Geogr. Fis. Dinam. Quat.,
17 (1994), 29-36, 4 figg., 2 tabb.

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GEOMORPHOLOGICAL EVIDENCES OF HIGH MOUNTAIN PERMAFROST IN CENTRAL APENNINES

ABSTRACT: DRAMIS F. & KOTARBA A., *Geomorphological evidences of high mountain permafrost in Central Apennines.* (IT ISSN 0391-9838, 1994).

This work, which is part of an italian-polish research program on the deglaciation in Central Italy, reports some preliminary results of a systematic geomorphologic investigation carried out on periglacial features in the Abruzzi Apennines.

Relict rock glaciers have been recognized on three of the examined mountain massifs (Gran Sasso, Velino and Maiella) at altitudes exceeding 2.000 m a.s.l. These landforms probably originated during the last cold period of the Late Glacial and are still well preserved.

In the Cannella Valley (Maiella massif), a particularly «fresh» looking rock glacier (whose features strongly suggest some ice content in the debris mass) has been recognized at an altitude ranging around 2.600 m a.s.l.

It seems therefore possible to shift to this point (*i.e.* 12° 05' N of latitude) the southernmost limit of the present-day mountain permafrost in Italy.

KEY WORDS: Rock glacier, Mountain permafrost, Central Apennines, Italy.

RIASSUNTO: DRAMIS F. & KOTARBA A., *Evidenze geomorfologiche di permafrost di alta montagna nell'Appennino Centrale.* (IT ISSN 0391-9838, 1994)

Il presente lavoro, svolto nell'ambito di un più ampio programma di ricerca sulla deglaciazione in Italia centrale, riporta alcuni risultati preliminari di un'indagine geomorfologica sistematica condotta sui rilievi dell'Appennino abruzzese, con particolare riguardo all'analisi delle forme periglacialii.

Su tre dei massicci montuosi esaminati (Gran Sasso, Velino e Maiella), a quote maggiori di 2.000 m s.l.m., sono stati riconosciuti rock glacier relitti la cui origine e da riferire con ogni probabilità all'ultimo periodo freddo del Tardiglaciale.

Il rinvenimento nella Val Cannella (Massiccio della Maiella), ad un'altitudine di circa 2.600 m s.l.m. di un rock glacier dall'aspetto particolarmente «fresco», che suggerisce la presenza di ghiaccio interstiziale al suo interno, consente di spostare a 42° 05' di latitudine Nord l'attuale limite meridionale del permafrost di montagna in Italia.

TERMINI CHIAVE: Rock Glacier, Permafrost di montagna, Appennino Centrale, Italia.

INTRODUCTION

Rock glaciers are among the few geomorphological features diagnostic of alpine (high mountain) permafrost (HAEBERLI, 1985). Relict rock glaciers are therefore regarded as informative palaeoevironmental indicators; geomorphological mapping of these landforms (either active, inactive or relict) may be profitably used when studying altitudinal and latitudinal limits of mountain permafrost.

Evidences of periglacial morphogenesis are frequently found in Central Apennines above approximately 2.000 m a.s.l. Above the timberline, distinct belts of active periglacial phenomena (such as patterned ground, stone-stripes, solifluction lobes, ploughing blocks, nivation landforms etc.) were distinguished by GENTILESCHI (1967 a and b), KELLETAT (1969), HOLLERMANN (1977) and others (fig. 1). Notwithstanding this interest in the topic, only very few studies were carried out on the rock glaciers present in the area (GIRAUDI, 1988; GHISETTI & VEZZANI, 1990; DRAMIS & KOTARBA, 1992), also because they are usually situated in highly elevated alpine terrain, making access difficult.

This study is a part of a wider research programme on the Post-Glacial evolution of Central Apennines with special regard to periglacial morphology.

THE SCOPE OF INVESTIGATIONS AND THE STUDY AREA

The aim of this project is to recognize in the uppermost part of Central Apennines geomorphological features due to periglacial conditions occurred during the latest phases of the Last Glacial and during the Holocene. Crucial point of the ongoing periglacial research is to know how far rock glaciers have developed in the area as a result of permafrost occurrence. Other questions strictly related to this problem regard rock glacier classification, origin, age and relation to glacial landforms.

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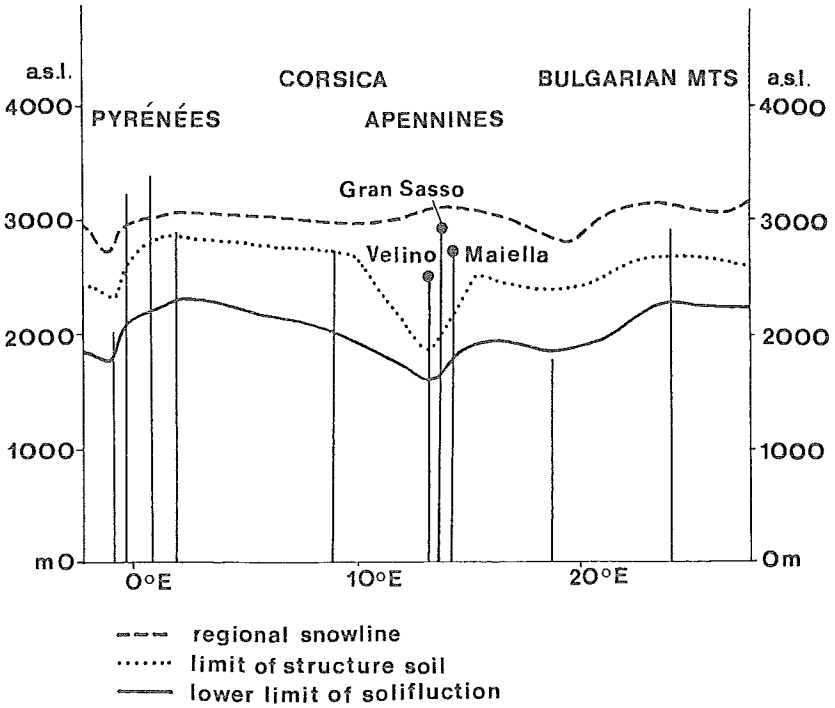


FIG. 1. - Recent altitudinal display of the mountain belts between the Pyrenees and the Bulgarian Mountains including Corsica and the Apennines (from HOLLERMANN, 1977). The uppermost parts of the Central Apennines are located within the belt of active periglacial mass movements.

Therefore, as a first step of the study, both deglaciation and periglacial patterns of landforms were investigated on air photographs in the following mountain groups: Sibillini, Laga, Terminillo, Sirente, Gran Sasso, Velino, Maiella and Greco. This paper presents some preliminary results of studies carried out on rock glaciers in the areas where these features were recognized (*i.e.* in the Gran Sasso, Velino and Maiella Ranges). Nature and distribution of all glacial and periglacial features were studied by means of photointerpretation with some detailed ground controls, giving background for detailed geomorphological maps at the scale of 1:10.000. Ortophotomaps at this scale (produced by the Regione Abruzzo) were used both in the field and during the final map drafting. The results of earlier studies by DEMANGEOT (1965), GENTILESCHI (1967 a and b), KELLETAT (1969), TOMASELLI & AGOSTINI (1991) were taken into account too.

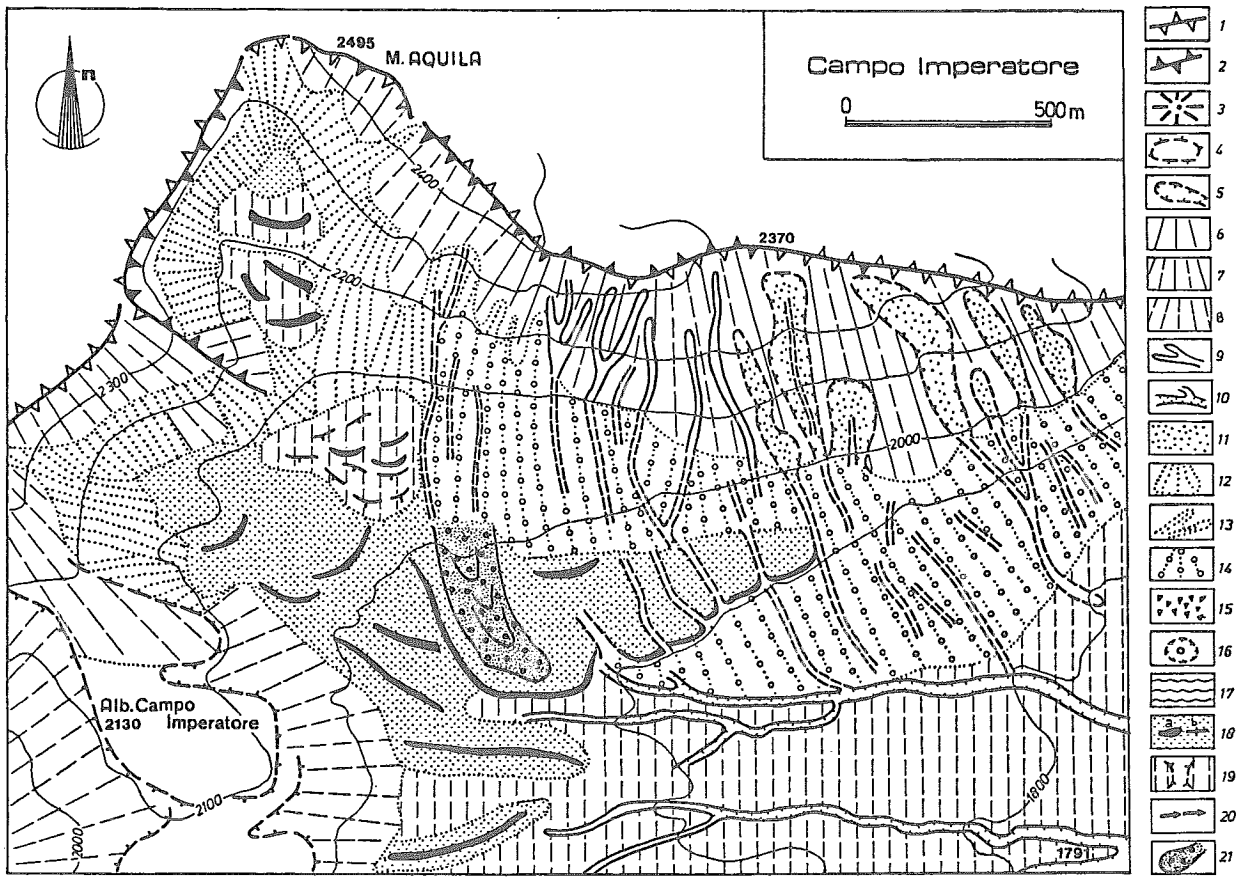
In Central Italy, climatic conditions for present day glacier existence are found only in the Gran Sasso d'Italia, in a small cirque located close to Corno Grande (2.912 m a.s.l.). In fact, the Calderone Glacier (or, better, *glacieret*) exists till now at a mean elevation of 2.780 m. TONINI (1961) suggested that while the present snowline and the 0° C isotherm in this part of the Apennines are located at an altitude of about 2.900-3.000 m, above the highest peaks, the former falls to 2.800 m at the Calderone Glacier, because of local factors such as northeastern aspect, abundant snow supply by wind and avalanches, shading by rocky walls. According to DEMANGEOT (1965), the tree-line position is more than 1.200 m lower, reaching around 1.650 m on the North-facing slopes and 1.850 on the South-facing ones. The same author calculated that during the Würm Glaciation the snowline in the Central Apennines was at an altitude ranging from 1.500 m (Morrone Massif) to 1.900 m (Laga Mts.), while the 0° C isotherm was several hundreds metres lower, indicating very dry climatic conditions, favorable to widespread periglacial morphogenesis.

CAMPO IMPERATORE VALLEY

The Campo Imperatore Valley is located in the uppermost part of the Gran Sasso Massif. It corresponds to a tectonic depression connected to the activity of an extensional fault system trending WNW-ESE and bordering to the South the Gran Sasso Massif. The structure is mostly made up of mesozoic limestones and dolomites with marly intercalations and, subordinately, by tertiary calcarenites and marls. The structure appears as a faulted monocline block dipping to NE, even though it is complicated due to the superposition of several tectonic units (also trending NE) which were emplaced during the Late Miocene-Lower Pliocene compressional phase of the Apennine tectogenesis (BIGI & *alii*, 1991). The extensional faulting which followed the compressional phase during Pliocene and Quaternary times is probably still active as suggested by geomorphologic evidences and by the high historical seismicity of the area (up to X MCS in the neighbouring L'Aquila basin).

After the emplacement of the thrust systems, the whole area underwent a general uplift whose rate strongly increased by the end of the lower Pleistocene. This latter phenomenon produced in the area a relief rise of more than 1.000 m (DEMANGEOT, 1965; DUFAURE & *alii*, 1989).

The valley shows evidences of glacial landforms and



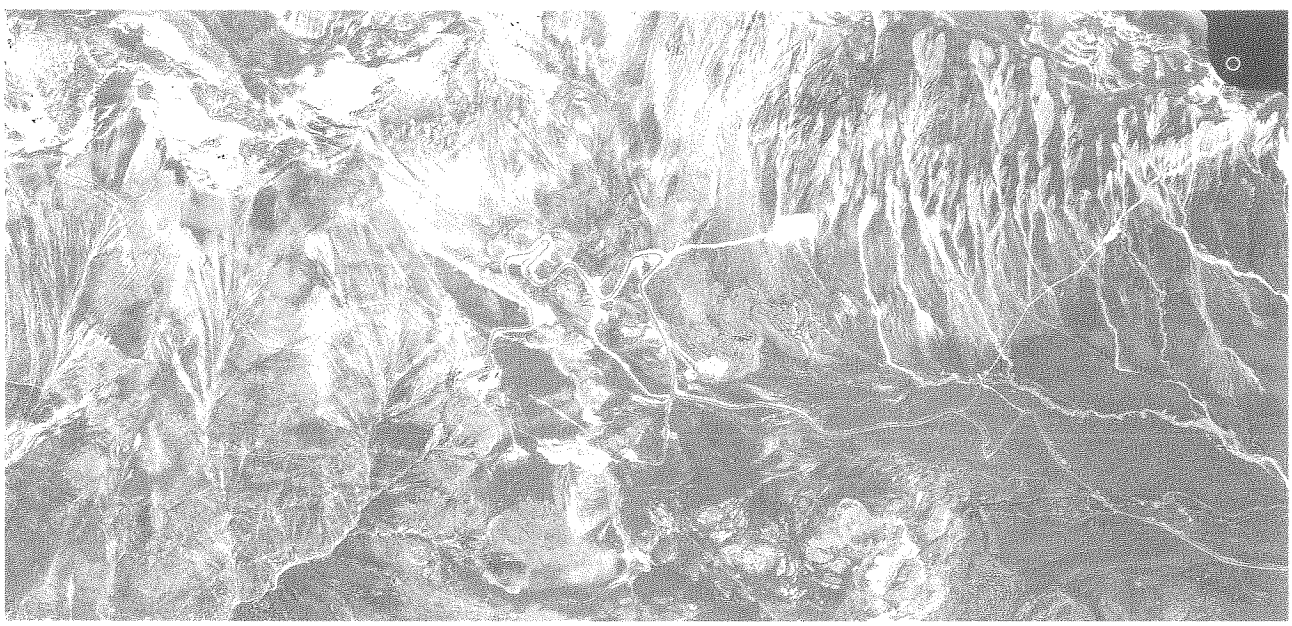


FIG. 2. - Vertical air photograph and detailed geomorphological map of Campo Imperatore and Mt. Aquila (Gran Sasso d'Italia). South-facing slopes have been affected by both pure gravitational processes and debris flow activity. Moraines supplied with slope debris were influential in developing the tongue-shaped rock glacier. Key: 1, narrow, rounded ridge crest, 2, narrow, knife-edged ridge; 3, dome-like summit, 4, broad, gentle elevated area limited by rounded break of slope; 5, broad, shallow denudation valley and gully in bedrock, 6, rockwall; 7, rocky slope; 8, debris-mantled slope; 9, chute; 10, stream channel cut in solid rock; 11, talus sheet; 12, talus cone; 13, debris stream; 14, debris flow cone; 15, boulder sheet, rockfall/rock-slide deposits; 16, sinkhole; 17, ground moraine; 18, distinct moraine ridge, a. frontal, b. lateral; 19, bedrock topography in valley bottom; 20, erosion furrow and meltwater channel; 21, rock glacier.

(Air photograph reproduced by permission of I.G.M., n. 282, 3.6.1982).

deposits which can be mostly referred to the last glacial expansion. More recent deposits are also present in the valley, which is filled by continental sediments such as glacial, fluvial and lacustrine deposits, to the depth of 200 m, as results from boreholes drilled for the construction of the Gran Sasso motorway tunnel (A.N.A.S. - CO.GE.FAR, 1979).

The western portion of the area was strongly affected by Pleistocene glaciations. Both erosional and depositional glacial forms were created and still dominate in this sector of Campo Imperatore. Within the glacial cirques hanging above the main depression, glacial drift deposits are poorly developed and, as a result of this, karstified bedrock topography covered by thin morainic deposits or individual erratic boulders is well visible in the field. Recessional moraine systems have been formed at varying altitudes: 2.250 m, 2.180 m, 2.000 m and 1.900 m. The South-facing slopes of Mt. Aquila were strongly remodelled by Late Glacial and Holocene slope processes. Weak rock complexes (mainly dolomitic and calcareous rocks strongly crushed by tectonics) have been transformed from rockwalls into rocky slopes and fragmented by debris flow gullies. Debris slopes located below them are reworked by substantial slope alluviation. Debris flow tracks of different size have been formed in the rocky gullies and produced a characteristic ribbon-like pattern of lateral levees and terminal lobes. Dense systems of rocky gullies show badland-like topography. Debris slopes, alluvial taluses and moraine system are dissected by debris flow tracks at an altitude of about 1.900 m. Glacial drift supplied by debris flows at the base of the South-facing slopes of Mt. Aquila were influential in developing the rock glacier shown at the centre of fig. 2. In this peculiar location, a strongly fractured sourcewall was potentially a site for debris production and rock glacier development at the foot.

As a result of moraine and talus debris displacement under cryogenic action, a few arcuate ridges have been formed in the lower part of the tongue-shaped body (locality Sorgente Fontari, ortophotomap n. 349 150 «Assergi»). Lateral limits and terminus zone are not well visible in the field, but due to surficial fluidal pattern there are no doubts that a relict rock glacier exists in this locality (tab. 1).

TABLE 1 - The Sorgente Fontari rock glacier

Altitude of the head	1.992 m a.s.l.
Altitude of the toe	1.910 m a.s.l.
Total length	400 m
Mean width	70 m
Surface area (on the map)	35.000 m^2
Slope angle of the head	20°
Slope angle at the centre	15°
Slope angle near the toe	10°
Slope angle of the front	25°

With some speculation, the age of the rock glacier formation could be related to the final recessional stages of the Campo Imperatore glaciation, marked by the moraines located at an altitude of about 2.050 m and 2.200 m.

MONTE VELINO AREA

The Velino Massif (maximum elevation 2.486 m a.s.l.) consists of Cretaceous limestones forming an anticline plunging NNE. Also in this case, a normal fault system dislocated into blocks the compressional structures, sometimes reactivating former shear planes (NIJIMAN, 1971).

The detailed geomorphological map of the northern side of the massif (fig. 3) shows the typical topography of an alpine glacial cirque, characterized by some 200 m high rockwalls with a set of gravitational talus cones below.

Rockwall taluses dominate below the rockwalls, while individual block falling. shattering and bouncing have been responsible for the development of talus cones. In general, bedrock topography dominates in cirque bottoms, even though two rock glaciers are present at the toe of talus cones.

The heads of the two rock glaciers are located respectively at 2.070 m (left-side landform) and 2.180 m a.s.l. (right-side one). At an altitude of 2.050 m, they merge in a 560 m long and 220 m wide tongue-shaped rock glacier body (area is about 195.900 m^2), whose toe is located at an altitude of 1.910 m. A few central furrows, extending downward for some 350 m, constitute a diagnostic pattern of cryogenic rock glacier. This voluminous deposit shows a transitional belt between pure talus debris system (in the source area) and glacial drift deposit system (in the lower part). All the observed geomorphological features make us sure that the deposit represents a pure talus debris rock glacier of cryogenic origin, that has been formed during the last cold period of the Late Glacial time.

MAIELLA MASSIF

The detailed geomorphological map of the Cannella Valley (fig. 4) in the Maiella Massif, just below the highest summit (Mt. Amaro, 2.792 m a.s.l.), depicts the high mountain landscape of an alpine type valley. The widespread plateau-like mature landscape of the Altipiano, with undulated dome-like summits, is elevated at a mean altitude of about 2.600 m. In this area, Paleogene limestones outcrop forming a wide anticline strongly affected by faults. Asymmetry of North- and South-facing valley sides is showy, North-facing slopes are steeper and developed as rockwalls or rocky slopes, with characteristic sharp rocky edges between slope and ridge crest. Coarse-debris talus slopes, produced by gravitational mass movements, show diagnostic features for dry creep — debris streams. As in other glacially transformed and highly elevated Apennine valleys, the moraine system is poorly developed. The flat valley bottom (some 800 m wide) shows bedrock topography of glacially polished and strongly karstified *roches moutonnèes*. Rockfalls from alpine cliffs supplied substantial amount of calcareous debris only to the foot of slopes. Close to the alpine cliffs, poorly developed systems of lateral or recessional moraines have been fossilized by slope debris. Mass movements are still very active due to both the high altitude (above 2.300 m a.s.l.) of the valley, that allows the formation of fresh debris

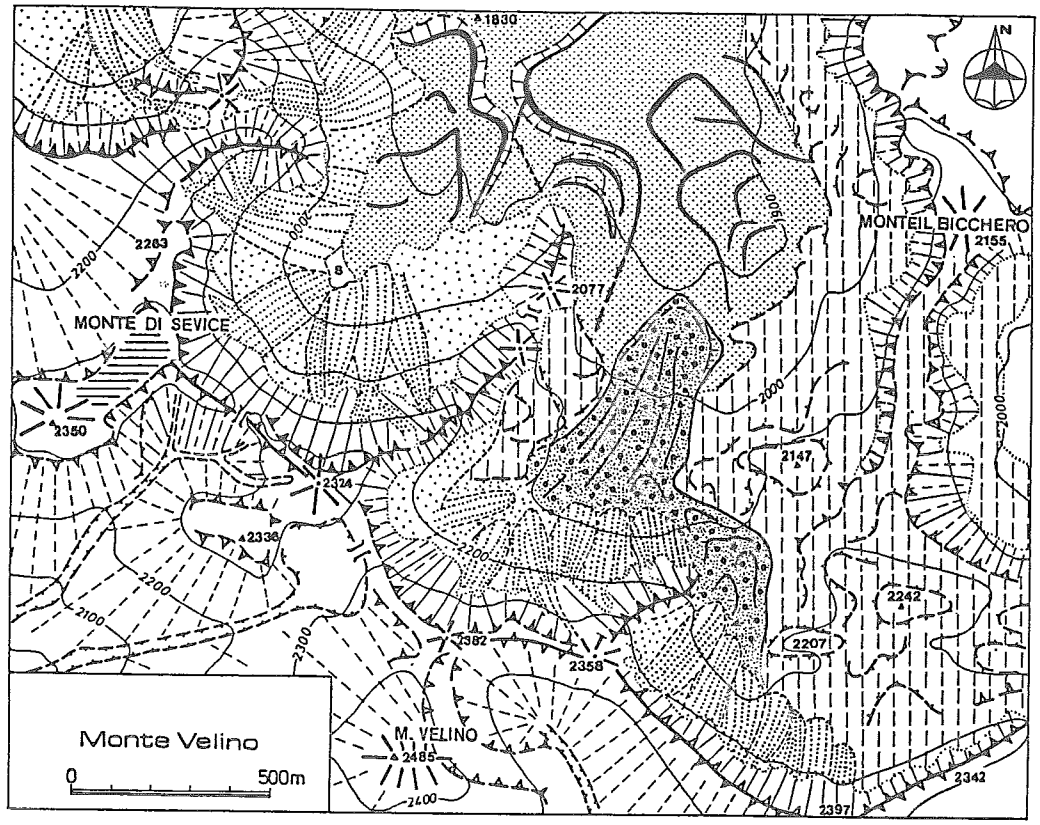


FIG. 3 - Vertical air photograph and detailed geomorphological map centred on glacial cirques of the Mt. Velino; North is at top. Within two glacial cirques, rock glacier features are coalescing into a well defined rock glacier tongue. Letter S in the glacial cirque North of Monte di Sevice shows the location of snow patches (September 13th, 1984). For the legend refer to fig. 2.

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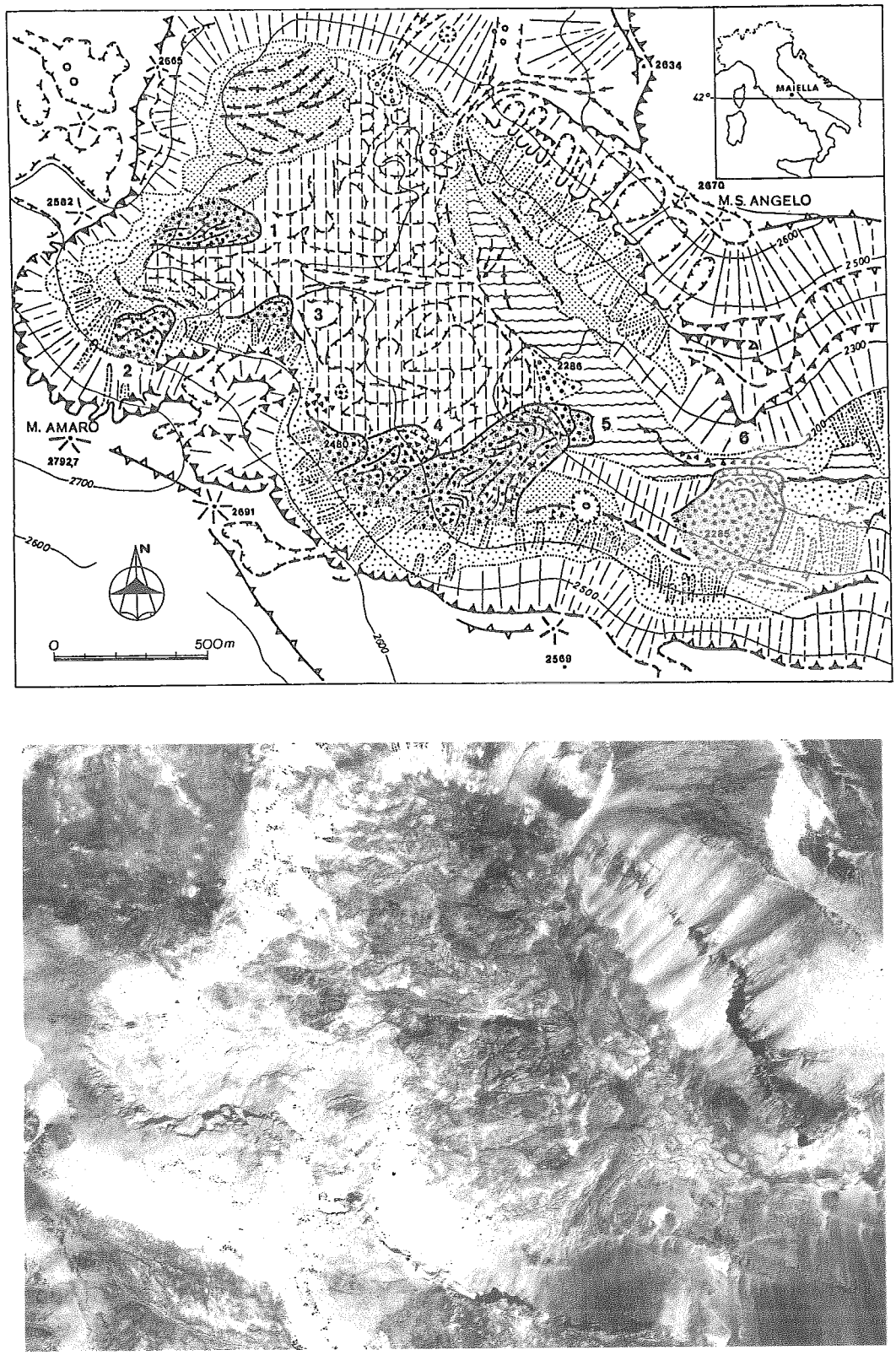

FIG. 4 - Vertical air photograph and detailed geomorphological map centred on the uppermost sector of the Cannella Valley (Mt. Amaro, Maiella Massif). Deglaciation patterns are poorly developed in comparison with classical cryogenic rock glaciers generated from North- and North-East facing talus cones. The rock glaciers are valley-wall type according to the terminology of OUTCALT & BENEDICT (1965). The uppermost rock glacier (n. 2), located North of Mt. Amaro, is still fresh and lichen-free. For the legend, refer to fig. 2.

(Air photograph reproduced by permission of I.G.M, n. 555, 6.12.1978).

slopes under the influence of present cryogenic processes, and the poor plant associations, representative for cold mountain desert (WHITEHEAD, 1951).

In the Cannella Valley, the most spectacular and voluminous rock glacier system has been identified on the North- and North-East- facing sides (fig. 4, tab. 2). These landforms occur below taluses originated mainly as a consequence of rockfalls and/or rockslides and only to a minor extent made up of fossilized lateral moraine debris.

TABLE 2 - The Cannella Valley rock glaciers (for the location refer to fig. 4)

Number of rock glacier	n. 1	n. 2	n 3	n. 4	n. 5	n. 6
Altitude of the head (m a.s.l.)	2.510	2.632	2.470	2.520	2.445	2.300
Altitude of the toe (m a.s.l.)	2.450	2.539	2.430	2.479	2.272	2.180
Total length (m)	320	200	120	320	835	220
Mean width (m)	160	200	110	150	236	270
Surface area (m^2)	42.500	28.700	18.300	21.260	191.340	93.500
Slope angle of the front (°)	-	40	-	20	28	-

The total surface area of rock glaciers in the studied valley is 395.600 m^2. When taking into account the taxonomic classification of rock glaciers proposed by CORTE (1987), the above described landforms are of a medium size (i.e. between 10^4 and 10^5 m^2 each). The longest one (835 m on the ground) is n. 5; it has been formed at the foot of debris slope and moved directly on the bedrock for at least 300 m. Non-glacial origin of all the rock glaciers recognized in the valley is evident. Preliminary results indicate that most of these «non-glacial» landforms are the products of a single phase of rock glacier activity. Only the longest one shows superimposed lobes indicating multiple phases of development.

The rock glacier n. 2, unlike the less elevated ones, is practically lichen free and shows fresh breaks in the surface which suggest present activity.

No measurements of movement have been yet made in the study area, therefore, the activity of the above landform is not confirmed by indisputable proof. Anyhow, taking into account that in the neighbouring multiannual snow patches exist in karst depressions (or in depressions within talus accumulations) starting from altitudes of 2.600 m, we can hypothesize that existence of permafrost (interstitial ice) is possible above these altitudes and that the rock glacier n. 2 represents a still perennially frozen debris body.

DISCUSSION

The first results of our investigations show that rock glaciers, diagnostic for creep of alpine permafrost (cryogenic origin) are rare in the Central Apennines. Their development required provision of a large amount of coarse debris, mainly supplied by rockfall/rockslide taluses and, to a minor degree, from alluvial taluses and glacial drift.

In Central Apennines, rock glaciers should be generally classified as relict landforms, generally covered by lichens (see also an example from the Northern Apennines by TOMASELLI & AGOSTINI, 1990). Only in the most elevated sector of the Maiella Massif (above 2.500 m a.s.l.) one landform looks active (i.e. fresh and almost lichen free). This suggests that the southernmost limit of present permafrost for the Apennines should be located at 42° 05' N latitude, at an elevation higher than 2.500 m a.s.l. This area is close to the 0° C — -2° C mean annual isotherm, where multiannual snow patches persist in ground depressions (DRAMIS & KOTARBA, 1992).

Two types of rock glaciers of cryogenic origin have been identified: a) landforms of pure talus type, called «talus rock glaciers», and b) landforms of moraine type, called «debris rock glaciers» after the terminology proposed by BARSCH (1987). Investigations demonstrated that type a) dominates in the Maiella and Velino Massifs (Fig. 3 and 4), while the Campo Imperatore area shows a relict rock glacier fed by lateral and ground moraines yield by alluvial taluses (fig. 2).

Within the study areas, rock glacier heads range between 1.992 and 2.632 m a.s.l., and toes occur between 1.910 and 2.539 m. This relatively narrow altitudinal belt is located above the lower limit of active structured soils and below the regional snowline. Above an altitude of 2.600 m, climatic conditions favourables for the existence of discontinuous mountain permafrost are present. This statement is based upon the observation (from air photographs taken in late summer) of multiannual snow patches at those altitudes.

The number of the studied rock glaciers is very small, so no relationship between elevation and aspect can be determined. It is only shown that most of them are located at the foot of North-facing slopes. According to GIRAUDI (1989), the Fucino area (located some 50 km S of the Gran Sasso, 30 km West of the Maiella and only 10 Km SE of the Velino Massif, at an altitude of 650 m a.s.l.), was characterized, about 13.000 years ago, by cold (and even severe) climatic conditions, favorable for rock glacier formation at altitudes above 2.000 m. After that period, climate was not severe enough to enable permafrost to persist at such altitudes over a long time, so the lower limit of high mountain permafrost shifted to at least 2.500 m a.s.l.

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