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ZIRCON TYPOLOGY IN THE AIT-OKLAN AND TEG-ORAK GRANITIC MASSIFS (PHARUSIAN TRENCH – HOGGAR)

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ABSTRACT

Typological study of zircons has been developed by Pupin and Turco (1970; 1972) and Pupin (1980). The behaviour of zircon during magma genesis and evolution is very important in that it is a host mineral for several trace elements, such as: Zr, Y, and REE. On the other hand, zircon is commonly used for geochronological studies of granites using the U/Pb method.

Modal and geochemical analyses of granitoids as well as typological analysis of biotites can define the geochemical affinity and the geotectonic environment of the granitoids. As a complement, zircon typology is an original method that can precisely define the magmatic affinity of the granitoids and, in many cases, shows the effects of contamination processes during granitoid genesis.

The aim of this study is, to describe this method and to test it on the Pan-African granitoids of Ait-Oklan and Teg-Orak, whose magamatic affinity has already been determined by petrologic and geochemical studies.

All zircon populations that are present in the Ait-Oklan and Teg-Orak granitoids show sub-types clustering around S20, S25 and P3 to P5 sub-types of the rocks that are characterized by S-type affinity. Comparison between the different zircon populations and their convergence to the order of crystallisation indicates a typological evolution relative to their time of crystallization. The majority of zircons are included in biotite flakes; they are weakly to highly coloured, but limpid varieties can occur in rare occasions.

The typological study of zircons confirms the sub-alkaline affinity of the Ait-Oklan and Teg-Orak granitoids.

Keywords: Hoggar - Granitoid - Pan-African - Magmatic affinity - Zircon typology.

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TYPOLOGIE DES ZIRCONS DANS LES MASSIFS GRANITIQUES D'AÏT-OKLAN ET DE TEG-ORAK (FOSSE PHARUSIEN-HOGGAR

RÉSUMÉ

L'étude de la typologie des zircons a été mise au point par Pupin (1970; 1980) et Turco (1972; 1980). Le comportement du zircon pendant la genèse et l'évolution des magmas est très important dans la mesure où il s'agit d'un minéral hôte pour divers éléments en traces tels que Zr, Y et REE. (D'autre part, il joue un rôle essentiel dans la datation des granites par la méthode U/Pb).

En complément à l'analyse modale et géochimique des granitoïdes ainsi qu'à l'analyse typologique des biotites, qui permettent de définir l'affinité moyenne et le site géotectonique des granitoïdes, la typologie des zircons est une méthode originale qui permet de préciser l'affinité magmatique des granitoïdes et parfois même de mettre en évidence des phénomènes de contamination dans la genèse des granitoïdes.

Le but de cette méthode est:
1/ de décrire cette méthode
2/ de l'appliquer aux granitoïdes panafricains d'Aït-Oklan et du Teg-Orak, dont l'affinité magmatique a été précédemment définie par une étude pétrologique et géochimique.

Les populations de zircons de tous les faciès des massifs d'Aït-Oklan et du Teg-Orak , ont été étudiées. Le nombre de sous-types est important ; ils sont concentrés autour des sous-types S20, S25 et P3 à P5. On observe une évolution typologique des zircons en fonction de leur période de cristallisation dans le magma granitique. Ces zircons sont assez nombreux, peu colorés à colorés, rarement limpides. La majorité des zircons est incluse dans les biotites.

Les résultats obtenus par cette méthode confirment l'appartenance de ces granitoïdes à une série sub-alcaline.

Mots clés : Hoggar - Granitoïde - Pan-africain - Affinité magmatique - Typologie des zircons.

I - INTRODUCTION AND METHODOLOGY

The method is based on the morphology of zircons and can be used to discriminate (petrologically and geochemically) between the igneous rocks of a given area, to define the original magma, its chemical features and temperature of crystallization.

Zircon offers several advantages in the way that it is a common mineral in plutonic rocks, often idiomorphic and alteration resistant.

Zircon typology gives a number of petrogenetic information on the studied rocks.

Zircon separates are obtained following the represation flowchart of figure 1:

Over one hundred zircon crystals have been microscopically observed. The types of zircons and their temperatures have been determined based on the relative development of prismatic and pyramidal faces of the crystals (fig. 2). The main factors that explain the typological variations regarding the relative development of

PREPARATION

Sampling

↓

Crushing 1 (jaw crusher)

↓

Crushing 2 (agate mill)

↓

Dry sieving (50 to 160 microns)

↓

Separation (heavy minerals - d = 2.87)

↓

Separation of apatite (± methylene iodine - d = 3.32)

↓

Electromagnetic separation (using different I levels) for separetes with "d > 2.89"

↓

Zircon separates

Fig. 1 - Schematic diagram showing the preparation steps for zircon separation
Schéma représentant les différentes étapes de la séparation des zircons

the pyramids (211)-(101) (A index) and the prisms (100)-(110) (T index) are, the chemistry (aluminous or alkaline characters) and the temperature of crystallization, respectively (Pupin, 1976; Pupin and Turco, 1972; 1975).

The dispersion and typological partitioning of zircon populations in granites that have comparable chemical compositions is essentially due to:

- the difference between the initial temperatures of magmas that generate the granitoids,

- the variability of the period of crystallization of the zircon, which may be early magmatic or overlaps the whole period of magmatic crystallization of the rock,

- the U content of the magma (Benisek and Finger, 1993).

II - TYPOLOGICAL STUDY

Accessory minerals have an important petrologic significance because they are very informative when considering the thermo-dynamic characters of the medium in which they crystallize. Pupin (1976) has proposed a typolo-gical method based on the crystal morphology of zircons after separation (fig. 1). He pointed out that the development of prisms (T index) is temperature dependent, whereas the development of pyramids (A index) is mainly related to the agpaicity ratio Na/(Al-K).

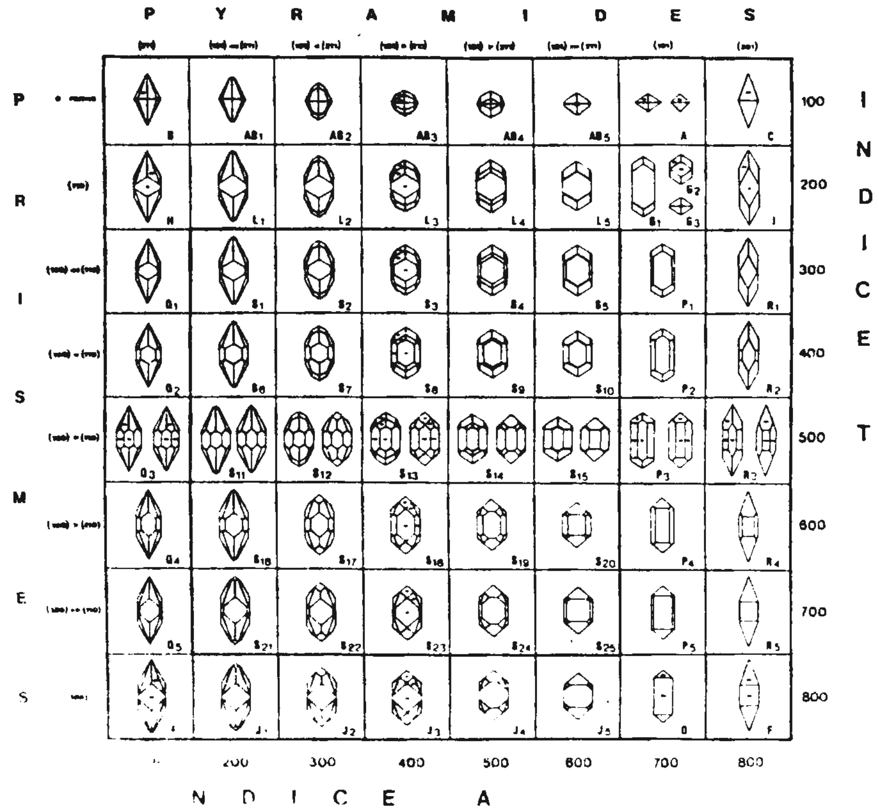


Fig. 2 - Fondamental types and sub-types of zircon classification (After Pupin and Turco, 1972 a, b) A and T indexes are also indicated

Types et sous-types fondamentaux de la classification des zircons (J.P. Pupin et G. Turco, 1972 a, b). Les indices A et T sont également indiqués

Qualitative analysis is carried out on more than one hundred idiomorphic and hypidiomorphic zircon crystals that are 50 to 160 microns long. This gives an acceptable statistical representation of the zircon population.

Zircon type is defined according to the predominance of the prismatic faces (110) or (100) and one of the pyramidal faces (211) or (101). All the results are reported, in percent for each type, on the diagram of Pupin and Turco (1973) (fig. 3).

The morphological study of zircons allows to:

- show the presence and concentration of fluid phases in the magma that generates the different types of rocks.

- evaluate the crystallization temperature of zircon relative to other mineral phases.

- define the rocks showing an alkaline affinity with respect to other magmatic lithologies.

III - STUDY OF ZIRCON POPULATIONS OF AIT-OKLAN AND TEG-ORAK GRANITES

1 - Petrography and geochemistry

According to recent studies, the Hoggar is com-posed of 23 different terranes (Black *and al.*, 1994) (fig. 4). The studied granitic complexes (Boulfelfel, 1989; 1996; Boulfelfel and Ouabadi, 2000) are located in the Iskel terrane. Teg-Orak

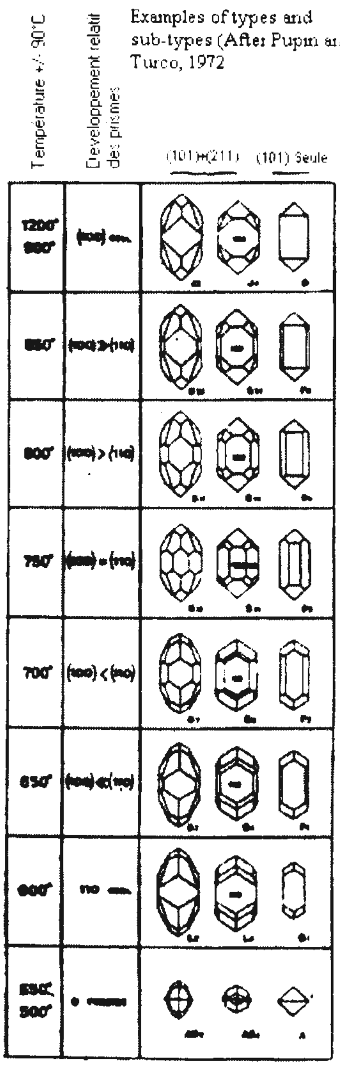


Fig. 3 - Zircon geothermometric data (After Pupin and Greco, 1972c)

Données geothérmometriques du zircon (d'après J.P. Pupin et G. Turco, 1972c)

pluton belongs to the oriental part of the Pharusian chain (4°50"E – 23°10"N). It is composed mainly of four lithologies that constitute a weakly fractionated suite spanning a range of composition from monzogranites to granites and showing a sub-alkaline affinity. The elliptical-shaped Teg-Orak is a composite massif that comprises four main facies. These are different according to their texture; from the inner zones to the outer zones several varieties can be distinguished (fig. 5):

- a fine-grained granite,

- an intermediate granite showing large microcline crystals,

- a coarse-grained granite in the eastern part of the massif,

- a leucocratic granite shaping the elevated ring structure in the western part of the massif.

The Ait-Oklan pluton (4°50"E, 24°50"N) is composed of two main lithologies (fig. 6); porphyroidal and granular. Most of the rocks show a monzogranitic composition with a calc-alkaline character. A porphyroidal granite in the centre surrounded by a medium-grained granite. The central granite is leucocratic but, in places, it shows pinkish colour. The grain-size is almost homogeneous except the presence of K-feldspar megacrysts that can reach 2 cm in size. The outer granite shows light-grey colours and granular texture.

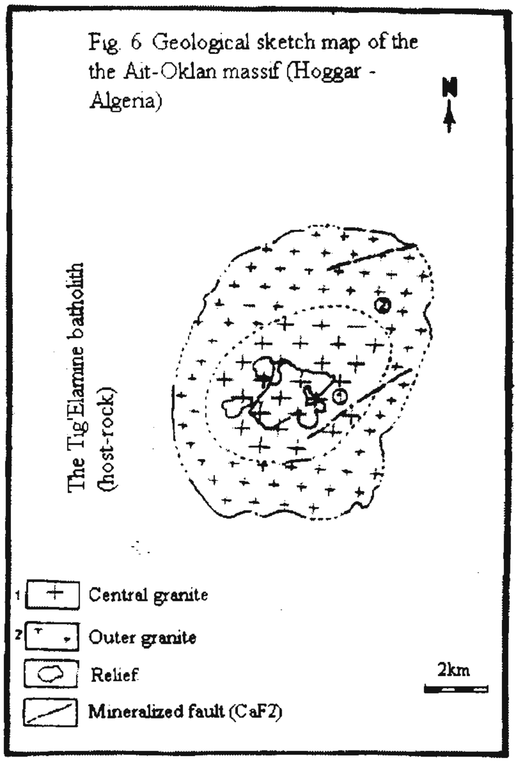
The geochemical data (table I) indicate that the Teg-Orak suite is weakly fractionated (72% < SiO_2 < 78 %) and weakly peraluminous (A/CNK comprised between 1.0 and 1.1). The $Na_2O + K_2O$ contents are higher than 8%, whereas the MgO, CaO and Sr contents are low.

Silica contents of the Aït-Oklan granites (table II) are comprised between 64 and 78 % and the $Na_2O + K_2O$ remains high (> 8 %). On the other hand, the MgO contents are often lower than à 0.50 %.

The studied granites, which belong to the Pharusian trench (Occidental Hoggar), can be related to the post-collision A-type granites, precisely the Highly Fractionated Calc-Alkaline granites (HFCA). They are also similar to most of the Pan- African granites of Central Hoggar that are emplaced during late Pan-African orogeny (650-525 Ma.), a consequence of the western African craton and the Tuareg shield collision.

Fig. 6 - Geological sketch map of the Aït-Oklan massif (Hoggar - Algeria)

Carte géologique schématique du massif granitique d'Aït-Oklan (Hoggar-Algérie)



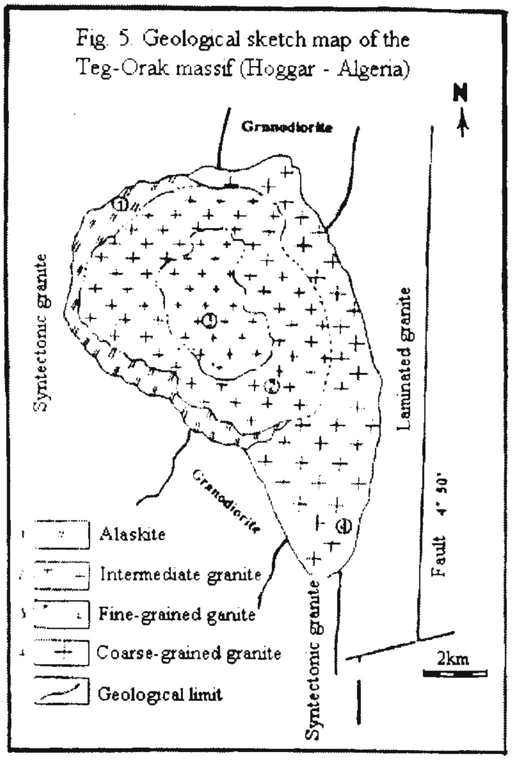


Fig. 5 - Geological sketch map of the Teg-Orak massif (Hoggar - Algeria)

Carte géologique schématique du massif granitique de Teg-Orak (Hoggar-Algérie)

Fig. 4 - Geodynamic framework of Taourirt suite, Central Hoggar (After Boissonnas, 1973 ; Blak *and al.* , 1994). It : In Tedeini ; Isk : Iskel ; La : Laouni ; Te :Tefedest ; Eg-Al : Egéré-Aleksod ; Az : Azrou-n-fad

Cadre géodynamique de la suite taourirt du Hoggar central (Boissonnas, 1973, Black et al., 1994). It. : In Tedeini, Isk : Iskel, La : Laouni, Te : Tefedest, Eg-Al : Egéré-Aleksod, Az : Azrou-n-fad

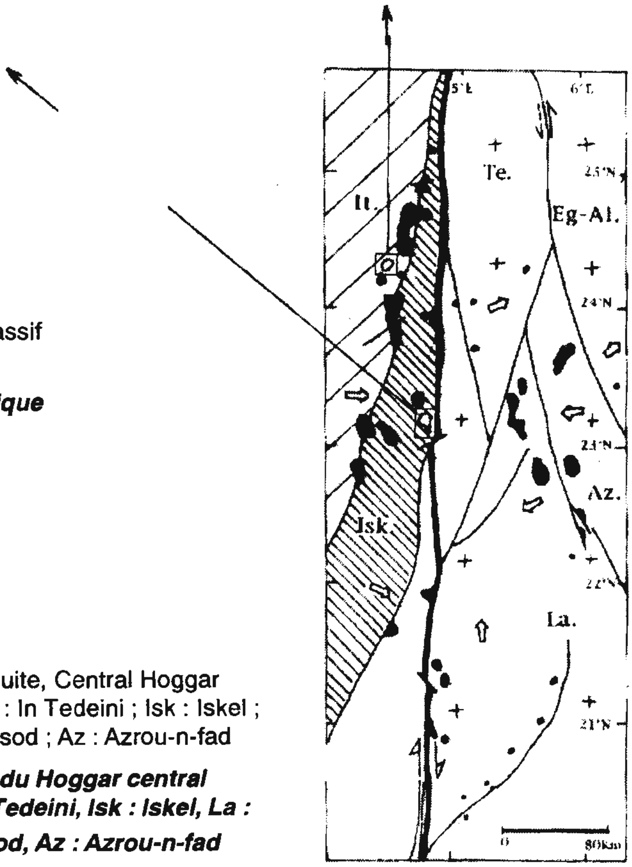


Table I - Chemical data of some representative samples from Teg-Orak massif (analyses CRPG, Nancy)

Analyses chimiques de quelques échantillons représentatifs du massif de Teg-Orak (analyse C.R.P.G. Nancy)

Sample	4314 E2	4315 E6	4316 E10	4317 E11	4318 E13	4319 E15	4320 E16	4321 E17	4323 R3	4324 R5	4325 R9	4326 R13	4327 R14	4328 R15	4329 R17	4330 R20	4331 R21
				Granite	Central							Granite	Bordure				
SiO2	72.72	70.36	73.12	72.94	71.39	76.65	72.19	67.32	64.94	74.06	77.95	72.40	72.93	74.88	69.15	67.59	75.29
TiO2	0.29	0.24	0.22	0.27	0.46	0.02	0.23	0.64	0.62	0.04	0.41	0.26	0.18	0.06	0.35	0.38	0.02
Al2O3	13.30	13.39	13.47	13.23	12.84	12.94	13.35	14.00	16.53	13.45	9.59	14.32	14.27	13.30	16.66	16.44	13.38
Fe2O3	0.88	1.34	0.58	0.60	2.22	0.17	0.75	5.12	1.02	0.43	1.08	0.69	1.25	1.08	2.29	2.98	0.33
FeO	1.50	0.99	1.24	1.73	1.60	0.28	1.31	0.04	2.31	0.53	1.88	1.11	0.25	0.00	0.00	0.00	0.49
MnO	0.05	0.06	0.05	0.05	0.08	0.01	0.05	0.12	0.05	0.04	0.04	0.40	0.03	0.04	0.05	0.04	0.03
MgO	0.12	0.12	0.12	0.18	0.31	0.00	0.19	0.56	1.45	0.12	0.43	0.43	0.36	0.12	0.48	0.45	0.00
CaO	1.19	0.98	1.14	1.25	0.99	0.61	1.31	1.40	2.95	0.73	1.18	1.59	1.28	1.10	2.60	1.74	0.65
Na2O	3.21	3.16	3.42	3.18	3.10	4.68	3.25	3.22	4.58	4.18	2.19	3.36	3.48	3.56	3.82	3.57	3.64
K2O	4.82	6.62	5.01	5.10	4.45	4.18	4.68	5.06	2.28	5.01	3.18	4.70	5.23	4.86	4.57	6.16	4.72
P2O5	0.04	0.09	0.04	0.04	0.20	0.00	0.04	0.12	0.24	0.00	0.05	0.08	0.15	0.00	0.20	0.30	0.00
H2O+	0.94	1.18	0.84	0.89	1.55	0.63	1.28	0.73	1.27	0.68	0.73	0.91	0.69	0.75	0.66	0.64	0.53
H2O-	0.21	0.35	0.13	0.13	0.76	0.11	0.29	0.20	0.18	0.18	0.15	0.29	0.21	0.22	0.16	0.21	0.11
Total	99.06	98.55	99.25	99.47	99.19	100.17	98.62	98.32	98.25	99.28	98.70	100.25	100.10	99.75	100.83	100.29	99.10
V	nd	29	31	30	31	nd	38	37	57	nd	45	32	30	31	39	28	32
Cr	nd	nd	nd	7	nd	nd	nd	nd	15	nd	nd	nd	nd	nd	1	nd	nd
Co	29	43	22	14	22	14	20	28	34	16	30	19	10	13	19	17	18
Ba	1122	1483	1314	1116	1006	771	146	1208	2230	868	1279	1896	1840	1297	2295	1490	1026
Ni	5	13	7	10	11	2	14	nd	12	2	12	nd	9	2	9	15	4
Cu	28	nd	12	14	11	11	27	31	4	25	28	51	nd	10	6	17	18
Zn	52	68	45	56	90	12	45	118	63	37	48	61	29	29	43	59	36
Rb	274	352	281	224	337	300	267	326	65	354	103	161	184	182	149	193	306
Sr	95	48	93	98	55	20	99	74	527	28	90	239	175	93	364	222	9
Y	75	73	67	58	85	47	70	117	12	62	45	13	32	28	15	41	40
Zr	257	224	222	259	405	36	236	438	123	88	225	164	161	81	250	316	82
Nb	27	27	25	27	30	23	25	50	5	13	16	13	20	13	18	29	19
Pb	37	61	37	24	44	34	44	26	22	49	13	25	20	24	30	25	38
Th	29	20	23	22	18	23	28	35	20	34	12	13	16	15	21	14	28
TOTAL	99.47	99.14	99.59	99.80	100.16	100.42	99.02	98.77	98.76	99.62	99.04	100.81	100.56	100.15	101.31	100.75	99.37

Table II - Chemical data of some representative samples from Aït-Oklan massif (analyses CRPG, Nancy)

Analyses chimiques de quelques échantillons représentatifs du massif d'Aït-Oklan (analyses C.R.P.G. Nancy)

Sample	A9	A12	A27	A11	GFin18	GFin19	GFin24	GFin22	GInt20	GInt60	GInt15	GInt32	GGr2	GGr36	GGr61	GGr65
SiO2	78.11	76.59	76.01	76.11	73.28	74.86	72.03	74.98	73.9	73.22	74.5	73.8	75.9	73.88	76.34	71.7
TiO2		0.02	0.03	0.04	0.24	0.12	0.11	0.18	0.18	0.2	0.13	0.21	0.08	0.12	0.05	0.3
Al2O3	13.02	13.12	12.8	12.58	13.17	13.01	14.93	13.31	12.76	13.4	13.19	13	11.86	13.38	12.37	13.67
Fe2O3	0.06	0	0.29	0.21	0.27	0.18	0.26	0.72	0	0.38	0.67	0.79	0.42	0.02	0.53	1.06
FeO	0.46	0.44	1.22	0.18	1.23	0.79	0.57	0.28	1.35	1.05	0.66	0.71	0.79	1.22	0.43	1.26
MnO	0.14	0.05	0.02	0.03	0.05	0.05	0.02	0.04	0.04	0.04	0.05	0.05	0.03	0.04	0.03	0.04
MgO					0.06					0.13						
CaO	0.17	0.24	0.75	0.85	1.46	0.87	1.43	0.65	1.39	1.48	0.91	1.26	0.84	1.08	0.73	1.57
Na2O	4.18	4.25	3.54	3.48	3.21	3.36	3.45	3.19	3.25	3	3.38	3.27	3.39	3.44	3.29	3.32
K2O	3.54	4.09	4.75	4.84	5	5.1	5.12	4.88	4.67	5.05	4.79	4.85	5.01	5.08	4.95	5.16
P2O5		0.09			0.1		0.05	0.07	0.08	0.07		0.08	0.06			0.07
Loss	0.82	0.61	0.65	0.56	1.13	0.77	0.95	1.01	1.42	1	0.83	0.7	0.79	0.74	0.64	0.78
TOTAL	**100.5**	**99.5**	**100.06**	**98.88**	**99.2**	**99.11**	**98.92**	**99.31**	**99.04**	**99.02**	**99.11**	**98.72**	**99.17**	**99**	**99.36**	**98.93**

TRACES

V	14					11			21							16
Cr	3	14	24	21	19	24	11	11	23	13	21	7	23	19	17	22
Co	5					8	5		18	12		8		7	23	42
Ni					2	3										
Cu	7	6	3	9	13	11	11	7	6	14	9	8	4	9	4	9
Zn	60	51	7	9	23	16	5	14	25	22	29	29	33	30	26	26
Ba	111	285	152	284	824	724	1413	846	952	1211	592	942		1025	310	874
Rb	1021	949	271	267	230	256	170	254	219	183	227	270	205	248	197	136
Sr	29	6	50	48	154	108	246	121	171	195	85	142	16	102	10	186
Y	56	190	29	27	31	31	15	37	27	21	51	38	37	34	32	25
Y	56	190	29	27	31	31	15	37	27	21	51	38	37	34	32	25
Nb	44	24	12	11	20	14	5	17	19	14	16	19	10	15	15	11
Pb	51	51	25	27	30	32	24	36	18	23	21	34	30	31	28	32
Th		1	1	2	13	7	7	2	17	5	4	13	2	8		5

The chemistry of granites shows a transition between calc-alkaline "normal" granites (related to subduction zones) and alkaline orogenic granites.

Typological study of biotites (fig. 7) confirms the sub-alkaline character of the granites; most of analysed biotites plot on the boundary between the calc-alkaline and sub-alkaline fields.

2 - Zircon populations

All the populations representing the facies of these two massifs have been studied (Boulfelfel, 1992; 2000). The results reveal a large number of rock sub-types mostly located in the lower right corner of the diagram (fig. 8). Comparison between the different zircon populations and their convergence to the order of crystallisation indicates a typological evolution relative to their time of crystallization. The majority of zircons are included in biotite flakes; they are weakly to highly coloured, but limpid varieties can occur in rare occasions.

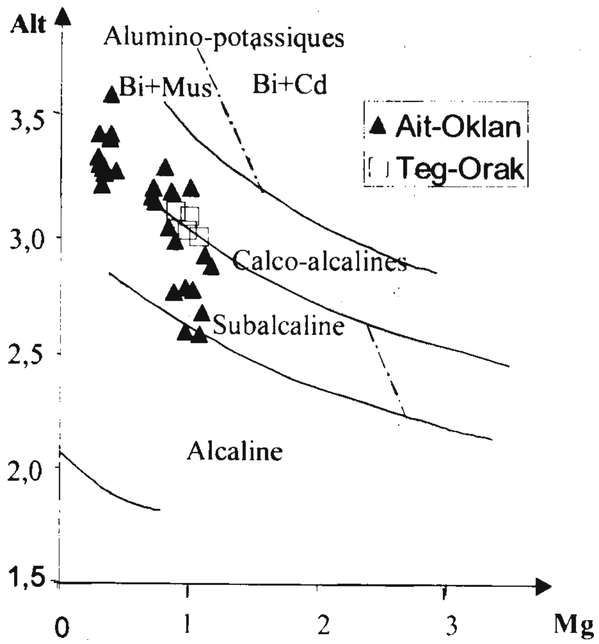


Fig. 7 - Mg-Alt diagram from Nachit *and al.*, 1984 illustrating sub-alkaline compositions of Aït-Oklan and Teg-Orak granitoids.

Diagramme Mg-Alt (Nachit et al.,1984) dans lequel sont projetées les biotites des granitoïdes d'Aït-Oklan et Teg-Orak

IV - TYPOLOGICAL DISTRIBUTION

The typological distribution of zircon populations shows the following features:

- A large number of sub-types (15 to 25) showing a set of high frequencies constituted by 5 or 6 sub-types, common to all samples.

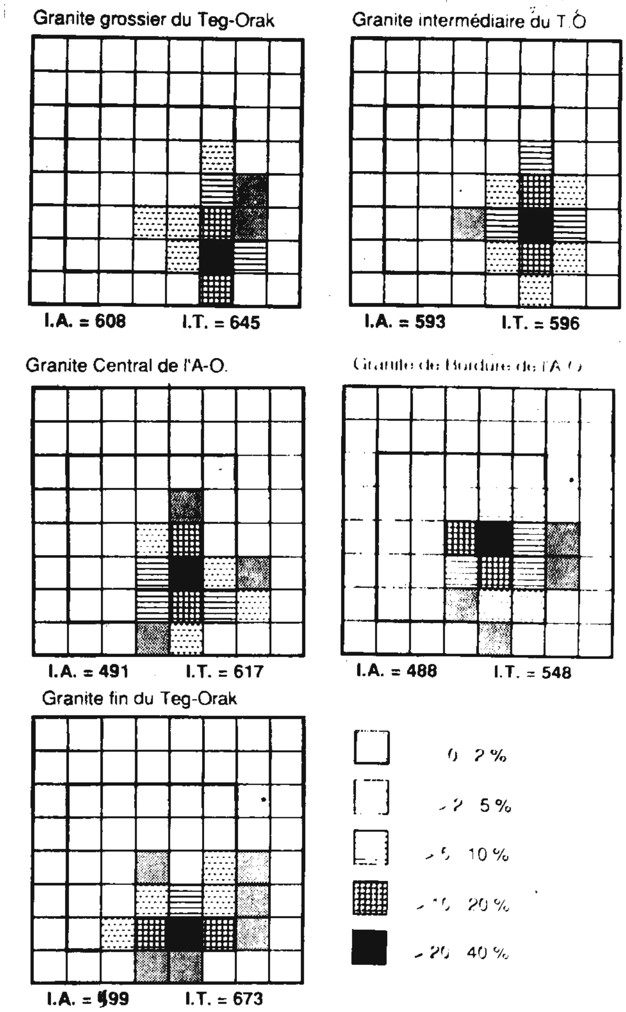


Fig. 8 - Typological distribution of zircons from the studied granitic massifs

Distributions typologiques des zircons des granites des massifs étudiés

- A dominance of the (100) prisms in comparison over (101) and of the (101) pyramid over (211) in all granite facies.

V - MEAN POINT (I. A., I. T.) OF THE ZIRCON POPULATIONS

The A and T indexes (Pupin and Turco, 1972) have been used to identify precisely the mean points of each population. The calculated mean points are then plotted on the genetic classification diagram (I.A., I.T.) of granites (Pupin, 1980) (fig. 9). All data points plot on the 4C-5 trend of sub-alkaline granite suites with medium I.A. and high I.T. values.

VI - TYPOLOGICAL EVOLUTION TREND

The typological evolution trend (TET) has been calculated for each facies and the results are plotted on the I.A. versus I.T. diagram. The interpretation of the diagram indicates that the evolution of the different populations is related mainly to continuous crystallization of zircon in the magma and also to the physico-chemical changes that occur during the magma evolution (Pupin, 1976). The variations of the mean parameters (I.A.; I.T.) of the different populations agree well with the trend (TET); i.e., I.A. increase with decreasing I.T. The TET boundaries define a field for the calc-alkaline series of the Ait-Oklan massif and a second for the sub-alkaline series of the Teg-Orak massif (fig. 9).

VII - GEOTHERMOMETRIC CORRELATIONS

According to Pupin and Turco (1972), the I.A. and I.T. are function of the chemistry (I.A.) and the temperature (I.T.) of the magma. These authors suggest a temperature scale for zircon crystallization with respect to the I.T. index.

The obtained temperatures on the Teg-Orak and the Ait-Oklan massifs are 750° to 800°C for all the granitic complexes. We note that these data are only considered for the crystallization temperatures of zircon (Pupin, 1976). The T dependance of IT has been strongly questioned by Benisek and Finger, 1993

VIII - TYPOLOGICAL DISTRIBUTION

The representative mean points of zircons for the different lithologies plotted on the I.A./I.T. diagram tend to scatter on a sub-vertical TET that have an I.A = 600.

The granites show an evolution towards a decreasing T index but with an almost constant index A.

The studied complexes have zircons with a, T index around IT = 500- 600. According to the frequency histogram of the index T, there are almost no zircons of high temperature; the strong majority of zircons crystallize at temperatures between 750-800°C. However, there is a late zircon population that crystallizes at 750°C.

IX - CONCLUSION

Zircons of the Teg-Orak and the Ait-Oklan massifs indicate medium temperatures of crystallization, close to the saturated granite solidus (Azzouni and Bonin, 1998). The fact that all the zircon crystals show overgrowths and occur as inclusions in biotites (whether interstitial or not), these are arguments supporting the late aspect of these zircons. How can we explain this typological evolution? Pupin *and al.* (1978) suggested two different hypotheses based on the role of water or rather the fluid phases intervening in the zircon crystallization. A high fluid content in a granitic magma favour a prolonged and /or delayed period of zircon crystallization.

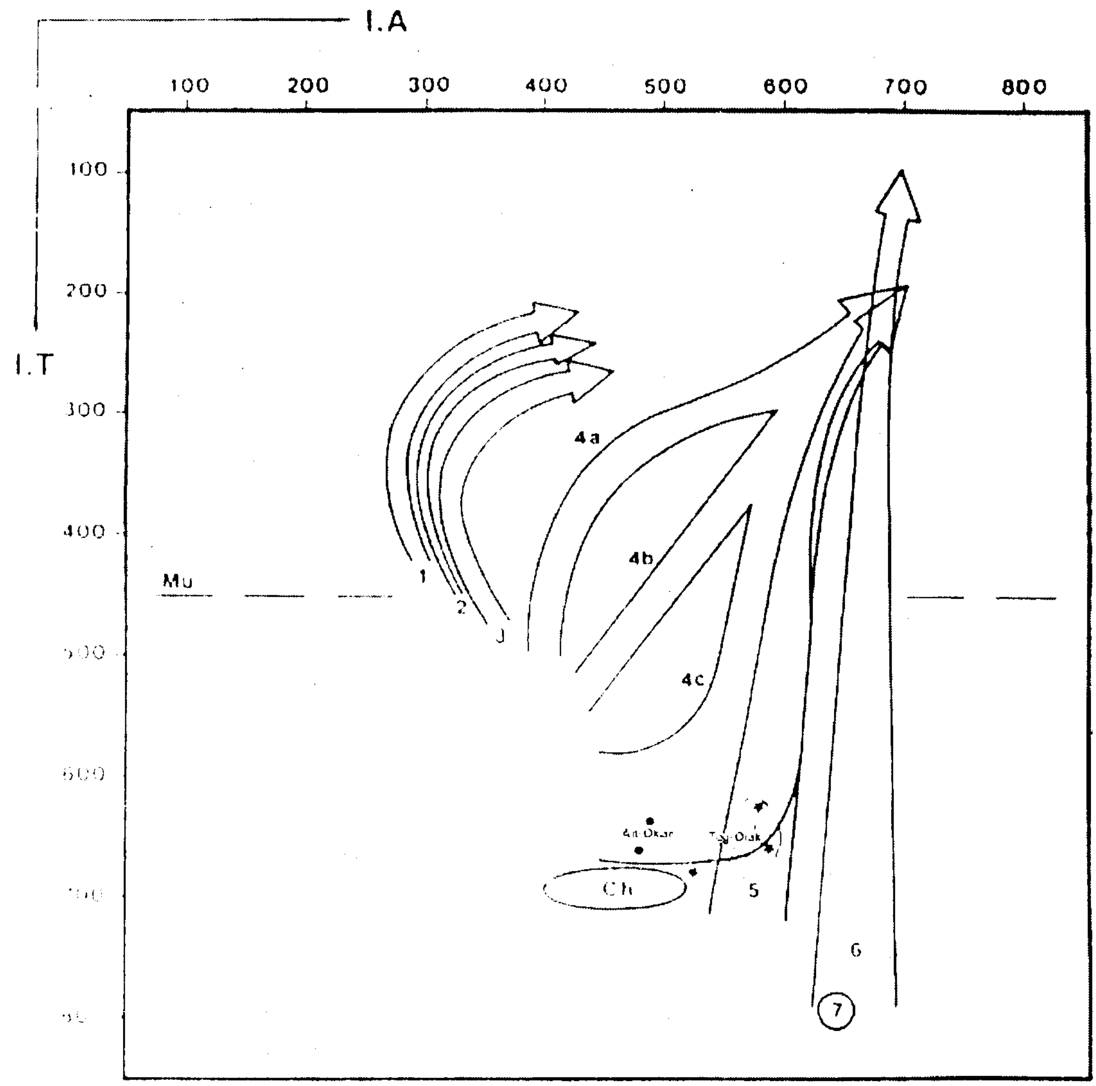


Fig. 9 - Teg - Orak and Ait-Oklan granitic facies in the mean typological evolution diagram of zircon populations (After Pupin, 1980)

Position des différents faciès des massifs granitiques du Teg-Orak et de l'Ait-Oklan dans le diagramme d'évolutions typologiques moyennes des populations de zircons des granites (J.P.Pupin, 1980)

* Partially or entirely crustal granites ***(Granites partiellement ou entièrement crustaux)***.
1. Peraluminous leucogranite ***(Leocogranites peralumineux))***.
2. (Sub -) autochtonous monzogranite and granodiorites ***(Granodiorites et monzogranites (sub-) autochtones)***.
3. Intrusive peraluminous monzogranite and granodiorite***(Granodiorites et monzogranites peralumineux intrusifs)***.
* Crustal+mantle derived granite (hybrid granites) ***(Granite d'origine crustale + mantélique (granites hybrides))***.
4a,b,c. Granites of the calc-alkaline suite ***(Granites des séries calco-alcalines)***.
5. Granite of the sub-alkaline suite ***(Granites des séries sub-alcalines)***.
* Mainly or entirely mantle derived granites ***(Granites d'origines principalement ou entièrement mantélique)***.
6. Granite of the alkaline suite ***(Granites des séries alcalines)***.
7. Granite of the tholeitic suite ***(Granites des séries tholéïtiques)***.
Mu. Muscovite-bearing granite boundary (IT= 450) ***(Limites du domaine des granites à muscovite (IT=450))***.
Ch. Magmatic granite field ***(Champ des granites magmatiques)***.

We can consider, for a start, magmatic liquids without crystals; the contents of the dissolved fluids in equilibrium with the silicate melt would influence the crystallization time of zircon, subsolvus granites are products of magmas highly saturated in fluids. Zircon would crystallize at different periods depending on fluid contents, and the crystals begin to form from the liquidus. The period of crystallization vary highly with the fluid contents of the magma (Azzouni, 1995); very early in dry magmas and late in saturated magmas. The overall points representing all the lithologies of the Teg-Orak and the Ait-Oklan complexes plot in the trend 5 which corresponds to the field of sub-alkaline granite series (fig. 9). This agrees well with the petrologic and geochemical data of these granitoids.

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