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Note illustrative del F. 070 Monte Cervino della Carta geologica d'Italia alla scala 1:50.000

Explanatory Notes of the sheet 070 Monte Cervino of the geological Map of Italy at 1:50,000 scale

di

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In copertina foto di Marco PANTALONI, *sullo sfondo*:
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"Ora si è riconosciuto che la geologia dei paesi difficili (e le Alpi sono difficilissime) non altrimenti si puo' condurre sicuramente che studiando passo a passo e nei più minuti particolari le regioni a cui si riferisce"

Quintino Sella, 1864

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figg. 123, tabb. 3

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Explanatory Notes of the sheet 070 Monte Cervino of the geological Map of Italy at 1:50,000 scale

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ABSTRACT - The Monte Cervino sheet and its explanatory notes are dedicated to the memory of our dear friend and colleague Alessio Schiavo, who unexpectedly passed away on October 11 2012 after lenghty field mapping for the Gran San Bernardo sheet.

Introduction (I) - The Monte Cervino sheet (070) of the Geological Map of Italy, scale 1:50,000 (CARG Project - ISPRA), covers the high mountains of the Pennine Alps from the northern flank of the middle Aosta valley (423 km^2) to the southern Valais (149 km^2). On the Italian side it covers the upper part of the Valtournenche and St Barthélemy valleys, the entire Valpelline and the eastern edge of the Conca di By (Ollomont). On the Swiss side it covers the Bagnes valley from the Mauvoisin lake upwards, and the glacial area towards the Zermatt valley (Mattertal), including the Matterhorn (Mt Cervino, 4478 m), the Dent d'Hérens (4175 m), and many peaks over 3500 m in altitute. This is a key area of the western Alps due to the birth and development of geological studies on Alpine tectonics, and is dominated by the Austroalpine-Penninic collisional wedge, a fossil subduction complex of continental and oceanic nappes. The Italian part of the sheet was surveyed on a scale of 1:10,000 and integrated by the interpretation of aerial and satellite images, structural analysis and laboratory work, including micropalaeontology, petrography, mineral and whole-rock chemistry and isotope dating. The Italian working group was coordinated by Giorgio V. DAL PIAZ and was composed of Andrea and Nicola BISTACCHI, Giovanni DAL PIAZ, Franco GIANOTTI, Antonio GUERMANI, Matteo MASSIRONI, Bruno MONOPOLI, Giorgio PENNACCHIONI, Alessio SCHIAVO and Giovanni TOFFOLON, and also greatly benefited from collaboration by Leonsevero PASSERI and Gloria CIARAPICA. Starting from the authors' original maps, a geological database first at 1:10,000 and then at 1:25.000 scales was processed by Bruno MONOPOLI, according to the technical specifications of the *Regione Autonoma Valle d'Aosta* and ISPRA, respectively. The Swiss part of the sheet was prepared at 1:50,000 scale, thanks to Yves GOUFFON (swisstopo) and based on the modern Chanrion-Mont Velan (BURRI *et alii*, 1998) and Matterhorn sheets (BUCHER *et alii*, 2004) of the *Geologischer Atlas der Schweiz*, scale 1:25,000. These maps were carefully "generalised" by Alessio SCHIAVO to a scale of 1:50,000 and harmonised to the Italian side and its legend. Lastly, the geometric primitives for setting up printing of the Monte Cervino sheet, scale 1:50,000, were prepared by Bruno MONOPOLI and La NUOVA LITO.

Geographic and morphologic features (II) - The geographic and morphologic features of the splendid environment of the Monte Cervino sheet are briefly illustrated in this chapter.

Geological setting and previous studies (III) - Two centuries of tectonic interpretations of the western Alps are extensively reviewed in this chapter, from the early fixistic tenets and basic contributions by GIORDANO (1869) and GERLACH (1871), to the birth of the nappe theory (BERTRAND, 1884; SCHARD, 1893, 1898) and its grandiose development in the Pennine and Western Alps by Emile ARGAND in the first quarter of the 20th century and the sudden impact of plate tectonics nearly fifthy years ago to the classic Alpine geology.

The subduction-related collisional wedge represented in the Monte Cervino sheet and its surroundings from the Aosta valley to southern Valais (fig. 60) consists of i) upper and lower Austroalpine outliers (Dent Blanche nappe *s.l.*) and

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the Sesia-Lanzo inlier; ii) the structurally composite ophiolitic Piemonte zone; iii) the underlying Monte Rosa-Gran Paradiso and Gran St Bernard (Briançonnais) nappe system, derived from the European passive continental margin. The upper Austroalpine outliers are represented by the Dent Blanche *s.s.*-Mt Mary-Cervino-Pillonet thrust system (subnappes) located on the top of the orogenic wedge, above the Combin zone, the upper tectonic element of the Piemonte zone: both are characterised by blueschist relics and a pervasive greenschist-facies overprint. The blueschist-facies imprint in the Pillonet klippe is dated to the Late Cretaceous, like the well-preserved eclogitic metamorphism in the Sesia-Lanzo zone (COMPAGNONI *et alii*, 1977). In contrast, the Mt Emilius, Glacier-Rafray, Etirol-Levaz and other lower Austroalpine outliers, all eclogitic, are inserted in the ophiolitic Piemonte zone, between its upper (Combin zone) and lower (Zermatt-Saas nappe) tectonic elements, or within the latter. Robust isotope dating documents the Eocene age of the eclogitic imprint in the lower Austroalpine outliers, as well as in the Zermatt-Saas unit and underlying Monte Rosa and Gran Paradiso continental nappes. To sum up, contrasting P-T-time histories identified two continental-oceanic groups of nappes cutting across the classic Austroalpine-Piemonte boundary, clearly separated by a temporal and metamorphic gap: 1) the upper, older group is composed of the blueschist upper Austroalpine outliers and the Combin zone; 2) the underlying younger group of the lower Austroalpine outliers and ophiolitic Zermatt-Saas nappe, both displaying an eclogitic imprint of Eocene age.

Stratigraphy (IV) - The legend and lithostratigraphic setting of the Monte Cervino sheet are described in this chapter, starting from the metamorphic bedrock. The upper Austroalpine outliers consist of three main tectonostratigraphic units: 1) the Roisan zone, a strongly transposed metasedimentary cover discontinuously preserved along the thick shear zone between the Dent Blanche *s.s.* and Mt Mary-Cervino-Pillonet subnappes (DAL PIAZ, 1976; CANEPA *et alii*, 1990; MANZOTTI, 2011). It consists of basal quartzites, Upper Triassic (CIARAPICA *et alii*, 2011) to Jurassic platform carbonates, syn-rift scarp breccias and some basinal limestones, followed by carbonate to terrigenous flysch-type metasediments of presumed Cretaceous age. A few Mesozoic metasediments are also preserved in Mt Dolin, near Arolla, beyond the northern boundary of the sheet (AYRTON *et alii*, 1982; BURRI *et alii*, 1998). No Mesozoic remains are presently associated with the eclogitic basement slices of the lower Austroalpine outliers. 2) The Arolla Series (unit) groups a suite of massive, feebly to pervasively foliated and mylonitic gneiss derived from Permian granitoids, minor pre-granitic paraschists (Mt Morion, Pillonet) and huge bodies of fresh to altered Permian gabbros and cumulus peridotites (Cervino, Collon, la Sassa: DIEHL *et alii*, 1952; DAL PIAZ, 1976, 1999; DAL PIAZ *et alii*, 1977; BUSSY *et alii*, 1998; MONJOIE *et alii*, 2005, 2007; BALETTI *et alii*, 2012). 3) The Valpelline Series (unit) is a fragment of lower continental crust (kinzigitic complex) including granulite to amphibolite-facies and partially melted paragneiss, mafic rocks and marbles (DIEHL *et alii*, 1952; GARDIEN *et alii*, 1994; MANZOTTI & ZUCALI, 2013). The contact between the Valpelline and Arolla units is mylonitic.

In the Aosta valley and southern Valais, the upper ophiolitic element (Combin zone) is dominated by carbonate and terrigenous flysch-type calcschists, alternating with tabular beds of greenschist-facies tholeiitic metabasalt (prasinite). In places, especially near the top, it hosts large olistoliths or tectonic slices of prasinite, metagabbro and serpentinite (DAL PIAZ, 1965, 1999; BEARTH, 1967; KIENAST, 1973; MARTHALER, 1984; SARTORI, 1987; VANNAY & ALLEMANN, 1990; BURRI *et alii*, 1998). Disregarding the metamorphic overprint, these sequences may tentatively be compared with the external Ligurian units in the northern Apennines. A Permian-Mesozoic *décollement* cover unit with continental affinity occurs discontinuously in the lower part or at the base of the Combin zone*, i.e.* the Pancherot-Cime Bianche and Frilihorn units on the Italian (DAL PIAZ, 1988; VANNAY & ALLEMANN, 1990) and Swiss sides respectively (MARTHALER, 1984; SARTORI, 1987). Extensively transposed by isoclinal folding, its stratigraphy can tentatively be reconstructed as follows: basal siliciclastic successions (Permian-Eotriassic?), dolostones and marbles (Middle-Late Triassic), slope breccias with dolomitic fragments (Jurassic?) and brownish calcschists (Cretaceous?). Since the facies affinity is not conclusive, partly recalling either the Briançonnais cover or the Southalpine domain, various paleogeographic sources have been suggested for the origin of these exotic sheets, *e.g.* the European (pre-Piedmont) distal passive margin (ELTER, 1971, 1972; DAL PIAZ, 1974; ESCHER, 1988), Adriatic margin (CABY *et alii*, 1978), or extensional allochthons between them (DAL PIAZ, 1999). As a whole, the upper ophiolitic nappe and its exotic interleavings constitute the Combin zone, an Argandian term which is still useful to indicate the eclogite-free footwall of the Dent Blanche-Mt Mary-Cervino-Pillonet thrust system.

The underlying Zermatt-Saas nappe is dominated by mafic and ultramafic ophiolites which, disregarding their eclogitic imprint, display a close affinity with the oceanic lithosphere, such as the internal Ligurian unit in the northern Apennines. Made famous by BEARTH's work (1967), the Zermatt-Saas nappe and its extension in the Aosta valley mainly consist of gigantic slices of mantle serpentinites, often passing upwards to ophicarbonate and metasedimentary breccias, discontinuous bodies of Mg- to Fe-Ti-rich metagabbros and/or massive to pillow metabasalts (BEARTH, 1959, 1967; KIENAST, 1973, 1983; CHINNER & DIXON, 1973; DAL PIAZ & ERNST, 1978; BARNICOAT & FRY, 1986; BUCHER *et alii*, 2004; ANGIBOUST & AGARD, 2010; BELTRANDO *et alii*, 2010). The generally thin metasedimentary cover is represented by impure quartzites (locally Mn-rich, DAL PIAZ *et alii*, 1979), siliceous micaschists and minor marbles, followed by terrigenous deposits converted into garnet micaschists ± Mg-chloritoid-glaucophane, speckled by red-ochre carbonate grains.

The mid-Penninic Grand St Bernard system underlies and is partly imbricated with the external part of the Combin zone, whereas the Zermatt-Saas nappe never goes beyond the Mischabel back-fold (figs. 36 and 60). This Briançonnais tectonic system is exposed in the north-west edge of the Monte Cervino sheet, emerging from the Boussine window, and is represented by the Mont Fort nappe and its Fallère and Métailler units (GOUFFON, 1993; BURRI *et alii*, 1998; SARTORI *et alii*, 2006).

The Neogene-Quaternary cover is represented by glacial, alluvial and gravitational deposits, mainly generated since the maximum glacial expansion began to retreat. The distinction of these deposits is based on *Unconformity-Bounded Stratigraphic Units* (UBSU) and their sedimentary facies. Closely interconnected glacial and fluvial deposits are subdivided into the Ivrea and Miage Synthems and various Subsynthems belonging to the Dora Baltea (Aosta valley) and Rhone (Valais) basins. The ubiquitous sedimentary units are described in the last part, including more randomly distributed gravitational and lacustrine deposits.

Metamorphism (V) - This chapter focuses on the principal metamorphic features of the collisional nappe stack (fig. 99). The prealpine high-grade metamorphism is well preserved only in the kinzigitic complex of the Valpelline unit, recorded by felsic and mafic granulites grading to amphibolite-facies conditions and partial melting (PENNACCHIONI & GUERMANI, 1993; Gardien *et alii*, 1994; Bucher *et alii*, 2004; Manzotti & Zucali, 2013). Amphibolite-facies assemblages and anatectic migmatites are also preserved in the pregranitic roof pendants associated with the Arolla series of Mt Morion (Bucher *et alii*, 2004). Minor high-T relics occurring in the Pillonet klippe (Dal Piaz, 1976) are dated to the Variscan (Cortiana *et alii*, 1998). Thermal perturbation with resetting of isotope systems and bimodal igneous activity are recorded during the Permian in the Valpelline and Arolla series, respectively.

The Alpine orogeny is characterised by diachronous (Late Cretaceous vs Eocene) and contrasting (blueschist vs eclogitic) subduction metamorphism, regionally followed by a collisional greenschist-facies overprint in the nappe pile exposed in the Monte Cervino sheet (Metamorphic map as fig. 100). Relict glaucophane-epidote facies metamorphism is documented in the upper Austroalpine outliers and dated to the Late Cretaceous in the Pillonet klippe, whereas a coeval eclogitic imprint developed in the inner Sesia-Lanzo zone (sheet 092 - Verres). Similar blueschist-facies relics are locally reported from the Combin zone, albeit without confident dating. A large number of Rb-Sr, Ar-Ar, Sm-Nd and U-Pb ages document the Eocene age of the eclogitic imprint in the Etirol-Levaz and other lower Austroalpine outliers, as well as the eclogitic and UHP imprints of the Zermatt-Saas nappe. Historical and modern P-T-t paths are shown as fig. 101. A few prograde relics inside garnet and a continuum of transformations at decreasing pressure mark the subduction and exhumation history of these rocks. The eclogitic peak generated garnet, omfacite and rutile ± zoisite in Fe-Ti-gabbros and unaltered tholeiitic basalts, together with various amounts of glaucophane, lawsonite, phengite, chloritoid, chlorite and carbonate in basaltic materials previously affected by hydrothermal alteration during the oceanic stage (Ernst & Dal Piaz, 1978; Barnicoat & Fry, 1986; Bucher *et alii*, 2004, 2005; Groppo *et alii*, 2009; Angiboust & Agard, 2010; Beltrando *et alii*, 2010). Therefore, a large spectrum of metabasalts, ranging from typical bimineralic eclogites to garnet-glaucophanites and garnet-chloritoid-chlorite schists concurrently developed during the HP climax. It should be noted that lawsonite has been identified as large losange-shaped pseudomorphs of white mica and epidote. Aggregates and veins of titan-clinohumite, Fe-rich olivine and diopside are the HP counterpart in antigorite serpentinite (Li *et alii*, 2008; Zanoni *et alii*, 2011; Rebay *et alii*, 2012). In siliceous metasediments and associated calcschists, the HP imprint is recorded by garnet, phengite and rutile ± chloritoid, glaucophane, zoisite and sodic pyroxene.

A blueschist-facies imprint of Eocene age, more or less preserved below the greenschist-facies overprint, occurs in both units of the Mont Fort nappe, mainly in mafic volcanic and/or subvolcanic bodies (Gouffon, 1993; Burri *et alii*, 1998).

Tectonics and Geodynamics (VI) - This chapter begins by describing the tectonic schemes at the margin of the maps and as figures 52 and 60, as well as the five geological profiles, scale 1:50,000, focusing on nappes, tectonic elements (subnappes), mylonitic horizons and ductile post-nappe deformations, from the capping upper Austroalpine outliers to the Mont Fort nappe through the Combin (Tsaté) and Zermatt-Saas nappes. Pre-Alpine high-T isoclinal folding, a second schistosity and amphibolite-facies mylonites are preserved in the Valpelline unit of the Dent Blanche and Mont Mary subnappes (Gardien *et alii,* 1994; Pennacchioni & Cesare, 1997). Three main Alpine folding phases (D_1-D_3) can be identified throughout the Austroalpine, Piedmont and Penninic nappes (Dal Piaz & Sacchi, 1969; Vannay & Allemann, 1990; Ballèvre & Merle, 1993; Pennacchioni & Guermani, 1993; Van der Klauw *et alii*, 1997; Reddy *et alii*, 2003; Forster *et alii,* 2004; Roda & Zucali, 2008; Malaspina *et alii*, 2011; Manzotti & Zucali, 2012). Continuous mylonitic horizons occur along the first-rank tectonic contact between the continental and ophiolitic nappes and inside them, for instance the kilometric shear zone between the Dent Blanche *s.s.* and Mont Mary-Cervino subnappes, where most of the Roisan metasediments were trapped. The Alpine regional schistosity is S_2, whereas S_1 is well preserved mainly at microscopic scale and, in the field, by some crenulated rocks. Many tectonic lines cut the nappe pile in the Monte Cervino sheet and surroundings (figs. 52 and 60). The important role played by the Oligocene Aosta-Ranzola normal fault (Ballèvre *et alii*, 1986; Bistacchi *et alii*, 2001) is emphasised, as it explains the tectonic lowering and preservation in the area of the Monte Cervino sheet of the eclogitic lower Austroalpine Etirol-Levaz outlier and Crebuchette slice. The ultramylonitic-pseudotachylytic segment along the Valpelline/Arolla contact of the Dent Blanche subnappe (Diehl *et alii*, 1952; Menegon *et alii*, 2007) is reinterpreted as brittle reactivation of the previous ductile shear zone by the Buthier fault. The Praz de Dieu-Vofrede fault clearly extends across the Dent Blanche-Cervino subnappes and Combin unit, from the Buthier fault (Valpelline) to the right slope of Valtournenche, vanishing in the large Motta di Pletè deep-seated gravitational deformation (figs. 60 and 104). The moderate seismicity and related tectonics in the North-Westhern Alps are briefly reviewed (fig. 112, tab. 3). Lastly, the evolutional history of this area is discussed, from the Variscan and older events to the polyphase Alpine orogeny, through the Permian-Triassic lithospheric thinning, thermal perturbation and Mesozoic continental rifting. Classic models of Western Tethys, characterised by oceanic channels alternating with one or more lithospheric microcontinents, are replaced by new palaeostructural reconstructions based on mantle denudation, hyper-extended margins and extensional allochthons (Dal Piaz *et alii*, 2003; Manatschal, 2004; Beltrando *et alii*, 2010, 2013; Mohn *et alii*, 2012).

Environment and Georesources (VII) - This chapter covers the main alluvial events and landslides, carefully inventoried by the *Regione Autonoma Valle d'Aosta* in its "*portale geologico*" (http://geologiavda.partout.it). It then illustrates the major "deep-seated gravitational slope deformations" active in the area and the Jumeaux Sackung, concluding with brief information on the sand and gravel quarry near Perrères, the principal springs, and dams for hydroelectric power plants.

Data Base (VIII) - The design and structure of Matterhorn's database (DB) were established by ISPRA (SGd'I) and its implementation by Land Technology & Services SrL, under the responsibility of *Regione Autonoma Valle d'Aosta*. The workflow can be summarised as follows:

- Geological DB, 1:10,000 scale, starting from the Authors' field maps, according to Region specifications;
- Geological DB, 1:25,000 scale, according to ISPRA specifications, through processes of generalisation, normalisation and transcoding of the DB at 1:10,000 scale.

The following steps were done for the cartographic layout and letterpress at 1:50,000 scale: i) acquisition and processing of the Swiss topographic base, scale 1:50,000, in raster format; ii) migration, normalisation and transcoding of the DB for the Swiss sector, received in digital format with different structure and coding; iii) generalisation of DB at 1:25,000 scale.

Lastly, the entire geological dataset of the *Regione Autonoma Valle d'Aosta* was normalised, transcoded, validated and then published (http://geologiavda.partout.it).