STUDIA GEOMORPHOLOGICA CARPATHO-BALCANICA
VOL. XXXIV KRAKÓW 2000 PL ISSN 0081-6434
LANDFORM EVOLUTION IN EUROPEAN MOUNTAINS ISBN 83-86726-96-2

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CONSIDERATIONS CONCERNING PERMAFROST PREDICTION IN THE FĂGĂRAŞ MASSIF (SOUTHERN CARPHATIANS)

Abstract. Analysis of the data registered at three meteorological stations demonstrates the harshness of the climate of the highest parts of the Făgăraş Massif. The author has established the conditions limiting and determining the characteristics of the periglacial belt, and shows comparative positioning of this massif within the European periglacial domain. At altitudes of 2,400–2,500 m and above permafrost is continuous, while down to approximately 2,100 m the permafrost becomes discontinuous, and at about 2,000–2,500 m (Bâlea Lac area) is sporadic.

Key words: periglacial domain, permafrost, Făgăraş Mountains

INTRODUCTION

The Făgăraş Massif lies at latitude 45° 30' N, longitude 24° 30' E, in the eastern half of the Southern Carpathians (Făgăraş–Iezer Section) (Fig. 1). It occupies an area of 1,500 km^2 and forms the most important mountain area in the Romanian Carpathians on account of its scale, high altitudes in excess of 2,500 m, inherited glacial relief and the periglacial processes and vast periglacial landforms still found there.

This article discusses the problem of whether or not to accept the concept of the periglacial environment, as a morphogenetic system which is now typical of high altitudes on the Făgăraş Massif. In order to deal with this concept, we will briefly review the discussions carried out and considerations taken into account to confirm the terminology and adapt it to some typical conditions.

The term "periglacial processes" was defined by W. Łozinski, in 1909, in Poland (Posea et al. 1976; Summerfield 1991; Thorn 1992) in order to mark the processes and landforms that are found around the Pleistocene ice sheet. Modern interpretations and emphasis are still being given to the term. The recent terminology is: incoherent, imprecise, incomplete and unsystematic (Hamelin, Cook 1967). E. de Martonne (1948, quoted by

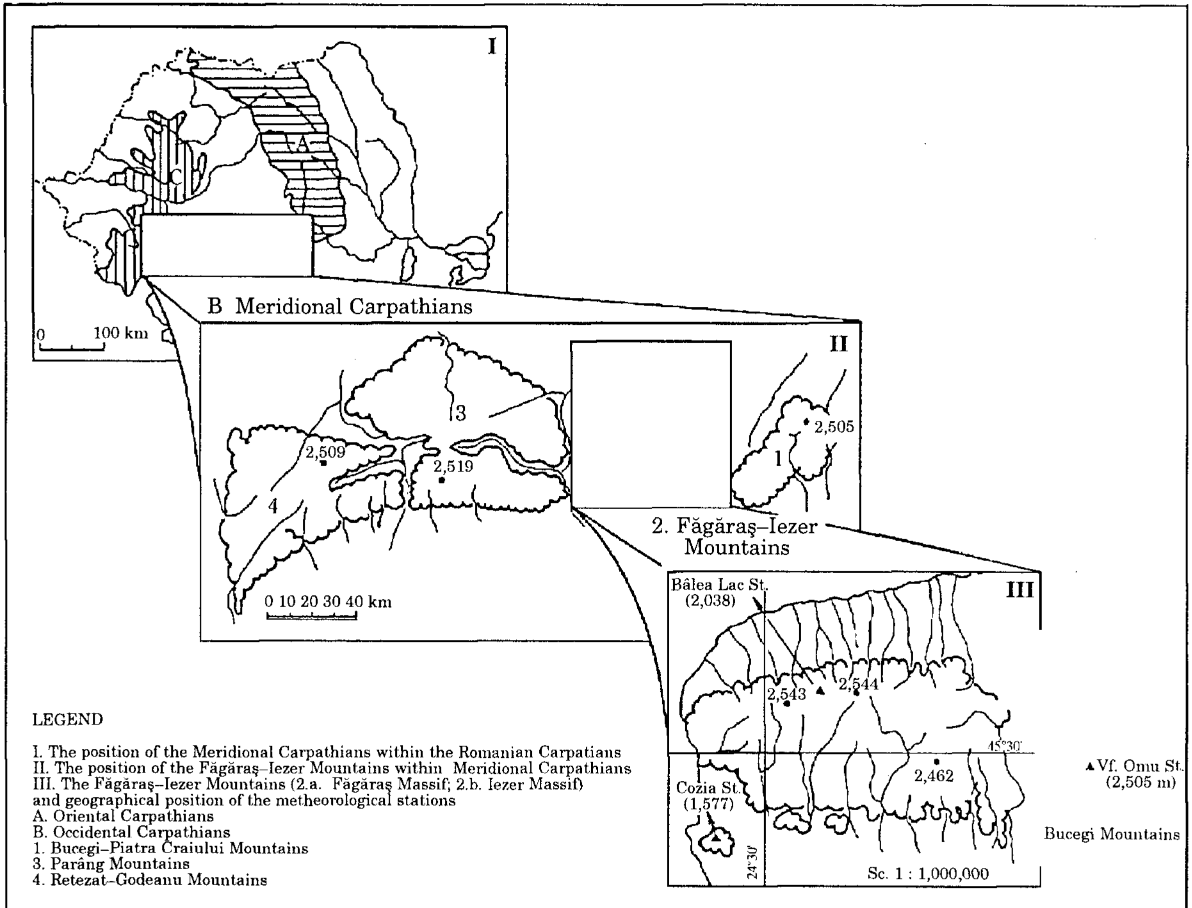

Fig. 1. The geographical position of the Făgăraş Massif

Mac 1996) talks in a wider sense about the nivation phenomenon. He associated the geomorphological processes that are produced both within a polar climate with no glaciers with those found under the action of snow and frost in mountain areas close to the limit of the permanent snow. Different terms but with a similar sense are used by other researchers (cited by Posea et al. 1976; Mac 1996): “paraglacial, subnival crionival criergic phenomena”. The term “periglacial process” as such was accepted by the IGU Periglacial Geomorphology Commission. Although the term of crionival quoted by A. Pissart (1987) was proposed in order to preserve the etymological significance relating to a position at the margins of glaciers, this was not followed. Today the wider sense of periglacial process is accepted. This refers not only to action around ice caps but also to action in areas where so called cold phenomena other than the traditional glacial and fluvio-glacial ones are acting on the relief. Put in another way, this refers to those areas where the process of frost-thaw constitutes the dominant action. It is considered that the concept of periglacial environment should be applied to areas with a yearly average temperature between –0.1°C and –0.3°C and precipitation below 1,000 mm (Summerfield 1991). Within these limits there is a large variety of climate types typical of high mountains at different latitudes. Other opinions have given an even more precise definition. One suggests that the periglacial belt as a high altitude zone on mountains is found between the bottom of the glacial zone and the altitude corresponding to the annual isotherm of 0°C (Francou 1993). This coincides with the line where the vegetation stops being present in a continuous layer and becomes fragmented. At the same time the same researcher assigns this higher belt to the “geocryosphere” or “cryosphere”. It is the domain with a strong stony component and with old inherited glacial features on which the cryonival and torrential processes are acting. Under these circumstances ice is temporarily or permanently present in the soil.

It seems that in Romania the term “periglacial” is only really applicable to the Pleistocene when Romania was under a completely cold climate and the soil was permanently frozen (*Geografia României*, 1983). Therefore the Făgăraş-Iezer area was included in the Carpathian periglacial domain: “the cryoplanation” or “intense weathering belt” or “the belt of intense weathering” and “the belt of thermal erosion or of solifluction” (according to *Geografia României*, 1983). At the same time it is considered that the use of the concept of cryonival belt is preferable when applied to Carpathian altitudes of over 2,000–2,200 m. This takes into consideration the insular, fragmenting character of the processes acting in the recent modelling of the relief, and relates to climate conditions where temperatures oscillate around the value of 0°C (according to Posea et al. 1974, *Geografia României*, 1983).

Permafrost as an attribute of the periglacial phenomenon, is evidenced by a soil and rock layer that remains frozen for more than two years. The isotherm of 0°C is taken into consideration in its spatial and character definition. This represents a threshold of discontinuity with profound implications on the type of alpine environment. Temperature variations, frost, snow and meltwater represent the main agents moulding the relief and create the processes typical of high altitudes (Urdea 1993). It is considered that when the average temperature of the air is –1°C, permafrost has a discontinuous character (Urdea 1992). On the other hand the same characteristic features are mentioned when the temperature varies between values of –1°C and –2°C (Francou 1993). Only at temperatures of between –8°C and –10°C is the permafrost considered to have a continuous character.

RESEARCH METHODOLOGY

The moulding of the cryonival relief is affected by the incidence of some climatic parameters, temperature and snowfall being the most important. Analysis of the data registered at three meteorological stations Vf. Omu, Bâlea Lac and Cozia (see Fig. 1.) demonstrates the harshness of the climate of the high mountains of the Făgăraş Massif which is characterised by several features:
— the monthly average temperature varies from 3.0°C at 1,580 m in Cozia Station area to –2.5°C at over 2,500 m (Vf. Omu Station), the isotherm of 0°C being placed at 2,050 m altitude on the northern slope of the Făgăraş Massif. It is interesting to mention the fact that the 0°C isotherm in the High Tatra Mountains lies on the northern slope at about 1,850 m altitude (Dobiński 1997). A. Kotarba et al. (1987) mentioned that a temperature of 0°C can occur in any month at altitudes between 1,800–1,850 m in the Tatra Mountains;
— monthly averages of under –4.0°C occur for about 3 months per year at the upper timberline, 4 months per year in the subalpine belt and 5–6 months per year in the alpine belt;
— the frost period varies with altitude: increasing from 181 days at Cozia Station in the period November–April to 212 days at Bâlea Lac Station in November–April and to over 240 days on the highest slopes in the period October–April;
— the alternance freeze–thaw may occur any time of the year at the altitude of the Bâlea Lac Station and above;
— in the alpine belt and the subalpine belt two periods of the year can be seen which have freeze-thaw cycles. These have a duration and a seasonal extension dictated by altitude. At the highest altitudes the first period falls during the months of April–May and the second during October–November and at the upper timberline the periods are respectively March–April and October–December (Fig. 2);
— high precipitation varying between 800–900 mm at the lower limit of the belt and 1,200–1,300 mm in its upper part, on the highest peaks;
— snowfalls that represent an extremely important climatic characteristic occur in almost every month at altitudes of 2,000 m and above, having their highest

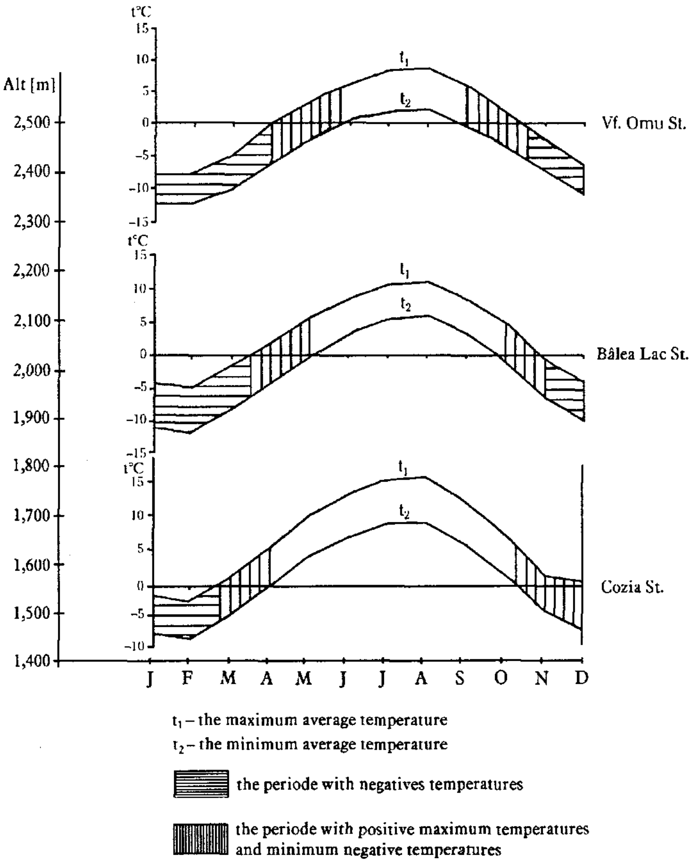

Fig. 2. Altitudinal variation of freezing cycles, multiannual average monthly values (1969–1997) at Vf. Omu Station, 1979–1997 at Bâlea Lac Station, 1983–1997 at Cozia Station

frequency during the period November–April or even November–May as follows: at the upper timberline (in the Cozia area) between 28.0–39.9% (in November and December), in the subalpine level, at the Bâlea Lac Station between 44.3–55.0% (in November, April) and on the highest peaks of the alpine belt between 38.6–55.4% (in November, May);

— the snow layer stays longer in the sheltered areas on the northern slopes, lying over 180 days at the upper timberline and 220–240 days on the highest peaks.

In the same context, I have established the conditions limiting and determining the characteristics of the periglacial belt in the Făgăraş Massif (Table 1) by considering the 10 climatic variables (identified by Francou 1993), that occur at the level of 0°C isotherm:

We should observe that the conditions necessary for the occurrence of glaciers do not exist in the Făgăraş Massif due to its altitude and latitudinal position.

Table 1

Climatic variables implicated in determining the characteristics of the periglacial zone in Făgăraş Massif (according to Francou 1993)

1	The altitude of the 0°C isotherm	2,050 m
2	The yearly average temperature at the ELA level	–2.5°C
3	The difference in level between the ELA altitude and the altitude of the 0°C isotherm	450 m
4	The thermal amplitude between the warmest and the coldest day of the year	17.2°C
5	The total yearly precipitation at the level of the 0°C isotherm	1,192.5 mm
6	The concentration of precipitation in the year (70% of the total occurs during "n" consecutive months)	6–8 months
7	Does 70% of the yearly precipitation occur during the warm season?	no
8	The duration of the snow layer at the level of the 0°C isotherm	> 8 months
9	The duration during which negative temperature values occur in the soil layer at the level of the 0°C isotherm	6 months
10	The presence/absence of permafrost	sporadic

Therefore the so called ELA (Equilibrium Line Altitude), which represents the separation line between the accumulation and thaw of the glacier and at the same time the upper limit of the periglacial zone, does not exist. Yet, using the climate data registered at Vf. Omu Station (where there is a continuous set of meteorological observations for a very long period of over 100 years) and by computing the temperature gradient (that is 0.63°C per 100 m) I could approximately establish the altitude at which ELA would appear as about 2,655 m.

The thermal amplitude between the average temperature of the warmest month, August (8.8°C) and the average temperature of the coldest month, February (–8.4°C) is 17.2°C which is typical for high altitudes. Also a specific characteristic is the yearly precipitation at the level of 0°C isotherm. Approximately 70% of the precipitation is concentrated during eight months a year with a strong contribution from the precipitation during the summer season. The pluviometric maximum occurs in June, followed by July, August and September. However the occurrence of 70% of the precipitation from the yearly total during the summer season is not achieved. The snow layer persists for about 11 months a year due to the snowfall in the winter-spring period in April and May, the period of the maximum nivometric, reaching the end of the summer. The maximum duration of the persistence of negative temperatures in the soil is about 6 months a year taking into consideration also that the average temperature registers negative values in the period October–March. Therefore the permafrost has a sporadic character in the subalpine belt at the level of the 0°C isotherm.

I have made a comparative analysis of the situation in the Făgăraş Massif and the situation in other European mountain areas (Table 2) using different climatic variables (see Francou 1993). This enables one to better place the areas studied within the context of the ensemble of the periglacial domain.

Table 2

Comparative positioning of the Făgăraş Massif within the European periglacial domain

Mountain area	Latitude	The altitude of the 0°C isotherm [m a.s.l.]	ELA altitude (reconstituted for Făgăraş Massif) [m a.s.l.]	The average temperature at the ELA level [°C]	The difference in altitude between the ELA and the altitude of the 0°C isotherm [m]	Total precipitation [mm]
Northern Alps (Switzerland)	47° lat. N	2,300	2,800	–3,0°	500	1,800
Central Alps (Switzerland)	46° lat. N	2,400	3,400	–5,0°	1,000	970
Southerm Alps (France)	45° lat. N	2,500	3,000	–3,0°	500	1,700
Tatra Mountains (Poland)	49° lat. N	1,800	2,600	–4,0°	800	1,800
Făgăraş Massif (Romania)	45° lat. N	2,050	2,655	–4,0°	605	1,193

It will be noted that the altitude of the 0°C isotherm is placed at over 2,000 m in the Alps but is differentiated (2,300–2,400–2,500 m) by the latitudinal position and implicitly by the preponderant climatic influence (wet, oceanic, continental). The average temperature at ELA level also varies, between –3.0°C and –5.0°C. The total precipitation is high in the Southern and Northern Alps (1,850 mm, 1,700 mm), which is exposed to wet climatic influences and low in the Central Alps, (only 970 mm), which is a good example of orographic shelter from wet air masses. The situation is different in the case of the Tatra Mountains. These lie at a relatively northerly latitude (49°N) compared with the other examples at the southern limit of the sector that corresponds to the so called continental transition climate (see

Kotarba et al. 1987). Therefore the altitude of the 0°C isotherm is lower at 1,800 m. The total precipitation is high at 1,800 mm, equal to the values found in the Alps, since the Tatras are exposed to wet air influences.

The Făgăraş Massif, lies at a latitude of 45°N and is therefore more southerly than the Northern Alps, Central Alps and Tatras. It lies more towards the interior of the European continent, and the continental nature of its climate is more accentuated. Therefore the annual precipitation is lower, reaching the value of 1,100–1,200 mm. This influence can be also found in the altitude of the 0°C isotherm which is found at 2,050 m, lower than that in the Alps and higher than that in the Tatras. The amount of precipitation at the level of the 0°C isotherm (Fig. 3) and the altitude difference between the ELA and the isotherm of 0°C are essential in the characterisation of high mountain domains, where periglacial processes play a significant role in giving them their specific character.

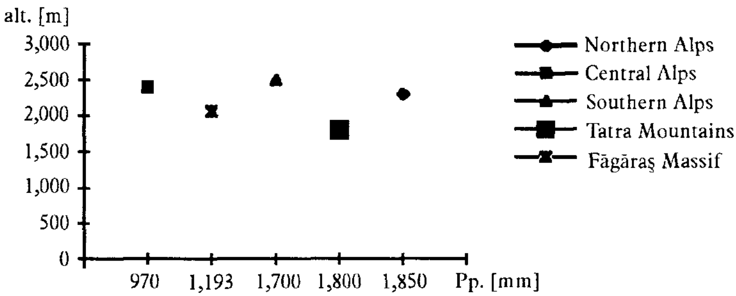

Fig. 3. The ralation between the altitude of periglacial belt and the amount of precipitation at the level of 0°C isotherm — comparative situation

I have positioned the areas occupied with permafrost within the Făgăraş Massif in the European context using the relation between the 0°C isotherm and latitude (Fig. 4).

One can see a group of mountain areas spread over a range of 2 degrees of latitude where the altitude of the 0°C isotherm lies over 2,000 m. This includes the Northern Alps, Central Alps, Southern Alps and Făgăraş Massif (see Table 2). Although the last mountain area has a higher degree of continentalism, due to its position inside the continent, it is exposed, as we have mentioned above, to higher precipitation as a result of the more northerly position of the wet ocean air masses. In the Tatra Mountains the northern latitude position determines, on the one hand, the lower altitude of the 0°C isotherm at under 2,000 m, (on the southern slope it is placed at about 1,850 m according to W. Dobiński (1997) and on the other hand, the high precipitation which results from its proximity to the northern ocean influences.

We can observe the areas with an essentially permafrost character within the Făgăraş Massif with the help of frost-thaw indices in a Harris type diagram (Harris

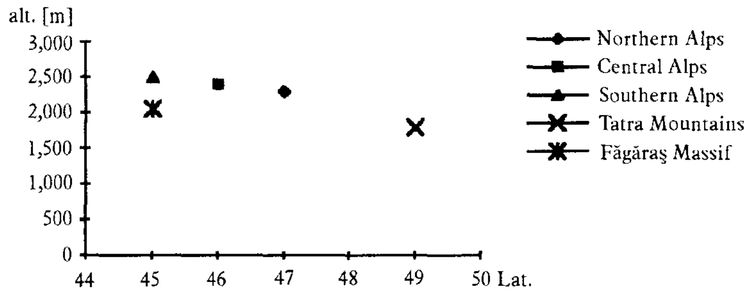

Fig. 4. The relation between the altitude of the 0°C isotherm and latitude — comparative situation

1981, 1982). Amongst these one finds some typical elements of the periglacial morphology. At altitudes of 2,400–2,500 m and above, i.e. a small area typical of the highest altitudes, the character of the permafrost is continuous. Down to approximately 2,100 m the permafrost becomes discontinuous, and at about 2,000–2,500 m altitude in the Bâlea Lac area, its character is sporadic. The other stations are outside the permafrost areas. Even though in the Făgăraş Massif the general climate is more extreme and continental, it presents similarities in location and position of the permafrost to the Alps which lies in a wetter, maritime (according to Harris 1981, 1982) type of climate. Using these indices it is possible to identify and classify the thermal domains that position the different periglacials. The method was also successfully used in the High Tatra Mountains (Dobiński 1997). Therefore a comparative analysis could be made of the two diagrams which shows significant similarities between the Făgăraş Massif area and the High Tatra (Fig. 5).

A first stage of our researches on the prediction of the mountain permafrost in the Făgăraş Mountains used the BTS method (Bottom Temperature Snow Cover), a method also successfully used in other areas and in the Retezat Mountains in Romania (Urdea 1992). A digital thermometer was used in order to measure the soil temperatures at different depths, altitudes and exposures. The values obtained were correlated with the value of air temperature (Pasotti 1994) (which varies together with altitude following a known gradient) using the equation $y = 16.61 - 0.0054\,x$ (Fig. 6).

Fifteen measurements were carried out between the altitudes of 1,665 m, where some sectors of the upper limit of the forest are found and 2,380 m, in the areas of the alpine and subalpine domains (Pasotti 1994). All these therefore took place in the mountain periglacial zone, i.e. between the upper limit of the forest and the highest peaks. It should be mentioned that the measurements were done at intervals of some days, at different hours, in the interval between the end of the summer and beginning of autumn, on land exposed in different directions: from sunny (SE–S–SW) and half sunny (E–SE, SW–W) to half shady (ENE–E, W–WNW) and shady locations (WNW–N–ENE) and including one measurement on a plane surface (Fig. 7) (Pasotti 1994).

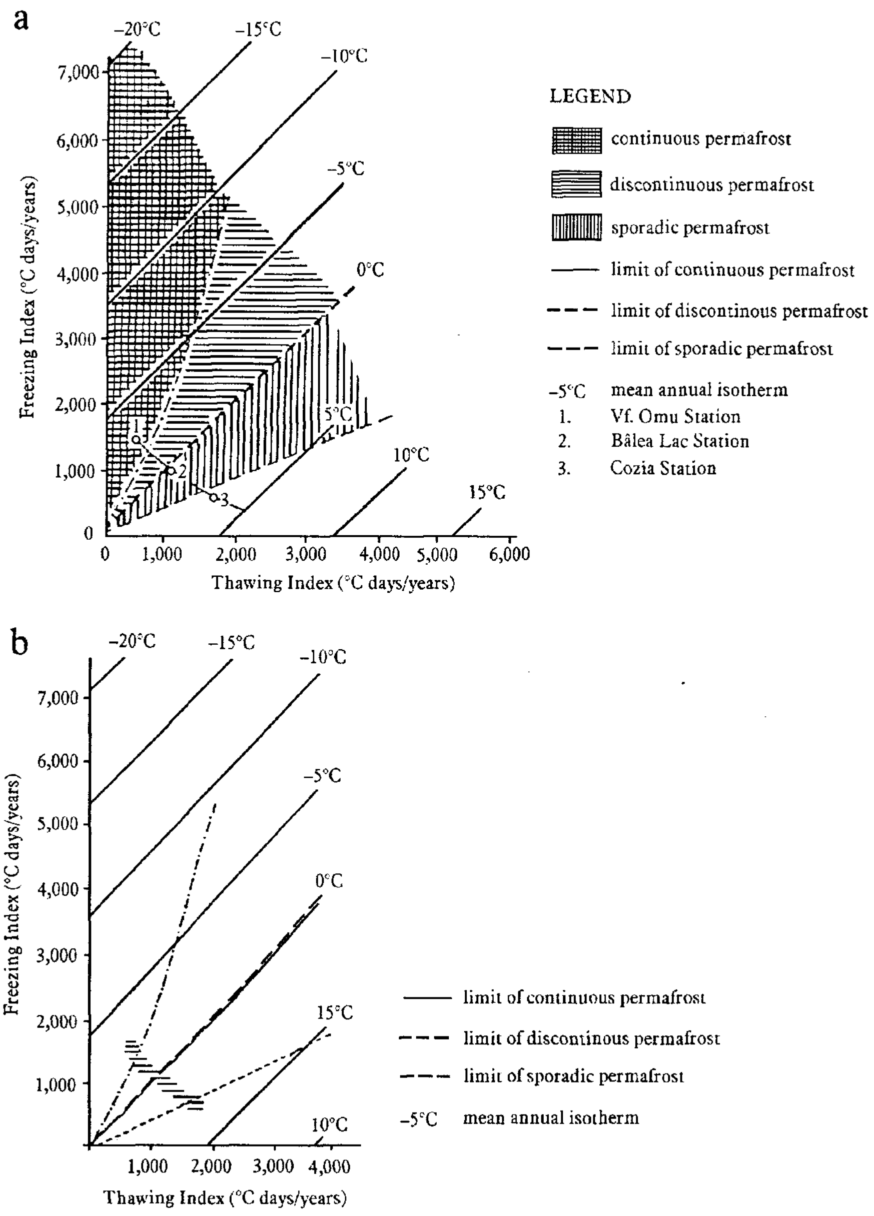

Fig. 5. Diagram of freezing and thawing indices (Harris type); a. Făgăraş Massif, b. High Tatra (according to Dobiński 1997)

The number of examples of measurement, on exposures in different directions and at variable altitudes are presented in the Table 3.

The variation of the soil temperature at different depths depends both on altitude and on exposure. Near the surface in a certain depth of soil, relatively

Făgăraş Mountains
*t air/t 40 cm = 0.39 (= t air/t 30 cm); t air/t surface = 0.9

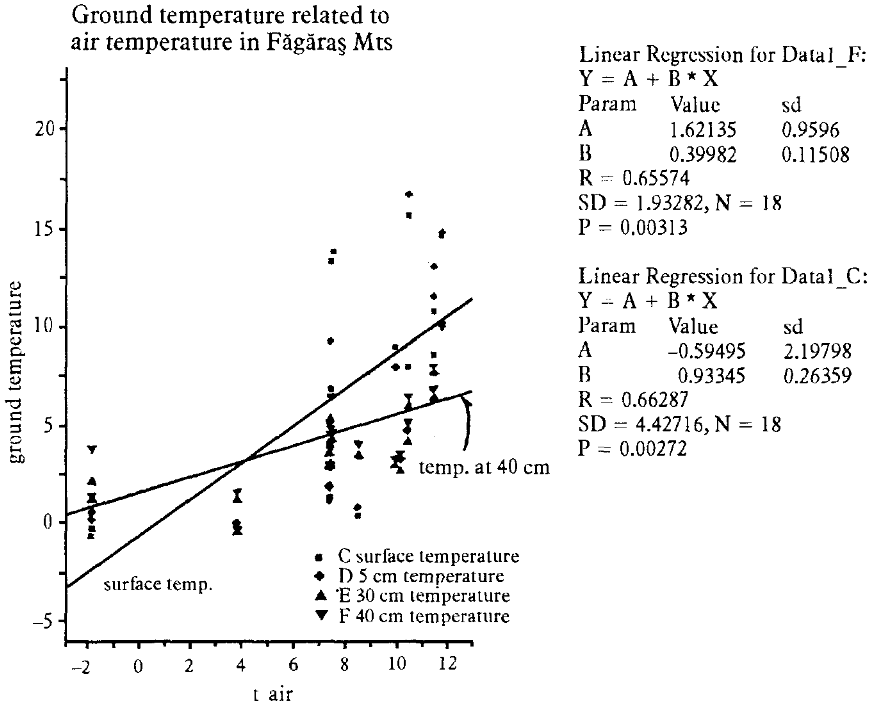

Fig. 6. The correlation between air temperature and soil temperature at different depths (from Pasotti 1994)

Table 3

The number of cases of different directions of exposure and their altitudes

Number of cases	Direction of exposure	Altitude (m)
3	W–NW	2,065–2,185–2,240
1	E–NE	2,290
2	E	2,320
1	E–SE	2,380
1	SE–S	2,010
2	S–SE	1,655–2,010
1	S	2,375
1	S–SW	2,270
1	SW–W	2,265
1	NW	1,950
1	Horizontal plane	2,370

small (for the season in which the measurements were done) changes in air temperature influence the soils thermal variation. On land exposed to the north–west a measurement was made at 1,950 m, in air temperature conditions of –1.9°C. At a depth of a few centimetres the soil was frozen. On the slopes exposed to the NW and W measurements were made at altitudes between 2,065–2,185–2,240 m, the air temperature having different values of 11.5°C, 15.0°C, and 8.5°C respectively. On the slopes exposed to the E and NE a measurement was made at 2,320 m, in freezing temperatures, the soil being frozen at a depth of a few centimetres. On the slopes exposed to the SE, a measurement was made at 2,010 m, and two measurements at 1,650 m, the air temperature being above 0°C in both cases, i.e. 7.5°C and 11.5°C respectively. Finally on the slope exposed to the south I have taken a measurement at 2,375 m, on the slope exposed to the south west at 2,265 m, and on the slope exposed to the south west at 2,270 m, the air temperature being 7.5°C. It is apparent that the variation of soil temperature at a given depth is determined by several factors: the variation in air temperature, which is itself influenced by altitude and the direction of exposure (and therefore by the amount of solar radiation), by the degree of cover of typical woody, creeping or grassy subalpine vegetation and by the degree of soil development.

In this context the seasonal variation in air temperature and the altitude of the 0°C isotherm (which in Făgăraş Massif lies at 2,050 m) are also important in determining the soil temperature. The soil freezes at variable depths depending on the value and persistence of negative air temperatures. At very similar altitudes, measurements of soil temperature have given differing readings, and at depths of over 40 cm the temperature is no longer dependent on the air temperature. One can look for an explanation in the differences in the input of the geothermal flux between certain areas, differences which we have measured, a fact that would suppose the existence of some patches of sporadic permafrost (Pasotti 1994).

CONCLUSION

If we correlate these first results with the graph of the freeze-thaw indices, we can determine at this first stage of our researches the existence of discontinuous and sporadic permafrost in the Făgăraş Massif of the High Carpathians.

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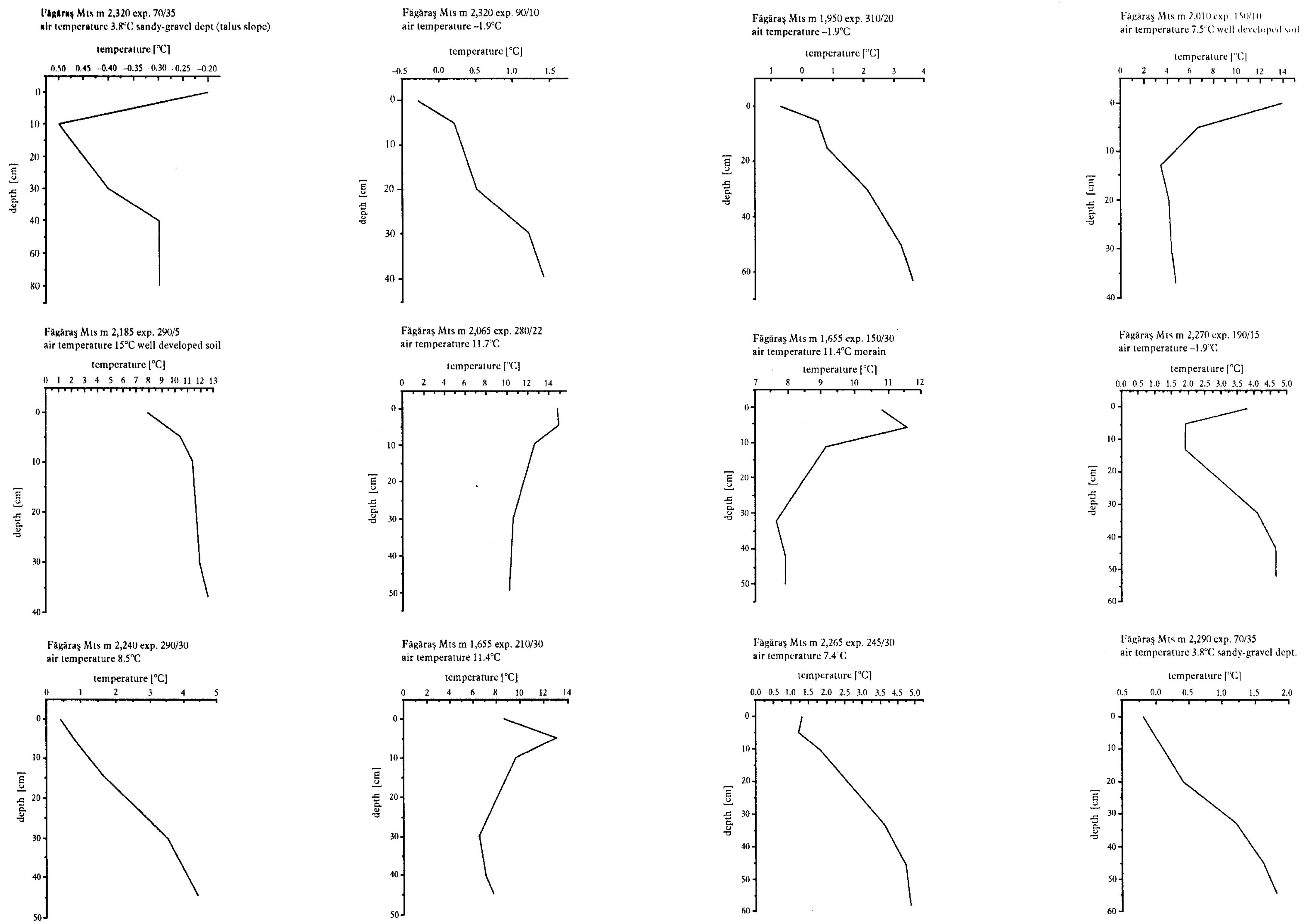

Fig. 7. Measurements of soil temperatures with a digital thermometer, at different altitudes and with different exposures (from Pasotti 1994)

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STRESZCZENIE

M. Voiculescu

ROZWAŻANIA NA TEMAT WYSTĘPOWANIA ZMARZLINY W MASYWIE FOGARASZU, KARPATY POŁUDNIOWE

Praca zawiera rozważania Autora na temat zjawisk peryglacjalnych na obszarze rumuńskich Karpat Południowych, a w szczególności masywu Fogarasz. Poprzez analizę parametrów służących do określania potencjalnych warunków niezbędnych dla wystąpienia zmarzliny wysokogórskiej, dochodzi do wniosku, że w masywie Fogaraszu istnieje możliwość zachowania zmarzliny ciągłej (wys. 2400–2500 m), nieciągłej (do wys. 2100 m) lub sporadycznej. Brak natomiast klimatycznych warunków dla istnienia lodowców, gdyż teoretyczna linia równowagi (ELA) występuje na wysokości około 2655 m n.p.m.