GEOGRAPHIA POLONICA
2011, 84, Special Issue Part 2,
107–115

THE DOLOMITES AND THEIR GEOMORPHODIVERSITY

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Abstract: Following the concept of *geomorphodiversity* which was introduced by the author (Panizza, 2009a), the peculiarities of the geomorphology of the Dolomites are summarized. First of all, they have specific geomorphological and landscape characteristics, which distinguish them from all other mountains in the world; i.e., they have greatly accentuated extrinsic geomorphodiversity on a global scale. In relation to morphostructural landforms, the Dolomites have a high degree of extrinsic geomorphodiversity compared with other mountains in relation to morphotectodynamics, morphotectostatics and morpholithology. They also have greatly accentuated intrinsic geomorphodiversity on a regional scale from the morphoclimatic viewpoint, considering their polygenesis linked to pre- or interglacial, glacial, periglacial, fluvial, relict, dormant or active landforms. Nevertheless, when some geomorphological features, chosen with a subjective criterion, are examined in detail on a regional scale (for example landslides) they show a great intrinsic geomorphodiversity. The Dolomites make up an important geoheritage that can be considered as a high-altitude field laboratory for research and development of geomorphological theories and understanding. The inclusion of these mountains in the World Heritage List is an important scientific goal and an event which stimulates in-depth studies, discussions and assessment of investigations and theories in the field of geomorphology.

Key words: geomorphology, geomorphodiversity, geoheritage, the Dolomites, UNESCO

INTRODUCTION

On June 26th 2009, the Dolomites were included in the World Heritage List because of their exceptional beauty and unique landscape (criterion vii), together with their scientific importance from the geological and geomorphological viewpoint (criterion viii). In particular, with reference to criterion viii and geomorphology, it was stated that "The Dolomites are of international significance for geomorphology, as the classic site for the development of mountains in dolomite limestone. The area presents a wide range of landforms related to erosion, tectonism and glaciation. The quantity and concentration of extremely varied carbonate formations is extraordinary in a global context, including peaks, towers, pinnacles and some of the highest vertical rock walls in the world. […]. Taken together, the combination of geomorphological and geological values creates a property of global significance".

The area of the Dolomites is part of the "Southern Alps", in the north-eastern area of Italy: it broadly stretches between the "Giudicarie tectonic line" and the "Pusteria tectonic line"; to the south and south-east it is bounded by the "Venetian and Friuli Pre-Alps" and to the east by the upper part of the Cellina valley, in the Carnia Dolomites (Fig. 1).

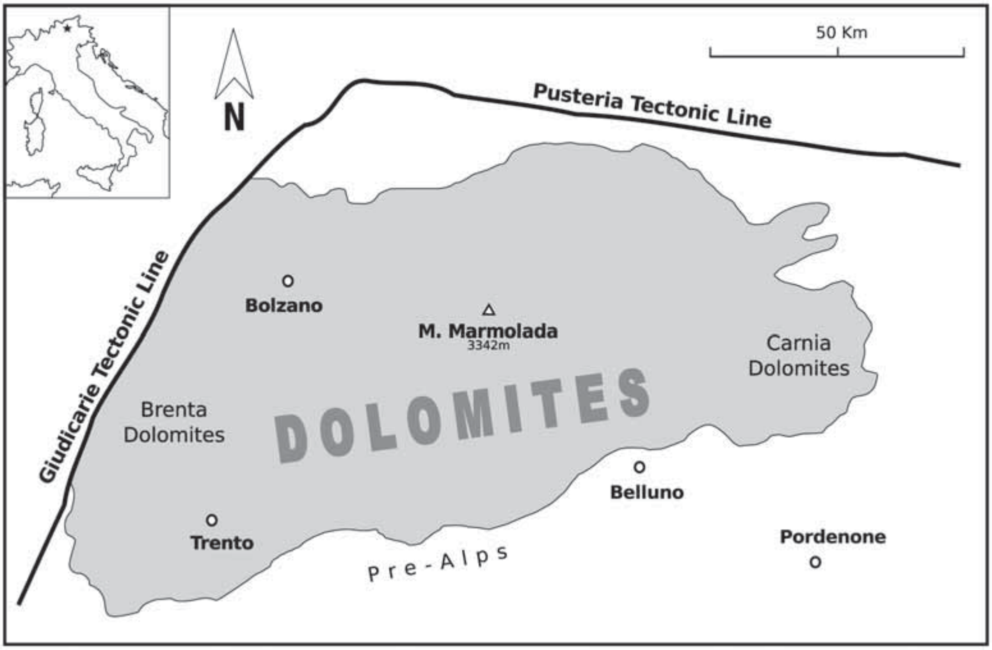

Figure 1. Location of the Dolomites

Out of the Dolomite range, nine different "systems" were chosen to represent an organic "series" of exceptional aesthetic and scientific values. The nine systems, contained in an area of approximately 142,000 hectares, are integrated and complementary: in fact they constitute a serial property, as they represent a unified whole, albeit dislocated and complex, both in terms of geography and landscape and from a geological and geomorphological standpoint.

THE GEOMORPHODIVERSITY OF THE DOLOMITES

The landscape and geomorphological features of this region have been created mostly by dolomite rocks (Fig. 2) that range in age from the Palaeozoic to the Cretaceous. The geological importance of the Dolomites is due to the extremely detailed and continuous manner in which they represent a large part of the Mesozoic Era, bearing witness to a tropical sea, which existed here between 260 and 200 million years ago. It is possible to reconstruct the geo-history of this period as if reading from the pages of a gigantic stone book, walking on ancient lagoons and visiting the margin with the remains of corals and sponges before descending the age-old slopes to reach the bottom of ancient oceans. You can map out the succession of ancient cliff faces in space and time, or assist at volcanic eruptions and discover the evolution of various forms of life from shellfish to dinosaurs.

From the geomorphological standpoint, the landforms took place in different ways and with different rhythms, also in relation with diastrophic activities, climate changes, and human works: dolomite and calcareous towers, crests, pinnacles and escarpments; ranges and ridges of volcanic rock, hollows in clayey soils, folded, faulted and twisted beds, talus cones and scree slopes, plateaus and small lakes, colours and shapes, light and shadow: their history is ancient, complex and fascinating. In the collective imagery the Dolomites are considered as spectacular geoheritage, a natural work of art. From the

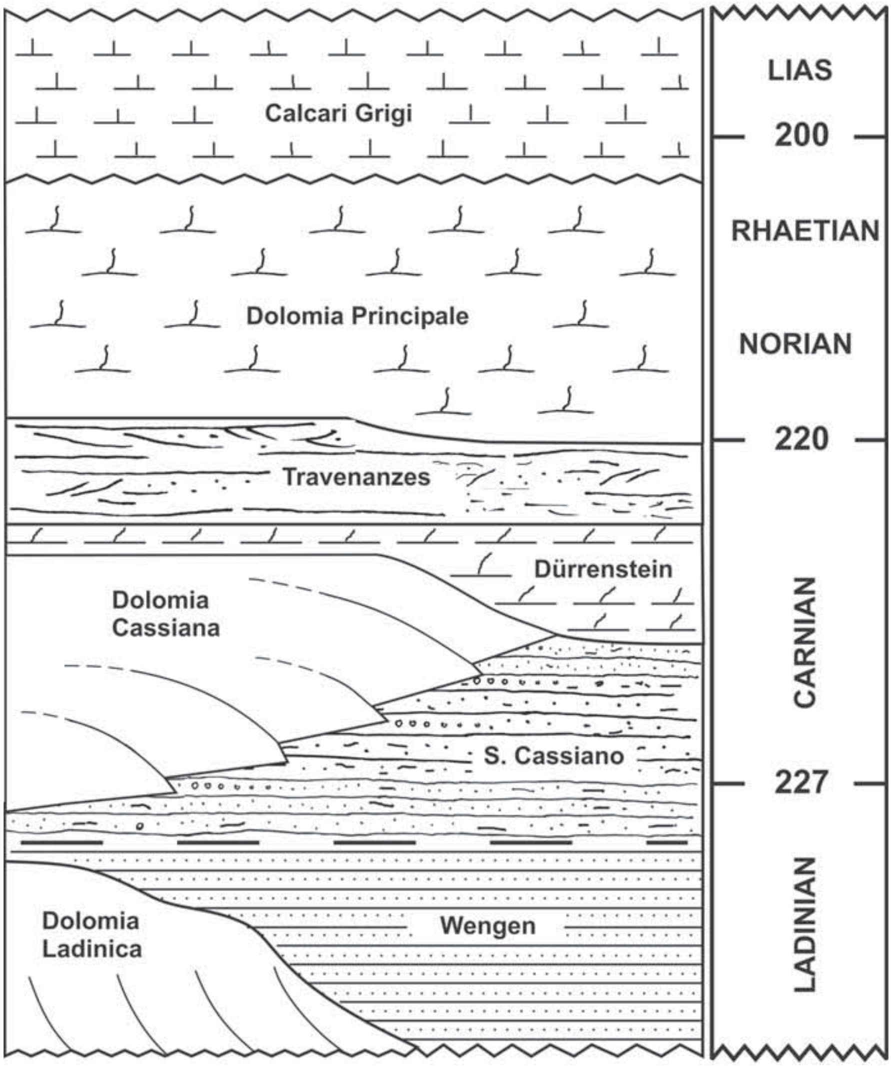

Figure 2. Schematic stratigraphic column showing the Upper Triassic dolomite formations. Thickness is not to scale; numbers indicate millions of years ago

Late Miocene, when rocks emerged from the sea, meteoric water began to flow on the new reliefs and waves used to break on its coasts. Changes of temperature and humidity caused the physical and chemical weathering of rocks and the force of gravity, water and wind moved and redistributed debris. Depressions and valleys were formed in correspondence with outcrops of the weak rocks or with important tectonic displacements and related cataclastic belts. On the contrary, more resistant rock types, such as calcareous, dolomite or igneous rocks underwent a different morphogenetic evolution and gave origin to the highest mountain tops of the region. The morphogenesis is moreover linked to glacial, interglacial and up to present-day vicissitudes, with a vast array of exemplary landforms. In particular, several traces resulting from the last glacial expansion of the Upper Pleistocene (LGM) are found, both as erosion landforms and debris deposits. Among the former: glacial cirques, hanging valleys, "roches moutonnées". Among the latter: moraine deposits, also with erratic boulders. Numerous are the examples of periglacial and gravitational morphologies (rock glaciers, protalus ramparts, scree slopes, talus cones, landslides, etc.), or of fluvial morphologies (gorges, terraces, alluvial fans, etc.).

The peculiarities of the geomorphology of these mountains are described from ***geomorphodiversity*** viewpoint (Panizza, 2009a): "the critical and specific assessment of the geomorphological features of a territory, by comparing them in an extrinsic and intrinsic way, taking into account the scale of investigation, the purpose of the research and the level of scientific quality".

This concept cannot be univocal: the whole set of all geomorphological data of the study area should be critically assessed, by comparing them with each other (in an *intrinsic* way) and with those from other areas (in an *extrinsic* way), in order to evaluate their specificity and therefore their geomorphodiversity. The scale of the investigations should be taken into the right account and the level of their scientific quality assessed. A proper choice of the geomorphological elements to be examined and evaluated in a specific way, in particular for applied purposes, might be important. Practically, it is a matter of carrying out original research, finalised each time towards well-defined goals, by avoiding statistical elaborations which are only an end in themselves.

With reference to the above defined concepts, the various types of geomorphodiversity in the Dolomites, at different scales of representation, can be illustrated.

Firstly, they have greatly accentuated *extrinsic geomorphodiversity* on a *global scale*, that is monumental, original and spectacular specific geomorphological characteristics distinguishing them from all other mountains in the world. It is here that the 19th century travellers found inspiration for

Figure 3. Landscape in the Dolomites: example of high extrinsic geomorphodiversity on a global scale. An oil painting on canvas by J. Gilbert (1862)

the "romantic" landscape (Fig. 3), and they still provide a fundamental reference point for defining the modern concept of natural beauty.

Moreover, the Dolomites, compared with other carbonate mountains on a *regional or global scale* in Europe or in the world and in relation to morphostructural landforms, have a high degree of *extrinsic geomorphodiversity.* In particular, with respect to *morphotectodynamics*, the Dolomites have a high relief energy, located within the belt of Alpine orogenesis, with considerable variation in height between mountain tops and valley floors. Besides there is evidence of active or recent tectonics with fault planes and scarps, stream cuts, fluvial elbows, saddles, crest displacements, etc. (Panizza et al., 1978; Corsini and Panizza, 2003; Panizza and Dibona, 1990). With regard to *morphotectostatics,* the most typical landscape is that of dolomite peaks sculpted along fractures in the form of towers, steeples, crests and pinnacles (Fig. 4). Moreover, the arrangement of the main valleys, the location of some passes and saddles, and the position of some of the most sheer and majestic rock walls are determined by the trends of important displacement lines. Furthermore, the attitude of layers in relation to the aspect of slopes and the horizontal top of Mesozoic shelves have considerably influenced slope gradients. With regard to *morpholithology,* the great variety of rock formations generates a series of selective-type landforms, like some passes or saddles, or steep walls and sheer peaks. In many cases compact rock types alternate with weaker ones or with rocks of different origin (sedimentary and igneous) or the proximity of rocks with different compositions have all created varied and contrasting morphology, characterised by mild slopes, ledges, steps, steep rock walls or uniform mountain massifs.

Climatic conditions directly influenced morphogenetic agents in the Dolomites.

Figure 4. The Tre Cime di Lavaredo made up of Norian-Rhaethian dolostones and dissected into towers along tectonic fractures: examples of high extrinsic geomorphodiversity on a regional scale (morphotectostatic)

Figure 5. The Sassongher dominating Corvara in Badia; the cloud level is more or less the altitude reached by glaciers during the last glacial maximum

Figure 6. Glacial cirques at the Marmarole: example of high intrinsic geomorphodiversity on a regional scale (morphoclimatic)

In fact, they show a very complex geoheritage from the *morphoclimatic* viewpoint: the warm or temperate and humid environments of the pre-Pleistocene and the alternation of cold and temperate ones of the Pleistocene and Holocene have generated a sequence of different landforms modelled according to various processes (Castiglioni, 1964; Panizza, 1973, 1988, 1990, 2009a; Carton and Pelfini, 1988; Carton and Soldati, 1993; Soldati, 2010). Therefore, they also have greatly accentuated *intrinsic geomorphodiversity* on a *regional scale*. Pre-Pleistocene morphologies represent some exhumed landforms and relict terraced surfaces. Rare interglacial deposits are recorded in the mid-valleys of Fassa and Gardena. Abundant reliable glacial morphologies are connected with the last Glacial period (LGM), when glaciers used to occupy all the Dolomite valleys, with ice thickness often exceeding 1,500 m (Fig. 5). They created a network of branches intersecting between one valley and another, and some Dolomite passes acted as transfluence saddles. The most evident glacial landforms are: cirques (Fig. 6), steps, hanging valleys and "roches moutonnées". There are also moraine deposits mainly ascribable to the Lateglacial phase, which started around 17,000 yrs BP. These are predominantly lateral moraines and frontal arcs.

Moreover, if some categories of "geomorphological objects" are *subjectively* taken into account, as, for example, *landslides*, they show, still on a *regional scale*, a considerable complexity of types, causes, ages, lithology, movement, extent, etc.; that is they have greatly accentuated *intrinsic geomorphodiversity* (Fig. 7). In fact, landslides are widespread in the Dolomites and mainly occurring from the Lateglacial. Practically all the different types of landslides, as defined in

Figure 7. Landslide in Corvara in the Badia valley, indicating the main geotechnical measurement instruments. Example of high intrinsic geomorphodiversity on regional scale

international "classifications" (see Varnes, 1958), can be found in the Dolomites. The analysis of the dated mass movements has allowed correlations to be outlined between increases in landslides activity and climate changes in this region (Soldati et al., 2004).

Furthermore, during the past few years there have been numerous falls and topples from over 2,000 m high Dolomite peaks. This is the consequence of the thawing of permafrost trapped in the fossil state in gaps between the rock (Panizza, 2009 b). The rise in summer temperatures has led to the thawing of part of this fossil ice. The gaps thus fill with thawed water, in addition to that coming from precipitation; during the following winter new ice forms in the same gaps, with an increase of around a tenth in the volume of water and the consequent widening of gaps; in the following summer these gaps are filled with an even larger amount of water, which then freezes again and further widens, deforms and ultimately breaks up the rock. Cycles of progressive freezing and thawing have created a greater tendency for portions of the rocks to break off, thus leading to collapse. In clayey sections, similar quantities of thawed water have instead made the rock more viscous, thus producing or reactivating slides or mudflows, as taking place on slopes overlooking various directions.

Another *subjective* example is offered by *karst* areas: they display in detail a vast array of landforms, that is, considerable *intrinsic geomorphodiversity* on a *local scale*. This surface and subsurface morphology is widespread: the most typical are large depressions, blind valleys, dolines, karrens, "kamenitza", pits, and caves.

CONCLUSIONS

When considered as a whole, these mountains offer an exceptional complexity of morphostructural and morphoclimatic landforms, even in the most minute details. In fact, the aggregation of all these landforms, either relict, recent or active ones, has produced with time a *geoheritage* that can be considered as a high-altitude field laboratory for research and development of geomorphological theories and understanding.

The various Dolomite ranges are characterised by extraordinary representativeness and high levels of protection, and are linked through an extensive genetic and aesthetic network of relations; thus providing an overview of a group of extraordinary mountains, unique landscapes created from rocks and relief forms, which tell the wonderful tale of a long interval in the history of the Earth and illustrate globally important geological and geomorphological processes.

Finally, the inclusion of the Dolomites in the UNESCO World Heritage List is an important scientific goal, owing mainly to their geomorphological importance. This event has also provided an incentive for studying in-depth, discussing and assessing investigations, results and theories in the field of Geomorphology.

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Paper first received: April 2011
In final form: August 2011