Characteristics of uranium mineralization in the Tin-Seririne sedimentary basin (Algeria)

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Abstract. This article presents the results of studying the uranium mineralization of various parts of the Tin-Seririne sedimentary basin located in the southern part of the Hoggar massif in south-eastern Algeria. Mineralization of uranium is localized at different stratigraphic levels: in altered rocks of the Archean basement and unconformity overlying basal conglomerates (Tahaggart region), and in Devonian sandstones (uranium ore occurrences Tamart-N-Iblis, Timouzaline, etc.). For laboratory studies, 07 samples were taken: As and A1 granites, Tedjart, Timouzaline and Tamart-N-Iblis sandstones, gneisses and conglomerates of the Tahaggart deposit. The samples were examined using gamma spectrometric, chemical and microprobe analyzes. Mineralization is represented by minerals of hexavalent uranium: autunite, torbernite, carnotite, vanuralite and uranophane. The hypergenesis zone of the deposit, it is noted that the geochemical features of the formation of uranium mineralization are typical for regions of arid climate. The arid climate corresponds to oxidative processes of chemical weathering, with weakly alkaline or neutral uranium-bearing solutions. When studying samples taken from different stratigraphic levels, a difference in mineral composition was noted, which indicates some differences in the conditions of formation of uranium mineralization.

1. Introduction
The Tin Seririne sedimentary basin, located in the southern part of the Hoggar massif, at the regional metallogenic level corresponds to the Algerian-Nigerian uranium province [1]. Uranium concentrations in the Tin-Seririne basin (figure 1) are localized at two stratigraphic levels: in altered rocks of the Archean basement and unconformity overlying basal conglomerates (Tahaggart region), and in Devonian sandstones (uranium ore occurrences Tamart-N-Iblis, Timouzaline and others) [2].

The Tahaggart area is located on the north-eastern flank of the Tin-Seririne sedimentary basin along the contact of the Precambrian basement rocks with unconformity overlying basal conglomerates in the western part. Uranium mineralization associated with zones of alteration appears sporadically. It occurs in weathered gneisses, weathered rhyolites and some weathered granites and consists of an association of U(IV) minerals: autunite, torbernite, metatorbernite, sabugalite, uranophane, and carnotite. The formation of uranium minerals occurred synchronously with the processes of changes in the host rocks [3, 4, 5, 6].
Uranium ore occurrences in Tamart-N-Iblis, Timouzaline and others are located exclusively in the Lower Devonian formations of the Tin-Seririne basin. Lithological studies have determined that numerous discontinuous sandstone deposits of the Lower Devonian form meandering ore deposits. These sandstone deposits contain a clay fraction, as well as organic detritus, which sometimes occurs in the form of coal interlayers with an increased pyrite content [7]. Petrographic and mineralogical studies of ore-hosting rocks show that uranium mineralization is usually found in interstitiums between grains of arkose sandstones, as well as in clay cement [8]. Microscopic studies and X-ray structural analysis of ore samples have established that mineralization is represented by minerals of hexavalent uranium: autunite, torbernite, carnitite, vanuralite and uranophane.

The volume of studies carried out earlier is insufficient to assess its potential prospects for uranium and rare metals, given the size of the Tin-Seririne basin. In this article, based on the results of the studies carried out on samples taken from the most important uranium ore occurrences in the Tin-Seririne basin, the geochemical features of the formation of uranium mineralization are considered.

2. Mineralogical sampling

Samples for mineralogical studies were taken on the surface in different places shown (Figure 1). The sampling was conducted based on two important factors: the presence of a strong radiometric background and uranium mineralization visible to the naked eye.

![Figure 1. Deposits and ore occurrences of uranium in the Tin-Seririne basin.](image)

1 - Quaternary deposits, 2 - Lower Carboniferous, 3 - Upper and Middle Devonian, 4 - Lower Devonian, 5 - Silurian, 6- Proterozoic-Ordovician, 7 - basement rocks, 8 - Tahaggart deposit, 9 - sampling sites: gneiss (Tah), granite (As, A1), sandstone (TNB, Tdj and TMZ) and conglomerate (GBT).

Below are the most important macroscopic characteristics of the selected samples:
• The Tahaggart deposit (Tah) - gneiss is altered, mineralized with very strong radioactivity, radiometric background >>> 20000cps;
• The Tahaggart deposit (GBT) - basal conglomerate, oxidized and mineralized, with visible yellow uranium mineralization, with very strong radioactivity. Radiometric background >> 20000cps;
• Uranium ore occurrence (As) - altered whitish-pink granite, syntectonic. Radiometric background > 3000cps;
• Uranium ore occurrence (A1) - altered red granite, post-tectonic, presence of mineralization with a radiometric background > 2000cps;
• Uranium ore occurrence Tamart-N-Iblis (TMB) - arkosic sandstone, altered and mineralized with a yellow product. Radiometric background > 3500cps;
• Uranium ore occurrence Timouzaline (TMZ) - arkosic sandstone, mineralized, the presence of a yellow product. Radiometric background > 4000cps;
• Uranium ore occurrence Tedjart (Tdj) - arkosic sandstone, oxidized and mineralized, the presence of a yellowish product with a very strong radiometric background > 18000cps.

3. Results of analytical studies

3.1. Radiation measurements (gamma spectrometric analysis)
Gamma-spectrometric analysis of samples from uranium ore occurrences in the Tin-Seririne basin (the linking of samples is shown in figure 1) was performed using a GAMMA-1P spectrometer based on the MVI method of gamma-emitting nuclides. The results of the analysis are shown in table 1. The obtained results of gamma-spectrometric analysis indicate the natural radioactivity features of uranium, Th-234, Ra-226 and Pb-210 which are daughter products of the decay of U-238. The decomposition products of the thorium series are below the detection threshold by this method (it can be assumed that they are absent).

| Sample code | Volume activity of radionuclides, Bq / kg |
|-------------|-----------------------------------------|
|              | Th-234        | Ra-226         | Pb-210         | Th-232         | Th-228         | Ra-228         | Th-232 |
| A1           | 500±70        | 530±65         | 450±65         | 80±25          | 85±25          | 80±20          | <3000  |
| TMZ          | 8000±1200     | 19500±3000     | 26450±4000     | <30            | ≤40            | <30            | 1200±300|
| TNB          | 56250±8500    | 40000±5800     | 26450±4000     | <30            | <30            | <30            | 1000±200|
| Tah          | 306250±45000  | 318500±48000   | 58100±8700     | <30            | <30            | <30            | <300   |
| As           | 7500±1100     | 4500±700       | 242000±36300   | <30            | <30            | <30            | 1000±200|
| Tdj          | 38750±5800    | 27300±4000     | 10300±1500     | <30            | <30            | <30            | <300   |
| GBT          | 475000±71000  | 480000±72000   | 340100±51000   | <30            | <30            | <30            | <300   |

The radioactive balance in all samples, with the exception of TMZ, was not disturbed, uranium and its decay products did not change, that is, uranium minerals are at the place of their formation, were not redeposited and were not exposed to leaching solutions (rain, groundwater, etc.). In the TMZ sample, radium and lead are in equilibrium, while thorium is 2.5-3 less, which indicates the presence of processes that involve Th-234.

The conglomerates and gneisses of Tahaggart have the highest radioactivity, sandstones TMZ, TNB, Tdj and As granites have the greatest radioactivity, and A1 granites have the lowest radioactivity.

3.2. Chemical composition studies (ICP AES)
Investigations of the chemical composition of the samples were carried out by inductively coupled plasma atomic emission spectroscopy (ICP AES) on a Varian Vista-Pro instrument with preliminary
sample preparation, IR spectrometry, and gravimetry. The chemical analysis results are shown in table 2.

Table 2. Chemical composition of ore varieties in the Tin-Seririne basin (sample linkage is shown in figure 1), wt. %.

| Constituent element | A1   | As  | TNB | TMZ | Tdj | Tah | GBT |
|---------------------|------|-----|-----|-----|-----|-----|-----|
| SiO₂                | 68.95| 71.34| 84.78| 81.03| 90.96| 68.26| 86.62|
| TiO₂                | 0.40 | 1.04| 0.18| 0.18| 0.073| 0.52| 1.66|
| Al₂O₃               | 16.68| 16.48| 6.77| 9.09| 3.73| 17.21| 2.13|
| Fe₂O₃               | 5.14 | 1.01| 1.20| 0.71| 1.22| 0.78| 2.84|
| CaO                 | 0.94 | 0.67| 0.57| 0.54| 0.47| 0.62| 0.61|
| MgO                 | 0.17 | 0.17| 0.24| 0.25| 0.17| 0.12| 0.10|
| K₂O                 | 0.37 | 0.42| 2.27| 4.33| 0.98| 0.24| 0.099|
| Na₂O                | 0.24 | 0.26| 0.33| 0.36| 0.30| 0.26| 0.25|
| P₂O₅                | 0.11 | 0.59| 0.12| 0.26| 0.030| 0.46| 0.11|
| V₂O₅                | <0.001| <0.001| <0.001| 0.045| 0.14| <0.001| 0.24|
| U                   | 0.009| 0.040| 0.33| 0.041| 0.20| 2.60| 2.70|
| Cu                  | 0.003| 0.003| 0.004| 0.002| 0.011| 0.012| 0.010|
| C                   | 0.07 | 0.03| 0.03| 0.02| 0.03| 0.01| 0.02|
| S                   | 0.01 | 0.02| 0.03| 0.02| 0.02| 0.01| 0.02|
| LOI                 | 5.79 | 6.66| 2.80| 3.34| 1.39| 7.63| 1.33|
| Total               | 98.882| 98.733| 98.954| 99.984| 99.724| 98.722| 98.739|

The samples are carbonate-free, sulfide-free, characterized by an aluminosilicate composition with a low content of other components. The results of chemical analysis fully confirm the data of gamma-spectrometric analysis: gneisses and conglomerates of Tahaggart contain the highest concentrations of uranium (whole %), lower uranium contents (tenths of %) are found in Tidjert and Tamart-N-Iblis sandstones, Timouzaline sandstones and As granites contain equal concentrations uranium (hundredths %), and the lowest (thousandths %) - A1 granites.

3.3. Microprobe study

To conduct microprobe studies, polished sections were preliminarily made from small pieces of each sample. Chemical microprobe analysis was performed on a Zeiss EVO LS10 scanning electron microscope (Zeiss, Germany) equipped with an Oxford X-Max50 energy dispersive spectrometer (Oxford, United Kingdom). After obtaining BSE-images of the sample in the backscattered electron (BSE) detection mode, the chemical micro-mapping method was used to estimate the relative content of chemical elements for the selected surface area. Subsequently, individual minerals were subjected to local point semiquantitative chemical microanalysis. The results of microprobe studies are shown in figures 2-8 and tables 3-9.
3.3.1. Gneiss altered Tahaggart (Tah)

Figure 2. Sample Tah: a) photo of polished section, taken away. x 5, b) BSE images.

Table 3. The results of the chemical microanalysis of the Tah sample (figure 2b).

| Weight% | C   | O   | Al  | Si  | P   | K   | Ca  | Ti  | V   | Fe  | Ba  | U   |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Spec. 56| 12.47| 49.38| 1.96| 5.32| 1.61| 0.98| 1.12| 0.27| 0.11| -   | 0.43| 26.36|
| Spec. 57| 10.53| 47.23| 2.94| 6.62| 1.96| 0.98| 1.27| 0.16| -   | -   | 0.46| 27.86|
| Spec. 58| 10.45| 50.69| 2.29| 12.25| 1.34| 0.77| 0.72| 0.69| -   | 0.25| -   | 20.55|
| Spec. 59| 10.47| 48.0 | 2.02| 8.59| 1.86| 0.81| 1.22| 0.15| -   | -   | 0.45| 26.43|
| Spec. 60| 16.83| 57.71| 1.84| 5.68| 0.5 | 0.42| 0.59| 0.67| 0.33| 0.08| 0.26| 15.1 |
| Spec. 61| 17.68| 57.41| 1.32| 3.3 | 0.29| 0.33| 0.57| 1.14| 0.51| 0.11| -   | 17.33|
| Spec. 62| 11.53| 47.11| 1.81| 4.59| 2   | 1.07| 1.32| 0.16| -   | 0.2 | 0.47| 29.74|
| Spec. 63| 9.24 | 58.72| 1.04| 28.55| 0.11| 0.08| 0.12| 0.05| -   | -   | -   | 2.09 |
| Spec. 64| 12.14| 59.58| 14.05| 12.53| 0.07| 0.06| 0.13| -   | 0.1 | -   | -   | 1.34 |

3.3.2. Conglomerate Tahaggart (GBT)

Figure 3. Sample GBT: a) photo of polished section, taken away. x 5, b) multilayer map energy dispersive spectrometer (EMF), c-d) BSE image.
Table 4. The results of the chemical microanalysis of the GBT sample (figure 3 c-d).

| Weight% | C     | O     | Na    | Al    | Si    | P     | Ca    | Ti    | V     | Fe    | Ba    | U     |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Spec. 26| 10.45 | 46.87 | -     | 1.08  | 7.05  | 0.24  | 0.97  | 4.78  | 0.72  | 0.62  | 0.95  | 26.26 |
| Spec. 27| 11.19 | 55    | -     | 0.45  | 8.39  | 0.05  | 0.19  | 21.53 | -     | 0.78  | -     | 2.42  |
| Spec. 28| 13.23 | 51.94 | -     | 1.33  | 6.42  | 0.16  | 0.74  | 4.29  | 0.77  | 0.48  | 0.63  | 20.02 |
| Spec. 29| 14.25 | 55.92 | -     | 1.32  | 6.69  | 0.11  | 0.4   | 8.88  | 0.49  | 2.24  | 0.6   | 9.1   |
| Spec. 30| 13.12 | 62.21 | -     | 0.44  | 23.34 | -     | 0.08  | 0.15  | -     | 0.09  | -     | 0.56  |
| Spec. 31| 9.94  | 60.12 | -     | 0.19  | 29.24 | -     | 0.08  | 0.15  | -     | 0.28  | -     | -     |
| Spec. 32| 8.1   | 58.55 | 0.33  | 0.17  | 32.11 | -     | 0.09  | -     | -     | -     | -     | 0.47  |
| Spec. 33| 10.46 | 59.05 | -     | 0.33  | 26.13 | -     | 0.13  | 0.46  | 0.1   | 0.16  | -     | 3.18  |
| Spec. 34| 11.81 | 48.64 | -     | 0.48  | 7.08  | 0.13  | 0.91  | 2.97  | 0.95  | 0.36  | 0.61  | 25.74 |
| Spec. 35| 9.26  | 45.02 | -     | 1.52  | 6.04  | 0.25  | 1.06  | 6.88  | 1.11  | 0.89  | -     | 27.95 |
| Spec. 36| 11.17 | 54.95 | -     | 1.29  | 5.35  | 3.92  | 1.06  | 0.87  | -     | 1.02  | -     | 4.41  |
| Spec. 37| 9.81  | 57.57 | 0.13  | 15.81 | 14.59 | 0.12  | 0.13  | 0.25  | -     | 0.17  | -     | 1.42  |
| Spec. 38| 10.49 | 58.37 | 0.15  | 15.45 | 14.26 | -     | 0.17  | 0.13  | -     | 0.31  | -     | 0.69  |

3.3.3. Sandstone Tidjert (Tdj)

![Image](a)

Figure 4. Sample Tdj a) photo of polished section, taken away. x 5; b) BSE image.

Table 5. The results of the chemical microanalysis of the Tdj sample (figure 4 b-c).

| Weight% | O     | Na    | Mg    | Al    | Si    | S     | K     | Ca    | V     | Fe    | Mo    | U     |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Spec. 11| 32.83 | 0.46  | -     | 0.68  | 15.59 | -     | 5.74  | -     | 7.05  | -     | -     | 37.65 |
| Spec. 12| 33.01 | 0.6   | -     | 0.96  | 15.65 | -     | 5.94  | -     | 6.69  | -     | 0.57  | 36.58 |
| Spec. 13| 32.56 | 0.39  | -     | 0.87  | 15.25 | -     | 6.26  | -     | 6.81  | 0.26  | -     | 37.6  |
| Spec. 14| 34.2  | 0.74  | 0.24  | 1.62  | 16.68 | 0.17  | 5.62  | -     | 6.3   | 0.36  | -     | 34.06 |
| Spec. 15| 52.73 | -     | 0.58  | 45.63 | -     | 0.24  | -     | -     | 0.23  | -     | 0.58  | -     |
| Spec. 16| 48.65 | -     | 0.62  | 16.53 | 27.27 | 0.3   | 0.63  | 0.32  | 0.45  | 4.14  | -     | 1.1   |
| Spec. 17| 50.36 | -     | 0.23  | 18.35 | 29.11 | 0.09  | 0.27  | 0.1   | 0.14  | 1.35  | -     | -     |
| Spec. 18| 52.88 | -     | 0.54  | 45.77 | -     | 0.21  | -     | 0.13  | 0.19  | -     | 0.29  | -     |
| Spec. 19| 31.39 | 0.25  | -     | 0.76  | 13.16 | 0.11  | 6.41  | -     | 7.68  | 0.26  | -     | 39.99 |
| Spec. 20| 32.75 | 0.42  | 0.33  | 1.51  | 14.62 | -     | 6.32  | -     | 7.01  | 0.32  | 0.32  | 36.39 |
| Spec. 21| 37.24 | 0.35  | -     | 1.33  | 21.67 | 0.16  | 4.77  | -     | 5.19  | 0.52  | -     | 28.78 |

6
3.3.4. Sandstone Tamart-N-Ibis (TNB)

![Image](image1)

**Figure 5.** Sample TNB a) photo of polished section, taken away. x 5; b-c) BSE image.

| Weight % | O | Mg | Al | Si | P | K | Ca | Ti | Fe | Zr | U |
|----------|---|----|----|----|---|---|----|----|----|----|---|
| Spec. 1  | 39,1 | - | 3,22 | 20,76 | - | 2,06 | - | - | 1 | 33,87 | - |
| Spec. 2  | 47,95 | 0,9 | 15,35 | 27,83 | - | 4,52 | 0,72 | - | 2,74 | - | - |
| Spec. 3  | 46,61 | - | 11,17 | 29,93 | - | 11,5 | - | - | 0,79 | - | - |
| Spec. 4  | 40,7 | - | 4,61 | 22,08 | - | 2,3 | - | 1,07 | - | 29,24 | - |
| Spec. 5  | 46,35 | 1,19 | 12,29 | 26,49 | - | 4,3 | - | 2,34 | 7,05 | - | - |
| Spec. 6  | 40,34 | - | 3,52 | 22,75 | - | 2,35 | - | - | 1,12 | 29,93 | - |
| Spec. 7  | 52,83 | - | 1,11 | 45,38 | - | 0,68 | - | - | - | - | - |
| Spec. 8  | 40,56 | - | 4,62 | 18,04 | 1,52 | 0,84 | 1,53 | - | 9,03 | 10,69 | 9,33 | 3,84 |
| Spec. 9  | 40,16 | - | 3,15 | 21,52 | 1,6 | 0,73 | 1,28 | 2,34 | 14,87 | 9,4 | 4,95 |
| Spec. 10 | 48,65 | - | 16,74 | 27,48 | - | - | - | 1,07 | 6,06 | - | - |

3.3.5. Sandstone Temouzaline (TMZ)

![Image](image2)

**Figure 6.** Sample TMZ a) photo of polished section, taken away. x 5; b) BSE image.
Table 7. The results of the chemical microanalysis of the TMZ sample (figure 6b).

| Weight% | C   | O   | Na  | Mg  | Al  | Si  | K   | Ca  | Ti  | V   | Fe  | Zn  | Mo  | Ba  | U   |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Spec. 49 | 14.33 | 53.48 | 0.16 | -   | 2.17 | 5.76 | 3.77 | -   | -   | 3.11 | 0.1 | -   | 0.23 | -   | 16.89 |
| Spec. 50 | 13.37 | 59.18 | -   | 0.35 | 8.68 | 12.36 | 3.41 | 0.31 | -   | 0.33 | 0.53 | 0.12 | -   | 0.16 | 1.2 |
| Spec. 51 | 16.16 | 58.41 | 0.34 | 0.16 | 3.12 | 7.15 | 2.33 | 0.46 | 0.14 | 1.82 | 0.25 | -   | -   | -   | 9.66 |
| Spec. 52 | 10.91 | 60.33 | -   | -   | 1.36 | 26.16 | 0.91 | -   | -   | 0.09 | -   | -   | -   | -   | 0.26 |
| Spec. 53 | 10.59 | 56.49 | 0.4  | -   | 7.17 | 17.65 | 6.84 | -   | -   | 0.11 | 0.09 | -   | -   | -   | 0.65 |
| Spec. 54 | 12.98 | 61.34 | -   | -   | 1.72 | 21.64 | 1.23 | -   | 0.06 | 0.14 | 0.08 | -   | -   | -   | 0.81 |
| Spec. 55 | 14.46 | 53.75 | 0.16 | 0.06 | 2.04 | 5.86 | 3.68 | -   | -   | 3.05 | 0.08 | -   | 0.22 | -   | 16.62 |

3.3.6. Granite As

Figure 7 - Sample As a) photo of polished section, taken away. x 5; b) BSE image.

Table 8. The results of the chemical microanalysis of the As sample (figure 7b).

| Weight% | C    | O    | Al  | Si  | P    | S    | K    | Ca  | Ti  | V    | Fe   | Ba  | U    |
|---------|------|------|-----|-----|------|------|------|-----|-----|------|------|-----|------|
| Spec. 44 | 8.21 | 52.97 | 3.56 | 9.63 | 0.16 | 0.04 | 0.14 | 0.11 | 24.65 | -    | 0.52 | -    |
| Spec. 45 | 10.43 | 58.89 | 12.67 | 16.78 | 0.11 | 0.04 | 0.2  | 0.11 | 0.54 | -    | 0.23 | -    |
| Spec. 46 | 8.73  | 58.91 | 2.39 | 28.93 | 0.09 | -    | 0.22 | 0.08 | 0.5  | -    | 0.16 | -    |
| Spec. 47 | 14.94 | 57.95 | 3.57 | 8.85  | 0.32 | 0.13 | 0.2  | 0.14 | 0.46 | 0.1  | 13.22 | -    | 0.13 |
| Spec. 48 | 10.74 | 60.19 | 2.19 | 25.1  | 0.15 | 0.05 | 0.14 | 0.08 | 0.93 | -    | 0.25 | 0.19 |

3.3.7. Granite A1

Figure 8. Sample A1: a) photo of polished section, taken away. x 5; b) BSE image.
As Tdj and TNB. Despite its active migration ability under oxidizing conditions, it is inactive in the weathering crust of rock basins, formed as a result of dissolution of rock minerals, which are found in weathered gneisses, weathered rhyolites, and other uranyl complexes. The deposition of uranium in these minerals, therefore, groundwater in a dry hot climate is characterized by alkaline reactions. 

| Weight % | C   | O    | Na  | Al  | Si  | P   | S   | Cl  | K   | Ca  | Ti  | V   | Mn  | Fe  |
|----------|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Spec. 65 | 11.01 | 60.05 | -   | 1.37 | 25.34 | -   | -   | 0.05 | 0.06 | -   | -   | -   | 2.11 |
| Spec. 66 | 12.47 | 52.32 | -   | 2.03 | 8.86 | 0.06 | 0.04 | 0.04 | 0.06 | 0.15 | 0.12 | 0.14 | 23.57 |
| Spec. 67 | 13.16 | 53.85 | 0.24 | 2.14 | 9.21 | 0.09 | -   | -   | 0.21 | 0.12 | 0.06 | 0.16 | 20.75 |
| Spec. 68 | 14.27 | 60.22 | 0.17 | 8.15 | 11.69 | -   | -   | 0.09 | 0.21 | -   | -   | -   | 5.2  |

According to the data of electron microscopic study, the uranium mineralization of the Tin-Seririne basin in the selected samples is represented by hypergene minerals of hexavalent uranium [9, 10, 11], mainly phosphates and vanadates:

- Tah - autunite, metaautunite, sabugalite, phosphuranylite, uranophane; bariouranophane, carnitite, uranyl hydroxides (figure 2 and table 3);
- GBT - autunite, metaautunite, sabugalite, phosphuranylite, uranophane, bariouranophane, vanuralite, carnitite (figure 3 and table 4);
- TNB - autunite, accessory minerals, clay cement (figure 5 and table 6);
- Tdj - carnotite (figure 4 and table 5);
- TMZ - carnotite (figure 6 and table 7);
- As - accessory minerals (figure 7 and table 8);
- A1 - no visible uranium mineralization was found (figure 8 and table 9).

4. Discussion
This region is characterized by a dry (desert) continental climate. Annual precipitation is between 5 and 10 mm. The arid climate corresponds to the oxidizing conditions of the processes of chemical weathering [12, 13]. Leaching, which is usually more pronounced in the upper than in the lower part of the weathering profile, led to the hydrolysis of silicates and the release of their constituent elements (Si, Al, Mg, Ca, K, Na, Fe, P, etc.) into the solution. Silicic acids, formed as a result of dissolution of rock-forming minerals, are completely neutralized by alkaline and alkaline earth cations from the composition of the same minerals, therefore, groundwater in a dry hot climate is characterized by alkaline reactions. U⁶⁺ leached from bedrocks is oxidized to U⁴⁺ by these waters, and uranyl UO₂⁴⁺ is formed, which migrates well in the form of water-soluble uranyl-carbonate UO₂(CO₃)⁴⁻, uranyl-sulfate UO₂(SO₄)²⁻ and other uranyl complexes. The depression of uranium in the form of hypergene minerals occurs due to changes in the pH of natural waters. In acidic media, uranyl forms mineral forms with the anions PO₄³⁻, AsO₄³⁻, less often with SO₄²⁻ in a neutral and slightly alkaline environment with VO₃⁻, MoO₄²⁻, SiO₄⁴⁻, SiO₂⁴⁻, CO₃²⁻ and OH⁻. The sequence of the formation of various mineral forms depends on the concentration of the corresponding anions and the acid-base regime of uranium-bearing solutions [14]. Uranium is also well absorbed by clays, silicate gels, and iron hydroxides.

The combination of the platform regime with a sharply dry climate created special conditions for the migration of uranium [15, 16]. Despite its active migration ability under oxidizing conditions, it is inactive in the weathering crust of deserts. Radium also migrates weakly, and therefore the radioactive equilibrium is almost not disturbed, which is confirmed by our gamma-spectrometric analysis.

Oxidation processes, which are intensely manifested in the landscapes of arid climates, in the Tahaggart region are revealed in the changes in the rocks of the Precambrian basement. Increased uranium concentrations appear sporadically and are associated with zones of crystalline rock alteration. They are found in weathered gneisses, weathered rhyolites and some mica shales. Much of the uranium may be associated with dark red altered porphyroid granites. The formation of uranium mineralization occurred synchronously with the processes of changes. Uranium minerals are in paragenesis with kaolinite, quartz, apatite and a lesser extent, iron oxides and hydroxides.
In conglomerates, uranium mineralization is found only in those areas that occur on mineralized weathered gneisses. Uranium minerals fill the interstices between quartz grains. Part of the uranium mineralization found in the conglomerate is inherited directly from altered gneisses by the presence of processed kaolinite in the matrix of this conglomerate. Later, the conglomerates pass through process of intense ferruginization.

As indicated by previous studies [3, 6], hypergene alteration, permeability, Eh and pH values, and basal paleotopography appear to be important parameters in determining the release, transport, accumulation and deposition of uranium in the alteration zone.

Such ore accumulations can be attributed to deposits of the weathering crust and oxidation zone. They usually concentrate only a part of that uranium, which, together with the host rocks, is exposed by the zone of surface weathering [17]. Part of the uranium, due to the active influence of surface and ground waters enriched with oxygen and carbon dioxide, is carried to the area of surface river runoff. And, probably, is one of the sources of uranium in the sandstone deposits of the Devonian age.

Possible sources of uranium in the Devonian deposits of the Tin-Seririn sedimentary basin are:

- Placer minerals (zircon, allanite, apatite) in the Lower Devonian sandstone deposits.
- Altered rocks at the contact between the crystalline basement and the sedimentary cover;
- Accessory minerals (apatite, zircon, sphene, allanite and monazite) of the Hoggar crystalline massif.

These chemogenic concentrations of uranium were formed in the process of precipitation of various chemical and colloidal compounds from the waters of the basin, impregnating the newly formed alluvial deposits. Increased insolation has led to an increase in the concentration of uranium in groundwater. As a result of further diagenesis, a redistribution of matter took place, which led to the formation of higher ore concentrations with corresponding ore textures in some areas. But the weak migratory ability of uranium in the hypergenesis zone in an arid climate did not contribute to the formation of large, rich ore deposits.

5. Conclusions
Uranium mineralization of the Tin-Seririne sedimentary basin in samples taken from altered rocks of the crystalline basement is represented by a wide range of hexavalent uranium minerals: autunite, carnitite, uranophane, bariouranophane, sabugalite, vanuralite, phosphuranylite, etc.

In sandstones, the main uranium mineral is carnitite. This indicates a different geochemical setting in which the formation of uranium minerals took place.

Sandstones Tamart-N-Iblis, being closer to the Hoggar massif, which is a feeding area for uranium-bearing solutions, occupy an intermediate position, they still retain unchanged accessory minerals, and the main process of uranium deposition is sorption.

Granites were slightly exposed to chemical weathering, uranium mineralization in them is mainly represented by accessory minerals.

References
[1] Badahmaoui T and Bugrieva E P 2019 Mineral resources base of uranium of the Hoggar massif Algeria. XIV International Scientific and Practical Conference “New Ideas in Earth Sciences”, MGRU-RGGRU, Moscow, Russia, Tom II, pp. 12-16.
[2] Khaldi A et all. 1997 Synthèse des travaux de prospection géologique et géophysique dans le bassin sédimentaires de Tin Séririné, Tassili Oua N’Ahaggar, Sud-est du Hoggar, Rapport internes CREM, Alger, Algérie.
[3] Chahdane R 2009 Contribution à l’étude géologique et géitologique des minéralisations uranifères de Tahaggart (Sud-est du Hoggar): minéralogie et géochimie d’une minéralisation liée aux altérations du socle et au conglomérat de base de la série détritique paléozoïque, Thèse de magister, USTHB, Alger, Algérie, 190 p.
[4] Hallalouche D 1995 *Etude de l'altération du socle précambrien à la périphérie du bassin de Tin-Séririne (Hoggar-Sud, Algérie) et minéralisations uranifères et thorifères associées*, Thèse Doctorat. – Université de Rennes I, France, p 222.

[5] Guettaf H, Becis A, Ferhat K, Hanou K, Bouchiha D, Yakoubi K, and Ferrad F 2009 Concentration–Purification of Uranium from an Acid Leaching Solution. *Physics Procedia*, 2, pp 765-771.

[6] Gherbi R and Becis A 2015 Fractional factorial design for studying uranium carbonate leaching of Tahaggart's ore. *International Journal of Mineral Processing*, 143, pp 59-64

[7] Mokaddem M 1980 *Le bassin sédimentaire de Tin Séririne et ses minéralisations uranifères (Hoggar-Algérie)*, Thèse Doct. 3ème cycle, Paris-Orsay, France, 110 p.

[8] Amieur M 2012 *Les minéralisations uranifères encaissées dans les formations détritiques dévonniennes du bassin de Tin Séririne (Sud-Est du Hoggar)*, Thèse de magister, USTHB, Alger, Algérie, 106 p.

[9] Isobe H, Ewing R C and Murakami T 1994 Formation of secondary uranium minerals in the Koongarra deposit, Australia: Unweathered zone, *Journal of Nuclear Materials*, 190, pp174-187.

[10] Finch R and Murakami T 1999 *Systematics and Paragenesis of Uranium Mineral*. In: P.C. Burns and R. Finch, (ed.), Uranium: Mineralogy, Geochemistry, and the Environment. Mineralogical Society of America, Washington, DC., 38, pp 91–179.

[11] Finch R J 1994 Paragenesis and crystal chemistry of the uranyl oxide hydrates, Ph.D. Thesis, University of New Mexico, 257 p.

[12] El-Kammar A, El-Wakil M, Abd El-Rahman Y, Fathy M and Abdel-Azeem M 2020 Stream sediment geochemical survey of rare elements in an arid region of the Hamadat area, central Eastern Desert, Egypt, *Ore Geology Reviews*, 117, pp 103-287

[13] Howari F, Goodel P and Salman A 2016 Metallogenic evolution of uranium deposits in the Middle-East and North-Africa deposits, *Journal of African Earth Sciences*, 114, pp. 30-42.

[14] Terekhov V Y, Egorov N I, Bayushkin I M and Mineev D A 1987 *Mineralogy and geochemistry of rare and radioactive metals*. Energoatomizdat, Moscow, Russia, 360 p.

[15] Gaafar I 2015 Integration of geophysical and geological data for delimitation of mineralized zones in Um Naggat area, Central Eastern Desert, Egypt, *NRIAG Journal of Astronomy and Geophysics*, 4, pp 86-99

[16] Mahdy N M, Shalaby M H, El-Afandy A H, El Kalioubi B A and Wohlgemuth-Ueberwasser C C 2015 Petrogenesis of U- and Mo-bearing A2-type granite of the Gattar batholith in the Arabian Nubian shield, northeastern desert, Egypt: evidence for the favorability of host rocks for the origin of associated ore deposits, *Ore Geology Reviews*, 71, pp 57-81.

[17] Ruoshi J, Xueming T, Xiaoguang L, Qinghong S and Wei W 2020 Genesis of sandstone-type uranium deposits along the northern margin of the Ordos Basin, China. *Geoscience Frontiers*, 11, pp 215–227.