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DATING AND CORRELATION OF GLACIAL DEPOSITS USING TEPHRA LAYERS AND LOESS: THE EXAMPLE OF MT MATESE (CAMPANIA-MOLISE), SOUTHERN ITALY

INTRODUCTION

The Mt Matese, located on the border between the Campania and Molise regions (Southern Italy) is formed of Meso-cenozoic carbonatic rock and reaches a maximum elevation of 2,050 m a.s.l.

The Matese conserves evident glacial traces, attributed to the last glacial maximum (LGM) and its phases of retreat by G. Palmentola and P. Acquafredda (1983) and G. Palmentola et al. (1990): yet the established chronology of the authors lacks direct dating. E. Jaurand (1994) indicates that the maraines located at the margins of the glacial cirque of Mt Mileto are covered by an andosol, developed in Central Italy after the deposition of the tephra of the Neapolitan Yellow Tuff, according to M. Frezzotti and B. Narcisi (1989), and deduces that they are older than 13,000 yr BP.

The scarcity of direct datings of the glacial phases is common throughout almost all of the Apennine: the known dates, relative to fluvio-glacial deposits, indicate that on the Velino Massif (Central Italy) the LGM developed in a period considerably more recent than 30,000 yr BP and older than about 15,000 yr BP (Frezzotti and Giraudi 1992), while there is no direct data on the age of the successive phases of stadial retreat.

METHODS

The scarcity of the direct data relative to the glacial phases in the Apennine appears essentially due to the scarcity of datable sediment in contact with the moraines.

The moraines subsequent to the LGM are found at elevations above 1,600–1,700 m. At such elevations the organic soils began to develop more or less during the initial phases of the Holocene, since in the course of the late glacial there might have been periglacial phenomena, limited areas of discontinuous permafrost (Dramis and Kotarba 1994; Giraudi 1994, 1996), and in general the environment must have been still rather inhospitable.

Furthermore, but for the few places where lacustrine sediments (rather inorganic) are present behind the frontal moraine, the lacustrine basins that are generally typical of glacial morphology, did not form immediately after the glacial retreat. This peculiarity is explained seeing that the principle massifs are formed of carbonatic rock subject to karst phenomena. Moreover, the moraines present at high elevations are formed of coarse clasts with little fine matrix, and are consequently quite permeable, not fit therefore to block the flow of water and to form small lacustrine basins.

To date the moraines, it is required to verify if, amongst the more recent sediments that are found on top of these, exist deposits which can be chronologically attributed and can serve as stratigraphic markers for correlations with dated stratigraphic series that are located in different places. Among the useable deposits there are certainly the loess having at least regional distribution, the levels of tephra, deposited also at great distances from the volcano of provenience, and some soils with determining characteristics.

The research carried out in the Central Apennine demonstrated that, associated with deposits of glacial origin, at least a level of loess, formed essentially of quartz, and at least two tephra are present (Frezzotti and Giraudi 1989; Frezzotti and Narcisi 1989).

Therefore a massif, glaciated during the LGM, which could have the best potentiality for the presence of the above mentioned loess and of tephra to use for the dating and the correlation between distant profiles, was studied. The Matese, located at just 70–80 km to the North of the Phlegrean Fields and Vesuvius volcanoes, seems to be a site suitable for the deposition of Campanian tephra. Moreover, it is noted from the literature (Frezzotti and Giraudi 1990a) that on the Matese are present, in some intermorainic depressions, both the loess made up predominately of quartz, diffuse also in Central Italy of which the chronological attribution is known, as well as the tephra of the Neapolitan Yellow Tuff (Frezzotti and Narcisi 1989).

The distribution of the above mentioned stratigraphic markers was investigated by carrying out drillings with an auger, on sediments which occupy the bottom of some depressions present on the moraines of the Matese. Besides the said elements, two other tephra interbedded between the base of the loess and the Neapolitan Yellow Tuff were found and resulted quite useful as stratigraphic markers.

RESULTS

The stratigraphic markers defined, are represented by loess and by three levels of tephra.

The loess, of brown-pink color, made up mainly of quartz, was recorded at the Matese and in Central Italy, by M. Frezzotti and Giraudi (1990a, 1990b): it is the only loess with similar characteristics recorded in Central Italy in the last 30,000 years. Not more than 20 cm thick, it is always confined among sediments from the pre-Holocene and after the moraines of the main phases of retreat of the LGM glaciers.

At the Aremogna Plain (Frezzotti and Giraudi 1989) the loess contains a thin level of tephra, covers fluvioglacial deposits of the first phases of retreat of the LGM and is covered by a peat dated $12,850 \pm 200$ yr BP with ^{14}C . The beginning of the deposition of the loess must have been considerably before this date.

At the alluvial fan of the Majelama Valley on the Velino Massif (Abruzzo) the end of the sedimentation of the fluvioglacial deposits, analogous to those of the Aremogna Plain, took place at a time preceding c. 15,000 yr BP (Frezzotti and Giraudi 1992). If the deglaciation, linked to climatic factors, began contemporaneously throughout the Central Apennine, the eolian sedimentation at the Aremogna Plain must have begun c. 16,000–15,000 years ago.

The presence of levels of tephra, of undetermined origin, on the moraines of the Matese was recorded (Palmentola and Acquafredda 1983), and subsequently the tephra of the “Neapolitan Yellow Tuff”, originating from the Phlegrean Fields, datable to c. 12,000 yr BP (Scandone et al. 1991) was identified by M. Frezzotti and B. Narcisi (1989).

The tephra that were found and used as stratigraphic markers in the course of this study are the following:

T1 — a level of gray-greenish colored tephra, about 3–5 cm thick, with a sandy grain size; the level is contained within the eolian sediments made up mainly of quartz, and could, therefore, be correlated with that found in an analogous stratigraphic position at the Aremogna Plain, datable to a time successive to 15,000–16,000 years ago and before $12,800 \pm 200$ yr BP.

T2 — a level of tephra, up to 10 cm thick, of a greenish color, with a coarse sandy grain size; this level covers the loess containing T1 and is covered by the Neapolitan Yellow Tuff.

T3 — Neapolitan Yellow Tuff. This tephra has a gray-yellowish color, is very coarse sand, up to 30–40 cm thick; it is generally covered by sands of yellow and rust color, of whose thickness can be more than a meter, corresponding to the products of its reworking.

THE GLACIAL TRACES

The main glacier that was present on the Mt Matese during the LGM was formed by the confluence of two tongues coming from Mt Miletto (2,050 m) and Mt Gallinola (1,923 m) and the equilibrium line altitude (ELA) was placed at about 1,550–1,600 m (Palmentola and Acquafredda 1983; Palmentola et al. 1990). The same authors stress that during the phases of retreat, the glacier gave place to the formation of a few stadial moraines, the last of which would be datable, based on the valuation of the variables of ELA and to the correlation between the Apennine and Alpine stages, to the Older Dryas.

In this work, the relative date of the moraines deposited by the glaciers of Mt Miletto and Mt Gallinola during the phases of glacial retreat following the LGM, was established based on the distribution of the tephra levels defined on the same moraines. Thanks to this tephra one can ascertain (see below) that on the Matese there are testified at least six phases of retreat (Fig. 1).

The phases of glacial retreat of the LGM appear more complex than what has yet been hypothesized and are documented by:

- a moraine formed again by the confluence of the two glacial tongues (V1 of Fig. 1 that permits the calculation of ELA a little higher than 1,600 m);
- three frontal or lateral moraines of the valley glacier coming from Mt Gallinola (V2-G, V3-G and V4-G in Fig. 1, which permit the calculation of ELA, placed respectively at c. 1,700 m, 1,720 m and 1,750 m);
- a frontal moraine of the valley glacier fed by the cirque of Mt Miletto (V2-M of Fig. 1, which permits the calculation of ELA to c. 1,650 m);
- two moraines of the cirque glacier of Mt Miletto (C5-M, C6-M of Fig. 1 which permit the calculation ELA respectively to 1,850 m, 1,900 m).

In the cirque of Mt Miletto, are also present two small proglacial ramparts behind the more recent moraines.

On the moraines V2-G, deposited by a valley glacier fed by Mt Gallinola, the following tephra series and eolian deposits were found (from bottom to top):

- pink-brown silt of eolian origin, consisting of a notable percentage of quartz, corresponding to the loess described above, about 20 cm thick; interbedded in this silt is a tephra level of graygreenish color, about 3–5 cm thick, with a sandy grain size (T1); the bottom of the silt was sampled for ^{14}C dating (AMS) and provided a date of $6,265 \pm 110$ yr BP (UA-11,333); such a date is not considered reliable in as much as it would imply a date more recent than 6,000 years ago for some of the moraines (see below) present at Matese. This would seem quite improbable, therefore, the sample must have been contaminated by organic substances, much more recent than the deposition of the loess, coming probably from the soil;
- a second level of tephra up to 10 cm thick, of greenish color, with a coarse sandy grain size (T2);

— another level of sandy tephra (T3), of gray-yellowish color, very coarse, up to 30–40 cm thick, corresponding to the Neapolitan Yellow Tuff, datable to c. 12,000 yr BP recorded by M. Frezzotti and B. Narcisi (1989), J. Sevink and S. Paris (1989);

— yellow and rust colored sands, more than a meter thick, corresponding to the products of the reworking of the Neapolitan Yellow Tuff. As recorded by G. Palmentola and P. Acquafredda (1983) these types of sediments are, at times, deformed to festoons, by cryoturbation.

The moraines V4-G, at the site where the drilling was done, result covered, from bottom to top, by:

— 15 cm of brown-pink loess, in which is interbedded a level of gray-greenish colored tephra, about 3 cm thick, with a sandy grain size (T1);

— 170 cm formed by the Neapolitan Yellow Tuff and by products of its reworking.

The above mentioned moraines, as for those indicated as V2-G, and obviously the intermediate V3-G also, are therefore older than the tephra T1

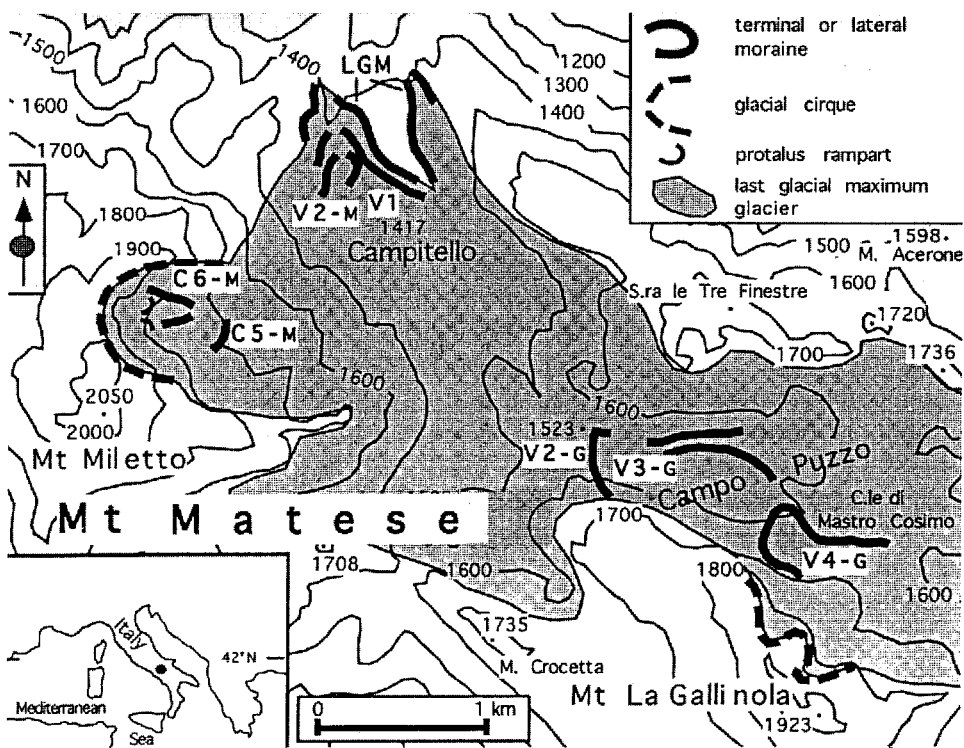


Fig. 1. Schematic map of the main glacial traces present from Campitello Matese, Mt Miletto, Mt Gallinola and Campo Puzzo, and the indicative extension of the glacier of the last glacial maximum Ryc. 1. Schematyczna mapa form lodowcowych na obszarze Campitello Matese, Miletto, Gallinola i Campo Puzzo. Pokazany zasięg lodowca w czasie maksimumostatniego zlodowacenia

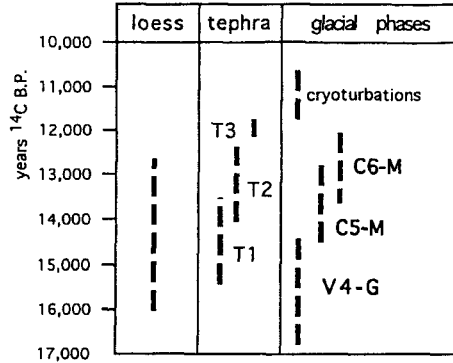


Fig. 2. Chronological framework of the last three glacial phases that took place on the Mt Matese Ryc. 2. Chronologia ostatnich trzech faz lodowcowych na obszarze G6r Matese

and the sedimentation of the loess (begun c. 15–16,000 years ago and ended before $12,850 \pm 200$ yr BP). The moraines V4-G were deposited by a glacier having ELA c. 1,750 m.

The moraines C5-M, at the site where the drilling was done, appear covered by:

- 20 cm of a greenish colored tephra, with a coarse sandy grain size (T2);
- 210 cm made up of the tephra of the Neapolitan Yellow Tuff and of the products of its reworking;
- 170 cm of colluvium mainly of silt containing a notable percentage of minerals of volcanic origin.

The moraines C5-M are therefore more recent than the end of the sedimentation of the loess and the fall of the tephra T1 and older than the deposition of the tephras T2 and T3. The sedimentation of the loess would have begun c. 15–16,000 years ago and ended before $12,850 \pm 200$ yr BP; the tephra T3 is datable to c. 12,000 yr BP. The retreat of the glacier that formed the above mentioned moraines appears therefore to include a period from a moment considerably after 15–16,000 yr BP and a moment considerably before 12,000 yr BP. The ELA of this glacier is c. 1,850 m.

The moraines C6-G, at the site where the drilling was done, were covered by:

- 30 cm of the tephra of the Neapolitan Yellow Tuff;
- 70 cm of products of the reworking of the above said tephra and of colluvia very rich in volcanic material.

The moraines C6-M are therefore older than c. 12,000 yr BP, and result more recent than the tephra T2. The moraines C6-M were deposited by a glacier having an ELA c. 1,900 m.

The debris that forms the protalus rampart covers the tephra of the Neapolitan Yellow Tuff: the protalus rampart are therefore more recent than c. 12,000 yr BP. Furthermore, in the depression on top of a protalus rampart

are present fill materials represented by colluvia, soils and by at least two levels of tephra different from those described. Of the two, the oldest appears quite different from the others for the presence of evident biotite crystals.

Based on the presented data, a preliminary chronological framework for the moraines present on the Mt Matese is obtained (Fig. 2), the framework being based on direct data and not on hypotheses based on the correlation between the variations of the ELA of the Apennines and that of the Alps. The dating of the events, even if not very precise, contribute to clarify that:

- the moraines V4-G must have an age older than c. 14,500 yr BP;
- the moraines C5-M must have an age from c. 14,500 to 13,000 yr BP;
- the moraines C6-M must have an age from c. 13,500 to 12,000 yr BP.

But from the observation of Fig. 2 emerges also a chronological attribution of the tephras T1 and T2:

- the tephra T1 must have an age from c. 15,500/16,000 to 13,500 yr BP;
- the tephra T2 must have an age from c. 14,000 to 12,500 yr BP.

For that which regards the dating of the oldest retreat moraines, stratigraphic elements different from those which served for the chronological framework of the V4-G moraines have yet to emerge. Since the phases of glacial retreat, being linked to climatic factors independent of local factors, and having taken place almost simultaneously at the regional level, it is possible to use the data relative to other massifs to better define also the phases of deglaciation of the Matese. In support of this assumption, one can observe that also at Mt Breccioso (1,974 m) in Abruzzo (Giraudi, in print), as at Matese, the last moraines deposited by a valley type glacier are covered with a quartz rich loess. On Mt Breccioso, at least two moraines of a valley glacier deposited during the first phases of glacial retreat, result before the deposition of a tephra a little older than $19,100 \pm 650$ yr BP: also at Matese, therefore, at least the moraines V1, V2-G and V2-M could be before such a date. The LGM of the Upper Pleistocene must have taken place at a time well before $19,100 \pm 650$ yr BP, and results therefore older than supposed without direct data.

A TENTATIVE TO IDENTIFY THE TEPHRA T1 AND T2

Trying to improve the datings obtained, an attempt to identify the two oldest levels of the tephra of the Neapolitan Yellow Tuff was undertaken.

The levels of tephra defined will be analysed only in a second moment along with the other new finds from the same massif. Yet, even without chemical-petrographic analyses, there are some stratigraphic and macroscopic elements which permit a preliminary hypothesis. That is, a correlation with the products of a few eruptions of the Campanian volcanoes that took place from the LGM to the age of the deposition of the Neapolitan Yellow Tuff.

The cores taken by a drilling of the sediments from the bottom of the Lago Grande di Monticchio lake (Southern Italy), about 100 km to the SE of the Matese, at 100–120 km from the Campanian volcanoes, recorded among

others, the tephra of the Neapolitan Yellow Tuff and three other tephra of Campanian origin (Narcisi 1996). These three tephra being older than the tephra of the Neapolitan Yellow Tuff, but more recent than the LGM. The analysed tephra, that must have been produced during the largest eruptions of that period, were correlated by B. Narcisi (1996), based on their chemical composition, with products of the eruptions, known from the literature and studied directly on the Campanian volcanoes.

The first of the tephra after the LGM is composed of black sands, and is attributed to the plinian basal eruption of Vesuvius. The products of this eruption cover paleosoils dated $16,250 \pm 130$ and $17,050 \pm 40$ yr BP (De Libria et al. 1979).

A second tephra is composed of a gray tuffite, and attributed to the "Greenish" eruption of Vesuvius; the products of this eruption cover paleosoils dated to $15,500 \pm 170$ and $14,420 \pm 160$ yr BP (Santacroce 1987).

The tephra that precedes the Neapolitan Yellow Tuff, is made up of olive colored sands and was attributed to the volcanic levels of the "unità dei tephra superiori" of the Phlegrean Fields. This unit has an age inferior to 14,000 yr BP (Alessio et al. 1976; Rosi and Sbrana 1987; Rosi et al. 1988).

The T1 tephra of the Matese, in so much as interbedded in the loess, has an age calculable from c. 15,500 to 13,500 yr BP and could correspond chronologically to the products of the "greenish" eruption of Vesuvius, more recent than paleosoils dated $15,500 \pm 170$ and $14,420 \pm 160$ yr BP.

The T2 tephra, in as much as interbedded between T1 and the Neapolitan Yellow Tuff and chronologically attributable to the period from c. 14,000 to 12,500 yr BP, could correspond to that present at Monticchio and identified as one of the products of the "unità dei tephra superiori" eruptions of the Phlegrean Fields, more recent than 14,000 yr BP.

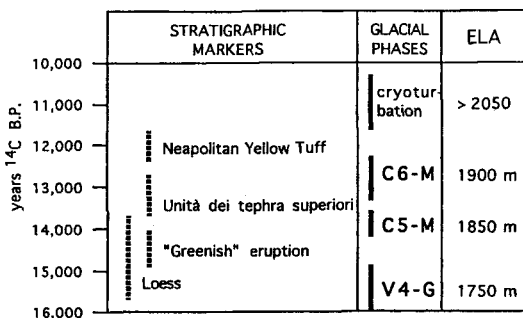


Fig. 3. Chronological framework of the last three glacial phases that took place on the Mt Matese, hypothesizing the correlation between the tephra found on the moraines and those studied in the sediments of the Lago Grande of Monticchio lake by B. Narcisi (1996)

Ryc. 3. Chronologia ostatnich trzech faz lodowcowych na obszarze Gór Matese zawierająca korelacje poziomów tufowych rozpoznanych na morenach z osadami oznaczonymi na obszarze Lago Grande Monticchio przez B. Narcisi (1996)

The T3 tephra, already determined by M. Frezzotti and B. Narcisi (1989) corresponds to the Neapolitan Yellow Tuff, dated to c. 12,000 yr BP.

On the moraines of the Matese, levels of tephra macroscopically similar to that present at Monticchio and attributed to the plinian basal eruption of Vesuvius have not been found.

If the correlation between the tephra of the Matese and that of the core of the Lago Grande of Monticchio lake is valid, a dating of the last stadial moraines of the Matese, more precise than that obtained by the use of the loess and Neapolitan Yellow Tuff, appears possible (Fig. 3).

The moraines V1, V2-G, V3-G and V4-G in Fig. 1, all precede the loess that contains the T1 tephra, datable to a little more recent than $15,700 \pm 170$ and $14,420 \pm 160$ BP. The said moraines would be therefore older than c. 15,000 yr BP.

The moraines C5-M, were deposited after the loess and before the tephra that is more recent than 14,000 yr BP and must have been deposited c. 14,000 yr BP.

The moraines C6-M, were deposited after the T2 tephra, more recent than 14,000 yr BP and before the T3 tephra, datable to c. 12,000 yr BP and must have been deposited c. 13,000 yr BP.

The protalus rampart and the cryoturbations are after the T3 tephra, therefore after c. 12,000 yr BP.

CONCLUSIONS

Based on what has been said so far, we can therefore conclude that on the Mt Matese exist six phases of retreat following the LGM: the four phases testified by the moraines formed by the valley glaciers of Mounts Miletto and Gallinola must be older than c. 14,500 yr BP, of these, the two lowest must be before $19,100 \pm 650$ yr BP; the two cirque moraines appear datable, between c. 14,500 and 12,000 yr BP. If the correlation between the tephra of the Matese and those of the core of the Monticchio Lake is valid, it is possible to establish that: the last moraine of the valley glacier is older than 15,000 yr BP; between the cirque moraines, the oldest is datable to c. 14,000 yr BP while the most recent to c. 13,000 yr BP.

These last datings seem supported by the chronological correlation with cold climatic events defined in other areas of the Apennines.

The studies of M. Frezzotti and C. Giraudi (1992) on the Velino Massif confirm the dates obtained at the Matese of the various phases of retreat characterized by valley glaciers: on both massifs they are older than 15,000 yr BP.

The stadial phase datable to c. 14,000 yr BP on the Matese, can be correlated to a phase of deposition of stratified slope deposits at Fucino (Abruzzo), which began c. $14,180 \pm 260$ yr BP, consequent to a cooling of the climate (Giraudi 1995).

The stadial phase datable to c. 13,000 yr BP can be correlated to a cold period identified at the Aremogna Plain by M. Frezzotti and C. Giraudi (1989) and dated to c. $12,850 \pm 200$ BP.

The moraines formed at the Matese before 15,000 years ago indicate an increase of the ELA, in respect to the LGM glacier, which reached about 150–200 m. The moraines formed c. 14,000 years ago indicate an increase of about 250–300 m, while those formed c. 13,000 years ago indicate an increase of about 300–350 m.

According to G. Palmentola et al. (1990) in the Central Southern Apennine the glaciers of the Apennine Stage II would be characterized by an ELA higher than c. 250–300 m in respect to the LGM, while those of the Apennine Stage III would be characterized by an increase of ELA in respect to the LGM of 450–500 m.

If the correlations between the entities of the ELA variations on the various massifs located at different latitudes is valid, one could deduce that, based on the data of the Matese just presented, the Apennine Stage II must be datable to c. 14,000 years ago. Nevertheless, there is need for caution when attempting this correlation: the moraines of the Apennine Stage II, as described by Federici (1979), are not cirque moraines, but seem to correspond, instead, to the moraines V4-G which might be older than 15,000 yr BP. It is believed that presently there are not sufficient elements to correlate the moraines of the Matese with the moraines attributed to the Apennine Stage II by P. Federici (1979). In any case, the last moraine of the Matese could not be correlated, on the base of ELA variations, with the Apennine Stage III of P. Federici (1979): during this Stage the ELA would have risen to, in fact, c. 600 m in respect to the LGM.

It is probable, moreover, that the cryoturbation, that involved the products of reworking of the Neapolitan Yellow Tuff, took place during a cold period, in which at Mt Greco (Abruzzo), located about 55 km to the NW of the Matese, developed a small rock glacier after the fall of the Neapolitan Yellow Tuff, at an elevation of c. 2,100 m (Giraudi 1996). This period must have coincided with the Younger Dryas, in as much that it does not seem believable that in the Holocene there could have been such a cold event to induce the formation of discontinuous permafrost at such low latitudes and at such altitudes. To the same period can be, doubtfully, ascribed the formation of the protalus rampart of Mt Miletto.

The presence of stratigraphic markers common to the Matese, the Aremogna Plain and Mt Breccioso, allow for the direct correlation between sedimentary series that are distant and from different environments: it is evident that the identification of the same stratigraphic markers in other places could permit correlations between events or series of events even in absence of radiometric dates.

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STRESZCZENIE

C. Giraudi

DATOWANIE I KORELACJA OSADÓW GLACJALNYCH ZA POMOCĄ TUFÓW WULKANICZNYCH
I LESSÓW: PRZYKŁAD Z GÓR MATESE (CAMPANIA–MOLISE), POŁUDNIOWE WŁOCHY

Późnoplejstocenijskie osady glacialne w Apeninach do tej pory nie posiadają dobrego oznaczenia wieku, ponieważ na zapleczu moren tylko sporadycznie występują jeziora i warunki dla zachowania substancji organicznej, które pozwoliłyby na datowanie osadów metodą radiowęglą ^{14}C . Jednak w okresie od 16 do 10 tysięcy lat temu wystąpiły różne erupcje wulkaniczne w Kampanii, a ich produkty były rozpoznane w środkowych i południowych Włoszech. W tym czasie miała również miejsce depozycja lessów. Na obszarze Gór Matese znaleziono pokrywy lessowe i trzy poziomy pokryw wulkanicznych. Występują one w zagłębieniach położonych po wewnętrznej stronie moren i dzięki temu pozwalają na określenie sześciu faz cofania lodowców. Cztery fazy określone systemami moren były utworzone przez lodowce dolinne, a dwie fazy przez lodowce cyrkowe. Pierwsze cztery są starsze niż 15 tysięcy lat BP, a dwie następne są datowane na okres około 14 i 13 tysięcy lat BP. Zjawiska krioturbacyjne uformowane w osadach zawierających najmłodsze warstwy tufowe wskazują, że powstały one w okresie młodszego dryasu.