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 Como 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 by 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), backstones and grainstones with marly mudstones (Eocene – Oligocene) and laminated marls and marly mudstones (Lower-Middle Miocene).

The study area generally follows a monoclinal 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 (Pareto & 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; Società 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; Ambrosen 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 (Riebeselberg, 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-foored 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. Mulini. Most of the glacial cirques produced during this phase have subsequently been reworked by the glaciers of the most recent glaciation. But on the warmer southern slopes and west-facing slopes of Mt. Preña, 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. 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 - fluviolacustrine 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).
The southwestern maximum lateral extension of the Piano Raccolo 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 southwestern 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 Raccolo, 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 solifluxion 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 Raccolo glaciation also produced glaciofluvial and glacialacustrine sediments. These deposits form an elongated hill (1,507 m a.s.l.) which is isolated 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 Raccolo 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 dominant. This has the form of a 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 south-eastwards, 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 fluvioglacial 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
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References


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