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To cite this article: T Badahmaoui *et al* 2020 *J. Phys.: Conf. Ser.* **1689** 012050

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

T Badahmaoui^{1,3}, E P Bugrieva² and A A Lavrukhin¹

¹ National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse, 31, Moscow, 115409, Russian Federation

²All-Russian Research Institute for Chemical Technology, JSC "VNIIT", Moscow, Russian Federation

³Nuclear Research Center of Tamanrasset, Tamanrasset, Algeria

tayeb.badahmaoui@yandex.ru

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^{6+} 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, carnotite, 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.

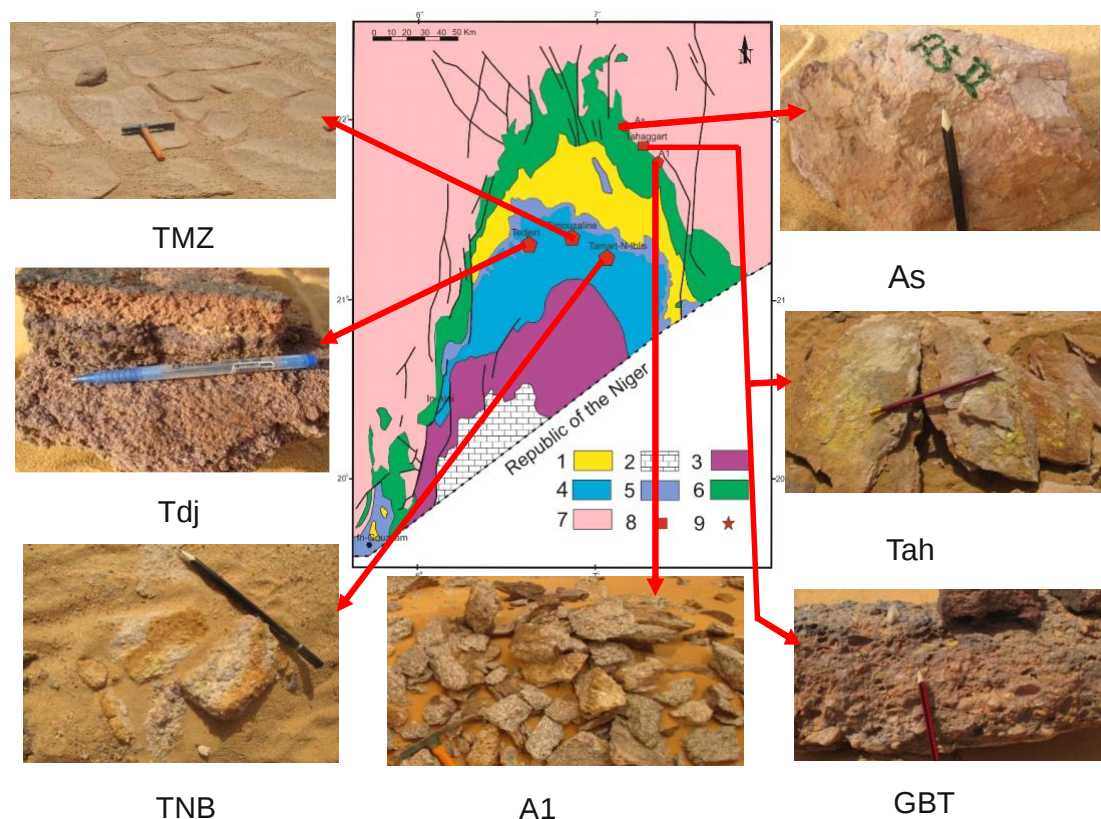


Figure 1. Deposits and ore occurrences of uranium in the Tin-Seririne basin.

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 Tahagart deposit (Tah) - gneiss is altered, mineralized with very strong radioactivity, radiometric background >>> 20000cps;
- The Tahagart 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).

Table 1. Results of gamma spectrometric analysis.

Sample code	Volume activity of radionuclides, Bq / kg						
	Th-234	Ra-226	Pb-210	Th-232	Th-228	Ra-228	K-40
A1	500±70	530±65	450±65	80±25	85±25	80±20	<300
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 Tahagart 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	Sample code						
	A1	As	TNB	TMZ	Tdj	Tah	GBT
SiO ₂	68.95	71.34	84.78	81.03	90.96	68.26	86.62
TiO ₂	0.40	1.04	0.18	0.18	0.073	0.52	1.66
Al ₂ O ₃	16.68	16.48	6.77	9.09	3.73	17.21	2.13
Fe ₂ O ₃	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
K ₂ O	0.37	0.42	2.27	4.33	0.98	0.24	0.099
Na ₂ O	0.24	0.26	0.33	0.36	0.30	0.26	0.25
P ₂ O ₅	0.11	0.59	0.12	0.026	0.030	0.46	0.11
V ₂ O ₅	<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)

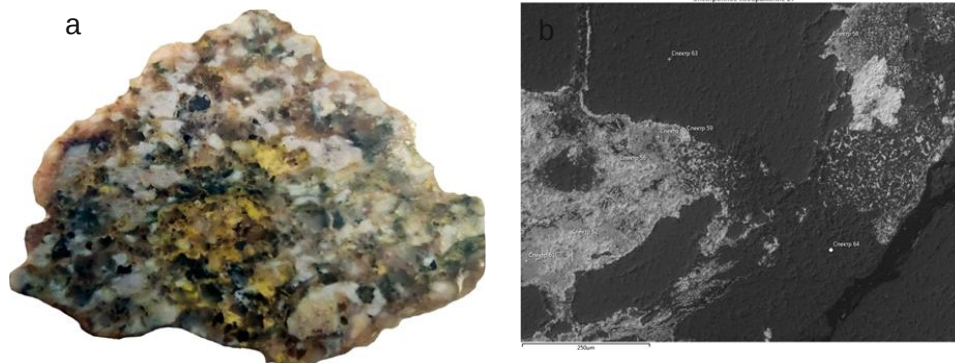


Figure 2. Sample Tah: a) photo of polished section, taken away. x 5, b) BSE images.

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)

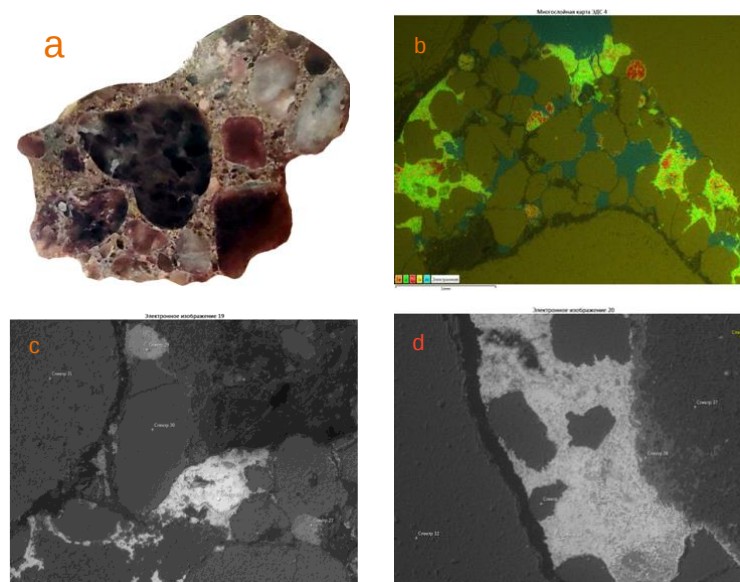
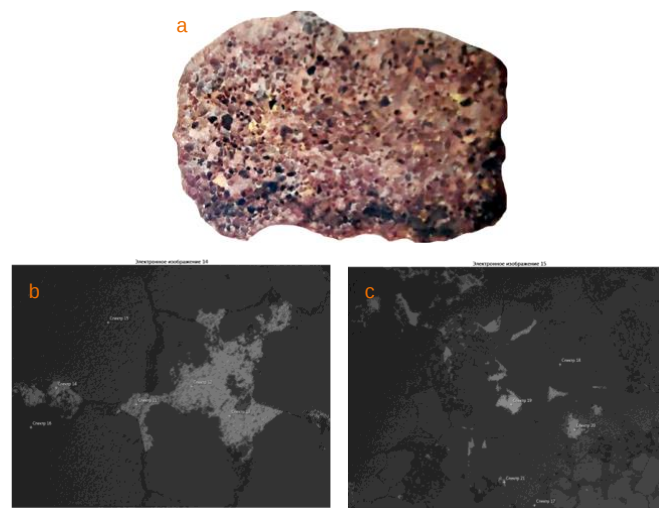


Figure 3. Sample GBT: a) photo of polished section, taken away. x 5, b) multilayer map energy dispersive spectrometer (EMF), c-d) BSE image.

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	-	11,29	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)

**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

3.3.4. Sandstone Tamart-N-Iblis (TNB)

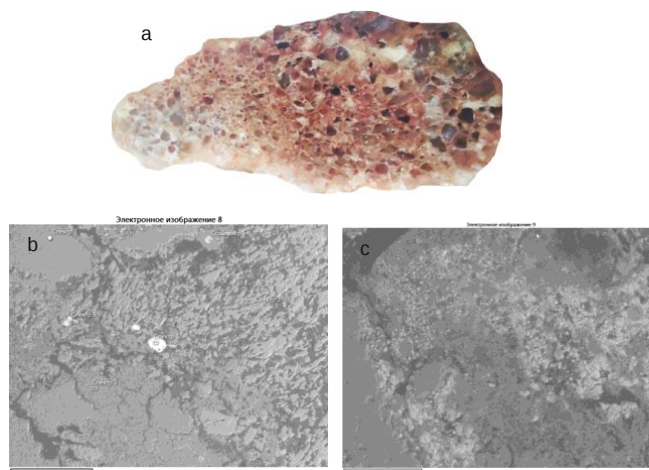


Figure 5. Sample TNB a) photo of polished section, taken away. x 5; b-c) BSE image.

Table 6. The results of the chemical microanalysis of the TNB sample (figure 5 b-c).

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)

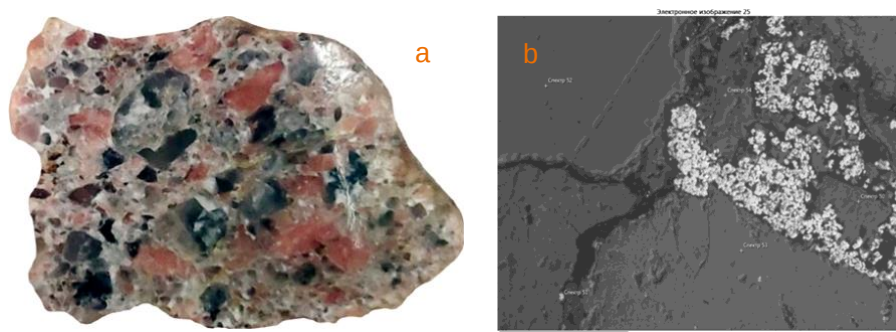
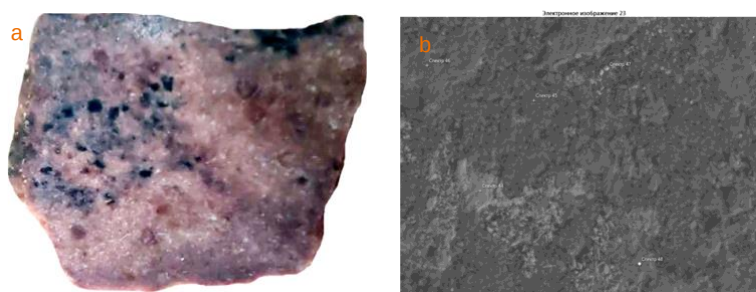


Figure 6. Sample TMZ a) photo of polished section, taken away. x 5; b) BSE image.

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

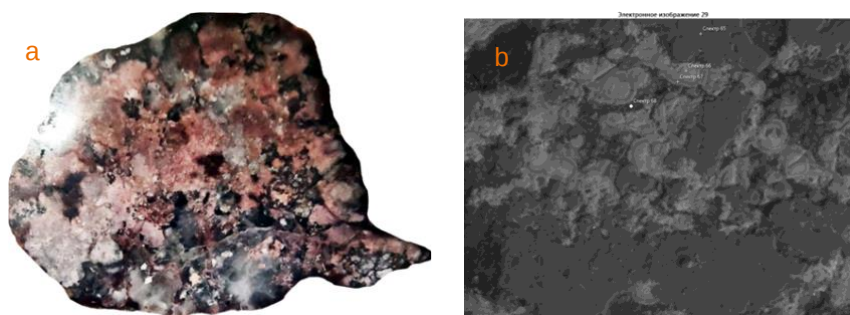
**Figure 8.** Sample A1: a) photo of polished section, taken away. x 5; b) BSE image.

Table 9. The results of the chemical microanalysis of the A1 sample (figure 8b).

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	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 hypogene minerals of hexavalent uranium [9, 10, 11], mainly phosphates and vanadates:

- Tah - autunite, metaautunite, sabugalite, phosphuranylite, uranophane; bariouranophane, carnotite, uranyl hydroxides (figure2 and table 3);
- GBT - autunite, metaautunite, sabugalite, phosphuranylite, uranophane, bariouranophane, vanuralite, carnotite (figure3 and table 4);
- TNB - autunite, accessory minerals, clay cement (figure5 and table 6);
- Tdj - carnotite (figure4 and table 5);
- TMZ - carnotite (figure6 and table 7);
- As - accessory minerals (figure7 and table 8);
- A1 - no visible uranium mineralization was found (figure8 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. U^{4+} leached from bedrocks is oxidized to U^{6+} by these waters, and uranyl UO_2^{2+} is formed, which migrates well in the form of water-soluble uranyl-carbonate $UO_2(CO_3)_4^{4-}$, uranyl-sulfate $UO_2(SO_4)_2^{2-}$ and other uranyl complexes. The deposition of uranium in the form of hypogene minerals occurs due to changes in the pH of natural waters. In acidic media, uranyl forms mineral forms with the anions PO_4^{3-} , AsO_4^{3-} , less often with SO_4^{2-} in a neutral and slightly alkaline environment with VO_4^{3-} , MoO_4^{2-} , SiO_4^{4-} , SiO_3^{2-} , CO_3^{2-} 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], hypogene 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, carnotite, uranophane, bariouranophane, sabugalite, vanuralite, phosphuranylite, etc.

In sandstones, the main uranium mineral is carnotite. 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.

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