CATENA vol. 17, p. 163–174 Cremlingen 1990

FROST ACTION FEATURES AS A CONSEQUENCE OF FIRE DEVEGETATION IN A MONTANE MEDITERRANEAN ENVIRONMENT

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Summary

As a consequence of forest fire devegetation in a Mediterranean zone (over 625 m a.s.l.) changes in geomorphological processes have been produced. Environmental changes, and in particular the ground climate, enhance the occurrence of frost-thaw structures previously absent in the zone with the usual forest cover. During the survey period (winter 1986–87) four months after the fire, the main frost action features observed were ice cementation, pipkrake and high laminar porosity and gaps around the stones. Extrusions of fine material not related to faunal activity and probably associated with frost-thaw processes were also observed.

In neighbouring areas with equal altitude and exposure but with forest cover, (outside the fire limit) no frost action features appeared, except in the small pathways where the local microclimate conditions were similar to the burned areas because of the absence of vegetation.

Thus, the environmental modifications derived from fire devegetation induce more severe soil temperature conditions and give rise to periglacial type processes, normally absent in this zone.

Analysis of polished blocks from hardened undisturbed soil samples aided the interpretation of the extrusions.

ISSN 0341–8162

D–3302 Cremlingen-Destedt, W. Germany
0341–8162/90/5011851/US$ 2.00 + 0.25

1 Introduction

In July 1986 a forest fire burned intensively about 5300 ha of land in the Montserrat area, totally destroying all the shrubs and grassland, and reaching almost all the tree crowns, as well as the forest litter (mainly pine needles) leaving no green vegetation cover on the ground.

A research team from the University of Barcelona is at present carrying out a study of the geomorphological consequences of the fire. To this end, a series of field surveys have been undertaken.

They highlighted the contrast between burned and non-burned zones particularly with respect to the effect of temperature at soil level. A study of the effects of freezing and thawing in the burned area was carried out and the results compared with observations in the unburned areas.

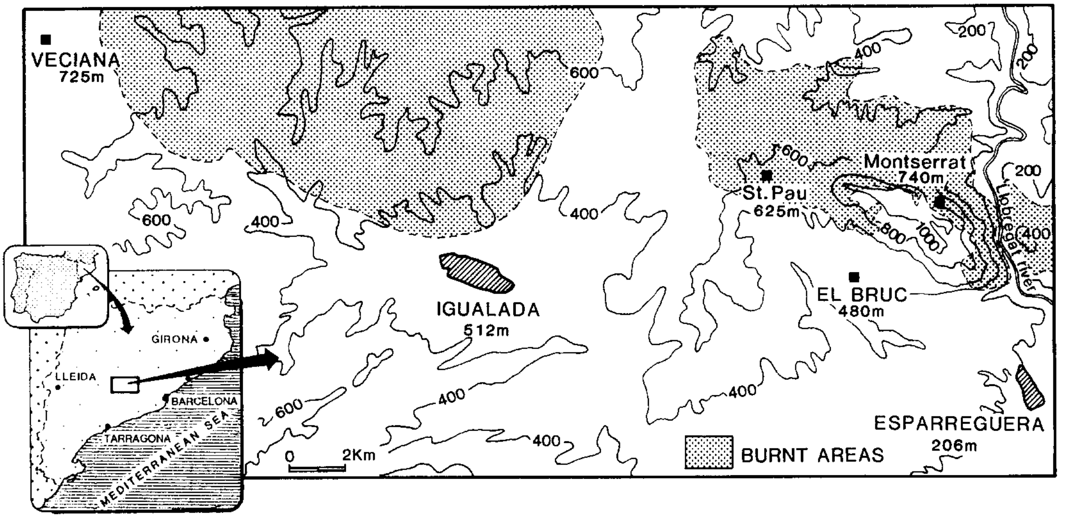

Fig. 1: *Location of the zone, the meteorological stations and the burnt areas.*

2 The study area

2.1 Location, lithology and morphology

The study zone is situated in NE Spain in the Prelittoral Catalan Range, in the locality of St. Pau de la Guardia, 41°36′53″ Lat. N and 1°44′55″ long E (fig.1). It lies 625 m above sea level forming part of the western end of Montserrat, a mountain which reaches the height of 1245 m at St. Jeroni.

The lithology of the substratum mainly consists of siltstones with interbedded layers of conglomerates and sandstones of Eocene age. There is a predominance of rounded ridges with slopes of around 20°, mainly oriented N-S, E-W and NE-SW.

2.2 Climate

The climatic characterization was based on the results from the nearby stations of Igualada, El Bruc, Esparraguera and Montserrat (fig.1).

For the above characterization temperature and rainfall data over a period of 30 years have been taken from the stations, taking into consideration altitude, geographical position and distance from the study zone, thus allowing a fairly representative interpolation.

According to Papadakis' classification the thermal regime is warm-temperate, the humidity regime is wet-Mediterranean. Consequently the climatic type is warm-Mediterranean.

The annual rainfall calculated is 675 mm reaching two marked maxima in May and September (85 and 75 mm respectively) and an absolute minimum in July (30 mm).

The mean annual temperature is approximately 13°C. Its evolution is steady, reaching a maximum in July and August (21.5°C) and a minimum in January (6°C). Although the average maximum temperature does not rise above 27°C the absolute annual maximum exceeds 33°C. Similarly the average minimum temperature never drops below 0°C, while the mean of the absolute minima of the coldest month was calculated to be around -6°C. These temperatures, however are not taken at soil level where they are obviously much more extreme.

The data from Veciana meteorological station has been taken into account as it is the station which provides temperature measurements at soil and subsoil level, essential for the study of frost action.

The temperatures at grass and at subsoil levels give an idea of the December 1986 to February 1987 period which is when freezing took place. However the minima reached in the study area were probably lower due to the lack of vegetation. Seventeen freeze-thaw cycles were reported at a depth of 5 cm, six of daily oscillation and the rest lasting several days and the minimum reached was -3.8°C. At a depth of 10 cm only temperatures of 0.1 to 0.8°C below 0 were reported between 18th to 23rd January. In the St. Pau de la Guardia area the frost reached a greater depth as was seen in the field surveys (10–12 cm on several occasions).

2.3 Soil characteristics

The soils of the area are mainly lithosols, rendzinas and cambisols depending on the soil thickness and following FAO Soil Classification. Cambisols from forested areas are usually eutric and seldom dystric, belonging to a rudic phase (gravelly).

The typical eutric cambisol of the studied area is quite shallow and shows a reddish-brown ochric epipedon, too thin to be mollic, a yellowish-red cambic horizon below and an extremely gravelly C horizon developed from the parent material.

The characteristics of a typical profile described in a 35 cm deep dug pit, in an area with prominent extrusion phenomena (discussed later) are:

Au1 0–0.5 cm. — Black in colour (5YR 2,5/1) with grey pockets (5YR 5/1). Loam. Very abundant burned plant remains. Very fine (inf. 1 mm) moderate crumb structure, very friable. Abundant earthworm casts of loamy texture. Abrupt wavy boundary.

Au2 0.5–15 cm. — Reddish-brown in colour (5YR 4/4). Loamy sand with abundant (15–30%) medium to very small stones (6–60 mm). Fine weak crumb structure, very friable. Common fine and medium tubular pores and many fine irregular ones randomly oriented. Very thin, few dark (organic ?) coatings around peds. Abundant all-sized roots (from 0.1 to more than 1 cm) inside and between peds. Abundant earthworm casts, in the upper part of horizon, chambers with abundant, very porous faecal material. Also in the upper part more compact masses intruding in the upper horizon and reaching the soil surface. Abrupt smooth boundary.

Bw 15–30 cm. — Yellowish-red in colour (5YR 4.5/6). Sandy clay loam with very abundant (>30%) very small to medium size stones (6–60 mm). Fine weak granular structure, friable. Few, fine and medium tubular pores and common very fine irregular ones. Fewer roots and less faunal activity than in the upper horizon. Gradual smooth boundary.

C from 30 cm on. — Gravelly layer from conglomerate parent material.

Bulk samples of the three upper horizons were taken. The particle size data are given in tab.1.

2.4 Previous vegetation and present characteristic of ground surface

The previous vegetation of the burnt area and the present cover of the neighbouring unburnt areas is characterized by a pine forest (*Pinus halepensis*) with "garrigues" (*Quercetum coccifera*) mainly in stony areas, scrub (Rosmarino—Ericion) and hemicryptophytic and chamaephytic pastures of *Aphyllanthion* more developed in shady areas.

Horizon	Gravel >2 mm %	Fine earth fraction <2 mm (100%)			
		2–0.05 %	0.05–0.02 %	0.02–0.002 %	<0.002 %
Au_1	3.8	43.4	9.5	19.6	26.9
Au_2	37.2	86.0	1.9	4.4	6.6
Bw	70.1	53.3	7.4	16.1	22.5

Tab. 1: *Grain size percentages of horizons A and B.*

As stated above, the vegetation cover was totally destroyed by a forest fire in July 1986. A blanket of ashes was left lying on the ground, thicker on the northward-facing slopes than on the southern ones because of the unequal development of former vegetation cover. Charred trunks, burnt branch remains and hollows produced by prolonged ignition after main fire extinction, especially in the trunks remaining from trees that had been cut down, were abundant on the slopes. The first rains after the fire washed away some of the ashes, but the soil remained black due to the presence of burnt organic matter. When the field survey commenced in October, vegetation recovery was practically non-existent. These characteristics persisted until December, when temperatures dropped to below 0°C. The faunal activity observed was quite reduced probably as a result of the destruction caused by the high ground temperatures reached during the fire.

3 November—February field surveys: soil conditions and appearance of frost action features

3.1 Soil conditions

Since the fire, the vegetation recovery had been very sparse. Throughout the winter only small patches of fresh vegetation were observed, with a cover of less than 10%. The ground was greenish-black in colour.

According to information collected, December 23rd was the first day that the ground froze, although air temperatures of below 0°C had been recorded for several days. On the field survey of this day the soil was frozen in the burnt area. Because of the limited surface surveyed it is not possible to state the extent of frozen soil, and the observations described should be representative of the same or higher altitudinal zones within the burnt area.

Small trenches were opened in order to assess the depth of the freezing front and ice features. The soil was frozen and ice-cemented to a depth of about 10–12 cm. Ice lenses, segregation ice and needle ice (up to 3 mm long) were present. On the northward-facing slopes no thawing was observed in the whole day and surface pebbles and remnants of burnt branches remained completely ice-cemented to the ground. Usually the southern and southeast facin slopes were ice-cemented early in the morning but the heat of the sun thawed the frozen soil by midday. This behaviour was recorded several times.

3.2 Features indicating frost action

Soil heaving as well as vertical uplift of stones and aggregates resulting from ice lensing and pipkrakes was observed. Although the soil was frozen on all the burnt slopes in the area, the effects of frost heaving were much more intense and evident in zones of concave morphology, that is to say, in small depressions. This may be related to the higher content of water present in those zones which enhances the development and growth of ice lenses.

After thawing the frost effects remained perfectly visible. The freeze and thaw cycles disrupted the soil surface (photo 1). The thawing of the ice lenses increased porosity as revealed by marked sponginess of the soil (photo 1 and 2) which gave away under pressure. Similar forms were observed by WHITE & WELLS (1982) in a burnt area of Jemez Mountains (New Mexico) but at altitudes of about 2195 and 2530 m. The soil was also disrupted and, as in our zone, an upward movement of fine particles with respect to coarse ones was recorded.

Another striking feature were the gaps around the stones (WASHBURN 1973), as seen in photo 2 and 3. As stated by VAN VLIET-LANOE (1985) the depressions around the stones may be related to the plastic deformation of the sediments by stone extrusion. In the study area only stone lifting by pipkrakes was observed but, although possible, no evidence of stone expulsion is available to date. These gaps around the stones may be explained by the pressure of ice growing around the stones due to greater thermal conductivity of the stones. Another possible explanation quoted by WASHBURN (1973) suggests that these gaps can be the result of heaving and lifting of the immediate surface material away from the stones. At the very start of freezing, the stones would be large enough and of such shape that they would escape being pushed up by needle ice or pulled up by adjacent soil.

3.3 Extrusions of fine materials

The faunal activity observed on previous surveys (before December) was greatly reduced. However during these surveys, some small anthills made up of microaggregates and earthworm droppings and casts yellowish brown in colour, were observed. They were carefully examined and always showed holes and burrow tracks.

At the end of December another kind of extrusion of fine sediments was recorded (photo 4). At that moment the extrusions were quite abundant and quite obvious because of the difference in colour between the ground and the extruded material.

The sudden abundance of extrusions this time, when the soil had been deformed by frost, suggested the possibility that these forms might have an origin other than faunal activity.

Several pits were dug in order to observe their characteristics. The best developed extrusions were cone-like in shape; the largest being of about 10 cm in diameter and 5 cm high. Because of their size they might be attributed to faunal activity, but the total absence of holes

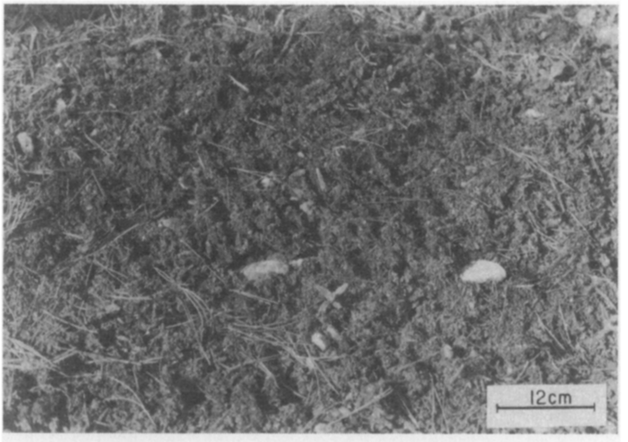

Photo 1: *Surface disruption and porosity increases as a consequence of frost-thaw cycles.*

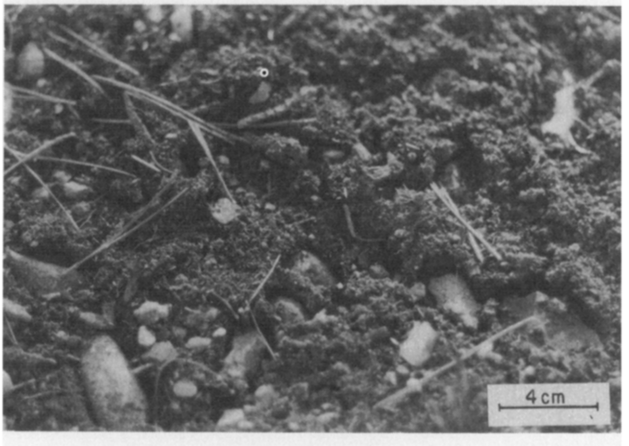

Photo 2: *Detail of the surface disruption and the gaps around stones.*

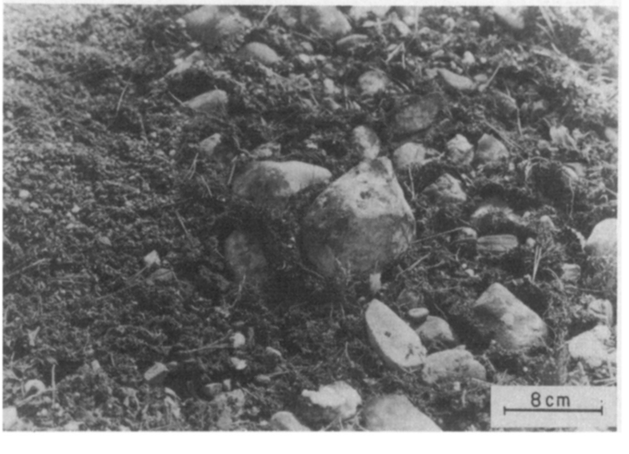

Photo 3: *Gaps around stones.*

Photo 4: *View of a zone with several extrusions which in the photo stand out in light grey against the darker background.*

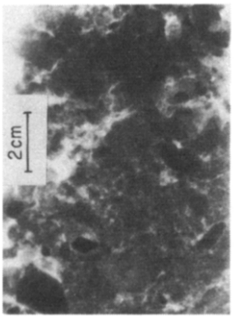

Photo 5: *Positive of a radiograph of a block slice showing the compact mass bordered by highly porous areas especially visible on the left side.*

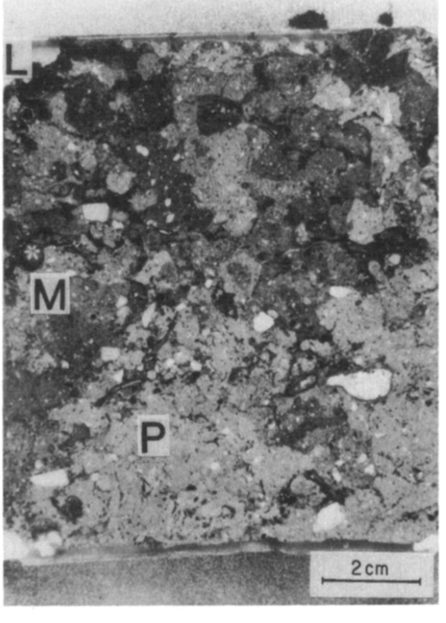

Photo 6: *A polished slice showing the three types of soil materials. In the photo material L is the darkest, P is the lightest and M shows the intermediate grey colours.*

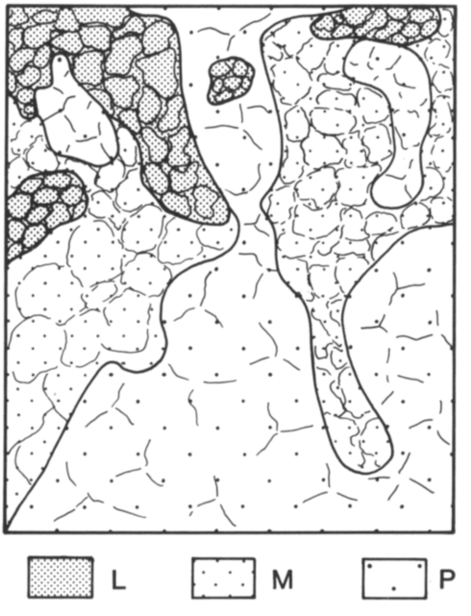

Fig. 2: *Schematic representation of a polished face in the central part of an undisturbed indurated sample, taken from photo 6.*

or burrow tracks can be considered as a reason to discard their biological origin. Moroever the core of the extrusion was massive, with high clay content.

Several extrusions were purposely sampled with Kubiena boxes (10 × 8 × 5 cm) so that the extrusion lays in the centre of the block, in order to analyse microstructures. Moreover, two bulk samples from the surface part of the extruded material were taken for texture analysis. The sample I was sandy clay loam and that of sample II, clay loam, both quite similar to the Bw horizon.

3.3.1 Polished block analysis

The undisturbed soil samples of extrusions were dried at room temperature first for one week, then at 40°C for two days, and were impregnated with a polyester resin under 100 mbar vacuum. The hardened blocks were sliced with a diamond saw, thus obtaining 7 slices from each block, about 6 mm thick. The procedures for the impregnation of samples were mainly based on MURPHY (1986). The two main faces of each slice were polished and numbered. Photographs of all faces and radiographs of every slice were systematically taken for comparison in order to detect any hidden feature. A Hewlet Packard "Faxitron" X-Ray camera was used, with a voltage setting of 40 kv and an exposure time of 30 seconds.

The radiographs of the slices reveal the differential compaction of the soil materials. Masses with high porosity or with organic fragments are more permeable to X-rays than the compact masses or mineral fragments. Consequently, the positives from the radiographs (photo 5) show stones and compact masses as black or greyish-black tones. Light grey colours corespond to porous matrix zones and white colours to fluffy matrices and voids. Soem dark grey areas have external morphologies that can be attributed to faunal passages. However, some other dark grey areas reveal an external mushroom-like shape which probably corresponds to the field-observed features related to the extrusion phenomena presumably due to frost action. Some of the massive forms may be clearly seen to be bordered by highly porous areas (photo 5). This porosity may be due to ice segregation. This will be discussed further on.

The analysis of the polished slices has enabled three types of differently-coloured fabric units named L, M and P, which are described below. According to BULLOCK et al. (1985) a fabric unit is a part of soil material homogeneous at the scale of observation (in our case, 1x to 50x). An example of them is given in photo 6, corresponding to a central slice of the undisturbed sample and fig.2 is a scheme of it.

L: This soil fabric unit is predominantly black and forms rounded aggregates with high internal porosity. The aggregates are made up of particles of organic nature. They occupy most of the upper centimetre in most of the polished faces, but are also present in scarce amounts at all depths.

M: This soil fabric unit is reddish brown and forms undifferentiated masses or rounded aggregates. It is made up of sand particles mixed with a finer differentiated matrix. Its internal porosity while still high, is lower than that of material L.

P: This soil fabric unit is yellowish red and shows low internal porosity. It is made up of a fine ma-

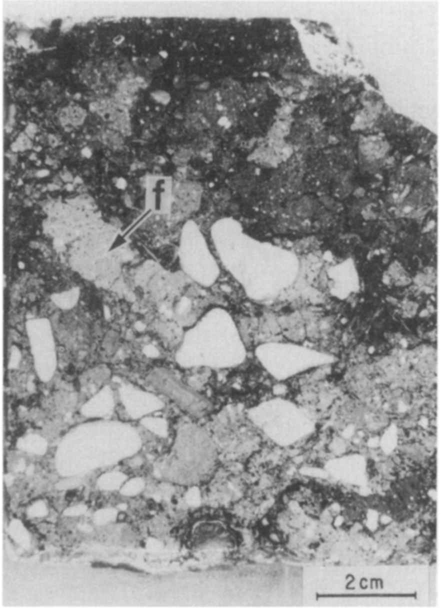

Photo 7: *A polished slice, corresponding to an external part of the block, showing a morphology of P material attributed to faunal passage (f).*

trix with some sand particles. Its external morphology is sometimes undoubtedly attributed to faunal activity (photo 7) but sometimes the forms are such that they seem to suggest that the mass has flowed or has been injected. These forms, as shown in photo 6, are roughly triangular.

Fabrics "L" and "M" present, besides a high intra-ped porosity, an inter-ped porosity dominantly of the planar type. Such kinds of porosity rarely affect fabric "P". The latter is always in contact either with voids or with "L" and/or "M" fabric units. Moreover the morphological study of the sequential polished faces of the sliced blocks has revealed that the faces showing the higher proportion of yellowish red "P" fabric were coincidently those of the central part of the block. Furthermore, the external block slices had a high proportion of L and M fabric units along with a higher inter-ped porosity.

3.3.2 Interpretation and discussion of extrusions

The interpretation that will be made of the extrusions is based on the following points:

a) absence of holes or burrow tracks

b) greater amount of this type of extrusions coinciding with the wintertime frost periods

c) composition with 100% of material less than 2 mm and clay content ranging from 20 to 40%

d) compactness of the inner masses of the extrusions free of features indicating freeze-thaw cycles (dislocations, porosity)

e) high porosity in the contact zones with these inner compact masses

f) triangular or mushroom shape of the inner masses.

The compactness of the inner masses indicates that these did not undergo freezing in spite of their lying at depths reached by the frost according to field observations. The greater porosity of the zones around these masses may be associated with the freezing of the water contained in these more porous areas. Thus the soil materials reacted differently to frost penetration according to their particular characteristics. The masses with higher clay content did not freeze and were subjected to the pressure of growing ice and ejected outwards through already existing cracks or fissures.

The above interpretation may pose problems since injections associated with frost have generally been reported in colder areas. On the other hand, in laboratory experiments (CORTE 1972, CORTE & HIGHASH 1972, PISSART 1982 and VAN VLIET-LANOE et al. 1985) a fair amount of freeze-thaw cycles have been needed for them to take place. Nevertheless it must be taken into account that in our case the material was heterogeneous as it had been previously modified by faunal activity, whereas in the laboratory, one is dealing with layers of different texture but perfectly homogeneous throughout the layer.

Moreover the fact that the majority of these forms have been described in areas of high latitude or altitude does not rule out the possibility of their occurring in less extreme conditions. These processes may occur to a lesser degree and may be masked by other dominant processes. Furthermore, if certain conditions do not arise they may well pass unnoticed. In our case the blackened surface due to the fire helped their identification, as in normal brown surface, the extrusion is basically of the same colour as the ground.

4 Contrast between burned and vegetated zones within the region

The features described above are conclusive of frost action on these burned slopes. Nevertheless, in the neighbouring areas with the typical forest cover (mainly formed on pines, shrubs and a liter of pine needles) the geomorphological behaviour was different. This cover creates a microclimate different from that of the devegetated areas. The thermal changes are reduced and the maxima and minima are moderate. In the study area the contrast with the forest-fire devegetated areas have stood out in the field surveys. In winter 1986–87 the air temperature dropped below 0°C several times, but in the forested area no freezing was observed (the knife penetrated easily into the ground). The only locations within the forest area where the ground was frozen at this time were the muddy pathways and the devegetated slopes bordering them. In these situations, under these special conditions, frost action features were observed similar to those of the burned areas.

This can be explained by analyzing the energy budget

$$Q_n = E_L \downarrow - E_L \uparrow + E_K \downarrow - E_K \uparrow$$

where Q_n is the flux of net radiation and E_L and E_K the long and short wave flux of radiation ($\uparrow$ = up, $\downarrow$ = down). For the short wave budget in spite of the fact that the albedo depends on the type, state and roughness of the terrain as well as on the vegetation, it is possible that the variation between burnt zones and non-burnt ones is small. This is probably due to the fact that the effect of deforestation on the albedo is balanced by the dark ground colour. The albedo of a coniferous forest oscillates between 10 and 25% whereas that of a dark ground ranges between 5–15%. Moreover, the freezing is at night when the short wave radiation is worthless.

On the other hand the emissive power of a coniferous forest is about 90% while that of a soil covered with ashes is 97%. Therefore, the increase in the emissive power in a deforested zone leads to cooling due to greater long wave emission.

Taking into account the equation:

$$Q_n = \pm Q_E \pm Q_Z \pm Q_G$$

where Q_E, Q_Z and Q_G are the flux interchange of latent, turbulent and ground heat, an increase in up-radiation leads to an increase of Q_G ($Q_z \simeq 0$ if there is no turbulence and $Q_E \simeq 0$ if there are no sources of water vapor), and, consequently to greater soil freezing.

A last consideration is that in a forest the trees emit long wave radiation towards the soil and reflect more of the short wave radiation reflected from the soil.

5 Conclusions

a) The destruction of the vegetation cover by fire has given rise to microclimatic changes which in the winter period have led to ground freezing on several occasions. Neighbouring forested areas did not undergo freezing.

b) In the burnt areas, forms resulting from frost action and freeze-thaw cycles appeared (ice-cementation, pipkrakes, soil disruption, porosity, extrusions, gaps around stones). These forms were absent in nearby forested areas.

c) The presence of a blackened layer on the ground due to the fire aided the identification of forms and processes which, under other circumstances, are difficult to observe.

d) Extrusions of fine sediments are interpreted as having been formed as injections associated with the irregular penetration of the frost front, favoured by the heterogeneous soil composition, even within the same horizons. The pressures exerted by ice growth on the non-frozen parts caused their deformation and injection through fissures.

e) The destruction of vegetation by fire leads to periglacial type processes which are unusual in these geographical areas.

Acknowledgements

This research was financed through a grant from CIRIT (Generalitat de Catalunya). Our thanks to Mr. and Mrs. V. Eslava, the owners of the land in which the surveys were carried out, for their kindness and cooperation, to Mr. E. Guillé and Mr. D. Llorens for furnishing the meteorological data for Veciana and El Bruc, and to Ms. M. Pereira for the careful translation.

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