THE UDINE SHEET OF THE GEOCHEMICAL MAP OF ITALY: EXPLANATORY NOTES

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INTRODUCTION

The area covered by the Udine Sheet on the scale 1:250,000 is included between 46° and 47° North Latitude and between 12° and 14° East Longitude. The Italian sector of this sheet belongs mostly to the Regione Autonoma Friuli-Venezia Giulia (Provinces of Udine, Pordenone, and Gorizia), the northern part of the Region of Veneto (Provinces of Belluno and Treviso), and a very small part of the Region of Trentino-Alto Adige (Province of Bolzano).

The mountain chain exposed in the area consists of two distinct paleogeographical domains: the *Southalpine domain* or Southern Alps and the upper and lower *Austroalpine domain*. The two units are currently separated by an evident tectonic line, which is named the *Insubric Line*. It is only present in the Pusteria Valley (Alto Adige) within the Udine Sheet. The Southalpine domain, which is shortened *in situ* and south-vergent, is present to the south of the Insubric line whereas, north of it the *Austroalpine* domain outcrops, translated into a number of northvergent nappes.

The geology and structural setting for each region are described in the order: Friuli-Venezia Giulia, Veneto, Trentino-Alto Adige.

GEOLOGY OF FRIULI VENEZIA GIULIA

The orographic system of Friuli-Venezia Giulia comprises different geological units (Figure1): the mountain chain called the *Carnic* or *Paleocarnic Chain*, along the border between Italy and Austria; the southern Carnic Alps (or Alps of Tolmezzo), further south, but to the north of the Tagliamento River; the Julian Alps, further east. The Prealps are subdivided in Carnic to the west of the Tagliamento River, and Julian, to the east of it. The upper Friulian alluvial plain lies to the south of the Prealps.

The stratigraphic sequence is very variable and complex in this region and it reaches up to 15,000 m in thickness. It formed over 460 million years starting from the Paleozoic (Upper Ordovician) and was affected by two orogenic cycles: the Hercynian and the Alpine.

The Hercynian Sequence in the Carnian-Paleozoic and the Permo-Carboniferous Sequence (from Vai et al., 2002; Venturini, 2002)

The Paleozoic succession can be subdivided into two sequences: the Hercynian sequence, which forms the highly deformed substrate, not affected by metamorphism, and the Permo-Carboniferous sequence, which is discordant on the Hercynian substrate (Venturini, 1990).

The first sequence is included between the Upper Ordovician and the Upper Carboniferous (Westphalian) and consists of prevailing carbonate terrains, laterally coeval with lithofacies made up of radiolarites and shales, followed by a terrigenous-volcanic sequence whose thickness is estimated to be ~ 2 km.

Figure 1. Orographic units of Friuli-Venezia Giulia. (from Vai et al., 2002).

Tetracorals and Tabulates, by Phillipsastrea limestones, and, finally, by Amphipora limestones formed in backbarrier lagoons. Nowadays, the Devonian reefs are diffusely exposed, without having been alterated by metamorphism, from Mt. Volaia to Mt. Cavallo di Pontebba, showing from 500 to 1200 m in thickness. The pelagic facies persists as Tentaculites pelagic limestones and radiolarites and graptolitic shales.

A sinsedimentary extensive tectonic activity started in the Upper Devonian (initial phase of rifting) leading to the dismemberment and drowning of reefs. This activity is testified to by the widespread calciruditic facies, also very coarse (megabreccias), exposed in the Passo di Monte Croce Carnico area. The dominant facies in this period consists of pelagic goniatite and climenid limestone and of radiolarites and siliceous pelites until the Lower Carboniferous. The overall thickness is about 200 m. Outcroppings are discontinuously found at Mt. Lodin, Zermula, Pizzo di Collina, Creta di Collinetta, and near Tarvisio.

When the rifting phase was still in progress, the so-called "Hercynian Flysh" deposited. It consists of the *Hochwipfel Fm* (Lower-Upper Carboniferous) and of the *Dimon Fm* (Upper Carboniferous p.p.), whose total thickness reaches 2 km.

The *Hochwipfel Fm* is made of prevalently fine siliceous clastites, intrepreted as turbidites. At their base, breccias, conglomerates and megabreccias (olistostromes) are found. These materials are due to erosion of emerged areas, which formed the first reliefs of the Hercynian chain that developed as consequence of the collision between the African and the North American plates. The formation is almost completely lacking in fossil remains, except rare plants. The most important outcrops are located between the Degano Valley and Mt. Zermula.

The *Dimon Fm* is characterised by vulcanoclastites (breccias, tuffs, hyaloclastites, basic volcanic rocks, such as diabases and pillow-lava flows) that alternate with sandstones and greenish-red argillites. The formation outcrops north of Ravascletto, at Creta di Mezzodì (Pramosio), at Mt. Dimon (NE of Paluzza), and between Paularo and Mt. Zermula.

The Carnic area was also involved in the Hercynian Orogenesis in the Upper Carboniferous (Westphalian) when the Paleocarnic chain originated. Compressive movements finished at the end of the Upper Carboniferous and the Permo-Carboniferous sequence started to deposit. It consists of fluvio-deltaic and marine shelf sediments whose thickness varies from 100 to 2000 m. Outcrops are concentrated in three distinct areas: Forni Avoltri, Pramollo (the most important in extension and variety), and Tarvisio.

The first unit of the Permo-Carboniferous sequence is called the *Bombaso Fm.* and is composed of materials derived from the emerged Paleocarnic chain. This formation consists of arenaceous and pelitic sediments and quartzitic conglomerates.

It is covered by the units of the *Pramollo Group* (Auernig group of Selli, 1963), in which sandstones, argillites, and siltites alternate with conglomerates. Subordinate intercalations of bioclastic limestones are also present. This group, rich in Brachiopods, Trilobites, Corals, and Crinoids, is exposed south of Forni Avoltri, and is ~ 1200 m thick.

The subsequent *Rattendorf Group* (Upper Carboniferous - Lower Permian) is characterised by carbonate facies. It outcrops in the Tarvisio area, is 400 m thick, and consists of three units:

- the lower *Pseudoschwagerina fm*, made up of massive biogenic limestones, alternating with bioclastic stratified limestones;
- the *Val Dolce fm*, characterised by a high quartz-terrigenous component;
- the upper *Pseudoschwagerina fm,* made of massive limestones and well-stratified biomicrites with algae and foraminifera.

The Permo-Carboniferous sequence in the Pontebba area ends with the Lower Permian deposits belonging to the *Trogkofel Group*, which constitutes most of the homonimous mount (Creta di Aip) and mainly consists of massive reef limestones.

The Permo-Triassic Sequence

The Permo-Triassic sequence in the Friuli-Venezia Giulia region can be divided in the Permo-Anisian sequence and the Ladinian-Rhaetian sequence.

1) *The Permo-Anisian Sequence* (from Venturini, 2002)

This sequence is exposed in the northernmost Carnic Alps (Carnia and Tarvisio area). It discordantly covers the deformed Hercynian substrate and, through low-angular discordance, the Permo-Carboniferous deposits.

The first two units of the sequence are prevalently formed by rudites up to ~ 60 m thick. They are named Tarvisio Breccia, with prevailing clasts of carbonate rocks (Figure 2), and Sesto Conglomerate. The Tarvisio Breccia originated from erosion of the underlying carbonates of the Trogkofel Group, whereas the Sesto Conglomerate covers the arenitic-pelitic units of the Permo-Carboniferous sequence, where these are present, and the deformed Hercynian sequence.

The depositional environment was continental for both units, with small alluvial fans interfingering the characteristic red pelitic and arenitic sediments belonging to the adjacent and subsequent *Val Gardena Sandstone*, also named *Val Gardena fm.*

These sandstones show variable thickness, ranging between 30-40 and 250 m (Venturini, 1986, 1990). In the thicker sequences (Forni Avoltri and Paularo), thin laminated gypsum and dolomicrites are found. The formation is overlain by lagoon evaporites (gypsum) and shallow water carbonate sediments (black and brown dolostones and black limestones rich in algae and microfossils)

The Permo-Carboniferous sequence is made up of an alternation of continental, deltaic and shallow- or deep-sea deposits, including terrigenous and carbonate facies, overlying the clastic basal unit. This sequence is interpreted as the postparossistic depositional phase related to the Hercynian-Carnian event.

The Paleocarnic chain is the sector where paleozoic rocks, known all over the world for fossiliferous formations, prevail. This chain extends along the northernmost belt of the region (Figure 1), part of Cadore (Veneto) to the west, Austrian territory to the north up to the Gail River Valley, and Slovenian territory to the east up to the Sava River Valley. The same chain is marked by a long depression consisting of the Pesarina, Calda, Pontaiba, Pontebbana and Canale valleys (Carulli, 1987). The whole paleozoic sequence, with a thicknes of 4000 m, starts from Ordovician and finishes to Lower Permian (Figure 2).

The oldest rocks are dated to the Ordovician p.p. based on their stratigraphic position. They belong to the *Val Visdende Fm* and *Fleòns Fm*, not reported in the scheme. These formations are exposed in the northwesternmost sector of the region, at the border line with Veneto, and, more precisely, on the western side of Mt. Avanza. They are made up of shales, siltstones, and sandstones. Some authors (Vai, 1994, Spalletta et al., 1982; Spalletta and Venturini, 1990) attribute these formations to the Upper Carboniferous and consider them equivalent to the metamorphic rocks belonging to the *Hochwipfel Fm* and *Dimon Fm*.

The overlying unit is known as the *Uqua Fm* or *Uggwa Fm*, from the name of the main outcropping area, in the Uqua Valley, north of Ugovizza. It is also exposed at Creta di Collinetta and north of Paularo. This formation was dated to the Upper Ordovician based on its fossiliferous content (Bryozoans, Trilobites, Brachiopods, Conodonts, Crinoids). It consists of greenish-grey siltstone in association with sandstones, changing upwards to calcarenites.

Very fossiliferous Silurian lithotypes lie above this unit. Selli (1963) organised these lithotypes into several characteristic facies on the basis of the sequences outcropping in distinct areas: the facies of *Collinetta, Ramàz, Coglians e Volaia, M. Cocco, Forca di Lanza*. According to recent stratigraphic schemes (Spalletta et al., 1982; Vai et al., 2002), the graptolitic shales are coeval with the carbonate facies of the Lower Silurian, whereas the Orthoceras limestone, about 30 m thick, deposited during the Upper Silurian. Other carbonate facies, such as the Cardiola beds, Megaerella beds and pelagic tentaculitid limestone, deposited laterally and above the previous ones. The overall thickness of the Silurian formations does not exceed 50 m (condensed facies) and typical outcropping sites are located at Mt. Cocco, in the Uqua Valley, at *Creta di Collinetta* and within the Coglians Group.

Two very distinct facies are recognised in the Upper-Middle Devonian: a shallow one (backreef, reef, and forereef) and a pelagic one, deposited in a some-hundred-metres-deep sea. As reported in the stratigraphic scheme of Figure 2, reef limestones are characterised by Pentamereus limestones, with Crinoids and Tetracorals, by Stringocephalus limestones, with

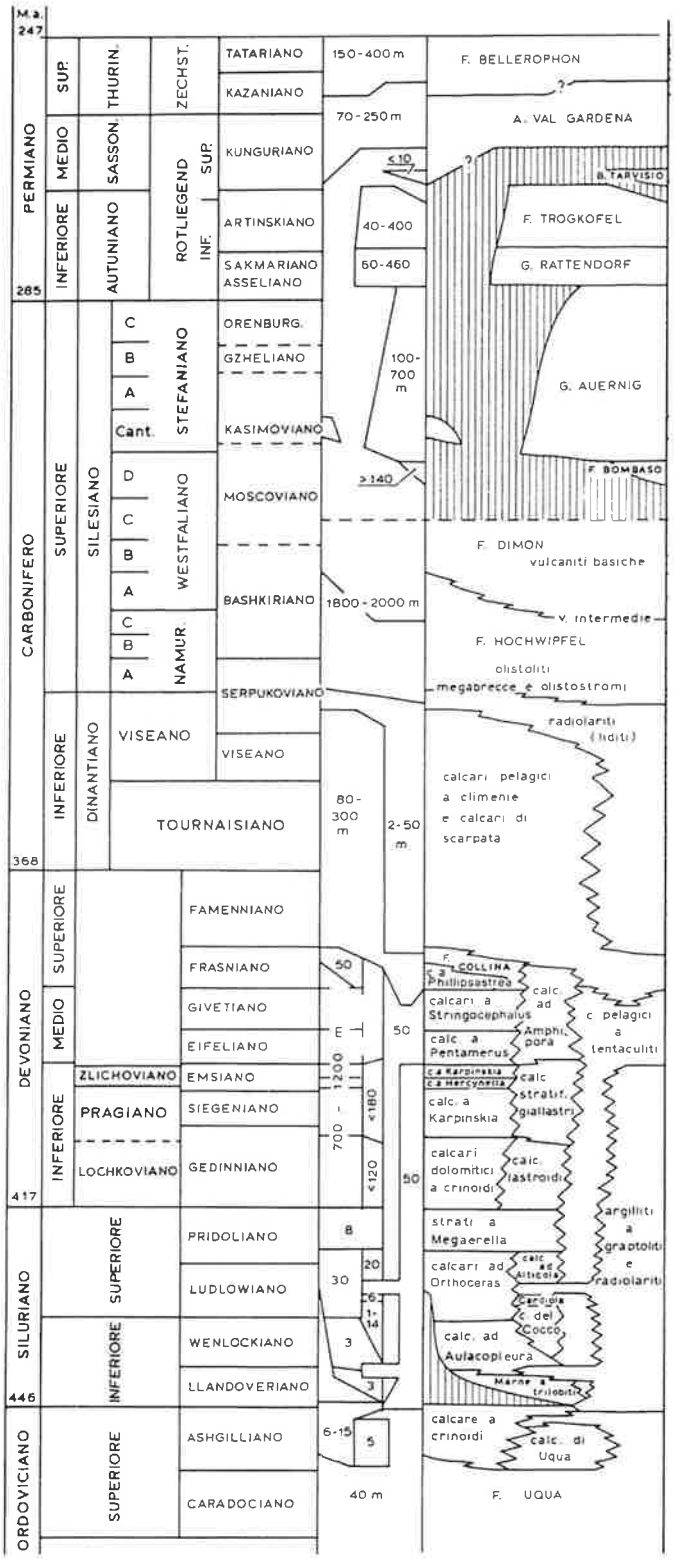

Figure 2. Stratigraphic scheme of Carnic Paleozoic (From Spalletta et al., 1982).

of the *Bellerophon fm.* (top of the Upper Permian). This formation appears intensively fragmented because of compression during the Alpine Orogenesis. It crops out near Treppo Carnico, Paularo and Lake Sauris.

The base of the subsequent unit, named *Werfen fm.*, represents the Permo-Triassic limit (Figure 3). The thickness of the Werfen formation is ~ 700 m in the Carnic Alps. The sediments belonging to this unit are mainly calcareous but a thick red horizon, made up of arenites and pelites, is present in the medium section of the formation (Member of Campil). The subdivision of this formation recently proposed for the dolomitic sector may be applied to the Carnic area as well (Broglio Loriga et al., 1983, 1990).

This formation is clearly overlain or interfingered by the *Lower Dolomia del Serla Fm.*, of Anisian age, which is informally subdivided into Lusnizza and Arvenis members. The Lusnizza member, usually characterising the lower portion of the unit, with variable thickness between 35 and 100 m, consists of a thick alternation of grey vuggy dolomites, dolomitic breccias, calcareous dolostones, and marls. The Arvenis member consists of micrites, dolomitic limestones and laminated dolomicrites and it has a thickness between 80-100 and 300 m.

The Upper *Dolomia del Serla fm.* (Upper Anisian) overlies the previous formation. This unit is the first Triassic "reef" body (platform-barrier) of the Carnic-Dolomitic area. It consists of dolostones and massive dolomitic limestones, with coarsely stratified banks, and overall thickness > 200 m.

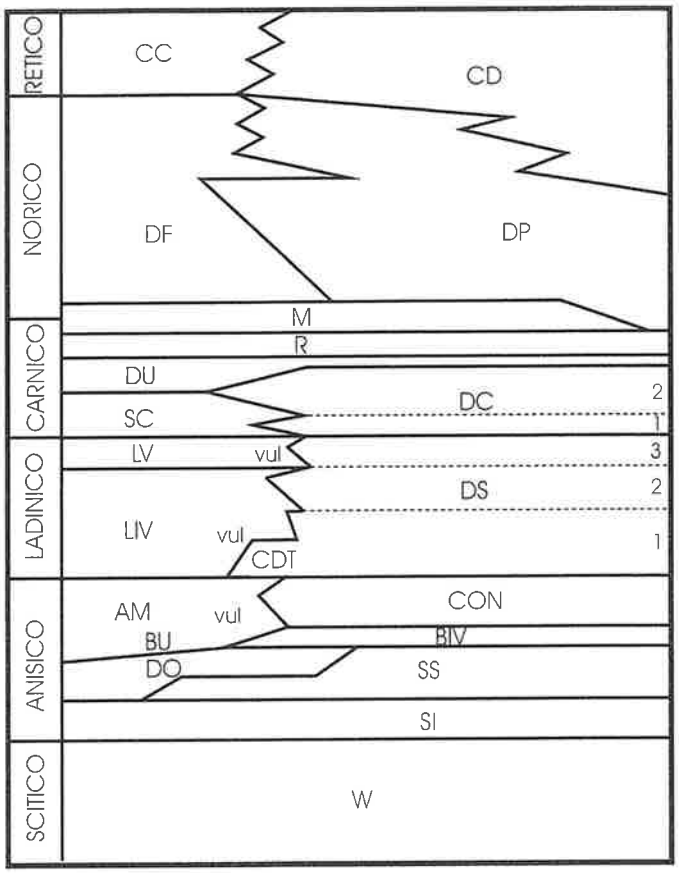

Figure 3. Stratigraphic scheme of the Triassic units. CC: Chiampomano limestone; CD: Dachstein limestone; DF: Dolomia di Forni; DP: Dolomia Principale; M: Monticello Fm.; R: Raibl Fm.; DU: Dürrenstein Fm.; SC: S. Cassiano Fm.; DC: Dolomia Cassiana; LV: La Valle Fm.; LIV: Livinallongo Fm.; DS: Dolomia dello Sciliar; CDT: Mt. Tiarfin dolomitic limestones; AM: Ambata Fm.; BU: Ugovizza breccia; CON: Contrin Fm.; BIV: Mt. Bivera Fm.; DO: Dont Fm.; SS: Dolomia del Serla superiore; SI: Dolomia del Serla inferiore; W: Werfen Fm.; vul: vulcanites. (from Ponton, 2002).

During the the Anisian p.p. three distinct and subsequent tectonic impulses produced tectonic-sedimentary sequences, similar to those of the Dolomitic sector, in the Carnic and Julian area. Each sequence is characterised by a coarse terrigenous episode of fluvio-deltaic environment (*Piz da Peres Conglomerate*, *Voltago Conglomerate*, *Ugovizza Breccia* or *Richtofen Conglomerate*) that is connected to subaerial reworking of emerged crustal sectors, followed, in a regressive sequence, by lagoon calcareous deposits (*Dadocrinus gracilis fm.*, *Agordo fm.*, *Morbiac limestones*). Of these deposits, only the Ugovizza Breccia is reported in Figure 3.

The third tectonic impulse determined the deepening of several areas, in addition to local vertical uplift. Here, thin basin units, represented by the *Dont fm.* and *Mt. Bivera fm.*, deposited.

The *Dont fm.*, some tens of metres thick, is initially coeval with the Upper *Dolomia del Serla fm.* (Figure 3), but it locally overlies the latter, where sinsedimentary tectonic activity favoured a rapid drowning of portions of the carbonate platform. This basin unit consists of nodular dark grey limestones with radiolaria, alternating with marls, siltites and, occasionally, rudites that, often as carbonate megabreccias, testify to the fragmentation and collapse of the faulted blocks of the Upper *Dolomia del Serla fm.* The *Dont fm.* contains ammonites, conodontes that allow it to be attributed to the Upper Anisian.

The *Dont fm.* is overlain by the *Bivera fm.* (Pisa, 1974), which is made up of limestones, nodular marly limestones, marls, and mostly reddisch siltites, and, locally, thin levels of carbonate breccias (olistostromes). Its total thickness varies from 0 to some metres.

The *Bivera fm.* is followed by the *Contrin fm.* (Upper Anisian), from a few metres to some tens of metres thick, organised as calcareous and dolomitic calcareous massive beds with frequent biogenic facies. The equivalent facies depositing in the adjacent basinal areas is represented by the *Ambata fm.* This unit consists of well-stratified micritic limestones with rare and thin tufitic interbeds. Between the But Valley and Pontebba, the *Aupa turbidites* (Jadoul and Nicora, 1979) are locally exposed. Their age seems to extend to the Lower Anisian. They are made up of an alternation of marls, arenaceous limestones, pelites, and turbiditic arenites and rare carbonate olistostromes, due to submarine slumping, for a maximum total thickness of 350 m.

The *Contrin fm.* is followed by the *Dolomia dello Sciliar fm.* of Ladinian age. A second carbonate platform is locally superim-

posed upon a first one as a unique lithosome, which is named as an undifferentiated carbonate platform. The following *Dolomia Cassiana*, belonging to the Upper Ladinian-Lower Carnian, could also be part of the same undifferentiated platform.

The terrigeneous and carbonate-terrigeneous units of Anisian age mentioned above, which deposited in continental, deltaic, perideltaic, lagoonal and basinal environments are comprised in the *Braies Group*. The Upper limit of the group is represented by the characteristic deposits of the *Livinallongo fm.* (or *Buchenstein group*), belonging to the Ladinian-Rhaetian sequence.

2) *The Ladinian-Rhaetian Sequence* (from Ponton M., 2002)

The terrains belonging to this time interval are extensively exposed in the Prealps, Julian Alps and southern Carnic Alps. In the stratigraphic scheme of Figure 3, all the most important Ladinian-Carnian lithological units are reported.

The Ladinian sequence is characterised by both platform deposits and basinal deposits. The platform named *Dolomia dello Sciliar (Schlern)* is almost ubiquitous, with a thickness ranging from 150-320 m, in the Carnic area, to 500 m in the eastern Tarvisio sector. In the western Carnic Alps, it is represented, at the bottom, by the *dolomitic limestones of Mt. Tiarfin*, whereas in central Carnia the *Dolomia dello Sciliar* forms most of the thick undifferentiated carbonate platform. This massive sequence is also present in the Julian Alps, where it includes the *Dolomia dello Sciliar* and the overlying *Dolomia Cassiana* (see below).

The dolomitic limestones of Mt. Tiarfin are representative of a platform body situated in an area affected by active tectonics (block-faulting) and volcanic activity. Upon the blocks acting as structural highs, pseudonodular red limestones with ammonites and dark siliceous-iron crusts (*Clapsavon Limestone*) deposited in the Upper Ladinian. The collapsed blocks were instead covered by terrigenous-volcanoclastic sandstones, made up of tuffs detritus (Pisa, 1974). These sandstones testify to a volcanic phase which is linked to that of the Riofreddo vulcanites in the Julian Alps (see below).

Nodular cherty limestones, calcarenites, sandstones, and tuffs siltites belonging to the *Livinallongo fm.* (also known as *Buchenstein group*) deposited in the basin during the Lower Ladinian and, partially, during the Upper Ladinian as well, with a thickness up to 200 m. The basinal sedimentation continued during the Upper Ladinian with limestones, marls, clayey marls, and sandstones belonging to the *La Valle fm.* (*Wengen fm.* Auct.).

An important rhyolitic-rhyodacitic volcanoclastic event occurred in the southern Julian Alps during the Lower Ladinian, as testified to by the *Riofreddo Vulcanites*, comprising terrigenous-tuffaceous and pyroclastic deposits, whose total thickness reaches 150 m.

A very thick carbonate platform, the *Dolomia Cassiana* (Upper Ladinian-Lower Carnian), overlies either the *Sciliar Dolomite fm.* or the terrigenous-carbonate sequences of the *La Valle fm.* and the overlying *S.Cassiano fm.* (Lower Carnian). It has a thickness of 150 m in the Carnic Alps and in Val D'Aupa. On the edge of the *Dolomia Cassiana*, in the westernmost sector of the Carnic area and the Julian Alps, the dolostones and well stratified dolomitic limestones of the *Dürrenstein fm.* are exposed.

The Lower Carnian stratigraphy is extremely complex and the relationships between the Ladinian-Carnian carbonate platforms and the mixed terrigenous-carbonate sediments outcropping between Ampezzo and Tolmezzo have not been completely understood yet. In early drowned zones, a 300-400-m-thick sequence of dark limestones and marls is found, with interbeds of coal and tuffs, related to the last Triassic volcanic phase, near the bottom. This carbonate unit is covered by several tens of metres of violet quartz arenites and red-grey siltites. The sequence is closed, almost everywhere, by marls, limestones, and massive dolostones, probably correlatable to the *Dürrenstein fm.*

Above the aforementioned lithotypes, there is a transgressive sequence characterised by multicoloured clays, gypsum, vuggy dolomites and dolomitic breccias of the Upper Carnian. This last sequence shows its maximum development in the western-central sector of the Carnic area and it is also present, with similar features, in almost all the eastern Southern Alps. According to several authors, this Carnian sequence is currently recognised as the *Raibl fm.*, from the homonimous locality (Cave del Predil), where the *Raibl group* was first established (Assereto et al., 1968). This group includes all the carbonate-terrigeneous units of Carnian age, i.e.: *Calcare del Predil*, dolostones and dark limestones rich in fishes, crustaceans, and plants; *Rio del Lago fm.*, limestones and marls with *Myophoria kefersteini*; *Calcare di Rio Conzen*, dolomitic limestones with *Megalodon carinthiacus*; *Tor fm.*, limestones, marls, and dolomitic limestones and grey dolostones.

The total thickness of the Carnian basinal facies in the eastern sector (Raibl Group) is extremely variable. It locally reaches 900 m whereas, eastwards, in the Mt. Mangart group and Slovenia it decreases to zero.

At the end of the Carnian, the whole Friulian area was characterised by a shallow water environment with restricted circulation. An extensive carbonate ramp, named the *Dolomia del Monticello*, whose top probably belongs to the Lower Norian, deposited. It consists of grey dolostones, interstratified, at the base, with pelitic levels. Its thickness varies from 500 m (Val Cellina) to 100-200 m in the north-eastern areas.

The *Dolomia Principale* (Norian) overlies the *Dolomia del Monticello*. It consists of the classic carbonate platform cyclothemes (including micritic facies with *Megalodon gümbeli* and stromatolitic facies). It is exposed almost everywhere, with a thickness ranging between 800 and 2200 m. In most of the Carnic and Julian Prealps an anoxic deposit named *laminiti organiche del Rio Resartico* (Fantoni et al., 1998) appears in the middle portion of the Norian sequence.

In the northern Carnic Prealps, between Forni di Sopra and Tolmezzo, the *Dolomia di Forni* is present at the top of the Dolomia

del Monticello. This is a 700-800-m-thick sequence, coeval with the Dolomia Principale, made up of dark grey dolostones, highly stratified, cherty at the bottom, with frequent pelitic levels rich in organic matter.

In the Julian Alps a thick calcareous sequence, deposited in the external sectors of a carbonate platform and known as *Dachstein limestone*, is referred partly to the Norian and partly to Rhaetian age.

The thickness of the formation reduces from east (~ 800 m at Mt. Canin) to west (about 50 m on the western side of Mt. Valcalda) and it disappears completely in the western Carnic Prealps. The thickness also diminishes from north to south, where it is substituted by the *Dolomia Principale*, such as at Mt. Cuar and Mt. Raut.

The corresponding basinal facies of the Dachstein limestone is the *Calcare di Chiampomano* (Ponton and Podda, 1995), which is present in a few sectors of the Carnic Prealps. It consists of a sequence, up to 450-m-thick, of blackish micritic limestones and calcarenites, often affected by *slumping*. It lies above the Dolomia di Forni and the uppermost part of this succession could be coeval with the *Soverzene fm.*

The Jurassic-Paleogene Sequence (from Venturini and Tunis, 2002)

This sequence is represented by carbonate rocks up to the Upper Cretaceous (Figure 4), whereas thick marly-arenaceous terrigeneous deposits are observed in the Paleocene-Eocene. Broad portions of the late Triassic peritidal platform began to drown in the Lias, revealing two main paleographic domains: the Friulian platform and the Belluno basin.

Carbonate Platform

The first lithostratigraphic unit of interest in the Friulian platform is represented by the *Calcari Grigi del Friuli* (Lower-Middle Lias). It is exposed in most of the prealpine area and its thickness ranges from 200 m (Mt. Cuar) to more than 600 m (Mt. Raut, Mt.

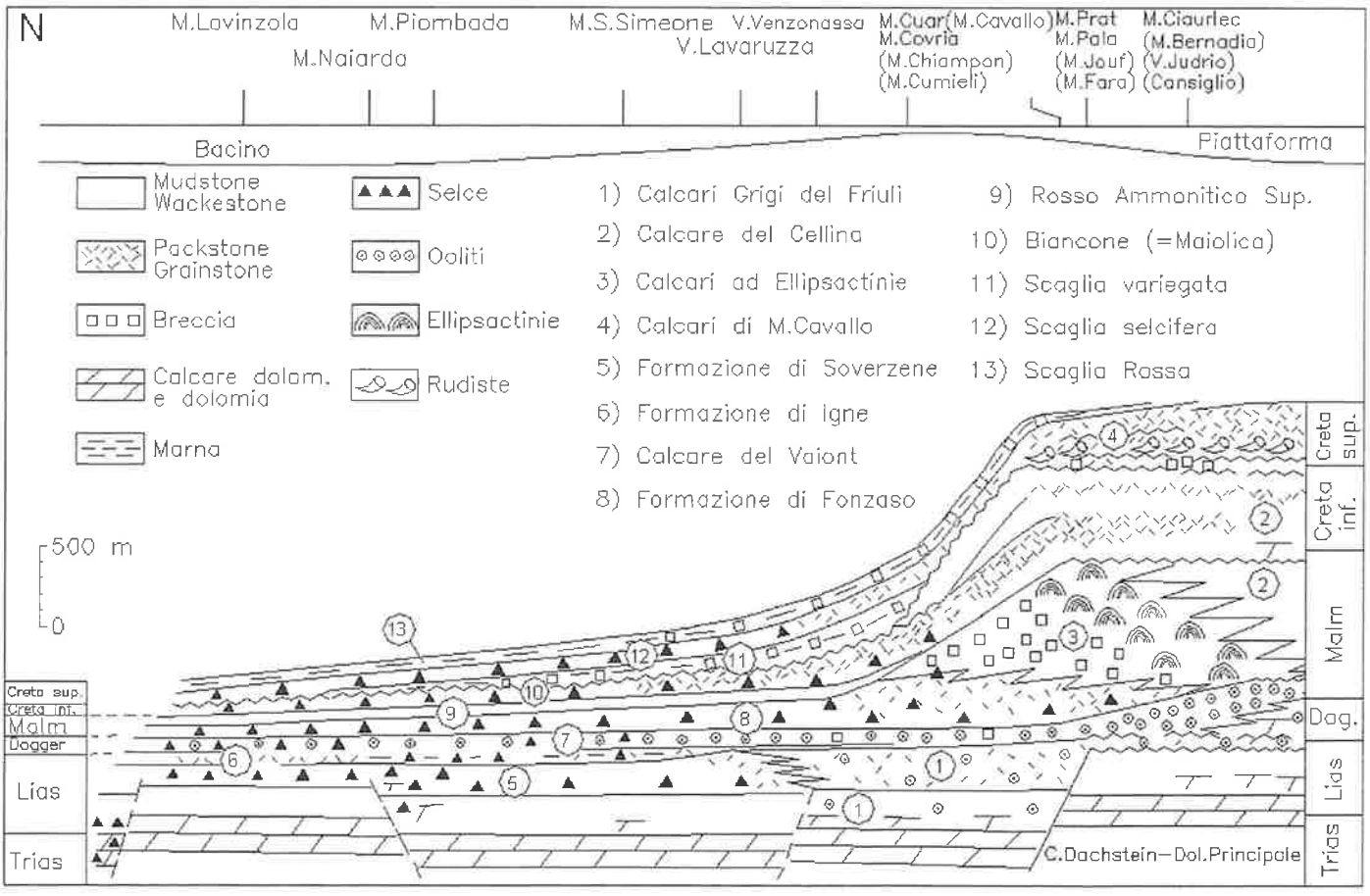

Figure 4. Stratigraphic scheme of the Jurassic-Cretaceous succession of the Friulian Prealps. (from Venturini and Tunis, 2002).

Piciat). The basal part of the succession consists of grey and brown micritic limestones (beds from 30 cm to 1 m thick), followed by whitish oolitic intraclastic, and bioclastic limestones, This unit changes into the *Soverzene fm.* moving towards the basinal areas.

The carbonate platform sequence of Dogger - Lower Cretaceous age is named the *Calcare del Cellina*. It consists of well stratified brownish grey micritic limestones, with scarce macrofossils, frequent emersion structures, sometimes with breccias and residual clays, and scattered stromatolites.

A relevant reef edifice, made of hydrozoans and corals (Ellipsactinie limestones, Oxfordian-Kimmeridgian), developed along the platform margin during most of the Upper Jurassic. This reef is exposed at Mt. Prat and on the eastern side of Cansiglio. The almost total absence of stratification makes it difficult to assess its thickness, which is estimated > 600 m.

A previous unit is covered by the *Calcari di M. Cavallo* (Cenomanian-Campanian) whose thickness ranges from 300 to 400 m. It is characterised by an abundant biogenic content, mainly represented by rudists. The unit generally shows a massive aspect and stratification is visible where micritic limestones, with plankton remains, are interposed.

Basinal and Slope Deposits

The *Soverzene fm.* sedimented in basinal areas heteropically to the *Calcari Grigi del Friuli* in the Carnic Prealps during Lower-Middle Lias. This formation outcrops as dolomitic facies in the western sector of the Carnian Prealps whereas it is exposed as calcareous facies in the eastern sector (Auct. cherty limestones). It is formed of dolostones or dark grey limestones, with cherty strata of 20-40 cm, and centimetre-thick marly levels. Fauna is essentially represented by radiolaria and spicules. The thickness of this unit ranges from 200 to 600 m.

A marly-calcareous, cherty, well stratified, sometimes nodular and ammonites rich unit, named the *Igne fm.* (Toarcian, Upper Lias), overlies the *Soverzene fm.* Locally, blackish marls rich in organic matter are present at the bottom of the unit, testifing to a Toarcian anoxic event. The thickness of this formation ranges from a few metres to more than 150 m.

The *Calcare del Vajont* (Dogger) is the following unit, prevalently formed by oolitic calcarenites, sometimes graded, in metre-thick strata and interposed by radiolaria-bearing micritic limestones. The maximum thickness (about 450 m) is attained in the Vajont Valley, whereas in the Julian Prealps, the unit thickness reduces to ~ 50 m.

At the beginning of the Malm, oolitic sedimentation stopped and different bioclastic materials proceeded from the platform margin. The *Fonzaso fm.* (Oxfordian-Lower Kimmeridgian) consists of well-stratified cherty limestones, with frequent calcirudites and calcarenites with platform elements. Thickness, on the whole, ranges from some tens of metres to 200 m.

The *Fonzaso fm.* is covered by the *Upper Rosso Ammonitico fm.* (Upper Kimmeridgian-Lower Tithonian). It consists of red or greenish-grey nodular micritic limestones, sometimes cherty, with ammonites, belemnites and the remains of pelagic crinoids (*Saccocoma*). Its thickness does not exceed ~ 30 m.

Sedimentation of white micritic limestones (*Biancone* or *Maiolica*) with nodules and chert, very rich in calpionellae and radiolaria, occurred in the Upper Titonian-Barremian *p.p.* following new turbiditic inputs and contemporary nannoplankton diffusion. Its thickness ranges from a few tens of metres to 150 m.

In the areas proximal to the platform there is a sequence characterised by frequent calcarenites, with a thickness up to 250 m. This slope sequence is named the *Calcare di Soccher*.

The Aptian-Albian age is represented by well-stratified, greenish, blackish, and reddish marly limestones and marls, and by cherty calcarenite, calcirudite and breccia beds. Coarse deposits frequently contain *Orbitolina*, rudists and reworked corals. This unit is called the *Scaglia variegata* and attains a maximum thickness of some tens of metres.

The prevalence of greysh, greenish and pink, slightly clayey, fine-grained cherty limestones, with subordinate calcarenitic interbedding charactirises the *Scaglia selcifera* (Cenomanian-Campanian). The well-stratified limestones frequently contain planctonic foraminifera (*Rotalipora*, *Globotruncana*, etc.).

The *Scaglia Rossa* formation (Upper Senonian-Paleocene-Lower Eocene *p.p.*) outcrops throughout the Friulian Prealps. This unit consists of a succession of marls and red marly limestones with some-metres-thick greysh horizons. Chert is virtually absent. Stratification is indistinct. In some places bioclastic calcarenitic levels or breccias levels with elements proceeding from carbonate platforms, with relevant thickness, are interposed. They are locally known with different names, such as Brecce di Grignes.

The upper limit, although diacronous, is everywhere represented by flysch, with a gradual transition, marked by an increasing arenaceous silico-clastic fraction.

The terrigeous succession of Friuli Venezia Giulia (southern Julian Prealps and Collio), more than 4000 m thick, represents the most complete Campanian (Upper Cretaceous)-Lutetian (Middle Eocene) turbiditic sequence of the eastern Southalpine domain. These units were mainly distinguished in members on the basis of the relative proportions of their silico-clastic component and the carbonate component.

The Neogenic Sequence (from Grandesso et al., 2002)

The Paleogenic turbiditic successions are discordantly covered by Miocene molasse deposits which make up a thick sedimentary sequence.

The Neogenic terrains form almost all the southern hills of the central-western Carnic Prealps. A natural section, where the limit between the Eocene Flysch and the molassa succession is exposed, is located along the Meduna River.

The molassa sedimentation began with the deposition of the *Preplans sandstone* (Lower Miocene) or, locally, with the *Peonis breccia*. The contact with the underlying flysch is characterised by both a hiatus and an angular discordance (Figure 5). The best outcrops of the *Preplans sandstone* are found at Forgaria, Andreis, and along the Meduna River.

The overlying *marna di Bolago fm.* (Lower Miocene) is represented by coarse greenish glauconitic arenites, marls, and marly siltites. Its thickness ranges from 20 to 50 m. This unit is followed by ~ 100-150 m of slightly glauconitic arenites interbedded with bioturbated arenaceous siltites known as *S. Gregorio sandstone.*

In the Lower Miocene, deposition of the *marna di Monfumo* took place. It consists of a thin pelitic unit with a maximum thickness of ~ 12 m. It is covered by a thick sequence (~ 200 m) of glauconite- rich arenites constituting the *Monte Baldo fm.*

The Middle Miocene-Upper Miocene is represented by epibathial and grey shelf marls rich in bivalves, developing up to a maximum thickness of 400 m (*marna di Tarzo*), covered by interbeded arenites and grey siltites with gasteropods, attaining a maximum thickness of ~ 350 m (*Vittorio Veneto sandstone*).

The sequence is closed by over 900 m of prevalently carbonate and dolomite conglomerates, siltites, and sandstones (*Conglomerato del Montello*).

Among the Quaternary deposits, the extended frontal morenic deposits located in the upper Friulian plain, near the Tagliamento River, should be mentioned. They are related to the Würmian glacial event.

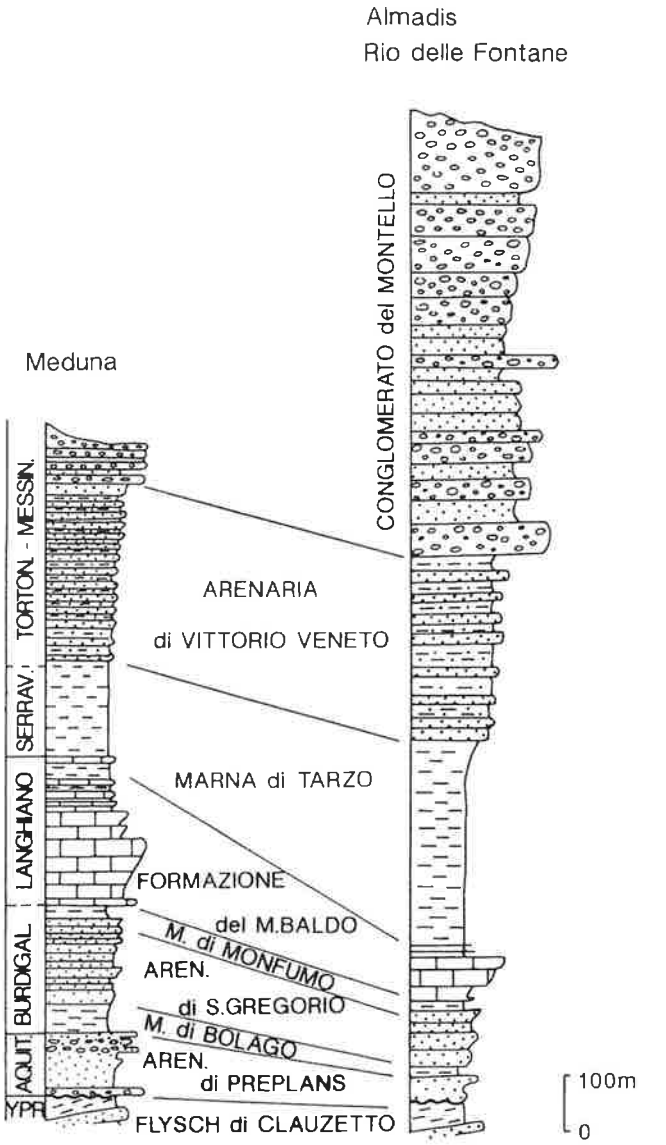

Figure 5. Friulian Miocene stratigraphic sequences (from Grandesso et al., 2002).

LITHOLOGY IN FRIULI VENEZIA GIULIA

This region, although rich and various in lithology, lacks intrusive rocks. Igneous rocks are not very diffuse, and are represented by effusive rocks, both lavas and pyroclastic deposits. Outcrops, not reported in Figure 6 due to a scale factor, are limited to the Alpine zone where volcanites are exposed in two parallel E-W alignments. The northernmost alignment extends from the middle of the Degano Valley to the upper Chiarsò Valley, and comprises a series of scattered and limited outcrops of pillow-lavas, breccias, diabases, and basaltic tuffs.

The second vulcanite belt extends from Forni di Sopra to the Fusine Lakes. The vulcanites exposed in the western sector include spilites and basaltic tuffs, whereas those outcropping in the central and eastern areas are mainly ignimbrites. The most extended outcrops (*Vulcaniti di Rio Freddo*) are located between the Chiarsò and Aupa valleys and in the Julian Alps between Valbruna and the Fusine Lakes.

Metamorphic rocks are not very diffuse in the region either.

Sedimentary rocks cover 90-95% of the whole area. Both calcareous and dolomitic rocks and clastic rocks (e.g., flysch, sandstones, marls, conglomerates) are present.

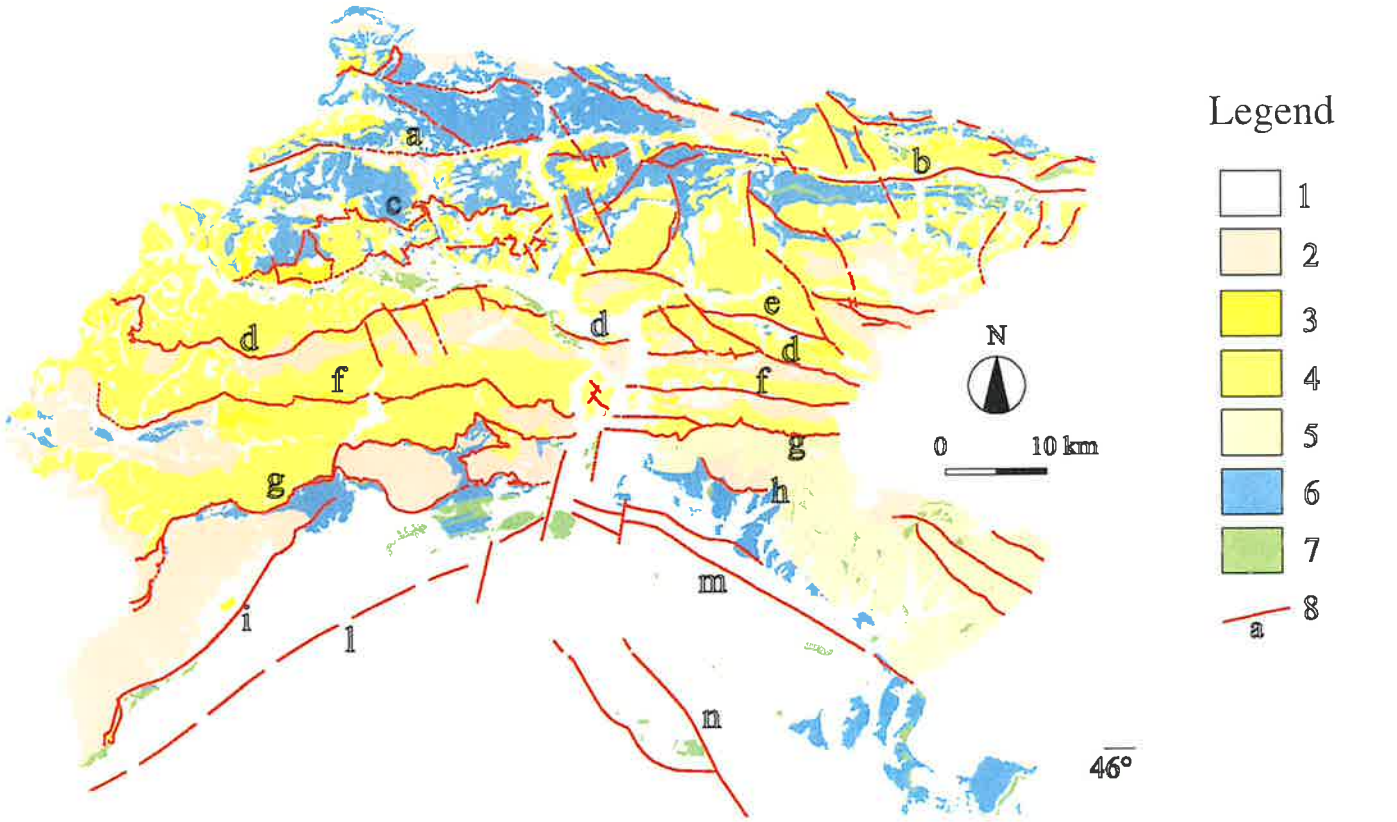

Figure 6. Lithologic-structural scheme of Friuli Venezia Giulia (from Cucchi and Piano, 2000). 1: surficial Quaternary deposits; 2: karstified limestones and evaporitic rocks; 3: more or less karstified limestones; 4: dolostones; 5: interbedding of carbonate sandstones and marls; 6: interbedding sandstones and marls, marls, volcanic rocks; 7: conglomerates with carbonate cement and breccias; 8: main faults and overthrusts; a: Comeglians-Paularo Line; b: Fella-Sava Line (backthrust.); c: Sauris Line; d: Mt. Dof- Mt. Auda Line; e: Val Resia Line (backthrust); f: Pinedo-Uccea Line; g: Barcis-Staro Selo Line; h: Mt. La Bernadia Line; i: Caneva Line; l: Sacile Line; m: Cividale Line; n: Palmanova Line.

REMARKS ON TECTONICS IN FRIULI VENEZIA GIULIA

The tectonic setting of Friuli Venezia Giulia is characterised by the presence of three systems:

- the Dinaric, NW-SE trending system, of Paleogenic age, in the south-eastern sector;
- the "*tilaventino*", E-W trending system, of Oligocene?-Pliocene age, in the central-northern area;
- the "*valsuganese*", NE-SW to NNE-SSW trending system, of Pliocene-Quaternary age, in the westernmost sector.

The *Dinaric system* is mainly characterised by NW-SE thrusts, NE vergent plains and right transcurrent subvertical faults, whose direction varies NW-SE to NNW-SSE (Figure 6). These structures are found in the Julian Prealpine sector and in the central-eastern Friulian plain where they affect the Quaternary molassa units at depth (Cividale and Palmanova lines).

The "*tilaventino*" system affects the whole mountain area. It represents the eastern continuation of the "*valsuganese*" system, from which it differs in direction and entity of shortening. Structures are north-vergent in the northernmost sector of the region, corresponding to the Paleocarnic chain. They are south-vergent in the rest of the area, except for two north-vergent backthrusts: the Fella-Sava Line and the Val Resia Line. The main south-vergent usually low-angular thrusts are (from south to north): the Barcis-Staro Selo Line, the Pinedo-Uccea Line, the Mt. Dof-Mt. Auda Line, which is named the Mt. S. Simeone-Saga Line further east, the Sauris Line, and the Comeglians-Paularo Line (Figure 6).

The "*valsuganese*" system is present in the westernmost sector of the region only, at the border with Veneto, and affects the outermost part of the chain and the bedrock below the Friulian plain (Caneva Line and Sacile Line). This system presents thrusts ENE-WSW in direction with NNW dipping plains.

It is also worth remembering that there are two NE-SW trending paleofaults of regional importance the Val Bordaglia Line, of Permo-Carboniferous origin, and the But-Chiarsò Line, active in the Middle Triassic.

METALLIFEROUS MINERALISATIONS (FROM ZUCCHINI, 1998)

In the Friuli Venezia Giulia region, metalliferous mineralisations are prevalently found in Paleozoic (Silurian and Devonian-Carboniferous) and Mesozoic (Anisian, Ladinian, Ladinian-Carnian and Norian) sedimentary rocks. Scarce and less important are those found in Cenozoic formations. Among the most notable, it is worh mentioning the following mineralisations.

At Mt. Cocco, north of Ugovizza, in the upper Val Canale, metalliferous mineralisations are found in Silurian rocks. These are rich in manganese and altered manganesiferous siderite, but hematite is also very common. Magnetite, siderite, ankerite, martite, pyrolusite, braunite, limonite, goethite, and chamosite are also present. Iron-maganese mineralisations extend through a thick and almost continuous belt, which thins from east (Mt. Osternig) to west (Mt. Volaia).

At Mt. Avanza, in the upper part of at Degano Valley a few kilometres north of Forni Avoltri, metalliferous mineralisations are found at the contact between the Devonian karstified limestones and the Carboniferous argilloschists. The most diffuse minerals are Hg-rich tetrahedrite, galena, sphalerite, pyrite and rare chalcopyrite in barite, calcite, and quartz. In addition, bournonite, goethite, azurite, cuprite, malachite, cerussite, covellite, cinnabar, hematite, allophane, pyrrhotite, stibnite, tenorite and smithsonite have been reported.

The cupriferous mineralisations of S. Giorgio di Comeglians, in the middle part of the Degano Valley, are similar to the Mt. Avanza deposits. Mineralisation affects graphitic schists, presumably of Silurian age, and Devonian limestones. The mineral paragenesis includes bournonite, tetrahedrite, galena, sphalerite, Ni-rich pyrite, chalcopyrite, chalcocite, barite, and fluorite. Traces of silver and gold of sedimentary genesis, are also present. Even the copper mines near Timau, in the upper part of the Val Canale di S. Pietro, are located in Paleozoic rocks. Tetrahedrite, chalcopyrite and pyrite are found in a carbonate gangue in Devonian karstified limestones at the contact with the *Hochwipfel* formation.

The mineralisation belt in Mesozoic terrains lies to the south of the Paleozoic belt. The Raibl mine, one of the most important Italian lead-zinc ore deposits belongs to this belt and is located in the Rio del Lago Valley, just a few kilometres south of Tarvisio. Mining activity was in operation till 1991. The ore deposit can be divided into two parts: the "primary deposit", rich in iron sulphides, galena, and sphalerite, which was generated by metal-rich aqueous solutions circulating along faults. The "secondary deposit", consisting of carbonates and hydroxy-carbonates, such as smithsonite and hydrozincite, formed through leaching of the "primary deposit".

Paleofaults dissecting the borders of the Triassic carbonate platform acted as trapping structures for the primary ore deposits. They established a peculiar paleo-hydrological regime which controlled mineral deposition in the upper part of the *Dolomia dello Sciliar (Schlern) fm.* of Upper Ladinian-Lower Carnian age (Assereto et al., 1977).

At Raibl, sphalerite is present as red, yellow, black, and grey types and contains a limited amount of cadmium and germanium. Galena, showing the typical brilliant blue-grey colour, is very pure, apart from scarce amounts of silver. In addition, cerrusite, anglesite, goethite, marcasite, pyrite, chalcopyrite, barites, and rare fluorite are quite common.

The Rio del Fus mine lies on both sides of the canyon formed by a right tributary of the Aupa Creek that excavated the Anisian Serla dolostone. The mineral assemblage includes galena, sometimes present as well preserved cubic crystals, yellow-orange sphalerite, pyrite, and marcasite. Sulphides are enclosed in a gangue made up of very abundant fluorite, and subordinated calcite and quartz.

The Rio Gelovitz mine is located in the valley called Canal del Ferro. The mineralisation is hosted in Sciliar dolomite, and is represented by centimetre-to-decimetre-thick levels of iron sulphides accompanied by the alteration products limonite, goethite and hematite. The last of these is present in concretions revealing a fibrous structure.

The only mineralisations situated in Cenozoic rocks are those of Peonis in the eastern Carnic Prealps. These pyrite-marcasite mineralisations are hosted in Miocene arenaceous rocks. Sporadic and fortuitous recoveries of native mercury happened in several places along the flysch belt of the southern Julian Prealps: Montemaggiore, Montefosca, Cravero, Ronchi, S. Giuseppe, S. Pietro di Poloneto and Spessa. Mercury probably derives from oxidation of cinnabar and it is widespread as little drops in the marls of the Paleocene-Eocene flysch.

Finally, a brief mention has to be made of the uranium mineralisation. Close to Ravinis, northeast of Paularo, thin lenses or discontinuous levels of uranium minerals, associated with coal and copper sulphides (bornite and covellite), are found in the Permian *Arenarie della Val Gardena* formation. The uranium minerals recognised are voglite and tucholite (uranium complex compounds). The same minerals are also present near Cercivento, again in the *Arenarie della Val Gardena*, but in sapropelitic clays and in association with azurite, malachite, and pyrite.

GEOLOGY AND LITHOLOGY OF NORTHERN VENETO (FROM ANTONELLI ET AL., 1990)

The oldest rocks of northern Veneto belong to the crystalline basement that is absent in Friuli Venezia Giulia. It is exposed with limited extension and it is restricted to the Comelico and Agordo areas, and partially in the Piova Valley near Lorenzago. Basement

rocks derive from sedimentary and effusive rocks, younger than the Upper Carboniferous, which suffered a complex geological evolution, characterised by metamorphic recrystallisation and several deformations lasting over 500 million years. The Hercynian processes acted deeply on these original deposits (sandstones, clays, limestones, volcanic rocks, etc.) that were transformed into metamorphic rocks (phyllites, argilloschists, quartzites, metarenites, gneisses, chloritic-epidotic schists, marbles, etc.).

Several formations have been distinguished in the Veneto basement and have been subdivided into two main groups (Figure 7). One group includes the oldest units, i.e., the *Col di Foglia fm.* (fossiliferous phyllites with acritarchs of Upper Cambrian age), the *Rivamonte fm.* (prevalently metarenites), the *Eores fm.* (quartzites and subordinate phyllites), the *Scisti filladici del Comelico* (quartzites and quartzitic schists) and the *Val Digon fm.* All these formations precede the Upper Ordovician age.

The other group comprises units of Upper Ordovician-Devonian age, i.e., the *Porfiroidi del Comelico* (Upper Ordovician), derived from volcanites and acid volcanoclastites, the *Mt. Cavallino fm.* (calcareous sandstones and acid volcanoclastites, of variable metamorphic grade), the *Filladi superiori* and the *Gudon fm.* of Silurian age (basaltic metavolcanites and associated schists rich in Fe, Cu, Ag, Pb, and Zn ores), the *Marmi or Calcari cristallini* (Silurian-Devonian), the argilloschists of the *Val Visdende fm.*, and the clastic formations of *Mt. Fleons* (semimetamorphic sandstones rich in volcanoclastic fraction) and of *Cima Vallona* (semimetamorphic conglomerates) of Silurian-Upper Ordovician age.

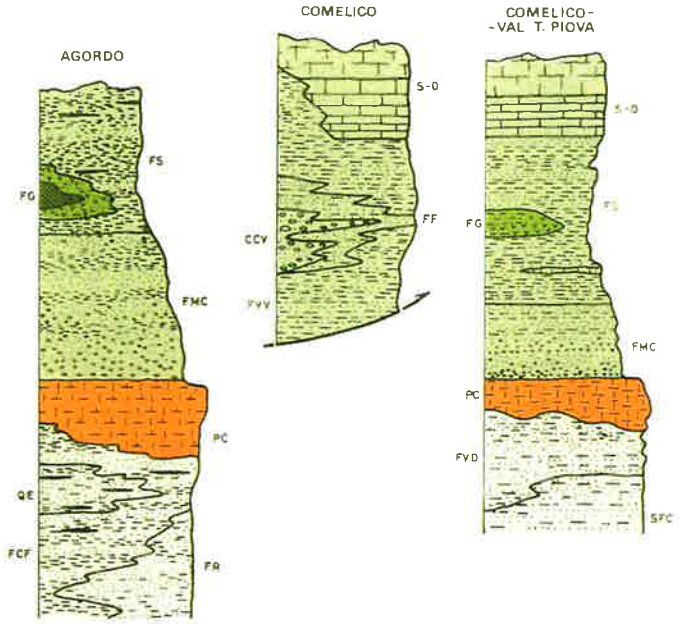

Figure 7. Stratigraphic sequence of the Venetian crystalline basement
FCF: Col di Foglia fm.; FR: Rivamonte fm.; QE: Eores fm.; SCF: Scisti filladici del Comelico; FVD: Val Digon fm.; PC: Porfiroidi del Comelico; FMC: Mt. Cavallino fm.; FS: Filladi superiori; FG: Gudon fm.; S-D: Marmi or Calcari cristallini; FVV: Val Visdende fm.; FF: Mt. Fleons fm.; CCV: Conglomerato di Cima Vallona. (from Antonelli et al., 1990).

The Permo-Carboniferous sequence directly overlies the basement: It is represented by a fluvial conglomerate, called the *Conglomerato di Ponte Gardena* (Upper Carboniferous-Lower Permian?), essentially formed by phyllitic and quartzitic clasts and exposed in the Comelico area.

The Middle-Upper Permian is characterised by sedimentation of coarse clastic deposits known as the *Conglomerato di Sesto*, whose clasts proceed from the crystalline basement. It is covered by the continental-terrigenous unit named *Valgardena sandstone* (thickness up to 500 m in the Comelico area). This formation is overlain by the carbonate and evaporite-carbonate deposits belonging to the *Bellerophon fm.* (Upper Permian), which is up to hundreds of metres thick (330-440 m near Lozzo di Cadore).

The Triassic Sequence

Triassic rocks are diffuse in northern Veneto. They are exposed in the Ampezzano, Cadore, Agordino, and Zoldano areas. The Triassic stratigraphic sequence (see Figure 3 in Section 8.1.1) is from 2000 to 5000 m thick and formed of a series of carbonate, terrigenous, carbonate-terrigenous sedimentary rocks and volcanoclastic and volcanic rocks. The *Werfen fm.*, sedimented in the Scythian, is formed of distinct lithotypes (sandstones, siltites, marls, oolitic limestones, dolostones, gypsum, breccias). Its thickness ranges from 300 m in the Agordino zone to 700 m in the north-eastern sector. Dolomicrites, often characterised by stromatolites, appear on the top, along with vuggy dolostones and intraformational breccias belonging to the *Serla inferiore* fm. (Lower Anisian).

Terrigenous and carbonate-terrigeneous continental, transitional, neritic, and pelagic deposits interposed between the *Dolomia del Serla inferiore* and the *Livinallongo fm.* are grouped in the Braies Group (Anisian) that includes *Conglomerato di Voltago*, *Conglomerato di Richthofen*, the *Agordo, Dont, Mt. Bivera, and Ambata* formations and the *calcari scuri di Morbiac*. The Braies Group is coeval with the carbonate platform bodies of the *Dolomia del Serla Superiore* and *Contrin fm.*

The *Buchenstein* Group (Ladinian) includes, from the base to the top, the *Livinallongo fm.*, the *Arenarie di Zoppè* and the *Acquatona fm.* The first consists of micritic limestones, sometimes bituminous and/or cherty, tuffs ("*Pietra Verde*") and sandstones. The *Arenarie di Zoppè* are formed by sandstones with clasts of phyllites and volcanites. The *Acquatona fm.* comprises marly limestones, argillites, and tuffites. The *Buchenstein* Group is coeval with a prograding carbonate platform (*Dolomia dello Sciliar* and *Calcare del-*

la Marmolada), whose overall thickness ranges from some tens of metres (Agordino and Zoldano) up to 700 m (Cadore, Sappada).

The subsequent *Wengen* Group (Ladinian) consists of the *Mt. Fernazza* and *La Valle formations*. The main lithologic characteristic of this this group is the abudance of volcanoclastic products and lava flows referable to the Middle Triassic magmatism of the Dolomites. The sediments of these formations are, in fact, formed by turbiditic sandstones derived from the reworking of vulcanites. The thickness is generally greater than 700 m.

The last Triassic basinal unit is the *San Cassiano fm.* (Carnian) that is exposed in the whole area of Cortina d'Ampezzo, Passo Tre Croci, Lake Misurina, and Carbonin and at the base of the Mt. Antelao and Mt. Marmarole group. It is made up of arenaceous turbiditic and calcarenitic deposits that testify to the progradation of the coeval carbonate platform (*Dolomia Cassiana*).

Another carbonate unit, known as the *Dürrenstein fm.*, consisting of limestones and dolostones with local lenses of sandstones, covers either the Carnian platform or the *S. Cassiano fm.*

The *Raibl Group*, formed by sandstones and multicoloured pelites, belongs to the Carnian. These lithotypes are associated with conglomerates, dolostones, oolitic dolostones and gypsum. The *Raibl Group* has about 100 m of thickness.

The *Dolomia Pricipale* deposited between the Upper Carnian and the Rhaetian. It is largely exposed in the Belluno and Cadore Dolomites, where it forms some of the most beatiful peaks, such as Tre Cime di Lavaredo, Mt. Cristallo, Pomagagnon, Sorapis, Le Marmarole, Le Tofane, le Conturines and most of Mt. Antelao, Mt. Pelmo and Mt. Civetta. It is also present in the Zoldano area, in the Cordevole Valley, between Mt. Schiara and Monti del Sole, and in the Mis Valley. This formation shows the same lithological features already discussed for Friuli Venezia Giulia.

In Cadore (Mt. Tudaio, Mt. Antelao, Le Marmarole, Le Tofane), the uppermost part of the Dolomia Principale is coeval with the "reef facies" named the *Calcare del Dachstein*. It reaches about 1000 m of thickness at Mt. Tudaio.

The Jurassic-Cretaceous Sequence

The Jurassic-Cretaceous sequence is very similar to that already described for Friuli Venezia Giulia, and it is almost totally represented by carbonate platform lithotypes and silico-carbonate rocks deposited in nearly basinal areas (see Figure 4 in Section 8.1.1).

Carbonate Platform

The *Calcari Grigi di Noriglio fm.* and the *Calcari Grigi del Friuli fm.* represent the Lower-Middle Lias carbonate platform.They are diffuse in the upper Boite Valley (Mt. Parei, Croda Rossa), in the Mt. Schiara area, and at Mounts Antelao, Pelmo and Civetta. These formations consist of thick beds of stromatolitic limestones, micritic limestones rich in large bivalves and oolitic calcarenites, and reach some hundreds of metres in thickness.

The *Encrinite di Fanes* lies upon the top of the previous formation. It consists of calcarenitic lenses with crinoids, and is particularly diffuse in the Cortina d'Ampezzo area. It marks the premature drowning of the Middle Lias Platform.

Carbonate platforms appeared again in the Cretaceous as as exemplified in the *Calcare del M. Cavallo* and the *Calcari di Cellina* formations. The first one represents the so-called "reef facies" and is exposed in the Mt. Cavallo-Cansiglio area, east of Alpago, with a thickness of ~ 500 m; the second one represents the "backreef facies" and outcrops on the southern side of Cansiglio.

Basinal and Slope Deposits

The basinal facies, which are part of the Belluno Basin, are also similar to those described for Friuli Venezia Giulia. They start with well stratified cherty dark dolostones (*Soverzene fm.;* Lower-Middle Lias), lying upon a carbonate platform made of *Dolomia Principale* or *Calcari Grigi del Friuli*, which were dismembered by Eoliassic extensional tectonic activity. The *Soverzene fm.*, whose thickness amounts to ~ 1000-1200, outcrops in the Belluno area east of the Cordevole River (Pian di Cajada, Mt. Pelf).

The *Igne fm.* (Upper Lias), directly lying upon the *Soverzene fm.*, appears as a marly facies, with interbedding of reddisch nodular limestones with ammonites, and cherty pelagic turbidites. The thickness reaches ~ 150-200 m.

The following formation, named the *Calcare del Vajont* (Dogger), is characterised by classic oolitic massive calcarenites, interbedded with thin basinal micrites. It reaches ~ 500 m of thickness and is exposed in the Belluno area east of the Cordevole River.

The basinal sedimentation continues in the Malm with the *Fonzaso fm.*, formed of cherty limestones, and the *Rosso Ammonitico superiore*. The Belluno basin is characterised by sedimentation of the so-called *Biancone* or *Maiolica* (from 100 to 300 m thick) from the Jurassic-Cretaceous limit to the Cenomanian (Upper Cretaceous).

The *Scaglia Rossa fm.* (Upper Cretaceous-Lower Eocene) is the last unit of the Mesozoic succession. Its base is not isocronous throughout the region: it is mainly of Turonian age (Upper Cretaceous), but is of Aptian age (Lower Cretaceous) in the Cortina d'Ampezzo area, of Santonian-Campanian age in the Belluno sector (where it covers the *Calcare di Soccher*) and of Maastrichtian age at Mt. Cavallo. Its thickness ranges from 30 m north of Cortina to 300 m at Belluno. It consists of well stratified reddish-pink limestones, with beds and nodules of chert and conchoidal fractures. The clayey fraction increases towards the top. East of Belluno, the *Scaglia Rossa fm.* includes interbeds of calcarenites and turbiditic conglomerates (*Cugnan fm.*, *Conglomerato di Rifugio Sasso*) produced through erosion of the Friulian reef.

In the Cretaceous, greenish- grey, and reddish, marls locally deposited. They form the so-called *Marne del Puez*, in the lower portion, and the *Antruilles fm.*, in the upper portion. The overall thickness is ~ 150-250 m. They are typically exposed on the Ampezzo plateau (Remeda Rossa, Fosses, Fanes) and near Cortina (Ra Stua and Antruilles).

The Terziary Sequence

The pelagic succession present as *Scaglia facies* in the Belluno area (*Scaglia cinerea* and *Marna della Vena d'Oro*) continued during the Paleocene and Lower Eocene. These formations either precede or are coeval with the Eocene flysch of the Belluno area.

The so-called *Flysch bellunese* is a sedimentary body, up to more than a thousand metres thick, extending from *Alpago* to the Feltre area. It consists of a rythmic alternations of clayey marls, calcarenites and sandstones. The pelitic layers are generally much thicker than the arenaceous beds, in which the carbonate fraction prevails over the silicoclastic fraction. The flysch sequence is of the Lower Eocene age in the Alpago and Belluno areas, where it is discordantly covered by the Cattian molasse (Upper Oligocene), with an important hiatus from the Middle Eocene to the Lower Oligocene. The molasse prevalently consists of arenites, siltites, and marls and has been subdivided into several stratigraphic units (Figure 8) informally defined as the: *Arenaria glauconitica di Belluno*, *Calcarenite dell'Alpago*, *Siltite di Bastia*, *Arenaria di Orzes*, *Siltite di Casoni*, *Arenaria di Libano* (all of them deposited between the Cattian-Aquitanian), and the so-called *Marna di Bolago* of Burdigalian age.

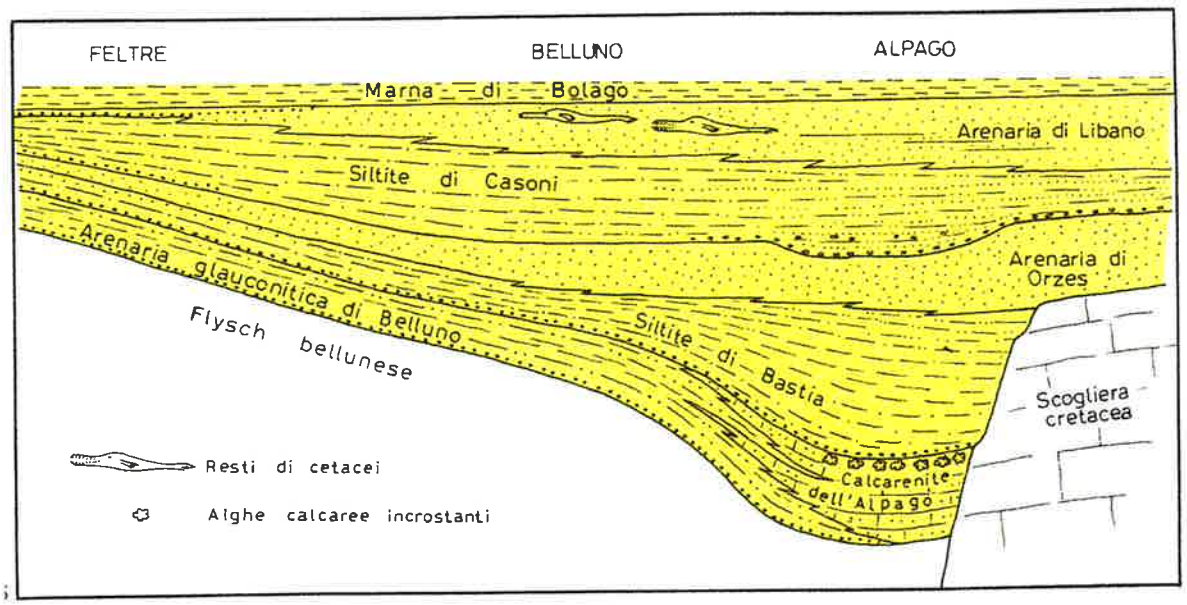

Figure 8. Stratigraphic framework of Molassa Bellunese (from Antonelli et al., 1990).

SOME REMARKS ON THE TECTONICS IN NORTHERN VENETO

All the sedimentary rocks deposited during the early Paleozoic were subsequently deformed, metamorphosed, and involved in a new mountain chain during the Hercynian Orogenesis of Carboniferous age. The Hercynian deformations are recognisable in the crystalline basement of Veneto in that they are characterised by NW-vergent isoclinal recumbent folds and by SW-vergent folds and thrusts.

The Alpine tectonics influenced the area even more extensively. However, the general effect is less marked that in the Friulian area, where structures are more closed and intensively deformed, and, consequentely, more shortened.

The tectonic setting of the Veneto region is characterised by south-vergent overthrusts and wide folds. These structures present the typical "*valsuganese*" trend, NE-SW and NNE-SSW oriented.

The main structures, from south to north, are as follows:

- the Cansiglio folds;
- the Belluno syncline, a wide fold with large fold curvature;
- the Belluno line, a south-vergent structure continuing in the Friulian sector as the Barcis-Staro Selo Line;
- the Pelf-Frugna anticline, which is the most continuous element of the area;
- the Valsugana Line, a south-vergent structure, which marks the south-eastern limit of the dolomitic synclinorium. It controls the outcrops of the crystalline basement and, further east, continues in Friuli as the Comeglians-Paularo Line;
- the Antelao Line, a south-vergent structure and subparallel to the previous one. It is connected, further west, to the Selva di Cadore Line.

METALLIFEROUS MINERALISATIONS (FROM ASSERETO ET AL., 1977)

In the northern sector of the Region of Veneto, metalliferous mineralisations only developed in Anisian-Ladinian rocks. They are all lead-zinc mineralisations, with Zn/Pb ratio close to 5. Here the low silver and sulphur salt content in galena and the abundance of chloride in sphalerite are peculiar. The presence of bitumen and/or organic substances, although in small amounts, must also be mentioned.

The most important deposit is that of Salafossa, located in the eastern Dolomites, 5 kilometres west of Sappada (Province of Belluno). The ore body was located on the northern side of Mt. Terza Piccola, and is hosted in Dolomia Cassiana (Assereto and Pisa, 1978)

The ore body essentially consists of blenda, pyrite and sphalerite and it can be subdivided into the following two parts:

1. the upper part (90-95% of the deposit), mainly consisting of a tectonic breccia cemented by both the ore minerals (sphalerite, galena, and subordinated pyrite and marcasite) and spathie white dolomite;
2. the lower part (5-10% of the deposit) consisting of a network of irregular cavities, mainly filled with colloform pyrite-marcasite with a white dolomite core; reworked sphalerite and galena fragments from the upper mineralisation are locally present.

The so-called "District of Auronzo" extending on both sides of the Ansiei Valley, from Auronzo to Mt. Rusiana needs to be mentioned. Here, the main ore occurences from west to east, are at Argentiera, on the right hydrographical side, and Ferrera, Grigna, and Pian del Barco, on the left hydrographical side.

The Argentiera ore deposit, about 7 km from Auronzo, developed in the Anisian *Dolomia del Serla fm*. The mineralisation consists of calamine in the form of yellowish sand, sphalerite, galena, pyrite, and marcasite.

The Ferrera, Grigna, and Pian del Barco mineralisations are located at about 1.5 km northwest of Auronzo, on the southern slope of Mt. Aiarnola. Again, mineralisation is hosted in the Anisian *Dolomia del Serla fm.* and is made of sphalerite, galena, pyrite, marcasite, and rare barite.

In the area of Mt. Rite-Inferno Valley, between Fornesighe and Cibiana, there are many small ore occurrences. They are found at the top of the *Dolomia del Serla* formation, near its contact with the Dont formation. They consist of sphalerite, galena, pyrite and barite at Mt. Rite. The Inferno valley mineralisation has a similar paragenesis, higher ore grade, and is associated with bitumen.

Close to the Giau Pass, 10 km south west of Cortina d'Ampezzo, there is the Col Piombin ore deposit, hosted in Sciliar dolomite near the contact with the sediments of the Wengen Group. The ore body consists of galena and, subordinately, sphalerite and pyrite.

GEOLOGY AND LITHOLOGY OF NORTHEASTERN TRENTINO ALTO ADIGE

The Trentino Alto Adige rocks exposed to the south of the so-called *Insubrica* Line (named "*Linea della Pusteria*" in this area) belong to the eastern *Southalpine* domain. The stratigraphic succession is almost identical to that already described for northern Veneto (see above), from the crystalline basement to the Lower Cretaceous. The crystalline basement is exposed along an east-west trend near the Pusteria Line.

The upper *Austroalpine* domain, north of the Pusteria Line in the Vila, Anterselva, and Casies valleys, is represented by paragneisses and phyllites with interbeds of porfiroids and "*pietra verde*" and by micaschists and phyllites (*fillade di Cima Dura e del Thurntaler*). All these lithotypes belong to the Lower Paleozoic basement. Close to the Pusteria Line, granitic and granodioritic gneisses of Ordovician-Silurian age are found (*Ortogneiss*, Auct.).

Some intrusive bodies of various size, granodioritic-tonalitic composition, and Oligocene age are present in this domain. The

largest intrusive body is the east-west trending "*plutone delle Vedrette di Ries*", extending from *Val di Riva* to the border with Austria. The *Cima di Vila* pluton is exposed further south, in the upper Vila Valley. Two other intrusive bodies (one at Tesido, north of Monguelfo, and one in the Planca in Casies Valley) are found close to the Pusteria Line.

The area named "*a scaglie di Matrai*" is situated north of the Upper *Austroalpine* domain, and belongs to the Lower *Austroalpine* domain. This area was formed by a tectonic *melange* made up of Austroalpine basement portions and metaophiolites and calcschists of the Piedmontese-Ligurian domain.

At the northern limit of the Udine Sheet, in *Val dei Dossi*, undifferentiated calcschists with ophiolites of Jurassic-Cretaceous age, and belonging to the Tauern window, outcrop.

SOME REMARKS ON THE TECTONICS IN NORTHEASTERN TRENTINO ALTO-ADIGE

The main tectonic structure is represented by the already cited WNW-ESE trending *Linea della Val Pusteria*, which crosses the homonymous valley, and joins the Gail Line, to the east and, the so-called *Linea delle Giudicarie Nord* and then, the *Linea del Tonale,* to the west. It consists of a series of sub-vertical fault planes with prevailingly transtensive displacements.

METALLIFEROUS MINERALISATIONS

An ore deposit of limited size is found at Cima Rolle, on the right side of of the Landro Valley, 5 km south of Dobbiaco, in the Province of Bolzano. This deposit is hosted in Anisian Serla dolostone. The mineralisation consists of sphalerite, mostly concretionary, and galena in crystalline aggregates. The two sulphides cement, along with white dolomite, a breccia made up of dolomite elements.

An extended scheelite mineralisation affects the lower part of the Thurntaler phyllite, close to Cornetto di Confine, in the upper part of the Pusteria Valley, between Dobbiaco and S. Candido. It is part of a so-called isogenetic formation of W, Sb, and Hg. Scheelite is locally associated with arsenopyrite.

GEOCHEMICAL MAPS

Arsenic distribution in stream sediments

Average As concentration, for a comprehensive dataset including 448 samples collected along a narrow belt close to the border with Austria, amounts to ~ 35 ppm. Values range between 5 and 231 ppm, whereas the standard deviation is 19 ppm. Frequency distribution, as reported in the cumulative curve and the histogram, is unimodal and close to a lognormal, with the median at 30 ppm. Arsenic concentrations in stream sediments appear influenced by the substrate lithology. Arsenic contents are relatively low (< 28 ppm) in the easternmost sector, where calcareous lithotypes (calcarenites and calcschists) and arenites, along with the turbiditic pelites of the *Hochwipfel fm.*, are exposed (Tarvisio-Mt. Cocco), in the central sector, near Mt. Avanza (argillites, siltites and sandstones), and in the upper Piave River Valley, where calcareous and dolomitic terrains outcrop. On the contrary, relatively high concentrations (> 45 ppm) are present in the areas of Mt. Volaia, Mt. Coglians, and Mt. Zermula. The highest levels are found in the northernmost sector of Veneto and in the upper Pusteria Valley, where the crystalline basement (phyllites) is exposed. In this sector, As levels frequently exceed the maximum permissible concentration for industrial soils (50 ppm).

Antimony distribution in Stream Sediments

The frequency distribution of Sb concentrations for the 160 stream sediment samples included in the Udine Sheet is unimodal. Concentration varies from 10 to 102 ppm, the standard deviation is 8.7 ppm and the median (13 ppm) closely matches the average content of the dataset, 15.3 ppm. Relatively low values (< 12 ppm) are found north of Tarvisio (silicoclastic turbidites of the *Hochwipfel fm.*), between Mt. Cavallo di Pontebba and Mt. Zermula, and along the upper Piave Valley, as already reported for As. Comparatively high concentrations (> 19 ppm) are found in restricted areas of the western sector: near Paularo (arenites and turbiditic pelites of the *Hochwipfel fm.*) and south of Mt. Zermula (argillites, siltites, and sandstones) in Friuli Venezia-Giulia; in northern Veneto, where sandstones, limestones, and dolostones are prevalently exposed, and near S. Candido, Alto Adige (limestones and dolostones). The Sb maximum limit for industrial soils (30 ppm) is exceeded in only a few cases.

Molybdenum distribution in Stream Sediments

The distribution map of Mo concentrations in stream sediments shows quite homogeneous values in the mapped area. The lowest levels are found in the zone immediately northeast of Timau, where the silicoclastic turbidites belonging to the *Hochwipfel fm.* and the arenites and pelites of the *Dimon fm.* Crop out. Relatively high concentrations (> 5 ppm) are found in restricted zones, such as near Mt. Cocco and Mt. Zermula (limestones, argillites, and slightly metamorphosed siltites), and in the area of northern Veneto where the crystalline basement (phyllite) outcrops.

The concentration range is from 2 to 31.6 ppm. The frequency distribution of the 306 data (see cumulative curve and histogram) is unimodal. The median, 3 ppm, matches the average content of 3.64 quite well, whereas the standard deviation is 2.75 ppm.

Cadmium distribution in Stream Sediments

The distribution map of Cd concentrations in stream sediments is based on a dataset of 55 samples only. The median is 1.65 ppm, the average is 2.5 ppm, and the standard deviation is 2.65 ppm. Cadmium concentration ranges from 1 to 16.4 ppm, often exceeding the maximum permissible concentration for residential-use soils (1.5 ppm). In Friuli Venezia Giulia, relatively high concentrations are found south of Mt. Osternig and, further west, near Mt. Lodin. Both zones are characterised by similar lithotypes (*Hochwipfel fm.,* limestones, marls, subordinate dolostones). In Veneto, comparatively high levels are found in the Piave Valley, where phyllites, sandstones, limestones, and dolostones are prevalently exposed. On the contrary, there is only one area showing relatively low levels (< 1.2 ppm), apart from the great number of samples with undetectable Cd levels. This area is situated between Mt. Creta d'Aip and Mt. Hochwipfel where limestones and dolomitic limestones, pelites, and arenites prevalently outcrop.

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