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Argille scagliose (scaly clay) is a geological term first used in 1840 to describe rocks in the Northern Apennines of Italy. The term was originally created to stress the mesoscopic scaliness of a type of rock that commonly outcrops in this area. The rock is also typified by a chaotic assemblage of blocky components that are embedded within the scaly matrix. Before the advent of plate tectonic concepts, the extreme complexity of these rocks posed an extreme challenge to interpret with then-standard concepts of deposition processes in sedimentary basins. Similar rocks were recognized in many other mountain belts, thus the term became widely used. At the same time, the emphasis of the term changed from a description of the matrix to a term with multiple, intensely debated, genetic associations. Only after the discovery of plate tectonics was it accepted that these rocks are formed at subduction boundaries, and that the multiple types of embedded blocks can have an origin from both slope-instabilities within an accretionary prism, and from tectonic reworking/deformation processes near the base of an active accretionary prism. This paper reconstructs the scientific evolution of thinking about argille scagliose during the years when it was one of the supreme challenges to sedimentary geologists. The often strong debate between competing hypotheses for the origin of these rocks led to many myths that still outcrop in the geological literature. We explore why this happened, the apparent future of modern research on chaotic rocks in the Apennines and other fossil accretionary prisms, and what is and should productively remain from the long geological controversy over argille scagliose.

Keywords: Argille scagliose; scaly clay; chaotic rock mapping; scaly cleavage; Northern Apennines

Introduction

Argille Scagliose (Bianconi 1840) was one of the few terms coined by Apennine geologists in the nineteenth century that is still widely used in mountain belts across the world. Many geologists continue to refer to it colloquially, especially within the field. But why has this term been so popular? In our opinion, it is a combination of two peculiar characteristics: (1) it is a general term descriptive of an easy-to-observe property of rocks cropping out in many mountain belts, and (2) it exemplifies the long-lasting controversy regarding the genesis of these rocks. The latter characteristic is strongly linked to a second, widely used term that originated in the Apennines in the 1950s: *olistostrome* (Flores 1955). Both terms, argille scagliose and olistostrome, were introduced to describe

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chaotic rocks with peculiar structures and formation patterns that bewildered pre-plate tectonic geologists accustomed to relying on stratigraphic principles to decipher the interrelationships of rock layers. Arguments regarding the use of the two terms illustrate the passionate discussion that accompanied the introduction of new ideas on mountain building. In the Apennines, this discussion was particularly intense. The first problem involved the acceptance of concepts regarding the superposition of nappes, introduced mainly by non-Italian geologists (Steinmann 1907). The second was regarding the driving force responsible for the horizontal translation of nappes. In the 1950s, Italian and foreign geologists considered gravity the main driving force, and it was impossible to make a clear distinction between the deformation and sedimentation processes. Argille scagliose and olistostromes were then considered to be generated by a continuous series of gravitational processes. The difficulty in distinguishing tectonic compression from gravitational tectonic products was associated with uncertainties in identifying large-scale tectonic deformation as opposed to localized stability problems producing large-scale mass wasting.

Looking at the history of Apennine geology through the concepts of argille scagliose and olistostrome provides a good paradigm of the evolution of geological knowledge in the last century. We present a summary of this evolution, analysing how acceptance of new, revolutionary ideas is difficult and how, instead, cultural barriers are reflected in the introduction of a multitude of new terms or in the misuse of already-existing terms. As happens frequently in science, time has dampened the controversy regarding chaotic rocks. In particular, now that work in tectonics focuses more on the mechanics of rocks and mountain belts, geologists often approach chaotic rocks without exploring their nature and significance; this omission is justified by the common opinion that problems regarding chaotic rocks' origin are solved. In this article, we review the great impact that the concepts of argille scagliose and olistostrome have had on understanding of mountain building processes. We also suggest a classification of chaotic rocks on the basis of the experience we gathered over two decades of mapping some classical argille scagliose outcrop areas. The concluding section is devoted to a discussion on modern usage of the geological term scaly fabric, the one remnant of the Argille Scagliose story that still has a central place in modern geology.

Evolution of knowledge of the chaotic rocks

Argille Scagliose (scaly clay)

Bianconi (1840) first used the term argille scagliose to describe clay-rich rocks cropping out in the Northern Apennines. The term meant an aggregate of interlocking flakes with characteristic polished surfaces of preferential separation (Figure 1a). The flakes, or scales, of sizes ranging from millimetres to centimetres, typically merge to form flakes of bigger size. In most cases the clay acts as a matrix surrounding variously sized blocks of stronger rock (Figure 1b). This purely descriptive term for the mesoscopic fabric of deformed clay-rich rocks became extremely popular and was soon used to describe similar and disrupted rock complexes at the regional scale, including both the blocks and clay matrix; in other words, it acquired a lithostratigraphic connotation for the rock unit instead of a characteristic of one of its components (Scarabelli 1848; Bombicci 1882; Bonarelli 1902). Blocks of limestone, marls and sand/silt/claystone were described together with Late Jurassic ophiolites (basalts, gabbros, serpentines, ophicalcites, cherts, etc.) (Figure 2) and pre-Triassic granites (Merla 1952).

In the then-new and controversial hypothesis that the Apennine architecture was formed by allochthonous nappes (De Launay 1907; Steinmann 1907), the argille scagliose

Figure 1. (a) Typical mesoscopic appearance of the argille scagliose. Penetrative scaly cleavage in the Cassio varicoloured shales (Secchia Valley, Northern Apennines). (b) Outcrop of argille scagliose whithout exotic blocks near Monteveglio (Bologna), all components belong to a known stratigraphic unit (Argille Varicolori della Val Samoggia). The deformation responsible for the chaotization is interpreted here as tectonic and the rock body as a broken/dismembered formation.

and their ophiolitic blocks became central to the interpretation of this mountain belt. The argille scagliose were soon linked to genetic processes driven by the Apennine geologists' growing interest in the importance of gravitational sliding during orogenesis (Anelli 1938; Migliorini 1933, 1948; Signorini 1956). Merla (1952), in particular, pushed the lithostratigraphic concept

Figure 2. (a) Sasso di Castro (Northern Apennines, Italy) is an ophiolitic rock body where the overturned crustal oceanic sequence holds basalts on top of the deep-water chert and limestone beds (reddish rocks). (b) Gabbro block in an olistostrome.

of the argille scagliose. In his interpretation the large masses – from hectometres to kilometres in size – of ophiolites and associated well-bedded rocks were also included in the argille scagliose (Figure 3). According to the definition published by Penta (1950), the argille scagliose were allochthonous formations generated by mud flowing and sliding on the slopes of migrating tectonic ridges. The scaly clays were then considered to be gravitationally emplaced allochthonous chaotic rocks (*tettonicamente trasgressive*: i.e. tectonically transgressive) on the autochthonous formations of the Apennines (Merla 1952), rather than being the result of fold–thrust nappe emplacement. Merla (1952) accepted this concept, and strongly promoted among the Apennine geologists the then-novel idea that units can be horizontally emplaced by tectonics while originating elsewhere (i.e. the concept of allochthony). It is necessary, though, to stress Penta's (1950) appeal to go back to the original meaning of argille scagliose. He pointed out that the term was appropriate only as a petrographic or lithologic name, because these rocks may be distinguished in different stratigraphic or structural units (Ligurides, Subligurides, etc.). For historical reasons, though, Penta (1950) allowed that one could use the term to describe the entire allochthonous Ligurian/Subligurian nappe in the Apennines, but only if there was a general consensus among the Apennine geologists to have this additional meaning for Argille Scagliose.

Later, Merla (1956) restricted the lithostratigraphic concept of argille scagliose to the classic definition as the more chaotic portion, characterized by blocks dispersed in a clayey matrix, of the allochthonous Ligurian and Subligurian complex. The allochthonous Ligurian and Subligurian complex, in turn, was defined to be the discontinuous blanket of eugeosynclinal rocks (i.e. oceanic) formed by both argille scagliose and coherent units, that cover the autochthonous formations (Maxwell 1959; Abbate *et al.* 1970b).

The interpretation of the mechanism of emplacement of the argille scagliose as orogenic landslides (Merla 1952) caused the overlap of the term with a particular genesis. This started a still ongoing controversy about gravity tectonics and mass-wasting sedimentary processes. Different stratigraphic, genetic, and geodynamic meanings were ascribed to the structural fabric, as illustrated in an influential paper by Page (1963). The classical interpretation viewed the stratal disruption typical of the argille scagliose as being caused by tectonic gravity sliding along the mechanically weak part of the nappe (Merla 1952; Signorini 1956; Maxwell 1959; Page 1963; Hsü 1967; Abbate and Sagri 1970). The investigators, however, soon realized that different processes could produce dismembering and scaliness within the gravitational emplacement of the nappe. The study

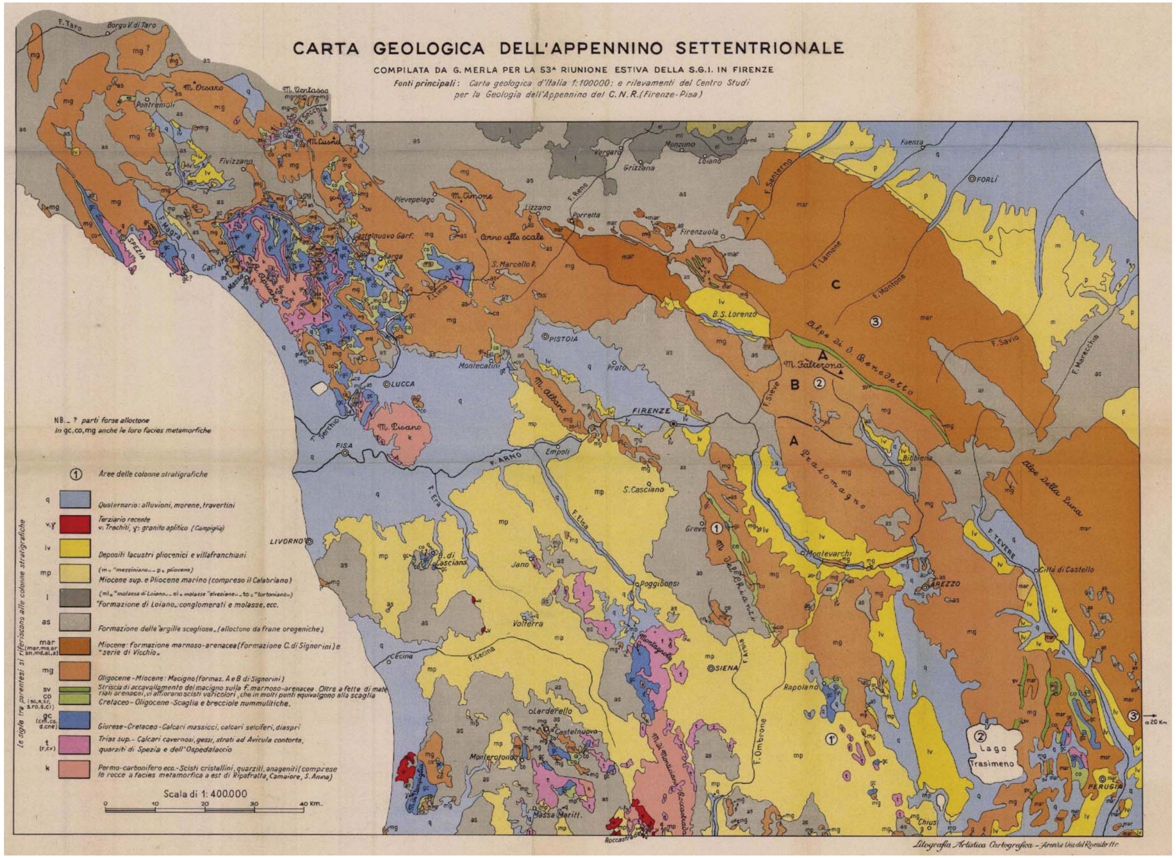

Figure 3. Geological Map of the Northern Apennines (Merla 1952). In this map the argille scagliose are mapped as allochthonous units emplaced through orogenic slides.

of allochthonous complexes in Sicily added new elements to the discussion. Ogniben (1953, 1954), for example, considered the chaotic structure of the argille scagliose in Sicily as being induced by diapirism that originated from the core of anticlines. He introduced the concept of a particular type of tectonites where the mechanical deformation was uncoupled from metamorphism. Later the same author (Ogniben 1969) clearly interpreted the scaly clay fabric of the argille scagliose as being caused by tectonic shearing of shaly rocks that were being deformed at shallow levels. But it was the concept of olistostrome that added a whole new dimension, or perhaps a whole new layer of confusion, to the interpretation of chaotic complexes (Beneo 1956a, 1957; Marchetti 1957; Jacobacci 1965; Broquet 1970a, 1970b, 1973).

Olistostromes

In Sicily, Beneo (1955, 1956b) reported the alternation of allochthonous argille scagliose within undisturbed Tertiary and Quaternary successions, and introduced the concept of large submarine landslides, or, *olistostromes* (Flores 1955, 1956). He devised a simple sedimentary gravitational phenomenon in contrast to the orogenic tectonic landslides of Migliorini (1933) and Merla (1952). In the mid-1950s the geological community agreed that all the argillaceous masses of chaotic appearance and containing exotic blocks were allochthonous (Beneo 1955, 1956b). The authors, though, were always thinking they were finding a rare form of accumulation. In those years, the systematic geological mapping of Italy and the first efforts in petroleum exploration multiplied the findings of chaotic rocks. This was accompanied by an eruption of new terms. For example, *brecce argillose* (clayey breccias), *argille brecciate* (brecciated clays) and *argille puddingoidi* (pudding clays), distinguished by the angular or round shape of the blocks, had chaotic texture and fauna typical of the depositional environment as well as exotic fauna (Beneo 1955, 1956a, 1956b, 1957; Rigo de Righi 1956). Clayey breccias and brecciated and pudding clay were, in turn, different from argille scagliose that were considered non-metamorphic tectonites that had originated as a result of the 'turbulent' motion typical of landslides and slumps (Beneo 1955, 1956b, 1957). Although compressional forces are mentioned (Beneo 1955, 1956b), the dilemmas that the authors confronted with these rocks is evident. Flores (1955, 1956) mentioned that the differences between argille scagliose and brecciated and pudding clay were only petrographic and insisted on framing them within the progressive evolution of gravity-deposited sediments, from fine-grained turbidites to conspicuous plastic masses containing large rigid bodies (see also: Beneo 1956a, 1957). In other words, argille scagliose and turbidites were two extremes of a continuous spectrum ranging from the proximal chaotic detachment from the substratum (argille scagliose, orogenic landslide) down to olistostromes and graded bedding of turbidity currents (Beneo 1956a, 1957; Flores 1955, 1956).

Olistostrome (from the Greek 'olistomai' – to slide – and 'stroma' – accumulation) is a term coined to describe deposits following sliding as 'sedimentary deposits occurring within normal geological sequences that are sufficiently continuous to be mappable, and that are characterized by lithologically and (or) petrographically heterogeneous materials, more or less intimately admixed, that were accumulated as a semifluid body' (Flores 1955, 1956). They show no true bedding except for possible large inclusions of previously bedded materials (i.e. olistolithes: Beneo 1956a, 1957; Flores 1955, 1956). Olistostrome was, in the intent of its inventor, the international form for argillaceous or pudding clay, considering the latter would have been used only in the Apennines. Olistostromes, in fact, were distinguished from the argille scagliose on the basis of different block-in-matrix fabric, because the matrix included millimetre to centimetre clasts (Flores 1955, 1956; Rigo de Righi 1956) (Figure 4a). Although Beneo (1955) and Rigo de Righi (1956) associated a

Figure 4. (a) Photograph showing the typical texture of mudflows or debris flows with clasts of various shape and lithology resting in a detrital–pelitic matrix supporting them. (b) 'Olistostrome' outcrop near Canossa (Reggio Emilia). This olistostrome, of early Miocene age, is part of the Epiligurian succession deposited on top of the Ligurian accretionary prism.

different and specific stratigraphic position to the olistostromes (younger) with respect to the argille scagliose (older), the genetic implication of the term was clear: olistostromes result from submarine mass transport (Flores 1955, 1956; Hoedemaeker 1973).

The conceptually ambiguous discrimination and misconception between tectonic (gravitational emplacement of nappes, i.e. orogenic landslides of Migliorini 1933, and Merla 1952) and sedimentary processes (such as gravitational mass-wasting phenomena) enabled some geologists to conclude that a distinction between olistostromes (i.e. brecce argillose or argille brecciate) and argille scagliose was meaningless (Beneo 1955, 1956a, 1956b, 1957; Marchetti 1957; see also discussion in Broquet 1970b; Ogniben 1969).

The olistostrome idea was successfully applied also in the Northern Apennines. A direct origin of the argille scagliose from submarine landslides was soon proposed (Beneo 1956a; Ruggieri 1956; Trevisan 1956; Görler and Reutter 1968). Bodies of argille scagliose inside normally bedded deposits in the continental Tuscan and Umbrian succession were recognized as olistostromes (Abbate *et al.* 1970a, 1981; Elter and Trevisan 1973). Analogous sedimentary bodies were also recognized in the coherent successions of the Ligurian nappe and the overlying slope and satellite basins ('semiallochthonous' or Epiligurian successions) (Figure 4b), where the investigators also described single, big – from few metres to kilometres – blocks called olistoliths (Figure 2a) (Fazzini and Tacoli 1963; Papani 1963, 1971; Abbate *et al.* 1970a; Elter and Trevisan 1973; Naylor 1981, 1982). Since the work of Abbate *et al.* (1970a), the term olistostrome, along with some of its derivatives such as endolistostrome and allolistostrome of Elter and Trevisan (1973) and olistotrim and olistoplate of Richter (1973; 1975), has not only been widely used in the Alpine and Tethyan literature (Richter 1973, 1975) but also successfully exported to other mountain belts, as argille scagliose had been much earlier.

In the early English translations of Italian geological works, the terms for argille scagliose were *scaly clay* or *scaly shales*, which were used more or less synonymously (Page 1963; Abbate *et al.* 1970a). The *Glossary of Geology* (Jackson *et al.* 2005) defines the argille scagliose as a sheet of chaotic and allochthonous material deformed as a highly plastic body that slid many kilometres under lateral or vertical stresses aided by gravity and/or diapirism. The authors also report the lithostratigraphic connotation. Deposits elsewhere have frequently been linked to the argille scagliose of Italy, for example, Audley-Charles (1965) on the Bobonaro mélange of Timor, Page (1978) on the Lichi mélange of Taiwan, Horne (1969) on the Ordovician volcanoclastic mélanges of Newfoundland, and Hsü (1965) on the Franciscan mélanges of Northern California. On occasion, usage in English has implied a stratigraphic aspect (Rangin *et al.* 1990; Harris *et al.* 1998), but mostly the connotation has been genetic. Bulk shearing is usually implied, its cause linked to processes such as submarine gravity sliding (Elter and Trevisan 1973; Boles and Landis 1984), tectonic deformation (Byrne 1984; Hamilton 1979), and diapirism (Barber *et al.* 1986; Brown and Orange 1993). Other situations where the term scaly clay has been employed, also with implied shearing, include glacially deformed deposits (Menzies and Maltman 1992; Suslikov 1989), geomorphology in tropical environments (Fan *et al.* 1996), and landslides (Larue and Hudleston 1987; Pettinga 1987). Additional complications arose in Italy from the link between bedrock of scaly clay and the derived loose material that commonly lead to unstable hill slopes. Consequently, Italian literature has been vast on the geotechnical properties of argille scagliose (Froldi and Lunardi 1994; Froldi *et al.* 1994), with additional specialized variations in terminology.

The geological literature of argille scagliose is therefore complicated by many apparent synonyms, including the previously mentioned olistostromes. Chaotic complex or formations, mélanges, tectosomes, megabreccia, tectonic mixtures, friction carpets, varicoloured clay, and wildflysch are the main descriptional quasi-synonyms. Scaly, lenticular, and chaotic are all derivative terms to describe the fabric of clay. Among these terms, chaotic complex, mélange, and tectosome deserve further examination, because of their relative popularity.

Chaotic complex

By the 1960s the allochthonous Ligurian and Subligurian complex of the Northern Apennines of Italy was considered to have been formed by coherent and disrupted portions. In the field, the coherent units were defined as thrust sheets bound by tectonic contacts and, although the thrusts were still considered as developed under gravitational forces, their internal deformation was recognized as consistent with tectonic emplacement (Elter 1960; Reutter and Groscurth 1978; Zanzucchi 1978). In the years that the Italian Geological Survey was mapping the Northern Apennines as part of the National Geological Map project, Abbate and Sagri (1970) suggested using the terms *chaotic complex* and *undifferentiated complex* as an alternative to argille scagliose. The chaotic complex was defined as a clay-rich unit characterized by a block-in-matrix fabric at the outcrop scale where the blocks could vary on the basis of age, lithology, and size. Its stratigraphic and structural position and/or primary genesis were not specified in the framework of the Apennine tectonic pile. The undifferentiated complex was, on the other hand, a mere lithostratigraphic container that includes formations of chaotic structures recognized as having the potential to be differentiated with the progress of the stratigraphic and structural knowledge (Abbate and Sagri 1970). The 1:50.000 sheets 'Firenze', 'Castel Fiorentino', and 'Arezzo', for example, reported 'complesso caotico' (chaotic complex) and 'complesso indifferenziato'(undifferentiated complex) in their legends. Also, the well-known summary map of the Northern Apennines by Bortolotti *et al.* (1970) followed this usage (Figure 5).

Mélanges

The occurrence of disrupted units, often with blocks of different natures, in many mountain belts resulted in the parallel evolution of similar terms. This is the case with the term *mélange*, from the French *mixture*, introduced by Greenly (1919), which shares with argille scagliose a controversy regarding its origin as a by product of tectonization or as a sedimentary deposit.

Greenly (1919) defined and mapped the Precambrian Gwna mélange in Wales through Anglesey and the Llŷn Peninsula onto Bardsey Island. The rock body was described as an assemblage of isolated, relatively obdurate lenticular blocks of different lithology – pillow lavas, basalt, quartzite, limestone, mudstone, granite – and different sizes from a few km to mm – that float in a more easily deformable matrix. Greenly (1919) added the adjective 'autoclastic' to specify the origin of disruption producing the mélange. In his view, in fact, mélange was just a descriptive term, whereas the word autoclastic alluded to the origin by the tectonic crushing of a previously alternated sequence of sedimentary and igneous rocks. Later, Shackleton (1969) interpreted the Gwna mélange as a sedimentary slide deposit (olistostrome). In fact the association of deep ocean sediment, pillow basalt, and a serpentinite/gabbro suite in the Gwna mélange was hard to explain before the advent of plate tectonics in the early 1970s. This is a north reoccurrence of Stainmann's famous 'trinity' that he first described in the Penninic Alps (Steinmann, 1907). More recent studies (Gibbons 1983; Thorpe 1978; Gibbons and Harris 1994), in fact, have interpreted the Gwna mélange as formed by processes directly associated with the subduction of an oceanic plate and arc beneath continental crust.

As had argille scagliose, the term mélange has also successfully spread across mountain belts. Bailey and McCallien (1950), Gassner (1959), and Boccaletti *et al.* (1966) were among the first to apply the concept of mélange outside the United Kingdom and interpret, for example, the disrupted rock body cropping out around Ankara as a mélange. Hsü (1968) described the Franciscan complex in California as an important example of mélange. The Franciscan complex is a heterogeneous assemblage that consists largely of dismembered sequences of massive and pillow basalts, greywacke, shale, serpentinite, thin-bedded chert, and rare limestone. Unfortunately, Hsü (1968) forced the association of the term mélange to include purely tectonic origin. Specifically the Franciscan mélange was described as deformed rocks characterized by the inclusion of tectonically mixed blocks, where the exotic ones have been detached as result of sliding under the force of gravity (Hsü 1968). The

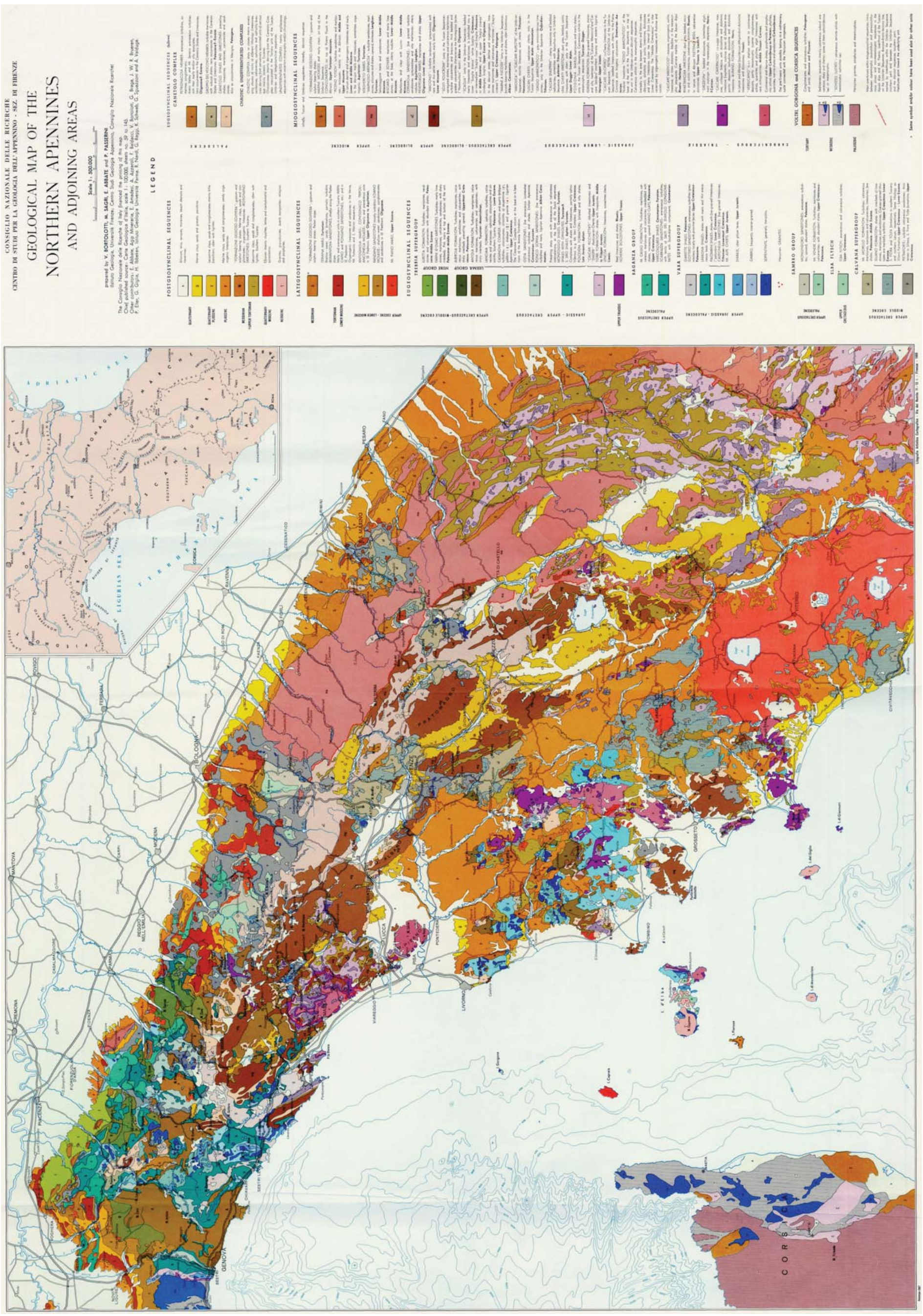

Figure 5. Geological Map of the Northern Apennines and adjoining areas (Bortolotti *et al.* 1970). Disrupted rocks are here mapped as chaotic complex – a shaly or clayey matrix enveloping chunks of rocks of different lithology (limestones, sandstones, calcarenites, ophiolites, and ophiolitic breccias) deriving from pervasively tectonized units of various age (mainly Jurassic to Eocene) – and undifferentiated complex – mainly argillaceous sequences with uncertain stratigraphy and/or chronology.

Franciscan complex has been the subject of various interpretations since. The close relationship between the Franciscan complex and subduction zones is at the base of classic interpretations of mélanges (Cowan 1974, 1985). Recently, different sub-domains within the Franciscan complex have been recognized and interpreted as different components of a subduction complex. The underthrusting of oceanic lithosphere (the Farallon plate) under the continental lithosphere (western North American plate margin) at different depths caused metamorphism ranging from zeolite to eclogite facies (Wakabayashi 1992, and references therein).

The argille scagliose of the Northern Apennines were described as an important example of a mélange (Bailey and McCallien 1963; Boccaletti *et al.* 1966; Hsü 1968). In the early 1970s a general consensus was reached on the gravitational emplacement of the allochthonous Ligurian complex in the Northern Apennines. The only remaining controversy was focused on the nature of the complex. The appearance of another term in the geological literature to refer to disrupted rocks further amplified the debate. In particular, the point was that within the argille scagliose it was possible to distinguish the slide deposits, the olistostromes, from the products of tectonics and it was debated that only the latter should be called argille scagliose and referred to as a mélange (Boccaletti *et al.* 1966). In this case too the definition of mélange is confused with its genesis, and here, since the authors refer to argille scagliose sensu stricto Merla (1952), the implication is whether pure gravitational displacement should be considered as a sedimentary or as a tectonic process.

In 1978 a Penrose conference on mélanges was held in Santa Barbara (California), where the participants reaffirmed how this term should be used without the implication of a particular genesis (Silver and Beutner 1980). They defined mélanges as a general term describing a mappable, internally fragmented and mixed rock body containing a variety of blocks, commonly in a pervasively deformed matrix. In other words, mélange is a handy descriptive term that can be used in the field without conforming to the classic principle of superposition.

If not solving, plate tectonics at least helped put into the right perspective the large variety of processes that can produce a mélange. For example, a particularly disturbing paradox was the occurrence of blueschist blocks in direct contact with poorly lithified rocks in the same mélange.

Mélange occurrences have been associated with subduction complexes (Cowan 1985; Byrne and Fisher 1987; Vannucchi *et al.* 2008), ultramafic ophiolite sequences obducted onto continental crust (Gansser 1974; Jones and Robertson 1991; Whitehead *et al.* 1995; Bortolotti *et al.* 1996, 2005; Polat *et al.* 1996), gravitational sliding under water (Bettelli and Panini 1989; Bettelli *et al.* 1996; Hampton *et al.* 1996; Pini 1999; Ivanov *et al.* 2003; Camerlenghi and Pini 2009), and diapiric intrusion of underlying and less dense material forced into brittle overlying and denser rocks (Camerlenghi *et al.* 1992; Kopf 2002; Brown and Orange 1993; Camerlenghi and Pini 2009), just to mention the most commonly proposed processes. Moreover, a mélange is defined as blocks in a matrix, to emphasize the importance of the fabric, rather than the nature of the blocks. A mélange, then, can either contain exotic blocks or be a broken/dismembered formation (Raymond 1984).

Finally, mélange is often used together with adjectives defining the genesis of the chaotic structure: tectonic, sedimentary, or diapiric. For tectonic and diapiric mélanges, the meaning is clear. Some problems arise with sedimentary mélanges because this term can refer either to the nature of the process (i.e. sedimentary process), the nature of the deposit (i.e. a sediment), or can also refer to the nature of the blocks (sedimentary versus metamorphic or magmatic). The alternative adjective, gravitational, is somewhat preferable because it refers to a process originating with a gravitational instability, even though we discuss above how, in the literature of the last century, gravitational tectonics was proposed to account for the emplacement of nappes.

Tectosomes

In the last few years, the term *tectosome* has been added to the overabundance of terms used to define Apennine chaotic rocks (Pini 1999; Cowan and Pini 2001). This term was associated with rocks recognized on the basis of texture and fabric as tectonically disrupted Ligurian units. Tectosomes are, then, the tectonic correspondent to olistostromes. The term is meant to stress the genetic connotation that is often associated to the definition of a chaotic body. This emphasis is the consequence of the recognition that part of the argille scagliose, or Ligurian units, were emplaced through thrusts associated to the evolution of a subduction complex (Treves 1984; Vannucchi *et al.* 2008), rather than gravitational tectonics.

The efforts of Pini (1999) and Cowan and Pini (2001), although convenient in the light of the long-standing habit of mixing descriptive and genetic terms, in our opinion go against an attempt to simplify the nomenclature. The tectosomes are tectonic mélanges (without exotic blocks) or broken/dismembered formations, where we can further specify the nature of mixed rocks, the type of fabric, and the intensity of deformation. In particular they are characterized by (1) constant lithological content with no exotic blocks, meaning that they come from disruption of single lithostratigraphic units, (2) a block-in-matrix fabric, and (3) deformation ranging from folded and boudinaged bed packages to blocks in a shaly matrix.

Toward a modern terminology

Starting from the early 1980s, the area of classic outcrops of argille scagliose in the Northern Apennines has been mapped extensively as part of the Geological Cartography Project of Italy (CARG). This project offered the opportunity to revisit some of the concepts regarding the nature, the description, and how to map the Apennine chaotic rocks (Castellarin *et al.* 1986; Bettelli and Panini 1989, 1992; Bettelli *et al.* 1989a, 1989b, 1996, 2002a, 2002c, 2004; Castellarin and Pini 1989; Pini 1999; Panini *et al.* 2002; Plesi 2002, Bettelli and Vannucchi 2003; Gasperi *et al.* 2006). Investigators have basically worked in two directions: (1) solving mapping problems following stratigraphic principles as much as possible and (2) describing the nature, deformation, and, if possible, origin of the chaotic rocks.

Because all of the Apennine chaotic rocks are non metamorphic sedimentary rocks, even though they often incorporate blocks of igneous rock, geologists soon realized that in this case it is possible to map these units by applying lithostratigraphic mapping techniques. The outcome was therefore the possibility of reconstructing the macroscopic tectonic structures, which are essential background to further proceed with meso- and microscopic investigations.

Understanding how a given chaotic rock body formed and how it was later disrupted is certainly a major objective, but Northern Apennine geologists learned that in the field it is often not possible to distinguish between disruption generated by sedimentary vs. tectonic processes. Objective criteria and characteristics to discriminate between the two processes are simply not known at this time.

In the field it became increasingly evident that the genetic approach to the study of chaotic rocks was possible only for the case of mudflow and debris flow deposits. Only these processes are able to completely destroy the texture and fabric of the source rock and generate a new sediment. The latter can be recognized and characterized only on the basis of objective criteria from the observation of the rock texture on the outcrop (Figure 4a).

In general, it was recognized that only the rock texture can be used as a common factor to understand the genesis of a chaotic rock. All processes except mudflows and debris flows can originate rock bodies with a deformation fabric indiscernible from that originating from a tectonic process. Therefore, it is possible only to distinguish (1) chaotic rocks generated by mudflows and debris flows and (2) chaotic rocks generated by other deformation, either sedimentary or tectonic. The sedimentary (gravitational) or tectonic definition of the deformation is thus a problem for interpretation that connects with the stratigraphic, palaeogeographic, and structural context of the studied units and related mountain belts.

Before describing our approach to the problem of classification and mapping of chaotic rocks, it is useful to remember some stratigraphical concepts. The 1978 Penrose Conference stated that mélanges are mappable rock bodies (Silver and Beutner 1980). NACSN (1983) in the North America Stratigraphic Code did not use mélange as a formal name, but it introduced the term lithodemic units, which, comparable to formations, include pervasively deformed rock, generally non-tabular and lacking primary depositional structures, and characterized by lithic homogeneity (i.e. a mixture of rocks of two or more types, or extreme heterogeneity of composition may constitute in itself a distinct form when compared with adjoining rock masses). In other words, a lithodeme does not follow the principle of superposition, and its contacts can be tectonic. A subunit of the lithodeme is the complex, an assemblage or mixture of rocks of two or more genetic classes, that is, igneous, sedimentary, or metamorphic, with or without a highly complicated structure (NACSN 2005). In particular, a structural complex is the product of tectonic processes (e.g. shearing, faulting) and some individual components of the heterogeneous mixture are too small to be mapped.

Stratigraphers around the world rejected the concept of a geological map on the basis of stratigraphic units defined on deformation and tectonic boundaries rather than on depositional and stratigraphic boundaries (Hedberg 1976; CCGG 1992; Salvador 1994). A Complex must be a lithostratigraphic term and follow both superposition and cross-cutting principles; only within these constraints should it be used. Accordingly, a complex is a rock body of heterogeneous lithology, with or without strong deformation that hides stratigraphic relations among the different lithologies forming the body so that it is not easy to subdivide them on stratigraphic grounds (CCGG 1992; Salvador 1994). An alternative name can be mélange, without an adjective defining the genetic process. On the other hand, the term olistostrome is not acceptable, since it contains a genetic meaning.

We hope that this brief summary has given the reader a better feeling for how the controversy on chaotic rocks also expanded into the criteria for their unambiguous mapping. Here we report on a mapping technique based on the stratigraphic principles that we have used. It should be applied after careful observation of the few objective indicators that reveal the mechanisms responsible for disruption of the chaotic rocks, which must be held separated from issues related to their present location.

If we want to know if a chaotic rock was generated by sedimentary vs. tectonic mechanisms, the objective characters are texture, lithologic assemblage, and internal structure of the rock. If, instead, we want to stress the mechanisms that are responsible for the present location of the chaotic rocks, the objective criteria are the relations and nature of its contacts with the surrounding rocks, the extension and thickness of the rock body itself, the presence or absence of exotic blocks, the presence of contrasting styles of deformation within the same rock mass, and the possible incongruent stratigraphic location and existence of contrasting palaeoenvironmental characters issues. In the Apennines, these criteria allow one to differentiate the following genetic types within the chaotic rocks formerly called argille scagliose (Figure 6):

(1) Chaotic rocks with a clastic texture of sedimentary origin at the scale of the rock sample. These are 'sedimentary clayey breccias' or 'sedimentary breccias' (Figures 4 and 7).

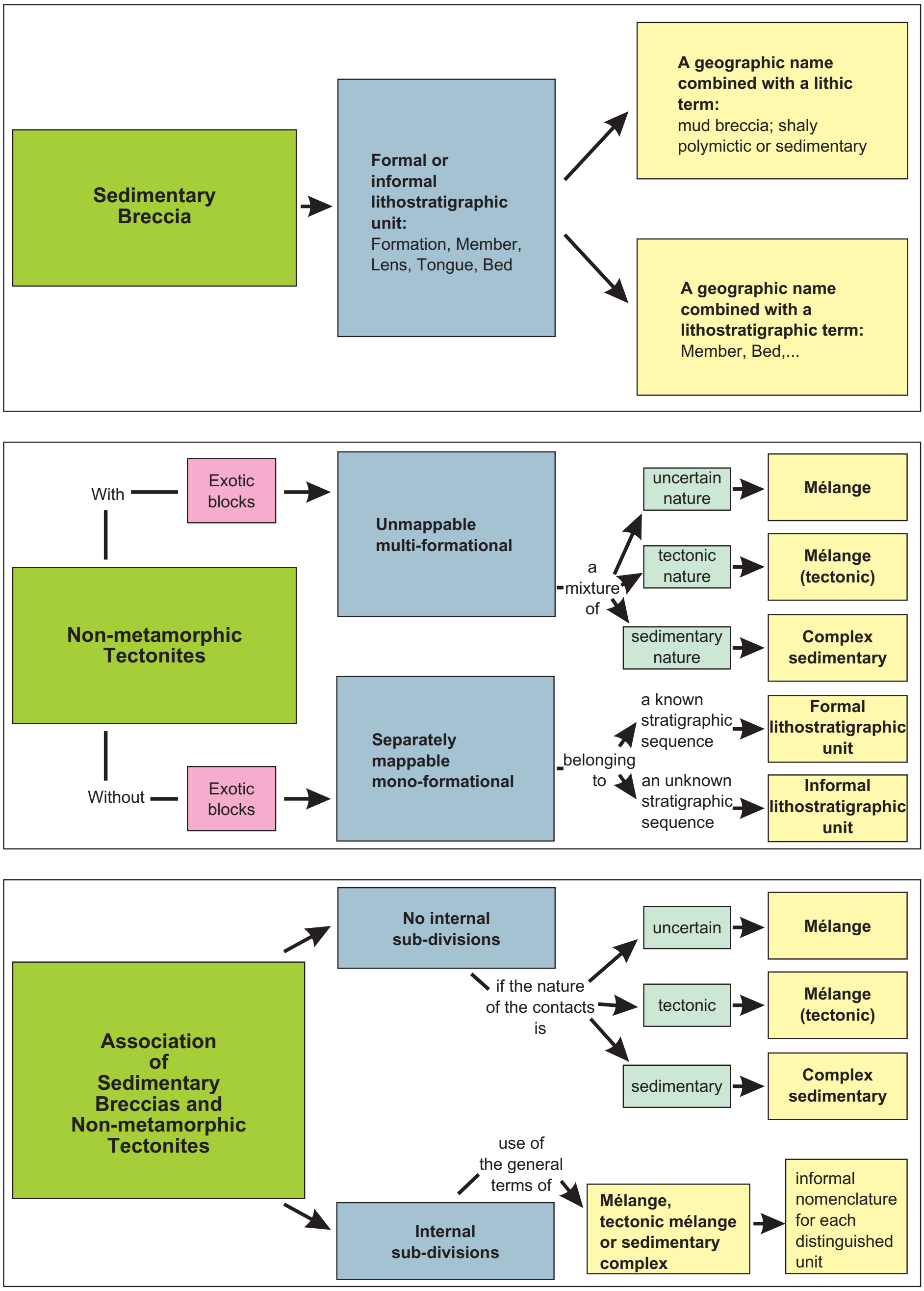

Figure 6. Scheme showing the classification of chaotic rocks used in the CARG project (modified from Bettelli *et al.* 2004). A mappable chaotic deposit identified as a sedimentary breccia, with or without a precise stratigraphic position within the sedimentary sequence, can be considered to be a lithostratigraphic unit, either formal or informal. The in situ monoformational non-metamorphic tectonites derived from the pervasive deformation of a single lithostratigraphic unit can be named using the traditional lithostratigraphic nomenclature. The use of general terms (like mélange or complex) may be necessary for multiformational non-metamorphic tectonites or tectonites displaced by gravity, association of sedimentary breccias and tectonites, if each component is not mappable on its own.

Figure 7. Sedimentary Breccias. (a) Scaly fabric on clastic texture typical of debris flows. Scaly cleavage here is related to the last phases of emplacement, when dewatering and subsequent pore collapse caused the alignments of clay minerals. In this photograph, scaly cleavage is further deformed by a network of anastomosing mesoscopic faults. (b) Epiligurian sedimentary breccias (basal slope–apron deposits), Sillaro Valley (Bologna Apennine).

(2) Chaotic rocks with a block-in-matrix fabric at the outcrop scale (only rarely at the sample scale along discrete brittle shear zones). These are broken/dismembered formations or nonmetamorphic 'tectonites *s.l.*' (Figure 8).
(3) Chaotic rocks formed by the complex association of clayey breccias and broken/dismembered formations or nonmetamorphic tectonites *s.l.* (Figure 9).

Figure 8. Nonmetamorphic tectonites or broken/dismembered formations. (a) limestone boudins enveloped in claystones showing scaly cleavage. (b) Block-in-matrix fabric in Argille e Calcari di Canetolo (Late Cretaceous–middle Eocene) Bobbio (Piacenza). (c) Block-in-matrix fabric in Argille a Palombini (Early Cretaceous) Abbadia San Salvatore (Siena). (d) Block-in-matrix fabric in Argille Varicolori (Late Cretaceous) Atessa (Chieti).

The application of the aforementioned principles to the classic outcrop areas of the argille scagliose of the Northern Apennines is what led to the disappearance of these terms from the modern geological literature of the region (Figure 10).

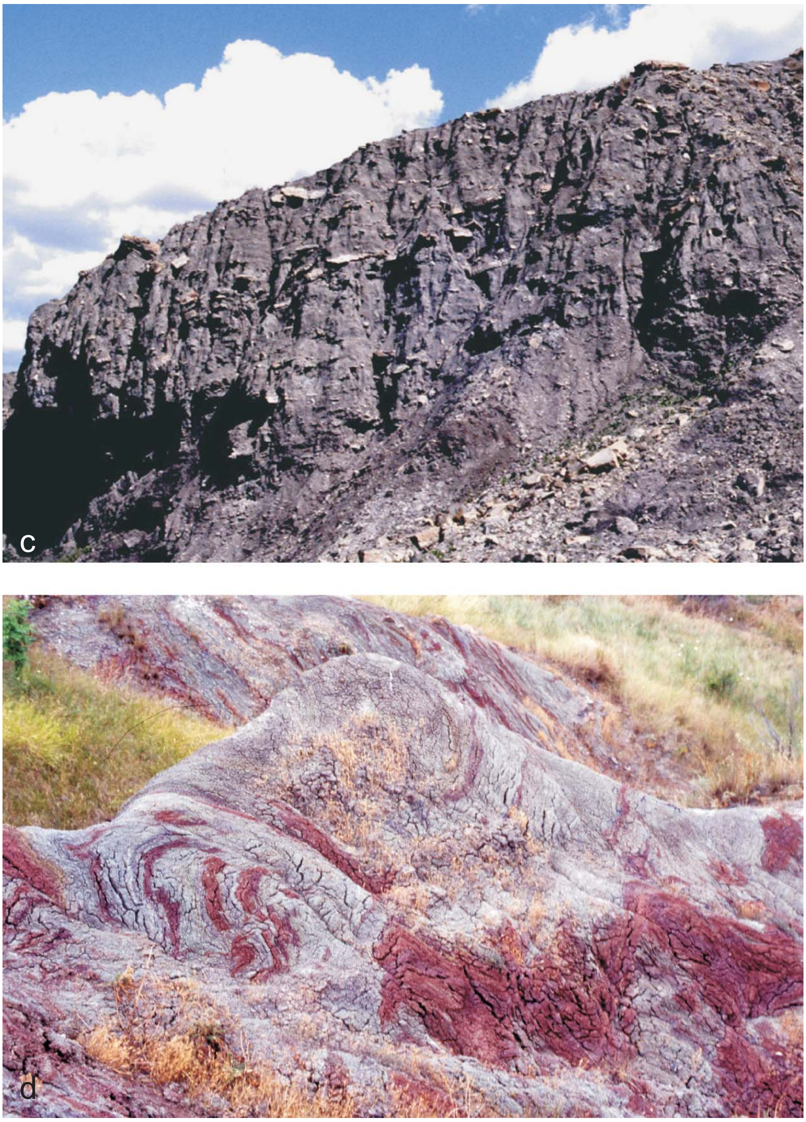

Figure 8. (Continued).

Sedimentary breccias (Figure 7)

Examination of hand samples and/or thin sections collected from different parts of the outcrop reveals the presence of clasts of various shapes and lithology resting in a detrital–pelitic matrix, usually supporting them (Figures 4a and 7a). The differentiation between matrix and clasts is somewhat arbitrary, because the texture is characterized by a regular reduction in clast size. These deposits are then real matrix-supported clayey breccias. This definition does not have a genetic connotation, unlike olistostrome, so that a sedimentary breccia is then correct as a lithostratigraphic term. Olistostrome, instead, not only has a genetic connotation, but would include any type of slide deposit, not only mudflows and debris flows; it would therefore be impossible to associate it with a particular sedimentary texture (Hoedemaeker 1973).

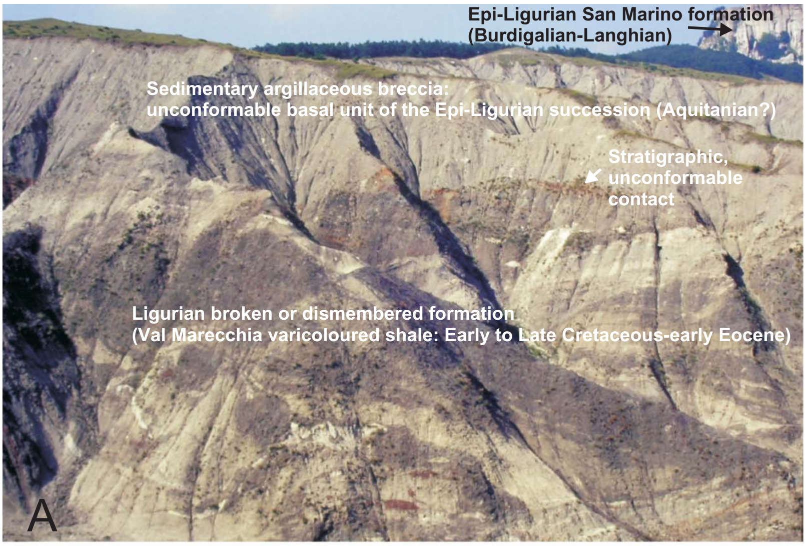

Figure 9. Association of sedimentary breccias and older tectonites. (a) Sedimentary breccias of the basal slope–apron deposited on top of the broken formation of the varicoloured shales (Early to Late Cretaceous-early Eocene) in the Marecchia Valley (Arezzo–Pesaro/Urbino–Rimini). (b) Sedimentary breccias, on top, and broken formation of the Argille a Palombini (Early Cretaceous) in the Sestola Vidiciatico unit near Vidiciatico (Bologna) if the association results in mappable blocks then they will be kept separated.

Sedimentary breccias may be characterized by polished anastomosing surfaces that cut through the rock body at a centimetre to millimetre scale. The resulting scaly appearance (Bianconi 1840; Penta 1950) may typify many of these deposits. In the last few years, the scaly fabric (Moore and Byrne 1987) has been defined to be a type of cleavage (Vannucchi

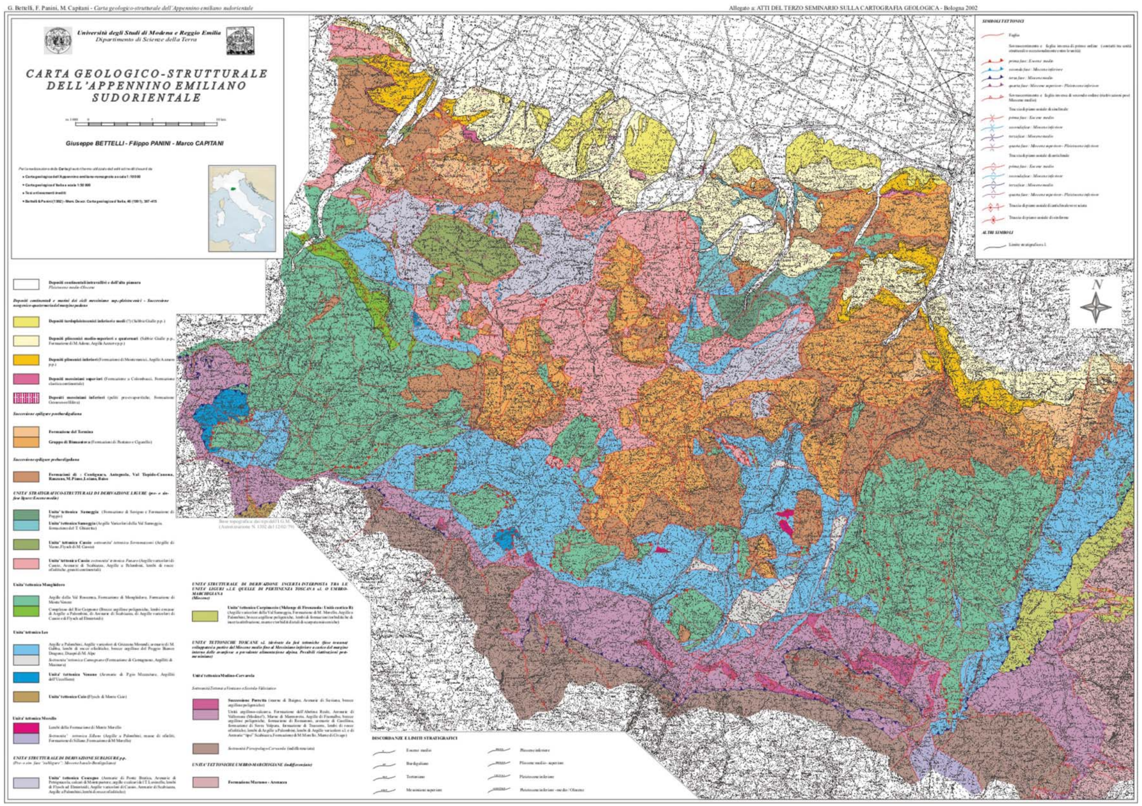

Figure 10. Structural map of the southeast sector of the Emilia Apennines (Bettelli *et al.* 2002b). Argille scagliose, chaotic complex and undifferentiated complex are not present in this map that has been mainly compiled from the 1:50.000 Sheets ‘Sasso Marconi’, ‘Pavullo nel Frignano’ and “Sassuolo” (Bettelli *et al.* 2002c; Panini *et al.* 2002). Single chaotic formations have been grouped in tectonic units or successions to be represented at a scale comparable to Figures 3 and 5: the Formazione di Baiso (a sedimentary breccia) is mapped as the basal part of the Successione Epiligure Pre-Burdigaliana; disrupted formations have been mapped according to the single lithostratigraphic units, for example the Argille a Palombini of the Unità Tettonica Cassio are a broken formation; the association of sedimentary breccias and tectonites is here represented, for example, by the Mélange di Firenzuola that has been mapped distinguishing each single block in the 1:50.000 sheet, while here because of scale reasons is grouped in the Unità Tettonica Carpinaccio.

et al. 2003). This cleavage was considered by Abbate *et al.* (1981) to be related to compaction and post-compaction tectonics. These mass flows, in fact, lacked sufficient viscosity to generate shear zones, while in the last phases of emplacement, dewatering and subsequent pore collapse caused the alignments of clay minerals (Vannucchi *et al.* 2003). Furthermore the sedimentary texture typical of mudflows and debris flows is usually overprinted by brittle deformation. In the Apennine clayey breccias this is easly detectable in the expression of non-penetrative polished structural surfaces of different orientation and spacing that overprint scaly cleavage where the latter is present.

Clayey breccias follow the stratigraphic laws of original horizontality and lateral continuity, even though the determination of bedding and bedding polarity is very difficult (Figures 4b and 7b). Usually, at the outcrop scale, it is possible to infer a preferential alignment of the clasts that can help to reconstruct the 3D setting of the rock body. Other useful information can come from analysis of the clasts to establish their possible source rocks.

Regarding age, usually it is only possible to establish a lower limit based on the age of the youngest inclusions incorporated in the clayey breccias. All attempts to analyse the matrix for microfossils, in fact, have resulted in barren samples, except for species already present in the source rocks. Most chaotic bodies showing a matrix-supported sedimentary texture were proved to be part of a stratigraphic succession unconformably deposited above the Ligurian units, that is, the Epiligurian succession (Figures 4b and 7b).

Broken/dismembered formations or non-metamorphic tectonites s.l. (Figure 8)

Clay-rich non-metamorphic rocks where gravity or tectonic processes caused disruption without complete re-sedimentation, as in the case of sedimentary breccias, did not modify their original sedimentary texture. They may develop instead new deformation structures or change the style of their pre-existent deformation structures (Figure 8). The mesoscopic fabric of these rocks can be described as blocks-in-matrix, with the matrix here being just the deformed, original pelitic component (Figures 1a and 8a). The first data to collect in the field are the source rocks, and whether the inclusions come from one or several formations. In the latter case, also to note whether they all belong to the same stratigraphic succession. The outcome of these data does not relate with the different structures of the resulting chaotic rock, but with the different deformation history, mechanisms, and structural environment.

This classification scheme can lead to three types of non-metamorphic tectonites at the map-scale: (1) monoformational or broken/dismembered formations (Figure 8), (2) pluriformational arising from a single stratigraphic succession, and (3) pluriformational arising from several stratigraphic successions. Only a good awarness of the regional stratigraphy can help in discriminating the degree of mixing in each assemblage of disrupted unit (Bettelli and Panini 1989, 1992; Bettelli *et al.* 1989a, 1989b). Ideally, it is possible to distinguish between tectonic or sedimentary mixing if the nature of the structural boundaries between the different components can be determined. In practice this distinction is very difficult, in particular because later tectonic events can obliterate the original contacts. In this case, the only interpretative information is from the regional geological framework.

Typically, these non-metamorphic tectonites are characterized by polished anastomosing surfaces that penetratively cut through the rock body at the centimetre to millimetre scale (Bianconi 1840; Penta 1950). Here scaly cleavage is formed by anastomosing shear zones commonly oriented at a low angle to the clay mineral preferred orientation and which possibly contain a s–c geometry (Vannucchi *et al.* 2003) (Figures 1a and 11).

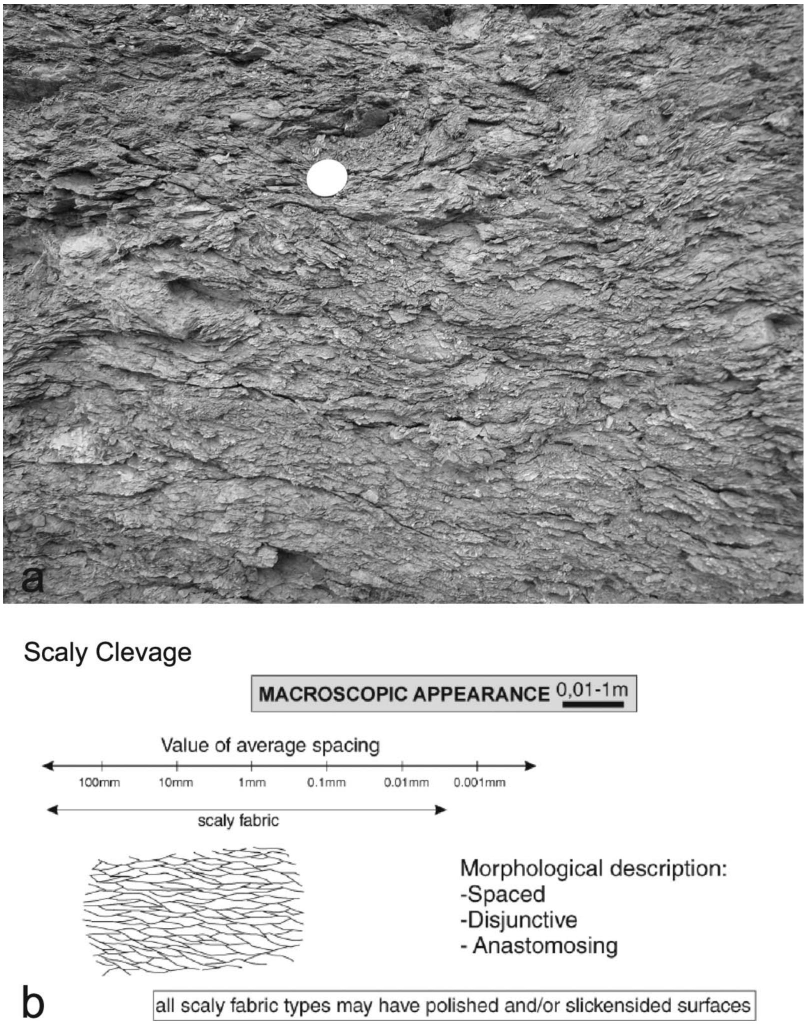

Figure 11. Photograph of scaly cleavage and terminology associated with mesoscopic elements observable in the field (modified from Vannucchi *et al.* 2003).

Mapping non-metamorphic tectonites is not an easy task, because the intense deformation can hide or remove the original stratigraphic sequence (Figure 8). Bedding is commonly transposed by isoclinal folding (Bettelli and Vannucchi 2003). In this case only the stratigraphic principles of cross-cutting relations and inclusions can be applied. Useful information can be inferred from a detailed distinction of their internal deformation and reciprocal relationships of the lithologic units (at least to the 1:10.000 scale). The iso-orientations of the bed fragments and scaly cleavage commonly form a planar anisotropy that can represent a tectonic bedding or mesoscopic foliation (Figure 8b, c). The careful mapping of this foliation is often the only tool to reconstruct the map-scale, 3D-geometry of these bodies.

Many of the classic outcrops of argille scagliose (Page 1963) are disrupted sequences of the so-called external Ligurian units of Early to Late Cretaceous age cropping out on the Adriatic side of the Northern Apennines (Treves 1984; Marroni *et al.* 1998; Pini 1999; Vannucchi and Bettelli 2002) (Figure 8c, d). They can be interpreted as monoformational non-metamorphic tectonites or broken/dismembered formations (Bettelli and Vannucchi 2003). In this case the undeformed rock can be viewed as a sedimentary multilayer where the soft, clay component is volumetrically important with respect to the strong component that can be represented by limestones or sand/siltstones. The competence contrast, often helped by different lithification levels, allowed the clay to flow while the stronger components were breaking apart (Bettelli and Vannucchi 2003) (Figure 8). Detailed mesoscale structural studies (Vannucchi and Bettelli 2002; Bettelli and Vannucchi 2003) revealed that these types of chaotic units all derive from multiple refolding of shaly multilayers and that their typical scaly fabric is the result of flexural-slip folding causing the concentration of brittle shear in the weak shaly interlayers.

In one case only a pluriformational assemblage of nonmetamorphic tectonites coming from several stratigraphic successions was detected, the Coscogno mélange (Bettelli *et al.* 1989b, 2002c).

Associations of sedimentary breccias and non-metamorphic tectonites s.l. (Figure 9)

A diverse set of rock assemblages results from the mixing, in variable amounts, of sedimentary clayey breccias and non-metamorphic tectonites. In the classic outcrop areas of the argille scagliose, that is the Adriatic side of the Northern Apennines, there are three different forms of this last group of chaotic rocks. The first form involves associations between the disrupted Ligurian non-metamorphic tectonites, interpreted as subduction accreted units (Vannucchi and Bettelli 2002; Bettelli and Vannucchi 2003), and the overlying Epiligurian deposits, interpreted as slope sediments (Figure 9a). The second association contains a disrupted late Eocene-middle Miocene unit known as the Sestola–Vidiciatico tectonic unit (Remitti *et al.* 2007; Vannucchi *et al.* 2008) (Figure 9b). The third association is the Eocene Rio Cargnone complex at the stratigraphical top of the Ligurian Late Cretaceous-early Eocene Val Rossenna succession (Bettelli *et al.* 1989b, 2002c; Papani *et al.* 2002).

The Epiligurian deposits, which unconformably overlie the more shaly component of the Ligurian substratum, are always represented by thick (~200 m) sedimentary breccias composed by elements coming from the Ligurian shaly non-metamorphic tectonites themselves (Figure 9a). Commonly, at the boundary between the substratum and these clayey breccias, there are mixed chaotic bodies containing blocks of non-metamorphic tectonites, clayey breccias, and small blocks (5–10 m) of the oldest, non-chaotic sediment deposited on top of the thick sedimentary breccias (Bettelli *et al.* 1996, 2004). In this case the contacts between these various components and the Ligurian substratum appear to be sedimentary (Figure 9), which implies an origin in submarine flows and slides of the Ligurian substratum and slumps of the sedimenting Epiligurian deposits.

The Sestola–Vidiciatico tectonic unit is about 500 m thick. It underlies the Ligurian units and covers the Olio-Miocene foredeep turbidites of the Adriatic plate (Remitti *et al.* 2007; Vannucchi *et al.* 2008). This unit is formed by tectonically and gravitationally reworked blocks of (1) the Ligurian non-metamorphic tectonites, (2) clayey breccias, and (3) late Eocene–middle Miocene slope sediments that were deposited on top of the Ligurian units (Remitti *et al.* 2007) (Figure 9a). The Sestola–Vidiciatico tectonic unit has been interpreted to be a large shear zone between the overriding European plate (the accretionary prism formed by Ligurian units) and the underlying Adriatic plate, in other words, it is a plate boundary mélange.

The Rio Cargnone complex has been interpreted to be a large mass wasting deposit generated by debris flows and mass movement of kilometre-sized blocks at the onset of the Ligurian tectonic phase (Bettelli *et al.* 1989b, 2002c; Papani *et al.* 2002). In identifying these rocks, it is necessary to first map and distinguish the single clayey breccia or tectonite blocks (Figure 6). For each, the following criteria need to be determined:

- for the sedimentary breccias – their age, lithology and provenance of clasts and matrix, and the possible presence of sediments deposited in-situ, contemporaneous of sedimentary breccia deposition;
- for the non-metamorphic tectonites or non-chaotic rocks – their age, provenance from one or more stratigraphic sequences, and possible alternation with concordant clayey breccias.

The most basic observation, though, is the nature of the contacts among the different blocks.

From scaly clays to scaly cleavage

Along with the effort to distinguish and give an appropriate lithostratigraphic location to the argille scagliose, *scagliosità* or *scaliness* became a general term to describe rock fabric. *Scaly fabric*, *scaly foliation,* or the more common scaly clay are terms that the current interest in convergent plate margins has led to wide usage in both modern and ancient subduction complexes. For example, on-land scaly clay was described as typical in mélanges from the Shimanto Belt in Japan (Kimura and Mukai 1991; Kiyokawa 1992; Kitamura *et al.* 2005; Fukui and Kano 2007), from Nias Island in Indonesia (Pubellier *et al.* 1992), from Taiwan (Chen 1997; Chang *et al.* 2000, 2001), and from Barbados (Enriquez-Reyes and Jones 1991). Scaly foliation has also been described in rock bodies of ancient orogenic belts such as the Northern Appalachians (Lash 1989; Waldron *et al.* 1993; Whitehead *et al.* 1995), the Antler Orogeny (Jansma and Speed 1993), and those related to the closure of the Palaeo- and NeoTethys (Babic *et al.* 2002; Hara *et al.* in press), to cite a few examples. This renewed interest has also spawned new, related terms (Lundberg and Moore 1986). For example 'scaly shales' have been reported in a Carboniferous-age Moroccan olistostrome, (El Chazi and Huvelin 1981), 'scaly deformation bands' have been described from the Northern Apennines (Labaume *et al.* 1991), and 'scaly argillite' from Kodiak Island, Alaska (Sample and Moore 1987).

Working with sub-seafloor cores, Aubouin *et al.* (1982) reported what they called 'microflakiness' and 'microscaliness' in sediments cored in the Middle America Trench. Scaly foliation has also become a typical fabric nomenclature in sheared mudstones drilled in submarine subduction complex (Moore *et al.* 1986; Maltman and Vannucchi 2004). Barbados (Cowan *et al.* 1984; Labaume *et al.* 1997; Takizawa and Ogawa 1999), Nankai (Taira *et al.* 1992; Maltman *et al.* 1993), Costa Rica (Vannucchi and Tobin 2000), and Cascadia (Clennell and Maltman 1995) all contain subduction complexes where scaly fabric is commonly associated with shearing. Scaly fabric has been also described in cores of basalts and boninites from the Mariana Trough (Hussong and Uyeda 1981) and from serpentinites in Guatemala (von Huene *et al.* 1985).

The occurrence of localized horizons of scaly fabric in drilling cores has been interpreted as being preferentially associated with shear and faults. In the same way faults cropping out on-land have been described as characterized by scaly fabric (Vannucchi *et al.* 2003; Meneghini and Moore 2007). In this case scaly fabric blends into other terms such as foliated cataclasite (Chester and Logan 1987; Wibberley and

Shimamoto 2003). This confusion in terminology is partly as a result of the practical problems of working with scaly rocks, in particular because of the sampling difficulties that arise from their inherently weak nature (Figure 11). Difficulties include sampling, both in the field and for microscopy, in observing the actual scaly surfaces as opposed to stronger intervening material; in distinguishing between natural and drilling-induced effects in drill cores, in sample preparation for microscopy, in the fineness of scale, even when viewed with the electron microscope, of complex clays, in defining at what point a scaly fabric evolves from a merely incipient stage (the latter described by Lundberg and Moore (1986) as pervasive on a large scale but without a distinct planar orientation), missing characteristics such as the polished fracture surfaces (Vannucchi and Tobin 2000) and the masking effects of later deformations.

Studies by Agar *et al.* (1989) and Vannucchi *et al.* (2003) have described a range of geological settings characterized by scaly clays. These studies noted a wide range of origins to demonstrate that this term should be used macroscopically and purely descriptively, without any specific genetic connotation. Moreover, like other surfaces that have little undulatory aspect and lack polish and striations, a scaly fabric would be better called a cleavage (Figure 11). It is useful to regard scaly fabric as a type of rock cleavage since it defines the tendency of the rock to break along surfaces with a specific orientation. For example, as Agar *et al.* (1989) suggested, the geometry of the anastomosing surfaces can be described by such terms as parallel, reticulate, and trapezoidal, which all derive from terminology for cleavage (Borradaile *et al.* 1982). Within a morphological classification for cleavage – based on shape and/or arrangement of the rock components – scaly fabric would be characterised by spaced, disjunctive, and anastomosing features (Vannucchi *et al.* 2003) (Figure 11). The average value of spacing can range from submillimetre, at the lower limit of eye resolution, to ups to tens of metres in completely unfoliated rock such as limestones. Such a nomenclature describes well the morphology and dimensions of scaly fabric and makes it unnecessary to invent new and potentially confusing terms.

Final remarks

The term Argille scagliose has now accompanied geologic concepts of mountain building for almost two centuries. This review of the evolution of the meanings of this term has been a journey through the geological exploration of mountain building processes. The difficulties in accepting new ideas, and in forming a common scientific vocabulary to describe geologic processes from a microscopic to regional scale are all elements of this story and its many long-lasting controversies.

We now find much of this controversy quaint in light of the current plate-tectonic framework for study of mountain-building processes. The use of argille scagliose as a macroscopic term to label a rock unit has now completely disappeared from modern geologic maps of the Northern Apennines, as have its 1970-era cognates 'chaotic complex' or 'undifferentiated complex' (Fig. 3,5,10). What remains is the use of scaly fabric as a mesoscopic term to describe its particular cleavage fabric. This nomenclature persists as a descriptive term in all mountain belts of the world (Fig. 11).

At present, many researchers essentially ignore the details of this type of chaotic rock as irrelevant now that we have a good big-picture model of their formation somewhere within an active collision complex. In fact, with precise and detailed mapping techniques, we can reconstruct many tectonic details in the generation of the units containing argille scagliose. Being Apennine geologists who still actively study these units, we are aware of continuing disputes in the scientific community about our interpretations for the detailled origin of these rocks by a combination of accretionary prism and plate boundary processes – each with often distinct and distinguishable mesocharacteristics. Instead, many geologists and geophysicists are currently comfortably binning these units as 'chaotic complexes' that do not need further study. Probably a large part of the modern lack of interest is related to technical difficulties in imaging these rock units in active systems. We can infer their probable existence in seismic images as the blurry regions within a decollement system, and perhaps from their best-developed example in a different part of the prism as olistostromes sandwiched between well-bedded turbidites. Usually these occur in particularly complex types of tectonic melanges. Recovery during drilling is difficult because these rocks are usually composed of incohesive material with strong contrasts in competence. This means that active modern examples of these rock-forming processes are still a particular challenge – and we must continually return to studying their fossil record in order to better unravel the processes of their genesis and evolution.

In recent years, great interest has been focused on a new mechanism to form this rock cleavage as a byproduct of diapiric processes such as mud diapirs and mud volcanoes. Other geologic environments where this clevage arises are related to shearing in fault zones, in particular in the regions of subduction plate boundaries near the updip limit of seismogenesis. Petroleum exploration is increasingly moving into deepwater environments with co-active sedimentary and tectonic processes where similar chaotic rocks are common and play an important role in localizing deformation. Finally, the rock units containing argille scagliose often play key roles in local slope instabilities, even as their geotechnical characteristics remain relatively poorly known. In this practical area, too, argille scagliose will continue to have an persistent large impact on our economy and society.

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