

## Stratigraphic and structural revision of the Massa “Schuppenzone” (Alpi Apuane, Northern Apennines)

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### RIASSUNTO

#### Revisione stratigrafica e strutturale della “zona a scaglie” di Massa (Alpi Apuane, Appennino Settentrionale).

L'Unità di Massa è stata interamente revisionata in tutta la sua area di affioramento usando un approccio integrato nel quale si è cercato di creare una reale complementarità tra gli strumenti dell'analisi stratigrafica e le tecniche dell'analisi strutturale classicamente adoperate in terreni metamorfici. La mancanza di continuità di sezioni ben esposte e l'elevata complessità delle strutture tettoniche presenti hanno reso necessario ricostruire pezzo per pezzo la successione stratigrafica della copertura tardo/post-ercinica. La fig. 2 mostra due sezioni colonnari rappresentative dell'intera successione stratigrafica ricostruita e fornisce una correlazione tra la successione dell'Unità di Massa e la successione di Punta Bianca.

Sono stati riconosciuti tre eventi deformativi da sin- a tardo-metamorfici. Il secondo evento è quello che ha generato le strutture tettoniche maggiori, rappresentate da pieghe chilometriche - spesso pieghe isoclinali rovesciate verso NE - di diversa lunghezza d'onda. Sono anche presenti importanti zone di taglio per lo più sviluppate in corrispondenza del nucleo di strette sinclinali. L'architettura strutturale derivante dal secondo evento deformativo raggiunge gradi di complessità molto elevati, ma la buona conoscenza delle successioni stratigrafiche si è rivelata in campagna uno strumento prezioso che ha consentito un'accurata ricostruzione delle geometrie.

A scala regionale l'Unità di Massa è composta da tre corpi rocciosi principali separati da zone di taglio duttile, sin-metamorfiche, che tagliano obliquamente l'edificio tettonico. Questi tre corpi prendono il nome dalle località che ne delimitano l'estensione: elemento di Bergiola Maggiore-San Carlo, elemento di Canevara-Monte Belvedere ed elemento di Vietina-Ripa.

Un risultato inaspettato è stato quello di scoprire che l'architettura strutturale della Zona di Massa non corrisponde a quella di una Schuppenzone, che dovrebbe essere caratterizzata da una pila di embrici, ma si sposa piuttosto con lo stile tettonico generale delle Alpi Apuane dove sono sviluppate pieghe sin- e tardo-metamorfiche che mostrano laminazioni di fianchi rovesci e decapitazioni di fianchi diritti lungo zone di taglio duttile mostranti sull'S0 evidenti angoli di *cutoff* a tetto e a letto.

**KEY WORDS:** *Massa Schuppenzone, Northern Apennines, stratigraphic reconstruction, structural architecture, Tuscany.*

### INTRODUCTION

The Massa Unit is exposed along the western margin of the Alpi Apuane window tectonically sandwiched between the Tuscan Nappe and the Alpi Apuane Unit (fig. 1).

Extensive microstructural and petrological investigation has been carried out on the different lithotypes of the Massa Unit in order to define the characteristics of the Alpine metamorphism (see among many others FRANCESCHELLI *et alii*, 1986; MOLLI *et alii*, 2000 and references therein). Conversely, quite weak efforts

have been dedicated to the reconstruction of the original stratigraphic sequence filtering the deformation and metamorphism effects. Major purpose of our study was to reach a more satisfactory knowledge of an area that represents a classic in the Apennine geological literature (see STAUB, 1932) using an integrated approach in which basic principles and tools of the stratigraphy closely conjugated with the classical techniques of the structural analysis in metamorphic terrains.

### STRATIGRAPHIC REVISION

The Massa Unit is composed of Hercynian metamorphites comparable to those of the Alpi Apuane basement overlain by Middle-Upper Triassic deposits with associated mafic volcanites affected by low-grade Alpine metamorphism. Remnants of upper Permian/lower Triassic terrigenous deposits are locally preserved at the base of the Triassic sequence.

The lack of well-exposed, continuous natural sections and the complexity of the tectonic structures made it necessary to reconstruct the stratigraphic succession of the post-Hercynian metasedimentary cover of the Massa Unit piece by piece, by measuring and correlating scattered short sections and by carefully mapping the entire study region at the scale 1:10,000 and 1:5,000. A reconstruction of the late/post-Hercynian metasedimentary cover of the Massa Unit is provided in fig. 2. The picture shows two columnar sections representative of the sedimentary sequence in the northern areas of the Massa Unit (Mt. Brugiana-Aghinolfi Castel) and in the southern areas (Ripa-Mt. Folgorito), as well as their correlations with the well-known Punta Bianca section.

The lowermost portion of the late/post-Hercynian sequence, well exposed in the area between Montignoso and Mt. Brugiana, is made up of flysch-type terrigenous deposits (Montignoso Formation) which have been recognized for the first time in the Massa Unit and are possibly correlatable with the Argentario Sandstone of Southern Tuscany (see LAZZAROTTO *et alii*, 2003 and references therein) attributed by CIRILLI *et alii* (2002) to the late Permian/early Triassic. The overlying Mt. Folgorito Formation (which includes the Folgorito Group of CIARAPICA & PASSERI, 1982) is represented by a fining- and deepening-upward sequence of alluvial metaconglomerates and overlying metasandstones of Middle Triassic age characterized by very-well-rounded quartz pebble lags. The Mt. Folgorito Formation is widely exposed in the central and southern parts of the study region where it reaches the maximum thicknesses. The uppermost part of the Mt. Folgorito Formation consists of dark-grey calcschists and black metapelites and of fine-grained metasandstones representative of

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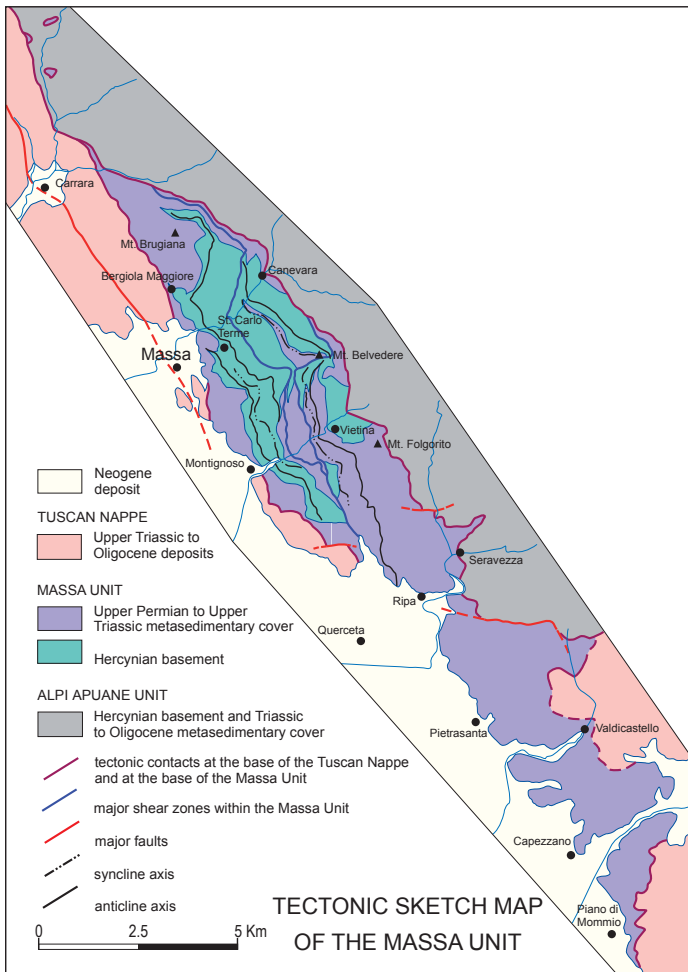


Fig. 1 – Tectonic sketch map of the Massa Unit in the whole type area.

a dys-anoxic terrigenous-carbonate shelf. In spite of the metamorphism, several fossils have been preserved in these deposits (crinoidal plates, echinoid spines, sclerites and ammonoid shell fragments). The overlying carbonate portion of the sequence with the associated metavolcanites (Mt. Brugiana Group) has been entirely reconstructed in the Mt. Brugiana area. The Mt. Brugiana Group is represented by three lithostratigraphic units. The first unit (Mt. Brugiana Marble), which represents the regressive, high stand system's tract of the Brugiana Cycle (see fig. 2), is made up of a shallowing-upward sequence of metacarbonates rich in crinoids in the lower portion and in reef-building sphinctozoan communities in the middle and upper portions where a Stromatolitic fabric is also present. Some remnants of benthic forams likely referable to *Turriplomina magna*, indicative of a generic Middle Triassic, have also been found. A more precise age attribution can be obtained by correlating the Mt. Brugiana Marble with the well-age-constrained uppermost Anisian-lowermost Ladinian Punta Bianca Marble (see VENTURI & TENNERONI, 1981 and BAGNOLI, 1982). The second unit consists of polygenic metabreccias while the third one is basically composed of metabasites. The polygenic metabreccias and the overlying metabasites testify to a sudden tectonically-controlled drowning event accompanied by submarine volcanism. This tectonic event led to the dissection of the previous carbonate ramp-like shelf and determined a slope-to-basin new physiographic configuration.

The Mt. Brugiana Group is unconformably overlain by the quartz-rich terrigenous deposits of the Verrucano Group. The Verrucano Group is represented by a thin layer of purple metapelites and metasilites followed by a few metres of massive metaconglomerates characterized by the occurrence of pinkish quartz-pebbles and tourmalinites ("anagenites" of the geological literature). In the southern part of the study area, the metacarbonates of the Brugiana Group are lacking and the quartz conglomerates directly overlie the Mt. Folgorito Formation. The uppermost portion of the Triassic sequence, represented just by a few meters of siliciclastic carbonates and metapelites stratigraphically overlying the Verrucano deposits, is exposed in a short section at Aghinolfi Castle near Montignoso. These peculiar carbonate-terrigenous deposits, known in Northern Tuscany (La Spezia) as the San Terenzo Schists (ABBATE *et alii*, 2005) are correlatable with the Tocchi Formation of Southern Tuscany (SIGNORINI, 1946; COSTANTINI *et alii*, 1980).

In the whole Massa Unit, as well as at Punta Bianca, the San Terenzo Schists are tectonically truncated by the Tuscan Nappe.

### STRUCTURAL REVISION

The most evident structural feature of the Massa Unit is a widespread penetrative cleavage systematically dipping towards the SW. In reality, behind this apparent simplicity field analyses have revealed a complex deformation pattern testifying the occurrence of at least three syn-metamorphic events. We shall describe the principal observed structures, starting from the youngest ones, and finally we shall give a brief description of the overall structural architecture of the area.

#### *Structures related to the third deformation event (D<sub>3</sub>)*

The S<sub>3</sub> cleavage, locally well developed in phyllites, quartzites and calcschists, usually appears as a penetrative foliation wrapping lenses of more competent lithotypes represented by massive quartz-conglomerates ("anagenites" Auct.), lithic metarudites, quartzites and marbles. In a few outcrops, generally in quarry or road cuts and along creek beds, the S<sub>3</sub> cleavage appears to be axial planar to decametric/metric folds. They are open to close, predominantly asymmetric to overturned folds with dominant southward vergence. The A<sub>3</sub> axes mainly trend NW-SE (N120-160° E) with gentle (10-15°) plunges.

#### *Structures related to the second deformation event (D<sub>2</sub>)*

The D<sub>2</sub> phase can be considered the most important deformation of the Massa Unit, which generated the bulk of the structural features observed at the regional scale. A strongly penetrative foliation S<sub>2</sub> is well developed in all lithotypes. In the most competent rocks as the massive quartz-conglomerates S<sub>2</sub> is manifested by irregular surfaces marked by rags of muscovite ± chlorite films and by wings of microcrystalline quartz aside clasts. In the whole Massa Unit, the S<sub>2</sub> cleavage shows dominant NW-SE trends with major 60-30° dips towards the SW and subordinate gentle dips towards the NE. This cleavage is associated to kilometric folds, often isoclinal folds overturned towards the NE, which show highly variable wavelengths. In some cases laminated, scattered masses of marbles and/or metasandstones/metaconglomerates (the latter

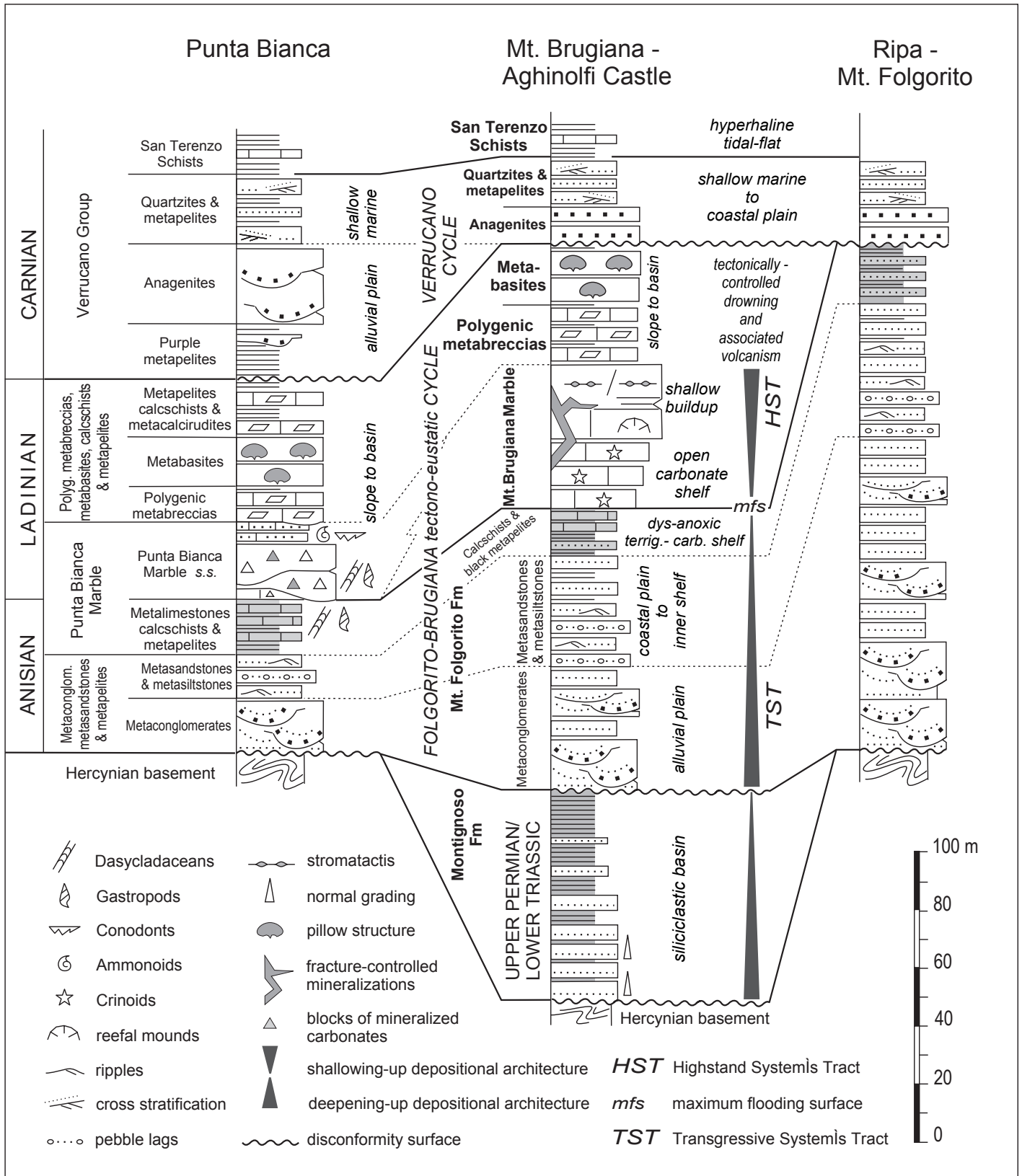


Fig. 2 – Columnar sections representative of the late/post-Hercynian metasedimentary cover of the Massa Unit in the northern areas of the study region (Mt. Brugiana-Aghinolfi Castle) and in the southern areas (Ripa-Mt. Folgorito) correlated with the Punta Bianca section. Because of the occurrence of syn-metamorphic deformations, thicknesses must be considered approximate. The Punta Bianca stratigraphic section is based on PASSERI (1985), RAU *et alii* (1985), MARTINI *et alii* (1986) and ABBATE *et alii* (2005), as well as on original data. The ages of the marine deposits of Punta Bianca have been derived from BAGNOLI (1982), as well as from ELTER & FEDERICI (1964), FEDERICI (1965, 1966) and VENTURI & TENNERONI (1981). The terminology used in the Punta Bianca section follows ABBATE *et alii* (2005).

referable to the Verrucano Group) mechanically included in older lithostratigraphic units mark important shear zones in correspondence to the core of tight synclines. The structural architecture referred to the  $D_2$  deformation is very complex, but the good knowledge of the stratigraphic sequence of the Massa Unit turned out to be a powerful tool for detailed geometric reconstructions.

#### *Structures related to the first deformation event ( $D_1$ )*

No structural feature at the mesoscale or megascale has been recognized. The only evidence of a  $D_1$  event is provided by rare small-scale  $D_2$  folds that deform (and the penetrative  $S_2$  cleavage often crosscuts) a previous  $S_1$  metamorphic foliation. At the moment this intrafoliar deformation pattern, though unquestionable, cannot be related to any regional structure.

#### *Overall structural architecture*

On the whole, the regional structural architecture of the Massa Unit is defined by three large-scale tectonic slices floored by syn-metamorphic shear surfaces along which significant portions of flanks of overturned folds have been likely cut off. These tectonic sheets are represented, moving from the NW to the SE, by the Bergiola Maggiore-St. Carlo, Canevara-Mt. Belvedere and Vietina-Ripa elements (see fig. 1). Within these elements, several minor tectonic laminations have also been recognized. It is noteworthy that the Middle Triassic marine metacarbonates are almost totally hosted in the uppermost element, whilst in the lowermost element the post-Hercynian sedimentary cover is basically represented by the continental deposits of the Mt. Folgorito Formation with a few and small remnants of quartzites referable to the Verrucano Group.

### CONCLUSION

The Triassic metasedimentary sequence of the Massa Unit has been entirely reconstructed in the whole type area. In addition, remnants of upper Permian/lower Triassic epimetamorphic deposits correlatable with the Argentario Sandstone of Southern Tuscany have been recognized for the first time in Northern Tuscany. The overlying Middle Triassic Mt. Folgorito Formation and the metacarbonates of the Mt. Brugiana Group form as a whole a terrigenous-carbonate sedimentary cycle abruptly interrupted by a tectonic-magmatic event well-known in the Dolomites. A precise age attribution has been obtained by correlating the Brugiana Marble with the Punta Bianca Marble.

An unexpected result was to discover that the internal structural architecture of the Massa Unit does not fit the geometric properties of a Schuppenzone (see "Schuppenzone von Massa" in STAUB, 1932), which should be featured by a stack of imbricates, but resembles the tectonic style of the Alpi Apuane Unit characterized

by the occurrence of syn/late-metamorphic folds showing frequent laminations of inverted fold limbs and decapitations of normal limbs along important late-metamorphic shear surfaces evidenced by  $S_0$  cutoff angles both in the hangingwall and in the footwall.

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