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Revisiting the Geology of the "Sillaro Line", Northern Apennines, Italy

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RIASSUNTO

Rivisitando la geologia della "Linea del Sillaro", Appennino Settentrionale, Italia

La "Linea del Sillaro" è il segmento nordorientale della "Linea Livorno-Sillaro" (GHELARDONI, 1965; BORTOLOTTI, 1966; NIRTA *et alii*, 2007) (Fig. 1A), uno dei più importanti lineamenti trasversali della catena dell'Appennino Settentrionale. In corrispondenza di questo lineamento, infatti, si può osservare il sovrascorrimento della Falda Ligure sui depositi di avanfossa della Successione Umbro-Marchigiana-Romagnola (BRUNI, 1973; DE JAGER, 1979; LANDUZZI, 2006). La "Linea del Sillaro" rappresenta, quindi, un'area chiave per la comprensione dei tempi e meccanismi del progressivo avanzamento della Falda Ligure sui depositi di avanfossa durante il Miocene e Pliocene.

KEY WORDS: *Ligurian nappe, mélange, Sestola-Vidiciatico tectonic unit, Sillaro line.*

The "Sillaro Line", the northeasternmost segment of the so-called "Livorno-Sillaro Line" (GHELARDONI, 1965; BORTOLOTTI, 1966; NIRTA *et alii*, 2007) (Figs. 1A and B), is one of the most important transverse lineaments of the Northern Apennine chain. In correspondence of this lineament, in fact, the overthrust of the Ligurian thrust nappe on the structurally underlying middle Miocene to Pliocene foredeep deposits of the Umbro-Marchean-Romagna succession can be observed (BRUNI, 1973; DE JAGER, 1979; LANDUZZI, 2006). Therefore, the "Sillaro Line" area represents a key area for the understanding of the timing and mechanisms through which the Ligurian thrust nappe progressively overrode the foredeep succession during the Miocene and Pliocene time.

In the "Sillaro Line" area BETTELLI & PANINI (1992) (Figs. 1A and B) for the first time showed that the structural superposition of the Ligurian thrust nappe onto the Umbro-Marchean-Romagna foredeep succession occurs through the interposition of a ~600 m thick chaotic body. They interpreted this body as a mélange of "uncertain origin", i.e., as a stack of olistostromes and olistoliths or as a tectonic mélange, which was informally named *Firenzuola mélange* (Fig. 1A). Within this mélange, later reinterpreted as a tectonic mélange by REMITTI *et alii* (2007, 2012) and VANNUCCHI *et alii* (2008), BETTELLI & PANINI (1992) distinguished two separate, partly superimposed informal chaotic units which were recognized on the base of their composition (nature, age and provenance of some rocks incorporated in the two chaotic units) and areal distribution: the *chaotic unit A* and the *chaotic unit B*. The basal contact of both chaotic units forming the *Firenzuola mélange* with the underlying middle to upper Miocene foredeep succession was recognized of tectonic origin (BETTELLI & PANINI, 1992). On the contrary, the nature of the contact between the two chaotic units forming the *Firenzuola mélange* remained an unsolved problem.

The nature and composition of the *chaotic unit A* also permitted to correlate it to the Sestola-Vidiciatico tectonic unit (BETTELLI *et alii*, 2002; REMITTI *et alii*, 2007, 2012; VANNUCCHI *et alii*, 2008). The latter unit crops out in the higher portions of the Emilia Apennines from the Futa Pass to the high valley of the River Secchia, forming a SE-NW striking belt, about ~100 km long, thrust over the Burdigalian to lower Langhian Cervarola Sandstone.

Subsequent studies by REMITTI *et alii* (2007) and VANNUCCHI *et alii* (2008) neglected the distinction in two different chaotic units made within the *Firenzuola mélange* by BETTELLI & PANINI (1992). Both *chaotic units A* and *B* were considered as two different products of the same process forming the Sestola-Vidiciatico tectonic unit. The new detailed geological maps realized throughout the "Sillaro Line" area in the last decade within the Italian Geological Mapping CARG Project (BENINI *et alii*, 2005; FARABEGOLI *et alii*, 2009) did not represent an advance in the understanding of the geology of the *Firenzuola mélange*. In those detailed maps, in fact, the presence of this mélange is either ignored or underestimated (e.g., FARABEGOLI *et alii*, 2009).

Here we review all the existing data and present the results of new field work in the area which are suggesting a new interpretation for this region.

The *Firenzuola mélange* of BETTELLI & PANINI (1992), as a whole, really corresponds to the Sestola-Vidiciatico tectonic unit as assumed by VANNUCCHI *et alii* (2008). Nevertheless, this tectonic mélange is actually formed of two lithologically quite different chaotic units, i.e., two different mélange units, which at present are structurally totally independent one from the other (Fig. 1B). Following BETTELLI & PANINI (1992) we refer to these mélange units as the *chaotic unit A* and the

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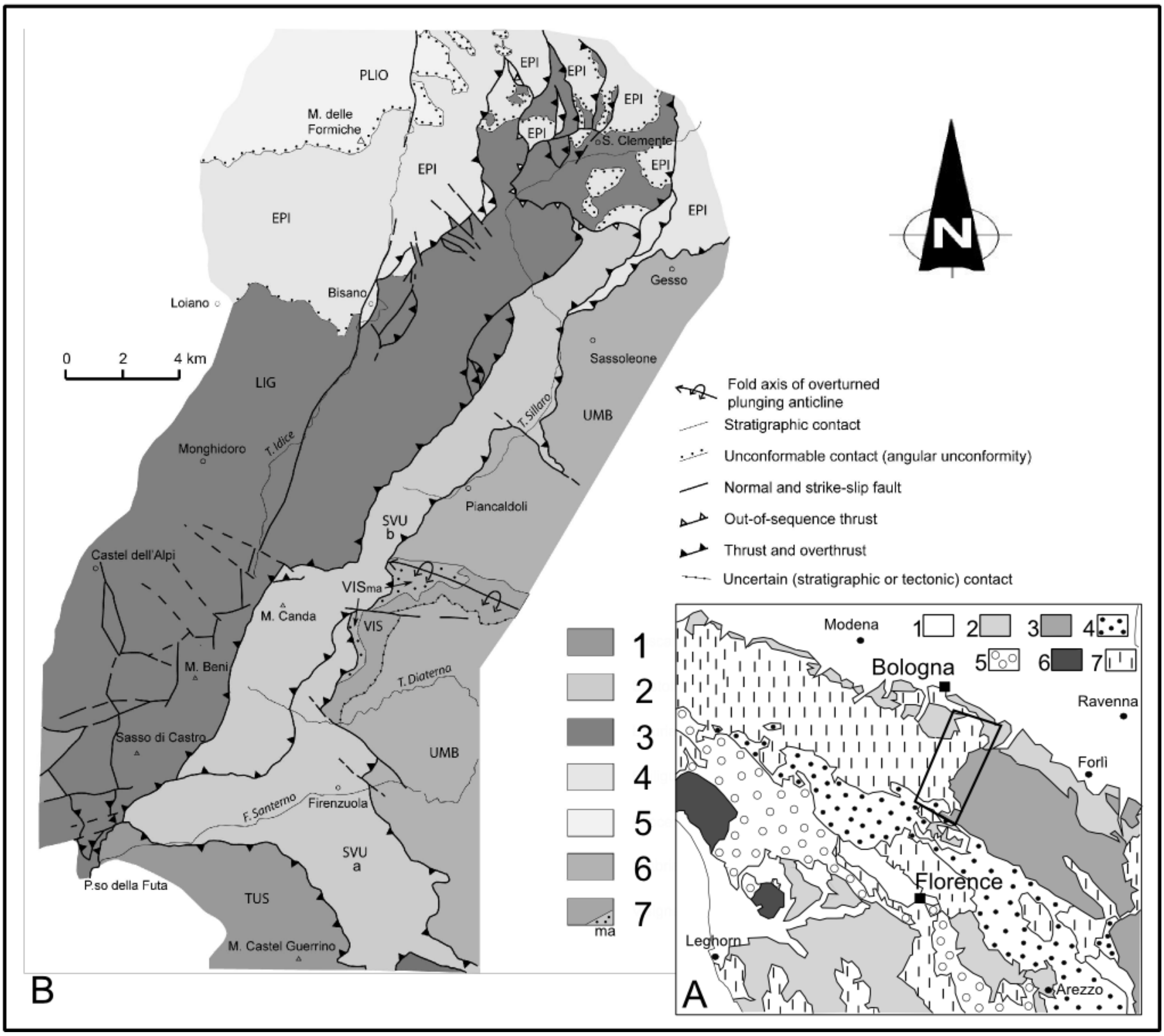

Fig 1 – **A**. Geologic sketch map of the Emilia-Romagna and Tuscan Apennines. 1) Quaternary alluvial deposits; 2) upper Tortonian/Messinian–Pleistocene marine and continental deposits; 3) Miocene Umbro-Marchean-Romagna Succession; 4) Modino/Cervarola/Falterona foredeep deposits; 5) Non-metamorphic Tuscan Nappe; 6) Apuane and Pisani Mts. Metamorphic Tuscan Units; 7) Epiligurian Succession, Ligurian, Subligurian and Sestola-Vidiciatico Units. **B**. Schematic Geologic map of the "Sillaro line" area (modified from Bettelli & Panini, 1992, and Vannucchi *et alii*, in press). 1) Tuscan Units of Aquitanian to Langhian age – TUS; 2) Sestola-Vidiciatico tectonic unit – SVUa (*chaotic unit A*), SVUb (*chaotic unit B*); 3) Ligurian Units – LIG; 4) Epiligurian Succession – EPI; 5) Pliocene deposits – PLIO; 6) Umbro-Marchean-Romagna Units of Serravallian to Pliocene age – UMB; 7) Visignano upper Serravallian/lower Tortonian intercalation of extra- and intra-basinal (VISma) materials ("Visignano olistostrome") - VIS.

chaotic unit B of the Sestola-Vidiciatico tectonic unit.

The *chaotic unit A* of the Sestola-Vidiciatico tectonic unit crops out in the internal, SW area going from the Giogo Pass to Peglio. This consists of thick submarine debris flow deposits and large blocks of Upper Cretaceous to lower Eocene Ligurian dismembered formations (Bettelli *et alii*, 2002). On the base of age and lithological characters, the Ligurian blocks can be interpreted as coming from the Ligurian Sillano Formation, which is today largely cropping out in northern Tuscany (Nirta *et alii*, 2007; Bortolotti *et alii*, 2009). New field mapping and sampling revealed that this chaotic unit contains exotic blocks ranging in age from the late Eocene to early Langhian. In this case, age, stratigraphy, sedimentology and lithological composition of all these exotic blocks suggest a correlation with the Fiumalbo Shale, Marmoreto Marl, Baigno Marl or Suviana Sandstone (Bettelli *et alii*, 2002; Benini *et alii*, 2005). Therefore, the *chaotic unit A* can be correlated with the Sestola-Vidiciatico tectonic unit cropping out in the Emilia Apennines containing inclusions, i.e., exotic blocks, which are always older than early Langhian (Bettelli *et alii*, 2002; Benini *et alii*, 2005).

The *chaotic unit B* of the Sestola-Vidiciatico tectonic unit crops out along an "anti-Apennine", SW-NE oriented belt which extends from Sasso di Castro to Sassoleone and Gesso area (Fig. 1B). *Chaotic unit B* is mainly formed by highly deformed, large blocks of the Val *Sillaro varicolored shale* (BETTELLI & PANINI, 1992), Sillano Formation and Mt. Morello Formation (BORTOLOTTI *et alii*, 2009). Subordinate amounts of debris flow deposits, mainly deriving from the reworking of the *Val Sillaro varicolored shale*, are also present. New field work on this chaotic unit revealed that it contains exotic blocks ranging in age from the late Eocene-early Oligocene to the early Miocene. These latter inclusions were already partly distinguished by BENINI *et alii* (2005) and FARABEGOLI *et alii* (2009). Their lithological and sedimentological characters are unique, and in disagreement with BENINI *et alii* (2005) and FARABEGOLI *et alii* (2009) we emphasize that they cannot be correlated with any known lithostratigraphic unit of the Emilia Apennines. They represent exotic blocks of slope deposits originally accumulated in a paleogeographic domain which occupied an intermediate position between the Epiligurian domain and the foreedep inner lower-slope, later destroyed by tectonic processes.

The "Visignano olistostrome", described among the others by LANDUZZI (2006), does not represent a klippe as proposed by BETTELLI & PANINI, (1992), but it really forms a large intercalation (DE JAGER, 1979; LANDUZZI, 2006), ~200-300 m thick, within the upper Serravallian-lower Tortonian Marnoso-arenacea Formation. The "Visignano olistostrome" is partly formed of extrabasinal Ligurian materials represented by very sparse debris flow deposits (of "*chaotic unit A*" type), blocks of Sillano Formation, Mt. Morello Formation and *Val Sillaro Varicoloured shale*. In addition, very rare and sparse blocks of Fiumalbo Shale and Marmoreto Marl are also present. All this material derived from both the *chaotic unit A* and *chaotic unit B* of the Sestola-Vidiciatico tectonic unit. The "Visignano olistostrome" is overlain by upper Serravallian-lower Tortonian marl and siliciclastic turbidite deposits which are mostly coeval with the underlying Marnoso-arenacea foredeep turbidites or a little younger, although locally (e.g., in the Peglio area) they are probably slightly older (possibly of early Serravallian age). Therefore, these marl and turbidite deposits cannot be interpreted as draping deposits of the topographical high originated in the middle-late Miocene by the emplacement of a mass wasting complex (LANDUZZI, 2006) or thrust sheet (DE JAGER, 1979) within the foredeep basin. They rather can be explained as sediments originally laid down on the foredeep lower slope and accumulated on top of the frontal part of the Ligurian orogenic wedge, i.e., in the wedge top depozone. These slope deposits were subsequently displaced, together with their original chaotic substratum, in the foredeep basin during the late Serravallian-early Tortonian through tectonic (DE JAGER, 1979) or mass-wasting processes (LANDUZZI, 2006).

The Marnoso-arenacea Formation and the "Visignano olistostrome" are folded into an overturned, NE-verging, plunging, large anticline (DE JAGER, 1979; LANDUZZI, 2006), which displays the typical characteristics of a synsedimentary growth fold, as previously claimed by various workers (e.g., DE JAGER, 1979; ROVERI *et alii*, 2002). SE of the Santerno Valley, this overturned anticline passes laterally into a thrust of regional extent (i.e., the Mt. Castellaccio thrust: ROVERI *et alii*, 2002, or the Castelvecchio-Palazzuolo structure: DE JAGER, 1979). The composition of the "Visignano olistostrome", its emplacement time and its implication in a synsedimentary map-scale fold are key factors for (1) unraveling the tectonic evolution of the *chaotic units A* and *B* of the Sestola-Vidiciatico tectonic unit and for (2) the reconstruction of the overthrusting history of the Ligurian thrust nappe onto the Miocene foredeep succession.

All the above data imply that the process of frontal tectonic erosion which originated the Sestola-Vidiciatico tectonic unit (REMITTI *et alii*, 2007, 2012; VANNUCCHI *et alii*, 2008) was clearly no longer active after the deposition of the oldest slope/thrust-top sediments overlying the exotic material of the "Visignano olistostrome", i.e., after the early Serravallian. Furthermore the synsedimentary deformation of the Marnoso-arenacea foredeep turbidites implies that, after the late Serravallian, the Sestola-Vidiciatico tectonic unit no longer represented the Northern Apennine interplate shear zone (REMITTI *et alii*, 2012; VANNUCCHI *et alii*, in press). Finally, before the early Serravallian both *chaotic units A* and *B* of the Sestola-Vidiciatico tectonic unit were not completely underthrust and they were still forming, at least partially, the frontal part of the Ligurian wedge.

On the basis of our new data it follows that, after the emplacement of the "Visignano olistostrome" (late Serravallian-early Tortonian), the *chaotic unit B* of the Sestola-Vidiciatico tectonic unit and the overlying Ligurian thrust nappe were progressively detached from the underlying *chaotic unit A*. *Chaotic unit B* also begun to override the post-early Tortonian foredeep deposits. This evolution explains why NE of the Visignano area the *chaotic unit A* is missing (Fig. 1B). It also accounts for the presence of tectonic slivers of early-late Serravallian marls and sandstone turbidites at the base of *chaotic unit B* in the NE outcropping area. The slivers, in fact, were possibly broken off from the "Visignano olistostrome" during the NE differential translation of the *chaotic unit B* with respect to the underlying *chaotic unit A*.

The differential translation may also explain the present-day structural relations between the two mélange units (i.e., the *chaotic unit*s *A* and *B*) and the Cervarola Sandstone in the internal, SW outcropping area of the Futa Pass. There, on top of the Cervarola Sandstone, the *chaotic units A* and *B* are missing (Fig. 1B), whereas, between the Futa Pass and Sasso di Castro, both the *chaotic unit B* and the overlying Ligurian Units show wedge-shapes with an abrupt thickness decrease. This wedge-shaped geometry allows in this area the direct superposition of the Ligurian Units onto the Cervarola Sandstone. The basal contact of the *chaotic unit B* and overlying Ligurian Units seems there to display the characteristic of a tectonic elision (see Fig. 1B). The nature of this contact is uncertain. Possibilities include a large, NE dipping low-angle extensional fault or a tilted NE-verging overthrust. In the latter case the tectonic processes responsible for the loss of thickness of the *chaotic unit B* and overlying

Ligurian Units from the Futa Pass to Sasso di Castro area should be considered. It is geologically unrealistic, in fact, the diapiric mechanism proposed by BORGIA *et alii* (2006) for the basal reduction of thickness of the Ligurian Units in the internal area of the Bologna Apennine, as discussed by PICOTTI & PAZZAGLIA (2007).

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