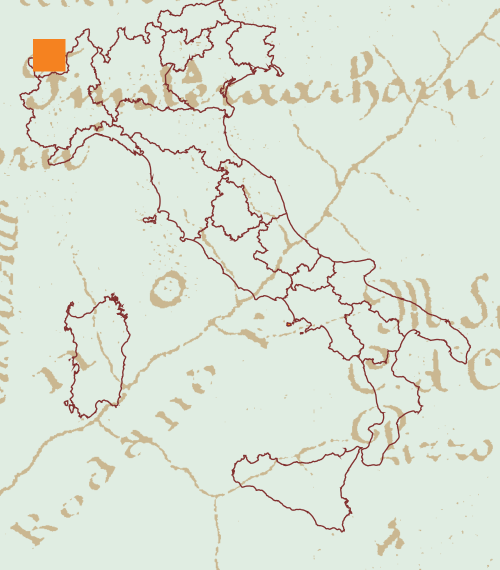
31



From the European continental margin to the Mesozoic Tethyan ocean: A geological map of the upper Ayas Valley (Western Alps)

Giorgio Vittorio DAL PIAZ

Dipartimento di Geologia, Paleontologia e Geofisica,
Università di Padova, Padova, Italia

31

ABSTRACT

The Piedmont ophiolite and underlying Monte Rosa nappe are exposed at the head of the Ayas Valley, in the Italian north-western Alps. The former is derived from the Mesozoic ocean, the latter from the European passive continental margin. Together with the overlying Dent Blanche nappe (African continental margin), these units belong to the fossil subduction complex extensively exhumed within the Austroalpine-Penninic collisional zone of the western Alps.

AIMS

The geological map shown in Fig. 1 and its explanatory note aim to describe a particular couple of continental (Monte Rosa) and oceanic (Zermatt-Saas) nappes which are peculiar from a geodynamic, tectono-metamorphic and lithostratigraphic point of view. Indeed, these nappes belong to the fossil subduction complex and collisional wedge of the north-western Alps, and both are characterized by an eclogitic imprint and a greenschist facies re-equilibration of Tertiary age. The Monte Rosa nappe is derived from the European continental margin of the lower plate, showing that the subduction-related thermal low lasted till the first stage of collisional accretion. In spite of Alpine reworking, this nappe extensively preserves (Castor-Perazzi area) the primary contact between the Late-Palaeozoic intrusives and roofing paragneiss. The overlying Zermatt-Saas ophiolite is mainly formed by eclogitic metabasalts and serpentinites derived from mantle peridotites, without a metagabbro layer between them. In addition, these ultramafics include abundant rodingitic gabbro dykes which may be representative of a sheeted dyke complex inside the former lithospheric mantle.

KEY WORDS

Exhumed subduction complex, Monte Rosa nappe, Zermatt-Saas ophiolite, Italian Western Alps

RIASSUNTO

La testata della Valle d'Ayas è costituita da rocce metamorfiche appartenenti alla Falda Ofiolitica Piemontese ed alla sottostante Falda pennidica del Monte Rosa, derivate rispettivamente dalla sutura dell'oceano mesozoico e dal margine continentale europeo. Assieme alla Falda della Dent Blanche, di origine africana e rappresentata, ad ovest Della carta, dal Monte Cervino, queste unità costituiscono la parte assiale della catena collisionale delle Alpi.

GEOLOGICAL MAP OF THE HEAD OF THE AYAS VALLEY, NW ALPS

OPHIOLITIC PIEDMONT NAPPE SYSTEM

ECLOGITIC LOWER UNIT (ZERMATT-SAAS NAPPE)

Large fragment of Mesozoic oceanic crust and mantle with eclogitic imprint (Mid-Eocene) and post-collisional greenschist facies overprint (Late Eocene-Early Oligocene), including a thin basal subunit of metabasalt.

Metasedimentary cover: Middle Jurassic-Cretaceous

1) Palon di Resy unit (mélange): Garnet micaschists and minor impure marbles with subrounded inclusions (mainly dm-cm) of eclogitic to retrogressed metabasalt.

2) Garnet-ankerite micaschist, phengite-chlorite-garnet quartzite and carbonaceous calcschist.

3) Major interbeddings of impure marble.

Ophiolitic suite: Jurassic

4) Greenschist facies tholeiitic metabasalt with scattered eclogite relics.

5) Minor bodies of eclogite, glaucophane-eclogite and garnet-glaucophanite from fresch to altered (oceanic metamorphism) Fe-Ti-rich tholeiitic basalts.

6) Massive to flaser Mg-metagabbro, locally garnet-bearing.

7) Eclogitic Fe-Ti metagabbro.

8) Antigorite-titanclinohumite serpentinite from mantle slices, including dykes of metarodingitic gabbro as intra-mantle sheeted complex, thin bands of chloriteschist and local ophycarbonate breccia.
9) Dykes (0.3-to-3 m thick) and boudins of coarse to pegmatoid rodingitic gabbro mantled by thin chloritic walls and made up of pure diopside (from igneous pyroxene), Ca-Fe garnet, epidote, green vesuvianite, prehnite (plagioclase), chlorite and accessory Cr-garnet (spinel), also as lithoclase minerals.

10) Major bands of talc-chlorite schist.

MONTE ROSA NAPPE

Continental top nappe of Penninic domain, derived from European passive margin, deeply subducted (Eocene eclogitic imprint) and exhumed (Barrovian overprint). Protoliths: pre-granitic (Variscan) garnet-sillimanite-cordierite-biotite metapelites, sharply intruded by Late Carboniferous porphyric granite, leucocratic bodies and dykes; primary features are largely preserved in a huge Alpine low-strain domain (Castor-Cresta Perazzi), where high-P imprint is mainly marked by kyanite pseudomorph after sillimanite and discrete white-schist shear zones inside granite. This relict body is mantled by a strongly alpinised complex of garnet micaschists and albite-epidote schists dominated by greenschist facies retrogression, and including leucocratic dikes and boudins of marble and mafic rocks, all from pre-granitic protoliths (Southern Furgg Zone).

Metagranitoids

11) Augengneiss.
12) Massive to poorly foliated metagranite, with scatterly oriented pluricentimetric K-feldspar and rare relict biotite, cut by various systems of aplite and pegmatite.
13) Dykes of gneissic aplite and garnet-tourmaline pegmatite, poorly (low-strain domains) to pervasively transposed along Alpine schistosity.
14) Silvery phengitic schists as Alpine high-P mylonite inside granite, including garnet, kyanite, Mg-chloritoid and talc.

Pre-granitic complex

15) Relict high-grade paragneiss and anatectic migmatite with static high-P signature: kyanite (from porphyroblastic sillimanite), garnet-kyanite (cordierite), garnet-phengite (biotite).
16) Garnet micaschists with high-P fabric, in places kyanite- and/or chloritoid-bearing and weakly retrogressed.
17) Retrogressed garnet micaschists and albite-epidote-chlorite-biotite schists with pervasive greenschist facies fabric.

18) Boudins of albite-epidote amphibolite of continental tholeiite affinity, with scarce high-P relics within strongly aplinised paraschists.
19) Small bands and boudins of pure to diopside-epidote-garnet marble from pre-granitic protoliths.
20) Major dykes of gneissic aplite and leucogranite transposed paralled to Alpine schistosity of paraschists.

LATE-ALPINE HYDROTHERMAL ACTIVITY

21) Dikes and veins of quartz ± chlorite, albite and carbonate, transecting Alpine schistosity, probably Oligocene

22) Metasomatic hard fault breccia (listvenite) within Rocca di Verra serpentinites (Zermatt-Saas nappe), consisting of carbonatized serpentinite fragments and calcite-dolomite-quartz matrix, with Cr-rich green mica (fuchsite) of Oligocene age.

QUATERNARY

Gravitational deposits
23) Recent slope debris.
24) Detrital and avalanche cones.
25) Fall deposits.

Glacial deposits
26) Recent (Little Ice Age) to current deposits.
27) Older glacial deposits.
28) Associated fluvial-glacial deposits.
29) Active and fossil rock glaciers.

Alluvial and lacustrine deposits
30) Undifferentiated deposits.
31) Alluvial cones.

SYMBOLS

lithological contact	Alpine regional schistosity (F1, F2)
first-rank thrust between oceanic and continental nappes	Alpine fold axis
second-rank thrust between subnappes	mineral lineation
fault	erratic block
morainic crest	rock glacier crest

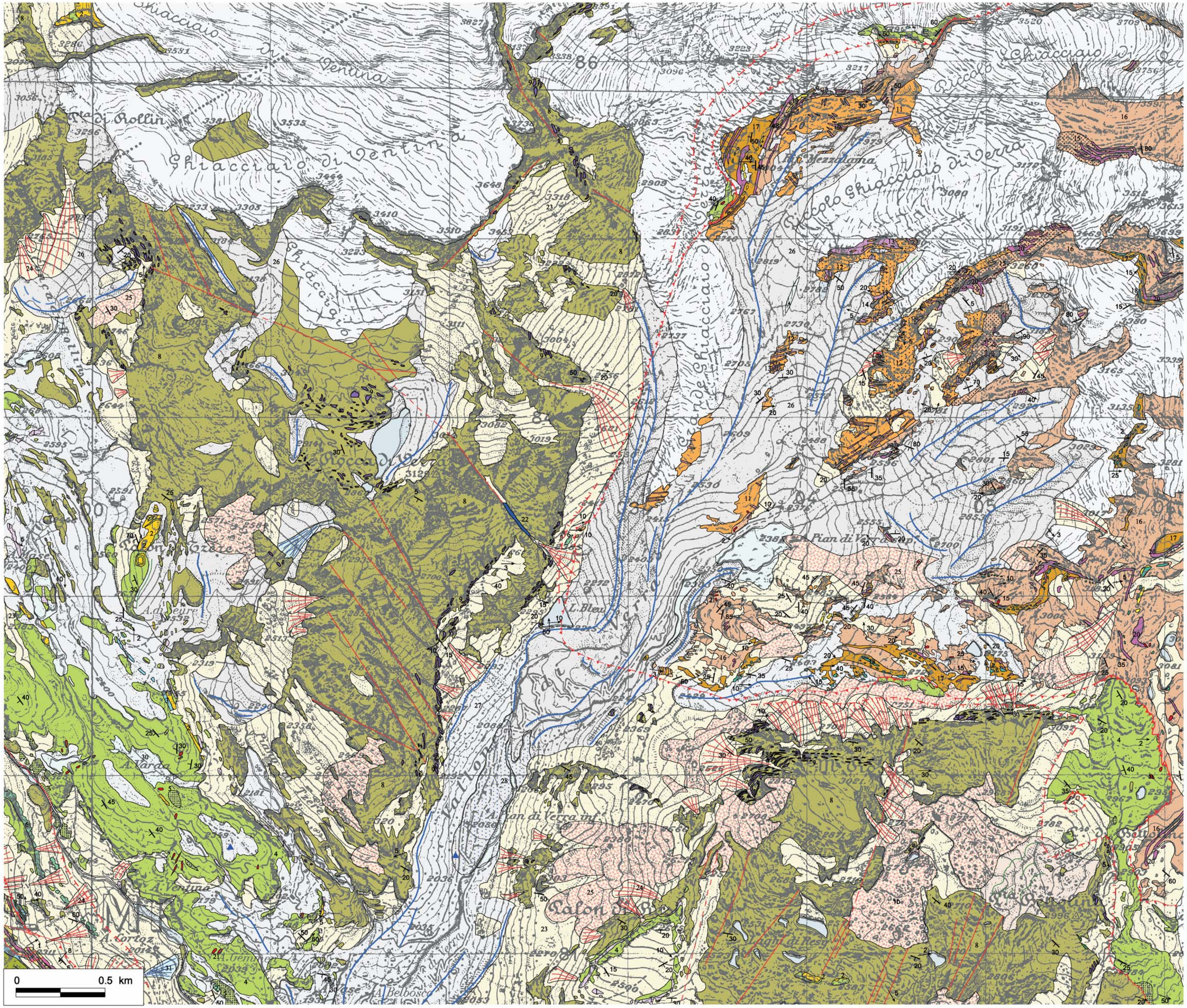


Fig. 1 - *Geological map of the head of the Ayas Valley, NW Alps.*

INTRODUCTION

The geological map was surveyed on a 1:10,000 scale in the 1970s and revised in the late 1990s. The mapped area is a significant example of the charming high mountain landscape and complex geology of the Alps (Fig. 2). It is located in Valle d'Aosta, at the head of the Ayas Valley (River Evançon), along the southern face of the Breithorn and Monte Rosa massif (Italian-Swiss boundary) (Dal Piaz, 1992). The study area extends from the Ayas-Gressoney divide and Verra glacial cirque through the Rocca di Verra-Gobba di Rollin ridge to the lower Cime Bianche Valley, and from Belbosco (ca 2000 m), north of the village of St. Jacques, to the summit of Castor (4221 m).

From a geological point of view, the Breithorn-Monte Rosa massif is a crucial piece in the intriguing puzzle of the north-western Alps, a continent-continent collisional belt which was generated by the Alpine orogeny over the last 70 million years (Ma) and is still active (moderate seismicity). The belt comprises a stack of coherent crustal fragments (nappes) of the European and African continental margins which, originally separated by the Mesozoic Tethyan (Piedmont) ocean, began to collide ca 50 Ma ago (Eocene), when the intervening ocean was completely consumed into a deep subduction zone. Note that in a geological sense, the term "ocean" refers to basalts and other rocks which form the present and past ocean-floors.

The collisional zone is marked by remnants of the "lost ocean", called ophiolitic suture, a composite nappe system (ophiolitic Piedmont zone) which consists of oceanic crust and mantle slices. This occurs along the tectonic contact between the European (Penninic) and overlying African (Austroalpine) continental nappes. From the Late Cretaceous to the Early Oligocene, these continental and oceanic nappes were dragged to 40-100 km in depth, and later exhumed and then pushed up to over 4000 m, their present-day altitude.

This complex journey is marked by metamorphic signatures which developed in high (eclogite facies) or very high (local coesite) pressure conditions (subduction metamorphism), followed by low pressure conditions (Barrovian greenschist facies overprint) during exhumation to shallower structural levels. Polyphase metamorphism and the related ductile deformations have partly or completely converted the original Mesozoic and Palaeozoic rocks (protoliths) into a very different lithological suite characterized by peculiar mineral assemblages and textures. Relics of protoliths are locally preserved, a case history of this being provided by the upper Ayas Valley.

The core of the continent-continent collisional zone is splendidly exposed between the Matterhorn and Monte Rosa continental basement units through the ophiolitic Breithorn-Pollux ridge (Figs. 2 and 3; Dal Piaz, 1992). From top to bottom, we see the following nappe stack which merges to the west by ca 20°: i) the Austroalpine Dent Blanche nappe, a fragment of African continental crust represented by the Matterhorn and other summits in the Aosta Valley (Valpelline, Mt. Emilius) and southern Valais (Dent Blanche, Weisshorn); ii) the ophiolitic Piedmont nappe system, including the

Fig. 2 - *View of collisional zone from the Penninic (European) Monte Rosa nappe (Punta Dufour, first plane) to the Austroalpine (African) Dent Blanche nappe (Matterhorn eastern face) through the Piedmont ophiolite (Zermatt-Saas unit: Breithorn northern face, on the left).*

Fig. 3 - *View of the Matterhorn-Weisshorn ridge (Dent Blanche nappe) and underlying ophiolitic Piedmont nappe system (Combin and Zermatt-Saas units) from the Rosà Plateau.*

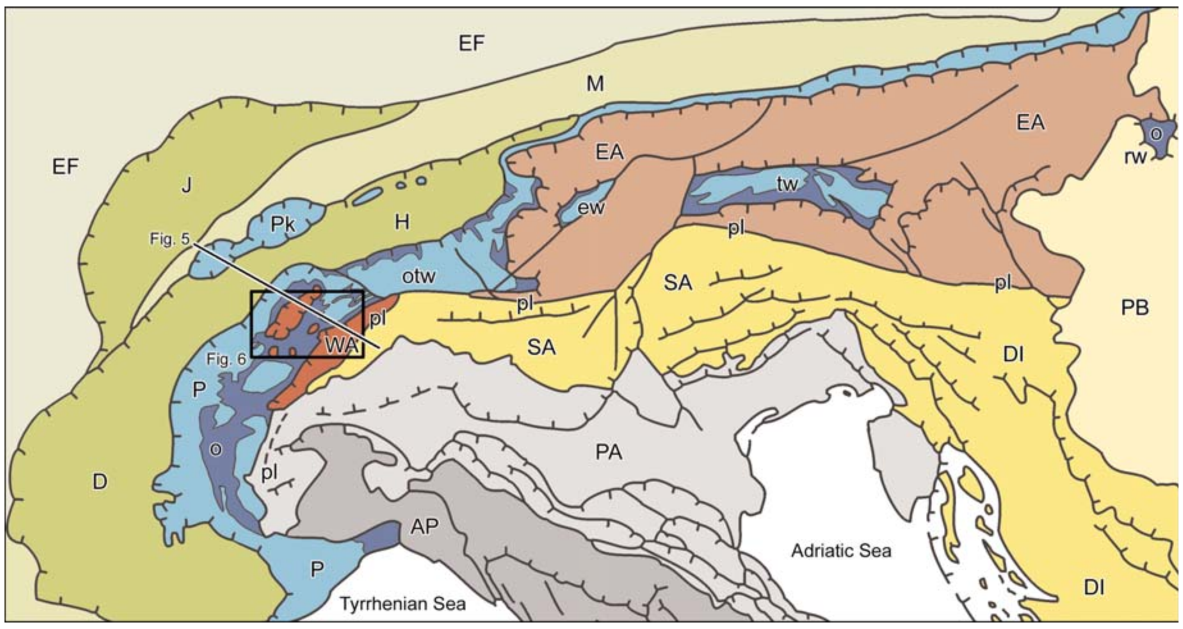


Fig. 4 - *Tectonic map of the Alps. 1) Eastern* (EA) *and Western* (WA) *Austroalpine, including Dent Blanche nappe; 2) Penninic* (P) *continental (light blue) and ophiolitic (dark blue) nappes; 3) Helvetic-Dauphinois* (H-D) *and Jura belt* (J)*; 4) Molasse foredeep* (M)*; 5) Southern Alps* (SA)*. Pannonian basin* (PB), *European* (EF) *and Po Valley-Adriatic* (PA) *forelands, Dinaric* (DI) *and Apenninic* (AP) *thrust-and-fold belts.*

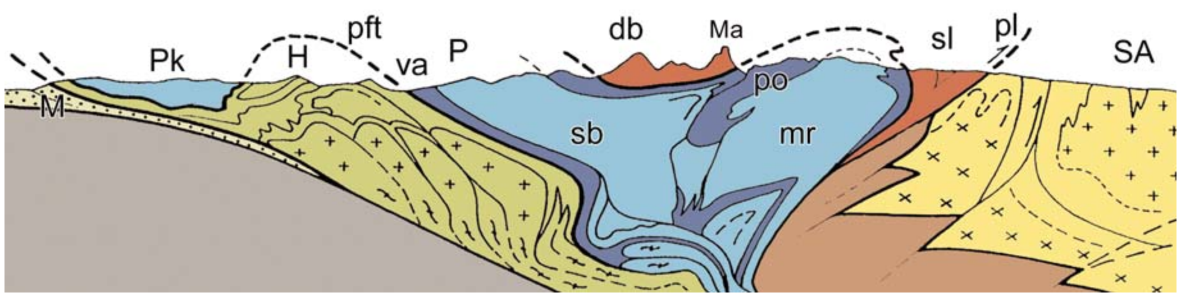


Fig. 5 - *Lithospheric profile across north-western Alps: 1) Austroalpine: Sesia-Lanzo inlier* (sl) *and Dent Blanche nappe* (db), *including Matterhorn* (Ma)*; 2) Penninic domain* (P)*: ophiolitic Piedmont units* (po), *Monte Rosa* (mr) *and Grand St. Bernard* (sb) *continental nappes, underlain by lower Penninic and outer Penninic Valais zone* (va), *Penninic klippen* (Pk), *Penninic frontal thrust* (pft)*; 3) Helvetic cover nappes and basement slices* (H) *thrust over inner Molasse* (M)*; 5) Southern Alps* (SA), *bounded northwards by Periadriatic fault system* (pl).

upper (Combin) and lower (Zermatt-Saas) nappes, the latter being exposed in the mapped area; and iii) the Penninic Monte Rosa nappe, a fragment of European continental crust occurring from Castor to the Liskamm-Dufour ridge and further eastwards. The location and structural setting of these units are shown in Figs. 4 to 6. The vertical section in Fig. 5 shows the anatomy of the north-western Alps on a lithospheric scale, inferred from surface geology and interpretation of deep seismic soundings. Note that the Austroalpine-Penninic collisional zone is a wedge-shaped nappe stack (collisional wedge); this is representative of a fossil subduction complex which, after extensive exhumation, now floats on the European lower plate and is indented and overturned by the African (Southalpine) lithosphere.

Focusing on the tectono-metamorphic framework of the ophiolitic Piedmont nappe system (Figs. 6 and 7), it is noted that the Combin nappe (south of the map) displays a blueschist facies imprint, like that found in the overlying Dent Blanche-Mt.Mary-Pillonet thrust system (upper Austroalpine outliers), whereas the Zermatt-Saas nappe is eclogitic, and locally coesite-bearing (Lake Cignana). Therefore, these ophiolitic nappes must have followed independent kinematic trajectories before their ultimate coupling at a shallower structural level marked by the greenschist facies overprint (BALLÈVRE *et alii*, 1986; DAL PIAZ, 1999; DAL PIAZ *et alii*, 2001).

In addition, the tectonic boundary between them is discontinuously highlighted by a Permian-Cretaceous décollement unit (Pancherot-Cime Bianche) of continental affinity and/or some eclogitic basement slices (Etirol-Levaz and other lower Austroalpine outliers).

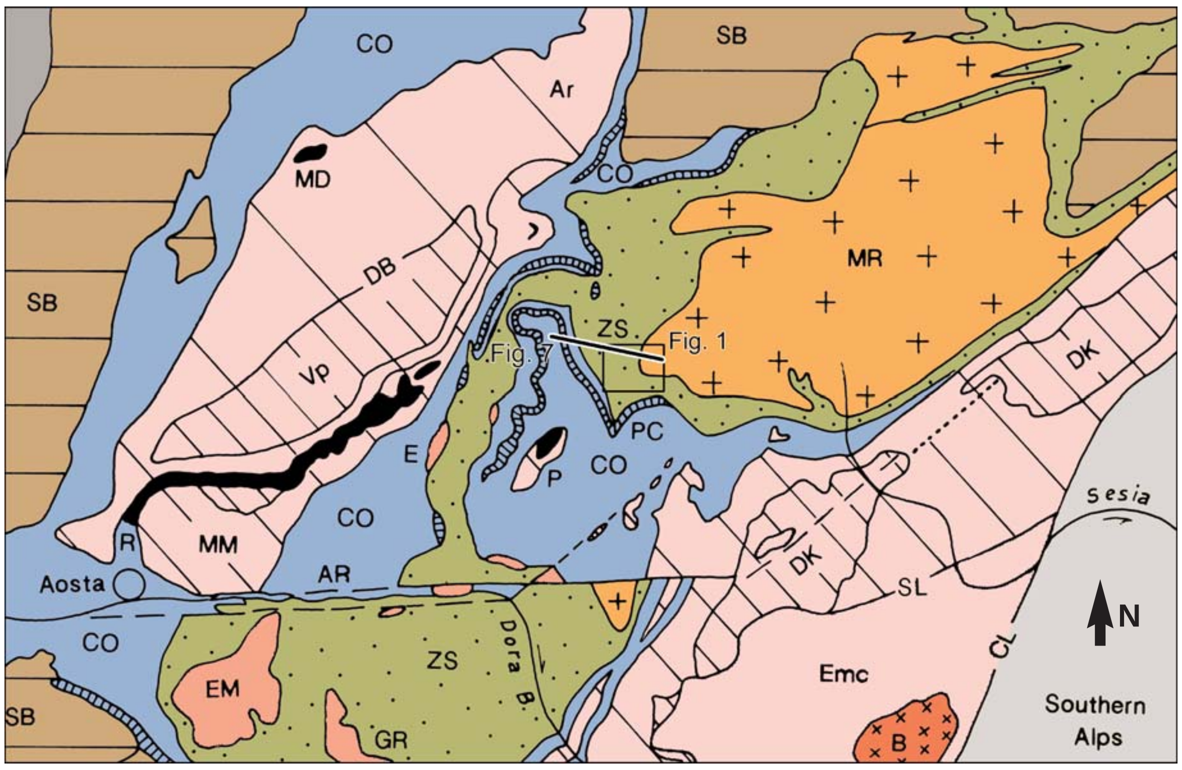


Fig. 6 - *Tectonic map of collisional zone in Aosta Valley and southern Valais (DAL PIAZ, 1999). From top to bottom: 1) Upper Austroalpine outliers (Dent Blanche:* DB*; Mt. Mary: MM; Pillonet:* P) *and Sesia-Lanzo inlier* (SL), *including Valpelline* (Vp) *and Diorite-Kinzigitic* (DK) *lower crust units and Eclogitic micaschist complex* (Emc)*; 2) Upper unit (Combin:* CO*) of ophiolitic Piedmont zone, including Pancherot-Cime Bianche* (PC) *décollement cover sheet; 3) Lower Austroalpine outliers (Mt. Emilius:* EM*; Glacier-Rafray:* GR*; Etirol-Levaz:* E)*; 4) Lower unit (Zermatt-Saas:* ZS) *of ophiolitic Piedmont zone; 5) Penninic Monte Rosa* (MR) *and Gran St. Bernard* (SB) *continental nappes. Aosta-Ranzola fault system* (AR), *Canavese line* (CL)*; Biella Oligocene intrusion* (B).

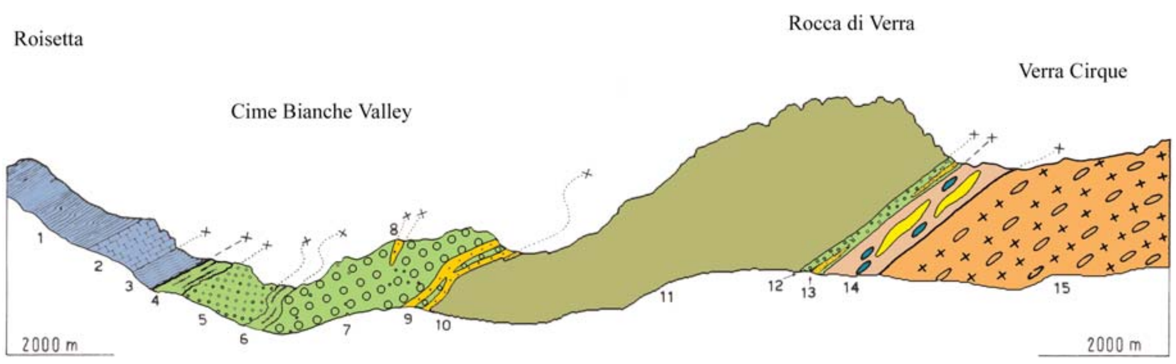


Fig. 7 - *Nappe stack along Verra cirque-Cime Bianche Valley profile (DAL PIAZ, 1992).*
Combin zone:
calcschists and minor tabular metabasalts (1), *Pancherot-Cime Bianche décollement unit* (2), *calcschist* (3), *serpentinite slices* (4), *metagabbro* (5)*; Zermatt-Saas nappe: mylonitic serpentinite* (6), *eclogitic to retrogressed metabasalt* (7), *Palon di Resy mélange* (8-9, *see Fig. 10), sheared serpentinite* (10), *serpentinite with rodingitic dykes* (11), *metabasalt basal slice* (12), *including minor serpentinite and metagabbro slivers* (13)*;*
Monte Rosa nappe:
strongly alpinized paraschists (14) *with leucocratic dykes and boudins of marble and metabasite (see Figs. 16 and 17), foliated augengneiss to massive metagranite* (15). *Rocks marked* 1 *to* 6 *are exposed south of the map.*

GEOLOGICAL SETTING

The mapped area includes part of the ophiolitic lower nappe (Zermatt-Saas) and the south-western corner of the underlying Monte Rosa nappe (Fig. 8), both characterised by an eclogitic imprint of Eocene age (RUBATTO *et alii*, 1998) and a Barrovian greenschist facies re-equilibration of Late Eocene-Early Oligocene age (HUNZIKER *et alii*, 1992).

Zermatt-Saas nappe

The ophiolitic Zermatt-Saas nappe occurs from the Ayas-Gressoney divide, through the Monte Rosso di Verra and Rocca di Verra mountains, to the Cime Bianche Valley (NW of St. Jacques), where it is overthrust by the Pancherot-Cime Bianche *décollment* unit (Figs. 7 to 9). This is a fragment of anomalous oceanic lithosphere which mainly consists of massive-to-pillow metabasalts and serpentinized mantle peridotites. The former occurs in the south-eastern and south-western corners of the map as a sequence of a few hundreds metres thick comprising eclogites and garnet-glaucophanites, associated with dominant retrogressed derivatives. Eclogites and garnet-glaucophanites are the high-P end-members of fresh-to-pervasively altered (hydrothermal oceanic metamorphism) submarine basalts. Zoisite, phengite, carbonate, rutile and opaques are common minor or accessory minerals.

Only a few remnants of the Mesozoic sedimentary cover are preserved here as thin interleavings of garnet-ankerite ± chloritoid micaschist, impure marble and quartzite. In nearby areas, however, the oceanic sedimentary cover begins with manganiferous quartzites derived from Jurassic cherts (DAL PIAZ, 1992; RUBATTO *et alii*, 1998).

Fig. 8 - *Verra cirque from alluvial and fluvio-glacial plain of Pian di Verra. The Monte Rosa nappe extends from Sella ridge* (1) *to Castor* (2) *and Rifugio Mezzalama* (3) *and is capped by the Zermatt-Saas serpentinite slice from Pollux* (4) *to Breithorn* (5) *and Rocca di Verra* (6).

Some metasedimentary horizons are characterised by centimetric-decimetric subpolygonal or rounded exotic inclusions of eclogitic-to-retrogressed metabasalt, probably fed by submarine pillow-breccia (Dal Piaz, 1992). This complex is called the Palon di Resy *mélange* (Fig. 10).

The volcano-sedimentary sequence is directly underlain by a huge serpentinized mantle slice, over 1.5 km thick (Breithorn ultramafic complex). Their contact is tectonic, highlighted by strongly sheared serpentinites. This slice extends from the Pollux-Breithorn-Gobba di Rollin range (Swiss-Italian divide, just north of the map; Fig. 11) to the Ghiacciaio di Ventina-Rocca di Verra area, and reappears, along the opposite side of the Ayas Valley, in the Monte Rosso di Verra-Punta Bettolina ridge.

It consists of magnetite-bearing antigorite serpentinite with lenses and veins rich in reddish titanclinohumite, diopside and olivine of Alpine age (high-P imprint). Sites of pre-Alpine minerals are locally preserved. The serpentinites are transected by swarms of metarodingitic gabbro dykes which are transposed parallel to the Alpine regional schistosity, extensively boudinaged and characterised by a coarse-to-pegmatoid igneous texture. A few of them, however, are fine-grained and perhaps derived from basalt dykes. As a whole, in places these bodies are so abundant that they recall an intra-mantle sheeted dyke complex. Primary pyroxene is replaced by pseudomorph pure diopside, locally rimmed by small garnets and chlorite, and cut by veins filled by these minerals. The matrix, mainly derived from igneous plagioclase, consists of a granoblastic aggregate of Ca-Fe-rich garnet, epidote, green vesuvianite, phrenite and chlorite. The same minerals also occur as wonderful crystals filling some vein generations. Every metarodingitic dyke and boudin is mantled by greenish chlorite schists, locally diopside- and/or magnetite-bearing.

The Rocca di Verra serpentinites and metarodingitic dykes are cut by a NW-trending subvertical fault, marked by a strongly metasomatized (listvenitic), very hard fault breccia, consisting of carbonatized serpentinite fragments within a matrix of calcite, Fe-dolomite, quartz and green Cr-rich mica (fuchsite), sometimes including submillimetric relics of chromite. This peculiar fault is linked to the post-metamorphic Aosta-Ranzola half-Graben and related hydrothermal activity, which

Fig. 9 - *View of Ayas Valley from Castor: P. Perazzi* (1), *Cime Bianche Valley* (2), *P. Roisetta* (3), *Gran Tournalin* (4), *Aosta Valley (5), Gran Paradiso* (6), *Grivola and Mt. Emilius* (7)*; Pillonet klippe* (P), *Combin unit* (CO), *Pancherot-Cime Bianche unit* (PCB), *Zermatt-Saas unit* (ZS, *Rocca di Verra serpentinite), Monte Rosa basement* (MR).

Fig. 10 - *Palon di Resy mélange, Zermatt-Saas unit: rounded fragments of eclogitic metabasalt within a matrix of carbonaceous garnet-micaschist.*

Fig. 11 - *Northern side of Verra cirque: P. Perazzi* (1), *Castor* (2), *Pollux* (3), *Roccia Nera (eastern Breithorn, 4), Rifugio Mezzalama* (5), *Gobba di Rollin* (6).

developed during the Oligocene (31-30 Ma) across the Austroalpine-Penninic nappe stack (PETTKE *et alii*, 1999; BISTACCHI *et alii*, 2001).

Below the ultramafic slice, the Zermatt-Saas nappe includes a thin basal unit of albite-epidote amphibolite (from basalt flows), minor sheared serpentinite, occasional metagabbro (Lago Blu) and impure marble (Rifugio delle Guide at Lambronecca). It occurs in the Verra cirque, as an half-ring around the Monte Rosa basement, and along the Ayas-Gressoney divide.

Monte Rosa nappe

The underlying Monte Rosa nappe (Figs. 8 and 11) is the Europe-derived, inner-upper continental unit of the Penninic zone. In the mapped area and, more generally, on the Italian southern side of the Monte Rosa massif, it consists of a crystalline basement devoid of Permian-Mesozoic cover metasediments, locally preserved on the Swiss side (DAL PIAZ, 2001, and refs. therein). In spite of polyphase Alpine metamorphism (eclogitic and later greenschist facies), two groups of protoliths are identified (BEARTH, 1952; DAL PIAZ, 1971, 2001). They are well preserved in a large low-strain domain which extends between the Piccolo Ghiacciaio di Verra and the Alpe di Verra Superiore, through the western crest of Punta Perazzi (Fig. 12), where Alpine structural reworking was relatively weak. Disregarding the Alpine overprint, we can identify:

1) a pre-granitic metamorphic complex, represented by high-grade pelitic paragneiss and anatectic migmatite, including concordant-to-discordant cordierite-bearing pegmatites.

The pre-granitic (pre-Late Carboniferous) high-grade regional fabric consists of garnet, biotite, sillimanite, quartz ± andesine, K-feldspar and cordierite, and was folded prior to the development of anatectic melts.

2) a granitic complex, represented by a granitic-granodioritic pluton, often porphyric, leucocratic granite in discordant stocks and concordant intrusions, and younger aplitic and pegmatitic dykes, locally preserving their primary features in the low-strain domain (Figs. 12 to 14). The intrusion age is inferred from U-Pb SHRIMP dating of zircon (270 ± 4 Ma) and monazite (268 ± 2 Ma) in the Verra cirque (LANGE *et alii*, 2000).

In the pre-granitic complex, Alpine metamorphism is marked by the high-P pseudomorphic replacement of porphyroblastic sillimanite and cordierite by very fine aggregates of kyanite and kyanite + garnet respectively, and of biotite by phengite + garnet. In the granitic complex, Alpine overprint is recorded by eclogite facies mylonites (called silvery schists by DAL PIAZ & LOMBARDO, 1986), consisting of quartz, large crystals of chloritoid, kyanite and talc (Fig. 15), together with a general alteration of igneous plagioclase and (partly) biotite in the surrounding poorly foliated metagranitoids.

The low-strain domains are mantled by a strongly alpinized zone which extends upwards to the basal thrust of the overlying Zermatt-Saas ophiolite (Fig. 7). Transition is marked by medium to very high strain gradients. Essential features of this Alpine high-strain zone are: i) partial to complete transformation of pre-granitic paragneiss and anatectic migmatite to Alpine high-P micaschist (garnet, phengite ±

Fig. 12 - *Northern face of P. Perazzi western ridge: Alpine low-strain domain with pre-granitic paragneiss intruded by leucocratic dykes and granitic apophises.*

Fig. 13 - *Detail of intrusion breccia, P. Perazzi western ridge.*

Fig. 14 - *Monte Rosa granitic complex. Poorly foliated pegmatitic dykes within porphyric metagranite north of Rifugio Mezzalama.*

kyanite, chloritoid, talc, Mg-chlorite), in turn partly evolving to greenschist-facies albite-rich schists; ii) increasing strain in the granitoids as revealed by the sequence: porphyric metagranite -> coarse-grained augengneiss -> micro-augengneiss, and progressive transposition of leucocratic dykes parallel to the Alpine schistosity. Paraschists are characterised by numerous boudins of extensively retrogressed eclogite (well-preserved in the nearby Gressoney Valley, Ingren glacier area; Fig. 16) derived from pre-Alpine granulite-amphibolite facies mafic rocks of continental tholeiitic affinity (FERRANDO, 2002; diploma Un. Genova), as well as by some boudinaged horizons of pre-granitic marble (Fig. 17). As a whole, the micaschist-mafic rock-marble association is known as the Southern Furgg-Zone (DAL PIAZ, 1966, 2001).

Petrological estimates carried out on the high-P shear zones inside metagranites are P = 1.7 GPa, T <600°C (LANGE *et alii*, 2000; see also DAL PIAZ & LOMBARDO, 1986, and PAQUETTE *et alii*, 1989) and confirm the deep subduction of the Monte Rosa nappe, probably occurring during the Middle Eocene. The Barrovian overprint is characterised by greenschist facies assemblages marked by albite, locally rimmed by oligoclase, biotite, white mica, epidote, chlorite (felsic systems) and albite, hornblende, actinolite, epidote, chlorite and titanite (mafic systems), revealing a Late Eocene-Early Oligocene age (HUNZIKER *et alii*, 1992).

Tectonics

The pre-granitic high-grade foliation is preserved to different extents in the roofing paragneiss of the granitic pluton: although partly replaced by subduction-related mimetic minerals, it is sharply intruded by granitic and leucocratic dykes in the low-strain domain of the P. Perazzi western crest- Piccolo Ghiacciaio di Verra cirque (Figs. 12 and 13).

The Alpine structural setting is regionally dominated by thrusting of the Zermatt-Saas ophiolite over the Monte Rosa basement nappe and later ductile-to-brittle deformations. Before thrusting, a first Alpine deformation, which developed in high-pressure conditions, is recorded in the Monte Rosa nappe by the eclogitic shear zones (silvery schists) within massive metagranite and rootless isoclinal folds in strongly alpinized paraschists and mafic boudins. This pattern is generally effaced by Alpine regional schistosity (S2), which is associated with D2 isoclinal folding and developed in greenschist facies conditions, and was followed by asymmetric folds D3 (A. GUERMANI, unpubl. data). Top-to-north tectonic transport is suggested by greenschist facies mineral lineations (L2). The exhumed nappe stack became brittle from the Oligocene, when it was cut by fault and fracture systems variously oriented which may be correlated to the Oligocene (31-30 Ma) Aosta-Ranzola Graben and other brittle features. This Oligocene activity is associated with pervasive hydrothermal activity, which was responsible for the development of metasomatic fault breccias (listvente) within serpentinites (BISTACCHI *et alii*, 2001). The best example of this in the mapped area is the NW-trending Rocca di Verra fault (near Lago Blu).

Fig. 15 - *Silvery schist north of glacial lake at 2782 m, below Piccolo Ghiacciaio di Verra: high-pressure granitic mylonite with large black crystals of chloritoid in a matrix of quartz, phengite, kyanite and talc (DAL PIAZ, 1971).*

Fig. 16 - *Monte Rosa basement in Indren glacier area: boudins of Alpine eclogite within polymetamorphic garnet micaschists.*

Fig. 17 - *Monte Rosa basement between Rifugio Mezzalama and Grande Ghiacciaio di Verra: boudin of pure and impure marble within polymetamorphic garnet micaschists.*

REFERENCES

BALLÈVRE M., KIENAST J.R. & VUICHARD J.P. (1986) - *La "nappe de la Dent Blanche" (Alpes occidentales): deux unités austroalpines indépéndantes.* Eclogae geol. Helv., **79**: 57-74.
BEARTH P. (1952) - *Geologie und Petrographie des Monte Rosa. Beitr. Geol.* Karte Schweiz, **96**: 94 pp.
BISTACCHI A., DAL PIAZ G.V., MASSIRONI M., ZATTIN M. & BALESTRIERI M.L. (2001) - *The Aosta-Ranzola extensional fault system and Oligocene-Present evolution of the north-western Alpine nappe stack.* Intern. J. Earth Sci., **90**: 654-667.
DAL PIAZ G.V. (1966) - *Gneiss ghiandoni, marmi ed anfiboliti antiche del ricoprimento Monte Rosa nell'alta Valle d'Ayas.* Boll. Soc. Geol. It., **85**: 103-132.
DAL PIAZ G.V. (1971) - *Nuovi ritrovamenti di cianite alpina nel cristallino antico del Monte Rosa.* Rend. Soc. It. Min. Petr., **27**: 437-477.
DAL PIAZ G.V. (1992) - *Le Alpi dal M. Bianco al Lago Maggiore*. Guide Geol. Regionali, SGI, BE-MA, 311 pp, Milano.
DAL PIAZ G.V. (1999) - *The Austroalpine-Piedmont nappe stack and the puzzle of Alpine Tethys.* In: G. GOSSO *et alii* (Eds), 3td Workshop on Alpine Geological Studies, Biella-Oropa 1997, Mem. Sci. Geol., **51**: 155-176.
DAL PIAZ G.V. (2001) - *Geology of the Monte Rosa massif: historical review and personal comments.* Schweiz. mineral. petrogr. Mitt., **81**: 275-303.
DAL PIAZ G.V. & LOMBARDO B. (1986) - *Early-Alpine eclogite metamorphism in the Penninic Monte Rosa-Gran Paradiso basement nappes of the north-western Alps.* Geol. Soc. Am. Mem., **164**: 249-265.
DAL PIAZ G.V., CORTIANA G., DEL MORO A., MARTIN S., PENNACCHIONI G. & TARTAROTTI P. (2001) - *Tertiary age and palaeostructural inferences of the eclogitic imprint in the Austroalpine outliers and Zermatt-Saas ophiolite, Western Alps.* Intern. J. Earth Sci., **90**: 668-684.
HUNZIKER J.C., DESMONS J. & HURFORD A.J. (1992) - *Thirty-two years of geochronological work in the Central and Western Alps: a review on seven maps.* Mém. Géol. Lausanne, **13**: 59 pp.
LANGE S., NASDALA L., POLLER U., BAUMGARTNER L.P. & TODT W. (2000) - *Crystallization age and metamorphism of the Monte Rosa Granite, Western Alps.* Abstr. 17th STSG Meeting, 51, Zürich.
PAQUETTE J-L., CHOPIN C. & PEUCAT J-J. (1989) - *U-Pb zircon, Rb-Sr and Sm-Nd geochronology of high- to very-high-pressure meta-acidic rocks from the western Alps.* Contrib. Mineral. Petrol., **101**: 280-289.
PETTKE T., DIAMOND L.W. & VILLA I.M. (1999) - *Mesothermal gold veins and metamorphic devolatilization in the north-western Alps: The temporal link.* Geology, **27**: 641-644.
RUBATTO D., GEBAUER D. & FANNING M. (1998) - *Jurassic formation and Eocene subduction of the Zermatt-Saas-Fee ophiolites: implications for the geodynamic evolution of the Central and Western Alps.* Contrib. Mineral. Petrol., **132**: 269-287.