

ABSTRACT

The mapping of chaotic rocks has led to the definition of principles, criteria and methods useful in their differentiation and characterization on the field. Basically, field mapping has allowed the distinction of four types of chaotic rocks: 1) argillaceous or shaly-matrix sedimentary breccias; 2) *in situ* non-metamorphic tectonites or broken/dismembered formations (subdivided in monoformational and multiformalional non metamorphic tectonites); 3) gravity-displaced non-metamorphic tectonites or tectonites in secondary position; and 4) association of sedimentary breccias and tectonites. Specific examples of selected areas from different tectonic settings of the Apennines (Southern Abruzzo, Oltrepò Pavese, and Southern Tuscany) are provided.

AIMS

The problems related to the mapping criteria for chaotic rocks and their field description are directed here through the study of three Apennine case histories: Southern Abruzzo, Oltrepò Pavese and Southern Tuscany. In particular our objectives were:

- the outcrop distinction of chaotic rocks produced by sedimentary vs. tectonic processes;
- the definition and classification of the lithostratigraphic units to be represented in the geological map;
- the restoration of the original stratigraphic succession;
- the proposition of graphic symbols suitable to represent field information in the geological map;
- the description of the texture and the meso- and macrostructural characterization of different chaotic rocks.

KEY WORDS

Chaotic rocks, mélange, Apennines, olistostrome, broken formation, Argille Scagliose

Mapping of chaotic rocks in Abruzzo (Central Apennines): Comparison with selected example from Northern Apennines

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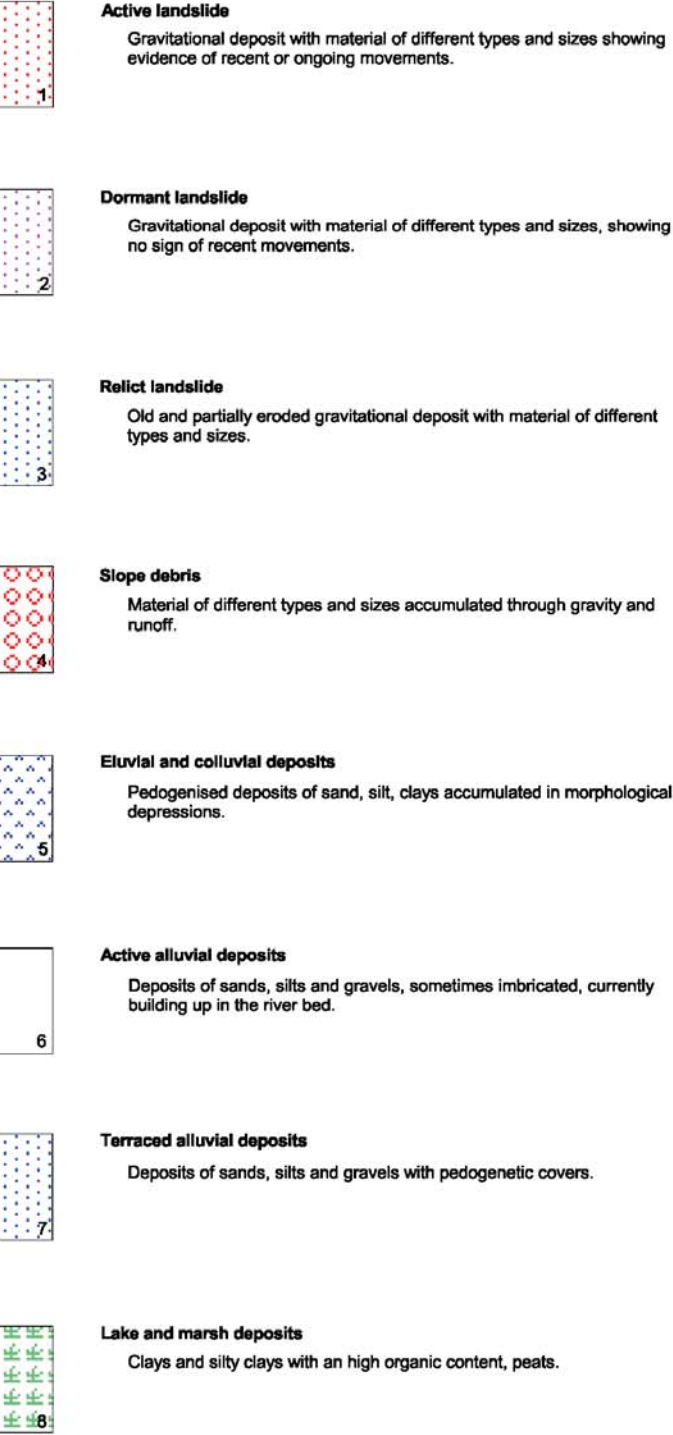
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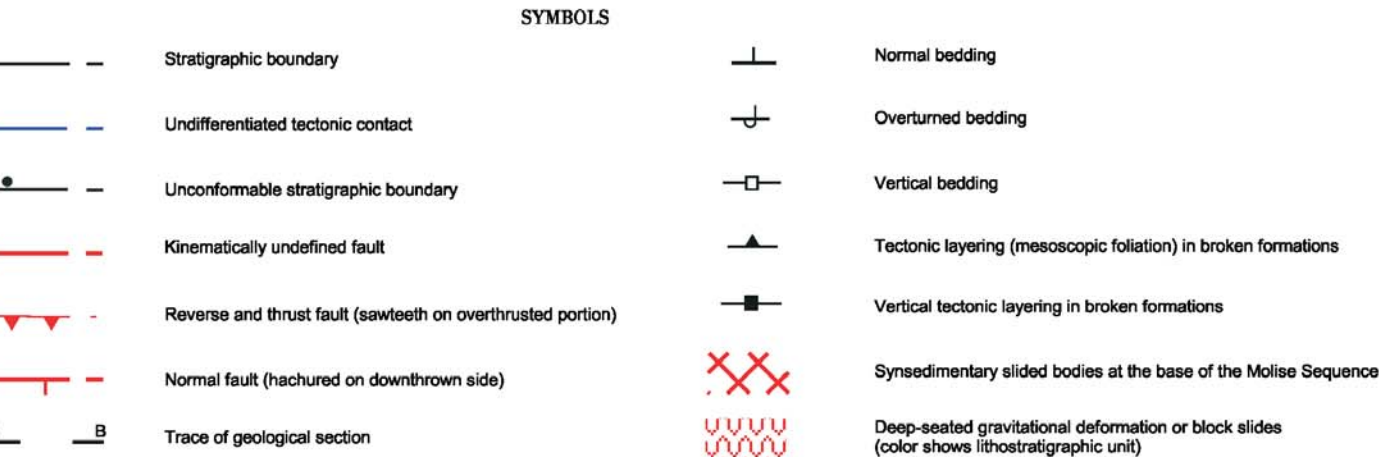
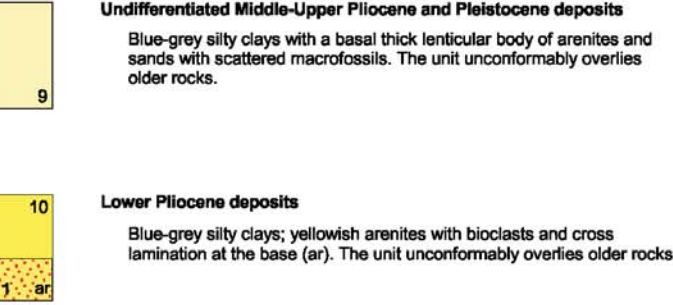
Il rilevamento di aree appenniniche con rocce caotiche ha portato a stabilire caratteri distintivi oggettivi che permettono di riconoscere se la genesi di tali rocce sia da attribuire a meccanismi sedimentari o tettonici. Utilizzando questi criteri diagnostici sono stati distinti i seguenti tipi di rocce caotiche: 1) breccie sedimentarie (depositi di debris flow e mud flow); 2) tectoniti in situ o formazioni smembrate in posizione primaria; 3) tectoniti dislocate dalla gravità o tectoniti in posizione secondaria; 4) associazioni di tectoniti e breccie sedimentarie. E' presentata e discussa una classificazione e una nomenclatura stratigrafica dei corpi caotici appenninici. Sono poi elencati brevemente i principali meccanismi ed i processi genetici dei corpi caotici distinguibili cartograficamente.

GEOLOGICAL MAP OF THE OSENTO AND SINELLO VALLEYS, SOUTH OF ATESSA (ABRUZZO, CENTRAL ITALY)

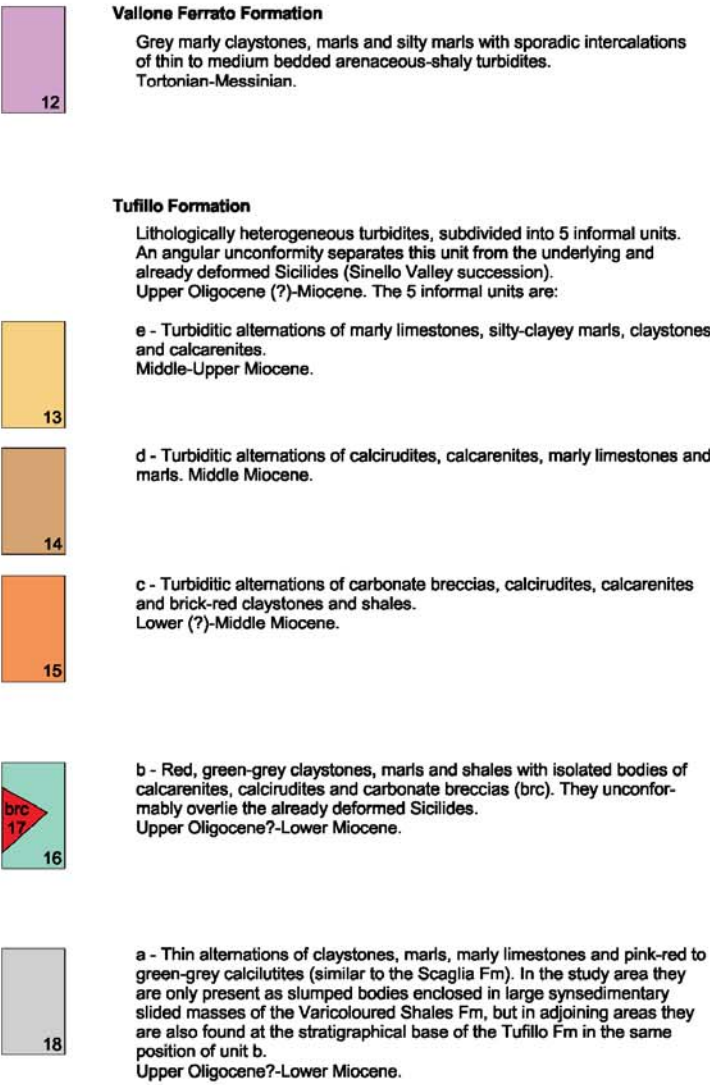
QUATERNARY CONTINENTAL DEPOSITS



PLIOCENE - PLEISTOCENE SEQUENCE OF ATESSA-CASALANGUIDA



MOLISE SEQUENCE



SICILIDES

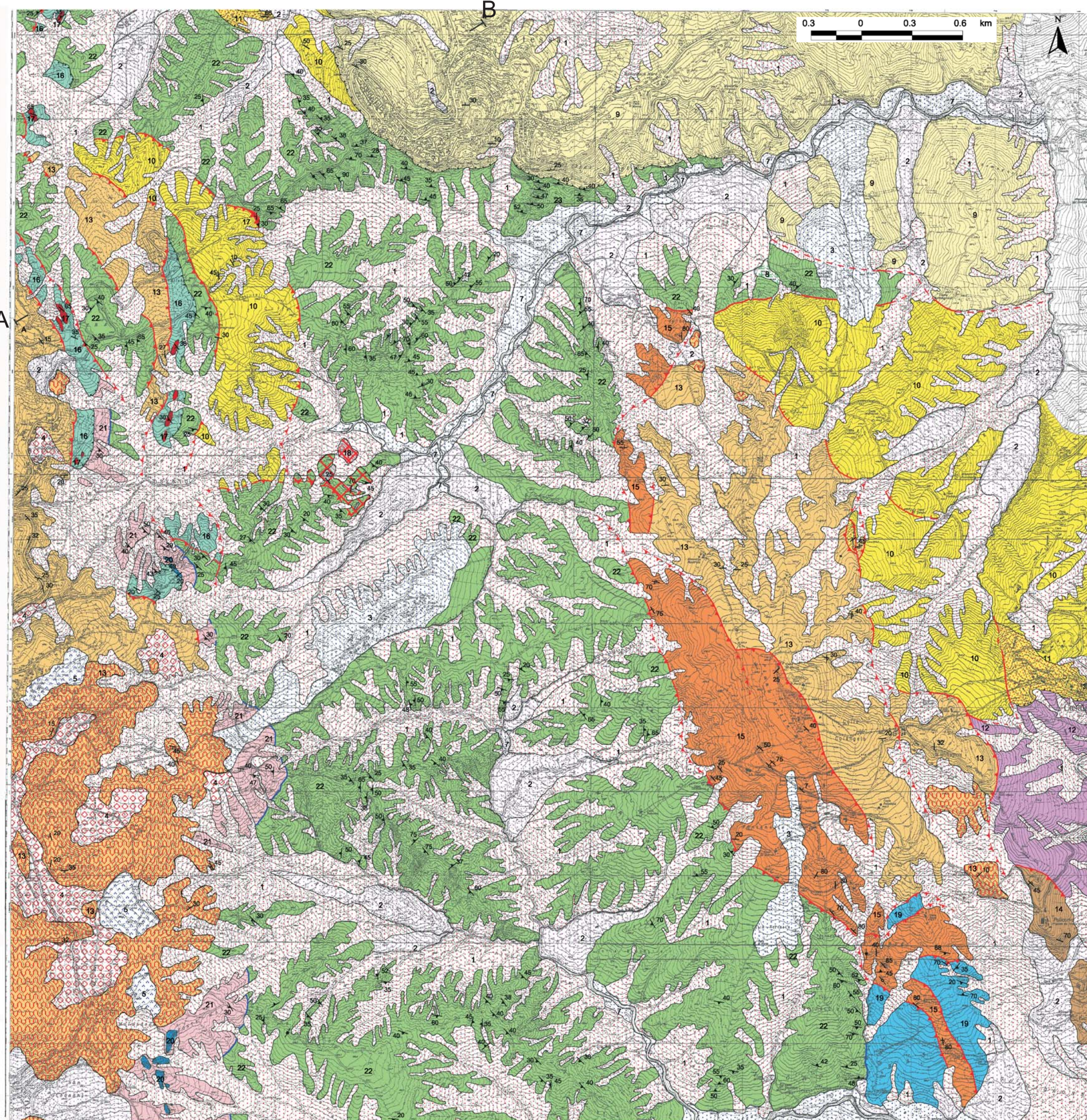
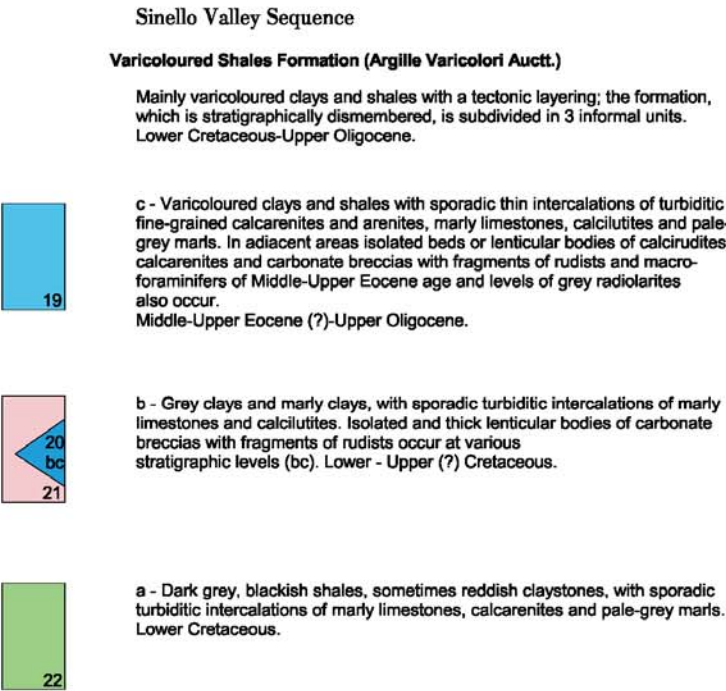


Fig. 1 - Geological Map of the Osentto and Sinello Valleys (Abruzzo, Central Italy). The geological survey has been performed by G. BETTELLI, S. CONTI, C. FIORONI, P. FREGNI, C. MONDANI & P. VANNUCCHI (Dipartimento di Scienze della Terra, Università di Modena e Reggio Emilia).

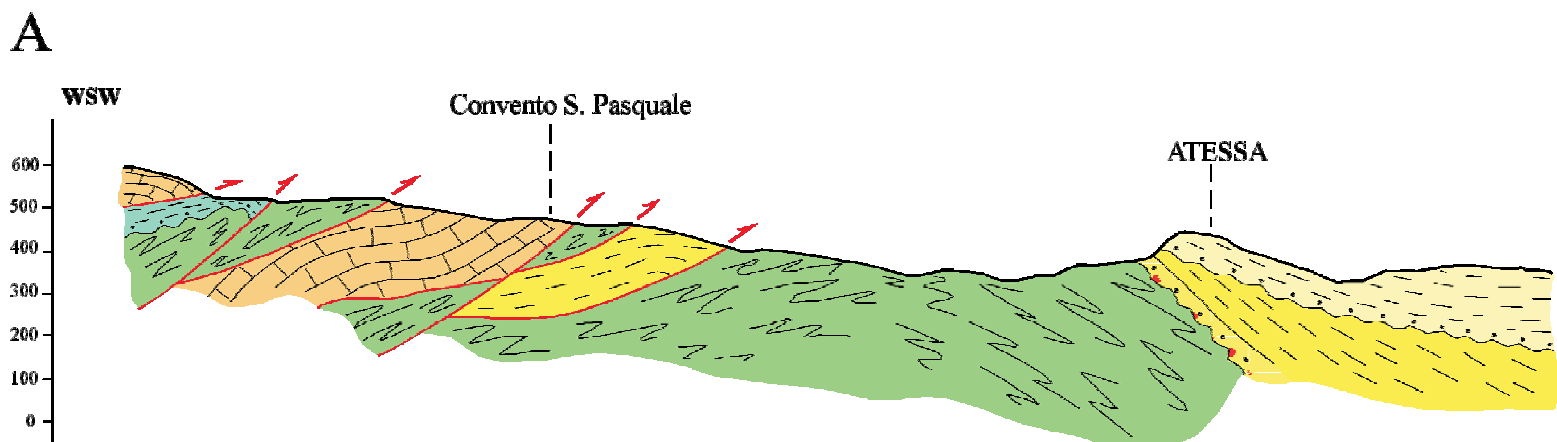


Fig. 2 - Geological cross-section of the Osentto and Sinello Valleys Geological Map.

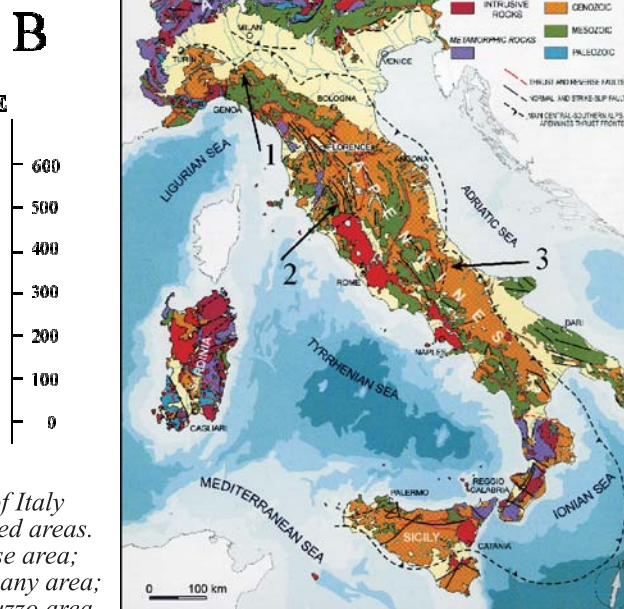


Fig. 3 - Geological sketch map of Italy and location of the studied selected areas. 1= location of the Oltrepò Pavese area; 2= location of the southern Tuscany area; 3= location of the southern Abruzzo area.

INTRODUCTION

Stratal disruption and block-in-matrix fabric are the peculiar features of chaotic rocks known as *mélanges* or broken (dismembered) formations (Hsü, 1968; RAYMOND, 1984; COWAN, 1985). From a genetic point of view, we can distinguish three types of *mélanges*: sedimentary, tectonic and diapiric (BYRNE, 1984; VOLLMER & BOSWORTH, 1984; KIMURA & MUKAI, 1991). At the mesoscopic (outcrop) scale, the block-in-matrix fabric generally characterizes both gravitational and tectonic *mélanges*, since it can be the result of either the mixture of blocks and mud, due to mud and debris cohesive flows, or layer-parallel extension and shearing, due to tectonic deformation (BRANDON, 1989; CHARVET & OGAWA, 1994; HASHIMOTO & KIMURA, 1999).

These units, characterised by a more or less severe degree of stratal disruption and/or blocks of different sizes chaotically embedded in a clay-rich matrix are extensively cropping out in the Apennines, where they have been called in different ways throughout 60 years of study: Argille Scagliose, argille brecciate, caotico eterogeneo, Chaotic Complex, Undifferentiated Complex, Ligurian *Mélange* and olistostrome (MERLA, 1951; FLORES, 1955; PAGE, 1963; ABBATE & SAGRI, 1970). Many of these terms used in the Apennines have been applied to disrupted rocks elsewhere: Hsü (1965), for example, identified some parts of the Franciscan Complex of California as "argille scagliose", and PAGE (1978) interpreted some Franciscan rocks as "olistostromes".

Particularly the term olistostrome, originally defined as a slid rock body (FLORES, 1955), has been successful and widely used for bodies of sedimentary rocks emplaced by gravity-driven processes without distinguishing between sedimentary (slides and other mass wasting transports) and tectonic (orogenic landslides, allochthonous gravity sheets) (HOEDEMAEKER, 1973; ABBATE *et alii*, 1981; RAYMOND, 1984; COWAN, 1985; CHANIER & FERRIÈRE, 1991; TAIRA *et alii*, 1992; ORANGE & UNDERWOOD, 1995; STEEN & ANDRESEN, 1997). In the last twenty years, new structural and stratigraphic studies and extensive mapping in the classic cropping area of the Emilia Apennines (BETTELLI & PANINI, 1989, 1992; CASTELLARIN & PINI, 1989; DE NARDO, 1994; BETTELLI *et alii*, 1995, 1996a, 1996b; PINI, 1992, 1999 and reference therein) showed that these rocks, previously grouped under the general Argille Scagliose or Chaotic Complex terms, are actually composed of two basic types of chaotic rocks: (1) tectonically deformed multilayered sequences (non-metamorphic tectonites or broken/dismembered formations) and (2) mud and debris flow deposits (sedimentary argillaceous/clayey breccias).

The recognition, significance, geometry and even the nomenclature regarding these chaotic rocks were always a challenge for field geologists. Different types of chaotic bodies have been defined based on informal terms (HOEDEMAEKER, 1973; ABBATE *et alii*, 1981; RAYMOND, 1975, 1984; PINI, 1999), but in many cases, they were not accepted, because too tied to genetic concepts.

The field experience acquired by studying the type areas of the Northern Apennines converged

in a research program, sponsored by C.N.R. and S.G.N. (Progetto Carte Prototipali), whose specific goal is to give indication about chaotic rock mapping and classification. Based on the presence of different types of incoherent sedimentary rocks, we have chosen three locations, Southern Abruzzo (Figs. 1, 2 and 3), Oltrepo Pavese (Figs. 3 and 5) and Southern Tuscany (Figs. 3 and 6), as different case histories to meet different situations in terms of regional geology. In these areas, we distinguished units previously grouped under the generic term "Chaotic Complex". The main results of the project and the proposed mapping principles and techniques are now accessible in the present atlas, through the exemplification offered by the Southern Abruzzo.

GEOLOGICAL SETTING

The Southern Abruzzo study area is characterised by the extensive presence of Sicilide Units, an allochthonous thrust-nappe consisting of rocks deposited in an internal palaeogeographical Apennine domain (BIGI *et alii*, 1992). In the Southern Apennine stack, the Sicilide Units pile up on top of both the Mesozoic-Cenozoic carbonate rocks of the Latium-Abruzzo-Matese and Campania-Lucania Units, and the more external Lagonegresi-Molisane Units as well as on the internal

Apulian Units (Maiella). The Sicilide Units (Fig. 1) are unconformably overlain by both Palaeogene and Neogene deposits (Irpinian Units: BIGI *et alii*, 1992, Molise Units in this work) and by sediments deposited in the Apennine foredeep during the Late Neogene (Fig. 1).

In the study area the Sicilide Units are represented only by the Varicoloured Shales Formation, which in the past has been variously named and considered with respect to its stratigraphic and/or palaeogeographical location. The Varicoloured Shales Formation is separated from the overlying Molise Units by a

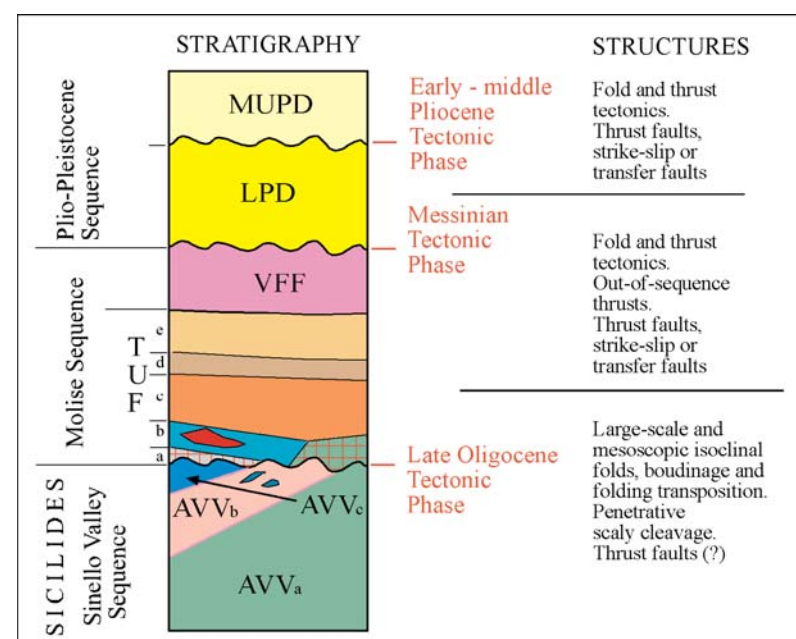


Fig. 4 - Stratigraphic scheme of the Oseto and Sinello Valleys Geological Map. Legend: AVV = Varicoloured Shales Formation (a, b, c: different lithofacies); TUF = Tuffillo Formation (a, b, c, d, e: different lithofacies); VVF = Vallone Ferrato Formation; LPD = Lower Pliocene deposits; MUPD = Middle-Upper Pliocene deposits. Main tectonic phases are synthetically reported.

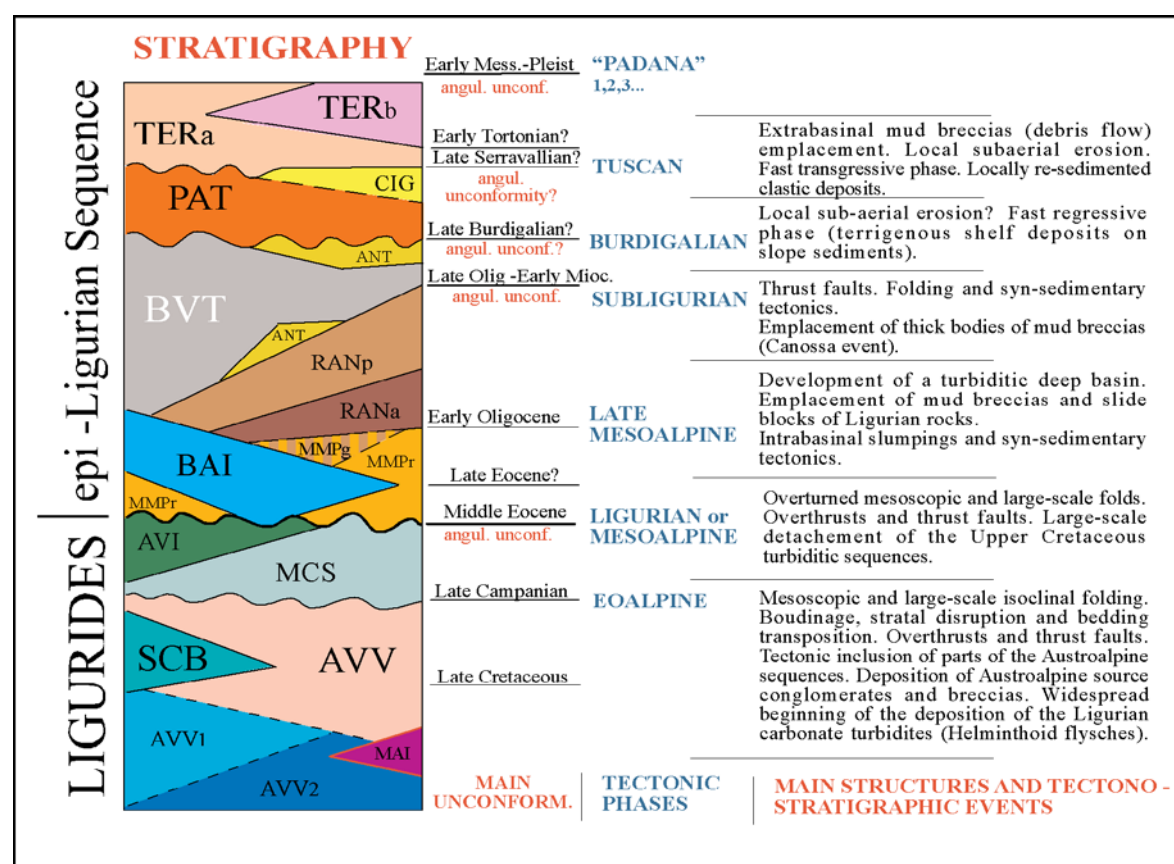


Fig. 5 - Stratigraphic scheme and main tectonic phases (Oltrepo Pavese, Northern Apennines).

The "Chaotic Complex" of the previous authors has been here subdivided into various units belonging to Ligurides and epi-Ligurian Sequence. Ligurides comprise tectonites characterised by a pervasive deformation related to a polyphase folding: Cassio Varicoloured Shales (AVV, Upper Cretaceous), Scabiazza Sandstones (SCB) and Viano Shales (AVI, Palaeocene-Lower Eocene). Chaotic sedimentary breccias of Middle Eocene-Upper Miocene age are included within the epi-Ligurian Sequence (Baiso Mud Breccias: BAI, Val Tiepido-Canossa Mud Breccias: BVT, Montardone member of the Termina Fm, TERb). Main tectonic phases are synthetically reported.

Legend: MAI=(Maiolica limestones); MCS = Monte Cassio Fm (Upper Cretaceous); MMPr = Monte Piano Marls (varicoloured lithozone, Middle-Upper Eocene); MMPg = Monte Piano Marls (grey lithozone, Upper Eocene); RANa = Ranzano Fm (arenitic lithozone, Lower Oligocene); RANp = Ranzano Fm (arenaceous-pelitic lithozone, Lower Oligocene); ANT = Antognola Fm (Upper Oligocene- Lower Miocene); PAT = Pantano Fm (Lower-Middle Miocene); CIG = Cigarello Fm (Middle Miocene); TERa = Termina Fm (calcarenites and sandstones, Upper Miocene).

net angular unconformity (Fig. 4), and is characterised by an internal penetrative deformation, which was developed before the deposition of the Molise Units, in the Late Oligocene (?)–Early Miocene. In the study area, the Molise Units are represented by the Tufillo Formation and the overlying Vallone Ferrato Formation (Fig. 4). Within the Neogene foredeep deposits, instead, the presence of an angular unconformity allowed the recognition of two major sedimentary cycles: the Lower Pliocene and the Middle-Upper Pliocene sedimentary cycle (Figs. 2 and 4).

At the map scale, the Sicilide Units and the Molise Units are distinctly characterised by a number of reverse and thrust faults striking NNW-SSE and NW-SE, verging to the Adriatic Sea and of Pliocene age (see Figs. 1 and 4). Even though the Molise Units show evidence that they have been folded before faulting as a consequence of older deformation phases, only the Sicilide Units present the mesoscopic penetrative deformation typical of "non-metamorphic tectonites" (i.e. broken or dismembered formations). As the correlative examples of chaotic rocks in the Northern Apennines, the Sicilide Units are characterised, in fact, by the widespread disruption of the original internal stratigraphic order.

MAPPING CHAOTIC ROCKS: PRINCIPLES, CRITERIA, METHODS AND STRATIGRAPHIC CLASSIFICATION

The concepts of "scaly shales" or "scaly clays" (BIANCONI, 1840) and "olistostrome" (FLORES, 1955) cannot be of practical usage in chaotic rock mapping. As PENTA (1950) pointed out the terms scaly shales or scaly clays have proper meaning only as petrographic or lithologic names, since these rocks may be distinguished in different stratigraphic or structural units (Ligurides, sub-Ligurides, Sicilides, etc.). For historical reasons, however, the cited Author admitted their use to indicate the whole allochthonous Ligurian/sub-Ligurian nappe of the Apennines.

The term "olistostrome" literally means "slided or slumped body" and it does not describe a well defined rock-body recognizable in the field on the basis of structural and textural characters: this term, in fact, is a genetic term embracing from sedimentary gravity flows to gravitational emplacements of rock bodies. Following this meaning, in the past, the term olistostrome was applied by the Italian Geologists to very different chaotic rocks, ranging from small debris flow deposits to huge shaly chaotic masses mostly characterised by widespread stratal disruption and lacking of lateral continuous beds. With the same terms were also indicated thrust-nappes or tectonic units whose emplacement was assumed as gravitational.

Moreover, since only an arbitrary limit can be placed between a body generated by an "orogenic landslide" and an "olistostrome" made up of huge blocks of hard rocks (ABBATE *et alii*, 1981), the term olistostrome cannot be restricted to specific chaotic rocks displaying a more or less fragmented texture (clasts dispersed in a shaly matrix: mature olistostrome).

The mapping of chaotic rocks in different areas of the Northern Apennines (BETTELLI *et alii*,

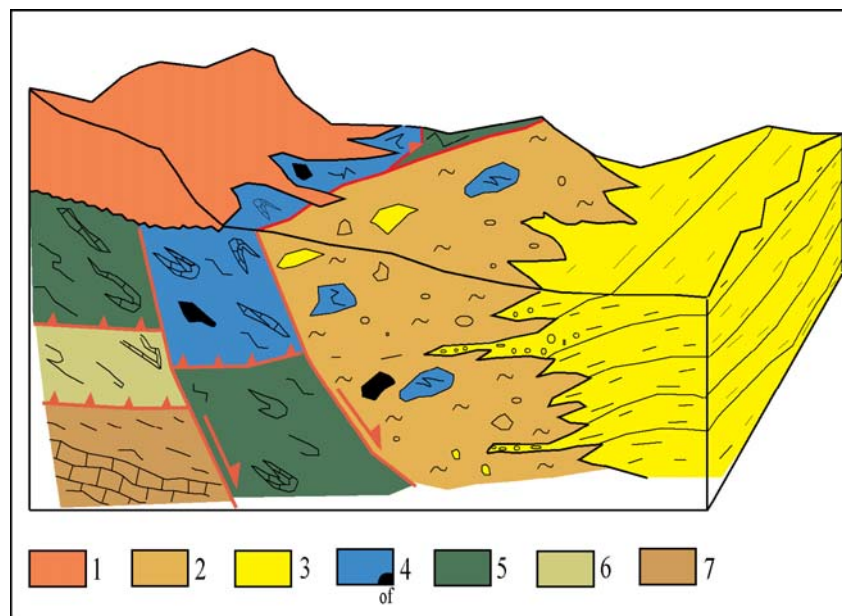


Fig. 6 - Stratigraphic-structural sketch of the southwestern side of the Radicofani basin (Southern Tuscany).

1) Pleistocene volcanic rocks of the Mt. Amiata. Pliocene deposits: 2) Chaotic sedimentary breccias generated by debris and mud flows: the clasts are from the Ligurian formations (mainly Palombini Shales) and from the conglomeratic-arenaceous lithotypes of the Pliocene units; 3) arenaceous-siltitic blue-grey clays intercalated with rudites and arenites. Ligurides; 4) Ophiolitic tectonic Unit (Palombini Shales including ophiolitic blocks: of) (Lower-Upper Cretaceous); 5) Santa Fiora tectonic Unit composed of turbiditic alternations of claystones and limestones

similar to the Sillano Fm (Lower Eocene-Cretaceous). 6) Canetolo Tectonic Unit. 7) Tuscan Nappe. A complex and irregular heteropic contact marks the transition between sedimentary breccias and Pliocene deposits making not always possible to map the interfingerings (see Fig. 7b). The Pliocene emplacement of chaotic sedimentary breccias is related to east-verging listric syn-sedimentary normal faults bordering the Radicofani basin; the continuous and rapid subsidence associated with the syn-sedimentary fault activity triggered sediment instability with abundant and large mass movements. The Palombini Shales and the Sillano Fm are typical tectonites (broken formations with a block-in-matrix deformed fabric).

1995, 1996a, 1996b) helped to establish few experimental and objective criteria useful to distinguish between sedimentary and tectonic disruption.

The sedimentary products result from high-density gravity flows involving cohesive material characterised by different proportions of mud and debris. These mechanisms generate a real new sedimentary rock (a new lithotype) through the almost complete disaggregation of a source rock (Fig. 7). For this reason, they can be objectively recognized in the field and they may be distinguished from the surrounding rocks on the basis of their peculiar texture and composition. Moreover, these sedimentary disrupted rocks maintain primary contacts (i.e. sedimentary) with the country rocks. On the other side, the chaotic rocks generated by deformation include both the products of pervasive tectonic deformation (Figs. 8 and 9a-c) and of gravity displacement of more or less intact large bodies (up to several km³ wide), i.e. slide masses, where their original lithology, textures and structural fabric can range from being totally maintained to slightly or completely destroyed (Figs. 10 and 11). The original contact of a gravity-displaced body with the country rocks is structural at the base, while the sediment on top can be either represented by a non-chaotic sedimentary sequence stratigraphically deposited soon after disruption, or by other gravity-displaced rock-masses and in the latter case also the top contact is structural (Figs. 10 and 11). Field methods are not able to differentiate among structural contacts that have been generated by sedimentary or tectonic processes.

Moreover, in the Apennines, some of the chaotic rocks result from more than one process, so that rocks already tectonically deformed before being displaced, have been emplaced in their final location due to successive either tectonic or sedimentary mechanisms.

In general, the experience of the last 20 years of fieldwork in the Apennine chaotic rocks leads to the conclusion that the problem of identify the mechanism responsible for disruption must be clearly held separated from the problem regarding their present location. If we want to

know whether the genesis of a chaotic rock is due to sedimentary or tectonic mechanisms, objective and distinctive characters are: the texture, the lithologic assemblage (coherence, incoherence: from the mesoscopic scale to the map scale) and the internal structure (the style of the deformation).

If, instead, we are interested in the mechanisms that brought a chaotic rock-body to acquire the present-day location, the characters to consider are: the relations and the nature of the contacts (i.e., if they are primary or secondary, sedimentary or structural) with the country rocks, and the extension and thickness of the rock body itself. Other useful criteria can be: the presence of exotic blocks or if the body itself constitutes an exotic block stratigraphically unrelated to the main mass (Fig. 11), the existence of contrasting structural styles within the same rock-type, the presence of an incongruous stratigraphic location, the existence of contrasting palaeoenvironmental characters.

In the Apennines, these diagnostic criteria allow the recognition and mapping of the following genetic types of chaotic rocks: sedimentary breccias or argillaceous (clayey) breccias (debris flow and mud flow deposits) (Fig. 7); *in situ* tectonites or tectonites still in their original position with or without "exotic blocks" (Figs. 8 and 9), gravity displaced tectonites or tectonites in secondary position (Figs. 10 and 11); associations of tectonites and sedimentary breccias (Fig. 12).

The lithostratigraphic classification and nomenclature of chaotic rocks

The terms commonly used for rocks that have a "block-in-matrix" fabric at the outcrop scale are olistostrome and mélange. In the more recent geological literature mélange is used exclusively as a descriptive, non-genetic term referring to the structure of the rock and not to the process by which it has been generated. On the contrary, the term olistostrome is clearly a genetic term which does not provide any information on the textural/structural characteristics of the rock itself; this term may be applied to whatever accumulation generated by any type of mass movements under gravitational influence.

The term *mélange* can, therefore, be used in the lithostratigraphic classification, the term *olistostrome*, instead, cannot be used for this purpose. The extensive field mapping carried out on the Po Valley side of the Northern Apennines, in Southern Tuscany and in the Abruzzo area, showed that in many cases it is not imperative to use a term like "*mélange*" in order to discriminate and to name mappable bodies of chaotic rocks. Fig. 13 shows the classification scheme and the stratigraphic nomenclature that we propose.

HYPOTHESIS ON THE MECHANISMS GENERATING THE CHAOTIC ROCKS IN THE APENNINES

Argillaceous or shaly-matrix sedimentary breccias

At present, detailed sedimentological studies of this particular type of chaotic rocks are

completely lacking, even though the gravitational processes and mechanisms of transport and deposition are well known. The palaeogeographic and palaeostructural conditions responsible for the formation of such regionally extensive and thick (up to 300 m) chaotic deposits are, instead, unknown. Some hypotheses assume the existence of structural highs generated by active thrust-faults or by alignments of mud-volcanoes and/or mud-diapirs (Fig. 14), but in the field there are no direct evidence supporting these ideas, because the source areas of the deposit is no longer detectable. For this reason, and for the purpose of the present project, we have chosen to study the Pliocene debris flow deposits of the Radicofani basin, where, on the contrary, the breccias source area is well established within the unstable basin margin undergoing active tectonics (Fig. 6). These Pliocene debris flows of the Radicofani basin reworked clay-rich

sediments already deformed and disrupted during previous tectonic events, that helped increasing the intrinsic weakness and allowed them to reach a high textural maturity without being transported for a long distance.

Tectonites formed by a single lithostratigraphic unit

Two different hypotheses have been advanced, so far, on the deformation mechanisms able to generate tectonites at the expenses of a single lithostratigraphic unit (Fig. 14). Both of them are related to offscraping and intraprisim deformation in a trench-forearc setting:

- Simple shear along "migrating" brittle fault-zones (a mechanism of fault zone thickening due to fluid expulsion and strain hardening) (Fig. 14D);
- Polyphase folding (Fig. 14A-C).

Since the tectonites are usually several hundred meters thick and they are commonly



Fig. 7 - Sedimentary breccias.

The sedimentary breccia or the argillaceous (clayey) breccia (matrix-supported breccia) is a chaotic rock characterised by a detrital matrix supporting larger, scattered clasts. This particular texture has been generated by high-density mud-flow and/or debris flow mixing heterogeneous source-rocks (e.g., multilayered rock-units characterised by alternating shaly, marly, limestone and sandstone beds). Few field objective criteria, as the close inspections of the detrital texture of fresh rock samples, can discriminate this type of deposit. For example, the chaotic deposits within the epi-Ligurian Sequence of the

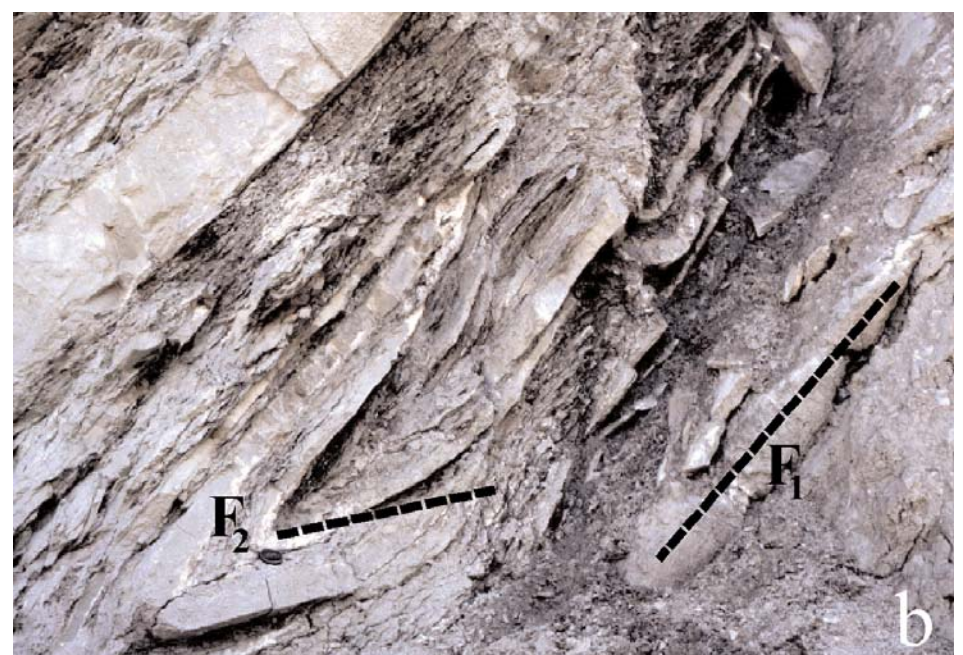


Emilia Apennines, Marecchia Valley, Oltrepo Pavese (Fig. 7a) and the Pliocene sequence of Southern Tuscany (Radicofani Pliocene basin: Fig. 7b) belong to these sedimentary chaotic rocks (olistostromes *sensu strictu*). a) Baiso argillaceous Breccias cropping out at the base of the epi-Ligurian Sequence (Oltrepo Pavese area). A thick (up to 100 m) chaotic body mainly made up of a detrital clayey matrix with a sparse few clasts of hard rocks. b) Tabular body of argillaceous breccias (B) intercalated in the Pliocene blue-grey silty clays (SC) of the Radicofani basin (Southern Tuscany). Note the sharp flat lower contact and the more undefined upper contact.



Fig. 8 - In situ non-metamorphic tectonites or broken/dismembered formations.

The in situ tectonites are characterised by a mesoscopic scale deformation fabric of "blocks dispersed in a deformed shale", unlike the hand-samples (Figs. 8a and 9a). The deformation produced a penetrative scaly cleavage in the original shaly layers (Figs. 8a and 9c), and a systematic boudinage and stratal disruption of the competent marly, sandy or calcareous turbidite beds (Fig. 8a). The common characteristic of these chaotic rocks is the loss of the original stratigraphic order, because of pervasive disruption and transposition by isoclinal folding (Figs. 8b; 9b and 9d). At the map scale the following types of tectonites have been distinguished: monoformal tectonites or tectonites without exotic blocks and multiformal tectonites or tectonites with exotic blocks. This distinction is based on the assumption that the composition of the original stratigraphic sequence is well known. Monoformal tectonites result from disruption of the "basal complexes" of: the Upper Cretaceous-Lower Eocene Ligurian Flysches



(Scabiazza Sandstones and Cassio Varicoloured Shales of the Oltrepo Pavese area and Varicoloured Shales, Palombini Shales and Sillano Formation of the Val Tiberina, Val Marecchia and Southern Tuscany areas), the Sicilide Units of the Southern Abruzzo and some lithofacies of the Tertiary Viano Shales cropping out in the Oltrepo Pavese and Emilia Apennines. A multiformal tectonite is the Coscogno *Mélange* of the Emilia Apennines, which is a tectonic unit formed by Ligurian, sub-Ligurian and epi-Ligurian rocks. a) Palombini Shales of the Southern Tuscany area. A striking tectonic layering due to the preferred alignment of limestone bed segments is apparent. b) Two orthogonal sets of superimposed isoclinal folds visible in a coherent portion of the Palombini Shales in the same outcrop of Fig. 8a (F1 and F2: first and second fold generation hinge-line, respectively). These coherent blocks represent different arrested stages of the progressive deformation leading to the block-in-matrix final stage through polyphase folding, boudinage and bedding transposition (see also Fig. 9d).

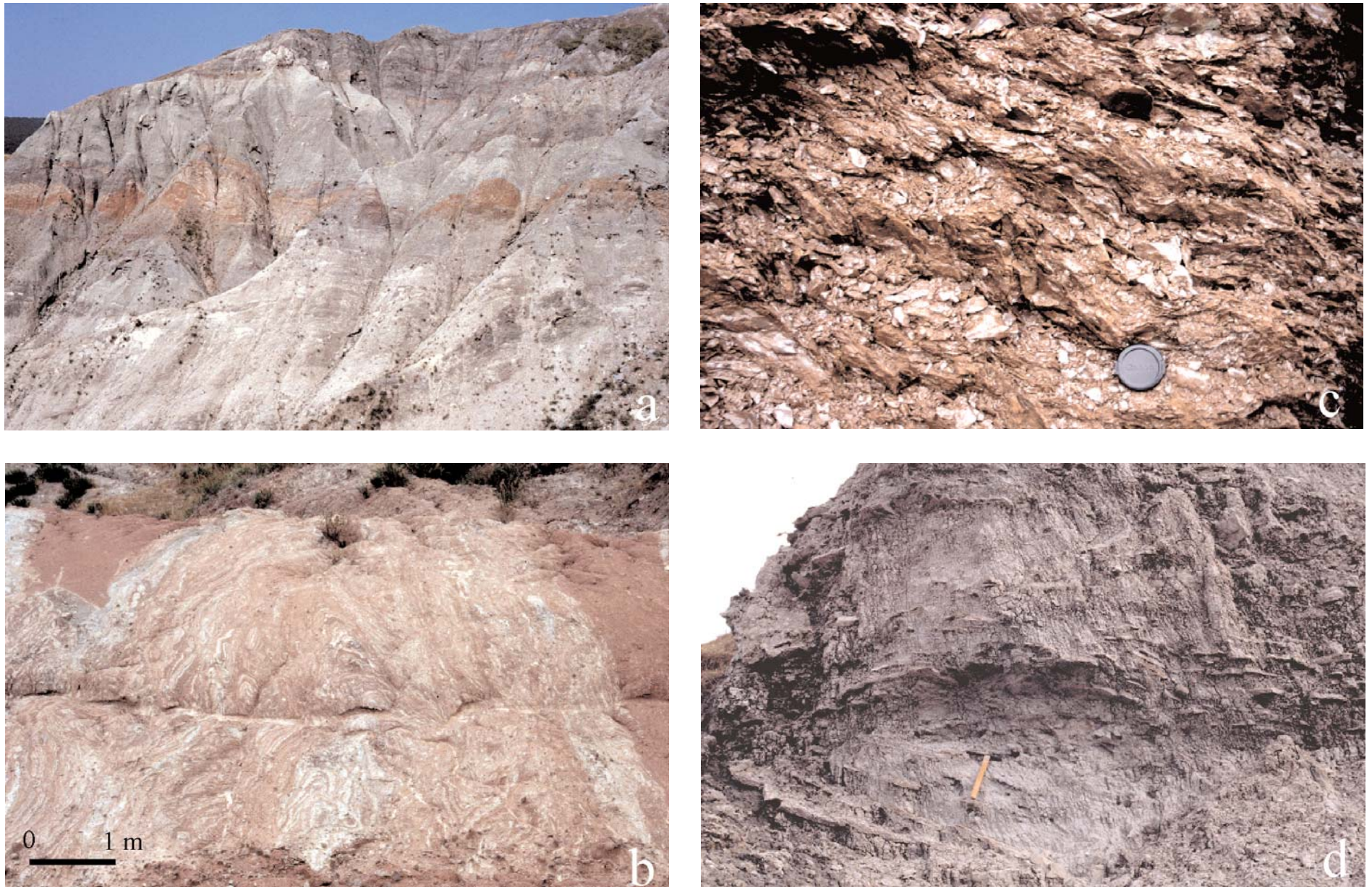


Fig. 9 - In situ non-metamorphic tectonites or broken/dismembered formations. The tectonic deformation of original multilayers where the shale is the major component, as for the various units of the "argille varicolori" of the Northern Apennines and Southern Abruzzo, is still represented by a typical "block-in-matrix" fabric, but the matrix is largely predominant on the blocks. The matrix is the original argillaceous sedimentary material characterised by a penetrative scaly cleavage which is the main character of the rock at the outcrop scale (Fig. 9c) together with the pronounced mesoscopic foliation (Fig. 9a), related to a preferential orientation of the stretched bed packages resulting in a striking colour banding. This banding was caused by brittle and ductile boudinage of formerly continuous turbidite layers and pelagic clays, through a mechanism of layer-parallel extension and flattening. On the other hand, the presence in the coherent por-

tions of close-to-isoclinal disharmonic refolded folds (Fig. 9b and 9d), and rootless folds/isolated fold-hinges in the incoherent sections clearly indicates that the boudinage occurred as layer parallel extension along fold limbs and that these units were characterised by a complete transposition during polyphase folding (VANNUCCHI & BETTELLI, 2002; BETTELLI & VANNUCCHI, 2003).

a) An incoherent portion of the Val Marecchia Varicoloured Shales (Marecchia Valley, Northern Apennines). b) A large coherent section of the Cassio Varicoloured Shales (Panaro Valley, Northern Apennines) displaying refolded isoclinal folds. c) Penetrative scaly cleavage in the Cassio Varicoloured Shales (Secchia Valley, Northern Apennines). d) Refolded isoclinal folds in the Scabiazza Sandstones (Panaro Valley, Northern Apennines).

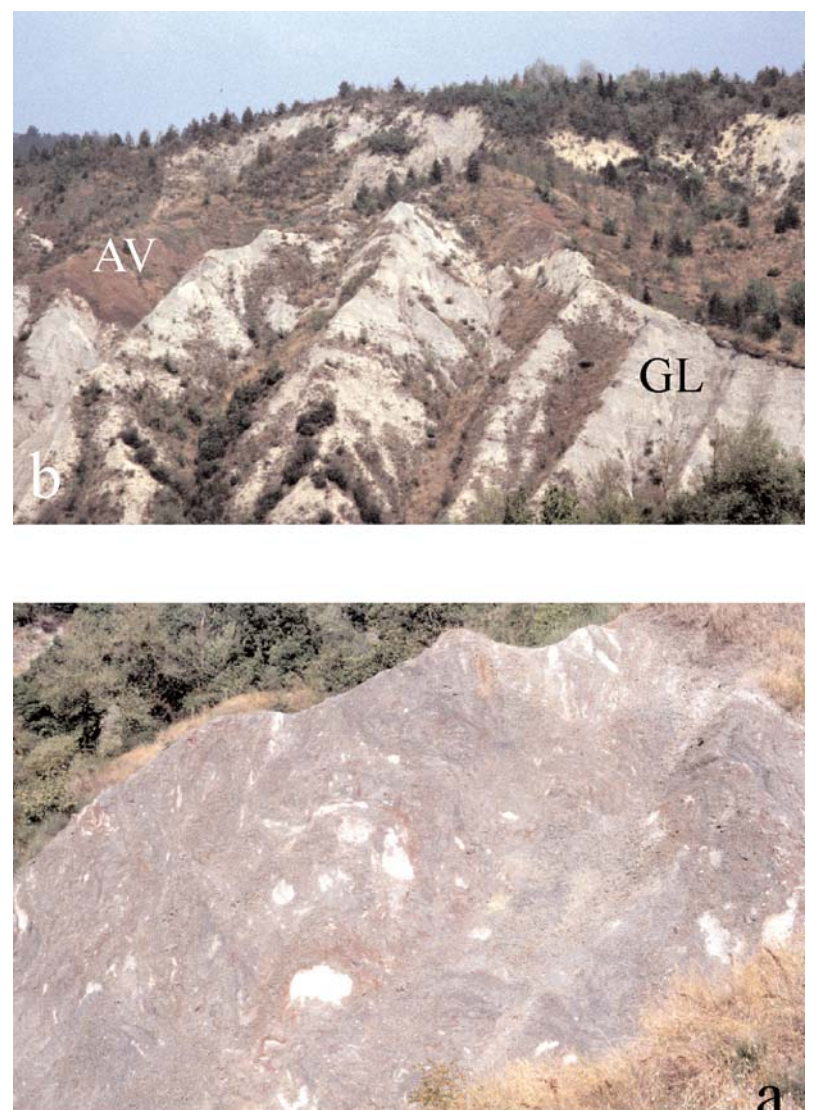
characterised by polyphase folds, we argue that the latter hypothesis better explains the observed disruption (VANNUCCHI & BETTELLI, 2002; BETTELLI & VANNUCCHI, 2003). However thickening of brittle fault zones is a valuable process that may well explain local situations.

Tectonites with "exotic" blocks

Even though the origin of the tectonites with exotic blocks is still puzzling, there are hypothesis and among them the most significant, according to the observed settings in the Apennines, are:

- Wide strike-slip fault zones within the Ligurian nappe of the Emilia Apennines;
- Underthrusting and underplating, through duplexes, along the basal décollement of the Lower Miocene orogenic wedge (Fig. 14D), that would well have resulted in a mixture of large blocks coming from different stratigraphic sequences (Ligurian and sub-Ligurian Sequences). Among the open problems concerning tectonites with exotic blocks there are also their exhumation mechanisms. Possible explanations can be related to out-of-sequence thrust or to tectonic denudation caused by large low-angle extensional faults active during the Lower-Middle Miocene gravitational collapse of the orogenic wedge.

Fig. 10 - Gravity-displaced tectonites. Gravity-displaced tectonites or tectonites in secondary position are difficult to identify in the field, because they are mostly subordinate to the recognition of the stratigraphic and structural settings: general criteria can not be established and each field case-history should be studied constraining the interpretation to the particular location. In addition to the well-known examples of the Northern Apennine Miocene foredeep, chaotic bodies of this type have been recognized at the base of the Emilia epi-Ligurian Sequence (Figs. 10a and 11b), in the Southern Tuscany (Radicefani basin) and in Abruzzo (at the base of the Tuffillo Formation south of the Mt. Maiella: "Colata dell'Aventino-Sangro", Fig. 11a). a) Slide block of Cassio Varicoloured Shales at the base of the epi-Ligurian Sequence (Baiso area, Emilia Apennines). The former mesoscopic structural fabric was slightly modified as a consequence of gravity displacement giving to the rock a more chaotic and unusual structure through the loss of the original planar foliation. b) Large slide block of the Ligurian Upper Cretaceous Marecchia Varicoloured Shales (AV) intercalated within the Ghioli di Letto Fm (Miocene foredeep sequence: GL). The lower and upper contacts with the host sediments are mechanical/structural and stratigraphical, respectively, and this may be a good evidence, but is not the key in interpreting the mechanism of the ultimate emplacement of the tectonite block.



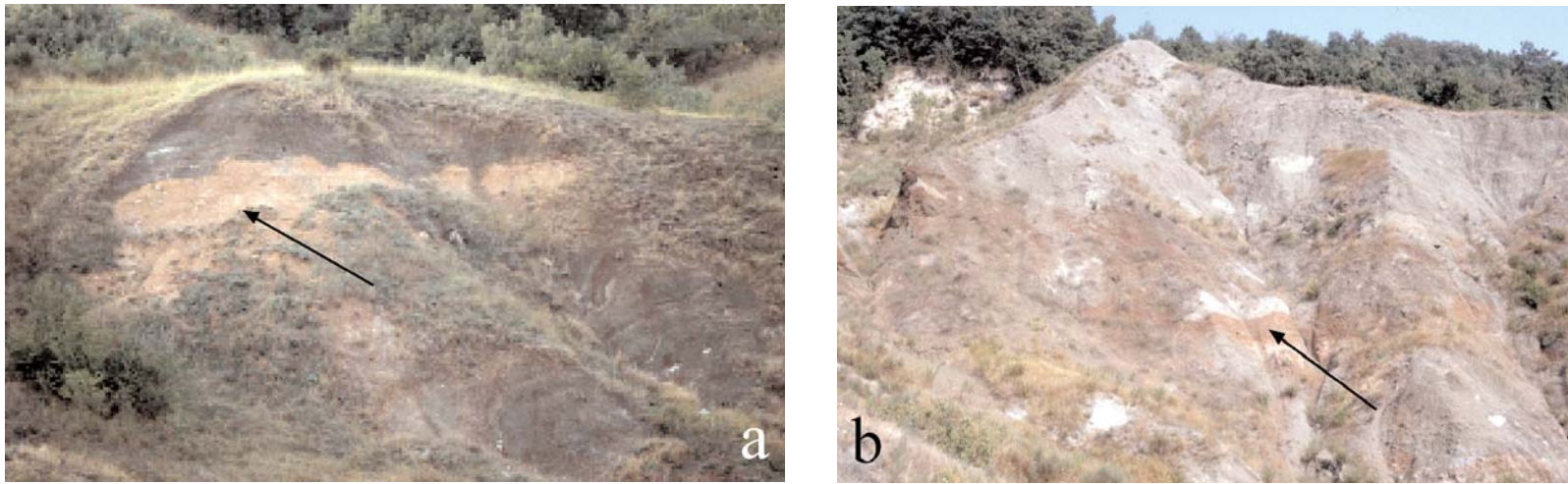


Fig. 11 - Gravity-displaced tectonites. Where tectonites contain exotic blocks pertaining to an overlying unconformably sequence, or where the tectonites itself are representing exotic blocks, the mechanism of their final emplacement may be well constrained.

a) Slide block of the Varicoloured Shales (Sinello Valley Sequence, Southern Abruzzo) containing a lenticular body of Upper Oligocene (?)–Lower Miocene reddish marls (arrow) belonging to the unconformably overlying Tuffillo Fm (unit a in Fig. 4).

b) Slide block of the Cassio Varicoloured Shales with an exotic small block (arrow) of the unconformably overlying Middle-Upper Eocene Monte Piano Marls of the epi-Ligurian Sequence (Emilia Apennines, Baiso area).

Tectonites displaced by gravity

Tectonites that have been displaced by gravitational processes are mainly recognizable through their stratigraphic setting and on the basis of the association with chaotic rocks of clear gravitational origin (i.e. debris flow deposits), rather than on detailed observations on their mesoscopic style of deformation. Only in few examples, in fact, as in the Baiso area of the Modena Apennines (BETTELLI *et alii*, 1996), the gravitational displacement of these already deformed rocks introduced some modifications on their style and degree of deformation (Fig. 10a).

Chaotic assemblages of tectonites and sedimentary breccias

Only few examples of these chaotic rocks have been recognised in Apennines where they don't have a direct correlation with a particular geological mechanism. For example, the Lower-Middle Eocene chaotic assemblage present on top of the Ligurian Val Rossenna sequence of the Emilia Apennines implies gravitational mass movements, which generated a stack of distinct slid rock bodies and debris flow deposits. In other cases, as for the Modino, Sestola-Vidiciatico, Firenzuola or Carpinaccio mélanges, which are present within or on top of the Oligocene-Miocene foredeep sequences of the Northern Apennines (i.e. Macigno, Modino, Cervarola and Marnoso-arenacea formations), this interpretation seems to be poorly constrained and manifestly inadequate. Such large assemblages of chaotic rocks (up to several km thick) may, in fact, have been generated either by sedimentary or tectonic processes at the toe of the advancing orogenic wedge. In the latter case, the observed debris flow deposits and the large blocks (up few km large) of Ligurian/sub-Ligurian tectonites would represent, at least partly, sedimentary deposits tectonically recycled by frontal accretion and underplating (Fig. 14D).

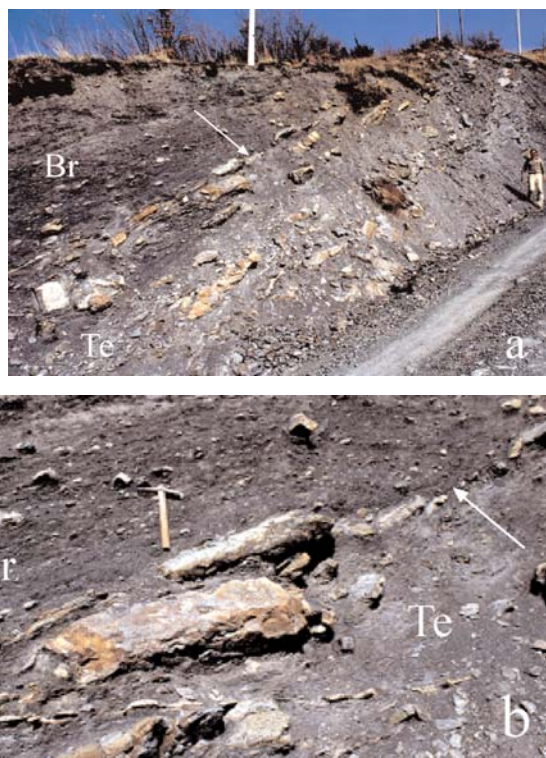


Fig. 12 - Association of sedimentary breccias and tectonites.

Some examples of this problematic type of association in the Northern Apennines, as the Rio Cargnone Complex, the Shaly-Calcareous Unit or Sestola-Vidiciatico tectonic Unit, and the Firenzuola Mélange, are lacking a full genetic explanation. When sedimentary breccias are prevalent respect to tectonites (e.g., the chaotic bodies at the base of the epi-Ligurian sequence in Emilia and Oltrepo Pavese areas: the Baiso Mud Breccias-Val Fossa Member), the whole chaotic mass has been interpreted as a debris flow deposit containing large slide blocks preserving their original fabric.

a) Sestola-Vidiciatico tectonic Unit: a close association of sedimentary breccias (Br) and huge blocks (Te) of Ligurian and sub-Ligurian tectonites (locally with few inclusions of slope apron deposits: Fiumalbo Shales and Marmoreto Marls). b) Close-up of the Fig. 12a: the nature of the contact (arrow) between the sedimentary breccia (Br) and the tectonite (Te) is uncertain.

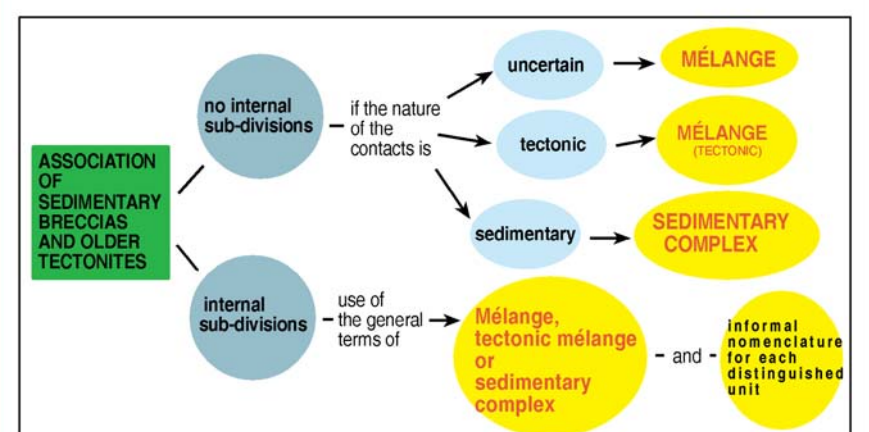
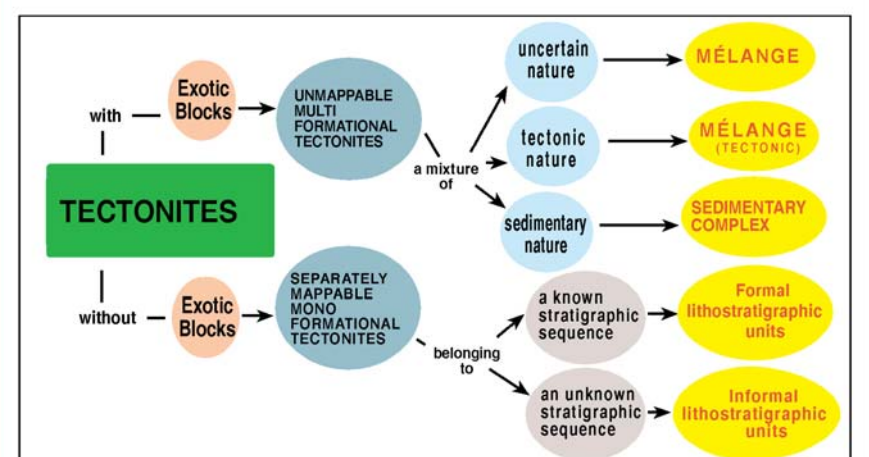
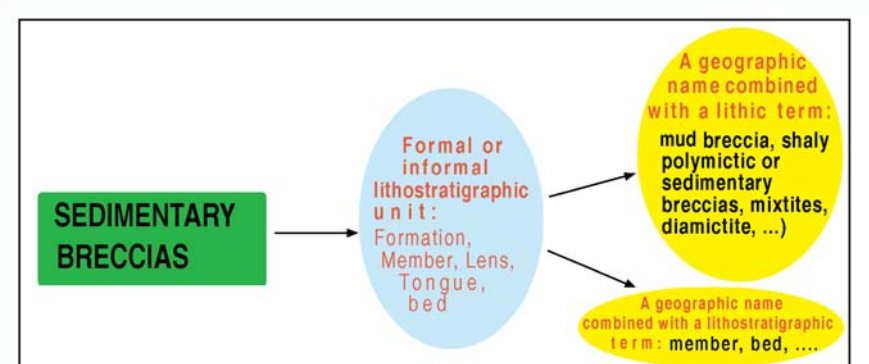
Fig. 13 - A proposal for the classification of Apennine chaotic rocks.

A mappable chaotic deposit identified as a sedimentary breccia, with or without a precise stratigraphic position within the sedimentary sequence, can be considered like a lithostratigraphic unit, either formal or informal, and may be named using a geographic name combined with a descriptive lithological term, as shaly-matrix sedimentary breccias or argillaceous breccias.

The in situ monoformal tectonites derived from the pervasive deformation of a single lithostratigraphic unit can be named using the traditional lithostratigraphic nomenclature.

The possible lack of primary undeformed contacts with the surrounding units can inhibit in considering a monoformal tectonite as a real formal lithostratigraphic unit. Therefore, lacking the undeformed sequence, it seems more correct to use an informal lithostratigraphic nomenclature.

The use of general terms (like *mélange* or *complex*) may be necessary for multiformal tectonites or tectonites displaced by gravity, association of sedimentary breccias and tectonites, if each component is not mappable by its own. Different types of map symbols, as overlapping symbols on map colours, can differentiate single units within this kind of chaotic assemblages.



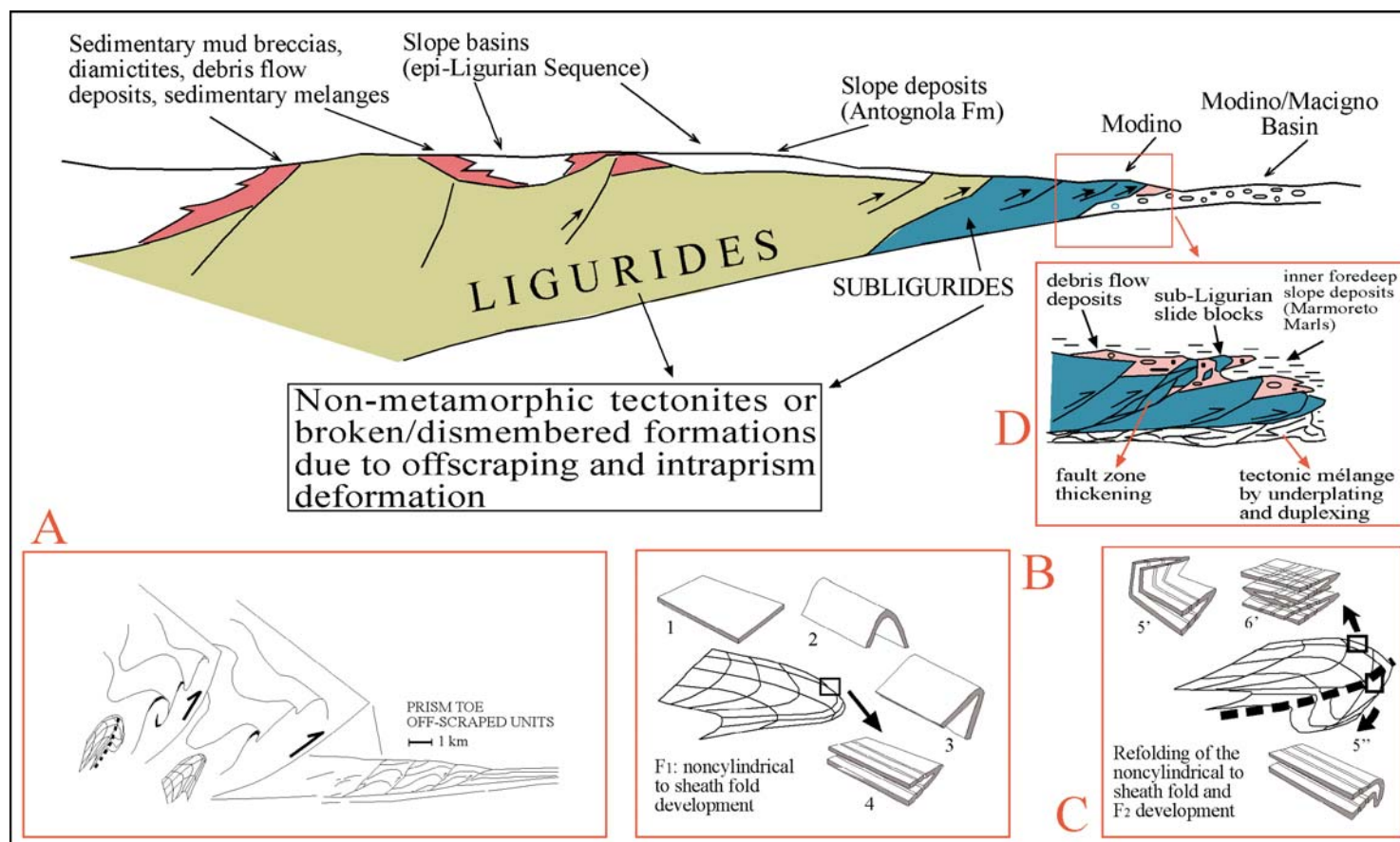


Fig. 14 - Hypothesis on the mechanisms generating the chaotic rocks.

Summary of the inferred sedimentary and tectonic settings where the different chaotic rocks of the Northern Apennines were generated. The tectonic wedge represents the Northern Apennine orogenic wedge during the collisional stage (Early Miocene).

Insets A, B and C show non-cylindrical to sheath folds development and coaxial refolding of offscraped units during the Cretaceous-Eocene oceanic subduction: this seems the more consistent mechanism accounting for the deformation style of the non-metamorphic tectonites of the Northern Apennines and Southern Abruzzo; generation of non-cylindrical folds (B) and coaxial refolding of first generation non-cylindrical folds (C). 1 to 4 are steps of

folding showing the boudinage of fold limbs (From VANNUCCHI & BETTELLI, 2002).

Inset D is a close-up on the deformation front at the wedge toe: debris flow deposits, slide blocks of Ligurian/sub-Ligurian tectonites and slope apron sediments, firstly accumulated at the wedge toe, are tectonically recycled by underplating and duplexing.

This mechanism is proposed for the origin of the extensive and thick mixtures of sedimentary breccias and tectonites (i.e., the Sestola-Vidiciatico tectonic Unit and the Firenzuola Mélange) thrust on the Miocene Northern Apennines foredeep sequences (Macigno, Modino, Cervarola and Marmoso-arenacea lithostratigraphic units).

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