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Structure and Current Dynamics of the Vegetation in the high Mountain Geocomplex of Jbel Tichoukt (Central Middle Atlas, Morocco): Geosystemic Analysis

Adil AZAMI HASSANI

University of Sidi Mohamed Ben Abdellah Fez 3000, Morocco

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ABSTRACT
This paper aims to investigate the current vegetation structure and dynamics in the in the high mountain Geocomplex of Jbel Tichoukt (Central Middle Atlas, Morocco). This study is based on the application of the Geosystemic method, which allowed us to analyse the complex relationships between the different biotic, abiotic and anthropogenic components of the environment and to identify the different dynamic trends of the vegetation within this Geocomplex.
The results obtained allowed the identification of five Geofacies within this Geocomplex, based on stationary conditions and the internal dynamics of its floristic composition, as well as the degree of human impact. The current vegetation dynamics in this geocomplex are controlled by the thermal and edaphic conditions that are unsuitable for the maintenance of the *Cedrus atlantica*, *Quercus rotundifolia* and *Juniperus thurifera*, which have no natural regeneration. The cold steppe vegetation of the high mountains currently invades the Geocomplex with the almost total absence of trees from 2400 m altitude.

1. Introduction:

The Geocomplex of the high mountain of Jbel Tichoukt represents a distinct eco-landscape, located upstream of the massif where it colonises the summit part of Jbel Tichoukt, on superficial to moderately deep soils, with rocky outcrops and essentially calcareous substrates, at altitudes between 1800 and 2700 m **[1]**.
Its quaternary Cryonival and karstic shape remains discrete and marked by the barely visible development of Cryoclastic phenomena on the ridge. On the other hand, its regular snow cover and its faulted structure on Liasic carbonate formations have allowed the Karstification of this area, giving rise to the genesis of some simple forms of Nivo-karstic depressions and snow pits. The Quaternary dissection and the recent erosive process are active on the steep Liasic slopes and on the vertical walls of the steep abrupt (abrupt of El Haj, Tichoukt el-Ari, Ouidah conch and the wall of Tizi-Tasguenfout) in the form of gullies, intense scratches, recent scree aprons and avalanche cones **[2]**.
Despite its orographic location, rainfall is less abundant, with local disparities depending on altitude and exposure. It receives an average annual rainfall of between 500 and 700 mm, with significant snowfall from December to March. The bioclimatic atmosphere is sub-humid with very cold to extremely cold winters at these altitudes, hence the rigour of the winter cold, which makes the cold season quite prolonged and can last for around 5 months at these altitudes. The lateral and horizontal distribution of the vegetation in this Geocomplex perfectly reflects its particular ecological conditions and allows the identification of five Geofacies with different internal dynamics.
In this article, we have tried to identify the different vegetation Geofacies that characterises this eco-landscape and to determine its current dynamics by applying the geosystemic method, which has allowed us to analyse the complex relationships between the different biotic, abiotic and anthropic constituents and to identify the different dynamic trends of the vegetation within this Geocomplex.

(*) Corresponding author:
Tel.: +212615073090
E-mail address: adilazami80@gmail.com

2. Material and methods:

2.1. The study area:

The Jbel Tichoukt is part of the central Middle Atlas, in its folded part. It is a high anticlinal chain, which culminates at *2794* m of altitude at the *Lalla Oum-elbent* peak and spreads out over nearly *30* kms from *S.W* to *N.E*. Administratively; it is located in the territory of four rural communes of the province of Boulemane (El Mers, Skoura-Mdaz, Guigou and Serghina) and one urban, the municipality of Boulemane.

This composite massif links the folded Middle Atlas ranges to the plains of the Upper Moulouya to the S/S.E., which gives it particular ecological conditions that vary in space and time, with the vertical and horizontal conjunction of several types of forest, pre-forest, pre-steppe and steppe ecosystems **[1]**.

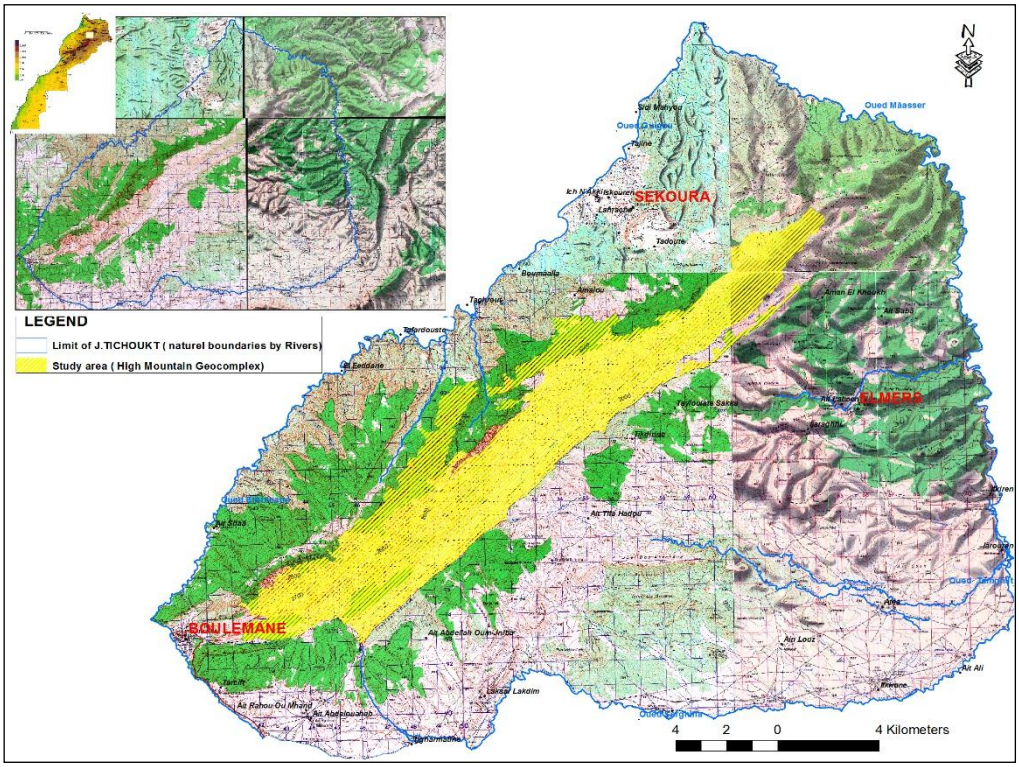

Figure 1. Study area and geographical location of Jbel Tichoukt (Central Middle Atlas).

2.2. The method applied:

We have oriented our methodological choice towards the Geosystemic approach introduced and developed towards the end of the 1960s by the pioneer of this method, G. Bertrand **[3]**, inspired by the work of Soviet Geography **[4,5]** and approaching the systemic method applied to the study of the natural environment. It is adapted to the mountainous nature of the study area **[1,3,6,7]**.

According to the Geosystemic approach which subdivides geographical space into homogeneous and hierarchical units, several classification systems of landscape complexes have been proposed, either in Morocco or elsewhere **[6,7,8,9]** in order to present the hierarchy and interlocking which structure each landscape studied. Among these classifications, we have adopted the one applied by the Biogeographer Labhar in 1998 (Table 1).

Table 1. Classification system of landscape complexes according to LABHAR, 1998

Chorological units	Identification criteria	Corresponding scale
Geocomplex	Combination of geomorphological (nature of substrate, surface formations, slope dynamics, etc.), climatic and hydrological factors	From 1/50.000 To 1/250.000
Geofacies	Homogeneous unit, soil variables and dominant plant formation	Between 1/10.000 and 1/50.000

Based on this classification and following ecological, phytogeographical and geomorphological criteria changing at the level of the Tichoukt massif, we identified the high mountain Geocomplex, colonised mainly by Cedar and thorny Xerophytes on steep slopes and calcareous substrate. In the latter, we proceeded to a division into homogeneous units

(Geofacies) according to the parameters and descriptors that best reflect the conditions of the environment (climate, exposure, substrate, slope, soil type, stratification and density of vegetation, dominant species and anthropic impact...).

2.3. Stratified sampling:

The technique adopted is stratified sampling. This method is recommended for the study of large heterogeneous areas, such as our study area, which is characterized by a mountainous appearance with a large number of interlocking landscapes and a vertically and horizontally changing floristic diversity. It consists of subdividing the environment into homogeneous spatial units, in the form of strata that will be sampled separately according to specific criteria. This stratification is carried out with the help of established thematic maps and available cartographic supports (Hypsometric map, Slope map, Exposure map, Soil type map, Topographic map at 1/50.000, Geological map at 1/100.000, Geomorphological map of Martin **[2]** at 1/100.000, Phyto-ecological map of Lecompte at 1/200.000 **[10]**.

2.4. Vegetation and environmental surveys:

We adopted the method of Phytogeographical surveys applied by Geographers (Bertrand, 1966 and 1984; Labhar, 1998; Nabil, 1985). It consists of a floristic inventory accompanied by quantitative and qualitative indices (abundance - dominance and sociability) according to the following coefficients **[11]**:

- **Abundance - Dominance :**
  - (+): Very low cover and abundance.
  - (1): Coverage ≤ 5 %: abundant species but low coverage.
  - (2): Very abundant species, but coverage between: 5 < R ≤25 %.
  - (3): Coverage between: 25 < R ≤ 50% and any abundance.
  - (4): Coverage between: 50 < R ≤ 75% and any abundance.
  - (5): Coverage between 75 < R ≤ 100%.
- **Sociability:**
  - (1): isolated individuals of the species.
  - (2): individuals of the species in clumps.
  - (3): individuals of the species in groups.
  - (4): individuals of the species in colonies.
  - (5): individuals of the species in stands.

2.5. Data processing:

After these field surveys have been carried out, a synthesis phase is carried out. The data processing consists in establishing Phytogeographical tables from which the synthetic characteristics of the vegetation cover emerge, in particular their overall physiognomy. This synthetic analysis makes it possible to identify and describe the dominant vegetation structure, the plant groupings present and the vegetation levels they occupy within each Geofacies of the landscape Geocomplex of the study area.

3. Results and Discussion:

According to the Geosystemic method, which subdivides this Geocomplex into homogeneous units (Geofacies), we have identified five, based on stationary conditions and the internal dynamics of its floristic composition **[1]**.

3.1 Geofacies of Coppice under Discontinuous High Forest (Cedrus atlantica; Quercus rotundifolia; Ribes uva-crispa and Berberis hispanica) on very Steep Limestone Slopes and Eroded and Rocky Soil:

This Geofacies is located to the S.W. of the northern side of Jbel Tichoukt and develops on a soulane slope, cut into the limestone with very steep slopes (60%) and altitudes between 1950 and 2350 m. A sample of two phytogeographical surveys representing its ecological characteristics. That are summarized in the following Table 2.

This Geofacies is represented by stands of mature *Quercus rotundifolia* coppice under an old discontinuous *Cedrus atlantica* forest. It includes a characteristic flora, among which we can see the infiltration of some species linked to pastoral practice and degradation, testifying to a long and ancient anthropic pressure. This composition contains the following species: *Cedrus atlantica; Quercus rotundifolia; Juniperus thurifera; Fraxinus dimorpha; Acer monspessulanum; Ribes uva-crispa; Berberis hispanica; Thymus comosus; Helianthemum croceum and Helianthemum cinereum*. The herbaceous stratum is poor, with only three species sharing the stratum: *Dactylis glomerata; Koeleria vallesiana* and *Isatis tinctoria*.

This unit reflects the precarious ecological conditions for the development of *Cedrus atlantica*, which is in competition with *Quercus rotundifolia*, and shows signs of decline and dead trees. The summer water deficit is very marked, accentuated by the southern exposure and the calcareous nature of the substratum, with a strongly eroded and rocky soil. Its bio-climate

is of the extremely cold sub-humid type and receives an average annual precipitation of no more than 700 mm, which often falls as snow in winter.

In these fragile stationary conditions, the unit is in slow biotic regression, since the regeneration of the two organizing species (*Cedrus atlantica* and *Quercus rotundifolia*) is almost non-existent and is in an advanced stage of degradation.

Table 2. Ecological characteristics of the Geofacies (1).

Statement No.	**C001**	**C002**
Location	Upstream of the Oum El-bent valley	Upstream of Oum El-bent valley
Altitude in (m)	2150	2280
Exposure	S	S
Slope in (%)	60	70
Topographical situation	Upper slope	Upper slope
Substrate	Limestone	Limestone
Surface formation	Medium-deep, undeveloped soil	Medium-deep, undeveloped soil
Tree cover (7m) (%)	65	60
Shrub layer cover (1 - 3m) (%)	5	5
Cover of the herbaceous layer (0.5m) (%)	10	10
Erosive dynamics	Stripping	Stripping

3.2. Geofacies of the Open Coppice Forest (Cedrus atlantica, Quercus rotundifolia, Fraxinus dimorpha, Ribes uva-crispa, Berberis hispanica and Rosa canina) on Steep Shaded Slopes on Shallow to Medium Deep Calcareous:

To the east of the previous unit, a Geofacies develops in the form of the open coppice forest on steep upper slopes, in an altitudinal range between 1800 and 2300m. Its ecological characteristics are represented by four surveys. That are listed in the following table 3.

This forest is a *Quercus rotundifolia* coppice under an open *Cedrus atlantica* forest, generally in a mature state and relatively vigorous in places. The tree and shrub layer is dominated by the following species: *Cedrus atlantica; Quercus rotundifolia; Taxus baccata; Fraxinus dimorpha; Juniperus oxycedrus; Ribes uva-crispa; Berberis hispanica; Bupleurum spinosum; Thymus comosus; Rosa canina; Buxus balearica; Alyssum spinosum. The herbaceous stratum is rich in species, the most frequent are: Festuca yvesii; Dactylis glomerata; Thymus comosus; Helianthemum croceum; Helianthemum cinereum; Bromus rubens; Koeleria vallesiana; Teucrium chamaedrys; Leuzea conifera ; Hypochaeris laevigata; cerastium gibraltaricum; Rhamnus atlantica; Bellis caerulescens; Medicago suffruticosa; Arabis josiae; Scorzonera pygmaea; Galium mollugo and poa bulbosa*. The topographical situation on a steep upper slope, with an abundance of Limestone boulders on steep slopes, has sheltered it from the local population and their herds. This is reflected in the limited trace of human action on this Geofacies (only few signs of *Quercus rotudifolia* woodcutting are present). However, despite its enjoyment of cool exposures, this forest develops under unfavorable edaphic and climatic conditions. The local improvement in water conditions (the presence of vigorous stands of *Taxus baccata* testifies to this) does not seem to have the same influence as the calcareous nature of the substratum and the accentuation of the winter cold. These stationary conditions are manifested by the infiltration of thorny Xerophytes in the clearings and of Heliophilous species belonging to the cold steppe of the high mountains, such as *Bupleurum spinosum* and *Alyssum spinosum*. From a dynamic point of view, this Geofacies is in slow biotic regression, since the spontaneous regeneration of its two usual competitors (*Cedrus atlantica* and *Quercus rotundifolia*) is totally absent.

Table 3. Ecological characteristics of the Geofacies (2).

Statement No.	**C003**	**C004**	**C005**	**C006**
Location	J. Ouidah	J. Ouidah	Tichoukt el-Ari	Tichoukt el-Ari
Altitude in (m)	2285	1920	1810	2050
Exposure	N.W	N.W	N / N.W	N.W
Slope in (%)	60	60	70	90
Topographical situation	Steep upper slope	Steep upper slope	Steep upper slope	Steep upper slope
Substrate	Limestone	Limestone	Limestone	Limestone
Surface formation	Shallow rocky to medium deep soil	Shallow rocky to medium deep soil	Superficial rocky	Superficial rocky
Tree cover (7m) (%)	30	30	20	20
Shrub layer cover (1 - 3m) (%)	30	30	15	20
Cover of the herbaceous layer (0.5m) (%)	20	20	10	20
Erosive dynamics	Tablecloth and gully	Tablecloth and gully	Tablecloth and gully	Tablecloth and gully

3.3. Geofacies of the Open Wooded Matorral (Ribes uva-crispa, Berberis hispanica, Bupleurum spinosum, Buxus balearica, Cedrus atlantica and Quercus rotundifolia) on Steep Limestone Slopes and Rocky Surface Soil:

This Geofacies is confined to the front and summit of Tichoukt in the form of four narrow and spatially disjointed blocks, with a total surface area of 821 ha. It colonises the escarpments of *Tizi tasganfout, Assat, Azder Hidoud, Manqoucha, Tahanout* and extends towards the S.W. of the massif on the northern bank of the *Oum El-bent valley*. It develops on various exposures between 1800 and 2400 m on steep slopes, on limestone substratum and rocky surface soil. Its ecological characteristics are represented by a sample of four Phytogeographical surveys. These samples are listed in the following Table 4.

Now, the forest is presented as an open wooded Matorral, marked by the abundance of species that characterize the clearings and open environments of the high mountains. The tree stratum is very limited and its cover varies between 2 and 20%, consisting essentially of an old, mature and very open *Cedrus atlantica* forest. The latter is not very vigorous; the majority are dead on the ground and exhibit signs of decay at the top. It is associated with an old, scattered and mutilated *Quercus rotundifolia* grove, with the infiltration of a few stunted, heavily shaken *Juniperus Oxycedrus* and *Juniperus thurifera*. Towards the top of the unit, this stratum becomes rare and the shrub stratum dominates the landscape with an average cover of 20 to 50%. Among its fairly common species are *Ribes uva-crispa, Berberis hispanica, Bupleurum spinosum, Alyssum spinosum and Buxus balearica.* The herbaceous flora is invaded by numerous species, most of which are linked to degradation and strong pastoral action. Characteristic species include *Thymus comosus, Helianthemum croceum, Helianthemum cinereum, Hieracium pseudopilosella, Hypochaeris laevigata, Festuca yvesii, Dactylis Glomerata, Bromus Rubens, Convolvulus Mazicum, Dianthus Gaditanus, Paronychia Kapela, Thymus Serpyllum var. atlanticum, Taraxacum obovatum, Anacyclus pyrethrum, Anthemis tuberculator, Poa bulbosa, Leuzea conifer, Teucrium chamaedrys, Cerastium gibraltaricum, Hypochoeris laevigata and Medicago suffruticosa.*

The Geofacies develops in the Mediterranean mountainous area and is part of the very cold variant of the sub-humid bio-climate. The cold season is rigorous and lasts about five months, with frequent snowfalls. The whole area is based on a limestone substratum and essentially superficial and rocky soils, heavily scoured by summer storms on steep slopes (between 80 and 90%).

Its vegetation is in the pre-forest stage due to unfavorable thermal and edaphic conditions, combined with strong anthropic pressure. It is in a regressive dynamic marked by a total absence of natural regeneration of *Cedrus atlantica* and *Quercus rotundifolia*.

Table 4. Ecological characteristics of the Geofacies (3).

Statement No.	**C007**	**C008**	**C009**	**C010**
Location	Upstream of the Oum El-bnet valley	Previous station to the E	Assat	Tizi tasganfout
Altitude in (m)	2180	2370	2190	2150
Exposure	N.W	N.W	N.W	N/N.W
Slope in (%)	80	80	80	80
Topographical situation	Mid-slope	Mid slope	High slope	High slope
Substrate	Limestone	Limestone	Limestone	Limestone
Surface formation	Superficial rocky	Superficial rocky	Superficial rocky	Superficial rocky
Tree cover (7m) (%)	10	5	10	10
Shrub layer cover (1 - 3m) (%)	50	40	10	20
Cover of the herbaceous layer (0.5m) (%)	20	20	10	10
Erosive dynamics	Sheet and gully	Sheet and gully	Sheet and gully	Sheet and gully

3.4. Geofacies of the Open Matorral with Thorny Xerophytes (Bupleurum spinosum; Berberis hispanica; Ribes uva-crispa; Alyssum spinosum and Juniperus thurifera) on Steep Limestone Slopes and Rocky Surface Soil:

All along the ridgeline, an open Matorral with thorny xerophytes based on *Bupleurum spinosum; Berberis hispanica; Ribes uva-crispa; Alyssum spinosum and Juniperus thurifera* develops on essentially superficial and rocky soil. It is a long slope spread over 5321.3 ha, with a steep S.W/N.E. orientation and cut into the limestone at an altitudinal range of between 2050 and 2400m. To determine its stationary characteristics, we carried out several phytogeographical surveys. Four surveys are represented in the following Table 5.

An open Matorral invaded by thorny Xerophytes and numerous degradation species currently replaces the forest. It is derived from an ancient matorralisation of the *Cedrus atlantica* and *Juniperus thurifera* forest. The pre-steppe look has overtaken the landscape, hence the striking scarcity of trees in some stations, or their total absence in others. Only a few

old *Cedrus atlantica* and *Juniperus thurifera* trees are present and they are severely undermined by the frequent passage of livestock. They are devoid of any regeneration. The shrubby undergrowth is fairly frequent, providing an average cover of 50%. It is dominated by the following characteristic species: *Bupleurum spinosum; Berberis hispanica; Ribes uva-crispa; Alyssum spinosum; Erinacea anthyllis; Juniperus communis; Cytisus balansae and Buxus balearica.* The herbaceous stratum is very poorly developed, with a cover of less than 20% throughout the unit. *Thymus comosus; Astragalus armatus; Dactylis glomerata; Scorzonera pygmaea; Agropyron marginatum; Helianthemum croceum; Helianthemum cinereum* are the most widespread species. The Geofacies develops in a good part of the Mediterranean montane floor of the sub-humid bio-climate with very cold and extremely cold thermal variants where frost and snowfall are more abundant due to a significant drop in winter temperatures. The bare limestone substrate is unsuitable for the roots of young seedlings, only old trees can withstand it. The dynamics of the unit are regressive due to the total absence of regeneration of the *Juniperus thurifera* and *Cedrus atlantica*, the strong pastoral pressure and the proliferation of the high mountain cold steppes to the benefit of the sylvatic species, indicating a progressive passage towards an asylvatic domain.

Table 5. Ecological characteristics of the Géofacies (4).

Statement No.	**C011**	**C012**	**C013**	**C014**
Location	Timsguida	Tabarkant	Upstream of the Tinzimat valley	Previous station to the west
Altitude in (m)	2370	2380	2250	2260
Exposure	S.E	S.E	S	S
Slope in (%)	70	80	40	50
Topographical situation	High slope	High slope	Upper slope	Upper slope
Substrate	Limestone	Limestone	Limestone	Limestone
Surface formation	Superficial rocky	Superficial rocky	Superficial rocky	Superficial rocky
Tree cover (7m) (%)	2	1	5	1
Shrub layer cover (1 - 3m) (%)	40	40	50	50
Cover of the herbaceous layer (0.5m) (%)	10	10	10	10
Erosive dynamics	Gullies and slicks	Gullies and slicks	Gullies and slicks	Gullies and slicks

3.5. Geofacies of the Open thorny Xerophyte Steppe (Erinacea anthyllis; Bupleurum spinosum; Alyssum spinosum; Thymus comosus and Juniperus communis) on steeply sloping limestone Substrate and Rocky Soil:

The Geofacies follows the previous unit towards the N.W. where it colonises the summit of Tichoukt between 2400 and 2793 m in altitude (*Lalla oum el-bent* is the highest point). It is found only on steeply sloping limestone substrates (70%) and on superficial rocky soil. Three samples from the phytogeographical surveys group its ecological characteristics. That are summarised in the following Table 6.

Table 6. Ecological characteristics of the Geofacies (5).

Statement No.	**C015**	**C016**	**C017**
Location	Lala oum el-bent	Upstream of Tabarkant	Upstream of Lalla Oum el-bent
Altitude in (m)	2700	2620	2400
Exposure	S	S	N.W
Slope in (%)	70	80	80
Topographical situation	Summit	Summit	Steep upper slope
Substrate	Limestone	Limestone	Limestone
Surface formation	Superficial rocky	Superficial rocky	Superficial rocky
Tree cover (7m) (%)	40	40	40
Shrub layer cover (1 - 3m) (%)	2	10	20
Cover of the herbaceous layer (0.5m) (%)	Scouring/Screeps	Stripping/Screeps	Scouring/ Screeps
Erosive dynamics	Lala oum el-bent	Upstream of Tabarkant	Upstream of Lalla Oum el-bent

This open Xerophyte steppe is clearly individualised above 2400 m altitude where the steppe-like Oro-mediterranean climate of the high ridges and saddles favors its extension. This is an asylvatic area, marked by the total absence of trees in

favor of a moderately dense shrub layer, ensuring a cover of around 40% and including the following characteristic species of the high mountain cold steppe: *Erinacea anthyllis; Bupleurum spinosum; Alyssum spinosum; Thymus comosus; Juniperus communis* (endemic and rare). The herbaceous stratum is poor, between 2% and 10% cover, with *Stipa parviflora; Agropyron marginatum; Dactylis glomerata; Sedum sediforme and Scorzonera pygmaea* being the most frequent species. The Geofacies develops in the Oro-mediterranean stage of the extremely cold sub-humid bio-climate. The soil is skeletal, eroded, with abundant outcrops of limestone blocks. In these, marginal thermal and edaphic conditions (severe winter cold, frequent frost and snow, high light and ventilation levels, and a limestone substratum devoid of any soil), only thorny species can develop. They constitute two climatic plant groups of *Thymo atlantici-Erinaceetum anthyllidis* above 2400 m altitude and *Juniperutum hemisphaericae* at the summit of Tichoukt. They are in equilibrium with the meso-climatic and edaphic conditions and regenerate perfectly despite the frequent passage of livestock in summer.

4. Conclusion:

The Geosystemic method is used to analyse the current vegetation dynamics in the high mountain Geocomplex of Tichoukt. It allowed us to restructure this landscape into homogeneous Geofacies according to ecological and phytogeographical criteria, as well as the degree of human impact. Its basic vegetation is dominated by *Cedrus atlantica* and *thorny xerophytes* on steep slopes and Limestone substrate. Its current dynamics is controlled by the thermal and edaphic conditions that are unsuitable for the maintenance of the *Cedrus atlantica, Quercus rotundifolia* and *Juniperus thurifera*, which have no natural regeneration. The geocomplex is currently invaded by Alpine steppes with the almost total absence of trees from 2400 m altitude.

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