1 The Environment of the Dolomites: A General Outline

After a brief description of the environment of the Dolomites (the climate, geology, and soils), the two principal criteria that were used for the study of the vegetation are presented: the analysis of current conditions (flora and plant communities) and the historical reconstruction of prior events (the formation of the Alps, glaciations, and the human impact).

Geographic Area and Boundaries

The Dolomites are a mountain system of incomparable beauty and a completely unique structure. Their confines are formed by the deep Puster, Adige, Piave, and Belluna valleys. In our study, attention will be focused upon the mountain systems consisting of dolomite and upon the volcanic environments of the Predazzo complex that are closely connected with each other. On the other hand, the Cima d'Asta group, although contiguous, will be excluded, since it possesses geological and biological characteristics that differ greatly.

The tallest peak of the Dolomites is the Marmolada (see Introduction, Fig. 1) which reaches 3,343 m. Many other peaks top 3,000 m. The main rivers that cross the territory are the Piave, Cordevole, Cismon, and Avisio, at times with a torrential character. In spite of the geographical boundaries that are rather clearly defined, this territory has never constituted a single political or administrative unit, and three languages are present in the resident population: German (in South Tyrolean dialects), Italian (including the Veneto dialect), and Ladin. This results in problems of toponymy, especially in transitional areas. In terms of governmental administration, the Dolomites are divided into three areas belonging to the province of Belluno (in the region of Veneto) and the autonomous provinces of Bolzano and Trento (in the region of Trentino-Alto Adige).

Aside from the Marmolada, the largest and highest orographic units are the Rosengarten, Langkofel, Sella, Pale di San Martino, Tofane, Cristallo, Drei Zinnen, Sorapis, Antelao, Pelmo, and Civetta. However, the landscape and biogeographic significance are not dependent merely upon the height of the mountains, and places of great interest may also be found at lower elevations, such as Lake Misurina, the Schlern (Sciliar), Fanes, Sennes, Pralongià, Seiser Alm, Vette di Feltre, Schiara, and the Prealps. Further on, the Dolomites continue into Austria (the Lienz Dolomites).

It does not appear that the uniqueness of the Dolomites was appreciated in the Classical period, nor in the Middle Ages and Renaissance. They are immortalized only in the paintings of Titian, born in Pieve di Cadore c. 1490 (the Marmarole, for example, may be seen in the backgrounds of *The Presentation of the Virgin at the Temple* and *Sacred and Profane Love*). The name of the Dolomites is derived from the French scientist Deodat de Dolomieu (1750–1801), who observed the mineral dolomite for the first time in 1791 and provided samples of it to Nicholas de Saussure, who determined its chemical nature to be calcium magnesium carbonate. The mountaineering exploration of the Dolomites is even more recent. It began toward the middle of the nineteenth century thanks to the British (Ball, Churchill, and Tuckett), followed by climbers who hailed from modern-day Austria and Germany (Grohmann, Winkler, and Zsigmondy) and Italy (Berti and Comici), as well as those from the local

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Table 1.1 Climate data (1970–1990)

Station	Elevation (m)	Average annual temperature (°C)	Average annual precipitation (mm)	Reference vegetation
Falzarego Pass	2,107	2.3	1,250.2	*Sesleria* grassland at low elevation
Rolle Pass	1,970	2.3	1,136.2	*Larici-Cembretum*
Misurina	1,756	2.7	1,124.8	*Larici-Cembretum*
Arabba	1,607	4.7	1,120.2	*Listero-Piceetum*
San Martino di Castrozza	1,444	4.3	1,450.1	*Oxalidi-Abietetum*
Sexten	1,316	4.7	856.9	*Listero-Piceetum*
Sauris	1,212	6.2	1,737.7	*Oxalidi-Abietetum*
Croce d'Aune	1,011	7.6	1,180.0	*Carici albae-Fagetum*
Cavalese	1,000	7.2	807.1	*Carici-Pinetum*
Pedavena	359	10.5	1,076.5	*Galio-Carpinetum*
Bolzano	266	11.5	705.3	*Orno-Ostryetum*

area (Delago, the Innerkoflers, Piaz, and Rizzi), names that have since become mythical. In the 1930s, one of us (Sandro Pignatti), while still a child, had his first contact with the Dolomites when his family came to vacation in Pera di Fassa. The opportunity to admire Tita Piaz, who was elderly but still active, as well as the loss of friends who died on the crags, such as Elio Dusso (on the Langkofel) and Sergio Nen (on the Vajolet), were episodes that, in later years, indubitably contributed to making the bond to the Dolomites a deep and enduring one. The life of the co-author (Erika Wikus, married from 1956 to S. Pignatti) was shaped by the daily view of the Lienz Dolomites where she lived starting in 1941, followed by her first climbing and botanical excursions in these mountains and later (1949–1952) by her doctoral thesis (*Die Vegetation der Lienzer Dolomiten*, 1960).

Climate

Providing a precise definition of the climate of the Dolomites is a difficult undertaking. First of all, it is a vast area with substantial variations from one extreme to the other. In addition, meteorological stations are situated for the most part in inhabited locations and thus provide data that are not always significant with regard to the actual living conditions of alpine flora which, as will result from our discussion, develops primarily above the boundary of 2,000 m. With regard to the entire area, we will present only recent data (1970–1990) from 11 stations (Table 1.1), referring to specialized works (such as Fliri 1975) for details. The highest station (the Falzarego Pass) is at 2,100 m which, however, is still below the timberline, while the others are all at elevations of less than 2,000 m. It must be taken into consideration, though, that since that time, conspicuous variations are being registered as a result of the phenomenon of global warming.

In Table 1.1, the stations have been arranged from coldest to warmest, which also corresponds with substantial approximation to the elevation levels, from the highest (the Falzarego Pass) to the valley floor (Bolzano). These data indicate a climate that at high elevations is continental—cold, with little rainfall, comparable to that of Scandinavia—while at the valley floor, the climate is sub-Mediterranean. Exceptions to this are San Martino di Castrozza, Sauris, and Croce d'Aune, which have substantially higher levels of precipitation and a climate that is suboceanic.

From the point of view of general climate, we find ourselves faced with a situation that can be interpreted as the combination of two fundamental gradients: altitudinal and longitudinal (Fig. 1.1):

- **Altitudinal gradient** (indicated by the broken arrow towards the top)—lower elevations have a higher temperature, while luminous radiation is attenuated as a consequence of absorption due to the atmosphere. Therefore, as one moves in the direction of the arrow, the progression is from the valley floor, with the warmest climate, to the high-elevation environment, which is cold with intense solar radiation (Fig. 1.2).

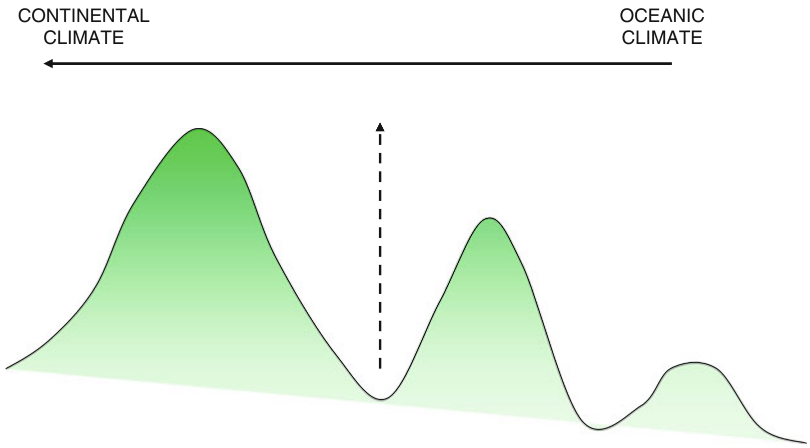

Fig. 1.1 An ideal cross-section of the area of the Dolomites, from the edge of the plains (*right*) to the interior Dolomites and the Puster Valley (*left*), indicates two climatic gradients: a gradient from oceanic climate to continental climate (*arrow with solid line*) and an altitudinal gradient from warm to cold (*arrow with broken line*)

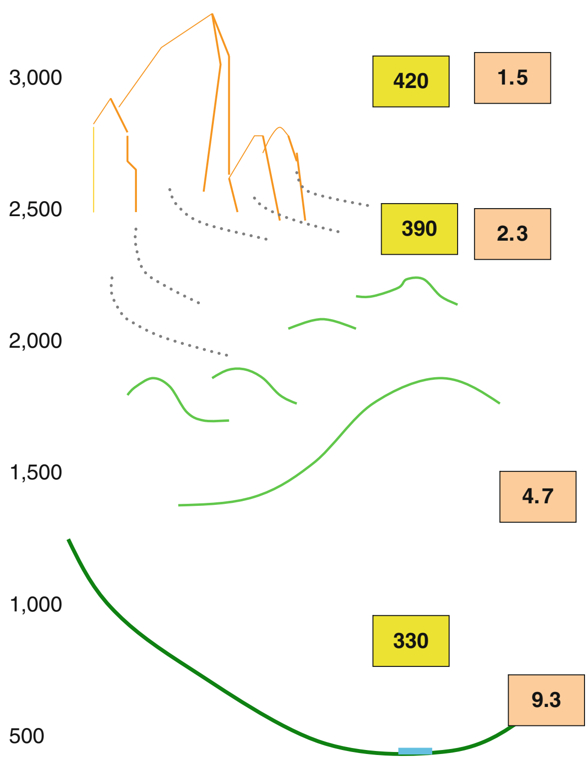

Fig. 1.2 Distribution of PAR luminous radiation values (*yellow*) and temperature (*orange*) in an ideal transect of the Dolomites during a sunny summer day. At the peaks, there is very intense luminous radiation but low temperatures; at the foot of the mountains, the situation is reversed: less intense radiation and higher temperatures

- **Longitudinal gradient**—if one moves northward from the southern edge of the Dolomites, the progression is from a zone with an oceanic climate to one with a continental climate. The southern ranges are in the direct path of moist airstreams originating from the Adriatic Sea and have a damp climate with frequent fog and abundant rain, even in the summer. In the internal ranges, there is less rainfall and it is concentrated in the autumn and spring, while the winter and summer are generally dry.

In reality, what is interesting in this case are not the average monthly data, but rather the actual conditions to which plants are subjected during the vegetative period. Those data which are in fact available are scarce and are of only orientational value.

Throughout the course of the excursions, numerous measurements were taken which, although they were lacking any systematic method, allowed for the obtaining of more direct information on the conditions in which plant life carries on in this environment. The three most important factors for photosynthesis were examined: light, heat, and the availability of water. And from the comparison of them, additional information was also obtained on the continentality of the climate, a highly significant climatic factor for the life of plants and the structure of vegetation. These data are presented in a detailed manner and

Table 1.2 Lithostratigraphic outline (from Tracanella, simplified)

Cenozoic	EOCENE-PLIOCENE	<65 million years	Flysh (limestones and sandstones)
Mesozoic	CRETACEOUS	145	Scaglia rossa
			Biancone
	UPPER JURASSIC		Nodular limestones
	LOWER-MIDDLE JURASSIC	205	Jurassic limestones
	UPPER TRIASSIC		Main Dolomite [*Dolomia principale—Hauptdolomit*]
		230	Raibler [*Raibliano—Raibler Schichten*]
	MIDDLE TRIASSIC		Ladinian-Carnian, strata of La Valle—Wengen Cassian dolomite [*dolomia cassiana—Kassianer-Schichten*] Schlern dolomite [*dolomia dello Sciliar—Schlerndolomit*]
			Strata of Livinallongo—Buchenstein
		240	Sarl dolomite [*dolomia del Serla—Sarldolomit*]
	LOWER TRIASSIC	250	Werfen [*Werfeniano—Werfener Schichten*]
Paleozoic	UPPER PERMIAN		Bellerophon limestones [*calcari a Bellerophon—Bellerophonschichten*]
	LOWER PERMIAN	280	Val Gardena sandstones [*arenarie di Val Gardena—Grödner Sandstein*]
	PRE-PERMIAN	>280	Phyllites [*filliti—Quarzphyllit*]

discussed in Chap. 14. For general information, refer to Fig. 1.2, which demonstrates how as the elevation increases, the luminous radiation clearly tends to increase while the temperature tends to decrease. The luminous radiation at the valley floor is around 300–350 PAR* (photosynthetically active radiation)[1] units, while at an elevation of 2,500 m, it increases to 400–450. On the other hand, the annual average temperature in the same environment goes from 11 °C to 2 °C (this variation corresponds for the most part to the relationship that holds true for the entire terrestrial surface). In any case, this remains a very general outline, and as shall be seen in Chaps. 14 and 21, the presence of vegetation permits the realization of adaptations that are highly complex.

Geology

The Dolomites represent a classic subject for research in the fields of earth sciences. As early as the second half of the nineteenth century, the complicated problems of these mountains attracted the interest of geologists and mineralogists. Predazzo became a meeting point and center for the exchange of experiences among scientists. It was a place where the essentials of the interpretation of the genesis and structure of the Alps were clarified and elaborated. Names such as Marzari Pencati, von Richthofen, von Mojsisovics, and Taramelli come to mind. In this chapter, we shall limit ourselves to summarizing some essential information, referring the reader who would like to go into greater depth to the classic works by von Klebelsberg (1928) and Leonardi (1967), as well as to the masterful evolutionary synthesis by Bosellini (1996). The stratigraphic series of the Dolomites has been summarized and illustrated in Table 1.2 with bilingual names to facilitate consultation in both Italian and German.

Dolomitic rock formed during the Mesozoic Era in a shallow area of the sea with an equatorial climate (for additional details, see section "An Historical View of the Plant Cover of the Dolomites" below). Coral formations such as reefs and atolls were built up that have reached us in the form of imposing masses of organogenic and dolomitic limestone (Sarl (Serla) Dolomite, Schlern (Sciliar) Dolomite, and Main Dolomite). Furthermore, during the Middle Triassic Period, an extensive volcanic complex formed which was centered at Predazzo and gave rise to several phases of activity interspersed with periods of calm.

[1] For all entries marked with an asterisk, see the Glossary.

Fig. 1.3 The Langkofel range as seen from the Col Rodella. In the foreground, the gentle molding of the strata of volcanic origin, covered by grasslands; in the background, the dolomite cliffs

In this way, zones of volcanic rock, lavas, tuffs, and breccias were formed, with interesting contact products where the eruptive material was superimposed upon organogenic deposits (Figs. 1.3 and 1.4). A current example of these conditions may be found in some of the island groups of Polynesia. In this environment, flora and fauna of the tropical type develop. Through the course of the Jurassic and Cretaceous Periods, there was a progressive subsidence of the Triassic platforms and a transition to the conditions of the deep sea (as found with the Biancone or Scaglia Rossa formations). The calcareous mass subsequently reemerged and was thrust upward by Alpine orogeny.

This framework turns out to be rather complex in and of itself. It is then further complicated, however, by the particular structure of the Dolomites. This area lies between the line of the Puster and Gail Valleys (a continuation of the *Insubric line*) and the Padano-Venetian plain. The geology of this area is determined by the relationships between the southeastern belt, which comprises the *Belluno rift* and the northern and western portion corresponding to the *Trento plateau*. Through the course of Alpine orogeny, the Trento plateau was thrust upward, with a series of fractures corresponding to two fault lines: the *Antelao line* and the *Valsugana line*. In this way, four structural units are determined, almost like four successive steps of the southern slope of the Alps:

- Tofane structural unit
- Antelao line
- Civetta and Antelao structural unit

Fig. 1.4 Section of soil along the Vial del Pan. *Below* the humified layer, sand is distinguished that is derived from volcanic activity in the Mesozoic Era

- Valsugana line
- Schiara and Sasso di Mezzodì structural unit
- Southern Alps overthrust line
- Belluno Rift and Veneto Prealps structural unit

Lines of discontinuity were therefore formed as a consequence of these tectonic movements, which were followed by episodes of thrust from one unit to another. These have made the interpretation of individual geological formations exceedingly difficult. In very simplified terms, in one transect from south to north, for example from Belluno to the Puster Valley, one finds first the strata of the Tertiary Period, then the Cretaceous Period, and, as early as at the Schiara Mountains, Norian dolomite. The same Mesozoic formations are also found on the Civetta and Pelmo, but from the Val di Zoldo to the Cortina basin, the substrate is for the most part characterized by Anisian limestone and Ladinian-Carnian limestone.

From the Tofane to the Drei Zinnen group, the Triassic-Cretaceous complex returns until the Puster rift, which represents the genuine northern limit of the Dolomites.

With regard to the consequences on the plant colonization, the most important difference is among calcareous rocks (basic) and silicate rocks (acidic). It must be kept in mind, however, that even now, we do not know if there are differences in the flora that are caused by the fact of growing on various types of limestone. Vascular plants are excellent indicators of the pH of the soil. Therefore, upon this basis, it is possible to differentiate between the following conditions:

- **Calcareous substrates**: different types of limestones and dolomite
- **Mildly acidic substrates**: Raibler and Werfen
- **Decidedly acidic substrates**: sandstones of Val Gardena, granites, eruptive rocks

Whenever possible, the attempt will be made to indicate the type of geological substrate to which the studied associations could be connected.

Soils

The geological substrate in the area of the Dolomites is for the most part composed of compact rock that cannot be directly colonized by vegetation. Nevertheless, the rock is subject to phenomena of alteration which progressively lead to the formation of soil. This process is known as *pedogenesis*. A variety of soils are formed in this way whose chemical characteristics at first closely depend upon those of the source rock but then progressively differentiate themselves more and more. The soil is the indispensable support of plant life (except for aquatic vegetation, which will be discussed here only in summary form). Soil and vegetation are connected in a complex system of actions and reactions in such a way as to create an inseparable whole: the *soil-vegetation continuum*.

Our research on the Dolomites has essentially examined the plant component, and with regard to the soil, we have been able to rely upon existing data: the classic research of Jenny-Lips (pedogenesis on limestone) and Pallman (silicate substrates) and the typology of Kubiena. In addition, the experience acquired during research in the high mountains of Stelvio (Giacomini and Pignatti 1955) was of assistance. This allowed us to study many characteristics of the soils on calcareous rock which are also present in that area. Important updates have been provided on the Dolomites in more recent years by D. J. Werner (Cologne), C. Wallossek, T. Verjans, and B. Erschbamer (Innsbruck).

The soils of the Dolomites fall within the general types that are widespread through the chain of the Alps. The study of soils is the subject of pedology and thus is not encompassed by the scope of this work. Nevertheless, the basic concepts that are necessary to comprehend the relationships between soil and vegetation within the environment of the Dolomites are summarized in Chap. 15.

Flora

Up to this point, no work has existed that is dedicated to the flora of the Dolomites. In order to document this topic, we have had to turn to either general works or else specialized works limited to individual areas or individual taxonomic groups. This gap will be filled to a great extent by the publication of the Atlas of Flora (as Supplement). In any case, the study of flora has also been a central aim for us. Indeed, the most intensive period of our research on the Dolomites was the decade from 1970 to 1979, which also corresponded to the period in which one of us (Sandro Pignatti) was primarily engaged in the compiling of *Flora d'Italia* (Pignatti 1982). The analysis of the vegetation of the Dolomites therefore also required an in-depth analysis of the study of the flora that represented an important source of information for the compilation of *Flora d'Italia* by means of the direct observation of the phenotypic variability and the ecology of an extensive number of species. Throughout the course of this research, vast documentation has been collected, and the possibility now exists to fill the gap regarding the flora of the Dolomites with the Atlas of Flora that completes this work. It clearly differs from floras of the traditional type that deal with the Alps in that the data have been collected on the basis of a geographic grid according to the method of flora census proposed for the area of the Alps by F. Ehrendorfer (Vienna) in the 1960s which we began to apply in the Sauris zone during the summer of 1967 and, beginning in July 1970, to the Dolomites, as well.

There are 2,252 species represented in the Atlas. To our current knowledge, there are more than 2,300 species present in the Dolomites, that is, more than one third of all of the flora in Italy, even though the Dolomites cover only a modest area (1.67 %) of the entire national territory (additional details are provided in Chap. 18). No attempt has been made to provide a precise total, because along the southern foot of the Dolomites, many species from the plains have settled in villages and towns, along streets and railways, and in many cases the decision as to whether or not to include them in a flora of the Dolomites is an arbitrary one. From an ecological and biogeographical point of view, though, these species do not belong to the flora of the Dolomites.

The evaluation of the frequency of the species also has little sense. Indeed, the species that turn out to be the most widespread (see Table 16.3), such as the *Alchemilla vulgaris* group, *Bellidiastrum michelii*, *Erica carnea*, *Juniperus sibirica*, *Larix decidua*, *Parnassia palustris*, *Picea abies*, *Poa alpina*, *Bistorta vivipara*, *Potentilla erecta*, *Rosa pendulina*, *Sesleria caerulea*, *Vaccinium myrtillus*, or *V. vitis-idaea*, are species that are clearly tied to the alpine habitat. However, they represent species which are extremely widespread, which are able to grow in the most varied of environments, and which are not particularly specialized, more or less the same species that could be observed outside of the valleys of the Dolomites. The most widespread genus is *Carex*. There are nearly 100 species of it present in the Dolomites which live for the most part in wet habitats. However, there are also species of *Carex* that are specialized to environments of alpine grasslands, forests, or cliffs. The species groups that attract the most attention are those which are most specifically tied to the alpine environment, such as *Androsace*, *Artemisia*, *Campanula*, *Cerastium*, *Dianthus*, *Doronicum*, *Gentiana*, *Leucanthemum*, *Phyteuma*, *Potentilla*, *Primula*, *Rhododendron*, *Saxifraga*, *Sempervivum*, and, of course, *Leontopodium alpinum*, the edelweiss.

The species which provide the greatest significance to a flora are those which are endemic. But the flora of the Dolomites is not particularly rich in endemism, perhaps as a result of the fact that during the glaciations of the Quaternary Period, these mountains were almost completely covered by the glacial ice cap. Peripheral areas, such as the Julian Alps and the Maritime Alps, are certainly richer in endemic species. The list is a short one and barely exceeds 0.5 % of the total:

- *Androsace hausmannii*
- *Arenaria huteri*
- *Campanula morettiana*
- *Draba dolomitica*
- *Festuca austrodolomitica*
- *Moehringia bavarica*
- *Moehringia glaucovirens*
- *Primula tyrolensis*
- *Rhizobotrya alpina*
- *Saxifraga depressa*
- *Saxifraga facchinii*
- *Sempervivum dolomiticum*

One can also add to these *Physoplexis comosa* (with a more extensive area) and critical species such as *Alchemilla lasenii*, *Rhinanthus helenae*, and *Euphrasia portae*.

Reference is made to the endemics because it can be supposed that they are the results of speciation that occurred in situ and that they can therefore provide direct testimony of the evolutionary processes that depend upon the biogeographic characteristics of the zone. In effect, with the distribution of these endemics, a tendency is often noted for them to be concentrated on the peripheral chains, both those that are most southern (such as Vette di Feltre, Monte Serva, and Monte Cavallo) and those that are northern (the Pragser and Sexten Dolomites). This fact is also connected with the extension of the Quaternary glacial ice cap. We shall have to return to these topics with the discussion of several associations.

Synchronic and Diachronic Interpretations

Whenever scientists study vegetation, it appears to them to be a static object that remains stable in time. Returning to the same site in subsequent years, they find the same situation that they were able to observe previously. In the animal world, on the other hand, everything is in constant motion. And this aspect, the continuous dynamics compared with fixity, reveals to what extent research activities in the fields of flora and fauna may differ from each other. Nevertheless, in both cases the subject remains the same: the living thing. It is thus clear that what is concerned are not differences regarding the essence

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