Landform Analysis, Vol. 2: 37–43 (1999)

The extent of Pleistocene glaciations in the western part of the Campo Imperatore (Gran Sasso Massif, Central Italy)

Carlo Bisci, Bernardino Gentili

Department of Earth Sciences,
University of Camerino,
via Gentile III da Varano, Camerino I-62032, Italy

Francesco Dramis

Department of Geological Sciences,
Third University of Rome,
Largo San Leonardo Murialdo 1, I-00146 Rome,Italy

Sirio Ciccacci

Department of Earth Sciences,
University "La Sapienza",
p. A. Moro, I-001, Rome, Italy

Adam Kotarba

Department of Geomorphology and Hydrology,
Polish Academy of Sciences,
ul. św. Jana 22, P-31018 Kraków, Poland

Landform Analysis 1999

Abstract: The Campo Imperatore is a virtually undrained tectonic depression located in the inner part of the Gran Sasso Massif, the highest relief within the Apennines (2,912 m a.s.l. at Corno Grande).

This paper reports some major geomorphologic features of the western part of this depression, which represents a specific and very fine example of glaciated mountain landscape, where landforms typical of glacial erosion are commonplace over 1,800 m a.s.l. Most of the glacial cirques are characterized by karstified bedrock topography, in places covered with thin drift deposits. Distinct recessional moraines are also present at various altitudes (i.e. around 2,250; 2,180; 2,000 and 1,740 m a.s.l.). However, the most typical landforms on the floor of the main depression are those due to glacial deposition. There, at altitudes ranging around 1,640–1,590 m a.s.l., stagnant ice deglaciation patterns dominate in the form of a wide lobate moraine system which rises 25–30 m above an outwash plain covered by glaciofluvial, lacustrine and alluvial deposits. Within the latter, small (less than 10 m high) hills, comprising glacial drift, protrude from the flat valley floor. The remnants of these strongly degraded, transformed and laterally-eroded moraines denote the maximum extent of an older glaciation, some 1.5 km remote from the main system.

Key words: glacial morphology, stagnant ice topography, Pleistocene glaciations, Central Apennines

Introduction

The cold phases of the Pleistocene period contributed effectively to the landscape evolution of most of the mountain areas of the Italian peninsula. Along the Apennines, in particular, it is possible to observe many well preserved relict landforms and deposits, typical of either a glacial environment (e.g. glacial cirques and moraines) or a periglacial environment (e.g. rock glaciers and stratified slope-waste deposits).

Periglacial morphogenesis is still active locally at the highest elevations (Dramis & Kotarba, 1994; Giraudi & Frezzotti, 1997; Bisci *et al.*, in press), while only one small debris-covered cirque glacier is present: the Calderone glacier, which is located on the northern slope of Corno Grande (Gran Sasso Massif, Central Apennines) between 2,867 and 2,676 m (Smiraglia & Veggetti, 1992).

The aim of this paper is to contribute to a better knowledge of the effects of past cold periods in the uppermost portion of the Apennines, by identifying and describing the landforms and deposits associated with the glaciations which affected the Campo Imperatore valley (Gran Sasso Massif) during the Late Quaternary (Figs. 1, 2, 3).

Description of the study area

The Campo Imperatore is a wide NW-SE trending tectonic depression located in the inner part of the Gran Sasso Massif (2,912 m). The study area, which will be described below, is its initial western part. This is more than 13 km long and c. 4 km wide, with elevations ranging from 2,494 m a.s.l. at its northernmost end (Mt. Aquila) to about 1,480 m a.s.l. at its lowest point.

The present-day climate of the Campo Imperatore is characterized of an average annual rainfall of 1,120 mm, with minimum precipitation in winter and summer (as recorded in the meteorological station located within the study area, very close to Albergo Campo Imperatore, at 2,138 m a.s.l.). The mean annual temperature is 4,7 °C, with an annual range of monthly averages of 16,2 °C (Demangeot, 1965). The 0 °C mean annual temperature is located around 2,900 m a.s.l., close to the highest peak of the Gran Sasso Massif (Corno Grande, 2912 m a.s.l.). The elevation of the Würm snowline was about 1,800 m, i.e. c. 1,100 m lower than at present (Demangeot, 1965).

The bedrock comprises of the following units (Ghisetti & Vezzani, 1986; Ghisetti *et al.*, 1990): massive dolomites (Lower Lias), bioclastic grainstones (Dogger – Lower Cretaceous), marls, shales and cherty mudstones (Upper Lias – Tithonian), bioclastic mudstones with cherty levels (Upper Jurassic – Lower Cretaceous), pelagic mudstones, marly mudstones and grainstones (Upper Cretaceous – Middle Eocene), packstones and grainstones with marly mudstones (Eocene – Oligocene) and laminated marls and marly mudstones (Lower-Middle Miocene).

The study area generally follows a monocline which dips gently to the northeast, even though the overall structure is the result of the tectonic superimposition of several units (following a NE trend), which took place during an Upper Miocene – Lower Pliocene compressional phase (Parotto & Praturlon, 1975; Ghisetti & Vezzani, 1990; Bigi *et al.*, 1991).

During the Quaternary, the area was subjected to extensional tectonics (Carraro & Giardino, 1992; Jaurand, 1992; Giraudi, 1994) which produced systems of normal faults, most of which trend ENE-WSW and which border the Gran Sasso Massif on its southern margins. This tectonic phase, which has continued up to the present, has resulted in a progressive lowering of the central portion of the basin with respect to the surrounding ridges.

On the slopes, present-day tectonic activity is indicated by the presence of spectacular triangular facets, fresh scarplets and intense badland-like erosional phenomena, the last of which affect brecciated dolomites. Locally, these faults also cut Late Quaternary deposits (stratified slope-waste deposits and alluvial fans) (Fig. 4).

Also, strong earthquakes recorded in adjacent areas (up to 10 MCS in the L'Aquila basin, located about 10–15 km to the west) clearly indicate the intensity of present-day tectonic activity (Postpischl, 1985; Societá Geologica Italiana, 1989). This extensional tectonics has been accompanied by tectonic uplift, the intensity of which increased considerably by the end of the Lower Pleistocene. This has enhanced the relief by up to 1,000–1,500 m (Demangeot, 1965; Ambrosetti *et al.*, 1982; Dufaure *et al.*, 1989).

The Campo Imperatore depression is partially filled by Quaternary deposits which, as discussed below, are primarily of glacial, glaciofluvial, alluvial, colluvial and lacustrine origin. The thickness of these sediments is considerable, as confirmed by a deep borehole, drilled in the uppermost portion of the valley, which went through some 200 m of continental sediments (Co.Ge.Far., 1979).

The study area represents an excellent example of classical glaciated mountain landscape (Klebelsberg, 1930–31; Suter, 1939; Demangeot, 1965; Ghisetti *et al.*, 1990; Bisci *et al.*, 1993). Both erosional and depositional landforms are present, showing evidence of both Alpine glacial morphology (at altitudes above c. 1,800 m a.s.l.) and a stagnant ice deglaciation pattern, characteristic of a flat-floored topography (at lower altitudes, along the valley floor).

The effects of the two main Pleistocene glaciations can be recognised throughout most of the investigated area (Bisci *et al.*, 1993; Giraudi, 1994). These glacial episodes have been distinguished by local names: "Piano Racollo" for the older glaciation and "Coppe di Santo Stefano" for the younger (Fig. 5).

The Piano Racollo glaciation

The Piano Racollo glaciation is the oldest and most extensive glacial phase recognised in the Campo Imperatore basin. It affected nearly the whole study area, from Mt. Aquila to the base of Mt. Bolza and Mt. Mutri. Most of the glacial cirques produced during this phase have substantially been reworked by the glaciers of the most recent glaciation. But on the warmer southern slopes and west-facing slopes of Mt. Prena, an old glacial cirque is present which was not reactivated during the last glaciation and which was strongly affected by both linear erosion, and, subordinately, by debris flows. During this ancient glaciation, the maximum length of the glacier was at least 12.5 km and its width at the depositional zone was c. 3 km. The glacial advance that produced the most extended glacial limit was reconstructed mainly on the basis of the distribution of erratic boulders and small moraine remnants.

Fig. 1. General view to Campo Imperatore tectonic depression from east. Corno Grande (2,912 m a.s.l.) in the background. Frontal look at Coppe di Santo Stefano terminal moraine system.

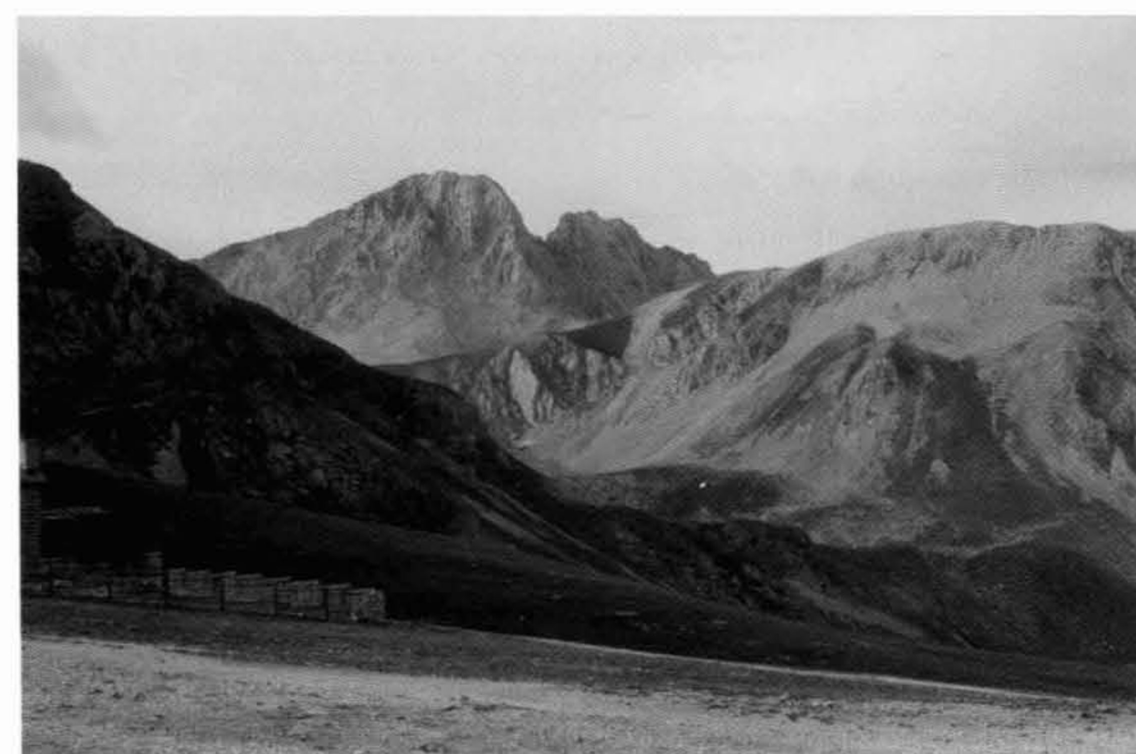

Fig. 2. The uppermost reach of Campo Imperatore. Landforms typical of glacial erosion below Mt. Aquila. Within glacial cirque karstified bedrock topography with thin drift deposits.

Fig. 3. Minor glacial cirques below Mt. della Scindarella. Regular, arcuate rampart classified as nival moraine.

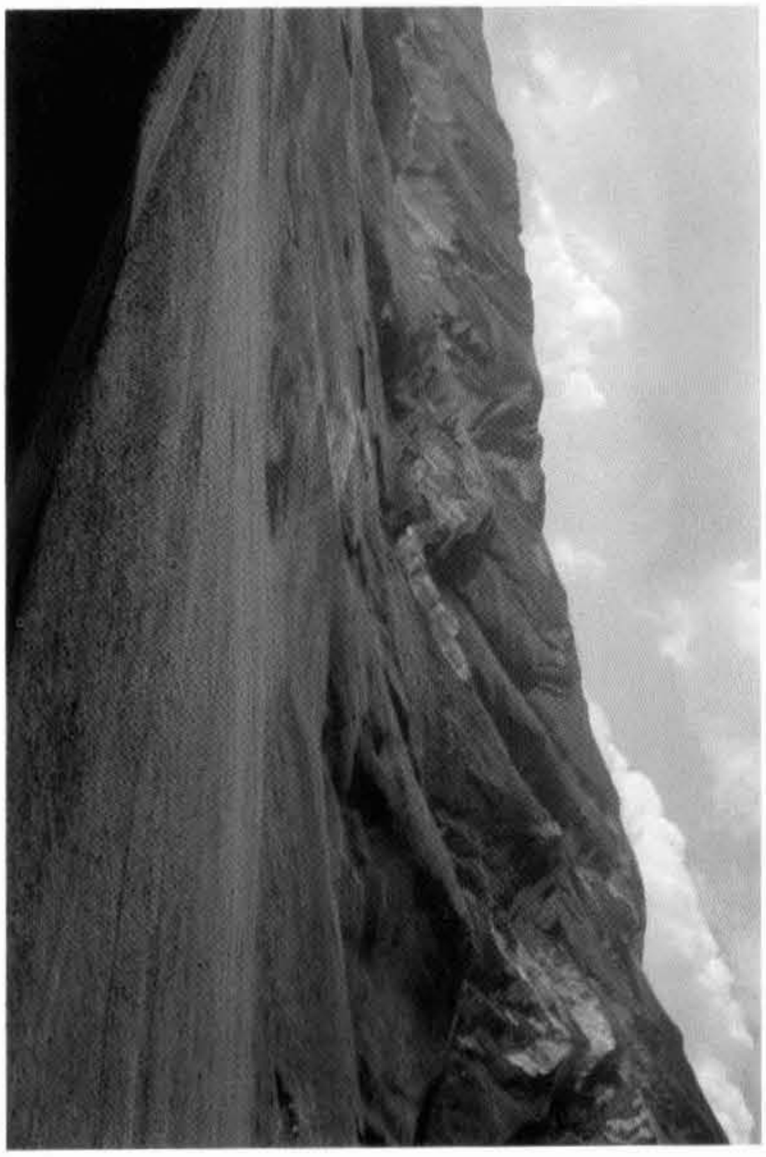

Fig. 4. Flat-floored valley bottom filled with generally non-cemented fluviolacustrine sediments (unit 3) close to Lago Petranzoni. Present-day tectonic activity is indicated by the presence of fresh scarplets and intense badland-like erosional phenomena.

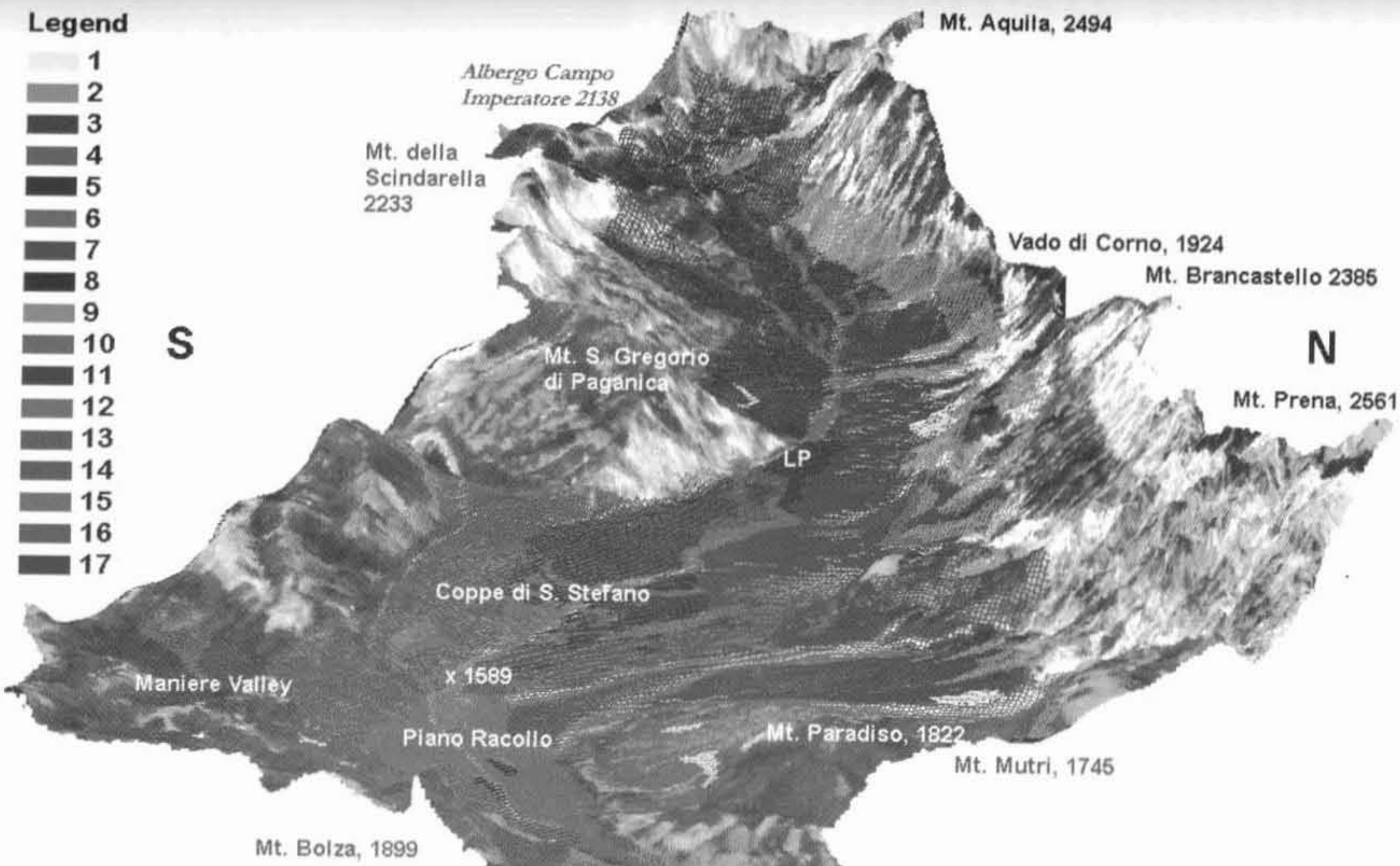

Fig. 5. Interpretative three-dimensional block diagram of the area. Legend: 1 – conglomerates; 2 – slope debris; 3 – alluvial fan; 4 – glaciofluvial deposits; 5 – lacustrine deposits; 6 – fluvio-lacustrine deposits; 7 – delta; 8 – glaciofluvial elongated hill; 9 – rock glacier; 10 – Piano Racollo moraine; 11 – 14-Coppe di Santo Stefano terminal moraines (successive stages); 15 – lateral moraine; 16 – ancient eroded moraine; 17 – glacial drift, LP – Lago Pietranzoni (lake).

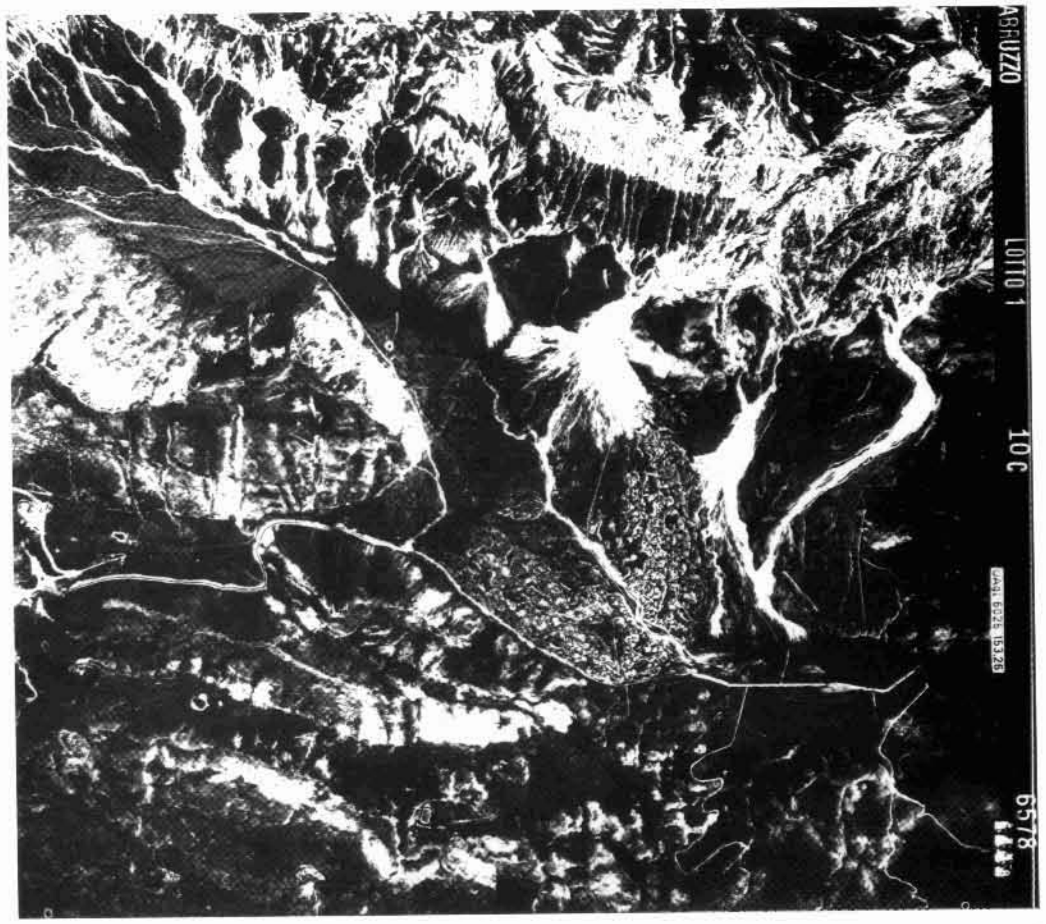

Fig. 6. Aerial photograph centred on the Coppe di Santo Stefano area where typical stagnant ice deglaciation patterns are clearly visible.

Fig. 8. South-facing slopes of Mt. Brancastello and Mt. Prena strongly modified by water erosion and periglacial processes. Between moraine topography of Santo Stefano Glaciation (frontal part of the photo) and rocky slopes, coalescing alluvial fans constitute the most spectacular landforms at Campo Imperatore.

The southwestern maximum lateral extension of the Piano Racollo glaciation is denoted by erratics deposited on the glacially-polished limestone hills of the Maniere valley. These boulders are mainly composed of well-cemented conglomerate (breccia), similar to that constituting the glaciated valley floor in the upper section of the depression (at altitudes ranging between 1,660 and 1,900 m a.s.l.). The less common red limestone erratics are also good indicators of long glacial transportation, since this lithotype crops out only close to the western end of the main watershed.

A rather well-preserved lateral moraine system, which has locally dammed minor side valleys (thereby causing lacustrine deposition) is a further feature of the southernwest margin of the Campo Imperatore. A small glaciofluvial delta produced by water flowing from the ice mass, which still exists in one of these small basins, provides evidence for this.

In Piano Racollo, only small patches of moraines (often strongly remodeled) are still recognizable within the outwash plain.

Along the southern side of the valley, at the base of the Cima di Mt. Bolza, remnants of the older glaciation are represented by narrow shelves of glaciofluvial sediments, formed as ice-contact deposits. The glacial/glaciofluvial origin of these deposits is confirmed by both the abundance of coarser sediments and the presence within these terrace-like features of badly preserved dead-ice hollows.

In the same area, a small hill composed of non-sorted, sharp-edged boulders and cobbles with a sandy-silty matrix protrudes about 10 m above the nearly flat valley bottom (outwash plain). The very gently undulating or planar crest of the hill, which is interpreted as a remnant of a moraine, shows evidence of creep and solifluction processes.

To the northwest, the limit of glacial deposition has not clearly been defined, since glacial deposits have been buried by very large coalescent alluvial fans, which have probably been active during the whole timespan from the end of this glacial period to the present. Only a very small morainic hill protrudes immediately to the west of the huge fan which borders the western slope of Colle Paradiso.

The Piano Racollo glaciation also produced glaciofluvial and glaciolacustrine sediments. These deposits form an elongated hill (1,567 m a.s.l.) which is elevated a few meters above the valley floor and consists of well-rounded cobbles and pebbles in a sandy-silty matrix. This landform (interpreted as an esker) still shows a well-defined morphology with relatively steep sides, and trends parallel with the reconstructed ice flow direction.

The Coppe di Santo Stefano glaciation

The more recent Coppe di Santo Stefano glaciation is characterised by extensive and well-preserved terminal (and, subordinately, lateral) moraines, which show a distinctive morphology. These glacial features differ significantly from those of the Piano Racollo glaciation, especially in respect of their freshness. The maximum extent of the glacier is clearly marked by the sharp morphological contrast between its morainic system and its outwash plain (Fig. 6).

The most conspicuous features in the main valley depression are landforms of glacial deposition. In altitude, these range from 1,640 to 1,590 m a.s.l. A stagnant ice deglaciation pattern is dominatand. This has the form of a c. 2.5 km wide lobate moraine system, rises 25–30 m above the surrounding plain. Within this widespread outwash plain, formed by glaciofluvial water, braided paleochannels show a well-preserved braided river pattern.

The morphology of the area affected by the Coppe di Santo Stefano glaciation suggests that most of the ice entered the central depression from the north-west (glacial cirques of Mt. Aquila, Mt. della Scindarella and Mt. S. Gregorio di Paganica) and then flowed southeastwards, along a relatively narrow (ca. 1 km wide) valley section between Mt. S. Gregorio di Paganica and Mt. Brancastello. Minor lateral glacial valleys and cirques generally show bedrock topography, only locally being covered by poorly developed recessional moraines.

The glacial erosion scarps present on the slopes of Mt. S. Gregorio di Paganica suggest that the ice body was at least 250 m thick. On reaching the Coppe di Santo Stefano area, the valley glaciers coalesced to form a 2.5 km wide piedmont-like glacier.

Supraglacial sediments (10–20 m thick) deposited during the more recent glaciation have been affected by differential ice melting. This has resulted in spectacular topographic irregularities, well visible both in the field and on air photographs (Fig. 6). This morphology is similar to the so-called "karst topography on stagnant glaciers" described by Clayton (1964) and Clayton and Moran (1974).

In the area immediately behind this terminal moraine system, comprising of partially coalescent morainic arcs which were deposited during successive stadial periods, older glacial sediments have been found to be partially covered by younger ones. Close to the Lago di Pietranzoni, there is a small patch of ancient till, which has been overridden by the younger ice body and fossilised by supraglacial deposition. In the same area, moderately thick fluviolacustrine deposits have infilled older depressions in the previous topography, so producing a flat plain. Distinct recessional moraines are also present at various altitudes. At least four main stadials are recognizable in the valley (i.e. close to 2,250; 2,180; 2,000 and 1,740 m a.s.l.).

As indicated by the small delta constructed by a stream which fed a minor depression dammed by the main moraine, the more recent glaciation also produced minor lacustrine basins.

Because deposits correlated to the "Tufo Giallo Napoletano" volcanic episode rest on the glacial drift (Frezzotti & Narcisi, 1989; Carraro & Giardino, 1992), the Coppe di Santo Stefano glaciation must have culminated before 13,000 yr. B.P.

Periglacial processes (more common along the northern slopes of the valley) were partially simultaneous with the glaciation and strongly affected the area after the ice retreat. In fact, since the broad valley depression of the Campo Imperatore was never completely filled by the Pleistocene ice body, the surrounding mountain slopes, mainly comprising tectonically fragmented calcareous and dolomitic rocks, were widely affected by geomorphic processes typical of the periglacial environment. In such an environment, on south-facing slopes, huge amounts of frost-shattered materials were produced. The presence of an abundant amount of water shifted the freshly-produced debris and converted it into stratified slope-waste deposits (grèzes litées). More ancient stratified slope-waste deposits, well cemented by pedologic processes in their uppermost part, are present at the base of the north-eastern slope of the valley. These deposits, which locally show evidence of having been affected by recent tectonic activity (Carraro & Giardino, 1992), are tentatively attributed to the Middle Pleistocene.

After the retreat of the last ice body, the upper portion of the main valley was strongly affected by periglacial morphogenesis. A relict rock glacier (Ghisetti *et al.*, 1990; Dramis & Kotarba, 1994) is fairly well preserved at an altitude of about 1,900 m a.s.l. on the western side of the valley. According to Giraudi & Frezzotti (1997) there are at least three generations of rock glaciers in the Campo Imperatore. They were distinguished by both absolute and relative dating and pedogenetic condition of these features.

Coalescent alluvial fans and composite debris flow cones are the most spectacular landforms in the Campo Imperatore; they cover large areas between the steep, mainly south-facing slopes and the drift-filled valley floor, thereby fossilizing the glacial depositional landforms (Fig. 8). The alluvial fans were formed during the Late Pleistocene, possibly during the second glacial phase, as testified by ^{14}C dating of paleosoils included within an alluvial fan located in the eastern part of the Campo Imperatore (Frezzotti & Giraudi, 1990).

Geomorphological studies by Giraudi (1994) show that alluvial fans have been developed in five phases, the last related to the present day alluviation of the area.

Geomorphologic units recognized

Links between the two glacial phases (and related landforms) described here can be observed within the framework of several geomorphologic units (Fig. 7).

Unit 1 – Glacial erosion landscape with hanging valleys: this is frequent at altitudes higher than ca. 1,800 m a.s.l., where the floors of glacial cirques are characterized by the presence of either poorly developed recessional moraine systems or occasional glacial erratics on a karstified bedrock topography.

Unit 2 – Erosional morphology of glacial valleys: this may be recognized at an altitude ranging from 1,850 to 1,660 m a.s.l., mainly on outcrops of breccia. Loose erratics, either of limestone or conglomerate, are locally present, but a continuous ground moraine is absent; lateral moraine is discontinuous, it is mostly present on the right-hand (southern) side of the main valley.

Unit 3 – Flat-floored valley bottom: this is filled with generally non-cemented fluviolacustrine sediments (locally covering older glacial deposits) and is present in the internal part of a distinct moraine system (unit 4) at an altitude of c. 1,640 m a.s.l.

Unit 4 – The moraine system of the Coppe di Santo Stefano: this well-preserved arcuate and complex moraine system, deposited during the more recent glaciation, dominates in the intermediate portion of the valley floor and features a spectacular stagnant ice deglaciation pattern.

Unit 5 – The foreland of the moraine system of Coppe di Santo Stefano: this is characterized by an outwash plain correlated with the younger moraine system. Within the latter, small hills protruding from the surface have been interpreted as the remnants of the moraine system created during the older glaciation. The latter was strongly eroded and reduced during the more recent cold phase. The maximum extent of the Piano Racollo glaciation is marked both by erratics and small moraine remnants, the latter being located at a distance of about 2 km from the slopes of Mt. Bolza.

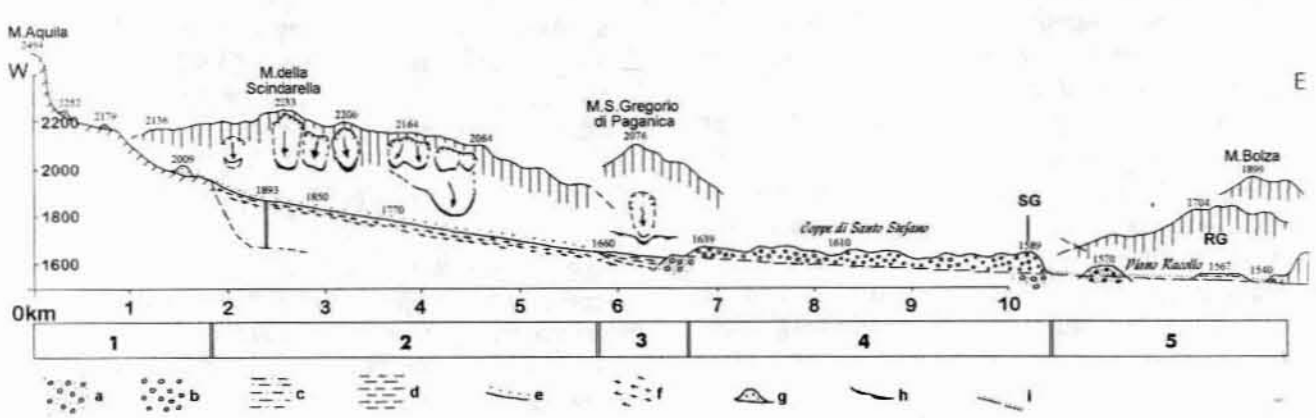

Fig. 7. Schematic cross section along the main valley, showing the principal geomorphologic units (numbers 1 to 5 in the bar below the section indicate the approximate extension of each unit; for their description refer to the text). SG and RG respectively indicate the maximum extension of the Coppe di Santo Stefano and the Piano Racollo Glaciation. Legend: a – moraine (Piano Racollo glaciation); b – moraine (Coppe di Santo Stefano glaciation); c – glaciofluvial deposits (Coppe di Santo Stefano glaciation); d – fluviolacustrine deposits (Coppe di Santo Stefano glaciation); e – glacial erratics on bedrock topography (Coppe di Santo Stefano glaciation); f – well cemented conglomerate (breccia), eroded by glaciers; g – recessional moraine (Late Glacial); h – lateral moraine (Coppe di Santo Stefano glaciation); i – outwash plain (Coppe di Santo Stefano glaciation).

Discussion and conclusions

Geomorphologic field works recently carried out in Campo Imperatore, have demonstrated that the glacial landforms there are related to two separate glaciations (Bisci *et al.*, 1993; Giraudi, 1994) and not to the single phase recognised by Demangeot (1965). The relative sharpness and freshness of the landforms associated with the more recent glacial period, the distance of different terminal deposits from glacial cirques, the degree of soil development and the lithological composition of sediments, are all insistent that the area has been affected by at least two major glaciations. Furthermore, it is clear that the more recent one was significantly less extensive than its predecessor.

The maximum extent of the first glacial phase (Piano Racollo glaciation) is not clearly defined owing to the scarcity of related moraines. Glacial depositional features relating to this have effectively been removed by the proglacial waters of the second glaciation and have often been concealed by the large alluvial fans which are widespread at the base of the mountains bordering the depression. On the basis of the distribution of erratics and small remnants of moraine deposits, it has been determined that the oldest glaciation extended down to about 1,550 m a.s.l. By contrast, the limits of the less-extensive glaciation have been very well defined by its distinct moraine pattern, typical of a supraglacial morphology, which reached c. 1,589 m a.s.l. (i.e. it extended for about 1.5 km less than the older one).

Taking into account the geomorphological position and freshness of the Coppe di Santo Stefano terminal moraine, the glacial phase responsible for its deposition might reasonably be correlated to the Würm III stage (Pleniglacial) which occurred in the Apennines, as elsewhere in continental Europe (Würm), from 21,000 to 18,000 years B.P. (Federici, 1979a). In fact, these glacial deposits are partly covered by the "Tufo Giallo Napoletano" which is dated c. 13,000 years B.P. (Frezzotti & Narcisi, 1989). By contrast, according to paleoclimatic reconstruction elaborated by Giraudi (1989) for the neighbour Fucino Lake area (some 30 km to the south, at an altitude of about 650 m a.s.l.), the last period with a damp-cold climate in the Apennines was between 24,000 and 20,000 years B.P. Thus, the recessional moraines recognized in the area may reasonably be referred to the Late Würm deglaciation, since it is probable that only at higher altitudes did a few small cirque glaciers (such as the still active Calderone glacier) survived during the Holocene (Federici, 1979a).

The most recent results of studies by Giraudi and Frezzotti (1997) in these areas have dated the maximum extent and Late Glacial stadial phases. In the Campo Imperatore, the last maximum advance was probably reached c. 22,680±530 yr B.P., and the major glacier retreat began c. 21,000 yr B.P. According to these authors, the glaciers (with the exception of Calderone Glacier) had disappeared at the beginning of the Holocene.

No chronological data are available on the age of the older glacial deposits. Immediately adjacent to the study area, volcanic ash dated at 460,000 years B.P. underlies deposits which have been interpreted as glacial by Carraro & Giardino (1992). Since the glacial expansion occurring during Würm III (i.e. the glaciation responsible for the emplacement of the Coppe di Santo Stefano moraine system) was the largest ever recorded for the Late Pleistocene (Boulton *et al.*, 1985; Dawson, 1992), it seems reasonable to correlate the glacial deposits present in Piano Racollo to the last cold stages of the Middle Pleistocene ("Riss" Auct.) (Federici, 1979b). This chronological reference is consistent with the recognition of pre-Würm glacial landforms and sediments in other parts of the Abruzzi Apennine (Demangeot, 1965; Pfeffer, 1967; Cassoli *et al.*, 1986; Societá Geologica Italiana, 1989) and, further north, in the Umbro-Marchean and Tuscan-Emilian Apennines (Dramis *et al.*, 1980; Federici & Tellini, 1983).

Acknowledgements

The authors wish to thank C. Di Nisio, C. Ginnici, C. Maineri, L. Papini, E. Petrilli, A. Pettini, R. Righetti, C. Romagnoli, A. Smisi and S. Tatoni for their fundamental help in the field surveys.

The present work has been carried out within the framework of a research programme on glacial and periglacial geomorphology of the Central Apennines, involving the Department of Geomorphology and Hydrology of the Polish Academy of Sciences (Kraków) and the Departments of Earth Sciences of both the University of Camerino, and the First and the Third University of Roma.

References

Ambrosetti, P., Carraro, F., Deiana, G. & Dramis, F., 1982: Il sollevamento dell'Italia centrale tra il Pleistocene inferiore e il Pleistocene medio. C.N.R. – Progetto Finalizzato "Geodinamica", Contributi Conclusivi per la Realizzazione della Carta Neotettonica d'Italia 2: 219–223.

Bigi, S., Calamita, F., Centamore, E., Deiana, G., Ridolfi, M. & Salvucci, R., 1991: Assetto strutturale e cronologia della deformazione della "zona d'incontro" tra le aree umbro-marchigiana e lazialeabruzzese (Marche meridionali e Lazio-Abruzzo settentrionali). *Studi Geologici Camerti*, special issue 1991/2, CROP 11: 21–26.

Bisci, C., Ciccacci, S., Dramis, F., Gentili, B. & Kotarba, A., 1993: Glaciated valley land system of Campo Imperatore, Gran Sasso (Central Italy). Programme with Abstracts, Third International Geomorphology Conference, August 1993, Hamilton (Canada): 103.

Bisci, C., Dramis, F., Fazzini, M. & Guglielmin, M. (in press): Climatic conditions and sporadic permafrost in the Maiella massif (Central Apennines, Italy). Geografia Fisica e Dinamica Quaternaria. VII Convegno Glaciologico Italiano, Bormio, sept. 1999.

Boulton, G.S., Smith, G.D., Jones, A.S. & Newsome, J., 1985: Glacial geology and glaciology of the last mid-latitude ice sheets. *Journal Geological Society*, London, 142: 447–474.

Carraro, F. & Giardino, M., 1992: Geological evidence of recent fault evolution. Examples from Campo Imperatore (L'Aquila – Central Apennines). Il *Quaternario* 5: 181–200.

Cassoli, A., Corda, L., Lodoli, C., Malatesta, A., Molaroni, M.V. & Ruggeri, A., 1986: Il glacialismo quaternario del gruppo Velino-Ocre-Sirente. *Memorie Societá Geologica Italiana* 35(2): 855–867.

Clayton, L., 1964: Karst topography on stagnant glaciers. *Journal of Glaciology* 5(37): 107–112.

Clayton, L. & Moran, R.S., 1974: A glacial processform model. *In: Glacial Geomorphology, Binghamton Symposia Series*, 89–119.

Co.Ge.Far., 1979: Gran Sasso; il traforo autostradale. A.N.A.S., Roma, 463 pp.

Dawson, A.G., 1992: Ice age earth. Routledge, London and New York, 293 pp.

Demangeot, J., 1965: Géomorphologie des Abruzzes Adriatiques. *Mémoires et Documents, CNRS*, 403 pp.

Dramis, F., Coltorti, M. & Gentili, B., 1980: Glacial and periglacial morphogenesis in the Umbria-Marche Apennines. Abstracts, 24th International Geographical Congress, Tokyo, 1: 114–115.

Dramis, F. & Kotarba, A., 1994: Geomorphological evidences of high mountain permafrost in Central Apennines. *Geografia Fisica Dinamica Quaternaria* 17: 29–36.

Dufaure, J., Bossuyt, D. & Rasse, M., 1989: Critères géomorphologiques de néotectonique verticale dans l'Apennin Central Adriatiques. *Ass. Bull. Franc. Et. Quat.* 2: 151–160.

Federici, P.R., 1979a: Una ipotesi di cronologia glaciale würmiana, tardo e post-würmiana nell'Appennino Centrale. *Geografia Fisica Dinamica Quaternaria* 2: 196–202.

Federici, P.R., 1979b: On the Riss Glaciation of the Apennines. *Zeitschrift f. Geomorphologie*, N.F., 23: 106–111.

Federici, P.R. & Tellini, C., 1983: La geomorfologia dell'alta Val Parma (Appennino Settentrionale). *Riv. Geografica Italiana* 80(3–4): 393–428.

Frezzotti, M. & Giraudi, C., 1990: Sedimenti eolici tardopleistocenici ed olocenici nell'Appennino Centrale. *Memoire Societa Geologica Italiana* 45(2): 836–883.

Frezzotti, M. & Narcisi, B., 1989: Identificazione di un andosuolo, possibile livello guida per la cronostratigrafia olocenica dell'Appennino centrale. *Memorie Societá Geologica Italiana* 42: 351–358.

Ghisetti, F. & Vezzani, L., 1986: Carta geologica del Gruppo M. Sella – M. Camicia – M. Prena – M. Brancastello (Gran Sasso d'Italia, Abruzzo). S.El.Ca., Firenze.

Ghisetti, F. & Vezzani, L., 1990: Stili strutturali nei sistemi di sovrascorrimento della catena del Gran Sasso (Appennino Centrale). *Studi Geologici Camerti*, special volume 1990: 37–50.

Ghisetti, F., Vezzani, L., Blumetti, A.M., Cellini, M., Centamore, E., Pittori, C., Ridolfi, M., Frezzotti, M., Giraudi, C., Clari, P., Bruzzone, B., De La Pierre, F. & Bigozzi, A., 1990: Carta Geologica del Gran Sasso d'Italia da Vado di Corno al Passo delle Capannelle. S.EL.CA., Firenze, *Studi Geologici Camerti*, special issue 1990.

Giraudi, C., 1989: Lake levels and climate for the last 30 000 years in the Fucino area (Abruzzo – Central Italy) – A review. *Palaeogeography, Palaeoclimatology, Palaeoecology* 70: 249–260.

Giraudi, C., 1994: Elementi di geologia del Quaternario della piana di Campo Imperatore (Gran Sasso d'Italia). *Atti Ticinesi di Scienze della Terra, serie speciale* 2: 137–143.

Giraudi, C. & Frezzotti, M., 1997: Late Pleistocene Glacial Events in the Central Appennines, Italy. *Quaternary Research* 48: 280–290.

Jaurand, E., 1992: Les moraines failles du Gran Sasso d'Italia (Apennin Abruzzais): intéret géomorphologique et neotectonique. *Géogr. Phis. Environ.* 44: 10–29.

Klebelsberg von R., 1930–31: Die eiszeitliche Vergletscherung der Apennines. I Gran Sasso – Maiella. *Zeitschrift f. Gletscherkunde Glazialgeologie* 18: 141–169.

Parotto, M. & Praturlon, A., 1975: Geological summary of the Central Apennines. *Quaderni della Ricerca Scientifica* 90: 257–311.

Pfeffer, K.H., 1967: Beiträge zur Geomorphologie der Karstbechen in Bereiche des Monte Velino (Zentralapennin). *Frankfurter Geogr. Hefte* 42: 85 pp.

Postpischl, D. (ed.), 1985: Catalogo dei terremoti italiani dall'anno 1000 al 1980. C.N.R., *Progetto Finalizzato "Geodinamica"*, 239 pp.

Smiraglia, C. & Veggetti, O., 1992: Recenti osservazioni sul ghiacciaio del Calderone (Gran Sasso d'Italia, Abruzzo). *Bolletino Societa Geografia Italiana*, serie XI, 9: 269–302.

Società Geologica Italiana, 1989: Elementi di tettonica pliocenico-quaternaria ed indizi di sismicitá olocenica nell'Appennino laziale abruzzese. Guida all'escursione, 31 maggio – 2 giugno 1989, C.N.R., Centro di Studio per la Geologia Tecnica – E.N.E.A.–P.A.S., Laboratorio di Geologia Applicata alla Sismotettonica, 129 pp.

Suter, K., 1939: Die eiszeitliche Vergletscherung des Zentralapennins. *Vierteljahrsschrift der Naturforschenden Gesel*, Zürich, 140 pp.