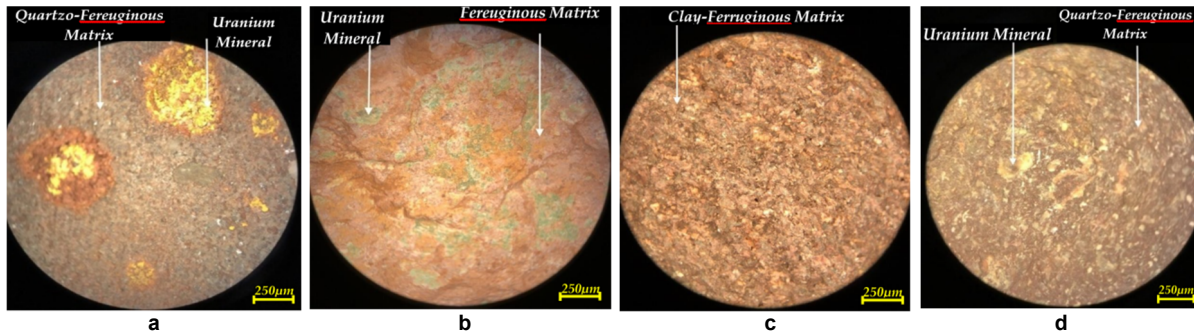


Fig. 3. Microscopic observation of matrices (x40)

**Petrographic study of conglomeratic sandstones in thin sections.** In polarized light not analyzed (PLNA), conglomeratic sandstones are composed of Quartz, in the form of grains of various sizes (millimeter to micrometer) (Fig. 4). These grains are rounded and sub-rounded and sometimes sub-automorphic. Quartz is often surrounded by discontinuous halos of secondary silica. It is also fissured, and the micro-fissures are sometimes filled with iron oxides and uranium minerals (Fig. 4a). Iron oxides, these are abundant, appearing as fillers in interstices and intergranular spaces, as well as in micro-fissures in quartz grains. Two generations of iron oxides are present. These oxides also imprint on the clay minerals present in the inter-granular

spaces (Fig. 4b). Clay minerals are not abundant and appear in the intergranular spaces often impregnated with iron oxides, and appear in small aggregates and in the form of small vermicular. According to studies carried out by Hallalouche, 1995 and Chahdane, 2009, these clays appear only as kaolinite (Fig. 4c). Accessory minerals occupy the intergranular spaces and appear as crystals of zircon and monazite (Fig. 4d). Uranium minerals in the Tahaggart are found mainly in carnotite ( $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ ) and autunite ( $Ca(UO_2)_2(PO_4)_2 \cdot 10-12H_2O$ ) (Mokadem, 1980, Hallalouche, 1995, Chahdane, 2009) also reported the presence of weeksite ( $K_2(UO_2)_2Si_6O_{15} \cdot 4(H_2O)$ ) (Fig. 5).

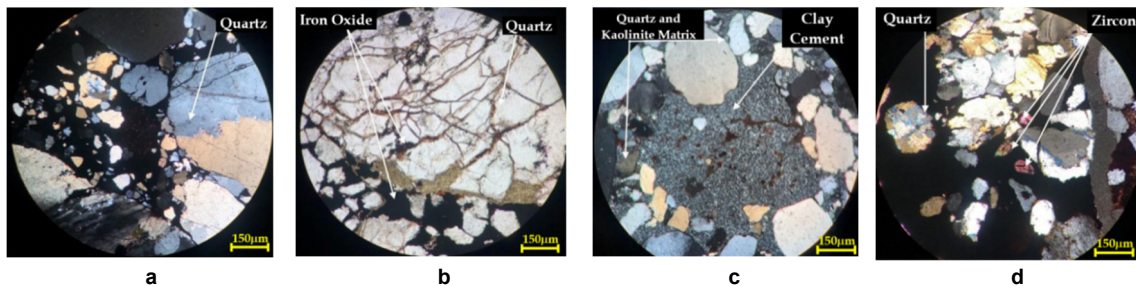


Fig. 4. Minerals in conglomeratic sandstones

Note that uranium ores contain yellow to golden-yellow minerals (in polarized light analyzed by PLA), sometimes canary-yellow, filling micro-fissures in quartz and

surrounding its grains, and appearing as small aggregates in the inter-granular spaces (Frankland et al., 2022; Aissa et al., 2022).

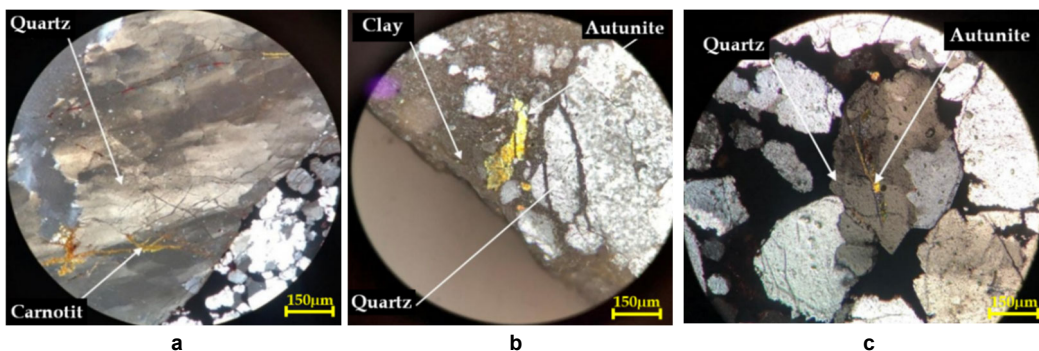


Fig. 5. Uranium minerals in conglomeratic sandstones

**Study of uranium ore associated with clay-quartz alterations.** In this section, we will use the microscopic study of uranium minerals in mineralized alterations. We find autunite  $Ca(UO_2)_2(PO_4)_2 \cdot 10-12H_2O$ , golden yellow to lemon yellow fluorescing in green, it occurs as prismatic crystals, flattened tablets and as aggregates (Frankland, 2020). Autunite often occurs as disseminations within kaolinite,

filling microcracks in quartz and as flattened tablets within the clay matrix and in quartz cracks (Fig. 6).

Torbernite  $Cu(UO_2)_2(PO_4)_2 \cdot 12H_2O$  occurs as veinlets and tablets, with a pale yellow to greenish-yellow color in natural light (NL), and a blue tint in polarized light (PL) (Syczewski, 2023). It also appears as microcrystalline aggregates within the clay matrix and iron oxides, filling fissures, flattened tablets and automorphic crystals (Fig. 7).

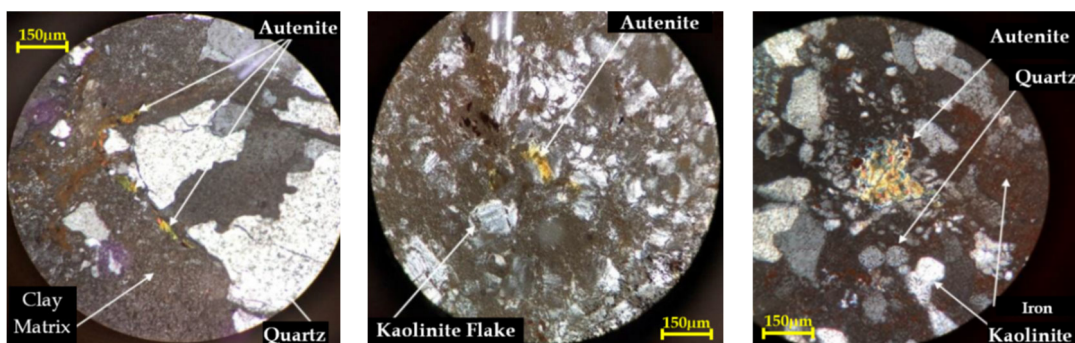


Fig. 6. Autenite in the clay matrix



Fig. 7. Torbernite in the clay matrix

Metatorbernite  $Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$ , in natural light (NL), shows pale green, pale blue to colorless hues similar to those of torbernite, with the transition in polarized light (PL) to a dark blue to purplish-blue color (Descostes, 2017) (Fig. 8). It appears as crack filling and in the form of small

tablets within the clay matrix. Observation also shows that metatorbernite can be observed on the edges of sheets, and filling the inter-sheet spaces of flakes and packets in the clay matrix (kaolinite).

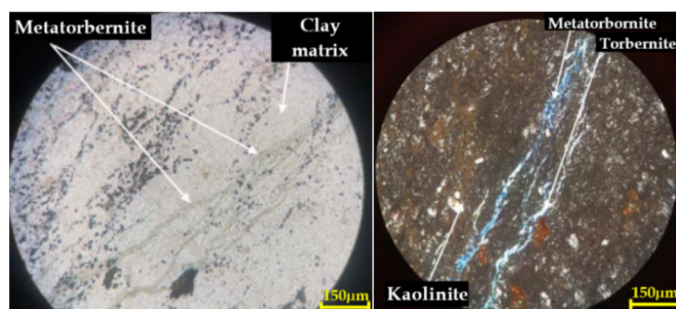


Fig. 8. Metatorbernite in clay matrix

**Chemical characterization of Tahaggart uranium ores.** Several Tahaggart ore samples, composed of conglomeratic sandstones and mineralized alteration rocks, have been analyzed by X-Ray fluorescence (XRF). Chemical analysis was carried out using a portable X-ray fluorescence spectrometer Thermo Ficher-Niton xl3t Golddt+) (Jarc, 2022), which enabled us to obtain its chemical composition for each type of sample.

**Analysis of uranium ore associated with conglomeratic sandstones**

**Major elements.** In samples related to conglomeratic sandstones, silica ( $SiO_2$ ) remains very abundant and omnipresent. Clays ( $Al_2O_3$ ) are also quite important in this facies (Tab. 1 and Fig. 9); magnesium, iron, and potassium are also present in moderate amounts; the other major elements ( $CaO$ ,  $VO_2$ ,  $P_2O_5$ ,  $TiO_2$ , etc.) appear at low concentrations.

Table 1

Concentrations of major elements in conglomeratic sandstones (%)

Element	Samp1	Samp2	Samp3	Samp4	Samp5	Samp6	Samp7	Samp8	Samp9
$P_2O_5$	0.5151	0.5334	0.5135	0,2705	0.0000	0.0012	0.0000	0.0000	0.0879
$K_2O$	1.5207	12.7147	1.2684	1.0578	0.1273	0.0011	0.0260	0.7057	2.3978
$VO_2$	0.4118	0.3881	0.3879	0.3748	0.3325	0.0009	0.0511	0.0948	0.0000
$Al_2O_3$	5.0962	4.9827	4.7962	4.6176	1.0970	0.0005	2.4439	5.6508	0.0395
$CaO$	1.6432	1.6234	1.5183	1.0844	0.1251	0.0004	0.0298	0.0278	2.2062
$TiO_2$	0.6943	1.0106	0.7830	0.4519	2.6446	0.0009	0.7953	1.0133	0.0000
$SiO_2$	37.8529	37.0517	39.4210	53.1192	74.1155	0.0005	84.3836	62.9949	0.0832
$Fe_2O_3$	8.1733	8.1800	8.4656	7.1862	18.6610	0.0023	10.8930	0.7523	0.0000

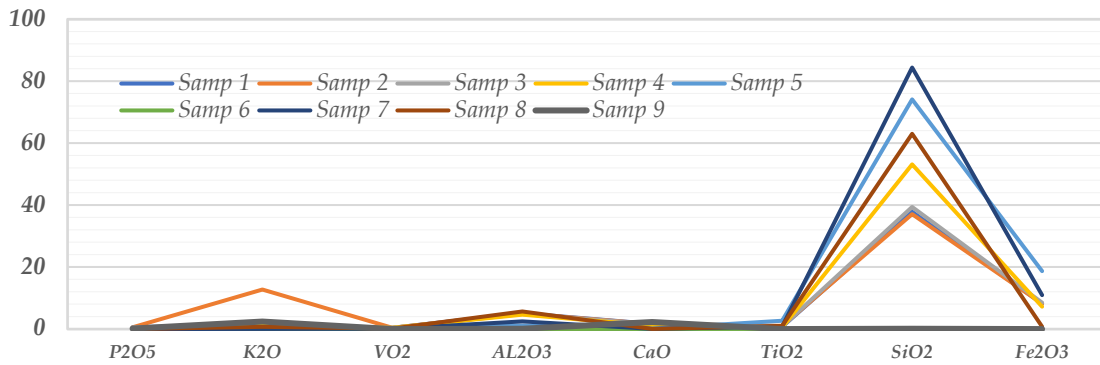


Fig. 9. Evolution of concentrations of major elements in conglomeratic sandstones

**Trace elements**

The results obtained show the presence of uranium from medium to high concentrations and high potassium and vanadium contents in conglomeratic sandstones. These are

the uranium minerals manifested, in particular by Carnotite. Zirconium and magnesium are also present but with moderate levels; copper and thorium have very low contents (Tab. 2 and Fig. 10).

Table 2

Trace element concentrations in conglomeratic sandstones (ppm)

Element	Samp1	Samp2	Samp3	Samp4	Samp5	Samp6	Samp7	Samp8	Samp9
U	5859.72	6432.53	7347.42	6226.62	3385.60	1262.73	59.95	5097.89	5133.29
Zr	280.98	325.85	404.15	249.31	1281.97	115.21	701.43	569.08	1.52
Cu	233.73	246.58	212.05	124.71	0.00	35.19	16.97	12.38	0.00
V	2529.40	2384.13	2382.91	2302.12	2042.56	5.76	314.43	582.80	0.00
K	12624.52	10552.95	10530.05	8782.07	1057.15	9.55	215.90	5858.58	19905.95
Th	9.15	15.10	11.16	9.95	94.17	24.99	37.11	68.93	0.00
Cs	0.00	0.00	0.00	0.00	0.00	2.83	0.00	0.00	0.00
Mg	2209.16	2937.74	2846.20	0.00	0.00	4.29	0.00	2079.66	970.39

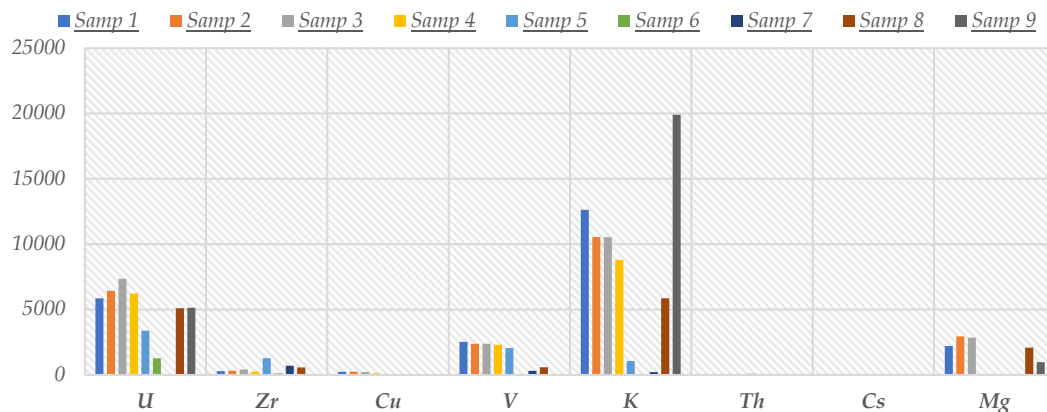


Fig.10. Evolution of concentrations of trace elements in conglomeratic sandstones

**Analysis of uranium ore associated with clay-quartz alterations**

**Major elements**

Silica (SiO<sub>2</sub>) is very abundant in clay-quartz alteration samples, with high concentrations of Al<sub>2</sub>O<sub>3</sub>, associated with

clays (Tab. 3 and Fig. 11); magnesium and iron are also present in moderate quantities, the other major elements (CaO, K<sub>2</sub>O,...) are present in very low concentrations.

Table 3

Concentrations of major elements in alteration samples (%)

Element	Samp1	Samp2	Samp3	Samp4	Samp5	Samp6	Samp7	Samp8	Samp9	Samp10
Al <sub>2</sub> O <sub>3</sub>	0.80	13.79	9.19	12.90	14.00	11.70	12.32	15.98	8.54	12.27
CaO	0.18	0.22	0.04	0.07	0.07	0.03	0.05	0.32	0.20	0.07
FeO	3.88	3.25	0.09	0.14	0.12	0.11	1.28	0.23	0.17	0.24
K <sub>2</sub> O	4.55	0.69	0.19	0.16	0.05	0.24	0.25	0.47	2.09	0.93
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.25	0.00
P <sub>2</sub> O <sub>5</sub>	0.10	0.07	0.16	0.27	0.22	0.13	0.13	0.25	0.38	0.32
VO <sub>2</sub>	0.00	0.02	0.09	0.02	0.02	0.01	0.01	0.08	0.02	0.08
SiO <sub>2</sub>	54.02	44.62	53.61	46.60	50.69	61.81	58.06	38.37	31.59	26.41
TiO <sub>2</sub>	0.51	0.85	0.36	0.36	0.25	0.26	0.45	2.22	0.67	1.87

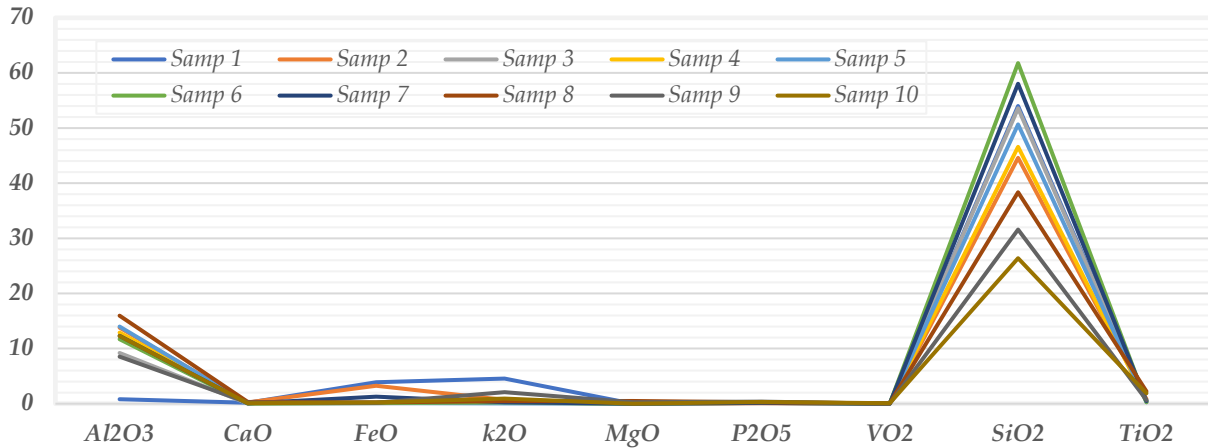


Fig. 11. Evolution of concentrations of major elements in alteration samples

**Trace elements**

Tab. 4 and Fig. 12 show a variation in Uranium concentrations in the various samples. There are highly mineralized alterations (Samp 9 and Samp 10), moderately mineralized alterations (Samp 5) and weakly or non-mineralized alterations. Vanadium is also present with

Uranium in the alteration profile. Zr levels reflect the abundance of Zircon in altered facies. A relatively low Th content is recorded. Other chemical elements, such as Copper (Samp 10), clearly indicate the phenomena and intensity of alteration.

Table 4

Trace element concentrations in alteration samples (ppm)

Element	Samp1	Samp2	Samp3	Samp4	Samp5	Samp6	Samp7	Samp8	Samp9	Samp10
U	9.88	84.26	127.31	537.23	1061.35	372.60	471.63	452.49	13193.99	9013.36
Zr	198.22	203.89	177.38	125.40	86.09	99.67	135.35	104.01	152.61	143.09
Cu	21.13	31.14	0.00	0.00	7.32	0.00	0.00	107.88	60.06	1050.87
V	30.21	115.71	55.78	111.92	138.85	55.99	77.49	469.80	136.15	463.78
Th	10.78	12.59	20.73	23.47	18.92	18.91	22.04	0.00	0.00	6.25
Cs	57.43	25.62	10.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00

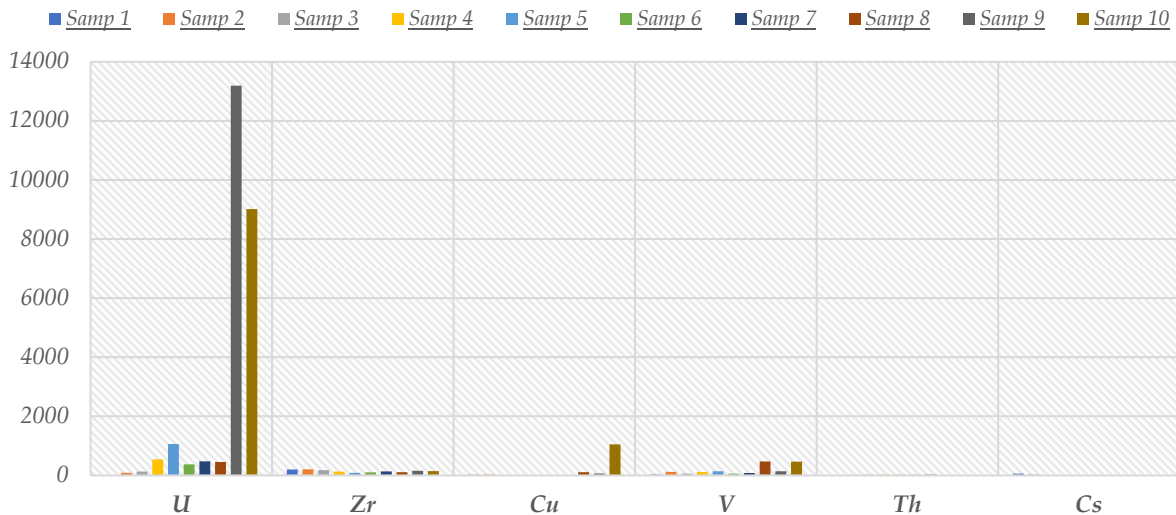


Fig. 12. Evolution of trace element concentrations in the alteration samples

Based on the analysis of samples from conglomeratic sandstones and altered facies we can conclude that three main chemical elements predominate in Tahaggart ore: silica, iron and aluminum; corresponding to sandstone and clay formations where iron is present at all levels with variable concentrations. It is richest in the conglomeratic sandstones, which are at the top of the series, compared with the altered rocks in the lower part. The other chemical elements, with varying grades in both facies, are generally

associated with typical uranium minerals and accessory minerals (quartz, rutile, zircon and monazite...) present in the Tahaggart ore. Uranium, the element of interest, is found in high concentrations in both facies. Uranium levels are higher in the alteration levels than in the conglomeratic sandstones.

**Results**

The results of analyses carried out on the various samples of Tahaggart uranium ores show the predominance of certain chemical elements over others. These elements

correspond perfectly to the chemical compositions of the dominant mineral phases observed under the optical microscope (petrographic study), namely: quartz, clays (kaolinite), iron oxides and hydroxides, uranium minerals and rutile. In summary, analysis of samples from conglomeratic sandstones and alteration facies shows that silica predominates over other Tahaggart ore components, with iron oxides and hydroxides more abundant in conglomeratic sandstones than in alteration facies. Clays are also present in alteration-related facies and to a lesser extent in conglomeratic sandstones, which appear as cement (matrix).

Carbonates, vanadates and phosphates and other chemical elements are present in small proportions in both facies and are generally bound to uranium and other minerals containing traces of uranium in their structures: carnotite, autunite, torbernite, metatorbernite (uranium minerals) and apatite, zircon, rutile and monazite (accessory minerals). Uranium grades in the Tahaggart deposit are significant, with 0.90 to 1.32 % in the mineralized altered levels and 0.34 and 0.74 % in the mineralized conglomeratic sandstones. Uranium is remarkably present in both facies, and is more concentrated in the altered levels. It is either associated with uranium-bearing minerals with high grades, or with lower grades in other minerals (apatite, zircon, rutile and monazite).

#### Discussion and conclusions

The petrographic (macro and microscopic) mineralogical and geochemical characterization of the main ore horizons; represented by the conglomeratic sandstones, and the alteration facies of which they are composed after synthesizing the results and overall data from the Tahaggart deposit, revealed the following: uranium grades are high (0.90 to 1.32 % in the mineralized altered levels and 0.34 to 0.74 % in the mineralized conglomeratic sandstones).

The Tahaggart uranium ore contains mainly secondary uranium-bearing minerals of autunite and torbernite, associated with iron oxides (hematite and goethite) and a clay matrix (kaolinite). Significant thorium and rare-earth mineralization is enclosed in a reddish Ordovician conglomerate.

There are also other uranium-bearing secondary minerals such as carnotite, sabugalite and uranophane. Silica predominates over the other components of Tahaggart ore, confirming its sandstone character, with the presence of iron oxides and hydroxides, which are more abundant in conglomeratic sandstones than in alteration levels.

Clays are also present in alteration-related facies, and to a lesser extent in conglomeratic sandstones, where they act as cement (matrix). Carbonates, vanadates and phosphates, and other chemical elements, are present in small proportions in both facies, and are generally associated with uranium-bearing minerals, and other minerals containing traces of uranium in their structures.

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## ПЕТРОГРАФІЧНА ХАРАКТЕРИСТИКА УРАНОВОЇ РУДИ ТАХАГГАРТ (ЕЛЬ-ХОГГАР, ПІВДЕННИЙ АЛЖИР)

**В с т у п .** Алжир давно намагався розробити свої родовища урану в регіоні Хоггар, метою є збут руди, використання частини продукції виключно в цивільній сфері, зокрема для виробництва електроенергії. Експлуатація та валоризація цієї руди вимагають дуже специфічного процесу розробки, характеристики та обробки. Основною метою цієї роботи є створення детальної та повної технічної таблиці для родовища Тахаггарт, що дасть змогу реалізувати технологію видобутку та збагачення уранової руди для отримання товарного продукту, відомого як "yellow cake".

**М е т о д и .** Для досягнення цієї мети було взято зразки з досліджуваної ділянки з подальшим мікроскопічним і макроскопічним аналізом нетонких зрізів для отримання петрографічної, мінералогічної та геохімічної ідентифікації.

**Р е з у л ь т а т и .** Аналіз підтвердив пісковиковий характер руди та переважання кварцу, глини, оксидів та гідроксидів заліза, а також мінералів урану та рутилу. Вміст урану в мінералізованих змінених рівнях коливається від 0,90 до 1,32 % і від 0,34 до 0,74 % в мінералізованих конгломератичних пісковиках. Уран трапляється або у високоякісних уранових мінералах, або в низькоякісних апатитах, цирконі, рутилі та в слідах у монациті.

**В и с н о в к и .** Різні дослідження, проведені в регіоні Тахаггарт; довели наявність уранових руд у значних кількостях, коливаючись від 0,90 до 1,32 % у мінералізованих змінених рівнях і від 0,34 до 0,74 % у мінералізованих конгломератичних пісковиках, однак, незважаючи на це та враховуючи стратегічне значення, яке уран має на міжнародному рівні; на сьогодні державна експлуатація цієї шахти не ведеться. Кращим методом очищення в цьому випадку є купкове вилуговування; коефіцієнт вилучення за допомогою цього методу може досягати 70 % урану у вигляді "yellow cake".

**К л ю ч о в і с л о в а :** уран, Тахаггарт, петрографічна характеристика, мінералогія та геохімія, вилуговування, "yellow cake".

Автори заявляють про відсутність конфлікту інтересів. Спонсори не брали участі в розробленні дослідження; у зборі, аналізі чи інтерпретації даних; у написанні рукопису; в рішенні про публікацію результатів.

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