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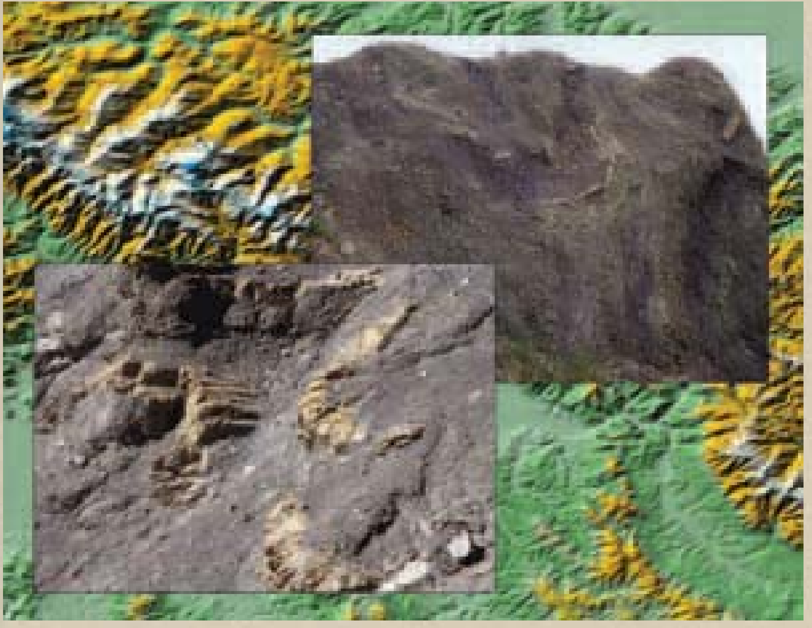
32nd INTERNATIONAL GEOLOGICAL CONGRESS

THE ROLE OF OLISTOSTROMES AND ARGILLE SCAGLIOSE IN THE STRUCTURAL EVOLUTION OF THE NORTHERN APENNINES



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THE ROLE OF OLISTOSTROMES AND ARGILLE SCAGLIOSE IN THE STRUCTURAL EVOLUTION OF THE NORTHERN APENNINES

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Front Cover:
Photograph in the lower left: Segavecchia olistostrome (stop 2-4). Upper right: tectonosome from Aptian-Albian member of the Sillaro scaly clays (stop 3-5).

Leader: G.A. Pini

Introduction

The influence of gravity in accretionary wedges is implied in the Coulomb critical wedge theory. Internationally, slope failure and mass wasting phenomena are increasingly considered to have had a strong impact on the geometry and internal features of accretionary wedges. They can directly influence important processes, such as movement and balancing of rock masses, erosional activity and exhumation of deep rocks, and the sedimentary budget in satellite and trench/foredeep basins. Therefore, they may control the mechanisms of accretion, offscraping/underplating and obduction.

Mass wasting phenomena are often part of the geology of a peculiar group of rocks, characterized by high internal deformation, up to the loss of the lateral continuity of beds (stratal disruption), and by different amounts of rock mixing. These rock units, frequently defined as mélanges, crop out as a consistent part of on-land fossil accretionary wedges and, thus, may represent opportunities to study the role of mass wasting processes in accretionary wedges through direct field observations.

The term mélange, after the re-introduction by Hsu (1968), has been used to indicate stratally disrupted and chaotic rocks elsewhere. The term should be used in a descriptive, non-genetic sense and the adjectives "tectonic" and "sedimentary" can be added to point out the different origin of the rocks (Silver and Beutner, 1980). However, mélange has been prevailingly used with the sense of tectonic product in mind by several authors in the American and International literature, with some exceptions suggesting a possible origin from mass wasting processes (see Cowan, 1985; Horton and Rast, 1989; Lucente and Pini, 2003 and references therein).

On the contrary, in the Apennines of Italy and in Sicily until the 1980's, the origin of chaotic units was almost unanimously related to mass wasting processes at different scales (see, among many others, Abbate

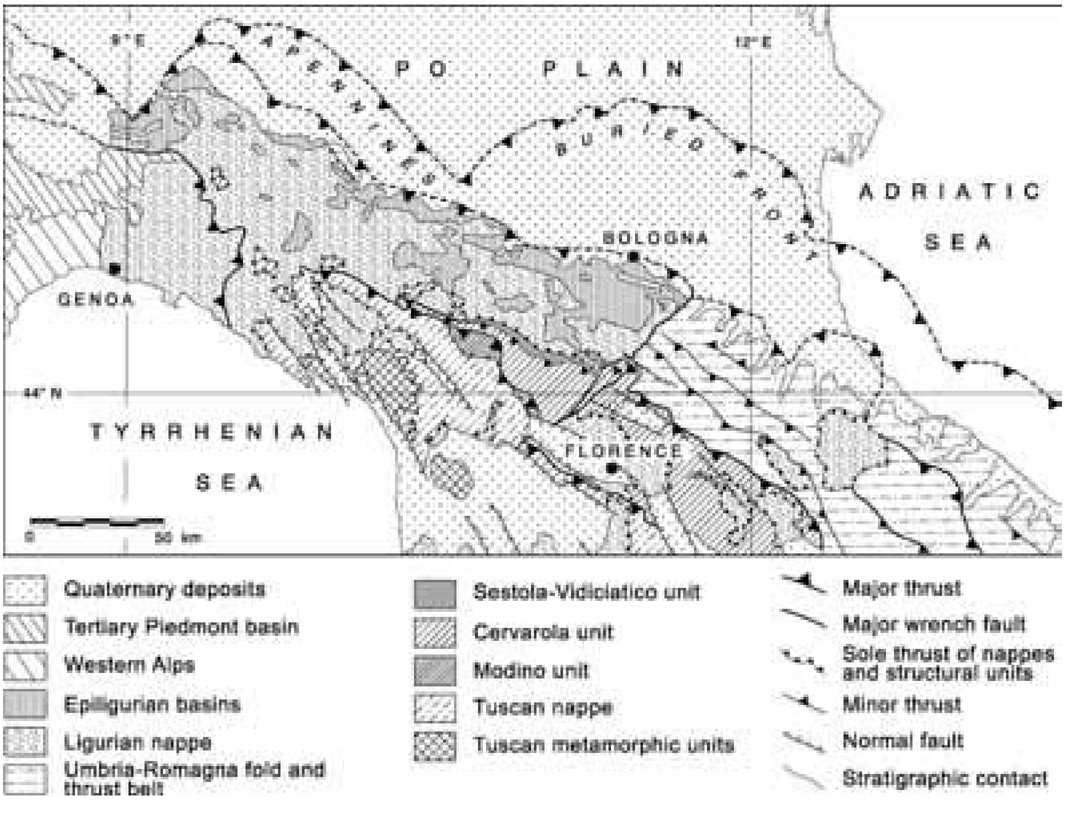

Figure 1 - Structural map of the north-western part of the Apennines. Adapted from Pini, 1999.

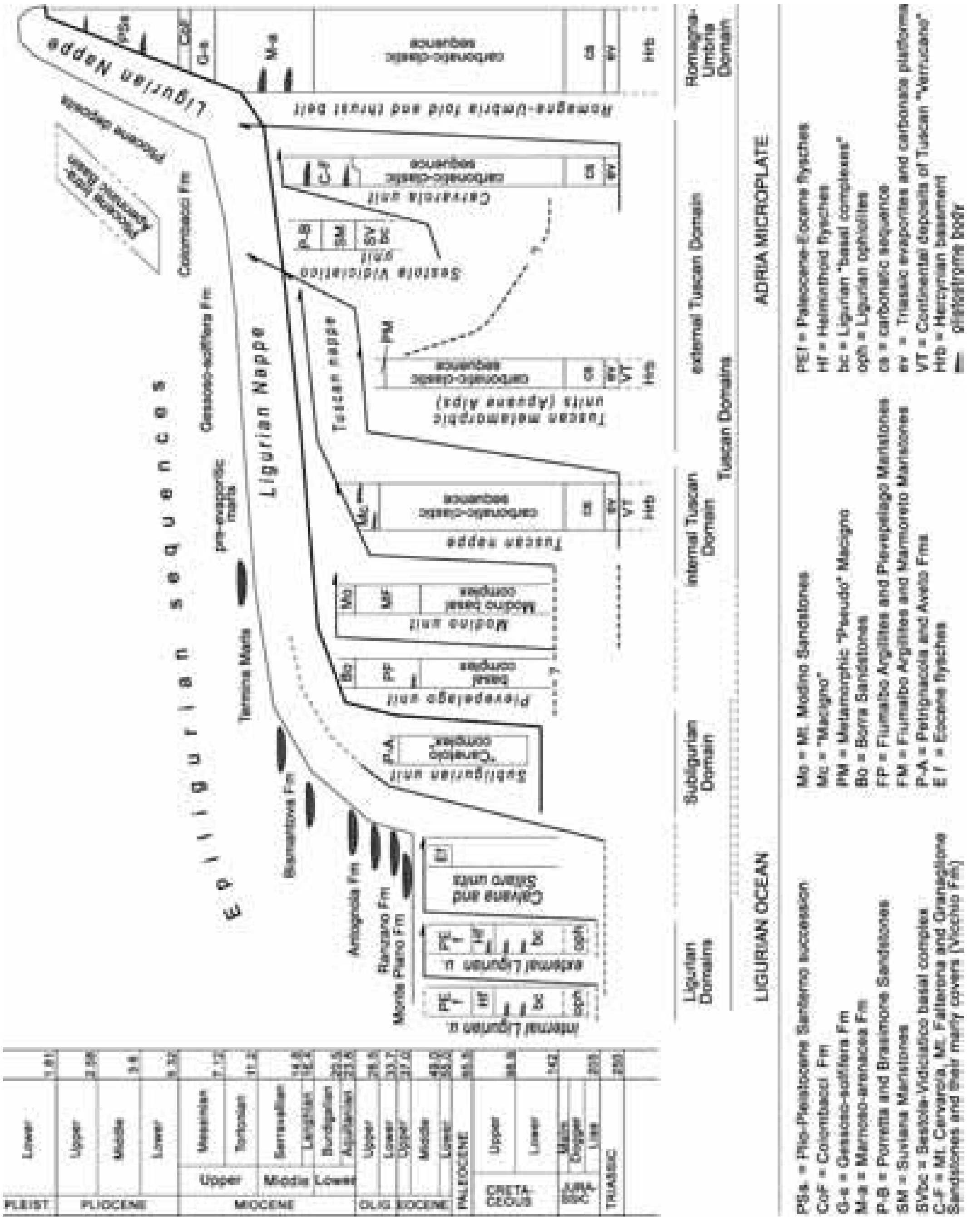

Figure 2 - Major structural units, lithostratigraphic intervals and units, and paleogeographic domains of the Northern Apennines. Modified from Pini, 1999

and Sagri, 1970; Elter and Trevisan, 1973; Naylor, 1982). In the last 20 years the term mélange has been restricted to sedimentary stratally disrupted rocks, which mostly contain exotic blocks, whereas, other bodies, which retain their original stratigraphic coherence but contain no exotic blocks, have been defined as broken formation (Bettelli and Vannucchi, 2003) or tectonosomes (Pini, 1999).

Notably, tectonosomes and sedimentary melanges all have variably disrupted bed packages and block-in-matrix rocks. Notwithstanding the similar aspect, there is now a general agreement on the aforesaid distinction and a general consensus on the distinctive criteria. The latter are based on the careful definition of the age and composition of rocks and on detailed study of fabric at outcrop to microscopic scale (see for example Cowan and Pini, 2001, and references therein). There is now a large diffusion of geologic maps based on these criteria distinguishing units of different origin and evolution into afore considered chaotic masses (Cerrina Feroni et al., 2002, and references therein; and various 1:10.000 and 1:50.000 scale official geological maps of the Regione Emilia-Romagna).

Some other issues about the internal features of the disrupted and chaotic units of the Apennines still remain open and are currently being investigated: 1) the discrimination between mass-wasting and tectonic processes that led to early stratal disruption within broken formations/tectonosomes; 2) the mechanisms that cause the stratal disruption in shallow level tectonics and their association with compaction and diagenesis; 3) the influence of different gravity-mass movement processes in olistostromes; and 4) the possible role of mud diapirism in the formation and deformation of olistostromes.

Moreover, some disrupted units, such as the basal complexes of the Modino, Pievepelago and Sestola-Vidiciatico units, are associated at the regional scale with the evolution of the Oligocene-Miocene foredeep complexes of the paleo-Apennines, which are some of the best exposed and preserved foreland-basin turbiditic successions elsewhere (Argnani and Ricci Lucchi, 2001 and references therein). These disrupted units disclose the role of large-scale gravitational collapse and mass wasting during the evolution of the paleo-Apenninic accretionary wedge and associated foredeep.

This field trip has been proposed as a part of the 32nd IGC Congress to display and discuss all the aforementioned issues, which are, in our opinion, of the greatest interest for the geology of mélanges and accretionary wedges elsewhere.

Regional geologic setting

The Northern Apennines are characterized by imbricated thrusts, thrust sheets and nappes that in general verge toward the NE. These structures bound several tectonic units, which can be grouped in the major units shown in Fig. 1.

Among these major units, the Ligurian nappe is the more far travelled and presently occupies the highest position in the chain (Fig. 2). The Ligurian nappe comprises three different groups of units: the Ligurian, Mesoligurian and the Subligurian units. The Ligurian units are the remnants of the Ligurian oceanic, a part of the Alpine Tethys, separating the European and the African plate during the Mesozoic and the early Cenozoic age (Ligurian domain in Fig. 3A). The Ligurian units are therefore composed of portions of middle Jurassic oceanic crust (ophiolites) and late Jurassic-middle Eocene deep marine sediments. The latter in general share a similar stratigraphy, which can be summarized in four lithostratigraphic intervals: the ocean-floor sediments; the basal complexes; the Helminthoid flysches, and the Paleocene-Eocene flysches (Fig. 2).

Sediments and ophiolites both participated in late Cretaceous-Eocene eo- and meso-alpine tectonic phases (Vai and Castellarin, 1993), which probably resulted in an accretionary wedge related to oceanic (“B”-type) subduction (Bortolotti et al., 2001 and references therein, Marroni et al., 2001). Different minor structural units originated from these deformational phases; some of these are shown in Figs. 4 and 5.

The Subligurian units derive from the deformation of the sediments deposited on the thinned continental margin of the Adria microplate, close to the Ligurian oceanic domain (Fig. 3). Adria has been considered as a separated microplate (Schettino and Scotese, 2002) or as a part of the African plate (African promontory, Channel et al., 1979).

Some other units, such as the Sillaro and the Calvana units and the so-called Modino lower basal complex, show stratigraphic characteristics that are intermediate between the Ligurian and Subligurian units (Cerrina Feroni et al., 2002), but they shared the same structural evolution as the Ligurian units during the eo- and mesoalpine tectonic phases. These units, here defined as Mesoligurian, can therefore represent an intermediate paleogeographic element separating the Ligurian and Subligurian domains (Fig. 3).

Generally, there are several problems in paleogeographic restoration of the different units of the Ligurian nappe. First of all, the different lithostratigraphic intervals are only seldom in stratigraphic continuity; they are often separated by tectonic contacts, so that several tectonic units consist only of a single lithostratigraphic interval. Moreover, the geological nomenclature is also quite complicated, due to the abundance of formational names and the coincidence of names between tectonic and lithostratigraphic units. Figure 4 has been conceived to simplify this nomenclature.

The continental margin of Adria has been extensively deformed during the Cenozoic phases of deformations (neo-alpine phases). Distinct phases of Oligocene, early Miocene, late Miocene, Pliocene and Pleistocene ages have been recognized on the basis of unconformities sealing tectonic structures (Castellarin et al., 1992, Cerrina Feroni et al., 2002).

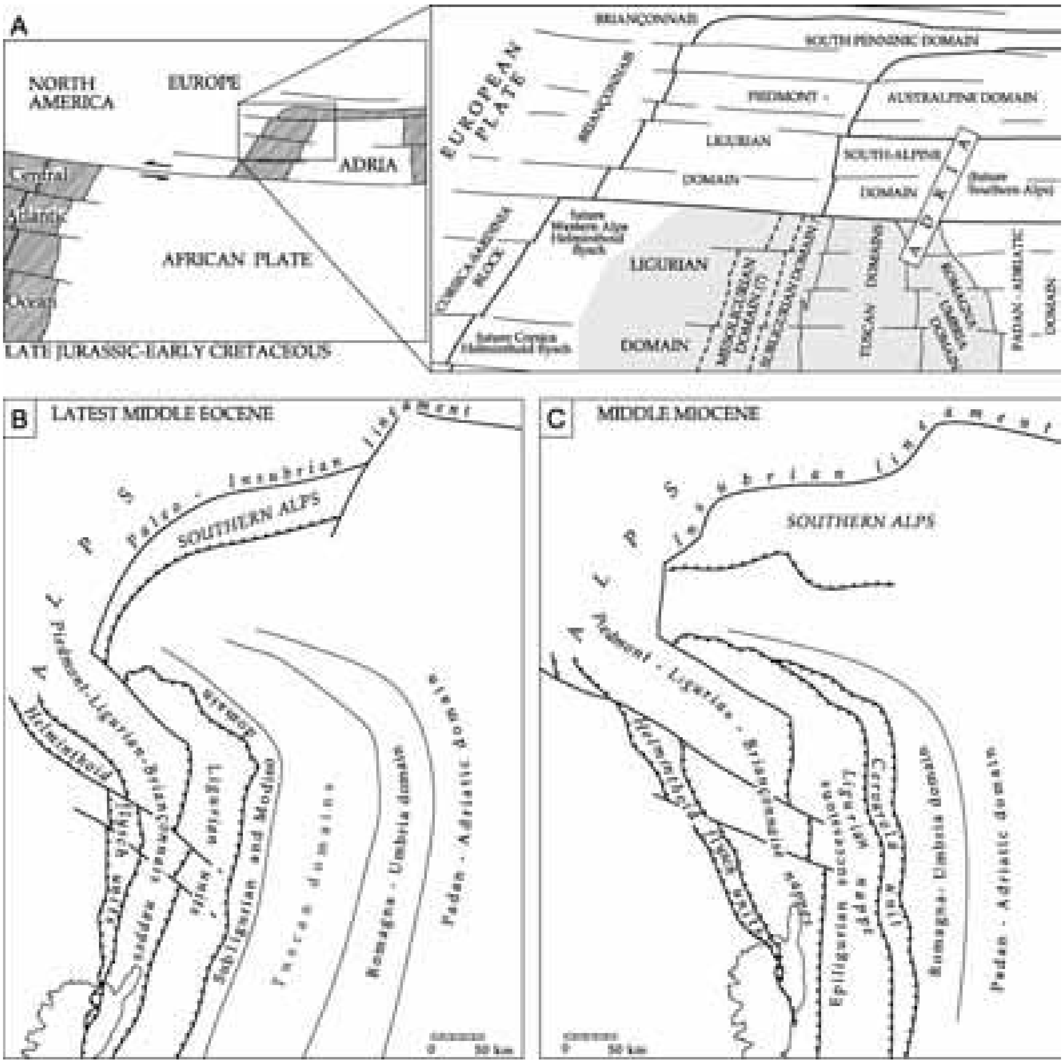

Figure 3 - Paleogeographic sketch maps of the Northern Apennines. Adapted from Castellarin, 1993 and Pini, 1999.

These deformational phases were responsible for the onset of thrust-fault bounded structural units, such as the Tuscan units (Tuscan nappe, Tuscan metamorphic and Cervarola units) and the Umbria-Romagna fold and thrust belt, which grossly coincide with the diverse paleogeographic domains of the continental margin of Adria microplate (Tuscan and Romagna-Umbria domains in Fig. 3). All these structural units are characterized by a common stratigraphy, from upper Triassic evaporites and shallow marine deposits, to Jurassic-lower Cretaceous carbonatic succession, to Cretaceous-Cenozoic carbonatic-clastic succession, up to Oligocene-late Miocene foredeep

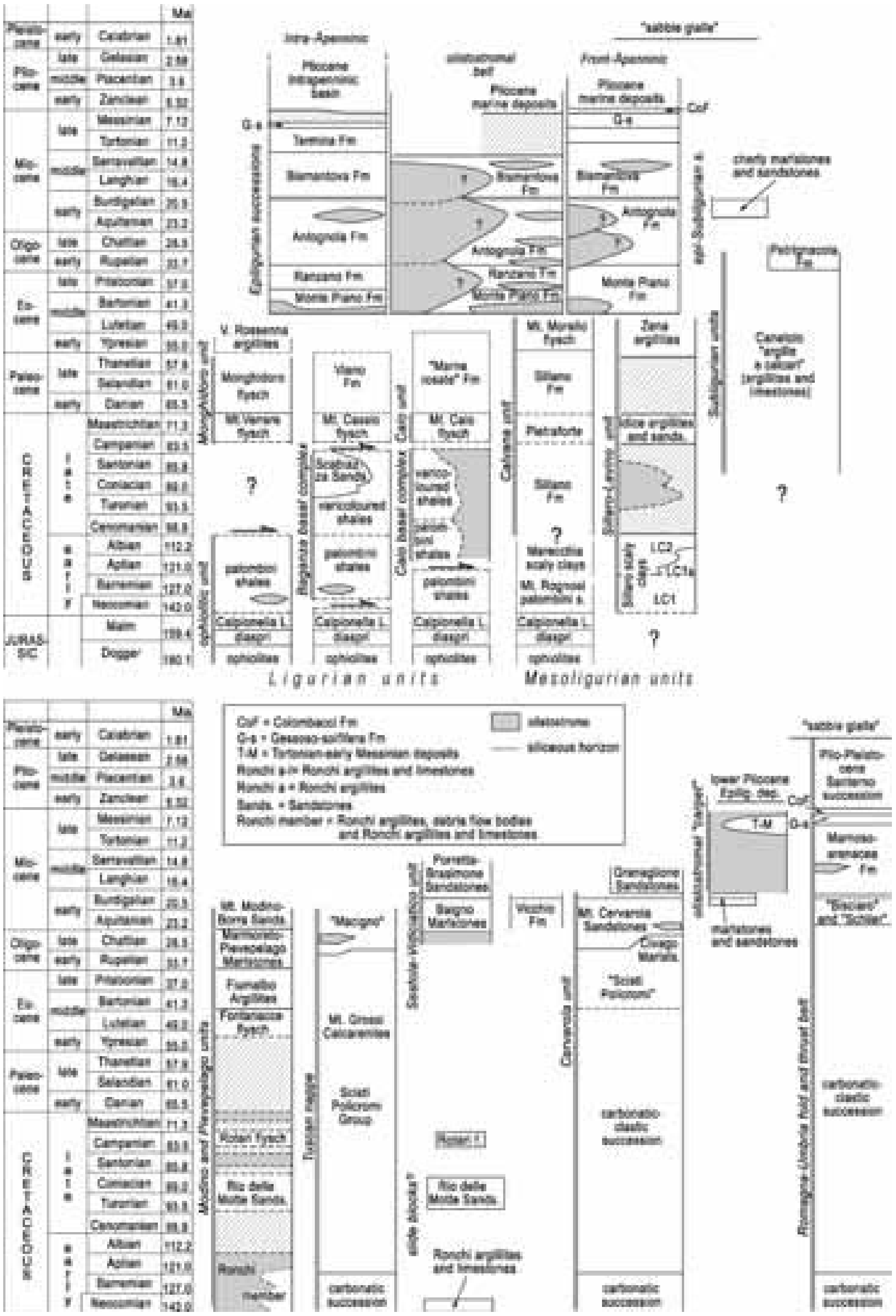

Figure 4 - Synoptic diagram showing the lithostratigraphic units of the main structural units and successions of the Northern Apennines

turbiditic deposits. The upper part of the carbonatic-clastic sediments is characterized by slope deposits that make a transition to the foredeep succession through an interval of thin bedded turbidites. The age of the turbiditic successions becomes younger from the Tuscan to the Umbria-Marche units. The age of the base of turbidite complexes changes from the early Oligocene in the western part of the North Apennines (coastal Macigno), to the late Oligocene along the Apennines main divide (Macigno), to latest Oligocene-early Miocene of the Mt. Cervarola and Mt. Falterona Sandstones, and to middle Miocene of the Marnoso-arenacea Fm. The sedimentation of these turbiditic complexes ended with the emplacement of the Ligurian nappe and/or mass wasting deposits from the front of the Ligurian nappe. In some cases, such as the Vicchio Fm on the Mt. Cervarola Sandstones, the turbiditic succession changes upward to slope and shelf deposits before the emplacement of Ligurian-related bodies and units. The succession deposited onto the Marnoso-arenacea Fm at the Po Plain-Apennines border extends up to shallow marine and continental deposits of late Miocene, Pliocene and Quaternary age (back cover map).

The high structural position of the Ligurian nappe has been maintained during the neo-alpine tectonic phases, so that the prevailingly marine sediments of the so-called Epiligurian succession have been deposited onto the Ligurian nappe in narrow, confined basins (satellite or piggy-back basins, see Ori and Friend, 1984; Ricci Lucchi, 1986). The persistence of the Ligurian nappe as the highest structural unit gave other important consequences: 1) the frequent collapses of rocks from the Ligurian nappe into the foredeep basins through time giving large mass-wasting deposits in the foredeep successions (olistostromes), and 2) the overthrusts and the thrust faults deforming and bounding the Tuscan and Umbria-Marche units developed prevailingly below the Ligurian nappe during its northeast-ward translation. A synsedimentary activity of some of these thrust faults has been proposed for the Marnoso-arenacea (De Donatis and Mazzoli, 1994; Conti and Fontana, 2002; Roveri et al., 2002), long before the emplacement of the Ligurian nappe.

As a result of younger, out-of-sequence re-activation, some of the thrusts offset the tectonic contacts among the different structural units, and the Tuscan units were thrust over the Ligurian and Subligurian units.

A final stage of extensional tectonics took over on the Tyrrhenian side of the Apennines from Tortonian to Recent and moved towards the more easterly part of the chain. Normal faults now offset the previous contractional tectonic structures along the watershed area and extend some tens of kilometres towards the Po Plain. West of the main divide, the normal faults border depressed areas, which extend longitudinally parallel to the Apennine chain. These elongated depressions have been prevailingly interpreted as graben or semi-graben (Martini et al, 2001 and references therein), even though an important control from contractional tectonic events on their evolution has been proposed by some authors (see, e.g., Boccaletti and Sani, 1998). The basin infill changes in age from Tortonian to Pliocene from the westerly (Tuscan-Tyrrhenian) to the easterly (intermontane) basins and the sediments change from marine to continental.

The mélanges of the Northern Apennines: a review

In the geological literature of the Northern Apennines, the block-in-matrix rocks of the Ligurian, Mesoligurian and Subligurian tectonosomes and the Epiligurian olistostromes together have been originally referred to as *argille scagliose* (literally "scaly clays"). This term was introduced in the 19th century to describe a peculiar characteristic of the clayey matrix, the scaly fabric. This term was later extended to include all the bodies with high stratal disruption and /or chaotic aspect (Merla, 1951; Maxwell, 1959), even to include the undoubtedly sedimentary bodies comprising rocks of Ligurian/Subligurian provenance interbedded within the well-bedded Tuscan and Umbria-Romagna foredeep successions.

The sedimentary bodies inside the layered foredeep successions were then later renamed *olistostromes* (Abbate et al., 1970), following Flores (1956). Olistostromes have been recognised also in normal bedded successions of the Ligurian, Subligurian and Epiligurian units (Abbate et al., 1970, 1981; Naylor, 1981; Pini, 1999 and references therein). The clayey matrix has a breccia-like appearance that is imparted by the presence of millimeter to sub-millimeter-size clasts of claystone and other types of rocks (brecciated texture). The scaly fabric also is present and it overprints, but not completely masks, the brecciated texture (Bettelli and Panini, 1985).

Terms such as caotico eterogeneo or Chaotic Complex have been favoured in the 70's and 80's to refer to the disrupted units of the Ligurian nappe. In turn, these new terms have also been extensively applied to the olistostromes in regional-scale maps (Boccaletti and Coli, 1982). Because a conceptual linkage with the olistostromes has always been maintained, the emplacement of the entire Ligurian nappe has been related to regional-scale slides, or gravitational nappe (Merla, 1951; Elter and Trevisan, 1973; De Jager, 1979; Pieri and Mattavelli, 1986, Van Wamel and Zwart, 1990; De Feyter, 1992). The stratal disruption of the chaotic complex of the Ligurian nappe has been considered the result of gravitational processes, or related to the strain caused by the translation of the gravitational nappe (Hsu, 1967; Abbate and Sagri, 1970; Page, 1978; De Feyter, 1992).

Recent investigations pointed out that the disrupted/chaotic masses can be distinguished in two groups: 1) units deriving from the pervasive deformation, up to the stratal disruption, of the ocean-floor sediments and the basal complex of the Ligurian units, as well as from the Mesoligurian and Subligurian units; 2) sedimentary bodies and masses deriving from diverse mass wasting processes which have a source from the rocks of group 1 and from the deposits of the Epiligurian, Tuscan and Umbria-Romagna successions.

The first kind of unit, the tectonosomes, are bodies that, notwithstanding a strong stratal disruption, still maintain their original stratigraphic coherency. These units are therefore mappable as single bodies which are characterized by common age and lithotypes. No exotic components have been documented in these units. The term tectonosome has been favoured, instead of more common terms, such as broken formation, to emphasize that the aspect at the outcrop is imparted by superposition of more deformational events of prevailingly tectonic origin, and these bodies include rocks that have different degrees of stratal disruption, from merely boudinaged to block-in-matrix fabric. A detailed study of these units outlines the different incremental steps of deformation, from the stage of wet, unconsolidated sediments to the anchizone through progressive consolidation of rocks. The contribution of mass wasting processes is often recognizable in the early phases of deformation.

The second group of mappable units and bodies, defined as olistostromes in this guidebook, are related to different en-mass sedimentary processes, such as submarine landslides, debris flows and avalanches. Depending on the prevailing mechanism of translation and emplacement, olistostromes display different fabric at the outcrops. Included bodies have different sizes: 1) tens of microns to millimetre-size microclasts always characterize the matrix (brecciated matrix), 2) centimetre to meters-size blocks are chunks of single beds, 3) slabs meters to tens of meters and even hundreds of meters (olistoliths) in size display bed packages, which maintain their original fabric from well bedded to completely stratally disrupted (tectonosomes).

Different textures are imparted by changes in the ratio of matrix/blocks/olistoliths. The end-members observed in the Apennines are: blocks and brecciated matrix with a different ratio (Type A), block-matrix assemblage supporting olistoliths (Type B), and assemblages of olistoliths without blocks and matrix (Type C). These end-members may be present in the same individual body and make gradual transitions. They represent different submarine mass wasting phenomena: type A and B are hyper-concentrated flows and cohesive debris flows; type C are debris avalanches and block slides.

Field itinerary

DAY 1

Topics: 1) the general setting of the Northern Apenninic chain, 2) the relationships among the Modino basal complex, the Tuscan nappe and Mt. Modino Sandstones, and 3) the style and significance of stratal disruption in the Modino basal complex.

Stop 1.1:

Panoramic view from Mt. Gomito.

Mt. Gomito is one of the most easily reached panoramic points along the main divide of the Northern Apennines. From here we shall have a panoramic view of a transect across the N. Apennine chain. The view to the north discloses the geological setting outlined in the two section A-A' and B-B' in Fig. 5.

To the northwest, a natural section along the north-south oriented watershed from Mt. Balzo delle Rose to Mt. Modino displays the direct superposition of the Modino unit on the entire Macigno succession. The interpretation of this geometrical superposition is still controversial, mostly because of the problematic stratigraphic relationship between the Mt. Modino Sandstones and the Macigno and the presence of a highly deformed level, the Modino basal complex (Fig. 7).

The Modino basal complex consists of an upper interval of middle Eocene-early Miocene age and a lower, apparently chaotic, body of Cretaceous-early Eocene age, which pertains to the Mesoligurian domain/units. The chaotic aspect is imparted by diffuse stratal disruption occurring with several degrees of internal strain up to block-in-matrix fabric. On the other hand, a certain internal organization can be outlined in the complex at both the outcrop and map scale. At the map scale, the older rocks are on the lowest part of the

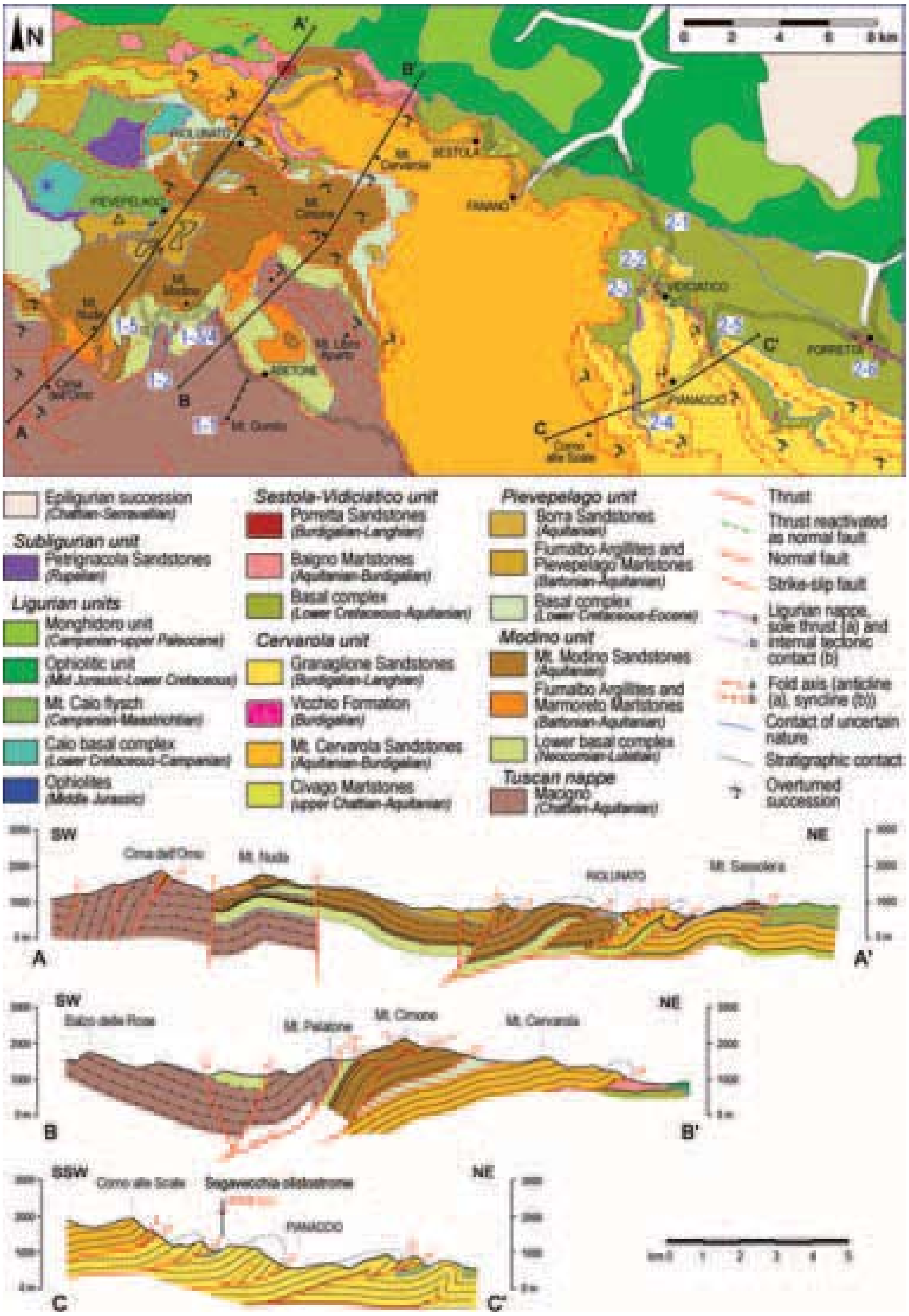

Figure 5 - Geologic map for days 1 and 2. Main sources: C.M. De Libero, Ph.D. Thesis, 1994; M. Chelli, Master thesis, 1998; Cerrina Feroni et al., 2002; Plesi et al., 2002.

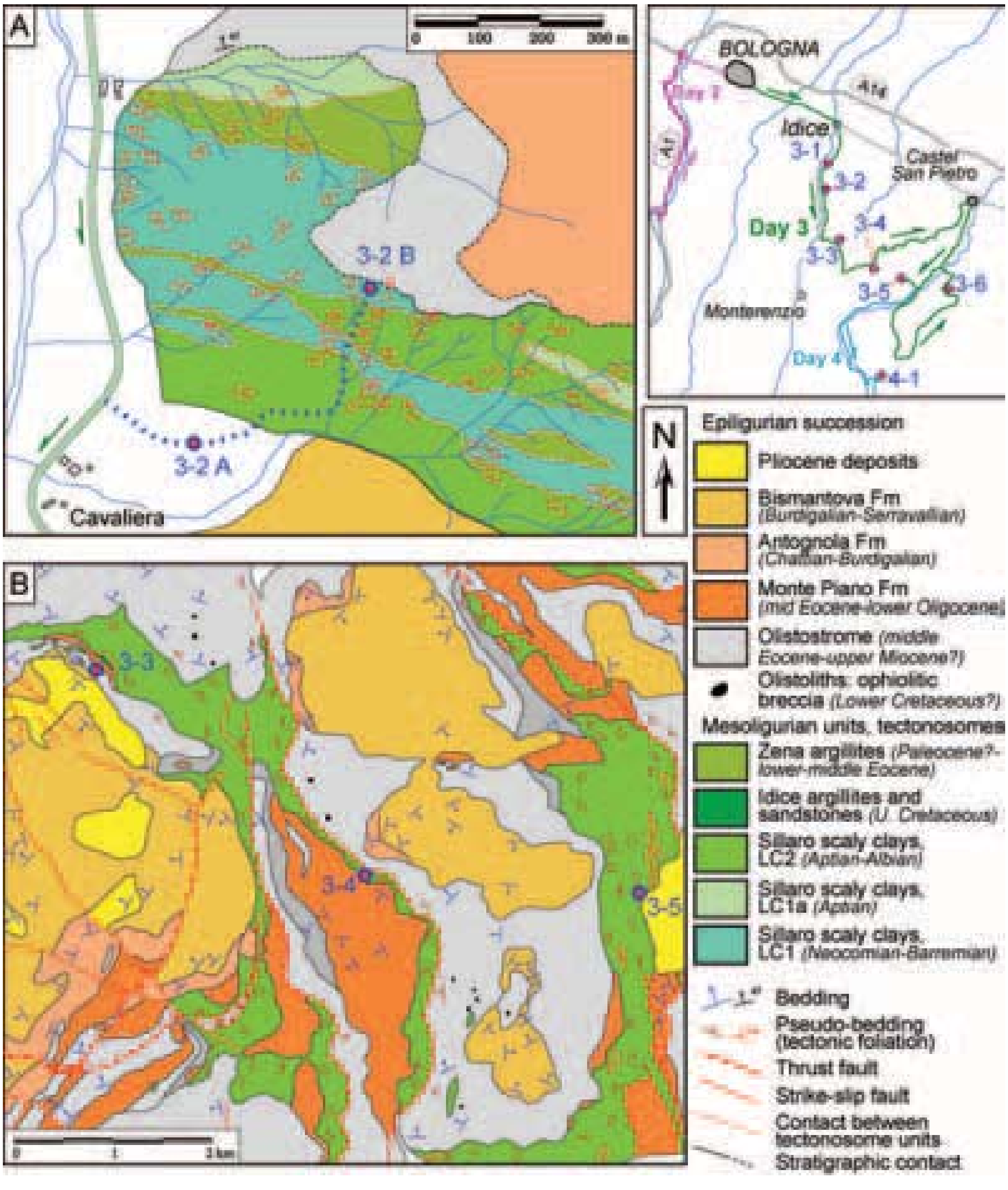

Figure 6 - Itinerary and geological maps for day 3. Map in B is from Pini, 1999, modified.

body and become progressively younger upward in all the studied sections (Chicchi and Plesi, 1992; Perilli, 1994; De Libero, 1998; Plesi et al., 2000). The different ages are associated with peculiar lithologic characters; thus, four different lithostratigraphic units can always be recognized and mapped (Fig. 7). The same ordered disposition is common in all the outcrops and confirms the interpretation of the body as a strongly deformed, but not completely disrupted stratigraphic succession (De Libero 1998 and references therein; Plesi et al., 2000).

The Mt. Modino Sandstones and the upper part of the Macigno share the same stratigraphic and sedimentological aspects (Bruni et al., 1994), and new dating

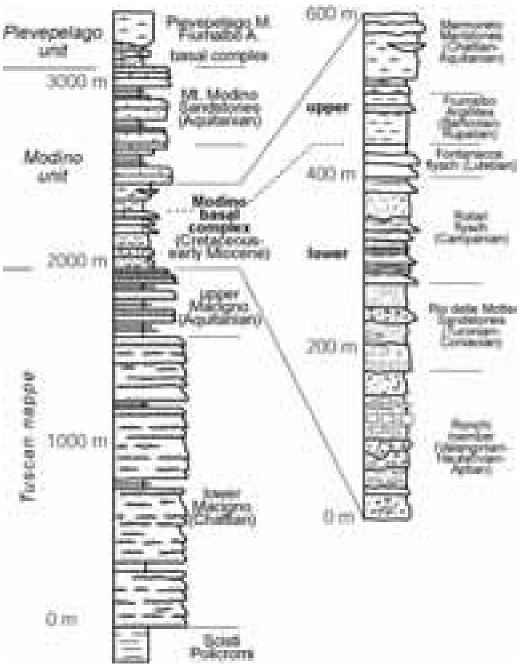

Figure 7 - Stratigraphy of the Macigno and Modino unit. Modified from De Libero, 1998

gave the same biozone (NN1-2 of Aquitanian age). Thus, the correct stratigraphic relationships between the two turbiditic successions cannot be discriminated and leaves the possibility of two discordant interpretations: 1) the Mt Modino Sandstones correspond to the continuation of the sedimentation of Macigno, after the emplacement of the Modino basal complex. The latter is regarded as a large submarine landslide in this interpretation (olistostrome hypothesis, Bruni et al., 1994 and references therein). 2) The Modino unit is a structural unit, which was first set up by deposition of slope deposits (the upper part of the basal complex) and basin plain turbidites (Mt. Modino Sandstones) on an already deformed portion of the Mesoligurian units (the lower basal complex). Than, these units together thrust over onto the top of the Macigno succession (tectonic hypothesis, De Libero, 1998 and references therein; Plesi et al., 2000).

The Pievepelago unit share several lithostratigraphic aspects with the Modino unit: the basal complex is partitioned in a lower interval of Mesoligurian origin and an upper interval made up of middle Eocene-early Miocene slope deposits (Fiumalbo Argillites and Pievepelago Marlstones). The latter passes upward to a turbiditic succession, the Borra Sandstones, comparable in age and composition with the Mt. Modino Sandstones (Figs. 4 and 5).

On the northeast (section B-B') the first mountain ridge (Mt. Libro Aperto-Mt. Pelatone) is the morphological evidence of an anticline of Macigno, the northern, overturned limb of which is in tectonic contact with the Modino unit. The Modino basal complex crops out immediately north of the Libro Aperto-Pelatone ridge, but the most evident structural and morphological element is Mt. Cimone, the highest peak of the Northern Apennines, which is made up of an upside-down succession of Mt. Modino Sandstones.

In this section, the normal superposition of the Modino unit onto the Macigno, whatever is the interpretation, has been complicated by the onset of younger thrusts. The upside-down setting of the Modino unit can be related to a large scale fold, possibly associated to thrusting (Mt. Libro Aperto-Mt. Pelatone anticline?). The overturned element of Mt. Cimone lies over the Pievepelago unit, reversing the normal order of superposition. Notably, the Pievepelago unit is also upside-down and this may suggest that the entire system of structural units has been overturned. In turn, this entire system thrusts over onto the upright succession of the Mt. Cervarola Sandstones, Cervarola unit, the internal setting of which will be discussed in detail on Day 2.

Normal faults offset this part of the chain and reactivated some of the thrust surfaces. Normal faults become more and more abundant and their displacement increases southwest-ward. They are related to the onset of the Garfagnana valley graben, one of the intermontane graben. In the case of Garfagnana, the extensional activity has been also related to the uplift of the Apuane Alps metamorphic complex (metamorphic core?) (Fig. 1). Active seismicity indicates that the activity of the normal faults is ongoing nowadays.

Stop 1.2:

Canalone di Ronchi, Tagliole valley.

The stop is at 15 minutes walking from the paved road. The contact on the Macigno and a large section of the lowest part of the Modino basal complex is observable in a small canyon (Fig. 8). This contact has been interpreted in two different ways, according to the aforementioned two general interpretations: the base of a sedimentary body from mass wasting or a shear zone at the base of a tectonic unit.

The Macigno shows a general decrease in stratal continuity up to the contact. Beds become pinched –and-swelled and lens-shaped at the scale of the outcrop

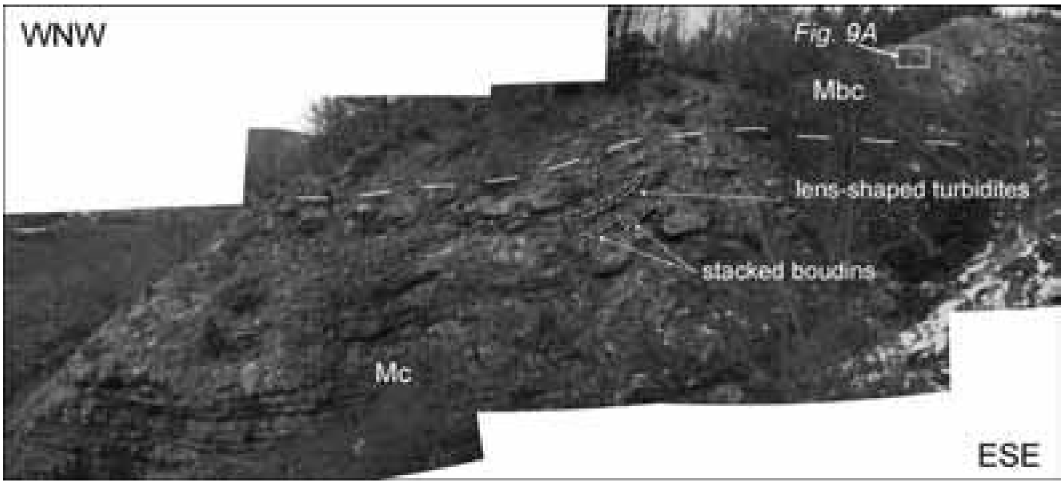

Figure 8 - Panoramic view of the contact between Macigno (Mc) and Modino basal complex (Mbc).

(Fig. 8). In the right side of the outcrop, a single bed seems to be boudinaged and the boudins imbricated (stacked). The style of structures seems compatible with the deformation of wet, non-consolidated sediments.

Brittle deformation occurs with calcite-filled veins and mesoscopic faults and seems to overprint the mesoscopic ductile structures. The presence of the latter is not by itself proof of a sedimentary origin of the contact (olistostrome hypothesis) instead of an origin from tectonics. A wet-sediment deformation can be related to both mass wasting and shallow level tectonic processes. However, some of the lens-shape beds are coarse-grained, thin bedded turbidites, and their aspect may be an original sedimentary feature. They may be interpreted as a turbiditic layer covering the irregular surface of a slump body and filling some small depressions. Thus, the disturbed beds in Fig. 8 could be related to a slump that occurred before the emplacement of the Modino basal complex.

The lowest part of the Modino basal complex, the Ronchi member, shows in general a block in matrix fabric (pebbly mudstone)(Fig. 9A), with blocks ranging in dimension from some meters to less than

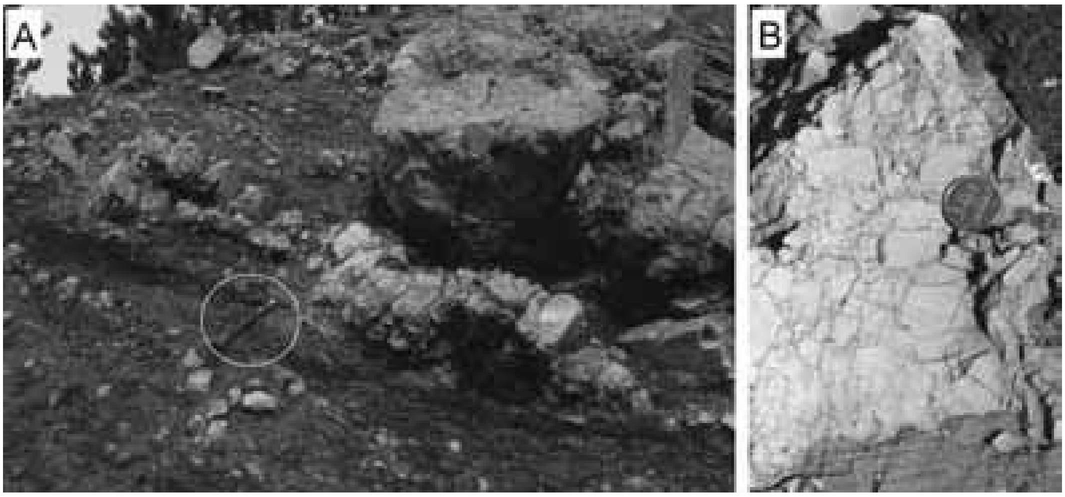

Figure 9 - Details of the Ronchi member of the Modino basal complex: A) alternation of debris flows bodies and boudinaged limestone beds and B) details of the in-situ brecciation of the fine-grained interval of a calcareous turbidite bed. The lower part of the photograph shows the laminated, calcarenitic interval of the turbidite (B from C.M. De Libero, Ph.D. thesis, 1994) .

a millimetre enclosed in a clayey matrix (brecciated matrix). A similar fabric is typical of the Apennine olistostromes of different units and setting (Abbate et al., 1981) and has been interpreted as typical of cohesive debris flows.

Blocks are made up prevailingly by micritic limestones and calcarenites, both massive and laminated, which are remnants of carbonatic turbidites (Fig. 9B). Some blocks are fragments of conglomerates and breccia horizons and contain micritic limestones, calcarenites, and green cherts (diaspri) as clasts. The age of limestone and calcarenite blocks and of the matrix is the Hauterivian-Valanginian (Perilli, 1994).

At the scale of the entire outcrop, a pseudo-bedding imparted by alignment of the clasts and pinch-and-swelling and boudinage of calcareous beds develops grossly parallel to the basal contact. The limestone beds are lens-shaped and have a lateral continuity of some meters. They are completely enclosed in pebbly mudstone levels, that is, in debris flow deposits (Fig. 9A).

The micritic limestones of the lens-shaped beds are brecciated having rounded to sub-angular clasts in a matrix composed of the same limestone (Fig. 9B). This texture may be related to in-situ brecciation of partly consolidated limestones (C.M. De Libero, Ph.D. thesis, 1994). On the contrary, the smaller clasts of micritic limestones inside the pebbly mudstones have a rounded shape and do not show any kind of brecciation.

The upper part of the outcrop is characterized by the presence of large, two meters thick, calcarenitic blocks and slabs of strongly deformed bed packages. The latter consist of an alternation of calcareous turbidites and green and black argillitic beds (Ronchi argillites and limestones, Ronchi a-l).

As a general interpretation of this lowest level of the Ronchi member, the single lens-shaped, pinched-and-swelled calcareous beds in between the debris flow deposits may correspond either to: 1) an original intercalation of debris flows and turbidites that have been altogether layer-parallel extended (boudinaged), or 2) the continuous beds are the remnants of the original stratigraphic succession preserved during stratal disruption leading to block-in-matrix rocks (pebbly mudstones). The same two interpretations can be extended to the presence of boudinaged slabs of Ronchi argillites and limestones.

The clayey matrix is deformed by anastomosing cleavage planes, which split the matrix in centimetre thick splinters (scaly fabric). Its pervasiveness and spacing outline domains of different deformation. Considering the entire outcrop, the scaly fabric is oriented grossly parallel or at a low angle with respect to the basal contact, but at a closer view it commonly changes in orientation with respect to the pseudo-bedding. This may be related to phenomena of diffraction related to the large blocks/layers.

Also the calcareous turbidite beds are offset by a system of calcite-filled veins of different thickness and by pressure-solution joints, which clearly overprint the structures of brecciation and are therefore related to later stage(s?) of deformation.

Stop 1.3:

Panoramic view from the Strada del Duca, Tagliole-Scoltenna watershed.

The panoramic view shows the geologic setting at the top of the mélange. The upper Cretaceous (middle-upper Campanian) Rotari flysch crops out in the lowest part of the La Fiancata-Mt.Modino slope shown in Fig. 10. This stratigraphic layer is similar in several respects to the Ligurian Helmintoid flysch, including the age and the same association of siliciclastic, carbonatic and mixed turbidite beds, as well as the presence of ophiolite-sourced turbidites and conglomerates (Fontana et al., 1995). The beds are pinch-and-swelled and folded with a mesoscopic ductile style suggesting that the deformation mostly occurred in wet, non- or partly consolidated rocks. The Rotari flysch is the topmost member of the lower part of basal complex in this section, and crops out below a sequence of Cenozoic rocks, which is the upper part of the complex. The latter consists of the middle Eocene-lower Oligocene Fiumalbo shales and the lower Oligocene-lower Miocene Marmoreto Marlstones, which are slope deposits. The Fiumalbo shales have been dated here at the lower Oligocene (NP21) and are characterized by severe folding that occurred when the rocks were not consolidated and which is possibly related to mass wasting phenomena. They make an abrupt transition to lower Miocene (NN1-2) slope deposits of the Marmoreto Marlstones. The slope deposits host two lens-shaped sandstone bodies representing the filling of small-scale channels (Fig. 10) and bodies of debris flows with Mesoligurian (Ronchi member and Rotari flysch) blocks and clasts inside a matrix composed of Marmoreto Marlstones. Moving upward, there is a thick level of this debris flow, the age of matrix of which is late Oligocene (NP25B). Above this interval, the age is early Miocene (NN1-2) and the Marmoreto Marlstones make a gradual transition to the Mt. Modino Sandstones through the progressive upward increase of thickness

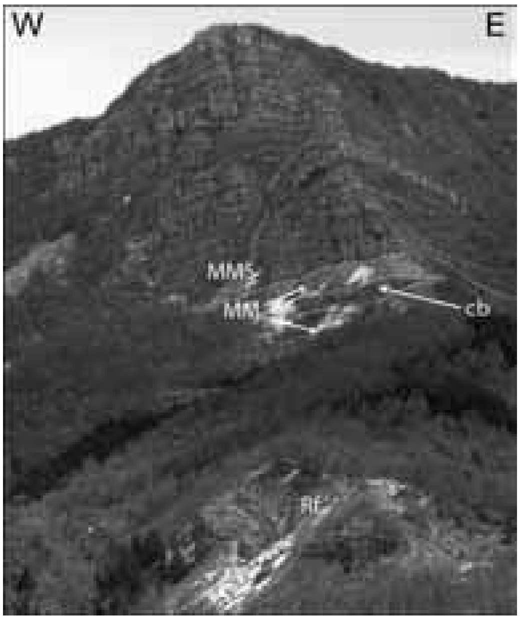

Figure 10 - Panoramic view of the la Fiancata-Mt. Modino slope (MMS=Mt. Modino Sandstones; cb=chanalized bodies; MM=Marmoreto Marlstones; Rf=Rotari flysch).

of turbidite beds.

These depositional conditions and the dating cannot help to discriminate between the olistostrome and the tectonic-unit hypotheses. They only suggest that the lower part of the Mt. Modino Sandstones have been deposited on an early Miocene, quite unstable slope, characterized by slides and slumps and by debris flows recycling the rock of the lower Modino basal complex.

Stop 1.4:

Outcrop along the Strada del Duca,
Tagliole-Scoltenna watershed.

Here it is possible to see the relationships among two different levels of debris flows (Fig. 11). The two bodies can be easily distinguished because of different composition of matrix and clasts and the matrix/clasts ratios. The upper debris flow body is composed mostly of calcarenitic clasts in a dark-grey argillite matrix. This body passes upward to an olistolith of disrupted calcarenites in varicoloured argillites (Ronchi a-l?). The lower debris flow body has a brown matrix enclosing clasts and bed chunks of limestones, calcarenites and clast-supported conglomerates/breccia. The contact between the two bodies is marked by a large calcarenite block that sunk from the base of the upper debris flow into the top of the lower (Fig. 11). This suggests that the two debris flow bodies were stratigraphically superposed at the origin.

Some blocks of the conglomerates are observable some metres south of the contact in Fig. 11; the clasts are made up of micritic limestones, calcarenites, dolomites, dolomitic limestones, green cherts, siltstones. Similar conglomerates crop out in large lenses south of stop 1-3 and include also clasts of rhyolites. The age of clasts varies from Triassic to early Cretaceous (Perilli, 1994). The source area of part of these clasts (rhyolites, dolostone) has been considered to be a continental margin, possibly the margin of Adria microplate.

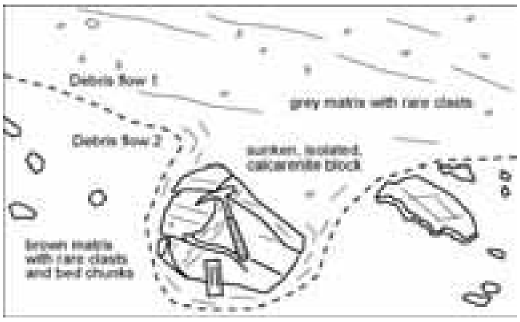

Figure 11 - Sedimentary contact between two debris flow bodies marked by a calcarenite block sinking in the lower

Stop 1.5:

Fosso delle Màcine, Tagliole valley.

We shall walk upward along a steep small canyon cut inside the Ronchi member of the lower basal complex. Here the presence of different bodies of debris flow is marked by thin levels of normal pelagic sedimentation, which consist of alternating levels of black/dark-grey and green argillites (Ronchi argillites)(Fig. 12A).

The debris flows bodies show the classic block-in-brecciated-matrix fabric. We shall observe several examples of debris flow bodies with different clast/matrix ratio climbing up along the Màcine creek. Moreover, some blocks have been plastically deformed possibly during mass transport and deposition (Fig.12B). The pelagic sediments have been also strongly deformed when wet and non-consolidated (slumping?) giving the observable pinch-and swell structures and the isoclinal folds (Fig. 12A). The argillite layers of this section have not been dated yet, but they are

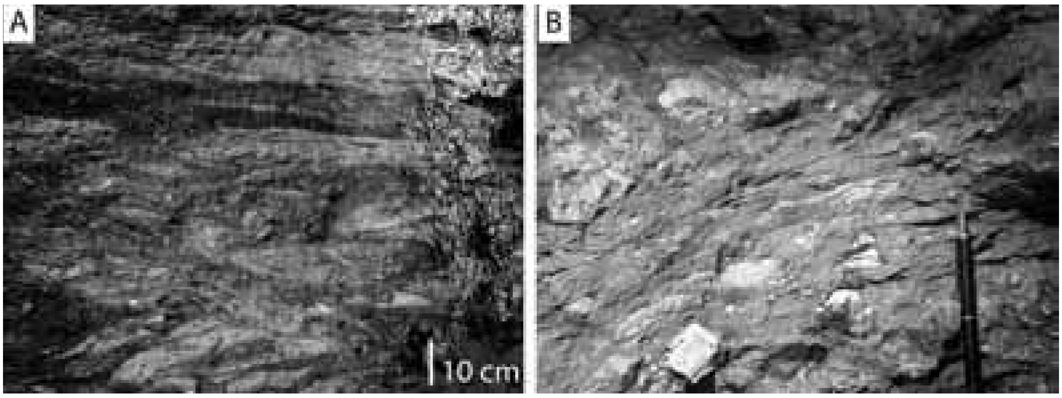

Figure 12 - Details of the Fosso delle Màcine succession. A) wet-sediment (slumping?) deformation in the Ronchi argillites; B) fluidal structures (?) deforming clasts in the Ronchi debris flow.

very similar as facies and mineralogical association to the varicoloured argillites of the Ronchi a-l of the Ronchi-La Fiancata succession (stops 1-2 and 1-4), that are of Early Cretaceous age (Valanginian-Hauterivian) (Perilli, 1994; De Libero, 1998).

Bed packages of Ronchi argillites and limestones crop out at the end of our itinerary. Limestone beds are pinched-and-swelled and affected by calcite-filled veins and fractures, which develop mullion-like structure with the bedding surfaces.

Bed packages of the same unit are present also in the lower part of the succession, but they are badly cropping out here. These levels display different degrees of internal deformation; in some cases stratal disruption by boudinage and folding of wet sediments increases up to block-in-brecciated-matrix fabric. This transition is gradual and occurs in a direction parallel to the sedimentary contacts. This can be considered an example of lateral transition from slumping to debris flow (De Libero, 1998).

There are two notable points worth stressing in this and the other outcrops of day 1. First, mass wasting deposits and deformations are quite abundant in the Modino basal complex, especially in the Ronchi member (stops 1-2, 1-4 and 1-5). A wide diffusion of deformation by mass wasting has been described in all the lower Cretaceous Ligurian and Subligurian successions in the Apennines. They have been interpreted as related to slope and basin instability in a passive margin setting (Naylor, 1981). However, contractional tectonics cannot be excluded; some of the more recent plate tectonic reconstructions display an active subduction in the Ligurian-Piedmont ocean in early Cretaceous time (Schettino and Scotese, 2002). As far as the mass wasting deposits and deformations in the upper Cretaceous units are concerned (Fig. 7), they may have been triggered by basin instability related to the eoalpine (late Cretaceous) tectonic phases.

As a second important point, post-depositional deformations took place together with compaction/ consolidation and diagenetic evolution of rocks. In the Ronchi member, a first stage of extensional flattening of partly consolidated rocks, e.g. the carbonate in-situ breccia of stop 1-2, can be related to either mass wasting or shallow level tectonic processes. The latter are responsible for systems of calcite-filled veins, mullion-inducing fractures and pressure solution joints/cleavage in the limestones and the scaly fabric in the clayey matrix/ argillites. Scaly fabric gave rise to a significant loss in water content due to dynamical compaction of clays and is indicative of deformations in a submarine accretionary wedge (De Libero, 1998 and references therein).

The upper Cretaceous-lower Eocene rocks have not been as strongly deformed as the Ronchi member. We think that the upper Cretaceous units were deposited on the instable external part of a late Cretaceous accretionary wedge (eoalpine phases), in which the Ronchi member was deforming (offscraping). The units of the lower Modino basal complex together have been deformed in a lower-middle Eocene tectonic phase, as suggested by the clear cut separation at the base of the Fiumalbo argillites, which seems to have been deposited unconformably onto the structures of the (meso)Ligurian accretionary wedge. The presence of a quite evident unconformity of middle Eocene age is a regional-scale, constant element in the geology of the northern Apennines and marks the end of the meso-alpine tectonic phase, at the base of the Epiligurian sedimentation (Ricci Lucchi, 1986 and references therein).

DAY 2

Topics: 1) the structural setting of the chain immediately north of the main divide, with special regards to the relationships between the Ligurian, Cervarola and Sestola-Vidiciatico units; 2) the Segavecchia olistostrome and the interpretation of the Sestola-Vidiciatico unit (tectonic unit or olistostromal complex?); 3) the fabric of strongly tectonically deformed olistostromes.

Stop 2.1:

Km 22 on national road 324, Panaro valley.

The panoramic view looking to the west shows, from left to right: the thrust splays of upside-down Mt. Modino Sandstones (Mt. Cimone) thrust over the Pievepelago unit, the Cervarola unit which underlies the Pievepelago unit and is, in turn, in tectonic contact to the north with the Sestola-Vidiciatico unit (Fig. 5, section B-B'). The Cervarola unit is arranged in a system of folds and imbricated thrusts, which derive from the evolution of fault-propagation folds. Different levels of evolution are observable, from close to tight, moderately inclined folds to tight to almost isoclinal, gently inclined folds. The latter are characterized by shear zones and faults offsetting the hinge zones of both the anticlines and synclines. The northern limbs of the folds are everywhere overturned and, in the case of more highly deformed structures, are dipping at low angles and flattened.

The decollement level of the structure observable in the field is localized inside the slope deposits at the base of the Mt. Cervarola Sandstones (Scisti Policromi and Civago Marlstone). Seismic data and wells show that a complete Umbria-Romagna-type carbonate-clastic, carbonatic and evaporitic succession is present below this decollement level (Anelli et al., 1992).

The Cervarola unit cropping out in this sector of the chain consists of Mt. Cervarola and Granaglione Sandstone formations of early Miocene (Aquitanian-Burdigalian) and middle Miocene (Langhian) ages, respectively. These formations therefore represent a younger stage of the foredeep complex than the Macigno.

The Sestola-Vidiciatico unit is made up of Ligurian-Subligurian stratally disrupted rocks and of debris flow bodies. The Ligurian-Subligurian rocks are the same as the Modino basal complex (Plesi et al., 2002). The debris flows are prevailingly composed of the same rocks. Some blocks and bodies of younger, early Miocene (Aquitanian) marlstone (Civago Marlstones) are present within the unit. The Sestola-Vidiciatico unit has been considered as either a tectonic unit or a large-scale mass wasting deposit. Whatever is the interpretation, as in the Modino case, slope deposits of Burdigalian age (Baigno Marlstones) and a turbiditic sedimentation of Langhian-Serravallian age (Porretta/Brasimone Sandstones) occurred on top of the "chaotic" unit.

Stop 2.2:

Panoramic view from the local road to Vidiciatico, Panaro-Silla watershed.

The panoramic view from this point discloses the regional-scale structural relationship among Sestola-Vidiciatico, Cervarola and the Ligurian nappe. Looking southeast, we are facing large anticlines separated by thrust surfaces deforming the Granaglione Sandstones. The anticline axes are gently plunging to the northwest and deform also the primary contact of the Sestola-Vidiciatico unit with the underlying Cervarola unit. The large outcrops of Granaglione Sandstones completely surrounded by rocks of the Sestola-Vidiciatico units, which are observable to the southeast and to the north, are the expression of the crests of some of these anticlines (Fig. 5). In some cases, at the front of the anticlines and thrusts, the Sestola-Vidiciatico unit lies below the Granaglione Sandstones, with an inversion of the original contact. We shall observe this contact at stop 2-5.

The Sestola-Vidiciatico basal complex is prevailingly composed of pebbly mudstones (debris flow deposits), which host slabs of Ronchi member, Rio delle Motte Sandstones, Fiumalbo Argillites and Marmoreto Marlstones of the Modino basal complex (Plesi et al., 2002). Some large slabs of the lower Miocene Civago marls are also present in the unit. One of these large bodies crops out along the contact between the Granaglione Sandstone and the Sestola-Vidiciatico unit. This body is prevailingly made up of fine-grained, thin-bedded turbidites which have been highly deformed when non- or poorly consolidated. They have been interpreted as slope sediments associated with the Cervarola/Granaglione basin(s?). Some authors consider the Civago Marlstone as the stratigraphic base of the younger, Aquitanian, Cervarola Sandstones. We shall have a closer view of this body on stop 2-3.

Notably, some slabs of rocks of Burdigalian age crop out in the Sestola-Vidiciatico basal complex and uncomformably lie on the Granaglione Sandstones. They everywhere display a stratigraphic succession with cherty marlstone in the lower part and glauconitic calcarenites at the top. These slope to shelf deposits are quite similar as age, composition and stratigraphy to the Vicchio Formation, which is the stratigraphic cover of the Mt. Cervarola Sandstones in its south-western area of exposure.

Stop 2.3:

Outcrops along the Mt. Corno alle Scale road, Silla valley.

The stop shows the relationships among the debris flow bodies, the disrupted bed packages of the Ronchi member and the Civago Marlstones of the Sestola-Vidiciatico unit. On the left side of the road cut in Fig. 13A, a sharp contact separates the Civago Marlstones from a block-in-matrix fabric assemblage of rocks. The sharp contact is not entirely outlined by brittle tectonics structures, such as striations and calcite veins, and follows a complicated and sinuous trend.
As for the disrupted rocks, they show two different fabrics: the part at the right has a block-in-matrix fabric, with small and almost isodiametric blocks randomly disposed in a brecciated matrix, which can be interpreted as a debris flow deposits (Fig. 13A). To the left, some layers of limestones have been boudinaged and pinched-and-swelled in a matrix that came from deformed argillite beds with a pervasive scaly fabric (Fig. 13B). The contact with the debris flow deposits is gradual and the scaly fabric disappears in the debris flow. This deformation seems independent from the contacts with the other components of the outcrop, and therefore should have occurred before the slab had been enclosed in the observable assemblage. We interpret this bed package as a slab (olistolith) of stratally disrupted Ronchi argillites and limestones included in a debris flow. The strongly boudinaged beds have an asymmetric, ⇑-type shape; this feature suggests that a simple-shear induced boudinage occurred in almost completely consolidated rocks. Deformation may be related to the same eo-mesoalpine tectonic phases suggested for the Modino lower basal complex.
The complicated trend of the contact between the debris flow body and the Civago Marlstones, as well as the intense slump folding of the latter observable in a steep cliff on the other side of the road, suggests multiple mass wasting episodes.

Stop 2.4:

Segavecchia hut and olistostrome, Silla valley.

We shall leave the bus at the Segavecchia hut and walk for 15/20 minutes along a forestry road to reach a couple of extensive outcrops of the Segavecchia

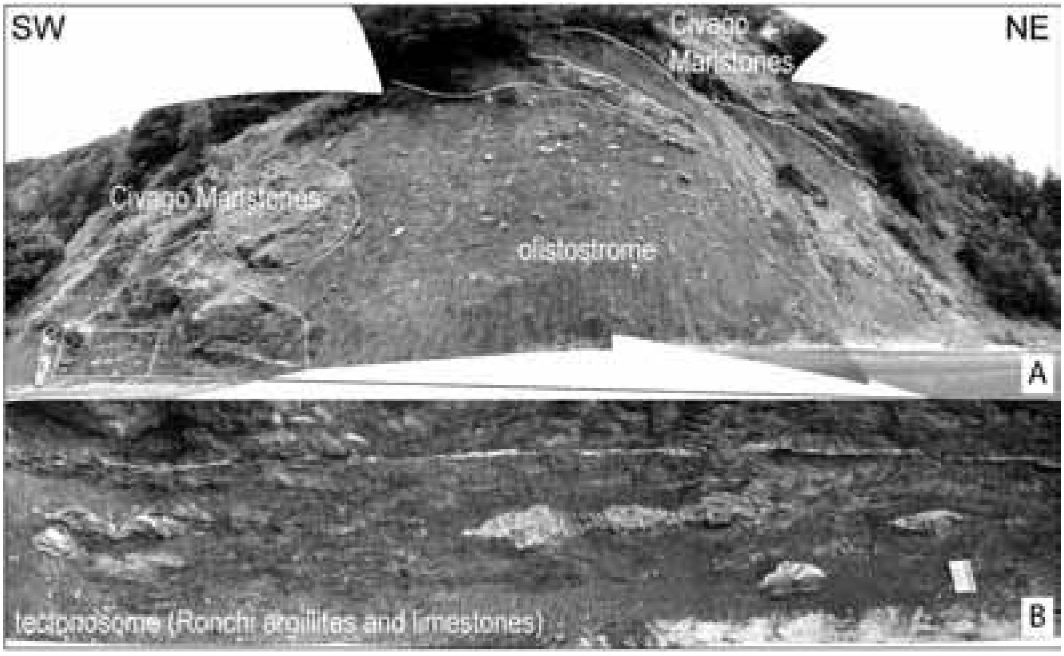

Figure 13 - General view of Stop 2-3 (A) and close-up on an olistolith of stratally-disrupted Ronchi argillites and limestones (B)

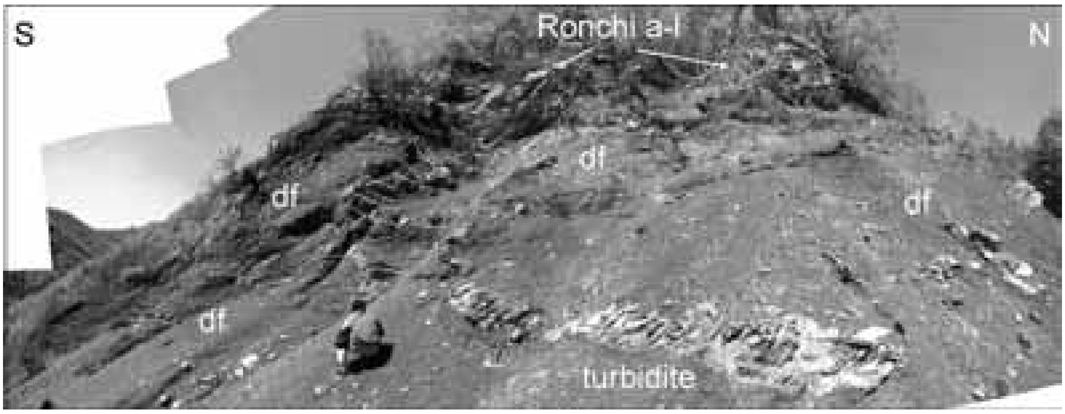

Figure 14 - Panoramic view of the lower outcrop of Stop 2-4 (Ronchi a-l = Ronchi argillites and limestones; df = debris flows deposits).

olistostrome in a small gully. The Segavecchia olistostrome is directly connected with the Sestola-Vidiciatico unit (Fig. 5) and shares the same composition (Modino lower basal complex).

Slabs of bed packages of the varicoloured argillite with calcareous turbidite beds of the Ronchi argillites and limestones and of the Rio delle Motte Sandstones are dispersed as floaters (olistoliths) in a predominant block-in-matrix assemblage (Figs. 14, 16). This assemblage has meter to some centimetres-sized blocks of limestones, calcarenites, sandstones, shales and argillites, dispersed in a clayey matrix of dark grey to black colour. The matrix is typically brecciated and includes clasts from a centimetre to less than a millimetre.

A typical feature is the graded sandstone/siltstone levels that have a lateral continuity of tens of meters inside the prevailingly pebbly mudstones (Fig. 14). At a closer view and in thin sections (Figs. 15A, B) these levels are in vertical continuity with the pebbly mudstones, as shown by the dispersion of small clasts of the matrix inside the arenitic interval of the turbidites. Notably, the upper part of the turbidites is strongly affected by bioturbation, indicating that these levels were exposed at the water/sediment interface for a while.

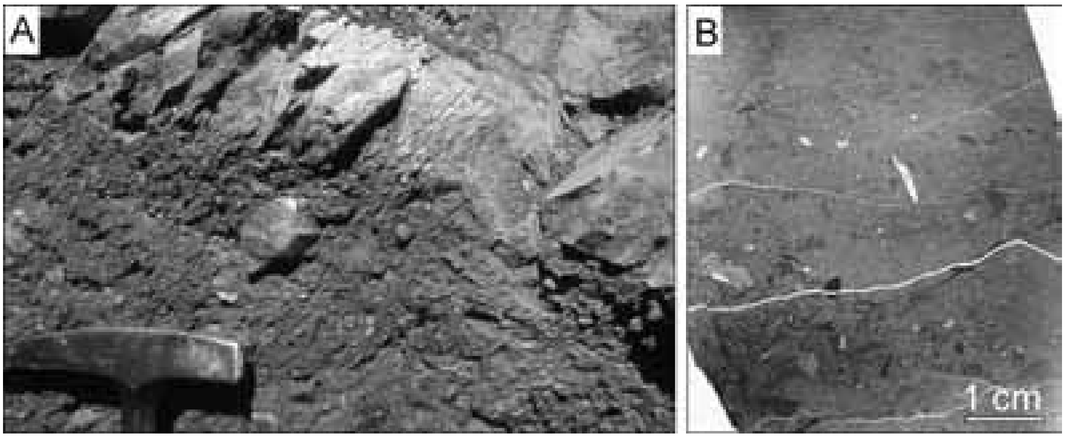

Figure 15 - Details of Fig. 14: A) transition debris flow-turbidites; B) transition debris flow-turbidite in thin section

The turbidites are folded and pinch-and swelled in the right part of the lower outcrop (Figs. 15A and front cover). The folds can be related either to slumping of the entire succession of debris flows, immediately after their deposition, or to the internal deformation related to the emplacement of the Sestola-Vidiciatico unit. In any case, deformation occurred in non-consolidated materials. A spaced but pervasive cleavage

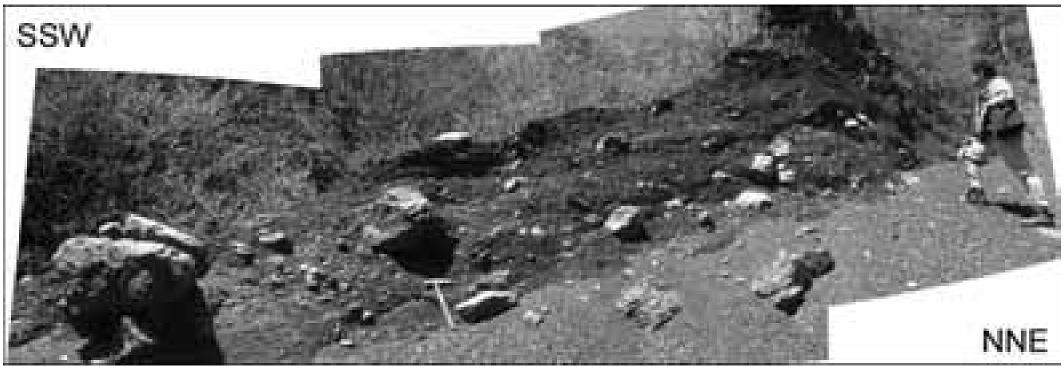

Figure 16 - Debris flow bodies in the upper outcrop of Stop 2-4. A parallel disposition of the more elongate clasts is evident and may correspond to flow and/or compaction features.

deforms both the pebbly mudstones and the turbiditic layers. This cleavage occurs parallel to the thrust surface, which repeats part of the succession of the Granaglione Sandstones and takes place onto the top of the olistostrome (map and section C-C' in Fig. 5). The basal contact of the olistostrome, observable in some points along the riverbed, is of sedimentary nature.

As far as the regional geological setting is concerned, the Segavecchia olistostrome is directly connected with the main body of the Sestola-Vidiciatico unit. It may represent either the lower part of the unit, or a debris flow body interposed between the Sestola-Vidiciatico and the Cervarola units.

Stop 2.5:

Porchia village, Silla valley.

This outcrop shows the apparent inversion of the contact between the Sestola-Vidiciatico unit and the Granaglione Sandstones. The turbiditic succession is upside-down and the deformation increases northward approaching the contact. Deformation is recorded by faults, fractures and large calcite-filled veins, which may be related to fluid overpressure. At the contact some beds of the Granaglione Sandstones are folded in an overturned syncline, the hinge zone of which is observable in the upper part of the outcrop (Fig. 17).

A strongly folded and boudinaged bed package of the Rio delle Motte Sandstones is at the base of the Sestola-Vidiciatico unit in the lower part of the outcrop. Therefore, the contact with the Sestola-Vidiciatico unit is not quite evident.

The Rio delle Motte Sandstones pass upward and northward to a pebbly mudstone (debris flow deposits) enclosing a large slab of marlstone, which can be tentatively attributed to the Civago Marlstones. Walking northward we shall observe alternations of debris flow deposits and pinch-and-swelled, boudinaged and folded bed packages (tectonosomes) of Rio delle Motte Sandstones and of Ronchi a-l (Fig. 17). The structures and pseudo-bedding in the tectonosomes develops at different angles with respect to the main contact with the Granaglione Sandstones and to the internal contacts with the debris flows. Stratal disruption is associated with a penetrative and pervasive, closely spaced scaly cleavage, which is folded together and follows the pseudo-bedding in the tectonosomes (Fig. 17). In some cases, as in the Ronchi a-l unit, it overprints a plane-parallel cleavage that can be interpreted as an early-stage compaction cleavage.

A second system of more spaced and less penetrative scaly cleavage offsets and crenulates at different angles the first scaly cleavage. It everywhere has the same attitude as the main contact. It is also present in the debris-flow bodies and becomes less pervasive going far from the main contact.

As a general interpretation, the internal organization of the Sestola-Vidiciatico seems to have been acquired before its emplacement onto the Granaglione Sandstones. The thrusting of the latter over the Sestola-Vidiciatico unit originated from the overturning of the original contact as a part of the upside-down flank of a fault-propagation fold (Fig. 5, section C-C'). This structure is responsible for the onset of the more spaced scaly fabric in the Sestola-Vidiciatico unit and for the limited deformation of the Granaglione Sandstones at the main contact.

Stop 2.6:

Panoramic view from the national road 64, Reno valley.

From this point we can appreciate the setting of the

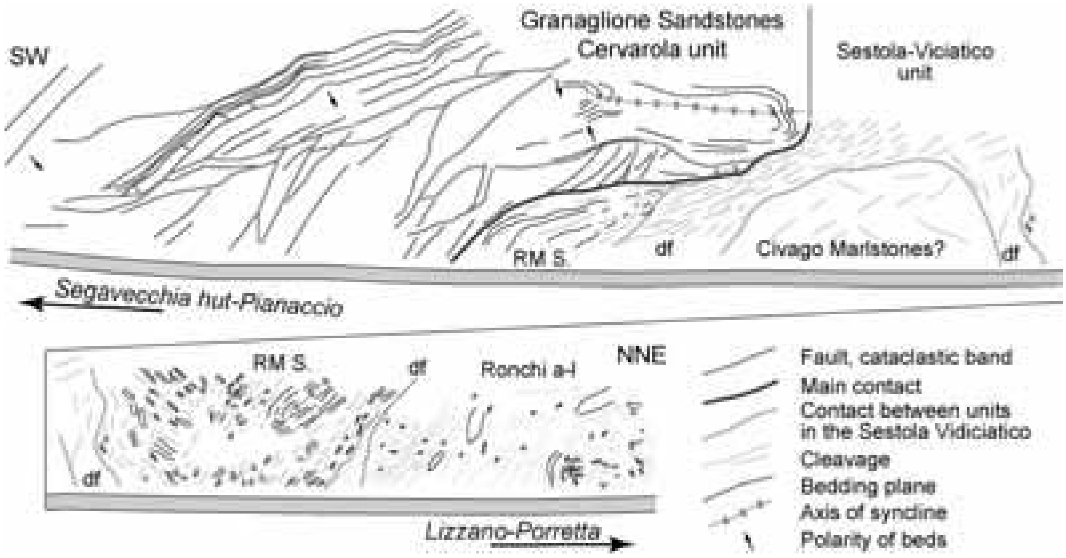

***Figure 17** - Interpretation of the contact between the Granaglione Sandstones and the Sestola-Vidiciatico unit (RM S. = Rio delle Motte Sandstones; df = debris flow deposits; Ronchi a-l = Ronchi argillites and limestones).*

Baigno Marlstones (Burdigalian) and the Porretta Sandstones (Langhian). The latter dip north at a very high angle and are covered by a further level of the basal complex, which has the same composition and internal setting of the lower body. The nature of this contact is not clear yet, due to the lack of good outcrops. The lower contact is sedimentary and the sandstones lies unconformably on the Baigno Marlstones, which show strong deformation of wet, non-consolidated sediments. A further unconformity marks the contact between the Baigno Marlstones and the basal complex.

As a general consideration on the Sestola-Vidiciatico basal complex, the tectonosome slabs (olistoliths) are chaotically distributed and completely surrounded by debris flows deposits. For these reasons and the high diffusion of debris flows bodies in the entire Sestola-Vidiciatico basal complex, even in its highest portion below the normal bedded sediments, we favour the interpretation of this unit as a sequence of early Miocene submarine landslides, including already deformed Mesoligurian rocks and slope deposits from both the lower and upper Modino basal complex. The presence of Miocene slope-shelf sediments of the Tuscan domain (Civago Marlstones and Vicchio Fm), together with Modino basal complex units, is one of the more intriguing aspects of the Sestola-Vidiciatico unit, showing that these units were exposed at the basin floor in some relative high position (slope?) at the front of the Ligurian nappe.

DAY 3

Topics: 1) the setting of the Ligurian units and the Epiligurian succession; 2) mechanisms of stratal disruption in the early Cretaceous tectonosomes; 3) fabric and setting of olistostromes of the Epiligurian and Umbria-Romagna successions; 4) micro-mesoscopic structures and mineralogical characteristics of the scaly clays.

Stop 3.1:

Castel dei Britti village, Idice valley.

We shall have a panoramic view of the Miocene-Pliocene deposits of the Epiligurian succession and discuss the general setting of the Apennines-Po Plain margin. The most evident rocks cropping out on the western side of the Idice Valley are the Messinian evaporites. The thick beds are some of the evaporitic cycles related to the salinity crisis of the Mediterranean sea (Krijgsman et al., 1999), which can be traced all along the Apennines margin, in some of the Tuscan graben and in Sicily. In the Po Plain side of the Northern Apennines, the evaporites are present both in the Umbria-Romagna succession and in the Epiligurian sequences and are characterized by both in-situ primary evaporitic gypsum (selenitic gypsum) and by resedimented gypsum covering a wide spectrum of processes ranging from block slides to turbidites (Vai and Ricci Lucchi, 1977; Roveri et al., 2001). The gypsum beds are a part of a late Oligocene-Pliocene succession dipping at high angle to the north and un-

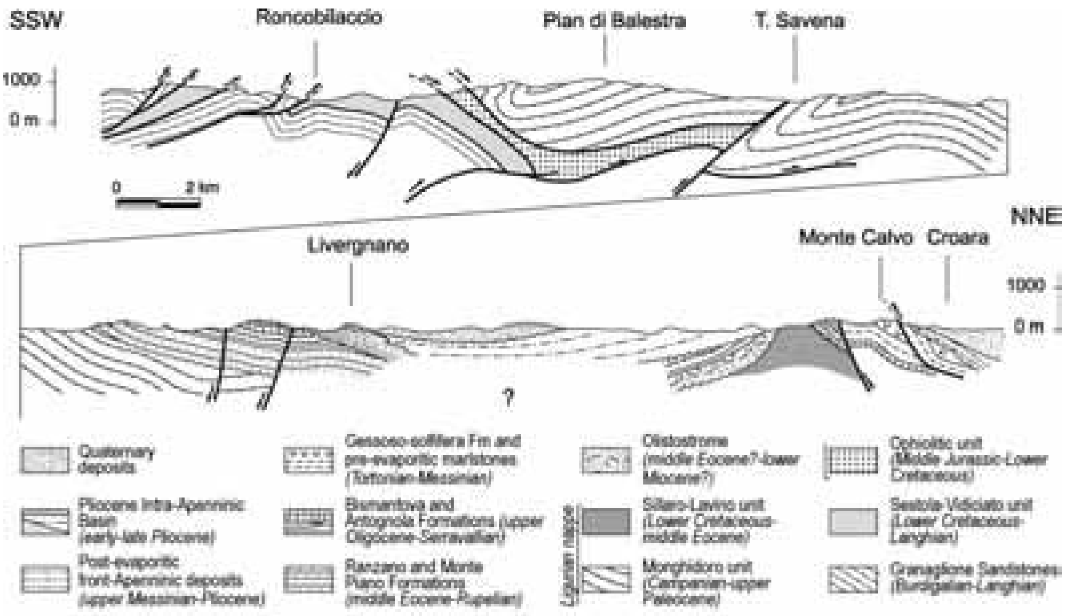

Figure 18 - Geological cross section of the Bologna Apennines. Modified from Pini, 1997. Location is on the back cover map.

conformably overlying the Ligurian nappe (Fig. 18). The Ligurian nappe is cropping out one kilometer south of here in a narrow ridge, is also present beneath the Epiligurian deposits, and extends some kilometres north of the Apenninic margin, beneath the Po Plain sediments, as outlined by seismic profiles and wells.

The Ligurian units cropping out in the ridge are tectonosomes from the Mesoligurian, Sillaro-Lavino unit (back cover map and Fig. 18). They subdivide two different successions of the Epiligurian deposits, the front-Apenninic and the intra-Apenninic successions, which show different stratigraphy (Fig. 4). Another peculiar succession prevailingly made up of olistostromes is associated to the Mesoligurian ridge (olistostromal belt). The Epiligurian olistostromal succession and the Mesoligurian tectonosomes have been long considered as a chaotic assemblage and mapped together as *argille scagliose* or chaotic complex. We shall see in the next stops that tectonosomes and olistostromes have different characteristics at the outcrop and the chaotic assumption is far from the actual setting of the tectonosomes.

The stratally disrupted Mesoligurian units pass to the south to a well- bedded Mesoligurian unit (early Eocene flysch) and to Ligurian units (flysches, oceanic-floor sediments and ophiolites)(see back cover map and Fig. 31).

Stop 3.2:

Cavaliera, Idice valley.

A panoramic view is the first part of this stop (site A in Fig. 6A) and displays the repetitions of two different early Cretaceous units, the lower and the upper members of the Sillaro scaly shales (Sillaro-Lavino unit, Mesoligurian). The lower unit (LC1 in Fig. 6A) is made up of light coloured shales hosting blocks from thick calcareous and thin siliciclastic turbidite beds. The blocks and matrix are of Neocomian age. The upper unit (LC2) is characterized by black, green and grey argillites of Aptian-Albian age with thin layer of siliciclastic turbidites and sparse white-coloured marlstone bodies. A sub-unit of varicoloured dark argillites with large blocks of calcareous turbidites crops out and displays an Aptian age (LC1a). It may be considered a transitional stratigraphic element in between the LC1 and LC2 units.

We shall walk up through a small canyon to see the nature of the contacts between the units and the style of stratal disruption. The contact between LC1 and LC2 is sharp and is parallel with the general alignment of the blocks, the colour banding of the argillitic matrix, and the pervasive scaly fabric. All these elements altogether outline a pseudobedding that can be observed in the field and mapped (Fig. 6).

The highest and steepest part of the badland discloses the internal setting of the LC1 unit (site B in Fig. 6A). Upright and upside-down portions of the same strati-

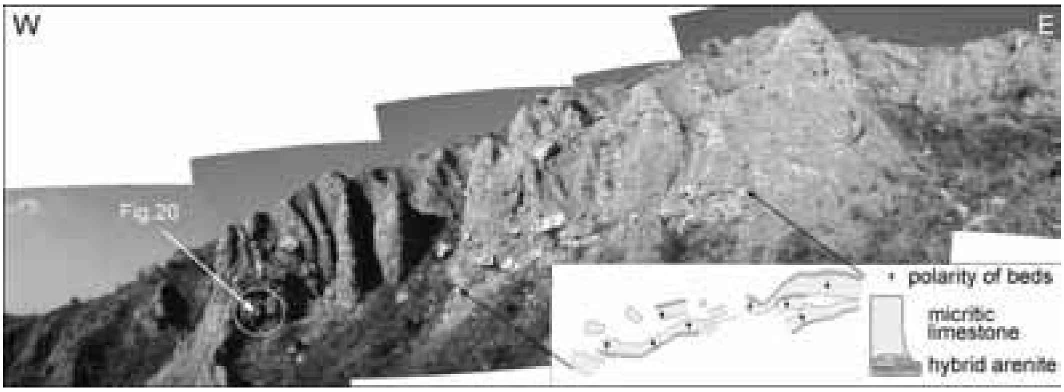

Figure 19 - Outcrop-scale fabric of the LC1 member of the Sillaro scaly clays (from P. Sommavilla, Master thesis, 2003, modified).

graphic succession are recognizable by sedimentary structures in the carbonatic turbidites (Fig. 19), which often display gradation with an arenitic base (interval c of Bouma) and a prevailing lutitic intervall (intervals d and e of Bouma). Plane-parallel lamination and well-developed ripples help in recognizing the bed polarity in some thick blocks of carbonatic turbidites. Because ripples are an uncommon structure in the LC1 unit, the blocks may correspond to separated boudins of a single turbidite layer, which can be traced notwithstanding a strong boudinage (Fig. 19). The onset of boudinage and the separation of boudins are related to layer-parallel flattening and occurred in partly to complete lithified rocks, as suggested by the sharp, angular and prismatic shape of the blocks.

Several blocks (boudins) are hinges of rootless small-scale isoclinal folds in the thin-bedded siliciclastic turbidites. Some larger blocks display type 2 and 3 interference patterns of folds. Generally, these folds are plane, non-cylindrical and the hinge zones are warped (Fig. 20). These complicated fold associations may be related to either the superposition of two deformational phases, or to a progressive refolding of sheath folds in a subduction-related deformational event (Vannucchi and Bettelli, 2002). Pini (1999) interpreted these mesoscale folds as an early stage of deformation, possibly associated with the onset of boudinage (Vannucchi and Bettelli, 2002).

Thrusting and stacking of blocks frequently affect the largest blocks of limestones and decouple and repeat the arenitic base and the lutitic interval. This phase of deformation occurred after, or in the last stage of separation of boudins. Finally, large scale folds deforming already boudinaged blocks developed as the last deformational stage. The overturning of large portions of the stratigraphic succession (Fig. 19) may be related to these last phases.

A pervasive and penetrative scaly fabric is ubiquitous in the argillites, but some zones around the blocks and in the hinges of the rootless isoclinal folds have escaped and show a plane-parallel cleavage. The latter can be related to the first phases of boudinage (and folding), and the scaly fabric accompanies the separation of boudins, block stacking, and large scale folding.

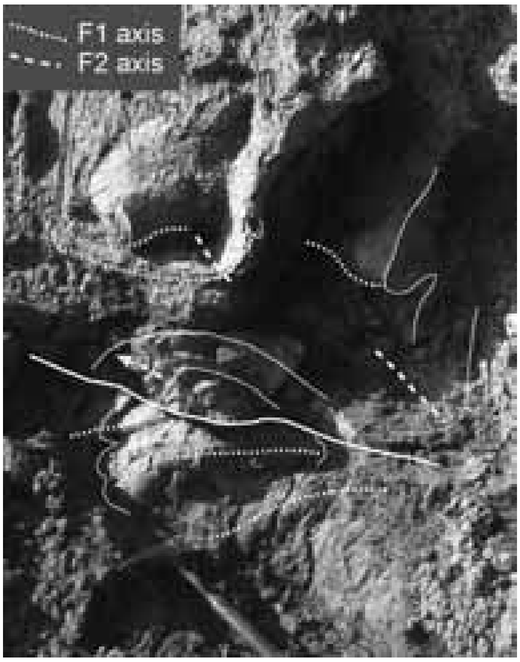

Figure 20 - Fold interference pattern developed in fine-grained siliciclastic thin-bedded turbidites. Location in Fig. 19.

Stop 3.3:

Local road to Mt. Calderaro, Ca del Vento olistostrome, Quaderna valley.

Here we can stress the difference in texture and fabric among the Mesoligurian tectonosomes and the olistostromes. This olistostrome body is a part of the olistostromal belt of the Epiligurian successions (Fig. 4). The olistostromes of this particular succession rest on the tectonosomes with the local interposition of the Monte Piano Formation, host slabs of tectonosomes and of Oligocene to lower Miocene Epiligurian sediments (Antognola Fm.) and have complicated relationships with the middle Miocene Bismantova Fm and younger deposits (Figs. 6B and 21A). Blocks have a quite variable composition and ages from early Cretaceous to Eocene.

At the scale of the outcrop the blocks are widespread and chaotically distributed, with the only exception of a slight common orientation of the more elongated blocks, which is parallel to the basal contact.

At a closer view, the matrix is typically brecciated, as shown by polished cuts and SEM observations (Figs. 21B, C). The scaly fabric is rare or absent; some banding of the matrix, fluidal structures, and a widely spaced scaly fabric are present at the base of the olistostrome bodies and will be shown in stop 3-6. Common orientation of blocks and fluidal features may impart an evident bedding, the one that can be observed in some outcrops to the north of our point of observation.

Stop 3.4:

Mt. Calderaro and San Clemente roads junction, Farneto locality, Quaderna-Sillaro watershed.

This outcrop discloses details on the scaly fabric in the LC2 (Aptian-Albian) unit of tectonosomes (Sillaro-Lavino unit of the Mesoligurian units). Scaly fabric in this outcrop is very penetrative and pervasive (Fig. 22). It develops in two discrete systems: 1) centimetric, prismatic to lens-shaped scales result from the interlacing of two or more sets of sub-parallel discontinuous cleavage (Fig. 23A). The cleavage surfaces are everywhere very well striated, and polished. All these features indicate slip along discrete planes (micro-faults). 2) sub-millimetric scales by closely spaced cleavages, the surfaces of which are not striated, but everywhere polished. The spacing is too pervasive and close to allow an appreciation of the shape of scales during field observation: using the SEM, the spacing of cleavage is about 10-30 µm and the scales show a lens-shape, defined by the interlacing of two or more sets of anastomosing, narrow (less then one µm thick) belts (Fig 23B). Belts are zones in which clay minerals have a strong parallel preferred orientation. This kind of scaly cleavage may be defined as a continuous and anastomosing, but not disjunctive, cleavage.

Both centimetre and millimetre scale cleavages are responsible for pinching-and-swelling and boudinage of the black, grey and green argillaceous beds and for

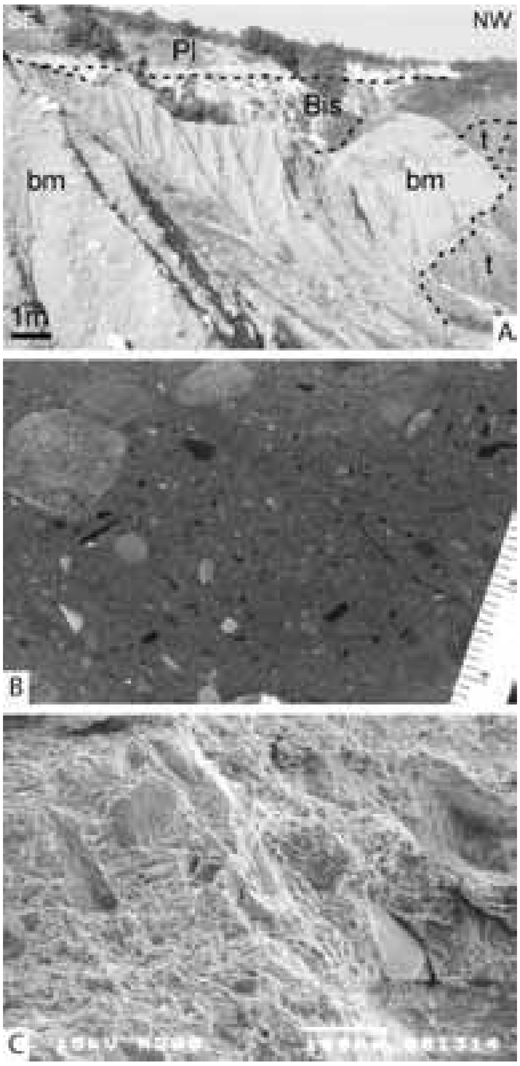

Figure 21 - Stop 3-3. A) block-in-matrix fabric (bm) of an Epiligurian olistostrome (t=olistolith of LC2 tectonosomes; Bis = Bismantova Fm; Pl = Pliocene deposits). B) brecciated fabric of the matrix, scale in centimetres; C) SEM observation of the brecciated fabric. From Pini, 1999, modified

their interfingering at the different scales of observations. In the same way, some remnants of the original bedding and of the plane-parallel cleavage are observable at the different scales (Fig. 22A)

Argillaceous fraction of both plane-parallel and scaly cleavage shales is characterized by illite, chlorite, kaolinite and a randomly ordered (R0) mixed layer illite-smectite (I/S), containing 40-50 % of illite. The presence of kaolinite and of a randomly ordered I/S indicates a low diagenetic degree with burial temperature lower than 60°C. Although possible occurrence of detrital illite prevents the use of illite Kubler index (Kubler, 1967) to establish the measurements of diagenetic degree, burial temperature around 50 °C was confirmed by using thermal maturity of organic matter.

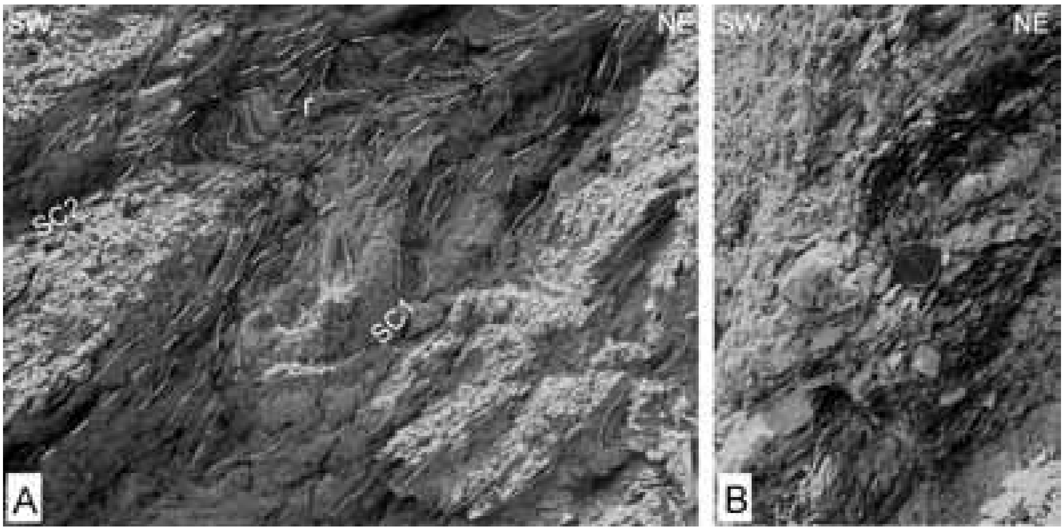

Figure 22 - Deformation of argillitic beds in the LC2 member of the Sillaro scaly clays). SC1 and SC2 in A are two different systems of centimetric scaly cleavage. Relicts of undeformed fine-grained beds (r) are preserved. Photograph in B is from Pini, 1999.

This outcrop represents the front of a Neogene thrust superposing the tectonosome units on the overlaying Epiligurian deposits and olistostromes (Figs. 6B and back cover map). Some striations on the planes of the centimetric scaly cleavage are coherent with a top-to-northeast, reverse-fault movement, but some striations display the top-to-southwest movement of a normal fault. Moreover, the system of planes giving the most widely spaced scaly fabric (SC2) overprints and arranges in a sigmoidal shape the other systems of scales (SC1 in Fig. 22A). This superposition resembles an S-C structure and is compatible with a top-to-southwest movement. Thus, the thrusting phase seems to be followed by a reactivation as a normal fault.

A short walk along the unpaved road to San Clemente allows us to observe the relationships between the LC2 tectonosomes and a large and widespread olistostrome body of the olistostromal belt (Epiligurian successions). The difference in fabric and aspect at the outcrop is dramatic: the well-ordered distribution of monomictic blocks and bands in the tectonosomes contrasts with the chaotic distribution of blocks of different ages, dimensions and shapes in the olistostrome. The contact is sharp and almost vertical and the mesoscopic foliation (pseudobedding) of the tectonosomes has become vertical as well.

Stop 3.5:

Ca’ Anzellara and Ca’ Cereto localities, Sillaro valley.

The first of the two panoramic views, of which this stop consists, concerns the general setting of a very large olistostrome of the olistostromal belt succession (Epiligurian) and its relationships with the other units (Fig. 24). The lower contact on the LC2 tectonosomes and the discontinuous levels of Monte Piano Fm is typically high angle (50-60° to vertical). Blocks of LC2 tectonosomes are commonly involved as large olistoliths inside the basal part of the olistostromes (see also Fig. 21A of stop 3-3). This relationship suggests an erosion of the substratum.

The Antognola and the Bismantova Fms lie as large slabs on the olistostrome with a sub-horizontal atti-

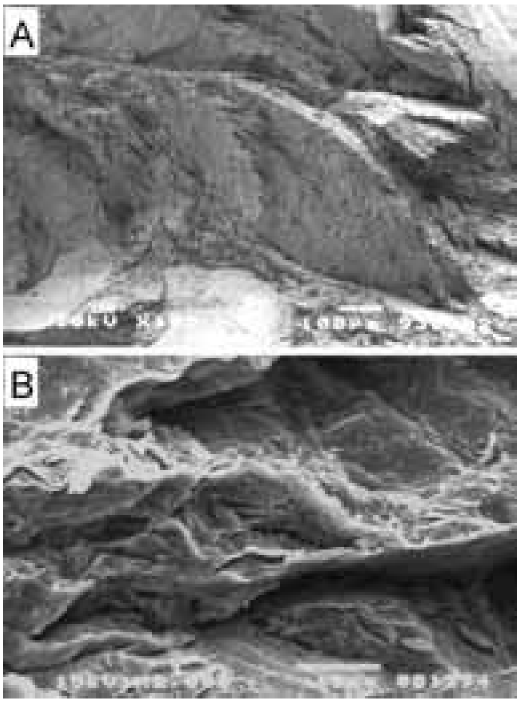

Figure 23 - SEM photographs showing a scale (shear lens) typical of the centimetric scaly cleavage (A) and some scales of the millimetric scaly cleavage (B). From Pini, 1999.

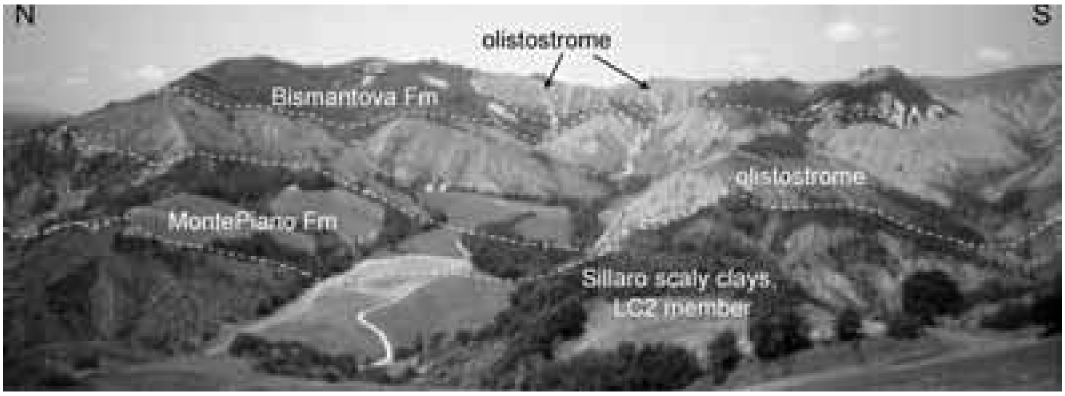

Figure 24 - Panoramic view showing the geometrical relations between the normal deposits (Bismantova Fm) and an olistostrome of the Epiligurian "olistostromal belt" succession

tude, but the contacts are commonly unconformable and the normal bedded successions seem to sink into the olistostrome. In the panoramic view we can appreciate a slab of Bismantova Fm, which has a vertical attitude of bedding and has been included in the olistostrome (Fig. 24). These top and bottom attitudes of the largest Epiligurian olistostromes can be explained in different ways: 1) the large slabs of Antognola and Bismantova Fms are olistoliths inside a huge, late Miocene mass wasting body; 2) the olistostrome is the product of coalescent mud volcanoes/diapirs piercing and intruding the Mesoligurian/Epiligurian host rocks; 3) the olistostromes are mass wasting deposits of late Oligocene-early Miocene age, which have been covered by younger Epiligurian deposits (top of Antognola and Bismantova Fms) and thrust later by the tectonosomes. This thrusting stage can have triggered a pseudo-diapiric remobilization of the olistostromes and caused the piercing of the overlying Epiligurian normal sediments and the reactivation of thrusts as normal faults (stop 3-4).

The second panoramic view displays the kilometre-scale lateral continuity and the large-scale common orientation of pseudobbeding attitudes in the LC2 tectonosomes, Sillaro scaly clays, marked by boudins of white marlstones (Fig. 25). At a closer view, the white boudins are carbonatic turbiditic beds with a calcarenitic base. Large scale folds deform the already boudinaged carbonatic and thin-bedded siliciclastic turbidites, as well as the pinched-and-swelled argillitic varicoloured beds (front cover). An elongated body of stratally-disrupted, lower-middle Eocene rocks (Zena argillites) can be recognized by its white and reddish colours. Notably the contact between LC2 and the Zena argillites units runs parallel to the pseudobedding attitude in the LC2.

Stop 3.6:

Castello di Fiagnano, Sellustra-Sillaro watershed.

The Castello di Fiagnano olistostrome (Fig. 26A) has a bi-convex shape and is 60 m long and about 5 m thick. The base of the body fills an erosive channel in

Figure 25 - Panoramic view of a large outcrop of the Sillaro scaly clays, LC2 member, in tectonic contact with a body of tectonosomes from the Zena argillites

the middle Pliocene clayey deposits. The base is decorated by smaller irregularities, which are very evident in the outcrop as deep cuts in the Pliocene deposits (Fig. 26B). The internal texture of this olistostrome is a typical block-in-brecciated-matrix:

- The blocks are prismatic, but almost isometric, and have sharp outlines. The distribution of the blocks is random; only the more elongated ones have a slight preferred orientation, parallel to the basal contact. Some bodies of matrix of different colors are present, as well as clayey bodies of Pliocene age; these bodies have an irregular lens-shape;
- The clayey matrix is brecciated. The microclasts have either rounded or angular, isodiametric or elongated shapes. The plane of the major axes of the elongated clasts is commonly sub-parallel to the basal contact. This common orientation defines a moderate anisotropic texture, which becomes a general attribute in zones close to the contact. The fluidal structure of the matrix imparted by microclasts iso-orientation is enhanced through plastic deformation and strong elongation of some clasts (Fig. 27). These clasts also display asymmetric boudinage, which developed mainly in the direction parallel to the longitudinal axis of the body. Fluidal features and the orientation of clasts are parallel to continuous and striated, anastomosing planes, which define a centimetric spaced scaly fabric. A ghost scaly fabric is slightly evident on weathered rocks and is associated with the fluidal features. The strong orientation of clasts and the scaly fabric are disposed at a low angle to the basal contact.

DAY 4

Topics: 1) geometric and sedimentary relationships between the Ligurian nappe and the Marnoso-arenacea foredeep basin; 2) internal features, stratal disruption and emplacement mechanism of a large submarine landslide deposited within the Marnoso-arenacea basin.

The long-term sedimentary history of the Marnoso-arenacea basin is expressed by two main evolutionary

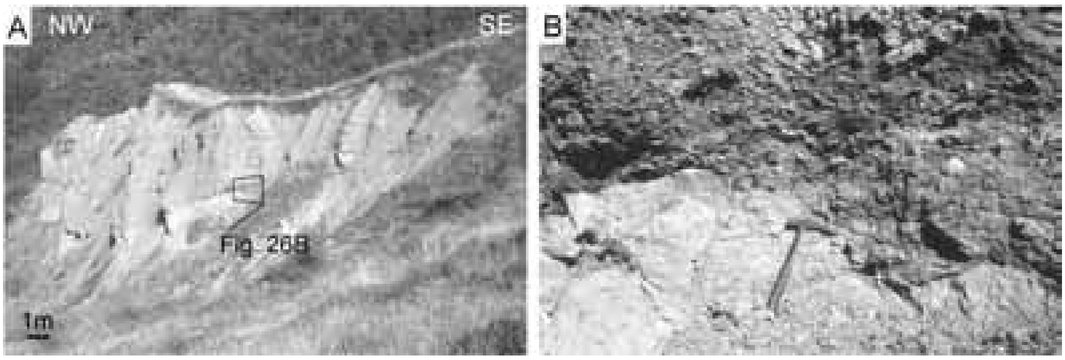

Figure 26 - Castello di Fiagnano olistostrome, panoramic view (A) and detail of the base (B). From Pini, 1999, modified

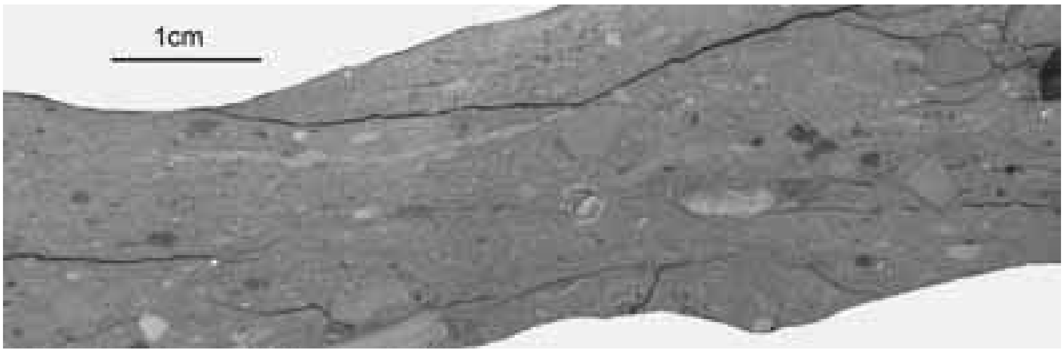

Figure 27 - Fluidal features deforming the matrix and some clasts in the basal portion of the olistostrome. From Pini, 1999, modified.

stages, an older inner stage (from Langhian to Serravallian) and a younger outer one (Tortonian, see Fig. 28). Turbidite sedimentation of the two stages differs in terms of facies and geometry reflecting changes in basin size and shape and sediment influx (Ricci Lucchi, 1975, 1981).

The inner stage represents the phase of maximum subsidence and lateral extent of the basin, with a large development of mud-rich, basin plain turbidites and fewer fan-fringe turbidites (Ricci Lucchi, 1975). The impressive parallelism and lateral continuity of individual beds are a reliable tool for stratigraphic correlations (e.g. Ricci Lucchi and Valmori, 1980). The most important key bed in the Marnoso-arenacea succession is the so-called Contessa megabed (early Serravallian, Ricci Lucchi, 1975). This basin-wide turbidite layer, with hybrid, bioclast-rich composition, is recognisable for more than 150 km from its proximal zone in the Gubbio area (Umbria) to the Santerno valley passing from a thickness of 15 meters to 10 meters downcurrent. Other thinner hybrid and carbonate-rich layers allow detailed basin-wide correlations both in the pre-Contessa (Contessine) and post-Contessa time (Colombine).

The sediment dispersal pattern was along the longitudinal axis of the basin (Ricci Lucchi, 1978; Gandolfi et al., 1983). Turbidites were mainly fed by Alpine sources through multiple entry points to the N and to the W. Alpine-sourced turbidites have a siliciclastic composition and paleocurrent data that indicate a prevailing transport toward SE. Minor sources of hybrid and carbonate composition flowing toward NW were located in shelf areas along the southern and south-eastern end of the basin.

The wide lateral continuity of beds through different thrust units suggests an original flat basin plain. However, at a closer scale, a topographic control on sedimentation through very gentle intrabasinal highs is suggested by facies changes, lateral thickness variation of both packages of strata and individual layers, and evidence of flow deflection and reflection (Roveri

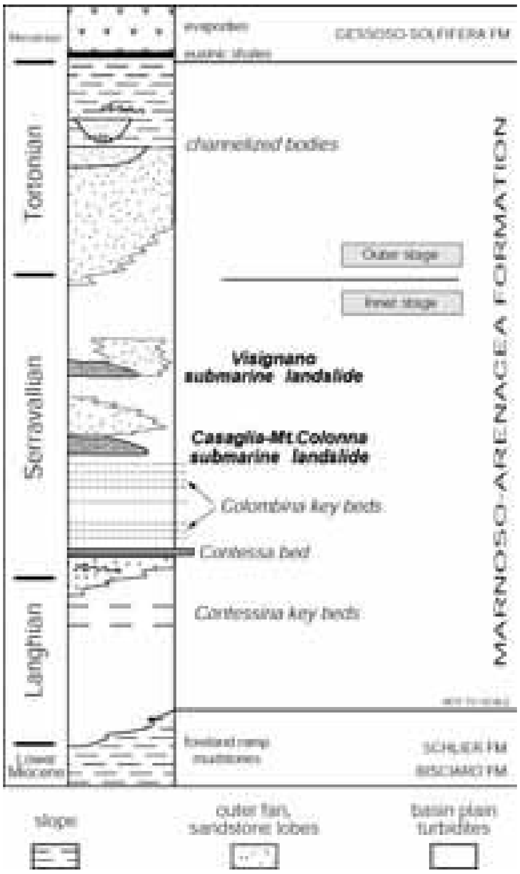

Figure 28 - Stratigraphy of the western Romagna Marnoso-arenacea Fm. From C.C. Lucente, Ph.D. thesis, 2000.

et al., 2002; Lucente and Pini, 2003). This argument is debated and only in the case of the Verghereto high the activity of a synsedimentary intrabasinal relief is fully accepted.

Many large submarine landslides, involving sediments of various origin and degree of consolidation, occur within the basin plain and slope deposits of the Marnoso-arenacea Fm. (Figs. 28, 29 and back cover map). Peaks in slide distribution occurred in the early Serravallian and late Tortonian and represent phases of strong instability at the basin-scale. The two largest events of basin instability in the MA foredeep occurred in the early Serravallian: the coeval emplacement of the Casaglia-Mt. Colonna and the Nasseto bodies, and later the coeval emplacement of the Visignano and Le Caselle bodies. All these large mass-wasting deposits are made up of both intrabasinal and extrabasinal sediments.

Stop 4.1:

Sassoleone, Firola creek, Sillaro valley.

This stop addresses the regional contact between the Ligurian nappe and the Marnoso-arenacea succession. Fig. 30 shows the discordance between the northward-dipping beds and the contact. A thick horizon of coalescent mass wasting deposits crops out in between the Ligurian nappe and the Marnoso-arenacea (olistostromal "carpet" complex). This complex hosts large olistoliths of Epiligurian deposits, as the Arenarie di Loiano (Monte Piano Formation, middle-late Eocene).

The overall contact displays a staircase trajectory as shown in Fig. 29. The time-transgressive boundary spanning from Langhian to Tortonian testifies a synsedimentary advancement of the Ligurian nappe. A fast advancement caused the overthrust surface to follow the same stratigraphic level (flat) whereas a

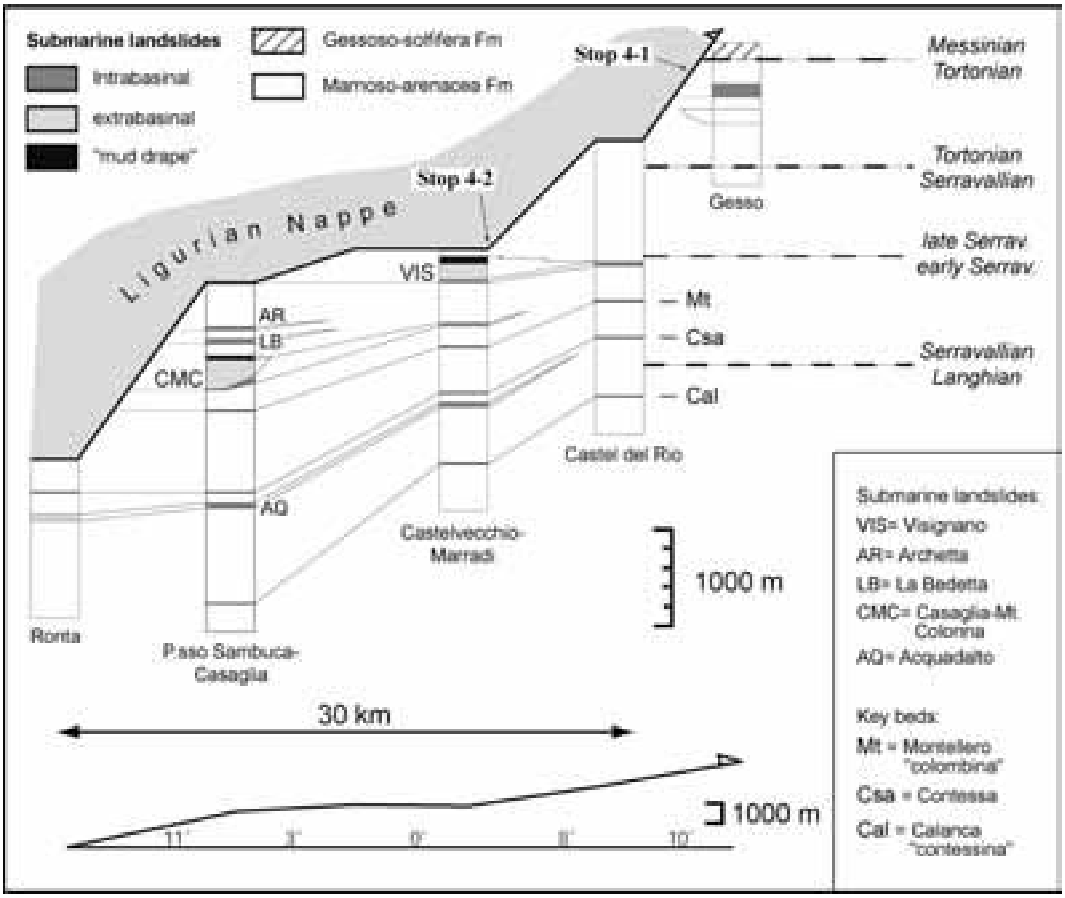

Figure 29 - Stratigraphic sketch of the Marnoso-arenacea Fm, showing the geometric relationship with the Ligurian Nappe. Horizontal distances have been restored to sin-depositional conditions (Redrawn from Landuzzi, 2004).

slow advancement in competition with the MA deposition promoted the cut off of the adjoining sediments (ramp). Moreover, a temporary standstill might have caused interfingering (see De Jager, 1979).

The emplacement mechanism of the Ligurian overthrust, whether related to thrusting or gravity spreading and sliding, is matter of debate. However, it is important to point out that the emplacement of the Ligurian nappe produced important effects on the MA foredeep, stopping the sedimentation, promoting the subsidence through its load, and shedding olistostromes that modified the sea bottom topography (Ricci Lucchi, 1986).

Stop 4.2:

Visignano-Poggio Belmonte, Diaterna-Sillaro watershed.

In this stop a panoramic view on the Visignano (VI) olistostrome and the Ligurian nappe can be appreciated (see the geologic map in Fig. 31).

The VI olistostrome is in continuity with the olistostromal complex at the base of the Ligurian nappe. It is mostly composed of slabs of Cretaceous-Eocene argillites of Ligurian –Mesoligurian origin and in its upper part also by chaotic marly bodies enclosing olistoliths of Oligo-Miocene marlstones and sandstones.

Deformed Marnoso-arenacea deposits are present at the bottom of the slide body. This horizon may be interpreted either as the result of the impact of the huge olistostrome on the Marnoso-arenacea sea-floor or as a forerunning slump episode.

Figure 30 - Panoramic view of the contact between the Ligurian nappe and the Marnoso-arenacea Fm.

After the panoramic observations, we shall move to look at a road cut exposure of an olistostrome belonging to the olistostromal "carpet" complex as defined before. This complex is made up by type A and B olistostromes composed prevailingly by Ligurian and Mesoligurian rocks, which are present as both blocks and olistoliths. An important component is also Oligo-Miocene marlstone and sandstones, the same that are present on top of the VI olistostrome, which belong to slope and shelf deposits of the Epiligurian succession. These Oligo-Miocene rocks crop out continuously in association with the olistostromes (Fig. 31).

Stop 4.3:

Passo della Futa, Idice-Sillaro watershed.

In this short stop, before or after a coffee break, we shall have a panoramic view on the structural units and the ophiolites of the Ligurian nappe. The ophiolites exposed in the quarry of Mt. Benni are one of the slabs of an upside-down sequence of oceanic crust, the stratigraphy of which is in Fig. 32.

Stop 4.4:

Bibbiana, Lamone valley.

The last three stops of day 4 are fully dedicated to the Casaglia-Mt. Colonna (CMC) submarine landslide. The CMC covers an estimated area of 350 square kilometres making this body comparable with present-day mass-wasting deposits. It is made up mainly by basin plain sediments but includes also subordinate slope deposits and extrabasinal rocks (Fig. 33). The extrabasinal slide component (olistostrome) is an apparently ordered aggregate of large preserved slabs of middle-late Eocene and lower Miocene age (type C olistostrome).

We shall stop at the Bibbiana small village, at the end of an unpaved mountain road. The stratigraphic succession at the base of the CMC can be fully appreciated along the road. Within the basin plain turbidites of this succession, some colombina-type key beds and one siliciclastic key bed were recognized (Fig. 33) and correlated so far as the whole extension of the CMC submarine landslide (C.C. Lucente, Ph.D. thesis, 2000).

The stratigraphic data allow to reconstruct the geometry of the submarine landslide. The CMC has a wedge shaped geometry with a maximum thickens of 300 meters in the Casaglia-Bibbiana area. Starting from

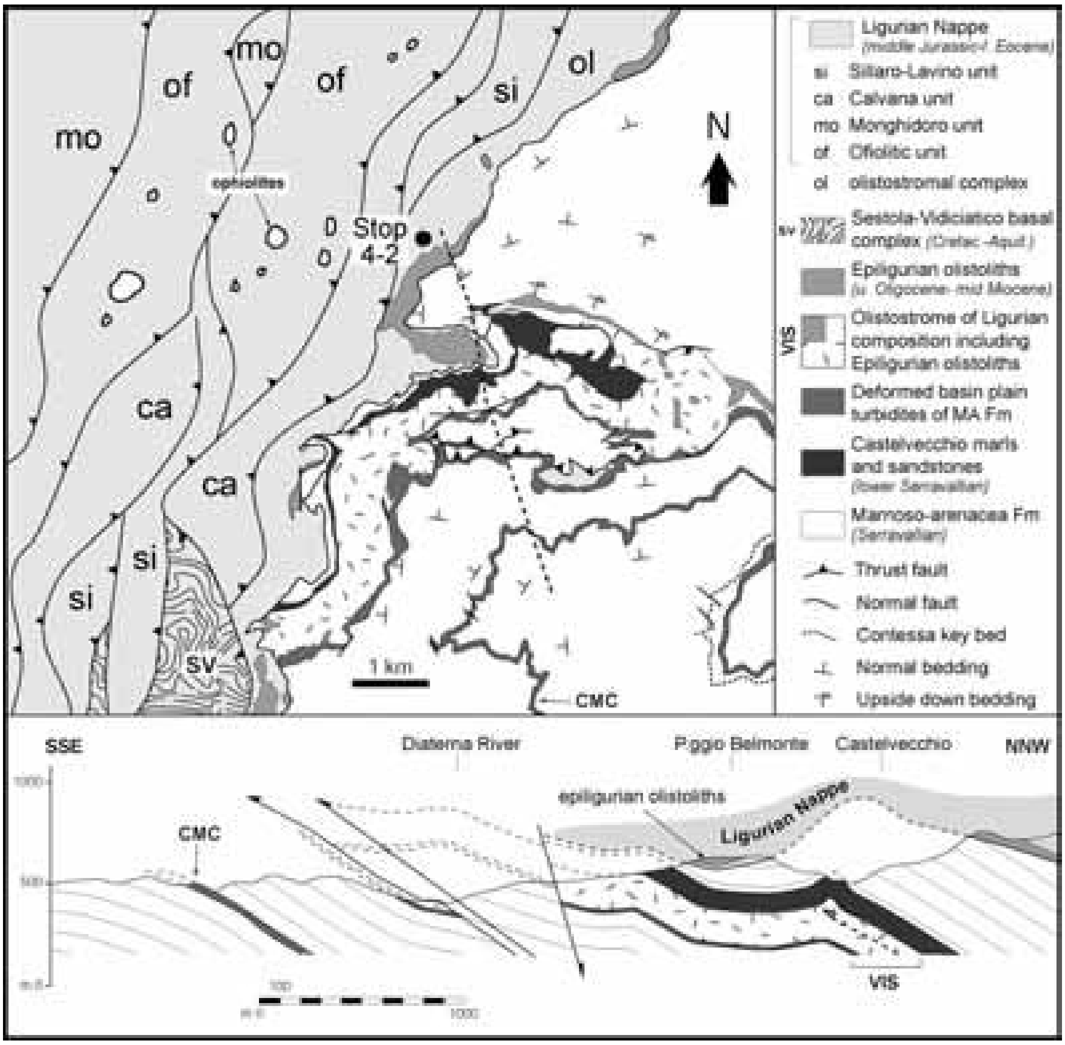

Figure 31 - Geological map and cross-section of the Visignano-Castelvecchio area. Sources: Cerrina Feroni et al., 2002; Landuzzi, 2004.

Bibbiana the slide thickness decreases towards NE and NW in accordance with the slide-bottom attitude, which displays a complex ramp and flat geometry. The ramps cut the underlying strata at different angles and in two different directions, SW-NE and SE-NW. In the cross-section of Fig. 33 the deepest SW-NE ramp, cutting off 200 meters of the footwall succession in 2 kilometres, can be appreciated.

In the stop the boundary between the extrabasinal and intrabasinal deformed sediments can be appreciated. In the intrabasinal part, tens of meters thick packages of very poorly deformed beds (slabs, intraformational olistoliths) rest on strongly deformed belts that are several meters thick (Fig. 34). The latter are characterized by close to isoclinal folds and by overfolds and appear to accommodate the relative movement among the different slabs within the slide, acting as shear zones. All the olistolith successions coincide with the stratigraphy beneath the slide body, as shown by the presence of key-beds (AV bed in Fig. 34A corresponds to key bed 4 in Fig. 33). The olistoliths are usually gently folded (slab 1 and 2), with the exception of the lowest slab, slab 3, arranged in a large scale, steeply inclined tight fold, with an overturned north-eastern limb.

The general attitude of the slabs and the arrangement and vergence of folds in the underlying shear zones suggest that the movement of the highest slabs (slabs 1 and 2) occurred in the same direction as the gen-

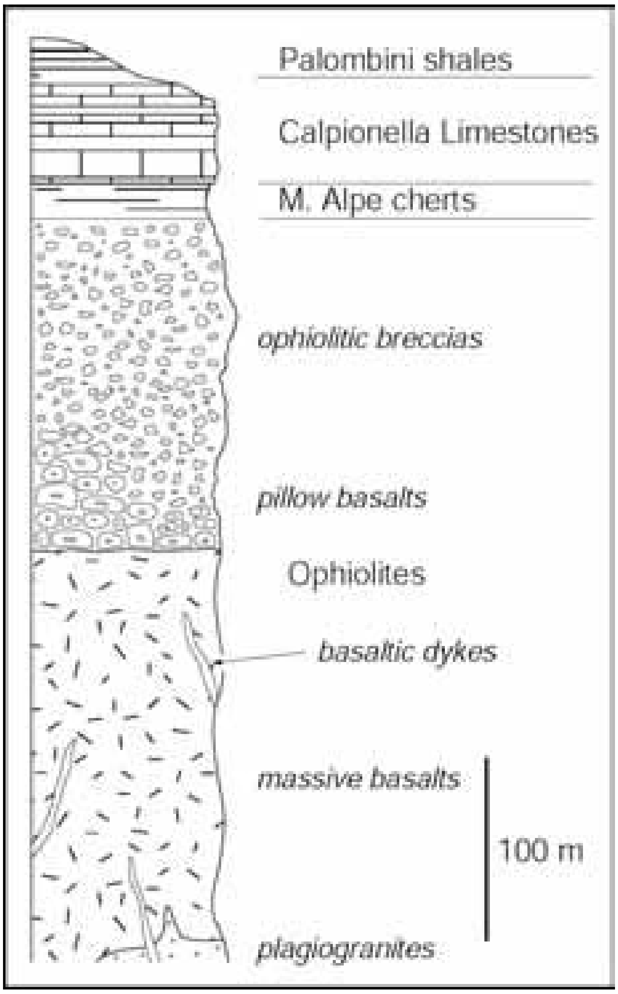

Figure 32 - Sasso di Castro-Monte Benni oceanic crust and ocean-floor sedimentary sequence (modified from Calanchi et al., 1987).

eral slide movement, but with the geometry of listric normal faulting. No significant folds developed below and at the front of the lowest slab (slab 3); its lower, overturned limb rests on upright bed packages. These packages form the base of the slide and are complicated by some small-scale thrusts, which seem to share the same north-eastward vergence of the folds. The emplacement of the second lens of the olistostrome at the front of the antiformal culmination may explain the tight fold of slab 3 and may also explain the vertical attitude of the folds in the shear zones between slabs 2 and 3.

At the scale of the entire CMC body, the vergence of folds and the other kinematic indicators inside the intrabasinal slide sediments are consistent with the direction in which the thickness of the slide decreases. These features suggest that the CMC moved towards NE in the zone southwest of Senio River (Figs. 35A, 36) and towards N northwest of Senio River. In the latter case sliding was confined to the east by a gentle intrabasinal high and was been deflected to the north; by contrast, in the former case slide deposits were free to spill over the adjoining basin plain (Marradi sector)(Figs. 35A and 36).

The schematic cross-section and the interpretive diagram of Fig. 35A and B show respectively the internal distribution of structures and the mechanical interpretation as far as the SW-NE moving part of the CMC is concerned (Casaglia-Marradi transect). The ramp zone has an antiformal stacking of duplexes and steeply inclined folds due to olistostrome emplacement pushing ahead just- deformed basin plain sediments (rear compression). Throughout the lobe zone, extensional and compressional structures coexist. Listric normal faults and extensive duplexes are concentrated in the upper part, whereas the lower part is deformed by flow structures as recumbent isoclinal folds, drag folds, boudinage and block stacking all associated with low angle thrust faults which are compatible with flow-induced heterogeneous simple shear.

Strain is partitioned in thickening and shortening in the ramp, and thinning and stretching in the lobe. The strain partition and the top and bottom attitude of the submarine landslide are analogous to the extruding-spreading nappe emplacement model (see Lucente and Pini, 2003 and references therein).

Buckle-induced structure such as box folds and opposite verging drag folds are confined to the more distal slide sector (Fig. 35). Buckling was probably related to slowing down and/or stopping of the sliding mass due to frontal confinement (basin-slope ramp?).

Also the degree of stratal disruption is very characteristic in CMC. As stated in Fig. 35A the dimension and frequency of slabs within the lobe zone decrease downcurrent. The degree of internal deformation also increases as the slabs become smaller.

Figure 35A summarizes also the different association of structures and the styles and degree of stratal

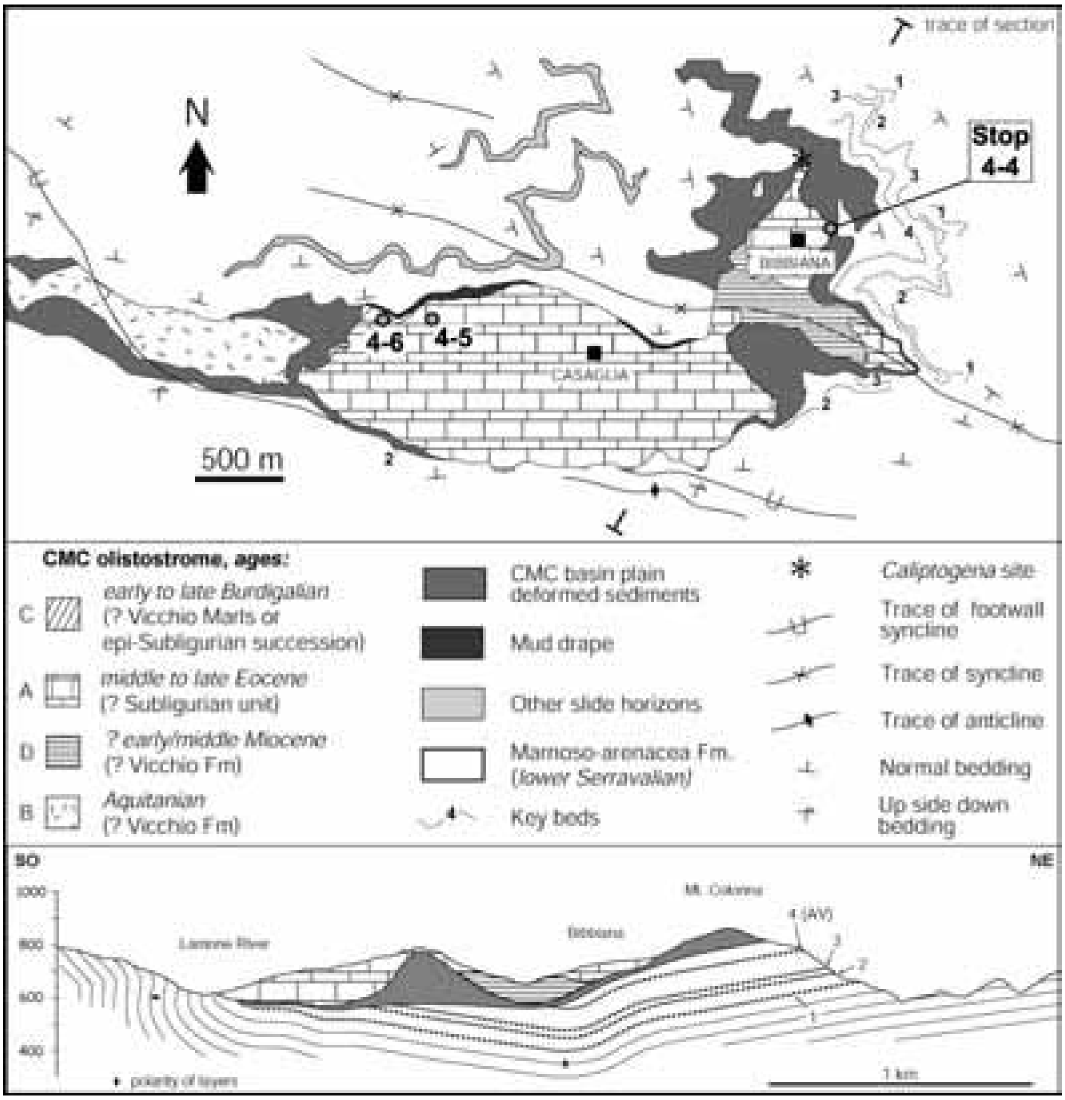

Figure 33 - Schematic geologic map and cross-section of Casaglia-Mt. Colonna (CMC) landslide body showing the relationship between extrabasinal and intrabasinal components. (Modified from C.C. Lucente, Ph.D. thesis, 2000).

disruption that occur in a well-defined portion inside the landslide body. These downflow changes may be diagnostic of the distinction between mass-wasting processes and shallow-level tectonics even if the single structures are similar to those in accretionary wedges.

Moreover, the relationship between the intrabasinal and extrabasinal sediments may provide insight on the mechanism and timing responsible for slide emplacement. In the case of CMC, where slope deposits and extrabasinal rocks rest on top of basin plain slide deposits, a synchronous or a retrogressive sliding seems to be the most reliable emplacement mechanisms. Following the second hypothesis, detachment occurred earlier in basin plain deposits (temporary slope) than in slope and extrabasinal sediments and rocks. This implies that the instability began in the foredeep basin and subsequently propagates to inner slope and then to the accretionary wedge front (Lucente and Pini, 2003).

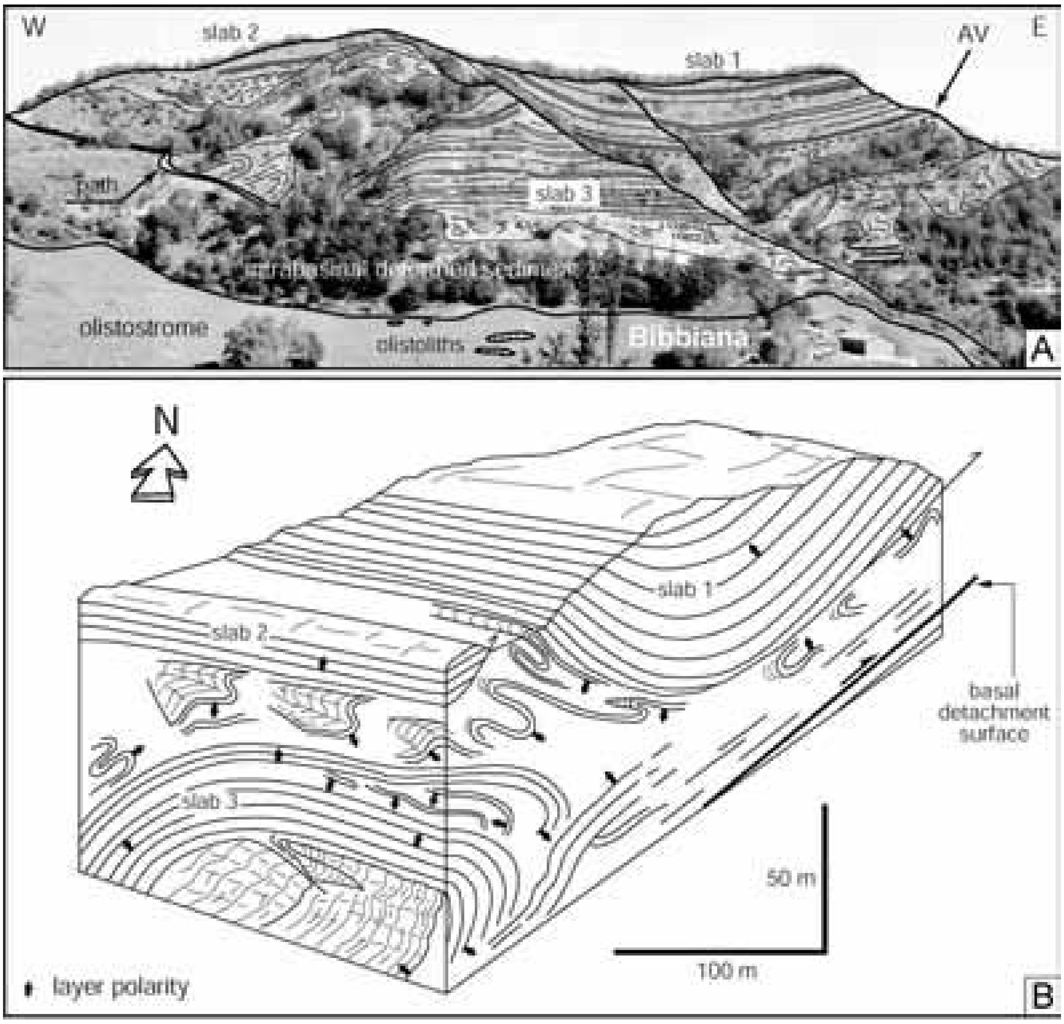

Figure 34 - Panoramic view (A) and interpretation (B) of the Bibbiana outcrop (from Lucente and Pini, 2003, modified).

Stop 4.5:

1km west of Casaglia village, national road 302, Lamone valley.

The panoramic view (Fig. 37) shows the marly body at the top of the CMC olistostrome interpreted as a "mud drape" (see Ricci Lucchi, 1975; De Jager, 1979). The mud drape has a lens-shaped geometry with a maximum thickness of 30 meters. The thickness seems to vary in relation to the original topography of the underlying olistostrome deposit. The deposit was an intrabasinal high probably standing some hundreds meters above the sea bottom, taking also into account the subsidence generated by the emplacement of the olistostrome. The mud drape is mainly composed of bioturbated hemipelagic marls and very thin-bedded turbidites (probably the upper most dilute flow of turbidite currents) passing gradually upwards to basin plain turbidites. Basin plain turbidites started to deposit at the top of the mud drape only after the faster sedimentation around the olistostrome belt had levelled the topographic differences.

Stop 4.6:

West of Rifugio di Casaglia, national road 302, Lamone valley.

The contact between the olistostrome belt and the "mud drape" is shown in this outcrop (Fig. 38). The lover portion of the olistostrome deposit is characterized by brown-green siliceous marlstones. Five

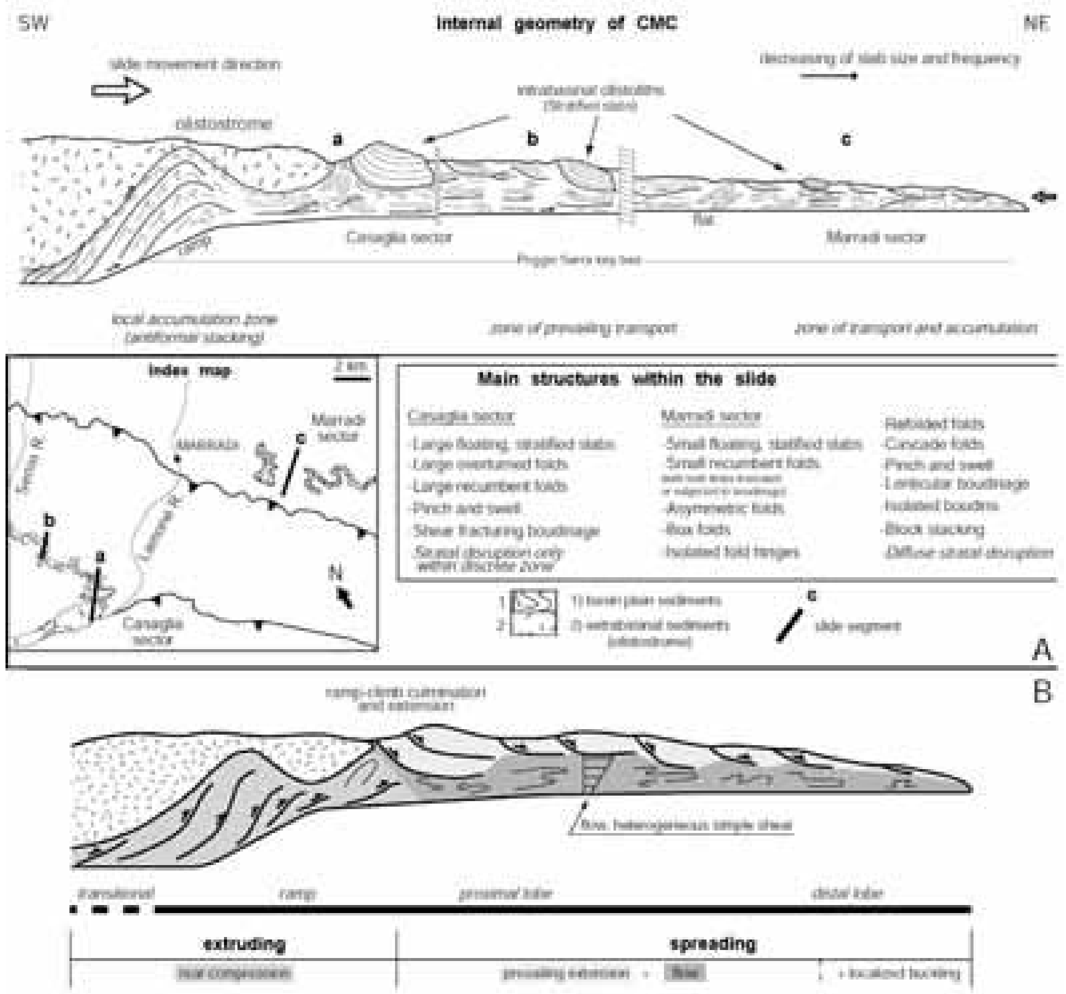

Figure 35 - A) Schematic cross-section of CMC parallel to the direction of slide movement showing the geometry and internal distribution of structures. B) Interpretative diagram of the slide kinematic. From Lucente and Pini, 2003, modified.

volcaniclastic beds are locally intercalated within the siliceous marlstones. The upper portion is made up by green-grey marls containing fine sandstone and siltstone beds. On the basis of their Foraminifera, the age of the lower portion is early Burdigalian and the upper part is late Burdigalian. The paleogeographic origin of these extrabasinal deposits is not clear. Due their age and macroscopic appearance, they may belong to the Vicchio Fm or to the epi-Subligurian succession.

We can also appreciate, walking along the road, the gradual transition between the mud drape and the basin plain turbidites of the Marnoso-arenacea Fm.

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F. Ricci Lucchi is kindly acknowledged for the helpful suggestions about submarine slides in the Marnoso-arenacea Fm (Day 4). The suggestions from K. Hisada contributed to define the field trip itinerary and the topics of stops.

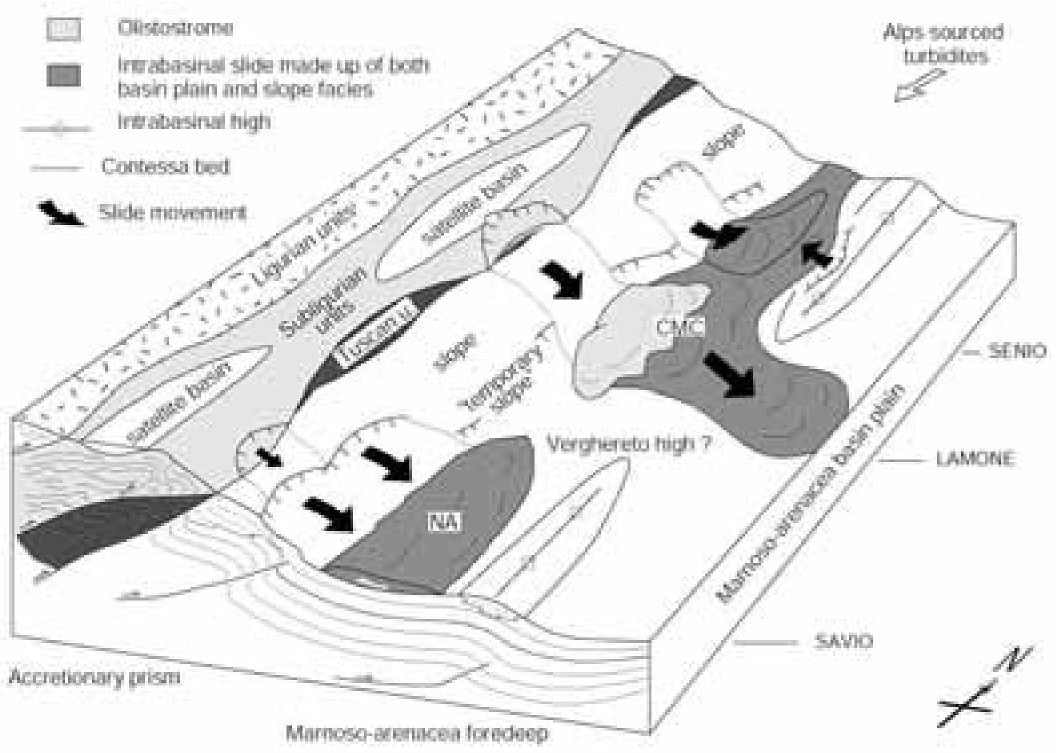

Figure 36 - Palinspastic block diagram showing the emplacement of the CMC (Lucente and Pini, 2003).

A.M. Borsetti, R. Barbieri and M. L. Colalongo are kindly acknowledged for dating the foraminifera associations of several samples. D. Dall'Acqua e P. Sommavilla helped in field work for Stops 2-5 and 3-2 respectively.
All the Ph.D. and Master theses cited hereafter are deposited at the Dipartimento di Scienze della Terra e Geologico-Ambientali of the Università di Bologna.

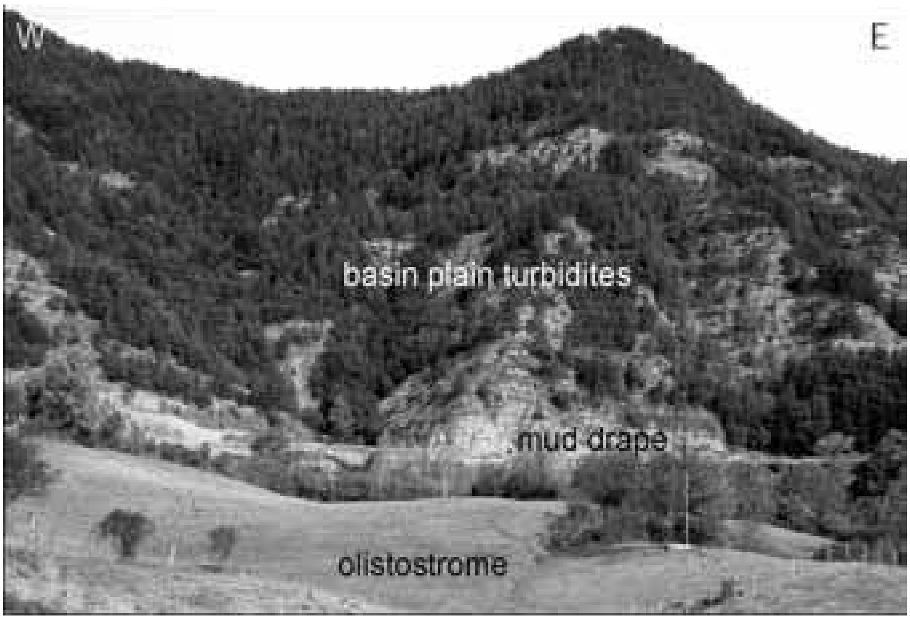

Figure 37 - Panoramic view of the "mud drape" at the top of the CMC extrabasinal part (olistostrome).

Figure 38 - Panoramic view of the sedimentary contact between the "mud drape" and the underlying olistostrome.

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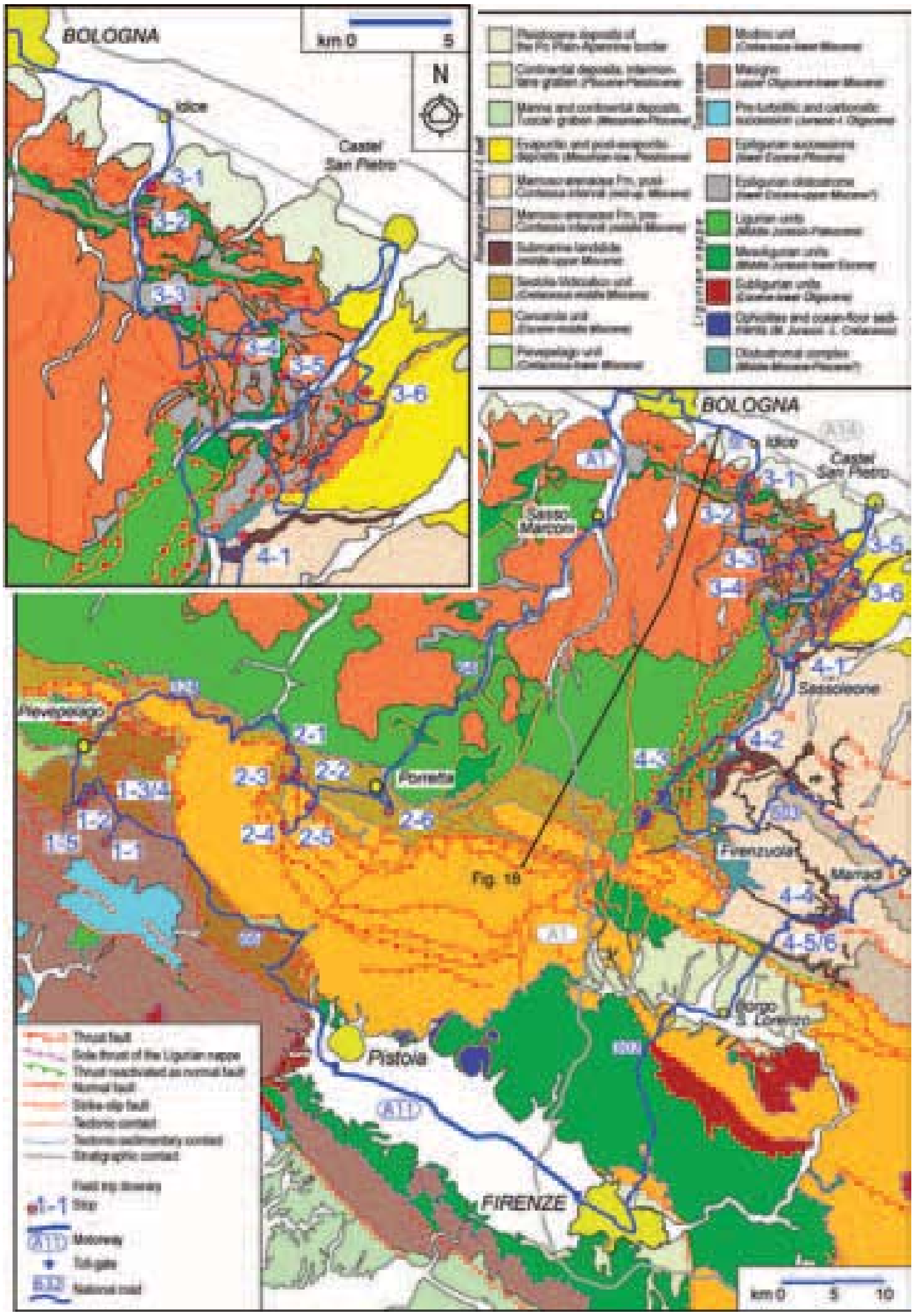
Back Cover:
Geological map of the Bologna-Firenze transect of the Apennines and outline of the field trip itinerary. Main sources for the map: Boccaletti and Coli, 1982; Pini, 1993; Bendkik et al., 1994; C.M. De Libero, Ph. D thesis, 1994; Benvenuti, 1997; C. Bondi, Master thesis, 1998; M. Chelli, Master thesis, 1998; C.C. Lucente, Ph.D. thesis, 2000; M. Zamboni, Master thesis, 2000; Cerrina Feroni et al., 2002; Geological Map of Italy, 1:50,000 scale, Sheet 252, Barberino del Mugello, 2002; Plesi et al., 2002; Landuzzi, 2004.

FIELD TRIP MAP



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