Geogr. Fis. Dinam. Quat.
26 (2003), 3-13, 8 figg., 6 tabb.

CARLO BISCI (*), FRANCESCO DRAMIS (**), MASSIMILIANO FAZZINI (*)
& MAURO GUGLIELMIN (**)

# CLIMATIC CONDITIONS AND SPORADIC PERMAFROST IN THE MAIELLA MASSIF (CENTRAL APENNINES, ITALY)

**ABSTRACT:** BISCI C., DRAMIS F., FAZZINI M. & GUGLIELMIN M., *Climatic conditions and sporadic permafrost in the Maiella Massif (Central Apennines, Italy).* (IT ISSN 0391-9838, 2003).

Climatic data were examined for some ten weather recording stations, in order to verify the presence of favorable conditions for preserving sporadic mountain permafrost in the Maiella Massif (Central Apennines, Italy).

The analyzed data refer to the time-span 1965-1990; they have been gathered for recording stations located at altitudes ranging from sea level (Pescara) to over 2100 m a.s.l. (Campo Imperatore, Gran Sasso Massif).

The mean annual average temperatures were *ca.* 6-7 °C in the higher areas; the seasonal means ranged from −4 °C in winter to 12 °C in summer. Average thermal gradients vary from 0.4 °C/100 m in January to 0.7 °C/100 m in July, with an annual average of 0.57 °C/100 m. Based upon these data, the altitude of the 0 °C isotherm in free air in the Maiella Massif is *ca.* 2500 m, whilst the −2 °C isotherm, which can be used as the lower climatic limit for the presence of permafrost, should be located slightly over 2750 m a.s.l., on average.

The precipitation regime generally has sub-Mediterranean features, which are progressively more evident moving from the Adriatic to the Tyrrhenian side. It shows a maximum in late autumn or winter and a minimum in summer, locally associated with a secondary maximum in late spring. Annual precipitation ranges around 1200-1400 mm, both in the high plains and on the main mountain peaks.

Snow falls are abundant, especially along the eastern sides of the mountain groups, because of direct exposition to Balcanic-Danubian cold currents. At 1000 m a.s.l., generally 150 to 200 cm of snow fall are recorded and a snow blanket is present for *ca.* 70 days, concentrated in the November-April period; at *ca.* 2000 m a.s.l. (Campo Imperatore), the snow fall sums up to 400 cm and 180-200 days of persistence are recorded from the end of October to the end of May.

Analyzing the above situation, it is possible to infer that the general climatic framework allows the presence of permafrost only close to the top of the Maiella Massif, at altitudes exceeding 2750 m a.s.l.

On the other hand, the bottom temperatures of winter snow cover (BTS) recorded in the Upper Cannella Valley, where sun irradiation is particularly reduced and wind blows very energetically during the cold period, demonstrate that permafrost can exist even at relatively low altitudes (*ca.* 2400 m a.s.l.) in particular morphologic conditions. This emphasizes the fact that micro-climatic conditions are instrumental in the energy balance of the ground, and therefore in the presence of permafrost.

KEY WORDS: Climatic conditions, Microclimate, Permafrost, Maiella Massif, Central Italy.

**RIASSUNTO:** BISCI C., DRAMIS F., FAZZINI M. & GUGLIELMIN M., *Condizioni climatiche e permafrost sporadico nel massiccio della Maiella (Appennino centrale, Italia).* (IT ISSN 0391-9838, 2003).

Sono stati esaminati i dati climatici relativi ad una decina di stazioni meteorologiche per verificare la presenza di condizioni favorevoli alla conservazione di *permafrost* montano sporadico nel massiccio della Maiella (Appennino centrale, Italia).

I dati analizzati sono relativi al periodo 1965-1990 e riguardano stazioni situate ad altitudini comprese tra il livello del mare (Pescara) ed oltre 2100 m (Campo Imperatore, Gran Sasso d'Italia).

Sugli altipiani più elevati, le temperature medie annue si aggirano intorno ai 6-7 °C; le medie stagionali vanno dai −4 °C dell'inverno ai 12 °C dell'estate. I gradienti temici medi variano invece tra gli 0.4 °C/100 m di gennaio e gli 0.7 °C/100 m di luglio, con una media annua di 0,57 °C/100 m. Secondo questi dati, si ricava che, nel gruppo della Maiella, la quota dello zero termico annuo nella libera atmosfera si aggira intorno ai 2500 m circa, mentre l'isoterma annua di −2 °C, utilizzabile come limite climatico inferiore per la presenza di *permafrost*, dovrebbe in media essere localizzata poco sopra i 2750 m s.l.m.

Il regime meteorico mostra caratteri generalmente sub-mediterranei, sempre più netti procedendo dal versante adriatico verso quello tirrenico, con un massimo tardo autunnale o invernale ed un minimo estivo cui, a luoghi, si associa un secondo massimo tardo-primaverile. I valori annui delle precipitazioni variano intorno ai 1200-1400 mm, tanto negli altopiani quanto sulle vette principali.

Le precipitazioni nevose sono abbondanti specie sui versanti orientali dei rilievi, a causa della diretta esposizione alle fredde correnti balcanico-danubiane. In media, alla quota di 1000 metri cadono dai 150 ai 200 cm di neve, che permane al suolo per circa 70 giorni, nel periodo novembre-aprile, mentre intorno ai 2000 m (Campo Imperatore) tali valori salgono a 400 cm e 180-200 giorni di persistenza, concentrati tra fine ottobre e fine maggio.

Dall'analisi della suddetta situazione, si può concludere che il quadro climatico generale consentirebbe la presenza di *permafrost* anche a quote relativamente basse (intorno ai 2400 m), evidenziando quindi come le condizioni microclimatiche locali siano detrminanti per il bilancio energetico del suolo e per la relativa presenza di *permafrost*.

TERMINI CHIAVE: Condizioni climatiche, Microclima, Permafrost, Massiccio della Maiella, Italia Centrale.

(*) *Dipartimento di Scienze della Terra, Università di Camerino.*
(**) *Dipartimento di Scienze Geologiche, Università "Roma Tre".*

## FOREWORD

This research starts from the finding in the Maiella Massif (Central Apennines, Italy), and particularly in the Upper Cannella Valley, of landforms which are characteristic of permafrost areas (Dramis & Kotarba, 1992). Among those, particularly interesting are some rock glaciers, and especially the one located at an altitude of *ca.* 2600 m a.s.l., which on the basis of its geomorphologic features (steep front, noteworthy inflation, irregular pattern, etc.) seems to have not been inactivated by the climatic amelioration characterizing the last period (Dramis & Kotarba, 1992, 1994).

With these information in mind and taking into account the relevance of climatic parameters in the study of permafrost distribution (Cheng Guodong & Dramis, 1992), systematic climatic analyses of the main mountain groups in the Central Apennines (Sibillini Mts., Laga Mts., Gran Sasso, Maiella and Velino massifs) were started, in order to determine the areal distribution of conditions favoring permafrost conservation.

This paper reports the first results of researches carried out on the Maiella Massif (and, namely, in the Upper Cannella Valley), giving a preliminary illustration of climatic conditions and thus furnishing indications on the chances of permafrost conservation at high altitudes. Measurements of bottom temperature of the winter snow cover (BTS), carried out on some of the rock glaciers recognized there, gave further confirmation of the possible presence of patches of sporadic permafrost. This should be the southernmost ever discovered in Europe (latitude slightly higher than 42° N).

## THE MAIELLA MASSIF

The Maiella Massif is located in the Central Apennines, some 35-40 km from the Adriatic shoreline, just to the north of the 42° parallel (fig. 1). It reaches its maximum altitude at Mt. Amaro (2793 m a.s.l.) and appears as a wide and slightly undulated summit surface having an average elevation of *ca.* 2500 m a.s.l., with many minor reliefs showing relatively gentle morphology.

The landscape is modelled over Paleogene limestone, folded following a wide-radius anticline and densely dissected by faults. The bedrock is strongly karstified; as a consequence, streams are extremely rare, springs are lacking and vegetation cover is very poor. Generally, south-facing valley slopes are less steep than north-facing ones, the latter being often characterized by the presence of scarps and rockwalls. Moraine deposits, produced during the cold Würm phases, are scarce, whilst much more abundant are coarse-grained slope deposits.

Notwithstanding the relatively high precipitation, because of the high permeability of the bedrock this environment is typical of a cold mountain desert (Whitehead, 1951), as clearly testified by the almost total lack of vegetation. This favors debris production by cryoclastic processes, gravitational movements, avalanches and eolian deflation.

## CLIMATIC FEATURES OF THE MAIELLA MASSIF

The climate of the Maiella Massif depends, among other things, on some major geographic factors, such as latitude, elevation, aspect and distance from the sea.

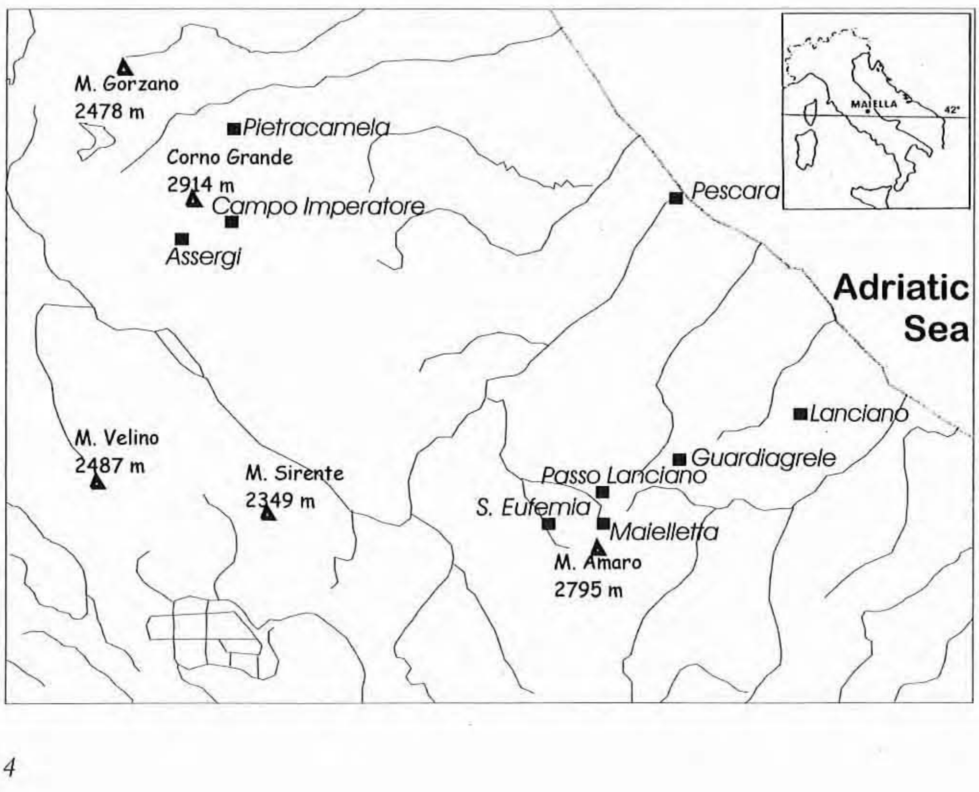



FIG. 1 - Location of the study area, depicted through the use of a shadow relief map following the UTM32 projection. Black squares indicate weather recording stations, whilst triangles indicate major peaks.

The rather low latitude (slightly higher than 42° N; *i.e.* more or less the same as Rome) suggests that Mediterranean influences should be relevant, both for temperature and precipitation. Anyhow, it has to be taken into account that the Adriatic side of the Italian peninsula has a more continental climate than the Tyrrhenian side. This implies colder winters, slightly warmer summers and precipitation which is less and with reduced seasonal differences (Bisci & *alii*, 2001; in press).

Altitude plays an opposite role, so much moderating the Mediterranean features that locally average winter temperatures are similar to those recorded along the Italian Alps at the same elevation.

Aspect locally contributes to make climatic conditions even more severe. Along north- and east-facing slopes, which are more exposed to cold continental wind, microclimates may be present that allow the activity of phenomena that are uncommon at such latitudes. In the neighbour Gran Sasso Massif, this is clearly testified by the presence of the small debris-covered Calderone glacier (Smiraglia & Veggetti, 1992).

For the climatic analyses, thermal, pluviometric and nivometric data from 8 sites (Servizio Idrografico, 1965-1990) referring to the time-span 1965-1990 were taken into account (tab. 1); 5 weather stations were selected in such a way to be more or less aligned perpendicularly to the mountain belt, *i.e.* about ENE-WSW (fig. 1). The recording station of Pescara was added to have information on the climate at sea level. Data recorded in the neighboring Gran Sasso area were taken into account too, given to the lack of stations located at more than 1500 m a.s.l. This second massif trends *ca.* E-W and is located *ca.* 40 km to the north of the Maiella Massif, at a comparable distance from the sea. There, the Campo Imperatore recording station, which was the highest in Central Apennines (2124 m a.s.l.), was active (up to 1987) at the north-western end of the homonymous valley.

The thermal records (tab. 2) show that in the area annual average temperatures vary from 15.0 °C at low altitude (Pescara, 2 m a.s.l.) to 8.3 °C at intermediate altitude (Passo Lanciano, 1470 m); in the Gran Sasso Massif, this value decreases to 3.2 °C (Campo Imperatore, 2124 m). In January, at the above stations, average temperatures respectively are, respectively, 6.3 °C, 0.5 °C and –3.6 °C, whilst in July their value are, respectively, 23.4 °C, 16.9 °C and 11.1 °C.

TABLE 1 - Geographic features of the investigated meteorological stations

| Site | Latitude | Longitude | Elevation (m) | Aspect |
|---|---|---|---|---|
| Pescara | 42° 28' 11" N | 14° 13' 49" E | 2 | Slope NE |
| Lanciano | 42° 13' 35" N | 14° 23' 15" E | 283 | Ridge |
| Guardiagrele | 42° 11' 25" N | 14° 12' 50" E | 577 | Summit |
| S. Eufemia | 42° 08' 25" N | 14° 01' 30" E | 872 | Slope WSW |
| Passo Lanciano | 42° 12' 05" N | 14° 06' 20" E | 1470 | Slope E |
| Campo Imperatore | 42° 26' 25" N | 13° 33' 25" E | 2135 | Highland SE |
| Pietracamela | 42° 31' 05" N | 13° 32' 45" E | 1000 | Slope NE |
| Assergi-Funivia | 42° 25' 25" N | 13° 31' 30" E | 1040 | Slope SW |

Therefore, conditions vary (tab. 2) from a humid subtropical climate (Cfa, following Köppen & Geiger, 1930), along the coastline and in the hilly area, to that of a marine west coast one (Cfb-Cfc), at intermediate altitudes; then, over 1800 m, we have first a humid continental climate with warm summers (Dfb) and then a continental subarctic humid microthermal one (Dfc).

A more detailed analysis demonstrates that in the Maiella Massif the influence of the Adriatic Sea is weak. This is more evident in summer, when even at intermediate altitudes average temperatures are quite high; in fact, only over 700 m a.s.l. does the climate become of the Cfb type. Anyhow, at *ca.* 2000 m of altitude, maximum values are always moderate, seldom exceeding 25 °C (when African anti-cyclones are present).

During winter, mostly along eastern slopes, Arctic or continental Russian masses lower the temperature to values that, in the Mediterranean basin, are unparalleled at those latitudes. In sites particularly exposed to those cold winds, at altitudes of 1000 m every year the temperature decreases to –10 °C and at *ca.* 2000 m cold is particularly severe: in Campo Imperatore, –23 °C were recorded and almost every year temperatures decrease to *ca.* –20 °C.

Moreover, during the cold semester, thermal inversions in anti-cyclonic conditions frequently occur, in the inner basins, in the high plateaux and in the glacial cirques close to the highest peaks. As a consequence, the above reported values can locally be even lower and particularly severe conditions can persist for several days. This, where the

TABLE 2 - Average temperatures and climatic types (Köppen & Geiger, 1930 and following) in the three studied stations

| Site | January | | | | July | | | | Year | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average of | | | Thermal | Average of | | | Thermal | Average of | | | Thermal | Annual | Climatic |
| | max | min | ave | Amplitude | max | min | ave | Amplitude | max | min | ave | Amplitude | excursion | type |
| Pescara | 10.2 | 2.7 | 6.3 | 7.5 | 28.2 | 18.6 | 23.4 | 9.6 | 19.5 | 10.5 | 15 | 9 | 18.1 | Csa |
| Lanciano | 9.5 | 3.3 | 6.4 | 6.2 | 28.5 | 18.3 | 23.4 | 10.2 | 18.9 | 10.4 | 14.6 | 8.5 | 17.0 | Cfa |
| Guardiagrele | 7.2 | 2.7 | 5 | 4.5 | 26.7 | 18.6 | 22.7 | 8.1 | 16.7 | 10.4 | 13.6 | 6.3 | 17.7 | Cfa |
| S. Eufemia | 6.3 | –0.6 | 2.9 | 6.9 | 25.7 | 13.6 | 19.6 | 12.1 | 15.6 | 6.3 | 11 | 9.3 | 16.7 | Cfb |
| Pietracamela | 6.7 | –0.2 | 3.4 | 8.9 | 24.8 | 15.1 | 19.9 | 9.7 | 15.2 | 7.1 | 11.2 | 8.1 | 16.6 | Cfb |
| Assergi | 5.4 | –1.9 | 1.8 | 7.3 | 24.9 | 12.6 | 18.8 | 12.3 | 14.7 | 5.4 | 10.1 | 9.3 | 20.6 | Cfb |
| Passo Lanciano | 3.8 | –2.8 | 0.5 | 6.6 | 22.2 | 11.5 | 16.9 | 10.7 | 12.5 | 4.1 | 8.3 | 8.2 | 17.4 | Cfc |
| Campo Imperatore | –1.2 | –5.8 | –3.5 | 4.6 | 13.9 | 8.3 | 11.1 | 5.6 | 5.7 | 0.8 | 3.2 | 4.9 | 14.6 | Dwb |

snow cover is thin or absent, causes a further considerable cooling of soil.

Also annual thermal amplitudes testify to an almost sub-continental climate, ranging from 17 °C to 20 °C (in Rome we have 14 °C). Diurnal amplitudes are obviously higher in the inner basins and along the valleys (S. Eufemia, 12.1 °C) than on the mountains (Campo Imperatore, 6.4 °C ). During winter, anyhow, the situation is inverted: this is probably due to the above mentioned thermal inversion phenomena, which during the day maintain the temperature low in the valleys and on the plateaux.

An average annual vertical thermal gradient of 0.59 °C/100 m (tab. 3) has been calculated using a linear interpolation (fig. 2) that obtained a very good statistical score ($R^2$ = 0.967). Following this interpolation, the 0 °C and –2 °C isotherms, instrumental for the analysis of permafrost distribution, are located slightly over 2800 and slightly below 3200 m a.s.l., respectively. Since in the Central Apennines the thermal gradient often increases a little at higher altitudes (Bisci & *alii*, 1989; Fazzini, 1997), a second order interpolating curve has been calculated (fig. 2); the optimal score obtained ($R^2$ = 0.988) supports this hypothesis. Using this interpolation, the above mentioned isotherms are located at considerably lower altitudes: *ca.* 2500 and slightly over 2750 m, respectively.

Moreover, thermal gradients (tab. 3 and fig. 2), which are similar along both sides of the massif, are higher in summer (0.6) than in winter (0.48). This emphasizes the dominance of the Adriatic influence on western slopes too, which are not exposed to the coldest winds.

For the Gran Sasso Massif, the 0 °C has already been calculated to be located some 200 m below the highest peak (Corno Grande, 2914 m a.s.l.), where an average annual temperature of *ca.* –1.6 °C has been hypothesized (Fazzini & *alii*, 1999). This value is slightly lower than those calculated by both Klebelsberg, for the time-span

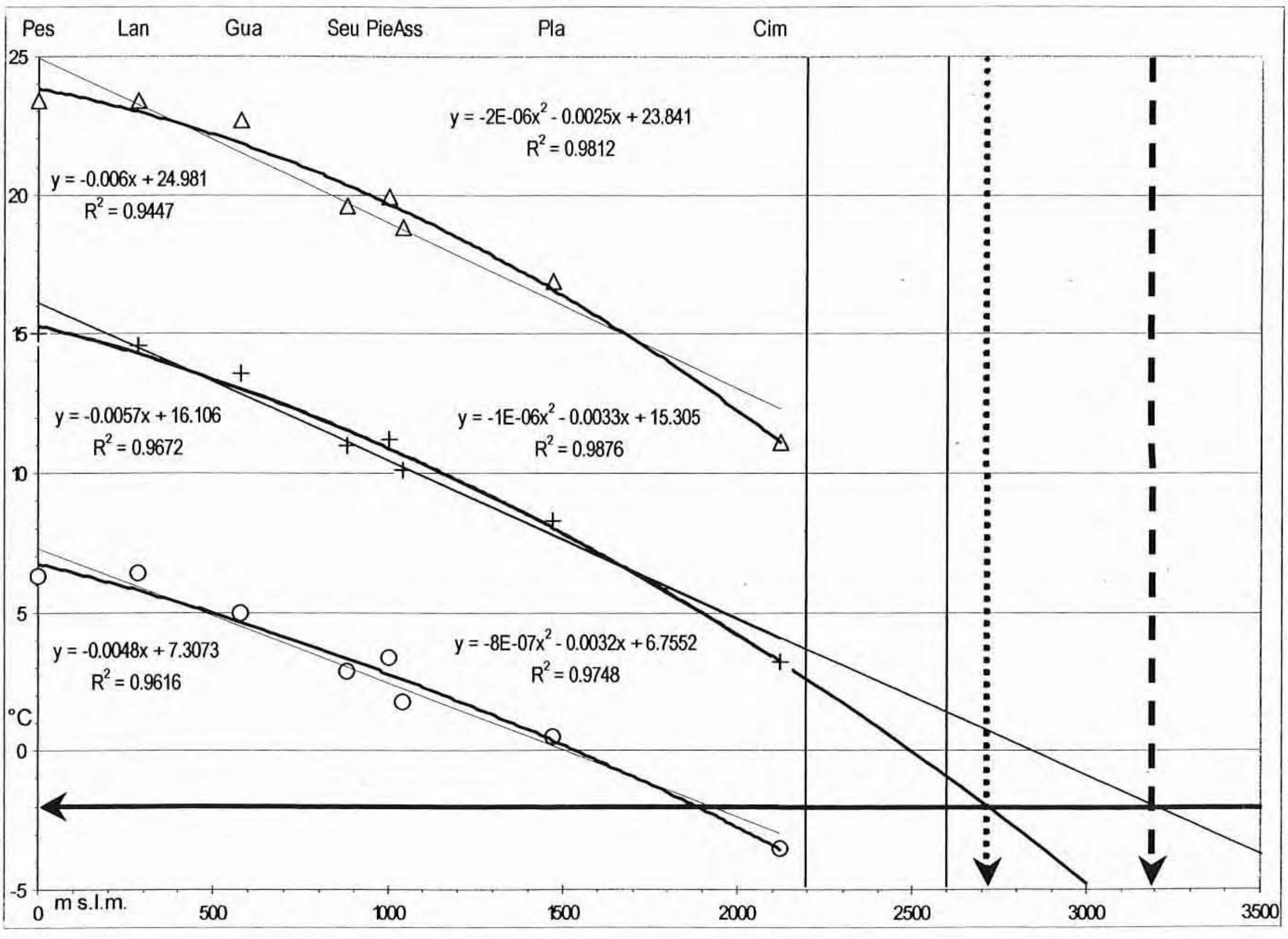



FIG. 2 - Altitude/Temperature ratios in the study area. The three graphs represent the average temperatures, from top to bottom, respectively of July (triangles), of the year (crosses) and of January (circles). The top line indicates the elevation of the eight stations (Pes = Pescara, Lan = Lanciano, Gua = Guardiagrele, Seu = S. Eufemia, Pie = Pietracamela, Ass = Assergi, Pla = P. Lanciano, Cim = Campo Imperatore). The formulas and $R^2$ values listed on the left refer to linear interpolations (thin line), whilst the ones to the right refer to polynomial ($2^{nd}$ order) interpolation (thick line).

TABLE 3 - Thermal gradients in the Maiella and Gran Sasso massifs (* = extrapolated data): 0 °C isotherm = 2754 m a.s.l.; –1 °C isotherm = 2925 m; –2 °C isotherm = 3084 m

| Site | Elevation | Average temperature Year | Jan | July | Δ h | Thermal gradients Year | Jan | July |
|---|---|---|---|---|---|---|---|---|
| Pescara | 2 | 15.2 | 7.4 | 22.8 | | | | |
| Lanciano | 283 | 15.3 | 6.2 | 23.4 | | | | |
| Guardiagrele | 577 | 13.6 | 5 | 22.7 | 294 | 0.37 | 0.5 | 0.39 |
| S.Eufemia | 878 | 11 | 2.9 | 19.6 | 301 | 0.58 | 0.48 | 0.48 |
| Pietracamela | 1000 | 11.2 | 3.4 | 20 | 122 | 0.66 | 0.62 | 0.74 |
| Assergi | 1040 | 10.1 | 1.8 | 18.8 | | | | |
| Passo Lanciano | 1470 | 7.8 | –0.5 | 16.9 | 430 | 0.59 | 0.60 | 0.5 |
| Campo Imperatore | 2139 | 3.2 | –3.5 | 11.1 | 669 | 0.62 | 0.42 | 0.53 |
| Monte Amaro* | 2793 | –0.1 | –7.4 | 10.3 | 654 | | | |
| Corno Grande* | 2912 | –1.6 | –8.4 | 5.7 | 119 | | | |

1930-1950, and Ortolani, 1940-1956 (both in Demangeot, 1965).

The Adriatic side of Italy is known to be dryer than the Tyrrhenian side (Bisci & *alii*, 2001; in press): this is evident also analyzing the precipitations in the study area. There, major events generally derive, during intermediate seasons, from Sirocco or western winds and, during winter, from north-eastern winds. The latter, the most humid period coinciding with the cold semester, often produce heavy snowfalls both on the mountains and along the plains.

The dominant precipitation regime is of sub-Apenninic Adriatic type (Fazzini, 1997), with a late-autumn maximum (progressively tending to shift to winter one moving southwards), sometimes a secondary maximum in spring, and a not very marked minimum in July.

Moving mountainwards, meteoric regimes progressively become more continental; in parallel, summer orographic-convective and advective precipitation increases (mostly during the second half of August), while it decreases in January, maybe because of the expansion toward the mid-Adriatic of the Russian anticyclone, which often brings low and stratified clouds that do not affect the higher reliefs. The above situation is confirmed by the data recorded in Campo Imperatore, where a secondary maximum in summer and a secondary minimum in winter are present.

Total precipitation generally ranges from 600-700 mm, along the coast and the plains, to 1000-1200 mm, in the mountain area. Examining its distribution (tab. 4), it is evident that no direct relation exists with altitude (fig. 3), in analogy with the Alpine situation; this feature has already been verified for contiguous areas (Bisci & *alii*, 1997; Fazzini, 1997; Bisci & *alii*, 2001). In fact, annual precipitation is higher in sites located upwind of the first-quadrant currents (such as the Orta Valley), or not completely downwind of the very humid third-quadrant ones, than on the surrounding mountains. As a consequence, the $R^2$ of the linear regression for the precipitation/altitude ratio (Fig. 3) is very low (0.54). However, the data distribution shows the presence of a pluviometric *optimum* at altitudes ranging around 1500 m a.s.l.; this is well described by the second-order interpolating curve, which obtains an acceptable statistical score ($R^2$ = 0.77). The above considerations allow us to hypothesize that precipitation does not exceed

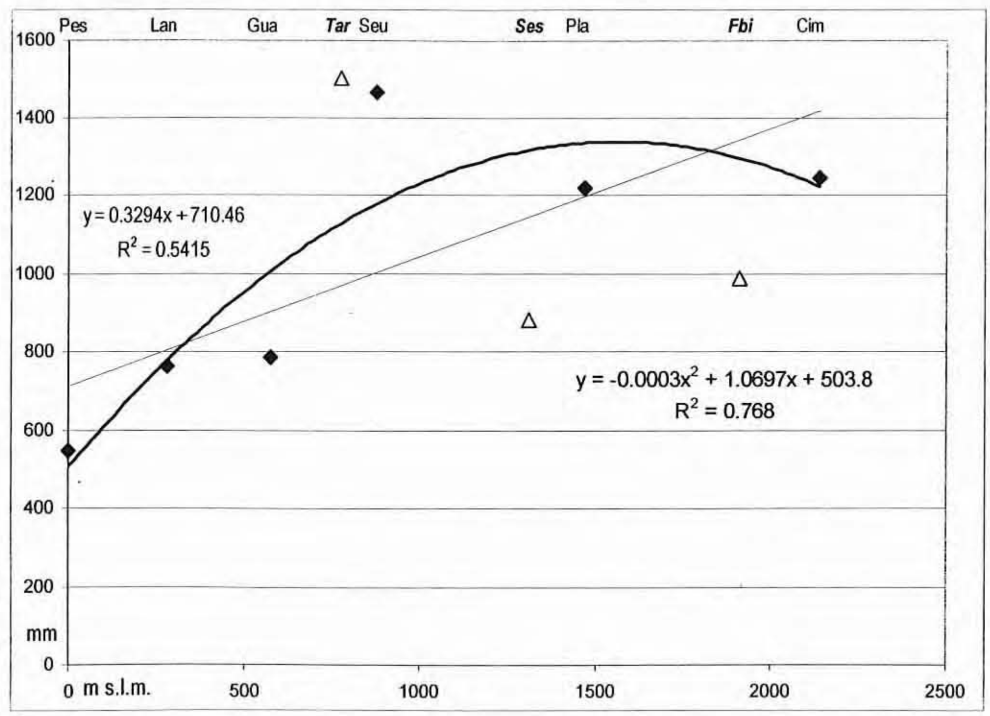



FIG. 3 - Precipitation/Elevation ratio. The top line indicates the elevation of the stations (in bold italics are reported some stations located in the eastern Alps, for purposes of comparison): Pes = Pescara, Lan = Lanciano, Gua = Guardiagrele, ***Tar*** = Tarvisio (UD), Seu = S. Eufemia, ***Ses*** = Sesto (BZ), Pla = P. Lanciano, ***Fbi*** = Fontana Bianca (BZ), Cim = C. Imperatore. The formula and $R^2$ value listed on the left refer to linear interpolation (thin line), whilst those to the right refer to polynomial (3[rd] order) interpolation (thick line).

TABLE 4 - Mean precipitation in the investigated stations, also in comparison with sites located in the eastern Alps at comparable altitude. Max 1 and max 2 indicate the season of primary and secondary maxima, whilst min 1 and min 2 indicate the season of primary and secondary minima

| Site | Elevation | mm | days | max 1 | max 2 | min 1 | min 2 |
|---|---|---|---|---|---|---|---|
| Pescara | 2 | 545 | 65 | Aut | | Sum | |
| Lanciano | 283 | 765 | 84 | Win | | Sum | |
| Guardiagrele | 577 | 787 | 88 | Win | | Sum | |
| S. Eufemia | 878 | 1466 | 113 | Aut | | Sum | |
| Passo Lanciano | 1470 | 1219 | 103 | Aut | Win | Sum | Spr |
| Campo Imperatore | 2139 | 1243 | 104 | Aut | Sum | Spr | Win |
| Tarvisio (UD) | 775 | 1501 | 136 | Sum | Aut | Win | |
| Sesto (BZ) | 1310 | 882 | 88 | Sum | | Win | |
| Fontana Bianca (BZ) | 1910 | 986 | 89 | Spr | Aut | Win | Sum |

1200-1300 mm close to the mountain tops (a rather low value, bearing in mind the orography).

Moreover, detailed statistical analyses for the mid-Adriatic side of Italy (carried out at more than 200 stations, taking into account the influence of more than 40 morphologic, morphometric and topographic variables, too) revealed that local precipitation depends primarily on the distance from the main mountain ridge and secondarily on the elevation of both the main divide and the slope located mountainward from the station (Bisci & *alii*, 1997; Fazzini, 1997; Bisci & *alii*, 2001). Summing up, the areal distribution of precipitation is rather irregular: its partial correlation with altitude may derive from the quite regular increase of relief in parallel with the distance from the coast.

The annual number of days of frost ranges from 5-10 along the coast, to 30-40 in the hilly area, to 60-70 at about 1000 m a.s.l., up to *ca.* 210 at Campo Imperatore: at the altitude of the Upper Cannella Valley, extrapolating the 2nd order spline this value ranges between 221 and 309 (fig. 4). Days of ice are significantly fewer in the mountains too (*ca.* 35 at Campo Imperatore, around 70 on the peaks). Therefore, it is logical to hypothesize that, mostly in spring, temperatures often oscillate daily around 0 °C. This determines a fast compaction of snow along the slopes but, on the other hand, also contributes to the formation of thaw-and-freeze crusts that could act as sliding surfaces for avalanches.

As previously said, due to a coincidence of dynamic and thermal meteorological factors, snowfalls are abundant over 1000 m a.s.l.: in fact, local values are similar to those recorded along the Italian eastern Alps at similar altitudes (tab. 5), with the exception of Tarvisio. On the other hand, the temporal distributions of snowfalls are different in the Alps and in the study area, since high-altitude Apennine stations show a maximum in January and February, whilst along the Alps the same period is rather dry and the maximum is recorded in spring.

However, examining the Campo Imperatore records (fig. 5), it is possible to recognize that at high elevations the nivometric regime becomes more similar to the Alpine one, showing a secondary maximum in April. Spring snow, generally brought by continental cold fronts, assumes «winter» features, having a not very high density and a low content of water. As a consequence, the duration of snow cover increases more rapidly at higher altitudes (fig. 6), arriving at more than 250 days a year in sites protected from solar radiation.

Moreover, because of the relevant daily thermal excursion, during spring, snowfalls are rather frequent (Fazzini

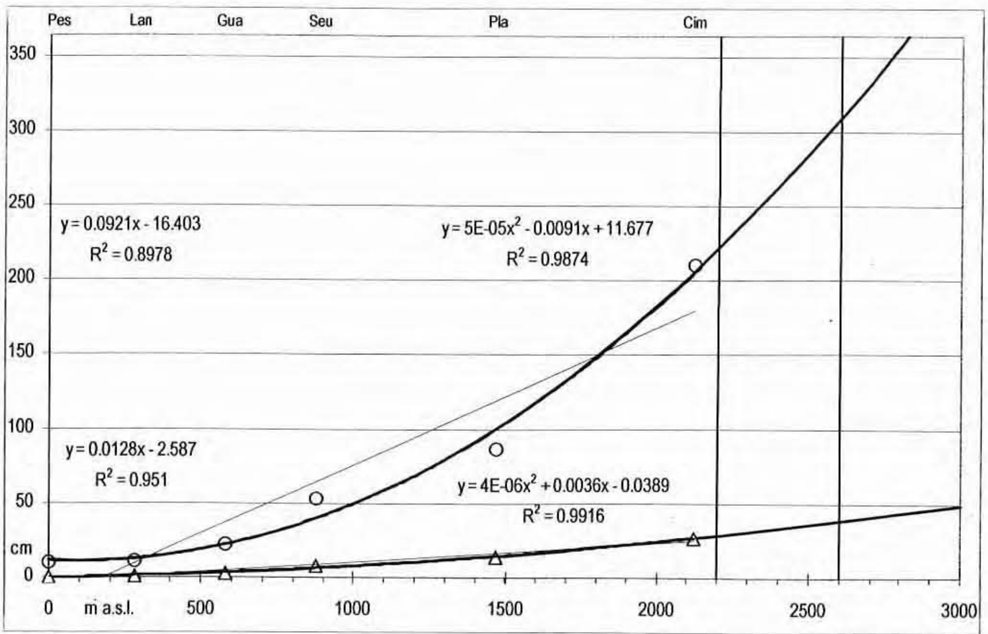



FIG. 4 - Days of frost (circles) and days of ice (triangles) in the study area. The top line indicates the elevation of the eight stations (Pes = Pescara, Lan = Lanciano, Gua = Guardiagrele, Seu = S. Eufemia, Pie = Pietracamela, Ass = Assergi, Pla = P. Lanciano, Cim = Campo Imperatore). The formulas and $R^2$ values listed on the left refer to linear interpolations (thin line), whilst the ones to the right refer to polynomial (2nd order) interpolation (thick line); those referring to days of frost are located above the ones regarding the days of ice. The two thin vertical lines show the range of altitudes of the Upper Cannella Valley.

TABLE 5 - Fresh snow fall (in cm), days of snow cover, nivometric coefficients (n.c. %) and precipitation (in mm) in the investigated stations, also in comparison with some sites located in the eastern Alps at comparable altitude

| Site | Elevation | Jan | Feb | Mar | Apr | May | Sep | Oct | Nov | Dec | Year | cover | niv c. % | precipitation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pescara | 2 | 4 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 11 | 5 | 2.0 | 545 |
| Lanciano | 283 | 3 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 4 | 16 | 7 | 2.0 | 765 |
| Guardiagrele | 577 | 2 | 6 | 0.5 | 0 | 0 | 0 | 0 | 10 | 21 | 39.5 | 10.5 | 5.0 | 787 |
| S.Eufemia | 878 | 76 | 67 | 47 | 25 | 1 | 0 | 3 | 34 | 58 | 311 | 62 | 21.2 | 1466 |
| Passo Lanciano | 1470 | 78 | 30 | 37 | 7 | 3 | 0 | 0 | 31 | 33 | 219 | 90 | 18.0 | 1219 |
| Campo Imperatore | 2139 | 106 | 53 | 40 | 73 | 11 | 4 | 37 | 56 | 69 | 449 | 197 | 38.2 | 1243 |
| Tarvisio (UD) | 775 | 120 | 131 | 48 | 35 | 0 | 0 | 0 | 0 | 72 | 406 | 95 | 27.0 | 1501 |
| Sesto (BZ) | 1310 | 28 | 45 | 29 | 18 | 4 | 0 | 8 | 33 | 38 | 203 | 141.2 | 23.0 | 882 |
| Fontana Bianca (BZ) | 1910 | 75 | 76 | 74 | 110 | 23 | 0 | 27 | 77 | 73 | 535 | 180.8 | 54.3 | 986 |

& *alii*, 1999), which locally increase the thickness of snow cover thus allowing a good thermal insulation of the soil.

The overall effect of the above situation is that, at high altitudes, the thickness of snow cover is generally higher during spring than during winter. This implies that the soil can be effectively cooled during the colder months whilst it is well protected from solar radiation and external thermal exchanges when the air temperature increases.

In the mountain area, the wind contributes to lowering the temperature of the air. In fact, data recorded along the Adriatic coast (at Pescara and Termoli) by Aeronautica Militare - Servizio Meteorologico (1999) and, most of all, at the base of Mt. Maiellletta (at Guardiagrele) by Corpo Forestale dello Stato - Comando di Guardiagrele (pers. comm.) show that stormy weather is frequent, mostly at higher altitudes. During winter, along the coast, winds mostly blow from N or NW, whilst in the remaining seasons they mostly come from the first quadrant. The high-altitude (1650 m a.s.l.) recording station, which is active exclusively from December to April, indicates that wind mainly comes from either N or NE, with an average speed of *ca.* 20 km/h and a mean temperature of about –3.5 °C (data referring to the period 1995-1999). Climate obviously is even more severe at higher altitudes: this implies soil cooling at temperatures below 0 °C for many months.

Moreover, in valleys exposed to the wind the snow cover (generally quite dry during the cold period) is effectively remodelled by deflation that in this way causes local variations of thermal insulation.

## THE UPPER CANNELLA VALLEY

The Upper Cannella Valley (fig. 7) has an average altitude of *ca.* 2400 m. In its higher portion it trends *ca.* NW-SE and is surrounded by a high mountain range culminat-

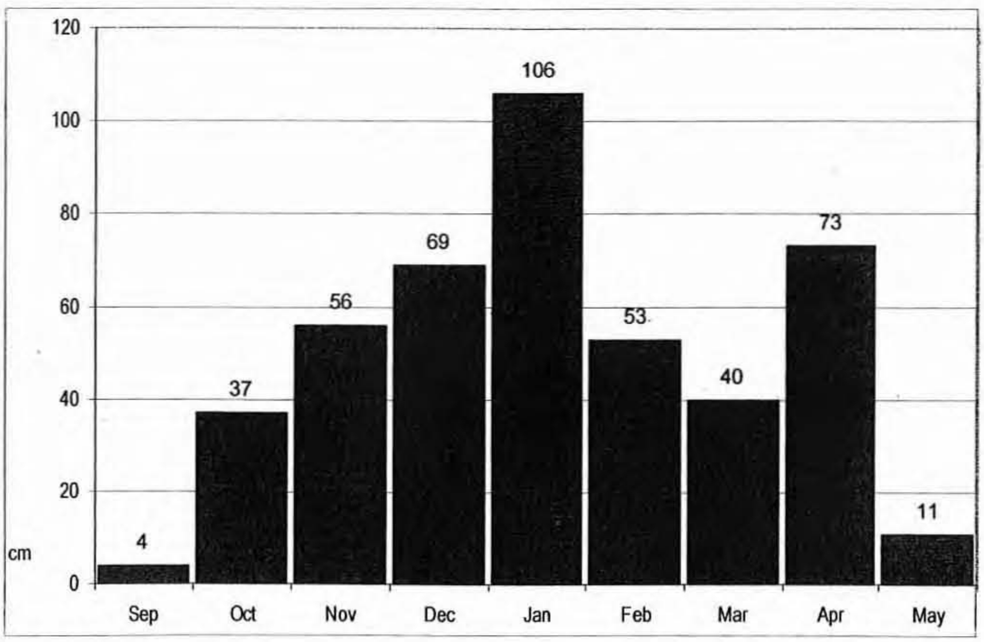



FIG. 5 - Average height of fresh snow (cm) at Campo Imperatore (2150 m a.s.l., Gran Sasso Massif).

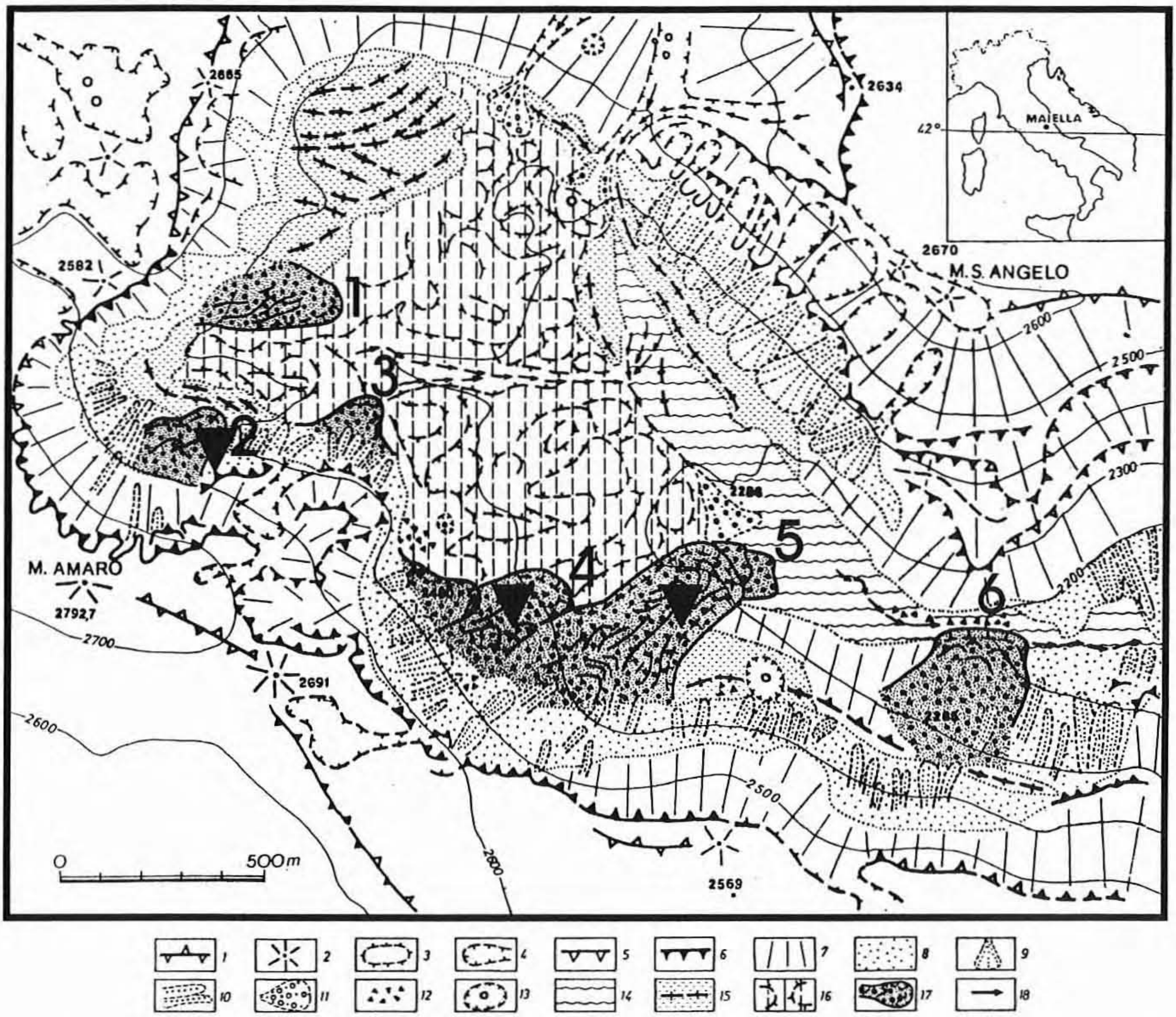



FIG. 6 - Geomorphologic sketch of the Upper Cannella Valley (slightly modified from Dramis & Kotarba, 1992). Legend: 1) rounded ridge; 2) dome-like summit; 3) broad, gentle relief limited by progressive change of slope; 4) broad, shallow valley or gully carved into bedrock; 5) distinct rock scarp; 6) rockwall; 7) debris-mantled slope or rocky slope; 8) talus sheet; 9) talus cone; 10) debris stream; 11) alluvial cone; 12) boulder sheet; 13) karstic sink-hole; 14) hummocky drift; 15) lateral moraine ridge; 16) bedrock topography along valley bottom; 17) rock glacier; 18) erosion furrow and meltwater channel.

ing in Mt. Amaro (2793 m a.s.l.) to the SW, Mt. Acquaviva (2758 m) to the north and Mt. Sant'Angelo (2670 m) to the north-east. Successively, it bends opening to the east. This orographic condition protects the area from the warmer southern and western winds, but leaves it exposed to the colder first-quadrant currents that are channelled through the mid reach of the valley.

The valley head, which derives form the remodelling of an ancient glacier cirque, is bordered both to the west and to the south by scarps and rockwalls producing wide shadow belts during summer, too. In this way, warming by direct solar radiation is dramatically reduced along the north- and east-facing slopes, where permafrost could have been conserved for longer periods (Abbey & *alii*, 1978; Hoelzle, 1992).

The calcareous bedrock is strongly karstified, thus allowing fast and deep infiltration of rainfall and meltwater that as a consequence only moderately contribute to the surface thermal balance. Moreover, this reduces capillary rising of water in the snow cover, which can therefore persist and maintain its density and temperature for longer time. This situation is responsible for the annual persistence of small

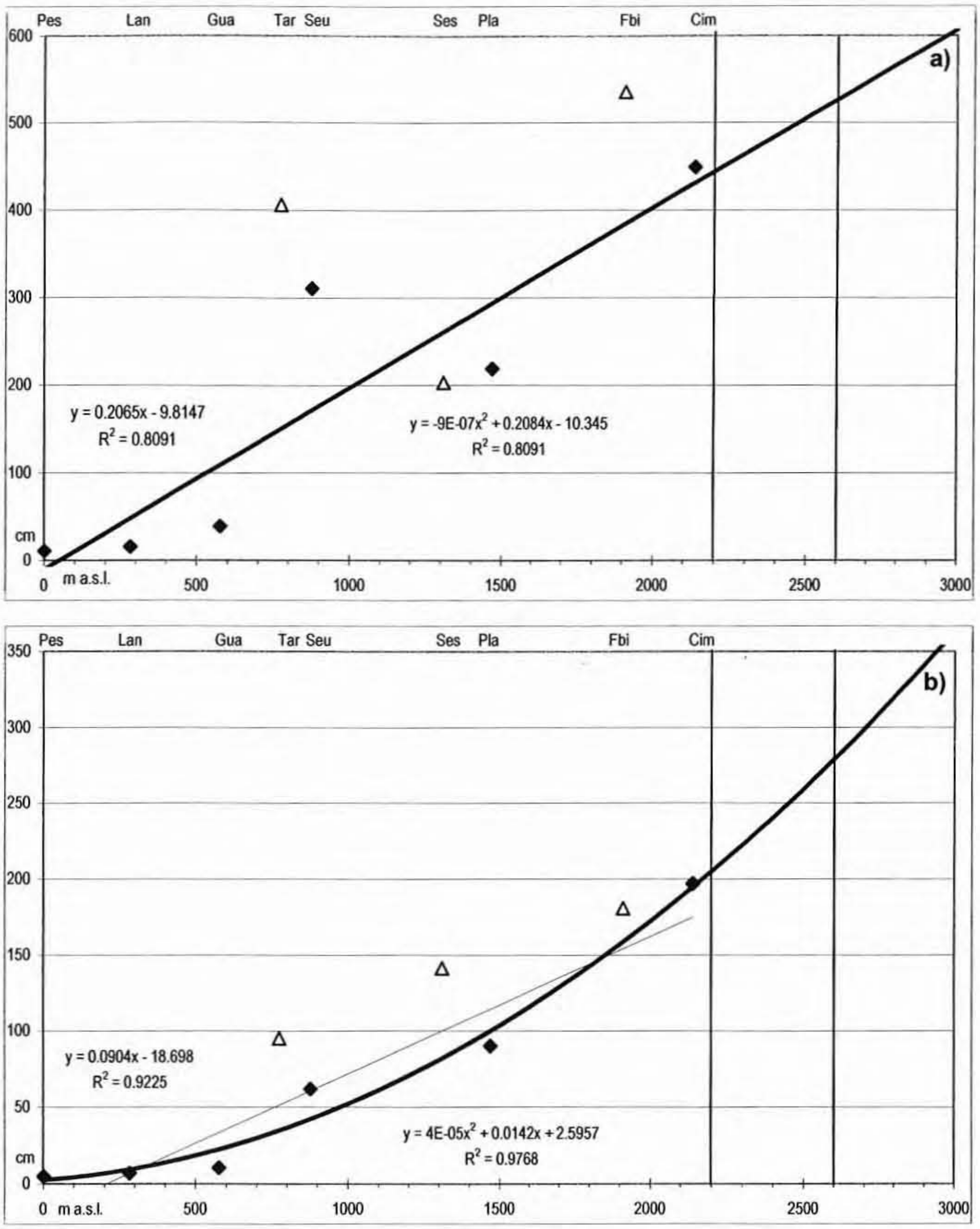



FIG. 7 - Relation between altitude and thickness of fresh snow in cm (a), and between altitude and number of days with snow cover (b). The top lines indicate the elevation of the stations (in bold italics are reported some stations located in the eastern Alps, added for purposes of comparison): Pes = Pescara, Lan = Lanciano, Gua = Guardiagrele, ***Tar*** = Tarvisio (UD), Seu = S. Eufemia, ***Ses*** = Sesto (BZ), Pla = P. Lanciano, ***Fbi*** = Fontana Bianca (BZ), Cim = Campo Imperatore. The formulas and $R^2$ values listed on the left refer to linear interpolation (thin line), whilst those to the right refer to polynomial (3rd order) interpolation (thick line). In fig. 5a, the two lines practically coincide. The two thin vertical lines show the range of altitudes of the Upper Cannella Valley.

snow patches in both doline bottoms and north-facing niches, starting at altitudes as low as 2600 m, a phenomenon contributing to the hypothesis regarding the presence of conditions which are locally favorable for conservation of sporadic permafrost (Dramis & Kotarba, 1992, 1994).

In the area, six rock glaciers, which are of the valley type, following Outcalt & Benedict (1965), have been recognized, covering altogether nearly 40 ha (Dramis & Kotarba, 1994). Among those, only one faces to the east and is located close to the valley head, along its western scarp, while the other five are aligned along its southern slope and have a NE-NNE attitude (fig. 7). Their origin seem to be most likely connected with rockfalls and rockslides affecting the scarp («talus rock glacier», following Barsch, 1987) than with reworking of moraine material (Dramis & Kotarba, 1992, 1994). Their areal extension varies from a minimum of *ca.* 18,000 $m^2$ to a maximum of more than 191,000 $m^2$, whilst their length ranges between 110 and 835 m: this allows them to be ascribed to the medium size ones (Corte, 1987). The altitude of their head ranges between 2632 and 2300 m, while that of their toes varies from 2539 to 2180 m (tab. 6).

TABLE 6 - Main features of the Upper Cannella Valley rock glaciers; numbers refer to fig. 6 (slightly modified from Dramis & Kotarba, 1994)

| Rock glacier # | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Head elevation (m a.s.l.) | 2,510 | 2,632 | 2,470 | 2,520 | 2,445 | 2,300 |
| Toe elevation (m a.s.l.) | 2,450 | 2,539 | 2,430 | 2,479 | 2,272 | 3,180 |
| Overall length (m) | 320 | 200 | 120 | 320 | 835 | 220 |
| Average width (m) | 160 | 200 | 110 | 150 | 236 | 270 |
| Surface area ($m^2$) | 42,500 | 28,700 | 18,300 | 21,260 | 191,340 | 93,500 |
| Front slope (°) | n.d. | 40 | n.d. | 20 | 28 | n.d. |

Only the mid-low portion of the higher rock glacier (n. 2 in fig. 7 and tab. 6) is almost lichen free and shows both fresh breaks in the surface and «porridge-like» appearance, which may testify to its present activity. To obtain further clues regarding the presence of patches of sporadic permafrost, a campaign of measurements of bottom temperature of winter snow cover (BTS) was carried out in the area. This method was introduced in the '70s (Haeberli, 1973) based on the hypothesis that, where the snow cover is long lasting and thick enough to insulate the soil from thermal exchanges with the atmosphere, the temperature of the Earth surface directly depends upon underground temperature. When permafrost or buried glacial bodies are present close to the topographic surface the measured temperature is well below 0 °C, otherwise it is close to 0 °C, since the excessive heat is used for snow melting (Haeberli, 1985). It has been empirically stated that BTS values lower than –2 °C indicate possible permafrost, whilst temperatures lower than –3 °C testify to probable permafrost (Haeberli, 1973).

At the end of March 1993, 49 BTS measurements were carried out: 13 on rock glacier No. 2 and on the neighbour moraine and debris deposits, and 32 on the rock glaciers No. 4 and No. 5. In 41 of the 49 sites, the thickness of the snow cover exceeded 80 cm, thus ensuring a sufficient level and making the measurements acceptable (King, 1986; 1990). It should be emphasized that snow was much thicker (1.5 m, as an average; locally, over 2 m) on landforms No. 4 and No. 5 than on No. 2 (95 cm, on average). Moreover, on the latter, hypothetically considered as active due to its morphology, relatively high temperatures were measured, theoretically not compatible with the presence of permafrost. On the other hand, permafrost seems to be present in the slightly less elevated landforms, whose morphology gives no hint of activity. This could lead to a dramatic revision of the morphodynamic attribution of the rock glacier n. 2, whose particularly irregular morphology could be due to recent activity of phenomena which are different from the genetic ones.

Anyhow, the gentler morphology of the other two rock glaciers (No. 4 and No. 5) are not in contrast with the probable presence of permafrost indicated by the BTS measurements (11 of them gave values below –2 °C, with 7 measured temperatures below –3 °C). In fact, presence of permafrost does not directly imply the existence of the mass of interstitial ice necessary for the activity of the landforms.

Basing upon the climatic parameters elaborated for the whole Maiella area, it was possible to hypothesize a thermal-nivometric framework for the Upper Cannella Valley. The values obtained in this way (calculated for an altitude of 2550 m, similar to that of the toes of the rock glaciers No. 2 and No. 4 and No. 5) are obviously affected by substantial inaccuracy. This mostly derives from the lack of recording weather stations in the study area and, more in general, at high elevation. To significantly improve this situation, we are planning to install mobile recording stations in the Upper Cannella Valley, to be located in sites that are instrumental for the reconstruction of local topoclimates. Monthly averages of air temperatures are there estimated to range between –8 °C and 6.5 °C, with an annual mean of *ca.* –1.6 °C. Absolute minimum temperatures should probably be around –28 °C, whilst maximum ones should not exceed 20 °C.

The nivometric regime of the Upper Cannella Valley is typical of high-altitude, low-mid latitude areas. This implies a major maximum of snowfall in December-January (corresponding with the period of maximum annual precipitation) and a secondary maximum in April, separated by a less intense period. Anyhow, snowfalls are relatively common for the whole period September-June (fig. 8).

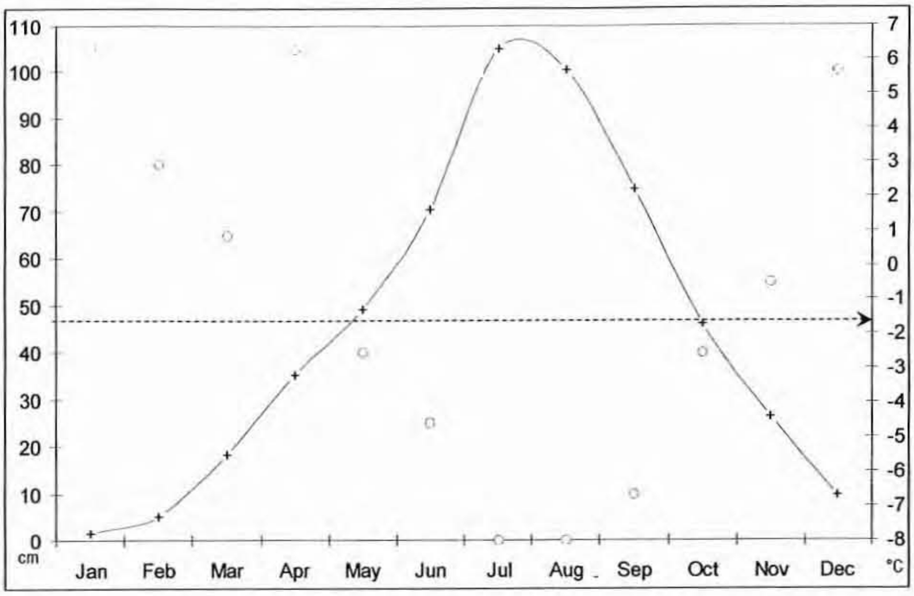
As previously said, the thickness of snow cover, besides on intensity and frequency of snowfalls, also depends on the local effects of eolian erosion and deposition, avalanches and different melting rates. Generally speaking, it reaches its maximum in spring, when it can locally exceed 3 m. On the other hand, the complex dynamics of snow may locally lead to almost total erosion of the snow cover in areas particularly exposed to wind and along very steep slopes and channels. As a consequence, it was impossible to carry out BTS measurements on rock glacier No. 1, since in March its surface was almost completely bare. Of course, significant removal of snow cover leads to greater thermal exchanges with the atmosphere, and therefore to deeper freezing during the cold period and faster warming during late spring (*i.e.*, from the beginning of May).

## CONCLUSION

To sum up, it can be stated that in the Upper Cannella Valley the climate, extrapolated from the records of stations located at a lower altitude, does not seem to be severe enough to allow the preservation of permafrost. Anyhow, taking into account the concurrence of many meteorological and topo-climatic factors, it can be inferred that soil temperature should locally be much lower than the values theoretically calculated. This may fully justify the presence of small residual patches of sporadic permafrost.

The importance of microclimates (mostly connected with morphology and aspect of the slopes) is testified by BTS measurements carried out on rock glaciers and in their neighborhood, which gave indications of the possible presence of permafrost at altitudes of *ca.* 2300-2400 m. On the other hand, they suggest the absence of frozen ground below the landform located some 200 m higher, even though it is the only one that shows landforms symptomatic of a possible periglacial activity.

FIG. 8 - Mean monthly temperatures (°C, right axis, thin black line with crosses) and thickness of fresh snow (cm, left axis, thick grey line with circles) in the Upper Cannella Valley (2550 m a.s.l.). The dashed line indicates the mean annual temperature.




## REFERENCES


ABBEY F.L., GRAY D.M., MALE D.H. & ERICKSON D.E.L. (1978) - *Index models for predicting ground heat flux to permafrost during thawing conditions*. Proceed. Third Int. Conf. on Permafrost, Ottawa, vol. 1, 4-9.

AERONAUTICA MILITARE - SERVIZIO METEOROLOGICO (1999) - *Data acquired from the Internet*. Site http://www.meteo.difesa.it.

BARSCH D. (1987) - *Rock glaciers: an approach to their systematics*. In: GIARDINO J.R., SCHROEDER G.F. JR. & VITEK J.D. (eds.) - *Rock glaciers*. Allen & Unwin, Boston, pp. 45-53.

BISCI C., CELLINI M., FARABOLLINI P. & PITTORI C. (1989) - *Le gradient thermique vertical dans les Marches méridionales (Italie centrale)*. Actes du Colloque de Pavia, Publications de l'Association International de Climatologie, 2, 48-55.

BISCI C., DRAMIS F., FAZZINI M., ALTOBELLO L. & DORIGATO S. (2001) - *Analyse des trends termo-pluviometriques du versant Adriatique compris entre la lagune de Venice et le Cap de Santa Maria di Leuca (Italie orientale)*. Actes du Colloque de Seville, Publications de l'Association Internationale de Climatologie, 14, 37-39.

BISCI P., DRAMIS F., FAZZINI M., GENTILI B. & PAMBIANCHI G. (2001) - *Topo-geographic parameters and spatial distribution of precipitation: first results in north-eastern Italy*. DEMs and Geomorphology, Special Publication of the Geographic Information Systems Association, Department of Geography, Nihon University, Tokyo, 66-67.

BISCI C., DRAMIS F., FAZZINI M., ROSSETTI R. & SPERANZA A. (1997) - *Rélation entre parametres topographiques et quantité de précipitation en le territorire de la Région Marche (Italie centrale)*. Actes du Colloque de Ottawa, Publications de l'Association International de Climatologie, 10, 128-129.

CHENG GUODONG & DRAMIS F. (1992) - *Distribution of mountain permafrost and climate*. Permafrost and Periglac. Proc., 3(2), 83-91.

CORTE A. (1987) - *Rock glaciers taxonomy*. In: GIARDINO J.R., SCHROEDER G.F. JR. & VITEK J.D. (Eds.) - *Rock glaciers*. Allen & Unwin, Boston, pp. 27-39.

DEMANGEOT J. (1965) - *Géomorphologie des Abruzzes Adriatiques*. Mémoires et Documents, CNRS, 403 pp.

DRAMIS F. & KOTARBA A. (1992) - *Southern limit of relict rock glaciers, Central Apennines. Italy*. Permafrost and Periglac. Proc., 3, 257-260.

DRAMIS F. & KOTARBA A. (1994) - *Geomorphological evidences of high mountain permafrost in Central Apennines*. Geogr. Fis. Dinam. Quat., 17, 29-36.

FAZZINI M. (1997) - *Analisi statistica delle principali caratteristiche meteoclimatiche della regione Marche, anche in funzione di alcuni parametri geografici e geomorfologici*. Fac. Sc. M.F.N., University of Camerino, unpublished thesis.

FAZZINI M., BISCI C. & DE LUCA E. (1999) - *Clima e neve sul massiccio del Gran Sasso*. Neve e Valanghe, 36, 36-45.

HAEBERLI W. (1973) - *Die Basis-Temperatur der winterlichen Schneedecke als morphologlicher Indikator für die Verbreitung von Permafrost in den Alpen*. Zeit. Gletsch. Glazialgeol., 9, 221-227.

HAEBERLI W. (1985) - *Creep of mountain permafrost: internal structure and flow of Alpine rock glaciers*. Mitteilungen der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie. Eidgenössische Technische Hochschule, Zurich, 77, 142 pp.

HOELZLE M. (1992) - *Permafrost occurrence from BTS measurements and climatic parameters in Eastern Swiss Alps*. Permafrost and Periglac. Proc., 3, 143-147.

KING L. (1986) - *Zonation and ecology of high mountain permafrost in Scandinavia*. Geogr. Annaler, 68A, 131-139.

KING L. (1990) - *Soil and rock temperatures in discontinuous permafrost: Gornergrat and Unterrothorn, Wallis, Swiss Alps*. Permafrost and Periglac. Proc., 1, 177-188.

KÖPPEN W. & GEIGER (1930 and following) - *Handbuch der Klimatologie*. 5 vols., Gerbrüder Borntrager, Berlin.

OUTCALT S.E. & BENEDICT J.B. (1965) - *Photointerpretation of two types of rock glaciers in the Colorado Front range, USA*. Journ. Glaciol., 5, 849-856.

SERVIZIO IDROGRAFICO (1965-1990) - *Annali idrologici. Bacini con foce al litorale adriatico dal Salinello al Fortore*. Presidenza del Consiglio dei Ministri, Dipartimento per i Servizi Tecnici Nazionali, Servizio Idrografico, Ed. Istituto Poligrafico dello Stato, Roma.

SMIRAGLIA C. & VEGGETTI O. (1992) - *Recenti osservazioni sul Ghiacciaio del Calderone (Gran Sasso d'Italia, Abruzzo)*. Boll. Soc. Geogr. It., Ser. XI, 9 (4-6), 269-302.

WHITEHEAD F.H. (1951) - *Ecology of the Altopiano of Monte Maiella, Italy*. Journ. Ecol., 39, 330-355.


*(Ms. received 15 March 2002; accepted 1 April 2003)*