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Middle to Late Holocene glacial variations, periglacial processes and alluvial sedimentation on the higher Apennine massifs (Italy)

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Abstract

The major climatic variations that have affected the summit slopes of the higher Apennine massifs in the last 6000 yr are shown in alternating layers of organic matter-rich soils and alluvial, glacial and periglacial sediments. The burial of the soils, triggered by environmental–climatic variations, took place in several phases. For the last 3000 yr chronological correlations can be drawn between phases of glacial advance, scree and alluvial sedimentation and development of periglacial features. During some periods, the slopes were covered by vegetation up to 2700 m and beyond, while in other phases the same slopes were subject to glacial advances and periglacial processes, and alluvial sediments were deposited on the high plateaus. Around 5740–5590, 1560–1370 and 1300–970 cal yr B.P., organic matter-rich soils formed on slopes currently subject to periglacial and glacial processes; the mean annual temperature must therefore have been higher than at present. Furthermore, on the basis of the variations in the elevation of the lower limit reached by gelifraction, it can be concluded that the oscillations in the minimum winter temperatures could have ranged between 3.0°C lower (ca. 790–150 cal yr B.P.) and 1.2°C higher (ca. 5740–5590 cal yr B.P.) than present minimum winter temperatures. During the last 3000 yr the cold phases recorded by the Calderone Glacier advance in the Apennines essentially match basically the phases of glacial advance in the Alps.

Keywords: Apennine chain; Middle; Late Holocene; Glacial; Periglacial; Alluvial sediments; Buried soils; Palaeoclimate; Minimum winter temperatures

Introduction

The Apennine chain forms the backbone of the Italian peninsula and extends down to the central area of the Mediterranean Sea (Fig. 1). The presence of limited glacial and periglacial environments on the mountain top, included between areas of temperate climate, means that the climatic variations, even if small, can produce appreciable changes in the extent of these environments. During the warmest periods of the Holocene, the periglacial and glacial environments could have completely disappeared and have later formed again as the consequence of cooling phases.

The aims of the present work are to recognize the climatic and environmental changes that took place in the second half of the Holocene in the summit areas of the highest massifs in the Apennines (Gran Sasso, 2912 m; Maiella, 2797 m; Velino 2485 m, Monti Sibillini 2475 m; Fig. 1), and to assess the relative temperatures, compared with present temperatures, in a number of past climatic phases.

The oscillations of the Calderone Glacier, the sedimentation of slope debris and alluvial deposits and the development of periglacial processes are considered in this paper. The chronological frame was obtained with radiocarbon dating of peat layers or wood fragments and the soils interbedded between the sediments. Dating of the soils was performed on the total organic content in the Ah horizon, and the maximum dry weight of each dated sample was 200 g or less. AMS analyses have been performed on small samples of the Ah horizon of soils, sampled by digging little holes in highly unstable scree slopes. All dates are in the

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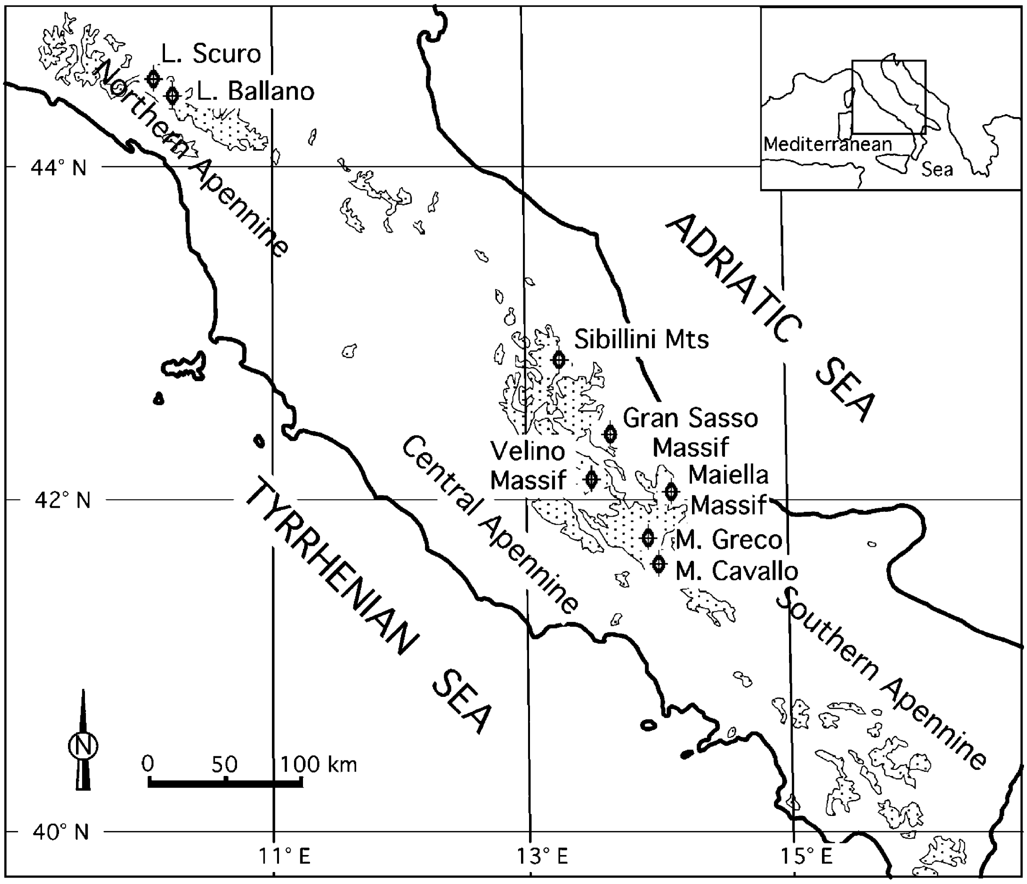

Figure 1. Location of the Apennine chain and of the main mountain massifs. Shaded areas are above 1000 m.

two-sigma calibrated range, obtained using INTCAL98 (Stuiver et al., 1998; Stuiver and van der Plicht, 1998; Talma and Vogel, 1993).

Dating soils can be quite complex to interpret, in particular the B and C horizons (Geyh et al., 1971; Scharpenseel and Schiffmann, 1977; Geyh et al., 1985; Matthews, 1993). In general, radiocarbon dating of soils do not yield dates relating to a precise moment, and their precision depends on the mean residence time of organic matter. However, Matthews (1993) considers that thin soils often yield reliable dates that can be interpreted in a relatively simple way.

In the present paper, the buried soils are thin and developed on very recent sediments, and the samples refer to their uppermost organic matter-rich portion. The dating carried out on the five buried soils interbedded with the alluvial sediments in the same exposure at Campo Imperatore (Fig. 2) indicates that their age is between the 5th–6th century A.D. and the present. The phases of pedogenesis that

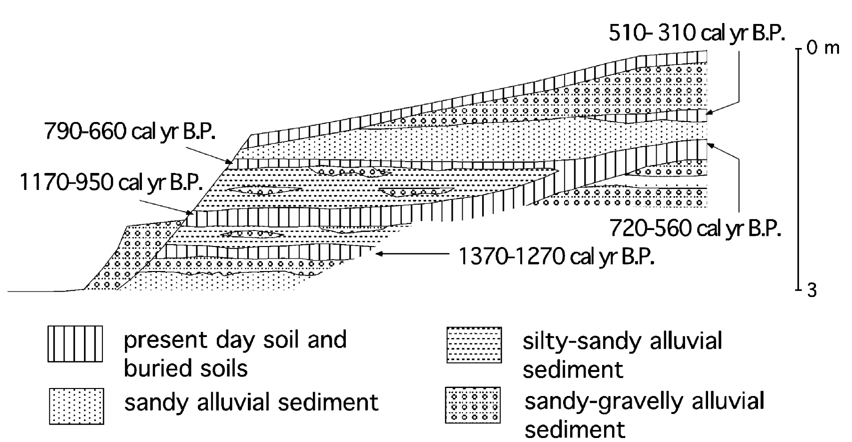

Figure 2. Stratigraphic sketch through the alluvial sediments in western Campo Imperatore (Gran Sasso Massif). Source of radiocarbon dates given in the text.

produced most of the soils are thus necessarily brief, and the mean residence time even shorter. In various cases, moreover, the dates provided by the soils are confirmed by those of thin levels of peat or wood fragments.

It is therefore thought that the dates can to a fair degree of approximation indicate the age of the burial of the soils and can be used to bracket the environmental/climatic variations recognized in the present paper.

Alluvial deposits

The alluvial deposits studied refer mainly to the Gran Sasso Massif as it is only on this massif that such sediments outcrop over fairly extensive areas at high elevations (1750–1550 m).

At Campo Imperatore, at an elevation of about 1700 m, alluvial sediments – overlying a soil dated 6170–5750 cal yr B.P. (5200 ± 60 ^{14}C yr B.P.; BO-285) and 6400–5950 cal yr B.P. (5410 ± 80 ^{14}C yr B.P.; BO-253) – are found in an alluvial fan on the southwest slope of Mount Prena.

At Campo Imperatore, at around 1600 m asl, there are soils dated 4830–4410 cal yr B.P. (4070 ± 70 B.P.; Beta-168676) and 2310–1990 cal yr B.P. (2130 ± 50 ^{14}C yr B.P.; Beta-168677) that underlie alluvial sediments. Also in the Northern Apennines, at Lake Ballano, at about 1550 m asl, alluvial sediments overlie a thin layer of peat dated 4820–4440 cal yr B.P. (4060 ± 60 ^{14}C yr B.P.; Beta-154565).

On Mount Cavallo, in the Central Apennines, at about 1750 m asl, sandy silty alluvial sediments overlie a layer of peat dated 2970–2750 cal yr B.P. (2.750 ± 110 ^{14}C yr B.P.; BO-176).

Again at Campo Imperatore, at about 1700 m asl, alluvial sediments and interbedded buried soils (Giraudi, 2003, 2005) are exposed (Fig. 2).

The first buried soil is dated in the range 1360–1270 cal yr B.P. (1410 ± 40 B.P.; Beta-164916), a date very similar to that of a soil overlain by alluvial sediments in the eastern part of Campo Imperatore dated 1420–1280 cal yr B.P. (1450 ± 50 ^{14}C yr B.P.; Beta-162900). In the Northern Apennines, at the head of the Parma Valley, on the shores of Lake Scuro, an alluvial sediment contains a wood fragment dated 1310–1080 cal yr B.P. (1310 ± 60 ^{14}C yr B.P.; Beta-154566): this date, close to but more recent than that provided by the soils, correlates to the inferred age of the alluvial sediments.

The second buried soil, developed on a gently sloping surface, and which has therefore been overlain at different times by alluvial sediments, is dated 1170–950 cal yr B.P. (1140 ± 50 ^{14}C yr B.P.; Beta-162902) in its topographically lowest part and 720–640 and 590–560 cal yr B.P. (720 ± 50 ^{14}C yr B.P.; Beta-162901) in the highest part.

There is furthermore another soil interbedded with the alluvial sediments dated 790–660 cal yr B.P. (800 ± 50 ^{14}C yr B.P.; Beta-162903).

The last soil has been dated 510–310 cal yr B.P. (380 ± 40 ^{14}C yr B.P.; Beta-164915) and is overlain by the coarsest alluvial sediments present in the section. In the same zone, just a few hundred meters distant, a soil overlain by alluvial sediments has been dated 430–680 and 180–150 cal yr B.P. (250 ± 40 ^{14}C yr B.P.; Beta-168678).

Glacial phases

On the Gran Sasso Massif is the only glacier in the Apennines, the Calderone Glacier, the most southerly one in all Europe (Gellatly et al., 1994). The chronological framework of the phases of glacial expansion (Giraudi, 2002, 2004) is based on dating by the radiocarbon method of soils interbedded with the till deposited at the threshold of the glacial cirque, and with the glacial drift a few hundred meters away (Fig. 3).

The phases of glacial expansion may be summarized as follows:

- the glacial expansion of the Calderone 1 stage is bracketed by soils dated in the range 4520–4090 cal yr B.P. (3895 ± 65 ^{14}C yr B.P.; UA-13828) and 2855–2725 cal yr B.P. (2650 ± 60 ^{14}C yr B.P.; Beta-122057);
- the glacial expansion phase that gave rise to the formation of the moraines of the Calderone 2 stage is bracketed by soils dated 2855–2725 cal yr B.P. and 1410–1290 cal yr B.P. (1450 ± 40 ^{14}C yr B.P.; Beta-145526);
- the glacial expansion phase that produced the moraines of the Calderone 3a stage is bracketed by soils dated 1410–1290 cal yr B.P. and 680–550 cal yr B.P. (670 ± 40 ^{14}C yr B.P.; Beta-145532);
- the expansion phase during which the moraines of the Calderone 3b stage were formed is younger than the soil dated 680–550 cal yr B.P.; and
- the expansion phase that gave rise to the moraines of the Calderone 3c stage is very close to the glacier margin documented at the end of the 19th century and should therefore date from the same period.

Periglacial processes

The periglacial processes taken into consideration in the present work are the sedimentation of slope debris, the development of patterned ground and solifluctions. The attempt to date the sediments involved in the periglacial features was carried out by digging several 30- to 50-cm-deep holes in the debris present in the summit areas of the highest Apennine massifs not colonized by vegetation. The debris lies mainly on the slopes facing the northern quadrants and, in particular, in the ancient glacial cirques.

In dozens of places the excavations carried out between approximately 2000 and 2700 m asl indicated the presence of soils underlying a variable thickness of debris. At times these soils were well preserved, rich in organic matter and at most 10 cm thick, sometimes appearing truncated and/or extremely thin. They have generally developed on top of a

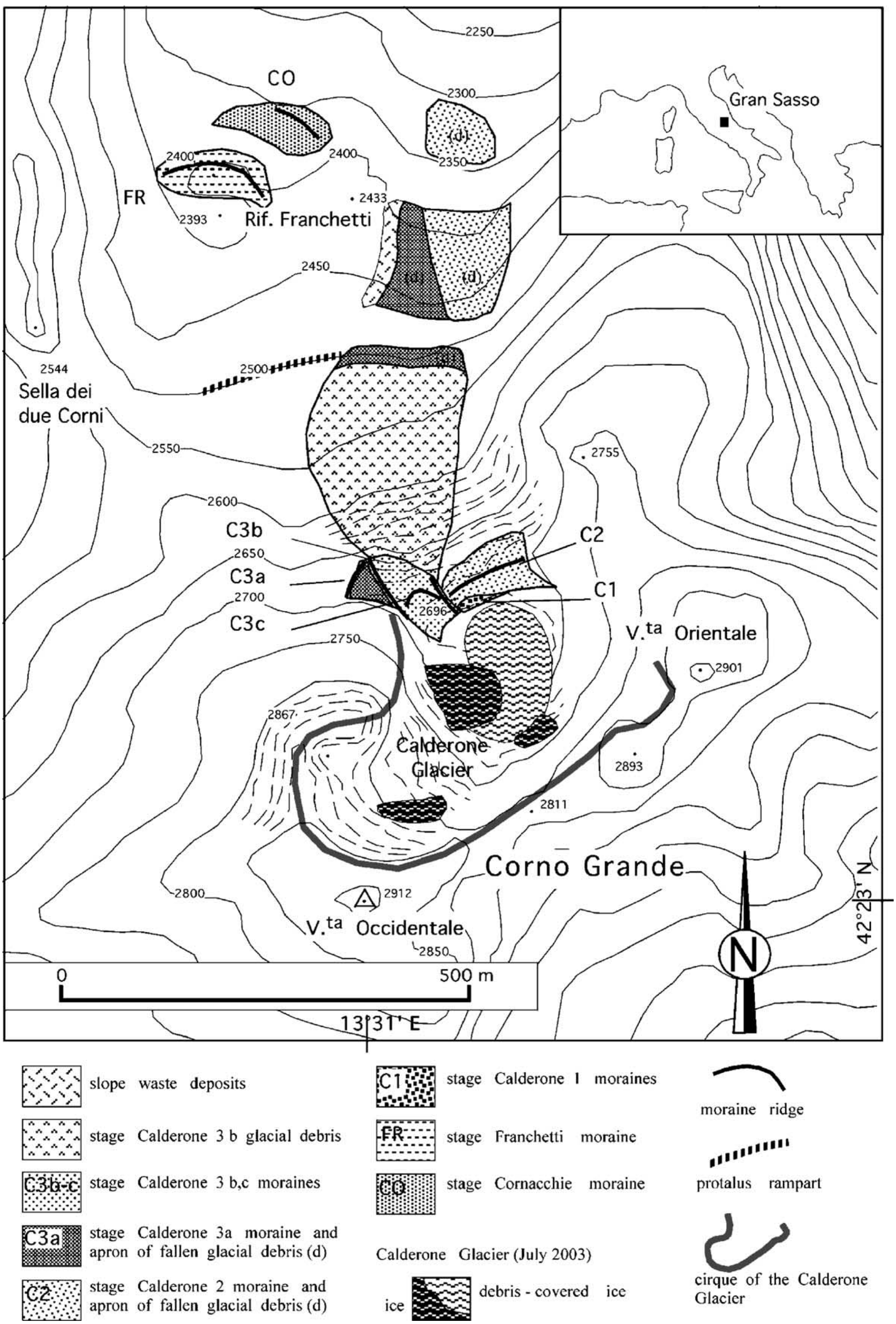

Figure 3. Geological sketch map of the glacial and slope debris deposits studied near the Calderone Glacier (Corno Grande, Gran Sasso Massif). Contours are 50 m, dashed contours are 10 m.

limited thickness of fine debris overlying horizons made by coarser debris.

Patterned ground

On a number of not very steep slopes at altitudes greater than 2400 m asl, patterned ground in the form of sorted stripes occurs. In these areas, surface debris overlies thin soils that have been dated in various places.

On the Majella Massif, at Mount Focalone, at an altitude of 2700 m asl, debris overlies a soil dated in the range 5740–5590 cal yr B.P. (4930 ± 50 ^{14}C yr B.P.; Beta-154572). On the Gran Sasso Massif (Giraudi, 2001) at an elevation of around 2400 m, debris overlies soils dated 3720–3360 cal yr B.P. (3310 ± 90 ^{14}C yr B.P.; Beta-134788) and 2950–2760 cal yr B.P. (2710 ± 70 ^{14}C yr B.P.; Beta-134787). Furthermore, at the Conca degli Invalidi (2625 m), a soil dated 1570–1360 cal yr B.P. (1590 ± 60 ^{14}C yr B.P.; Beta-168679) is overlain by debris with sorted stripes.

Slope debris

Many slopes at present devoid of vegetation are formed by slope debris which overlies soils or preserves traces of soils removed by erosion. This demonstrates that in the past pedogenesis took place in these areas.

The oldest soil covered by debris was found near Campo Pericoli (Gran Sasso Massif) at an altitude of 2250 m asl and was dated 2150–1885 cal yr B.P. (2060 ± 60 ^{14}C yr B.P.; Beta-134786).

Soils buried by debris found on Mount Vettore (Sibillini Massif) at an elevation of 2350 m, on Mount Focalone (Majella Massif) at an elevation of 2580 m, on Mount Scìndarella at an elevation of 2100 m and on Corno Grande (Gran Sasso Massif) at an elevation of

Table 1
Radiocarbon dates on buried soils, peat and wood samples

Laboratory number	Conventional radiocarbon age (^{14}C yr B.P.)	^{13}C/^{12}C ratio (‰)	Two-sigma calibrated range (cal yr B.P.)	Material	Locality	Elevation (m asl)
BO-253	5410 ± 80	−27.0	6400–5950	buried soil	Gran Sasso M.	1700
BO-285	5200 ± 60	−27.0	6170–5750	buried soil	Gran Sasso M.	1700
Beta-154572	4930 ± 50	−25.0	5740–5590	buried soil	Majella M.	2700
Beta-168676	4070 ± 70	−25.0	4830–4410	buried soil	Gran Sasso M.	1600
Beta-154565	4060 ± 60	−25.0	4820–4440	peat	Lake Ballano	1550
UA-13828	3895 ± 65	−24.7	4520–4090	buried soil	Gran Sasso M.	2690
Beta-134788	3310 ± 90	−25.0	3720–3360	buried soil	Gran Sasso M.	2400
BO-176	2750 ± 110	−24.0	2970–2750	peat	Cavallo M.	1750
Beta-134787	2710 ± 70	−25.0	2950–2760	buried soil	Gran Sasso M.	2400
Beta-122057	2650 ± 60	−25.0	2855–2725	buried soil	Gran Sasso M.	2450
Beta-168677	2130 ± 50	−25.0	2310–2230 and 2190–1990	buried soil	Gran Sasso M.	1600
Beta-134786	2060 ± 60	−25.0	2150–1885	buried soil	Gran Sasso M.	2250
Beta-168679	1590 ± 60	−25.0	1570–1360	buried soil	Gran Sasso M.	2625
Beta-154573	1530 ± 50	−25.0	1530–1310	buried soil	Majella M.	2580
Beta-160268	1510 ± 60	−25.0	1530–1300	buried soil	Gran Sasso M.	2100
Beta-154556	1510 ± 40	−24.3	1510–1310	buried soil	Sibillini M.	2350
Beta-162900	1450 ± 50	−24.0	1420–1280	buried soil	Gran Sasso M.	1450
Beta-145526	1450 ± 40	−25.3	1410–1290	buried soil	Gran Sasso M.	2450
Beta-169248	1420 ± 50	−25.0	1400–1270	buried soil	Greco M.	2170
Beta-164916	1410 ± 40	−24.0	1360–1270	buried soil	Gran Sasso M.	1700
Beta-154566	1310 ± 60	−25.0	1310–1080	wood	Lake Scuro-N. Apennine	1550
Beta-135240	1240 ± 80	−25.0	1300–970	buried soil	Majella M.	2650
Beta-145531	1210 ± 40	−23.0	1250–1050	buried soil	Sibillini M.	1980
Beta-145525	1190 ± 50	−25.0	1170–1060	buried soil	Velino M.	2130
Beta-162902	1140 ± 50	−23.9	1170–950	buried soil	Gran Sasso M.	1700
Beta-135386	1130 ± 60	−25.0	1180–935	buried soil	Gran Sasso M.	2130
Beta-154571	1100 ± 40	−25.0	1070–940	buried soil	Sibillini M.	2450
Beta-160267	840 ± 60	−25.0	920–670	buried soil	Gran Sasso M.	2100
Beta-162903	800 ± 50	−24.0	790–660	buried soil	Gran Sasso M.	1700
Beta-145530	780 ± 40	−24.6	760–660	buried soil	Gran Sasso M.	2300
Beta-162901	720 ± 50	−24.0	720–640 and 590–560	buried soil	Gran Sasso M.	1700
Beta-145532	670 ± 40	−26.1	680–550	buried soil	Gran Sasso M.	2460
Beta-164915	380 ± 40	−25.2	510–310	buried soil	Gran Sasso M.	1700
Beta-136926	340 ± 80	−25.0	525–275 and 175–150	buried soil	Velino M.	1950
Beta-168678	250 ± 40	−24.7	430–680 and 180–150	buried soil	Gran Sasso M.	1730

2430 m have provided very similar ages: 1510–1310 cal yr B.P. (1510 ± 40 ^{14}C yr B.P.; Beta-154556), 1530–1310 cal yr B.P. (1530 ± 50 ^{14}C yr B.P.; Beta-154573), 1530–1300 cal yr B.P. (1510 ± 60 ^{14}C yr B.P.; Beta-160268) and 1410–1290 cal yr B.P. (1450 ± 40 ^{14}C yr B.P.; Beta-145526).

Other soils overlain by debris occur at Rifugio Sebastiani (Velino Massif) at an elevation of 2130 m, on Mount Scindarella (Gran Sasso Massif) at an elevation of 2100 m, at the Pilato Lakes (Sibillini Massif) at an elevation of 1980 m and lastly on Mount Acquaviva (Majella Massif) at an elevation of 2650 m and have provided the following radiocarbon dates: 1170–1060 cal yr B.P. (1190 ± 50 ^{14}C yr B.P.; Beta-145525), 1180–935 cal yr B.P. (1130 ± 60 ^{14}C yr B.P.; Beta-135386), 1250–1050 cal yr B.P. (1210 ± 40 ^{14}C yr B.P.; Beta-145531) and 1300–970 cal yr B.P. (1240 ± 80 ^{14}C yr B.P.; Beta-135240) (Table 1).

Three other buried soils have been dated. The first and second ones, found on the Gran Sasso Massif, in the Upper Val Maone at an elevation of 2300 m and on the Corno Grande at an elevation of 2460 m, have been dated in the range 760–660 cal yr B.P. (780 ± 40 ^{14}C yr B.P.; Beta-145530) and 680–550 cal yr B.P. (670 ± 40 ^{14}C yr B.P.; Beta-145532), and the last one, found at Capo Pezza (Velino Massif) at an elevation of 1950 m, has been dated 525–275 and 175–150 cal yr B.P. (340 ± 80 ^{14}C yr B.P.; Beta-136926).

Solifluctions

Solifluctions have been investigated, with shallow excavations, on Mount Scindarella (Gran Sasso Massif) at an elevation of about 2100 m, on Mount Vettore at an elevation of 2450 m (Sibillini Massif) and on Mount Greco at an elevation of 2170 m.

In the first case, the solifluction lobes are formed by a grass-covered silty soil at the top of a layer of debris with an abundant silty matrix: the lobe overlies a silty soil on coarse debris. One sample of soil covered by the solifluction lobe has been dated in the range 920–670 cal yr B.P. (840 ± 60 ^{14}C yr B.P.; Beta-160267).

In the other cases, the solifluction lobes form debris terraces without soil, a few decimeters high on the nearby ground, and limited by a grass strip on the rim of the lobe. The debris covers thin organic soils, dated 1070–940 cal yr B.P. (1100 ± 40 ^{14}C yr B.P.; Beta-154571) on Mount Vettore and 1400–1270 cal yr B.P. (1420 ± 50 ^{14}C yr B.P.; Beta-169248) on Mount Greco.

The results obtained thus indicate that in the second half of the Holocene, periglacial processes and pedogenesis phases alternated in the summit zones of the massifs studied on slopes not at present colonized by vegetation.

Discussion

The alternating layers of buried organic matter-rich soils and alluvial, glacial and periglacial sediments show that several environmental–climatic variations affected the summit slopes of the higher Apennine massifs during the last 6000 yr. However, the data refer mainly to the last 3000 yr (27 radiocarbon dates) while only seven dates refer to the period between about 6000 and 3000 cal yr B.P. Because the data related to the older period are scanty, they will be discussed separately.

Within the last 3000 yr, a correlation can be drawn between the burial of soils, peat, and wood by glacial debris, scree, periglacial features and alluvial sediments during three periods dated between 2970 and 2725 cal yr B.P., between 1530 and 1270 cal yr B.P. and between 680 and 150 cal yr B.P. (Fig. 4).

The correlation between the burial of soils by scree, periglacial features and alluvial sediments during a period dated between 1250 and 935 cal yr B.P. also seems clear. During this period a Calderone Glacier expansion is inferred (Fig. 4).

In the period between 6000 and 3000 cal yr B.P., the data are minimal; no correlations can be made among burial of the soils by glacial debris, scree, alluvial sediments and periglacial features. It can be observed that two phases of burial of soils by alluvial sediments occurred, the first around 6400–5650 cal yr B.P., the second around 4830–4410 cal yr B.P.; periglacial features covered soils dated 5740–5590 cal yr B.P. and 3720–3380 cal yr B.P., and the Calderone glacier expanded after 4520–4090 cal yr B.P.

The Late Holocene environmental changes reflect two main climatic–environmental scenarios in the Apennines:

(1) In correspondence with the glacial advances and the decrease in temperatures, the thinning out of the vegetation caused the soil to be strongly affected by freezing and thawing, allowing periglacial processes to start and, as low as elevations of about 2000 m, debris was produced by gelifraction which buried the soils; streams had a significant increase of sediment load and these produced alluvial sedimentation and soil burial downstream. This scenario is defined as "cool temperate" climate.
(2) In correspondence with the phases of glacial recession and temperature increases, the periglacial processes stopped, gelifraction diminished; the vegetation was able to colonize the debris up to very high elevations (2700 m, or even more). The streams, having less sediment load, cut down into the alluvial sediments deposited earlier; this scenario is defined as "warm-temperate" climate.

The present situation, with the Calderone Glacier on the threshold of disappearing, and with the deposition of slope debris limited to slopes above 2500 m, corresponds fairly well to the warm-temperate climate scenario reconstructed with the data set given in this paper; however, periglacial processes are still partly in progress

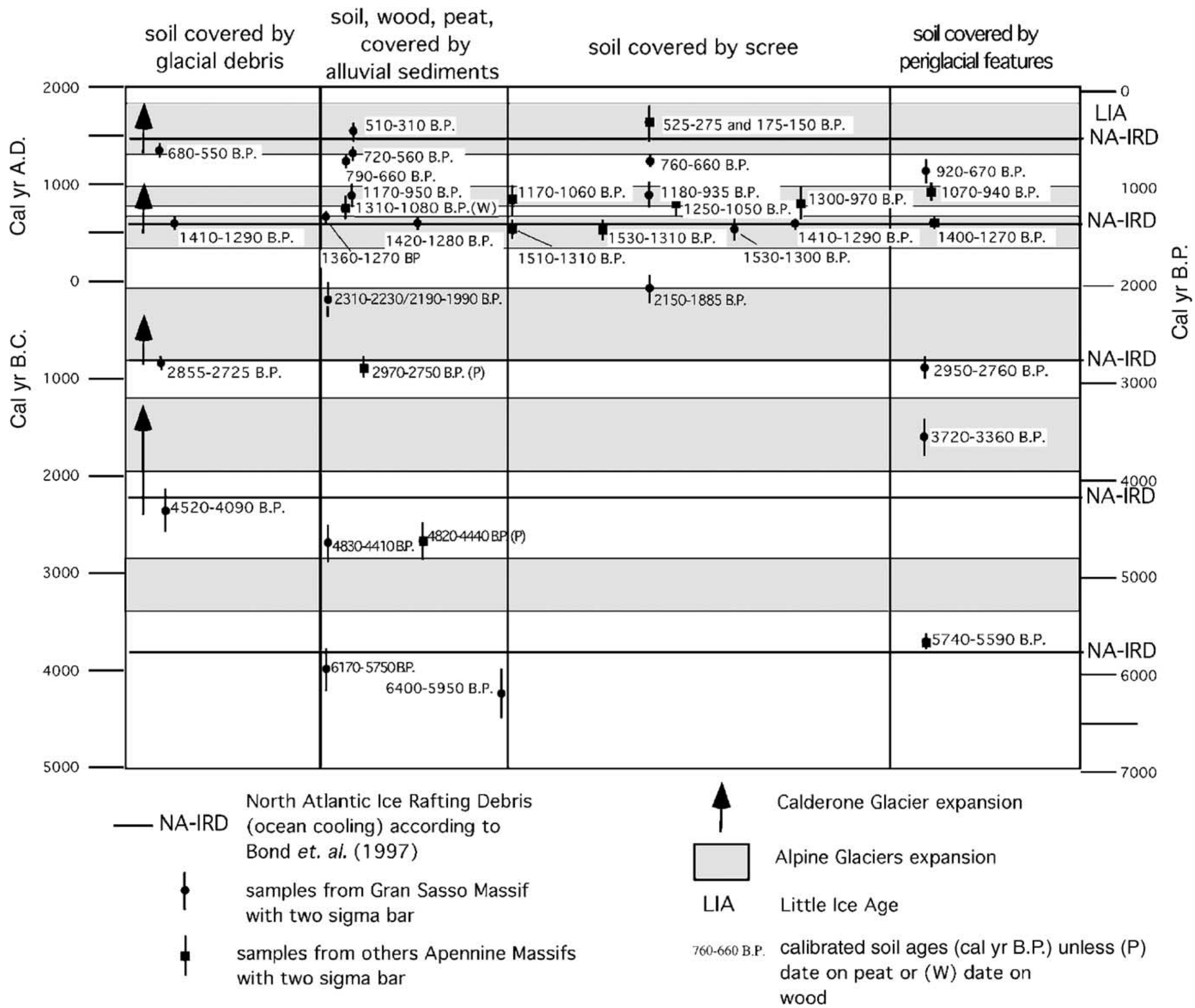

Figure 4. Chronological framework of the occurrence of glacial advances, alluvial and debris depositions, development of periglacial processes on the Apennines and comparison with the alpine glacial advances and North Atlantic cooling. Source of radiocarbon dates given in the text.

above 2400 m, gelifraction is still active above 2500 m and the vegetation has not yet reached the elevations indicated by the buried soils. It must therefore be assumed that the present mean temperature on the highest slopes of the Central Apennines has not yet reached the maximum values reached both in the first half of the Holocene and between the 6th and 11th–12th centuries A.D.

If we assume that the migration of the elevation of the lower limit of the slopes on which gelifraction occurs is due simply to variations in the winter minimum temperature, we can estimate the difference between the winter temperatures reached in the latter half of the Holocene. The following formula may be used for the calculation:

$$(\mathrm{GMA} - \mathrm{GMP})k = \Delta T$$

where GMA is the minimum elevation at which gelifraction takes place in the period considered, GMP is the minimum level at which gelifraction currently takes place and k is the thermal gradient.

The minimum elevation at which gelifraction takes place on the northern slopes today is about 2500 m; at around 1300–970 cal yr B.P. the lowest limit of the slopes subject to gelifraction was at elevations of over 2650 m; the vertical thermal gradient calculated by Tonini (1961) for the Gran Sasso is about 6°C/km; applying the above formula it can be calculated that in the course of a period around 1300–970 cal yr B.P., the minimum winter temperatures were at least 0.9°C higher than at present; this temperature regime has to be maintained for fairly long periods to permit plant colonization and the development of soils on slopes where vegetation is at present lacking. When the soil dated 5740–5590 cal yr B.P. developed, the minimum winter temperatures must have been at least 1.2°C higher than at present.

The lowest winter temperatures were reached in a period subsequent to 525–275 and 175–150 cal yr B.P., when gelifraction developed as low as elevations of 2000 m; applying the above formula it can be calculated that in the course of a number of phases in the Little Ice Age (LIA), the minimum winter temperatures reached values 3.0°C lower than at present. The stronger lowering of the winter temperature thus occurred in the course of the LIA, corresponding to the maximum neoglacial advance of the Calderone Glacier. It is to be stressed that the minimum winter temperature variations are a maximum value because changes in precipitation and humidity are not taken into account.

The Calderone Glacier advances appear basically coeval with those of the Alps (Fig. 4) as indicated by Orombelli and Porter (1982), Orombelli and Pelfini (1985), Baroni and Carton (1991), Orombelli and Mason (1997) and Strumia (1997) and of other European mountain chains (Grove and Gellatly, 1997; Jania, 1997) as summarized by Grove (1997).

It can be observed, moreover, that two soils and a peat layer dated between 2970–2750 and 2855–2725 cal yr B.P. and eight soils, dated between 1530–1300 and 1400–1270 cal yr B.P., have been buried by glacial debris, scree, periglacial features or alluvial sediments during environmental changes that are nearly coeval with two cooling cycles on the North Atlantic waters. The cooling cycles were identified by the presence of layers of ice-rafted debris in the ocean cores and dated ca. 2800 and 1400 cal yr B.P. by Bond et al. (1997), and confirmed by the variations in the amounts of terrigenous dust in ice cores in Greenland, reported by O'Brien et al. (1995). The possibility of a chronological correlation between cooling events on the North Atlantic waters and some Apennine phases of soil burial might be considered due to the 2970–2750 cal yr B.P. date on the burial of the peat layer, but at present the ages obtained by soils are not adequate to establish a detailed correlation.

Conclusions

In the highest Apennine massifs, on slopes not at present colonized by vegetation, the major climatic variations in the last 6000 yr are shown by alternating layers of organic matter-rich soils and alluvial, glacial and periglacial sediments. The soils were buried during several phases starting from 6400 to 5950 cal yr B.P.

Within the last 3000 yr, a correlation can be drawn between the burial of soils, peat and wood by glacial debris, scree, periglacial features and alluvial sediments during three periods dated between 2970 and 2725 cal yr B.P., between 1530 and 1270 cal yr B.P. and between 680 and 150 cal yr B.P. (Fig. 4).

Around 5740–5590, 1560–1370 and 1300–970 cal yr B.P. organic matter-rich soils formed on slopes currently subject to periglacial and glacial processes; thus, the climate must have been warmer than at the present. The variations in the winter temperature between the periods characterized by extreme climates in the last 6000 yr can be fairly marked, and the mean temperature in the last few decades is not the highest reached in the latter half of the Holocene.

During the last 3000 yr, the burial of some soils by glacial and periglacial processes seems basically coeval with glacier expansions in the Alps. The possibility of a chronological correlation between two cooling events on the North Atlantic waters and Apennine phases of soil burial can be considered, but at the present the ages obtained by soils are not adequate to establish detailed coincidences with North Atlantic events.

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