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THE LOWER PERMIAN VOLCANICS ALONG THE ETSCH VALLEY FROM MERAN TO AUER (BOZEN)

by

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1. Introduction and Geological Overview

The Southalpine metamorphic basement exposed between the Periadriatic Line and the Tertiary-Quaternary Po Basin represents a segment of the Variscan collisional belt (Fig. 1). It is covered in unconformity by post-orogenic Westphalian to Lower Permian continental sediments (BARGOSSI et al., 1998, 1999, VAI & COCOZZA, 1986). In the Latest Palaeozoic, ~285–275 Ma, the whole Southalpine domain has been affected by a magmatic activity that produced voluminous basic to acidic volcanic and plutonic rocks (BARGOSSI et al., 1999; RIVALENTI et al., 1981; STILLE & BULETTI, 1987; DI BATTISTINI et al., 1988; BORIANI et al., 1988, 1995).

The precise age, origin, and the geotectonic significance of the Permian calc-alkaline magmatism in the Southern Alps are still controversial (e.g. ROTTURA et al, 1997, 1998; MAROCCHI et al., 2005). Two main tectono-magmatic models have been proposed:

a) Permian magmatism originated in response to post-orogenic lithospheric extension, without any relation to subduction processes (VOSHAGE et al., 1990; BORIANI et al., 1995; QUICK et al., 2003; SINIGOI et al., 1994; ROTTURA et al., 1997, 1998; BARGOSSI et al., 1999, MAROCCHI et al., 2005);

b) Permian magmatism originated in an Andean-type continental margin at the southern flank of the Variscan belt (VISONÀ, 1982, LORENZ & NICHOLLS, 1984; STILLE & BULETTI, 1987; DI BATTISTINI et al., 1988, FINGER & STEYRER, 1990).

The rocks represent a continuum of lithologies ranging from basaltic andesites to rhyolites, and from gabbros to monzogranites, respectively. Acidic varieties are more common. The metaluminous to slightly peraluminous rocks exhibit mineralogical, petrographic, and geochemical characteristics of a calcalkaline suite. Isotopic and geochemical evidence support a hybrid nature of both volcanic and plutonic rocks being derived by complex interactions between mantle melts and crustal material (ROTTURA et al., 1998, MAROCCHI et al., 2005, in prep.).

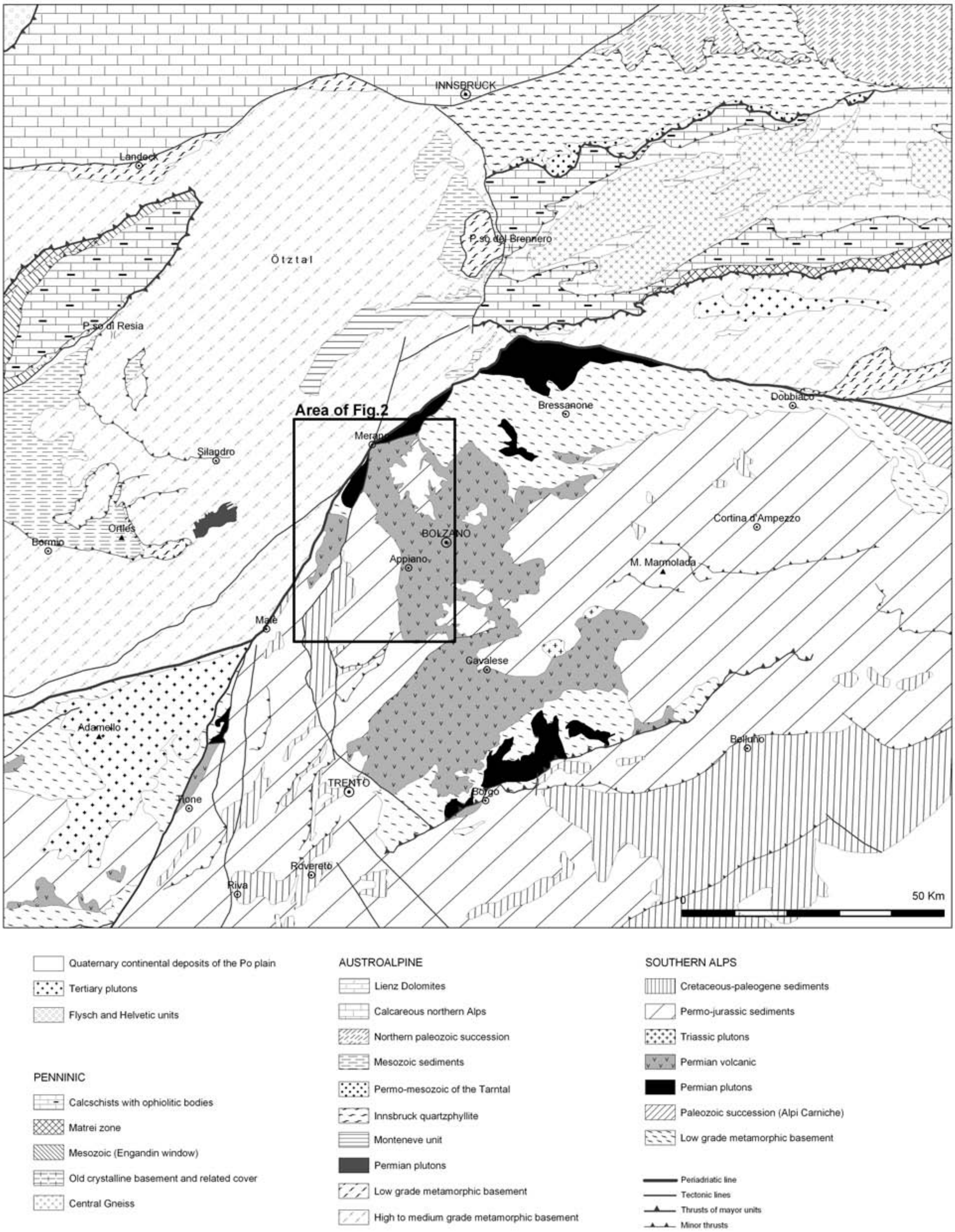


Fig. 1.
Geological overview of the Athesian Volcanic Group (AG).

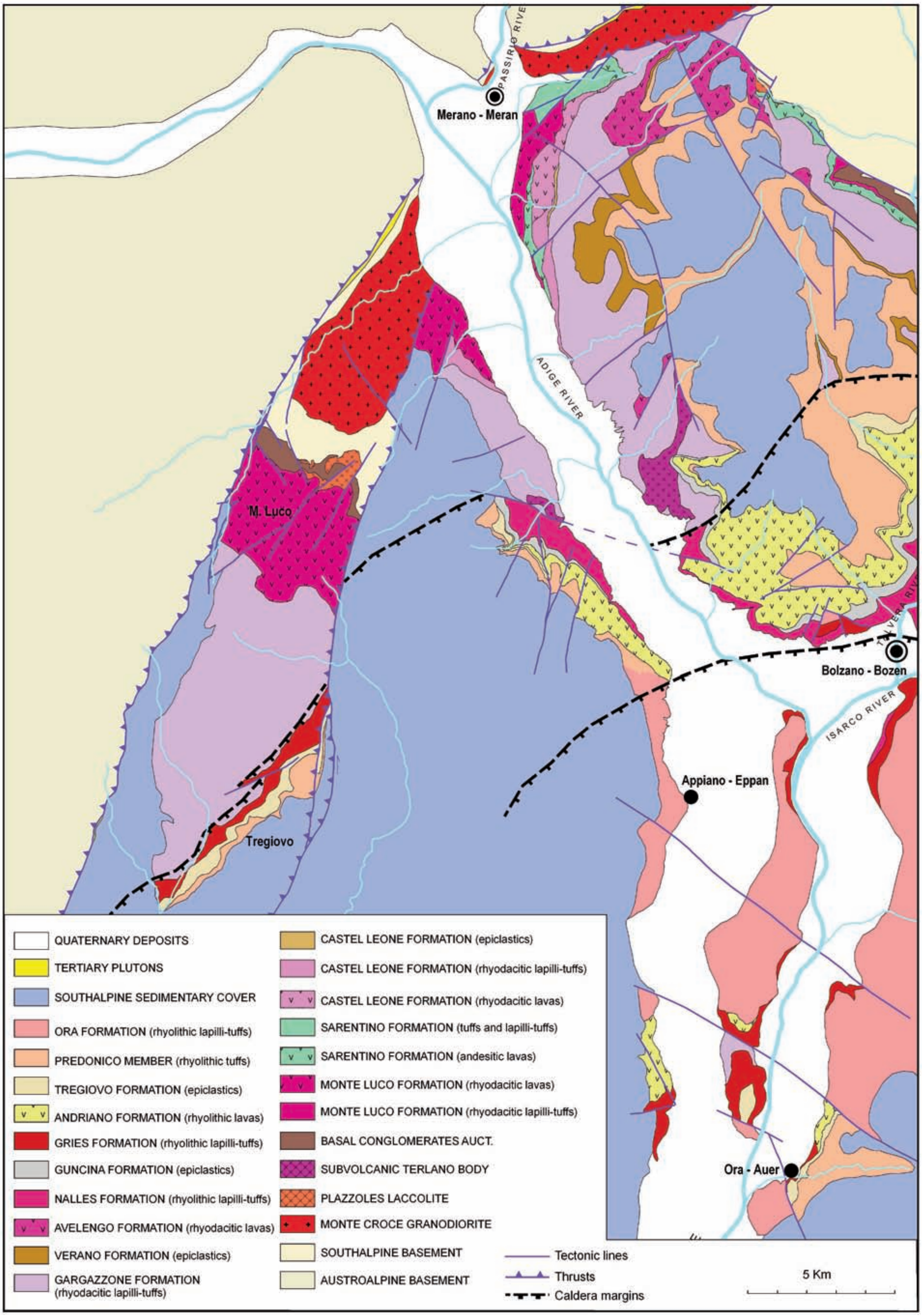


Fig. 2.
Schematic geological map of the NW sector of AG.

In the Trento and Bolzano area the Permian volcanics are termed Athesian Volcanic Group (AG). The AG covers in outcrop an area of ~2000 km2, bounded to the NW by the Periadriatic Lineament and to the SE by the Valsugana Line (Fig. 1). The volcanic rocks are either in direct contact with the Southalpine metamorphic basement or overlie basal conglomerates of an alluvial-fan setting (Ponte Gardena Conglomerate, Lower Permian). They are topped in unconformity by continental clastic deposits (Val Gardena Sandstones, Upper Permian). These pass laterally and upwards into shallow marine sediments (Bellerophon Formation, uppermost Permian). Alluvial and lacustrine sediments are also found at different levels within the volcanic succession, reflecting breaks in the volcanic activity.
Detailed field mapping over an extended area of ~800 km^2 within the CARG project (National Geologic Mapping Project), has allowed the reconstruction of the stratigraphic succession of the AG and the associated sediments. Figure 2 presents a geological overview of the main volcanic products of the north-western sector of the AG.

2. Stratigraphy of the AG volcanics

The stratigraphic succession could be divided into a mainly rhyodacitic-andesitic lower part and a rhyolitic upper part. The volcanic products are represented by prevailing lapilli-tuff with minor lavas, more abundant in the lower part, associated with epiclastic levels.
The whole thickness is about 4000 m, even though it can be reduced from place to place due to synvolcanic extensional tectonic activity.
Figure 3 presents a geological reconstruction of the north-western sector of the AG. The base of the sequence is well exposed in the Monte Luco area where basal conglomerates directly overlie the Variscan low-grade basement. These clastic sediments are comparable to the Ponte Gardena Conglomerates. They are formed by polygenic conglomerates and subordinate sandstones with rhyolitic tuff intercalations, testifying a pristine volcanic activity.
Upwards, the thick succession of the Monte Luco Formation (MLC) is the result of an extensive volcanic activity that mainly drove the formation of rhyodacitic lava flows and huge domes. Talus deposits together with discontinuous pyroclastic levels and epiclastic basins are intercalated.
Just south of Merano, near Sinigo, on the left side of the Adige Valley, the Monte Luco Formation is overlain by the Sarentino Formation (RTO) andesitic lavas which have a thickness of 100 m. These lavas in Val Sarentino effused directly on the metamorphic basement or on the Basal Conglomerates and can reach up to 400 m-thickness.
The volcanic sequence continues with rhyodacitic pyroclastic flow deposits (ignimbrites) of the Castel Leone (ICL) and Gargazzone (IGG) Formations which have a wide extension and huge total thickness of about 1000 m.
After the Gargazzone Formation emplacement, a first important collapse of the south-eastern sector of the AG took place. At the same time the north-western sector was subject to erosion and clastic deposition (COV) with local lavas effusion (AGO). The collapsed south-eastern sector was infilled by a huge volcanic and volcanoclastic sequence (NAL, FMG, LAN, TGV and ORA).
The volcano-tectonic collapse is related to the intrusion along fractures of the subvolcanic rhyodacitic body of Terlano (TRL) and is followed by a geochemical composition change from rhyodacitic-andesitic to rhyolitic products.

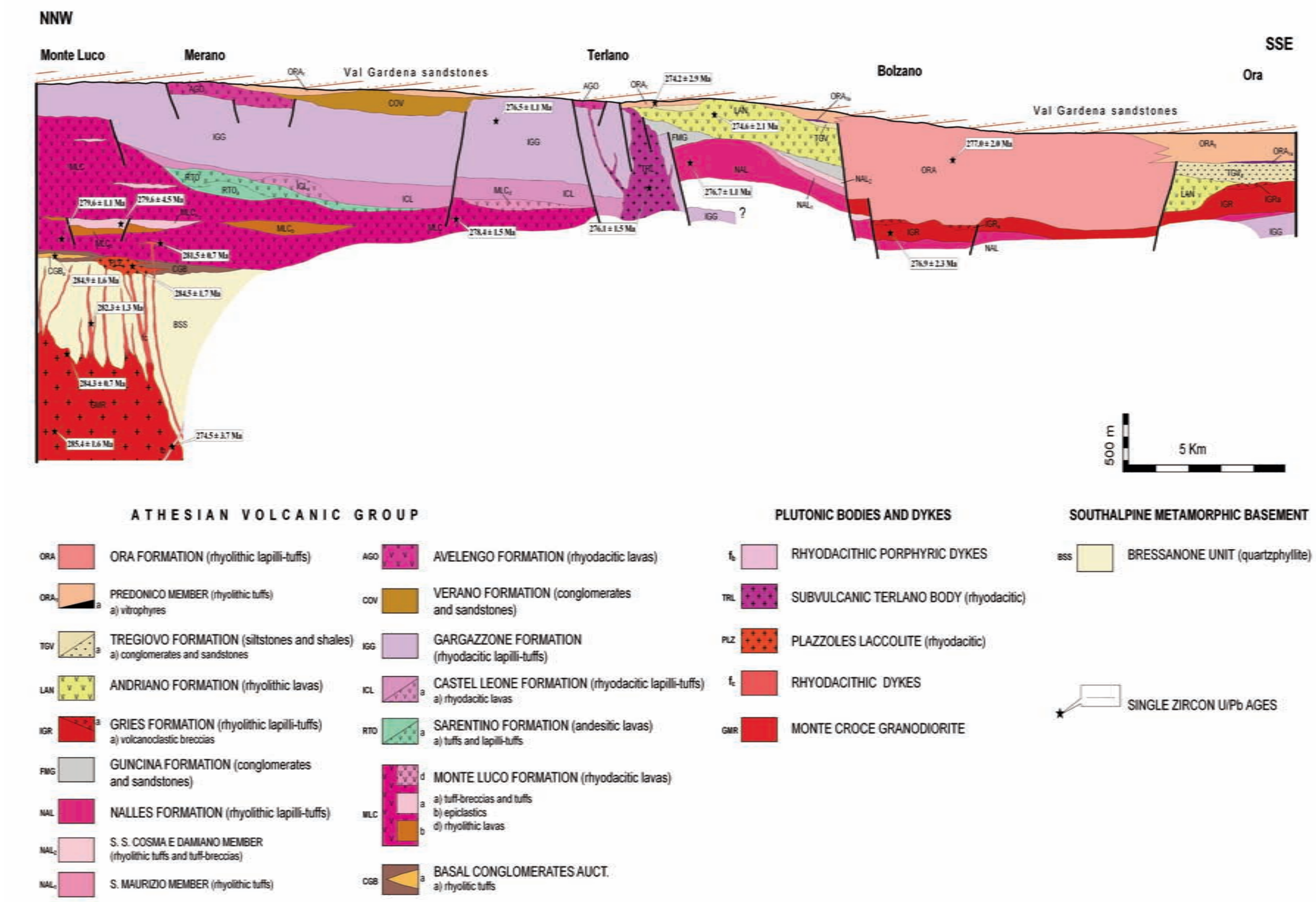


Fig. 3

Schematic stratigraphic cross section of the AG from NNW to SSE. Single zircon U/Pb ages are from MAROCCHI et al., 2005).

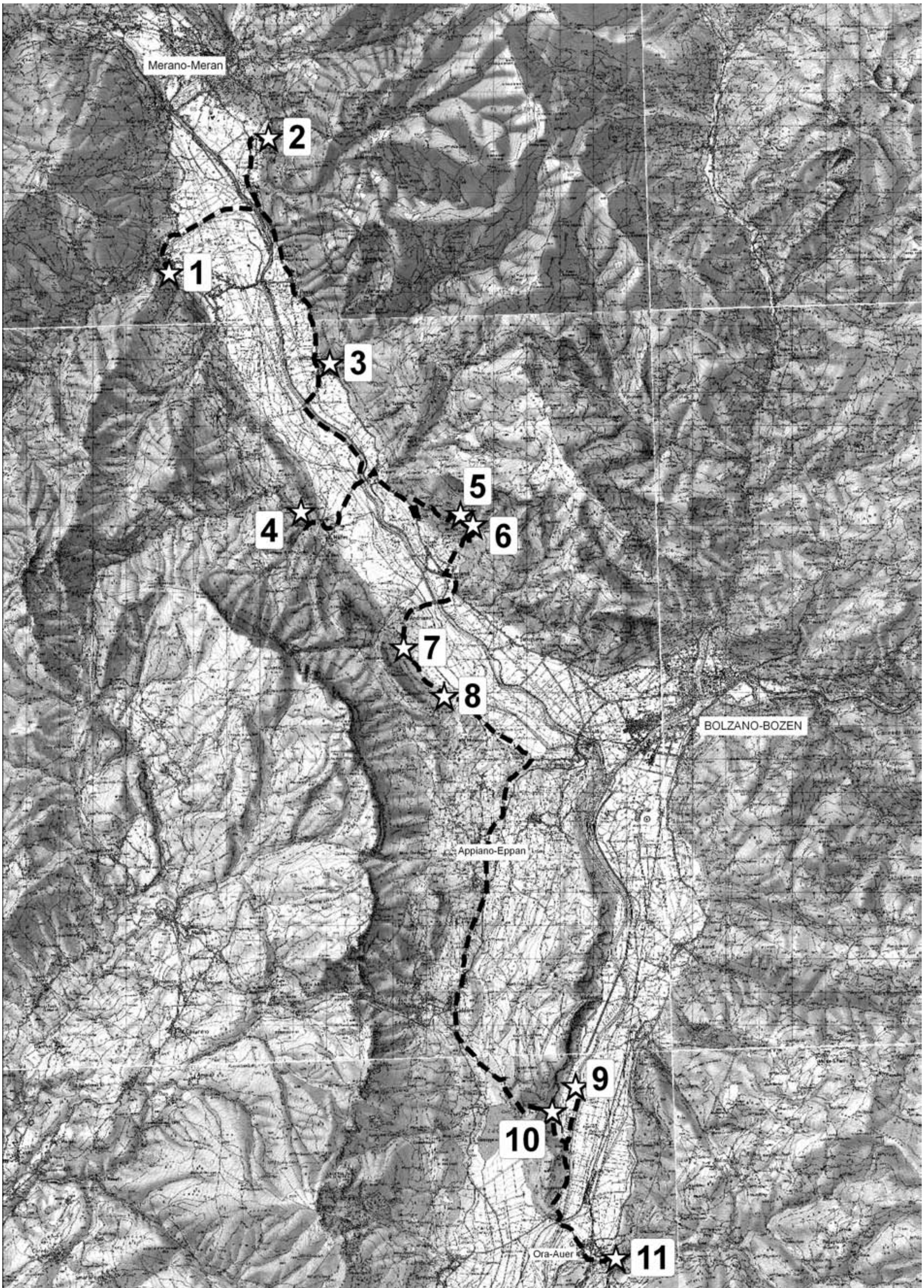


Fig. 4
Map with the excursion itinerary and location of the stops.

A second important collapse escarpment with ENE-WSW trend is present 5 kilometres to the south, close to Castel d'Appiano and Bolzano, and produces a considerable depression of the southern sector. The lowered area was infilled by more than 1000 m of pyroclastic flow deposits (ignimbrites) (IGR and ORA). Only the last products (ORA1) were able to fill up the depression and to expand outside of it in a wide area (more than 1500 km2) with a thickness variable from 250 to 10 meters. These ignimbrites (ORA1) close the AG volcanic activity covering in unconformity different older Formations.

It is important to stress the significance of the epiclastic deposits which are not extended in all the studied area but are restricted to limited sectors. In fact, they do not represent a period of stop of the general volcanic activity but only local erosional episodes contemporaneous with volcanic eruptions in other areas.

Considering the location of the most important and widespread epiclastic Formations (Guncina and Tregiovo), it is evident that they do not separate Formations of different chemical composition but are present between similar volcanic episodes.

Radiometric ages carried out during the CARG Project are reported in Figure 3 (MAROCCHI et al., 2005, in prep.). These data point out that the AG volcanic activity lasted for ~11 Ma, from 284,9 ± 1,6 to 274,1 ± 1,6 Ma. Radiometric ages suggest that the volcanic activity had not a uniform accumulation rate during the whole period.

In fact, the first pyroclastic flows (GCBa) and the Monte Luco Formation deposited in a long period of 6 Ma, whereas starting from the Gargazzone Formation the deposition rate increased and the rest of the volcanic succession accumulated in only 2-3 Ma.

Therefore, the different formations could not be distinguished only on the basis of the radiometric ages because the detection limit is greater than the time span.

3. Field trip itinerary

STOP 1 - Landscape of the volcanic succession exposed on the left side of the Adige Valley between Merano and Gargazzone.

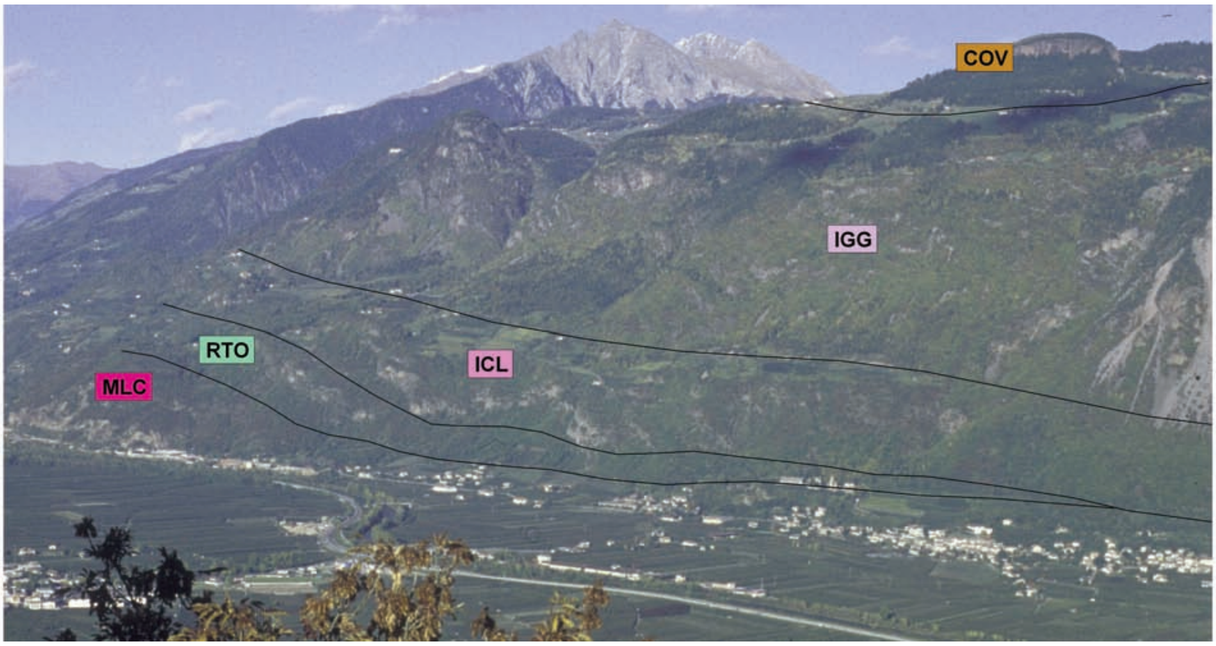
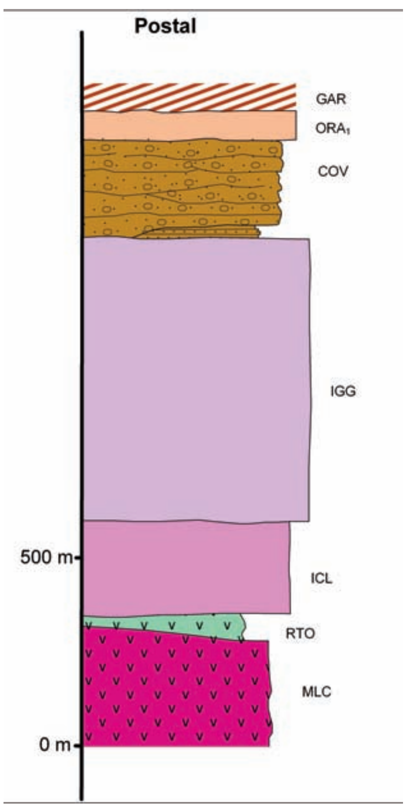


Fig. 1.1

On the slope between Sinigo and Postal the boundaries among the main volcanic units of the lower sequence are well exposed. Abbreviations as in stratigraphic column reported below.



Typical succession of the sector above Postal. From bottom to top:

- **MLC** – Monte Luco Formation: rhyodacitic domes and lava flows (thickness at least 400 m)
- **RTO** – Sarentino Formation: andesitic lava flows (thickness up to 120 m)
- **ICL** – Castel Leone Formation: rhyodacitic ignimbrites (thickness up to 250 m)
- **IGG** – Gargazzone Formation: rhyodacitic ignimbrites (thickness up to 800 m)
- **COV** – Verano Formation: continental sandstones and conglomerates (thickness up to 250 m)
- **ORA_1** – Predonico Member of the Ora Formation: rhyolitic ignimbrites with minor thickness (up to 50 m).
- **GAR** – Val Gardena Sandstones: continental sandstones.

STOP 2 - Outcrop of the Monte Luco Formation lavas.

Massive rhyodacitic lavas with irregular and spaced joints; colour from pink-brown to purple. This rock has porphyritic texture with abundant idiomorphic phenocrysts of pink plagioclases (2-4 mm), biotite, pyroxene, and less abundant quartz in plurimillimetric and subrounded crystals. The groundmass is homogeneous and micro-cryptocrystalline. A planar magmatic flow foliation is present. This outcrop is characterised by the presence of subvertical flow bands passing laterally to low angle ones (Fig. 2.1); this seems to imply the occurrence of growing domes which formed close to magma feeding fractures.

The rock is medium to coarse-grained with a porphyritic index ranging from 30 to 40 (Fig. 2.2). The phenocrysts are represented by usually idiomorphic plagioclases in symplectite associations and glomeroporphyritic aggregates, pervasively substituted by sericite, chlorite, calcite, clay minerals and albite; rounded, embayed and fractured quartz; biotite frequently pseudomorphosed by chlorite, sericite, quartz and opaque minerals; pyroxene totally substituted by chlorite, sericite and opaque minerals. Apatite and zircon are the accessory minerals. Groundmass is constituted by quartz-feldspar microcrystalline aggregates generally with perlitic and snow-flake textures derived by recrystallization of glassy groundmass.

Fig. 2.1
Monte Luco Formation. Rhyodacitic lavas with evident magmatic flow foliation.

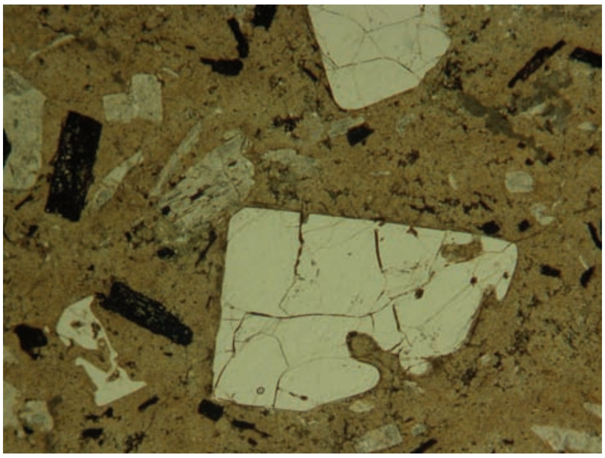


Fig.2.2
Microphotograph of the Monte Luco Formation lavas. Medium-coarse grained rhyodacitic lavas with porphyric fluidal structure and embayed quartz, feldspars and biotite phenocrysts inside a micro-cryptocrystalline groundmass. Plane-polarised light.

STOP 3 - Boundary between the Castel Leone and Gargazzone Formations.

Fig. 3.1
Castel Leone Formation lapilli tuff covered through a sharp boundary by the Gargazzone Formation lapilli tuff.

In this outcrop the sharp boundary between the two rhyodacitic ignimbrites, showing different volcanic facies, is visible (Fig. 3.1).
The lower unit is represented by the Castel Leone Formation (ICL), whose deposits are constituted by the most ancient pyroclastic products, of a certain thickness (50-250 m), cropping out in this sector of the AG.
These rocks consist of welded rhyodacitic lapilli tuffs and could be more or less coherent, with colour ranging from dark to bright red, locally with grey-green shades. The deposits are made of metric to decametric stratified units with irregular surfaces; inside a single bed the rock is usually massive with preferential alignments parallel to the flow unit dip.
The fracturation is usually irregular and spaced; a fiamme-like structure is generally well developed (Fig. 3.2). The texture is constituted by small (1-2 mm) and abundant white feldspar crystals, quartz and minor biotite, inside a homogeneous microcrystalline groundmass.

The petrographic analysis shows a clastic orientated microstructure made of crystal lapilli and ashes (40-50 %) inside a fluidal glassy-cryptocrystalline groundmass with spherulitic portions. The crystals are represented by plagioclase (pseudomorphosed by albite, sericite and calcite), rounded and embayed quartz, making also angular fragments, deformed biotite (substituted by opaque minerals), and pyroxene completely pseudomorphosed by chlorite, sericite and opaque minerals. Zircon, apatite and allanite are the main accessory phases.

The fiamme have porphyritic texture with plagioclase, quartz and biotite inside a microcrystalline flattened groundmass. The volcanic lithics are constituted by several fine quartz fragments, rare plagioclase and zircon inside an oxidized glassy groundmass.

The upper unit is represented by the Gargazzone Formation (IGG). It outcrops, up to 800 m thick, in a wide area both on the two sides of the Adige Valley to the north of Nalles and Terlano, in the southern sector of the Monte Luco as far as Tregiovo, and more to the north-east in the Sarentino Valley and Isarco Valley. It results from huge pyroclastic flows (ignimbrites) which, made of several welded flow units, cover most of the northern sector of the AG filling up the depressions. The lower boundary with the MLC, RTO e ICL is a sharp paraconformity or disconformity.
It's represented by welded rhyodacitic lapilli-tuff, very homogeneous and extremely coherent. The colour ranges from black to a greenish-dark grey with red-purple shades along fissure due to oxidation. This last one can be locally so deep to substitute completely the original colour. The rock is generally sharply divided into very regular slabs (1-30 cm) by sub-vertical fractures; two other fracture sets, approximately orthogonal each other and to the first one, are also present, although less evident (Fig. 3.3). The formation top shows a strongly more foliated facies due to abundant red-purple fiamme. The structure is characterised by several crystals (1-3 mm) of white and/or light pink plagioclase, quartz and biotite inside a homogeneous groundmass. The juvenile inclusions (fiamme) are widespread with a porphyritic microstructure and dimensions ranging form cm to dm; they are usually flattened and isoriented, representing probably magma residual portions, partially crystallized before the magma fragmentation during its rising. Volcanic lithic xenoliths, less frequently metamorphic and plutonic, are locally present.
The petrographic analysis shows a clastic oriented structure, without any granulometric sorting, with abundant crystal lapilli and ashes (40-60%) of idiomorphic or rounded plagioclase, rounded and embayed quartz and altered biotite and pyroxene; they are inside a groundmass made of a felsitic pseudo-fluidal, locally spherulitic, cryptocrystalline aggregate. The presence of sanidine altered to clay minerals is rare. The fiamme display a porphyritic microstructure characterised by the same phenocrysts association already described, with a recrystallized groundmass rich of quartz-feldspar flakes.

Fig. 3.2
Castel Leone Formation Lapilli tuff with abundant fiamme.

Fig. 3.3
Gargazzone Formation Lapilli tuff with typical vertical fracturation.

STOP 4 - Mountainside panorama above Terlano: a sin-volcanic paleo-depression border is visible.

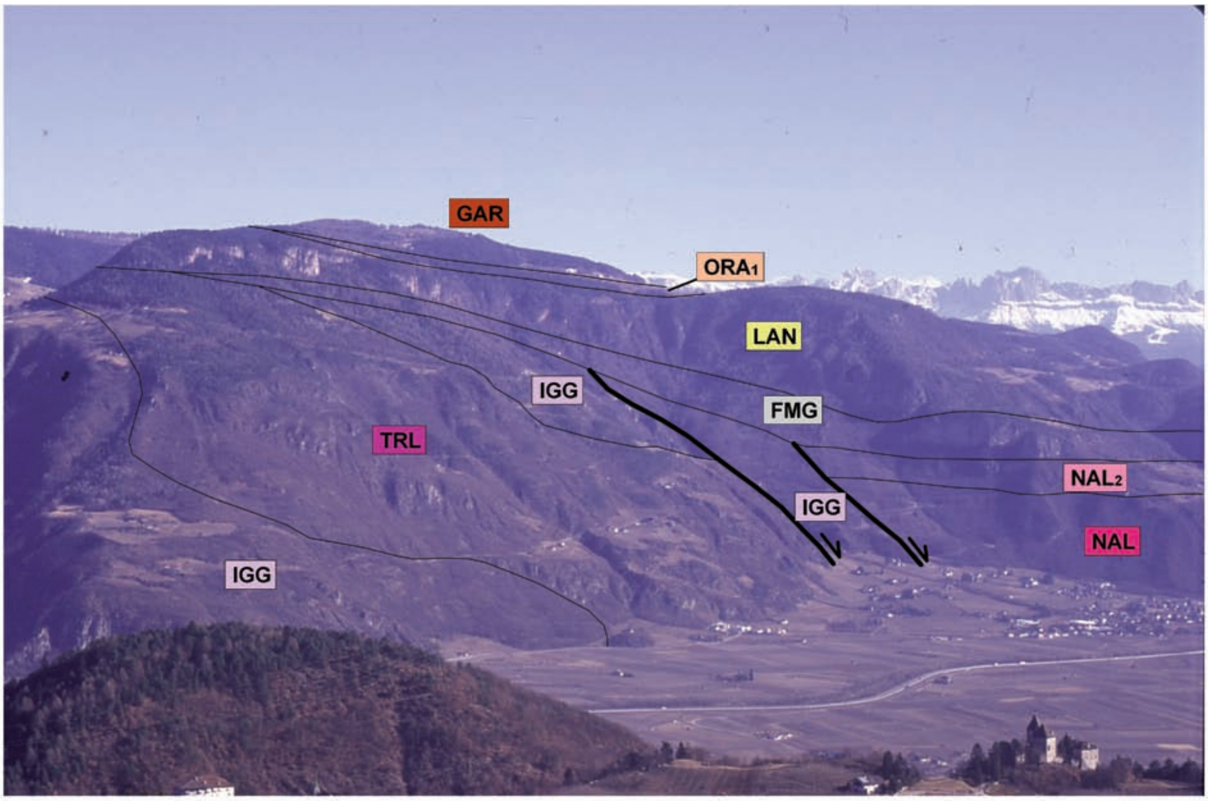
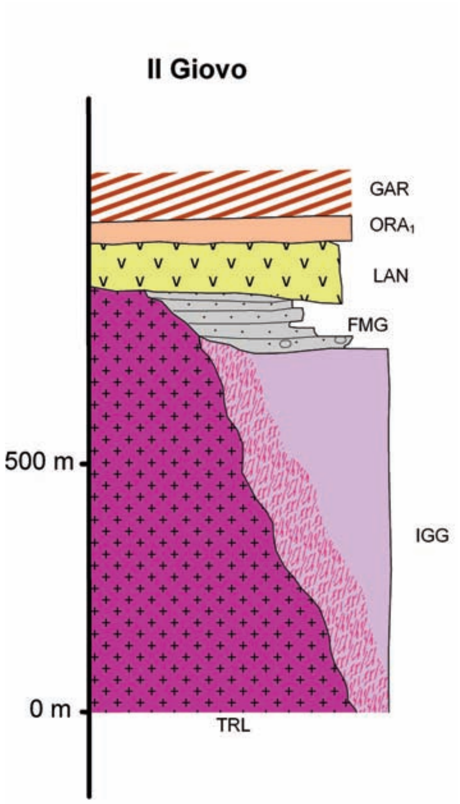


Fig. 4.1

In the mountainside above Terlano it is possible to observe the sharp juxtaposition between younger volcanic sequences (east) and older ones (west). Abbreviations as in the stratigraphic columns reported below.

A paleo-contact along which, during the Permian time, an important collapse of the south-western sector took place is still visible nearby Terlano (Fig. 4.1). Such collapse happened just after the Gargazzone Formation effusion (IGG); while the area to the NW remained substantially in erosion, the SE sector was filled up by a thick volcanic and volcanoclastic sequence (NAL, FMG, LAN, e ORA1). It is worth to notice that the volcanic activity migration was contemporaneous to a clear change in the chemical composition of the emitted products: from rhyodacitic to rhyolitic compositions.

A subvolcanic body (TRL) intruded the Gargazzone Formation along the above mentioned paleo-structure. Its intrusion has to be related both temporally and structurally to the sin-volcanic dislocation.

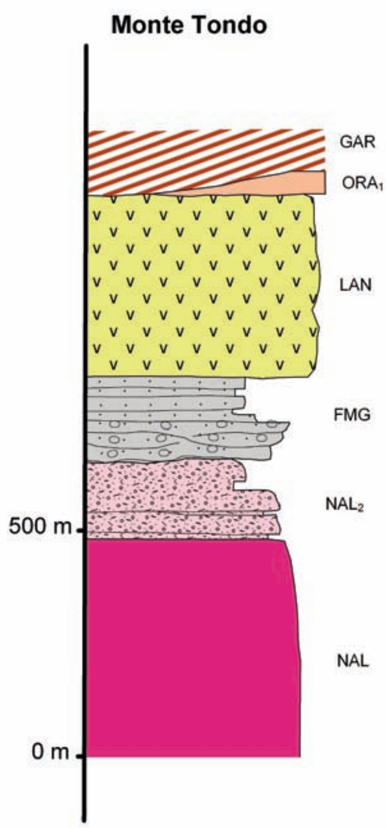


Typical succession of the sector located just NW of the Terlano tectonic collapse. From bottom to top:

- **IGG** – Rhyodacitic ignimbrites of the Gargazzone Formation.
- **TRL** – Terlano body: subvolcanic rhyodacite intruding the IGG.
- **FMG** – Guncina Formation: continental clastic deposits, erosional on IGG and TRL.
- **LAN** – Andriano Formation: rhyolitic lava flows with reduced thickness (max 100 m), rapidly thinning toward the NW.
- **ORA_1** – Predonico Member of the Ora Formation: rhyolitic ignimbrites with reduced thickness.
- **GAR** – Continental sandstones of the Val Gardena Formation

Typical succession of the sector located just SE of the Terlano tectonic collapse. From bottom to top:

- **NAL** – Rhyolitic ignimbrites of the Nalles Formation.
- **NAL_2** – Pyroclastic breccias and surge horizon (S.S. Cosma e Damiano Member of the Nalles Formation)
- **FMG** – Guncina Formation: continental clastic deposits: maximum thickness (250 m) and more coarse-grained facies close to the tectonic contact.
- **LAN** – Andriano Formation: rhyolitic lava flows with up to 500 m thickness.
- **ORA_1** – Predonico Member of the Ora Formation: rhyolitic ignimbrites with reduced thickness.
- **GAR** – Continental sandstones of the Val Gardena Formation.



STOP 5 - Terlano sub-volcanic body and its boundary with the IGG ignimbrites.

In the Terlano area, intruding the Gargazzone Formation, a big sub-volcanic rhyodacitic body displays a sub-vertical trend, orientated roughly N-S, with a maximum thickness of almost two kilometres. The same lithotype can be observed also on the other side of the Adige Valley, near Nalles. Here again it cuts the IGG with a sub-vertical NW-SE trend; the maximum thickness is around 300 meters.
The rock is massive, less fractured and less compact than the surrounding ignimbrites. It doesn't show evident internal textures and the colour is a greenish-grey with rusty-brown shades. This sub-volcanic rock presents a porphyritic structure, characterised by the presence of cm-sized light pink K-feldspar phenocrysts (orthoclase), usually idiomorphic, zoned and geminated. They are set in a groundmass formed of smaller phenocrysts of idiomorphic pink and/or white feldspar (plagioclase), sub-rounded and embayed quartz, biotite, pyroxene and pyrite (Fig 5.2).

A slight lithological difference exists between the lower and the upper part of the subvolcanic body. The latter usually presents a less crystallized groundmass than the former; sometimes K-feldspar phenocrysts are absent. The sub-volcanic body is almost totally intruded inside the IGG ignimbrites; at the boundary the ignimbrites typically show propylitic zones, assuming in this case a yellowish colour and loosing coherence (Fig 5.1). Besides, some centimetric to metric quartz, dolomite and barite bearing dykes occur (Fig 5.3): they show diffuse sphalerite and galena mineralization, which were intensely mined in the past.

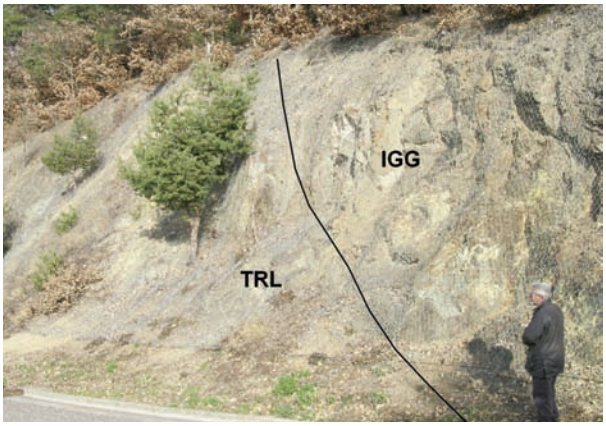


Fig. 5.1
Deeply altered boundary between the Terlano body (TRL) and country rock (IGG).

Fig. 5.2
Typical porphyritic texture of the Terlano rhyodacite.

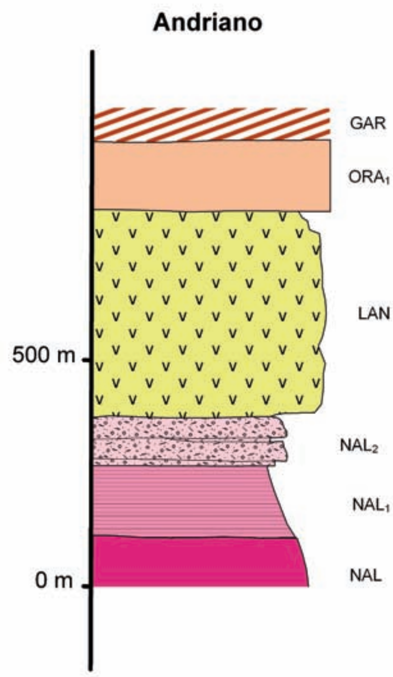
Fig. 5.3
Quartz and barite bearing dykes, partially mineralized, cut the country rock (IGG) close to the boundary with the Terlano body.

STOP 6 - View of the right side of the Adige Valley above Andriano.

Fig. 6.1
On the right side of the Adige Valley above Andriano it's possible to well observe the boundaries among the main volcanic units which make the upper sequence. Abbrevations as in the the stratigraphic column reported below.

Typical succession of the mountainside above Andriano. From bottom to top:

- **NAL** – Rhyolitic ignimbrites of the Nalles Formation.
- **NAL_1** – Fine-grained rhyolitic ignimbrites (S. Maurizio Member of the Nalles Formation)
- **NAL_2** – Pyroclastic breccias and surge horizon (S.S. Cosma e Damiano Member of the Nalles Formation)
- **LAN** – Andriano Formation: rhyolitic lava flows with up to 500 m thickness.
- **ORA_1** – Predonico Member of the Ora Formation: rhyolitic ignimbrites up to 200 m thick.
- **GAR** – Continental sandstones of the Val Gardena Formation



STOP 7 - Volcanic succession exposed at Unterberg quarry of Andriano.

In the volcanic succession exposed at the quarry face it is possible to observe in detail the sequence of pyroclastic events which represent the San Maurizio e S.S. Cosma e Damiano Members (upper portion of the Nalles Formation).

In the lower part (a) the characteristic rhyolitic tuff, representing the San Maurizio Member, are visible. The rock, which colour ranges from dark red to grey-purple, shows a fine-grained homogeneous structure, with few or rare small, microscopic quartz and feldspar crystals. The flow structure is well marked by the repeated isorientation (parallel to the pyroclastic flow) of glassy thin levels (mm thickness, 1-3 cm length) (Fig 7.2).

The microstructure is clastic and oriented with crystal ashes (20-30 %) mainly consisting of plagioclase, sanidine, quartz, biotite and pyroxene, set in a devitrified groundmass with felsitic and flaky microstructure rich of fluidal shapes. Locally, the groundmass is represented by a series of glassy shards which give the rock a typical eutaxitic microstructure (Fig. 7.3). This Member has extremely gradual lower and upper boundaries and the maximum observed thickness is about 70 m.

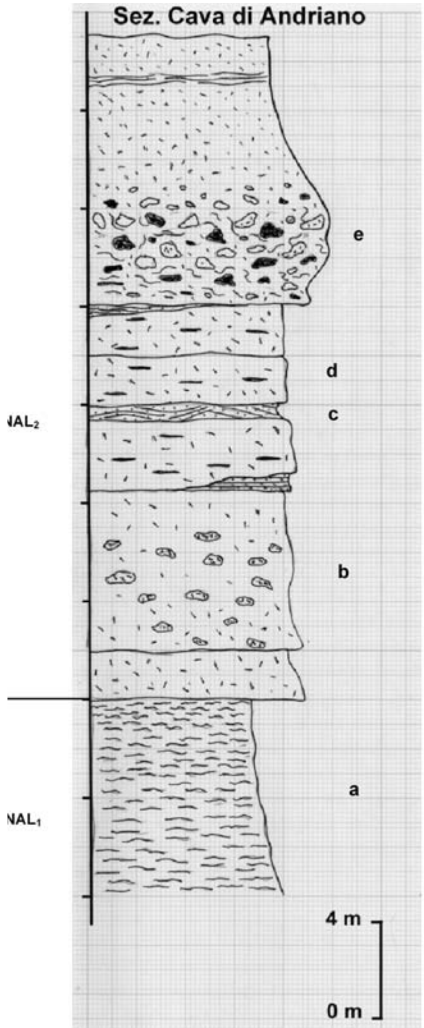


Fig. 7.1
Unterberg quarry log

Fig. 7.2
Typical facies of the San Maurizio Member of the Nalles Formation.

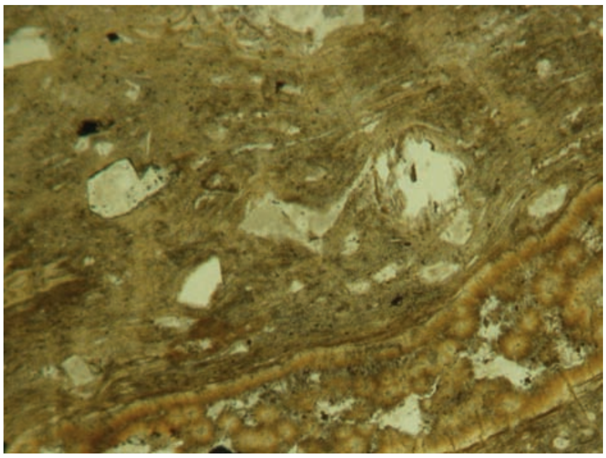


Fig. 7.3
Microphotograph of the Nalles Formation. Fiamme showing spherulitic recrystallization and groundmass with eutaxitic microstructure. Plane-polarised light.

In the upper part a typical succession of the S.S. Cosma e Damiano Member (NAL2) outcrops; it consists of an alternation of tuff-breccia, lapilli-tuff and tuff of rhyolitic composition.
The tuff-breccia (b) is organized in very thick parallel beds, made by variable portion of volcanic lithic and juvenile fragments inside a clastic matrix of crystal fragments and ashes. The lithics show different grain sizes (up to 1 m), they are both sub-rounded and angular and of various composition (Fig. 7.4); few of them preserve characteristic thermal alteration rims. The juvenile inclusions are dark, aphanitic and partially flattened or elongated along the foliation. Some beds have an erosional base and reverse or direct gradation where the lithics show the coarsest grain-size (e) (Fig 7.6). They result from small volume and high energy pyroclastic flows.
The lapilli-tuff (d) makes tabular metric beds constituted by crystal fragments and ashes with small juvenile aphanitic inclusions, which are flattened and isoriented (*fiamme*).
Alternated with the lapilli-tuff some thin stratified tuff deposits occur (c) (Fig 7.5). They display good granulometric sorting and parallel or low angle cross-lamination; graded levels of finer grainsize are also present (fine ashes). The majority of the fine-grained levels are the product of low density explosive events (surge).
The vertical alternation of laminated tuff and lapilli tuff with fiamme is characteristic of this outcrop. Each pair probably represents the product of a single explosive pyroclastic event, in which at the flow front a high speed surge episode developed, depositing the fine laminated part (tuff); this is then followed by the main portion of the flow (lapilli tuff).

Fig. 7.4
Tuff-breccia with abundant lithic xenoliths, some of which present a thermal reaction rim

Fig. 7.5
Laminated tuff at the base of an ignimbrite episode.

Fig. 7.6
Tuff-breccia horizon with reverse gradation of the lithic inclusions at the base, passing to direct toward the top.

STOP 8 - Outcrop of the Andriano Formation lavas.

This is a characteristic unit cropping out in the sector between Terlano and Bolzano on both sides of the Adige Valley, with extremely variable thickness up to 450 m.
It's made by massive rhyolitic lavas of red-orange to brick red to red-purple colour, with diffuse lava flow bands of variable thickness from 5 to 20 cm; these have been pointed out by the selective erosion, which acts preferentially along the joints. These laminations are generally flat-parallel or slightly wavy (only locally strongly wavy); it is possible to observe also band sets intersecting each other with variable angles (Fig. 8.1).
The rock has a porphyric structure with idiomorphic phenocrysts (1-3 mm) of white or pink feldspar and quartz inside a fine-grained homogeneous groundmass. The percentage of phenocrysts is really variable and levels poor of phenocrysts or even aphanitic are not uncommon.

The petrographic analysis outlines a porphyric, locally oriented, microstructure, from medium- to coarse-grained, with a porphyric index ranging from 35 to 45 (Fig. 8.2). The phenocrysts are represented by rounded and embayed quartz; the plagioclase, often associated with K-feldspar (sanidine) commonly forms symplectite or glomeroporphyric aggregates. Biotite and pyroxene have been almost completely replaced by opaque minerals. Apatite and zircon are the main accessory phases.
The groundmass, glassy in origin, appears completely recrystallized with snow flakes motifs, which can pass to polygonal secondary quartz aggregates. The lavas, besides, contain rare magmatic xenoliths with a granophyric quartz-orthoclase bearing microstructure. A metamorphic xenolith, with green hercinitic spinel, fibrolitic sillimanite and quartz, has also been observed.

Fig. 8.1
Rhyolitic lavas with typical wavy flow bands.

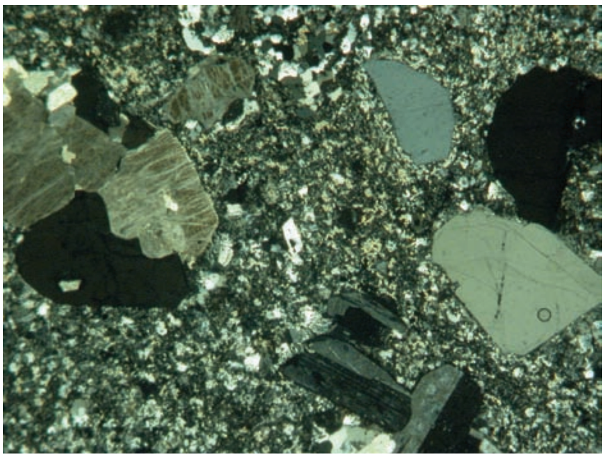


Fig. 8.2
Microphotograph of the Andriano Formation rhyolitic lavas, characterised by a typical porphyric microstructure. Crossed-polarised light.

STOP 9 - Panoramic view of the typical volcanic succession of the caldera sector southern of Bolzano.

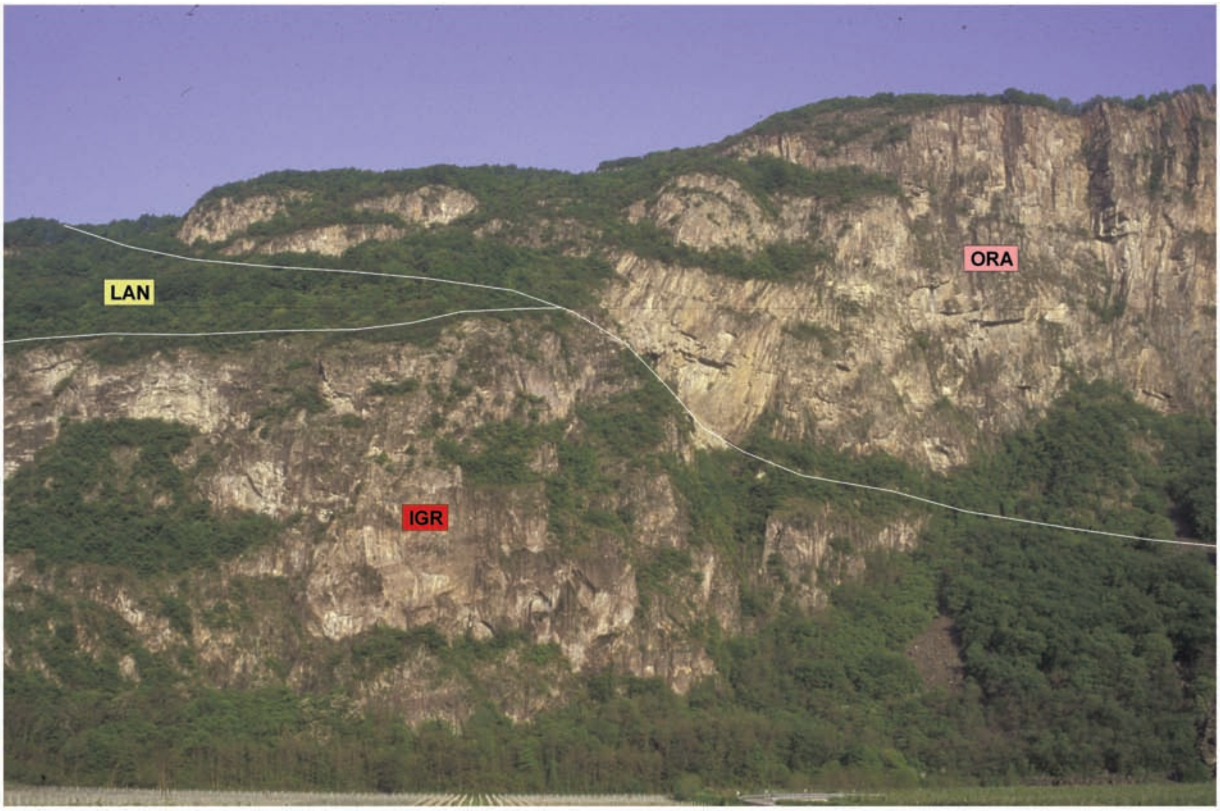


Fig. 9.1

On the right side of the Adige Valley, at Laimburg, the boundaries among the main volcanic units representing the sequence of the caldera sector southern of Bolzano are well visible. Note the "on-lap" termination of the Ora Formation (ORA) on the Gries (IGR) and Andriano (LAN) Formations.

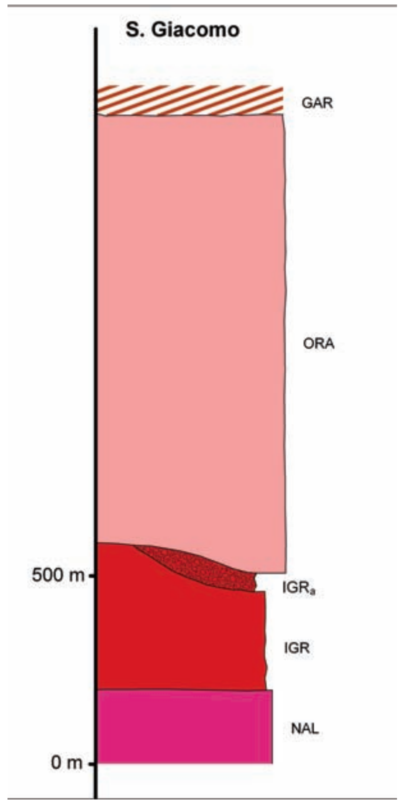
The Ora Formation (ORA) represents the younger volcanic deposit within the AG. It is the product of huge volumes of pyroclastic flows, which deposited in the deeper sectors between Bolzano and Ora, where they overlap the Gries Formation (IGR). The lower boundary of the Ora Formation is characterised by a strong irregularity due to a pre-existing irregular topography, sutured by these pyroclastic flows.

This Formation is made by welded rhyolitic lapilli-tuff, which is very coherent and homogeneous, with a colour ranging from pink-red to orange-red. The rock has a sharp and regular sub-vertical fracturation along two orthogonal sets. A third less evident set of fractures is roughly horizontal and more spaced. Occasionally the original cooling, columnar jointing is preserved (Fig. 9.2).

The hand-specimen structure is characterised by abundant sanidine, pink plagioclase and quartz crystals (2-4 mm), inside a felsitic, fluidal groundmass, which is not homogeneous due to small crystal fragments. The fiamme are frequent and made by dark aphanitic or juvenile porphyric inclusions with the same composition of the rest of the rock. In big outcrops it's possible to observe discontinuity lines, 8-10 m spaced, which cut the rock parallel to the orientation of the *fiamme*. They could represent the separation of different ignimbrite flow units.

Typical volcanic succession of the caldera sector southern of Bolzano:

- **NAL** – Rhyolitic ignimbrites of the Nalles Formation.
- **IGR** – Rhyolitic ignimbrites of the Gries Formation.
- **IGR$_a$** – Volcanoclastic breccias at the Gries Formation top.
- **ORA** – Rhyolitic ignimbrites of the Ora Formation.
- **GAR** – Continental sandstones of the Val Gardena Formation.



The Ora Formation lapilli tuff shows a clastic, oriented microstructure with crystal lapilli and ashes (30-55%), inside a glassy groundmass, which was subject to a felsitic recrystallization in quartz-feldspar aggregates with pseudo-fluidal motifs underlined by fine-grained oxides. The crystalline component is represented by quartz, altered sanidine (hematite and clay minerals), sericitized plagioclase, secondary quartz, opaque minerals, biotite and pyroxene.

The Gries Formation (IGR) crops out in restricted areas just northern of Gries and at the base of the sides of the Adige Valley among Bolzano, Vadena and Ora. Other outcrops are located in the Tregiovo zone. This formation has up to 150 m thickness: the lower formation boundary lies in conformity on NAL and in disconformity on IGG and FMG.
It's made of welded rhyolitic lapilli-tuff of dark red-purple colour; it presents both massive aspect or slightly oriented along the flow lines. The structure consists of abundant mm-sized crystals of sanidine, pink plagioclase and quartz, inside a red-purple, felsitic and fluidal groundmass. Locally, both volcanic and metamorphic lithic inclusions, with a reaction rim, are present; more frequently it is possible to observe juvenile inclusions (fiamme), with porphyric structure, flattened along the flow direction.
Locally, the upper part or the whole Formation is represented by volcanoclastic breccias, which are partly roughly stratified with chaotic, metric to centimetric, sub-rounded or sub-angular clasts set in a less coherent, micro-granular matrix.
The rock microstructure appears clastic, oriented, with crystal lapilli and ashes (30-50 %) formed of altered plagioclase and sanidine, sub-rounded and embayed quartz, biotite and pyroxene. The groundmass is devitrified and made by quartz-feldspar, felsitic aggregates, with evident pseudo-fluidal microstructures underlined by opaque minerals.

Fig. 9.2
Cooling columnar jointing in the Ora Formation ignimbrites.

Fig. 9.3
Ora Formation ignimbrites.

STOP 10 - Panoramic view of the typical volcanic succession on the mountainside above Ora.

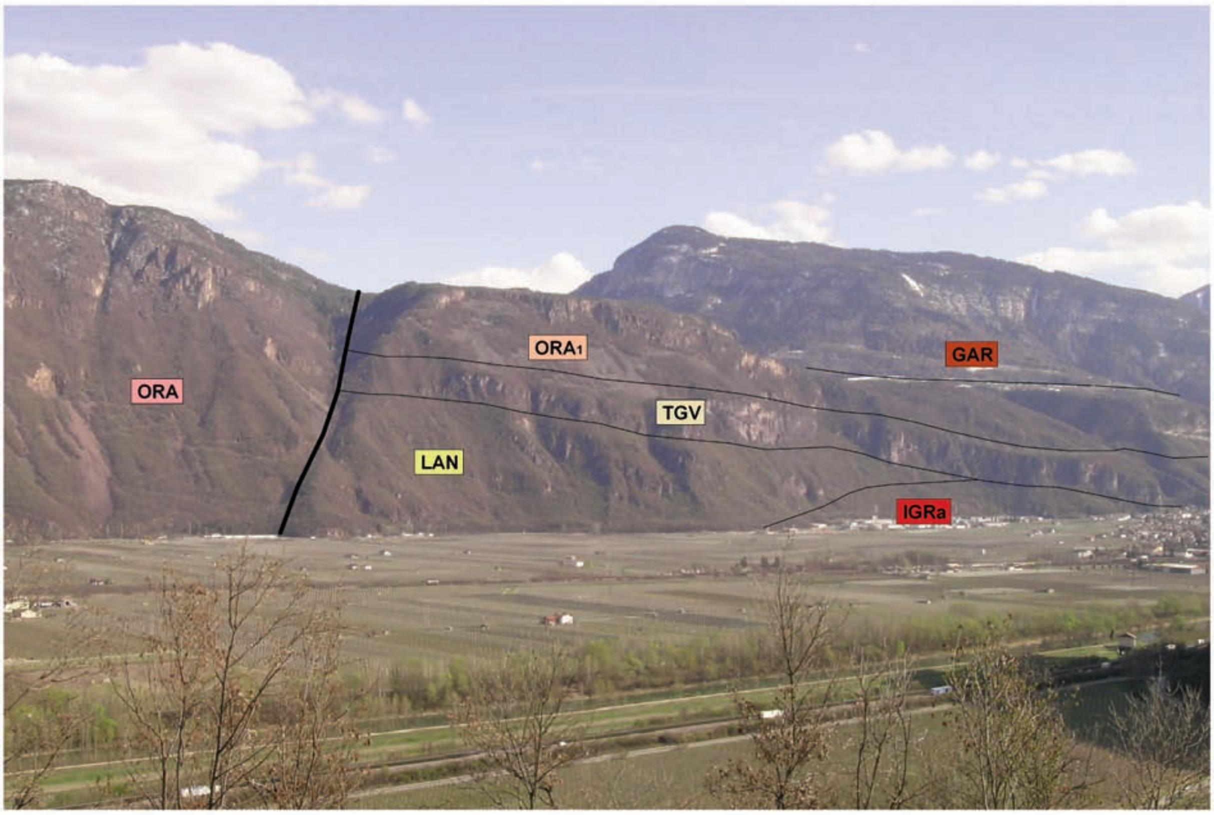


Fig. 10.1
On the left side of the Adige Valley, nearby Ora, it is possible to observe the tectonic contact between the Ora Formation inside the caldera (left) and the Formations of the external sectors of the caldera (right).

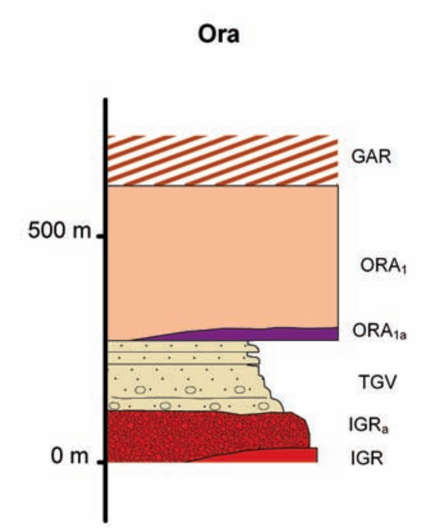
In this locality, we observe the lateral transition from the caldera succession, with the Ora Formation lapilli tuff, to the volcanic succession characteristic of the caldera boundary (Fig. 10.1). In particular, at this stop it is possible to observe the development of a continental clastic succession (with a positive sequence from conglomerates to fluvial sandstones) of the Tregiovo Formation (TGV), which covers in disconformity the older volcanic deposits, i.e. Andriano Formation (LAN) and Gries Formation (IGR).

STOP 11- The Rio Nero succession at Ora.

Along the "Katzenleiter" footpath, which goes from the campsite located at the intersection between Rio Nero and the Adige Valley up to Mt. Castello, we observe the succession illustrated in the stratigraphic column below.

Succession of the mountainside above Ora.
From bottom to top:

- **IGR** – Rhyolitic ignimbrites of the Gries Formation.
- **IGR_a** – Volcanoclastic breccias at the Gries Formation top.
- **TGV** – Tregiovo Formation: conglomerates and fluvial sandstones.
- **ORA_1** – Predonico Member of the Ora Formation: Rhyolitic ignimbrites with ~ 300 m of thickness; at the base there's a vitrophyric level (**ORA_{1a}**)
- **GAR** – Continental sandstones of the Val Gardena Formation



At the bottom close to the campsite, the typical chaotic facies of the volcanoclastic breccias of the Gries Formation are exposed. The rock is constituted by sub-rounded or sub-angular, metric to centimetric, chaotic clasts, immersed in a less coherent brown-red matrix. The clasts as well as the matrix are made only by fragments of the ignimbrite below. This facies is interpreted as the result of debris flow processes which attained the pyroclastic unit.
Climbing the footpath it's possible to observe the gradual transition to coarse-grained clastic facies more and more stratified (Tregiovo Formation): they are pebbly sandstones with chaotic, cm-dm-sized, volcanic clasts (debris flow); the clasts range from angular to sub-rounded. These conglomerates are interbedded with medium/coarse-grained sandstones, which become more frequent upward, until they completely replace the conglomerates. The sandstones have massive, from medium to thick, beds with cross-lamination. The colour is generally red; only occasionally isolated, decimetric, volcanic clasts occur.

Further higher there is an abrupt transition to the Predonico Member rhyolitic ignimbrites (Ora Formation). This Member represents the equivalent of the Ora Formation lapilli tuff described at the Stop 9. It consists of welded rhyolitic tuff and lapilli-tuff, generally red coloured, characterised by smaller and scattered crystals of sanidine, plagioclase, quartz, rare biotite and by a greater occurrence of juvenile aphanitic inclusions (fiamme) (Fig. 11.1). The rock is very coherent and shows a vertical fracturation less pronounced and regular than the rest of the Ora Formation. At the bottom some black vitrophyric levels of metric thickness occur. They are extremely compact, the structure and composition are the same of the rock above; the only difference is the presence of unaltered glass in the groundmass, which gives the rock a black bright colour. The transition from the vitrophyre to the rock above is characterised by the presence of more or less altered and kaolinitized metric portions.

The microstructure is clastic and oriented with crystalline lapilli and ashes (25-40%), contained inside a vitreous groundmass, which has been subject to felsitic re-crystallization in quartz-feldspar aggregates also with spherulitic microstructure. The glass and the crystalline components are well preserved only inside the vitrophyre (ORA1a), where the perlitic fracturation and the eutaxitic microstructure are particularly clear, with glassy shards forming pseudo-fluidal motifs marked by hematite (Fig. 11.2). The crystalline component is almost the same as in the Ora Formation.

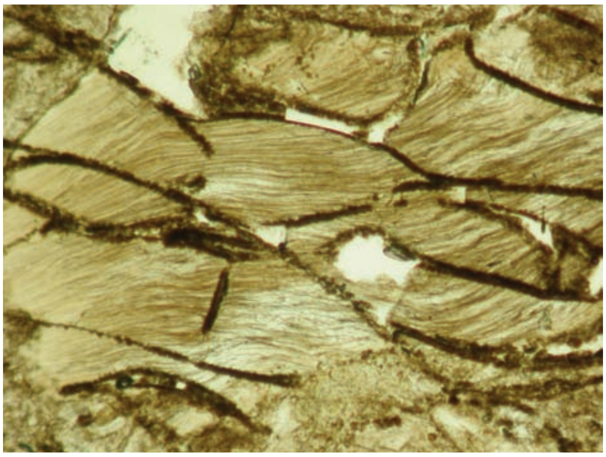


Fig.11.1
Fiamme-bearing ignimbrite of the Predonico Member of the Ora Formation.

Fig. 11.2
Vitrophyric rhyolitic tuff with eutaxitic vitreous groundmass showing perlitic fracturation marked

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