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GEOMORPHOLOGICAL MAP OF THE SAN PELLEGRINO PASS (DOLOMITES, NORTHEASTERN ITALY) *SUPPLEMENTARY MATERIAL*

SYNTHESIS OF PREVIOUS GEOLOGICAL AND GEOMORPHOLOGICAL STUDIES

Several authors studied the northern slope of the San Pellegrino Pass (Autonomous Province of Trento, Northern Italy), located in a well-known area of the Dolomites between the San Pellegrino and the Biois valleys, but mainly from a geological point of view. The Quaternary deposits, and in some cases the connected landforms, have been synthetically mapped in several geological maps, but almost never described. Only a few works of physical geography dealt with the morphogenesis of this part of the San Pellegrino Valley.

Information on the structure and the lithological succession is given in Castiglioni & *alii* (1930), Vardabasso (1930, 1931a, 1931b), Rossi (1962), Leonardi (1967), Rossi (1967), Leonardi & *alii* (1970), Rossi & *alii* (1977), Brondi & *alii* (1977), and Mantovani (1987a). In a recent paper (Abbà & *alii*, 2018), an interpretation of the local structural setting in the framework of the tectonics of the Dolomites and an accurate mapping of the lithological units allowed the authors to recognise folding and dislocations and to draw brittle and ductile Alpine tectonic deformations with unprecedented detail. While here we focus on the geomorphological literature of the area, reference should also be made to Abbà & *alii* (2018) for a more comprehensive analysis of previous geological literature.

A first and articulated interpretation of the geomorphological evolution was provided by Bruno Castiglioni (Castiglioni, 1926) in his study on the morphology of the Biois Valley. The author traced the genesis of the San Pellegrino Valley back to the downcutting of an ancient extensive surface: the so-called *Gipfelflur* by geologists of German origin (Schwinner, 1923; Nangeroni, 1937, 1940; Sestini, 1955). The upper part of the Costabella chain, between 2700 and 2900 m a.s.l. in Ponte Ciadine (Cima Cadina), Palon de Jigole (Punta Cigola), Cima Ombrettola, and Monte la Banca, are regarded by Castiglioni (1926) as bearing traces of the remains of this surface.

This surface is considered to correspond to the top plateaus of the Sella and Pale di San Martino and in general to the *Surface of the Vette* ("summit surface") occurring in several mountain groups of the Dolomites. The San Pellegrino Valley and the upper part of the Biois Valley are mainly set on the northern limb of the Cima Bocche anticline, with a direction not very distinct from the axis of the anticline itself. Castiglioni (1926) hypothesised that the two opposing valleys are a direct derivation of a primitive valley carved in the *Gipfelflur* set on the Cima Bocche anticline, within easily erodible rocks of the Upper Permian and Triassic, now completely eroded.

The deepening of this former valley led to the outcropping of the porphyritic nucleus of the Cima Bocche anticline, forcing the erosive processes to adapt to this resistant rock mass. The supposed valley, considered to be originally located more or less in correspondence with the anticline hinge, would then have split into two isoclinal valleys on the northern and southern sides of the porphyritic ridge, moving away from each other; thus, the carving process formed the Travignolo Valley to the south and the San Pellegrino Valley to the north.

The same author (Castiglioni, 1926) suggested that the Valfredda, Fuchiade, and Tegnousa valleys, now draining into the Biois Valley, show genetic relationships with the San Pellegrino Valley, thus suggesting that they formerly belonged to the catchment of the Avisio river. In the morphological sketch at a scale of 1:80,000 in his work, Casti-

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glioni (1926) drew the ancient watershed further east of the current one (Forca Rossa Pass, Col Becher, i Marmoi, Col de Mez, and Col Margherita, outside of our map).

In the same study, the eastwards transfluence of the Avisio glacier during the LGM through the San Pellegrino saddle is documented by abundant erratic boulders of rocks belonging to the Avisio catchment (monzonites, porphyrites, etc.) that are found all along the northern side of the Biois Valley. The extensive Quaternary deposits of the Campagnacia, partially mapped in the above-mentioned morphological sketch, are interpreted as "glacial deposits" often modelled in moraine ridges. The number and position of such ridges suggest the existence of several glacial stadials (at least six), which outnumber those described by Penk & Brückner (1909).

A further study entirely focused on the geomorphology of the San Pellegrino Valley was published by Bianchi Castiglioni (1960). The author considered and confirmed the evolutionary framework proposed by Castiglioni (1926), providing new data on some significant aspects. Particular attention was given to glacial deposits, which were analysed in relation with the cirques from which the glaciers were generated. The high number of frontal and lateral ridges, sometimes incomplete or irregular, does not allow easy recognition of the main glacial stages. Nevertheless, the author attempted a chronological assessment of the moraines and a reconstruction of the snow line, in some cases discussing a correlation to the depositional phases. This reconstruction proved to be extremely difficult in the area of Costabella due to the large number of moraine ridges and their stacked pattern. Considering only the main ridges, the reconstructed snow line rose by only 50-60 m or even less between one stop to the next, attributable to stadials between Gschnitz and Daun and almost all pre-Daunians (Bianchi Castiglioni, 1960). In the morphological sketch attached to the paper, all the represented ridges were classified as "morainic ridges", thought the dense succession of transverse ridges might also represent the morphologies of large "block streams" (as in Capello, 1960). No author previously noted this aspect, except in the 1930 edition of Sheet #11 "Monte Marmolada" of the Geological Map of the Tre Venezie at a scale of 1:50,000 (Castiglioni & *alii*, 1930) in which the glacial deposits were generally mapped as "*morainic in place or reworked*". Bianchi Castiglioni (1960) also described in detail the karst landforms mainly found in correspondence to the *Bellerophon* Formation.

In an exhaustive study concerning the geology of the southern part of the Marmolada Group, Rossi (1962) dedicated a number of pages to describing the Quaternary deposits and to the geomorphological evolution of the area, essentially reporting what was proposed in the two previous works presented above. The area covered by this study was fully represented in the attached geological map at a scale of 1:12,500. The map shows for the first time with some precision the articulated system of the Campagnacia ridges taken from the aerial photos at a scale of c. 1:30,000 of the Ente Italiano Riprese Aeree (E.I.R.A.). However, all these ridges were still interpreted as moraines, even if the drawing representing some of them unequivocally suggests the typical pattern of rock glaciers. However, even Rossi, in his chapter on glacial deposits in the monumental study on the Dolomites by Pietro Leonardi (Leonardi, 1967), illustrated in a photograph the extensive deposits of the Tegnousa Valley, indicating them as a "*rock glacier phenomenon following the extinction of a local glacier*".

The difficulty of estimating the chronology of the glacial deposits of Campagnacia was also highlighted by G.B. Castiglioni (1964). In the attached 1:125,000-scale map of the stadial moraines of the Dolomites, the ridges close to the Costabella chain were referred to the Daun stadial, those near the pass to the Gschnitz stadial, but a significant number between the two were identified as "*moraines not easily referable to one of the stages ... and moraines in intermediate position referable to supernumerary stages*". The same map also highlighted the transfluence direction of the glacier through the San Pellegrino Pass during LGM, reported by Castiglioni (1926); it also documented the inversion of glacial flow already in the Gschnitz stadial, mapping some frontal moraines facing west, immediately to the west of Lèch de Sen Pelegrin (San Pellegrino Lake).

The Campagnacia deposits described and partially represented in the geological map "Monte Marmolada" (Rossi & *alii*, 1977) were still attributed to the late Würm and Holocene. In the 1980s, a series of studies once again analysed the geographical and physical features of the study area. A detailed geomorphological sketch of the entire zone (scale 1:25,000) and a detailed description of the landforms, albeit for dissemination purposes, took into consideration the geomorphological evolution of the area (Carton & de' Luigi, 1980). In a geomorphological map (scale 1:20,000) printed some years later, but never officially published (Mantovani, 1987b), some ridges were interpreted, for the first time, as rock glacier transverse ridges. However, the document was reductive in its representation of the moraines of Campagnacia, part of which (those close to the Costabella range) were erroneously interpreted as a protalus rampart.

The geomorphological processes that shaped the slopes were addressed in two works by Soldati (1988; 1989). In addition to lithology and tectonics, frost shattering was also taken into consideration. All the rocks near the pass were characterised from a physical and mechanical point of view and subject to freeze-thaw weathering tests. It emerged that the Val Gardena Sandstones and the limestones and gypsums of the *Bellerophon* Formation are rather prone to frost weathering, while porphyritic rocks and limestones from Werfen, Livinallongo, and Sciliar formations are much less sensitive to this process, leading to different production of debris and to the occurrence of different slope processes.

One scientific study to test the reliability of the DEM-derived from LiDAR in the Quaternary and the geomorphological research in two sample areas in the Dolomites (Zanoner, 2010) produced a geomorphological map of the area of the San Pellegrino Pass, which has been also used as a basis for this study. A subsequent note (Zanoner, 2011) highlighted how important LiDAR data are in solving some geomorphological problems, and the rock glacier of Tegnousa was analysed in detail.

The national geological cartography project (CARG Project - Geological Map of Italy at the 1:50,000 scale - ISPRA) has not yet covered the area of the San Pellegrino Pass with new surveys. Meanwhile, the Geological Survey of the Autonomous Province of Trento has published online a geological map including the study area at a scale of 1: 10,000 (Provincia Autonoma di Trento, 2017). Here, the Quaternary deposits have been classified according to allostratigraphic principles. Landforms considered by many previous authors as moraines have been correctly interpreted as rock glaciers; however, the genetic attribution of many forms located close to the Costabella chain is often confused and not always sound.

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