GEOLOGY OF TUSCANY: EVOLUTION OF THE STATE-OF-KNOWLEDGE PRESENTED BY GEOLOGICAL MAPS AND THE NEW GEOLOGICAL MAP OF TUSCANY, 1:250,000 SCALE

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3

ABSTRACT

In this paper we illustrate the evolving intepretations of the geology of Tuscany as presented in the many geological maps published by various authors since 1800. We start from the earlier maps of middle 1800 mainly realised to explore natural resources, and the geological maps of the end of 1800-early 1900 made by B. Lotti and D. Zaccagna on behave of the Italian Geological Survey ("Servizio Geologico Italiano"). Later on the discussion focused on the autochthonous and allochthous interpretation of the northern Apenines as evidenced in geological maps of German and Swiss geologists and in the fundamental works of Merla, that dominate the geological interpretation of Tuscan geologists for many years. The Nappe theory finally advanced in the Italian literature only at beginning of the 1940s for the works of Burckhardt, Ippolito, Spicher and Rittmann based on geological survey for the Centro Ricerche Geominerarie of the I.R.I.
In the 1960s, research addressed the stratigraphy of the Tuscan Nappe, its regional extension, the frontal overthrust, tectonic transport direction, and unconformities and discontinuities in many stratigraphic sections. A fundamental contibution to these studies come from Trevisan and many geologists of the Pisa University. At the same time studies led to substantial improvement of knowledges on ophiolites and mode of oceanic rifting and related sedimentation as testified by maps of P. Elter in northern Tuscany and Liguria.
At the end of 1960s many innovative interpretations of the geology in Tuscany were put forward, following the extraordinary development of cartography. The Italian Geological Survey created initiatives to complete and remapping much of the Geological Map of Italy, producing the 1:100,000 scale geological atlas of Italy. This initiative stimulated the confrontation amongst the various research institutions which were studying the northern Apennines chain (especially the Universities of Genoa, Florence, Parma, Pavia, and Pisa). A new and important synthesis of the Northern Apennine geology was then published in 1970 by Florence geologists, with a new geological map at 1:500,000 scale compiled according to the geosynclinal theories. In more recent years many geological maps at various scale are published in Tuscany, following recent view of geological intepretations, strongly supported by modern concepts of sedimentology, stratigraphy and structural geology of deformed rocks.
At the end of this paper we introduce the new Geological map of Tuscany at 1:250,000 scale. We illustrate the basics of the legend organization and compilation of the map units.

The evolving knowledge regarding Tuscany and its geology, and the Northern Apennines in general, can be seen in the several versions of geological maps, and their related observations, from the twentieth century. The history of the extraordinary development of these maps actually begins in the mid-1800s, as geological investigations assumed great importance due to the exploration and utilization of natural resources (Figure 1). In 1867, the Royal Geological Committee of Italy (*Regio Comitato Geologico d'Italia*), was instituted in an initiative similar to that occurring in other european countries (beginning with France).
The Geological Office, the executive organ, was created within the Committee. Tuscany, with its significant mineral sector, was the subject of an intensive research program.
Numerous maps at 1:100,000 scale were produced from the end of the 1800s to the 1910s; maps at a scale of 1:50,000 and 1:25,000 (Figure 2) were also produced from some of the strategically important sectors, such as the mining districts of the so-called "*Catena metallifera* (metaliferous chain)." This significant undertaking of geological surveys produced a precious and also objective scientific body of knowledge, which has remained valuable over time even as theories have changed. These geological surveys also display a noteworthy homogeneity since only a few scientists, all essentially stratigraphers, were responsible for guiding the extensive surveys. Therefore, the geology was tied to a rigorously autochthonous framework.
Thus, stratigraphic discontinuities and anomalous contacts were described as real and proper orogenetic unconformities, with extensive emersional and erosional sub-aerial lacuna. Two principal transgressions were identified: one in the Jurassic ("between the Late Liassic and the Tithonian"), and the other in the Cretaceous ("between the Neocomian and the Senonian"). Lotti (1910) applied Suess' nomenclature and called these the "Bathonian transgression" and the "Cenomanian transgression."
Domenico Zaccagna and Bernardino Lotti were essential the authors of the many geological maps of Tuscany of that time, even though P. Savi, G. Meneghini and C. De Stefani are by consensus considered the "fathers" of Tuscan geology. The stratigraphic successions proposed by Zaccagna and Lotti are similar, as can be seen from the legend (we provide an example in Figure 3) of two summary maps—one for the *Alpi Apuane e Regioni limitrofe* (Apuan Alps and neighbouring regions), at 1:250,000 scale (Zaccagna, 1932), and the other for *Toscana*, 1:500,000 scale (Lotti, 1910). Each is accompanied by an impressive volume, which forms part of the *Memorie descrittive della Carta Geologica d'Italia* series. Some differences of opinion do emerge

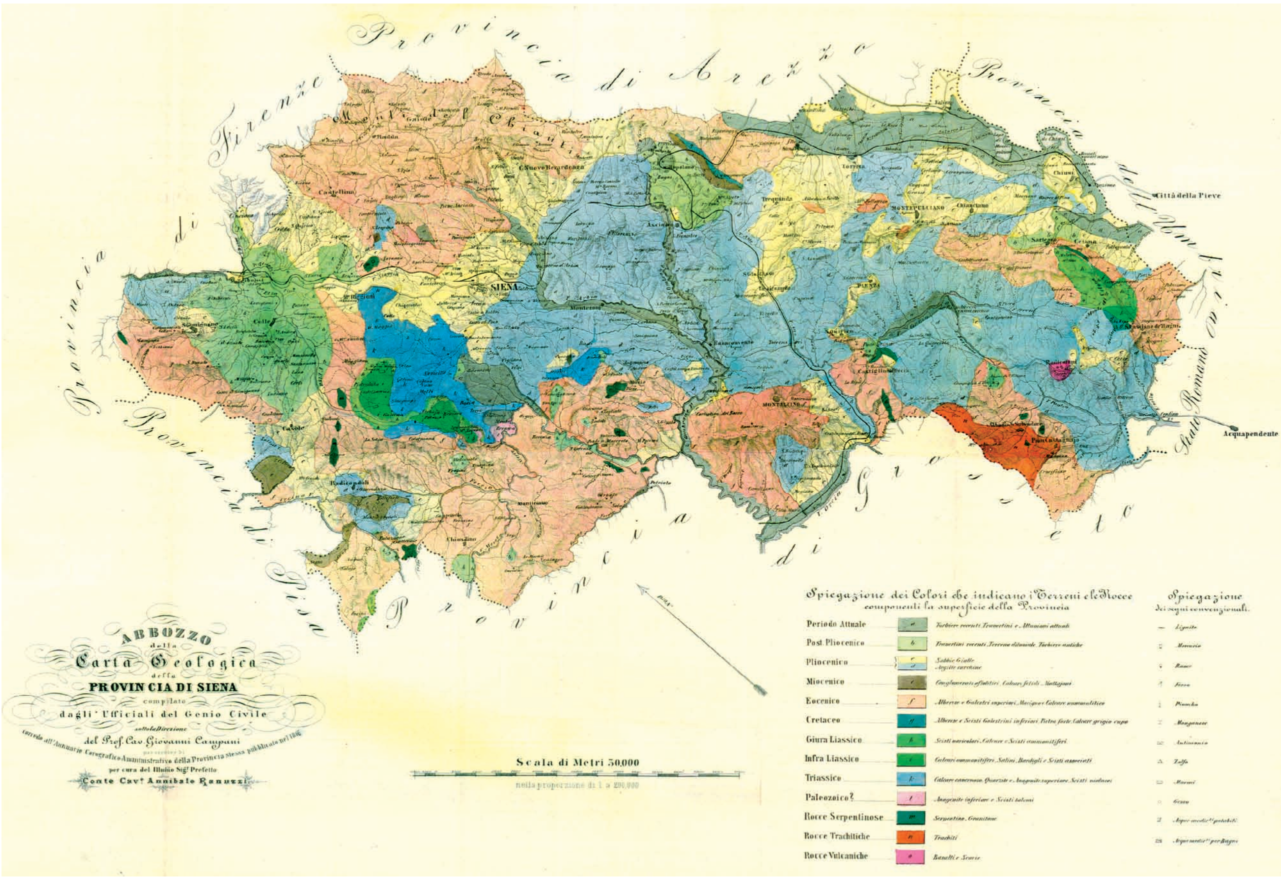

Fig. 1- Map of Siena Province, by Prof. G. Campani and dating to 1865.
The original is at a scale of 1:200,000, 46 by 63 cm, is preserved at the *Accademia dei Fisiocritici di Siena*.

amongst the authors cited, related to the possible existence of some tectonic structures. In principal, De Stefani denied the existence of any faults. Zaccagna began to believe that faults existed, although he did not show them either on the maps or cross-sections except in very obvious cases related to Lotti's reports. In fact, Lotti draws a fracture line (*linee di frattura*) on the Tyrrhenian side of the Northern Apennines, oriented NW-SE in the north and N-S in the south, in Table II, of his work in the *Memorie descrittive della Carta Geologica d'Italia*. In the text Lotti mentions a "*sprofondamento subitaneo* (sudden subsidence)" on the coastal zone of Tuscany at the end of the Pliocene.

The autochthonous framework would dominate in the Geological Service for the first half of the 1900s, and even into the later decades, though in a more subdued manner. Difficulties in reconstructing the stratigraphic successions arose, where repetition of the series was very evident. Findings from new fossiliferous locations (in the Alpi Apuane, Monte Pisano, and Montagnola Senese) created "*opinioni aberranti rispetto alle idee classiche della geologia toscana* (deviant opinions with respect to the classical beliefs of Tuscan geology)." Convoluted explanations were given to explain the reoccurrence of the same formation at different heights in a sedimentary succession: therefore, for example, the Verrucano and the Cavernoso at the base of the Tuscan Nappe was assigned to the Early Cretaceous (Wealdiano) by Fucini (1925); and the controversial paleontological identifications of Vinassa De Regny which managed to attribute to older age the ammonites in the Liassic marls of Monte Pisano (Vinassa De Regny, 1932; 1933) thereby creating subsequent errors in his devoted follower, R. Redini (1935).

However, even in the early 1900s, many other european geologists did develop Nappe-based interpretations, as an alternative to the autochthonous model followed by most of the Italian geologists. De Launay and Steinmann, in 1907, were the first to propose, on different basis, that the Ligurian units were allochthonous. Subsequently, other allochthonous units within the Tuscan succession were identified, culminating in the proposal of a nappe structure for the Northern Apennines (Tilmann, 1926). Lencewicz (1917) hypothesized that the "limestone Apennines (*Appennino calcareo*)," found underneath the ophiolitic nappe ("*Falda superiore*"), might actually be allochthonous. He identified two units: the non-metamorphic Sicilian Nappe (*Falda di Sicilia*), and the underlying metamorphic Calabrian Nappe (*Falda di Calabria*).

The Nappe theories were further elaborated in the

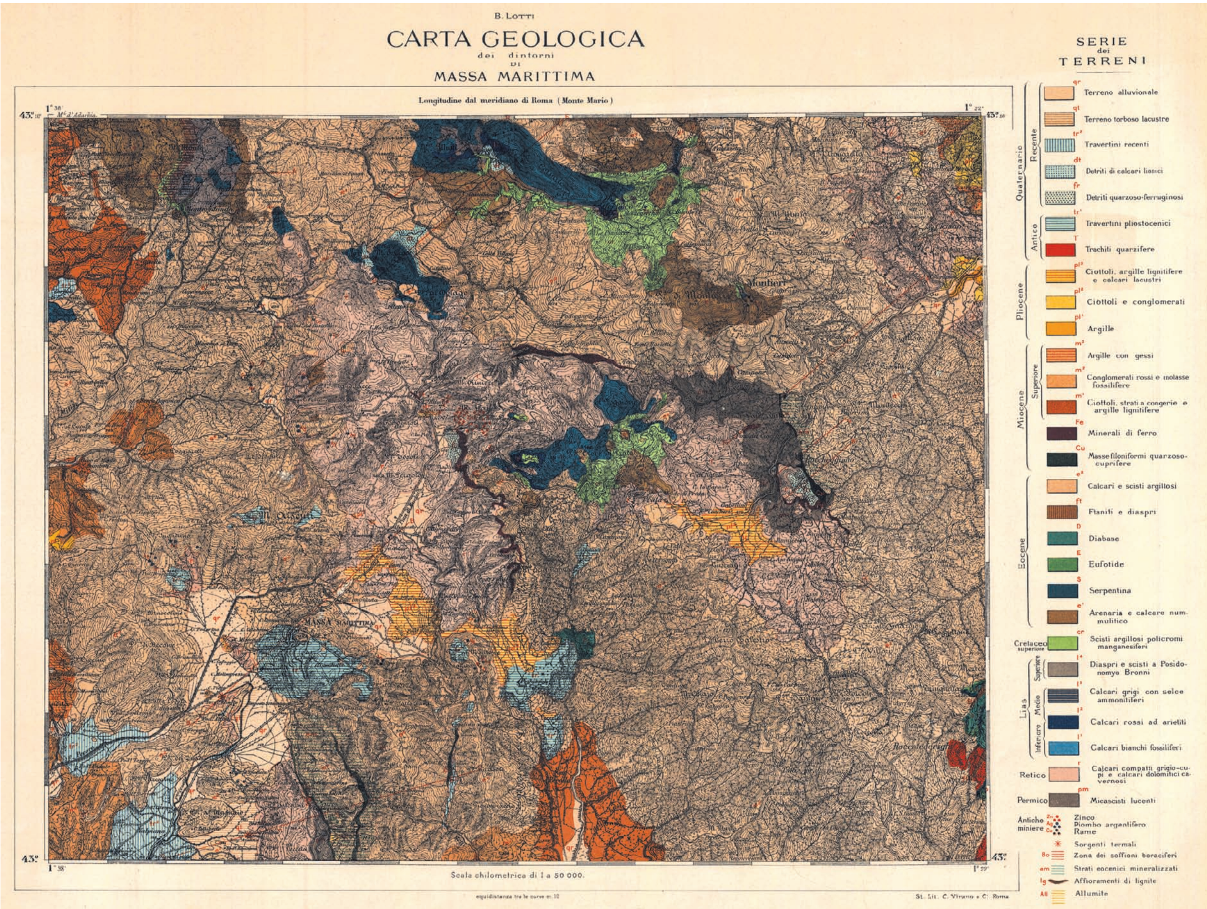

Fig. 2 - Geological map of Massa Marittima and adjoining area, by B. Lotti.
The original at the scale of 1:50,000 measures 40 by 46 cm.

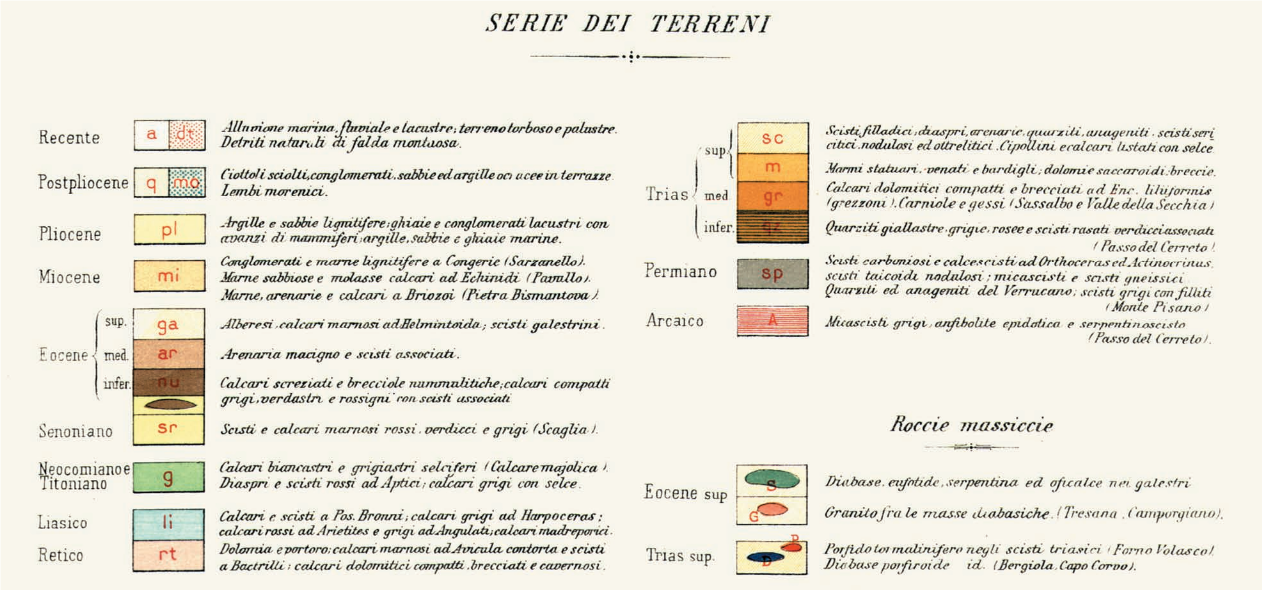

Figure 3a

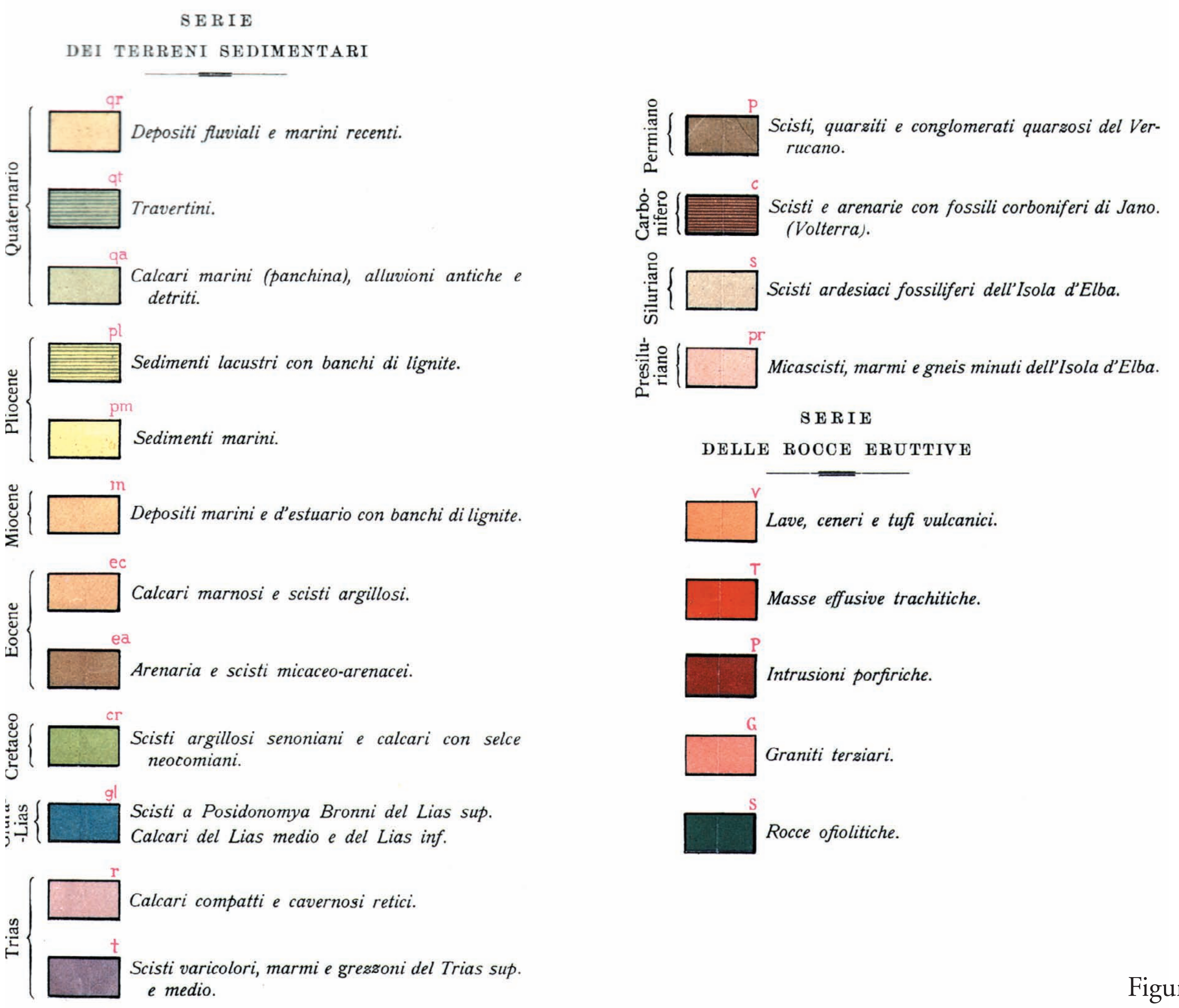

Figure 3b

Fig. 3 - (a) Map legend taken from Zaccagna's synthesis of the Apuan Alps and vicinity, scale is 1:250,000, and (b) from Lotti's synthesis of Tuscany, scale is 1:500.000.

1930s, with many publications in the German language (Tilmann, 1926; Staub, 1932; De Wijkerslooth, 1934; Teichmuller, 1932; 1935; etc.). Below the *Falda ligure* (Ligurian Nappe), and within the three main outcrops of the *Catena metallifera* (which are the *Alpi Apuane*, *Monte Pisano* and *Montagnola Senese*), the following units were recognized (from top to bottom): "Toscanide II," the non metamorphic, and the"Toscanide I." The Toscanide I proposed to comprise all the metamorphic terrain found in all three nuclei. "Toscanide I" was subsequently divided into two: the upper, para-autochthonous part was composed primarily of the Triassic Verrucano, found in the western and southern part of the Apuan Alps (*Schuppenzone von Massa* of Staub); and the lower unit was autochthonous.

In the 1930s, a group of Tuscan geologists, recognized that the ophiolitic layers were allochthonous. Merla (1952) states: "On the other hand, the complete

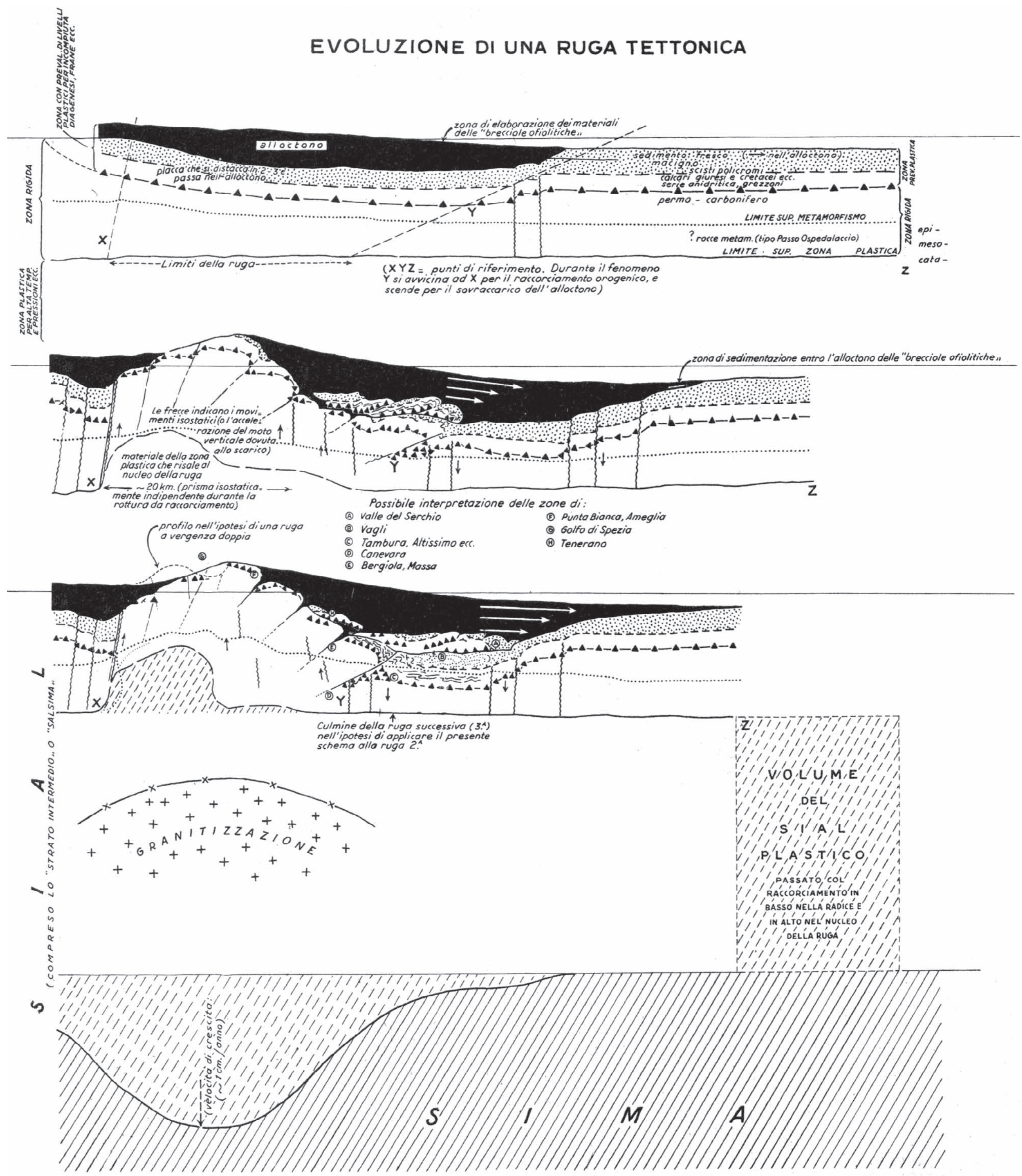

Fig. 4 - Diagram of the evolution of a tectonic ridge, from Table II of Merla (1952).

allochthonous nature of the superficial layers, the "scaly clay" has definitely been advanced. Up until 1933, this idea found little acceptance amongst Italian geologists. Yet, from Rovereto (1939) and now this author, the idea has quickly become accepted. However, it must be emphasized this acceptance has not been as part of the Nappe theory (that is a coherent tectonic mass which is either pushed from behind, or blocks that slide under the influence of gravity, and with mylonite and friction breccias at the base), yet rather within the framework of tectonic landslides and their chaotic masses, or "orogenic slides." Migliorini, in 1933, proposed this model based upon predictable gravitative forces operating within the orogenesis." Migliorini's model was subsequently refined in the introduction of a paper regarding "composite wedges (*cunei composti*)" (Migliorini, 1948). His two papers became the basis for the reconstruction of the Northern Apennines, presented by G. Merla in 1952.

The main concepts of Merla's theory are reported here, for they would dominate the geological interpretation of Tuscan geologists, and especially in Florence, for at least a decade. The theory (see Chapter 1, paragraph 14) is "based on the concept that the Apennine terrain is generally autochthonous, except perhaps for some surficial cover (such as the scaly clays, "*argille scagliose*") or plates of limited extent, as are seen at the base of the allochthon" (Figure 4); and "of a rising intumescence, or "tectonic ridge (*rughe tettoniche*)" which rose successively in time from the Tyrrhenian to the Adriatic;

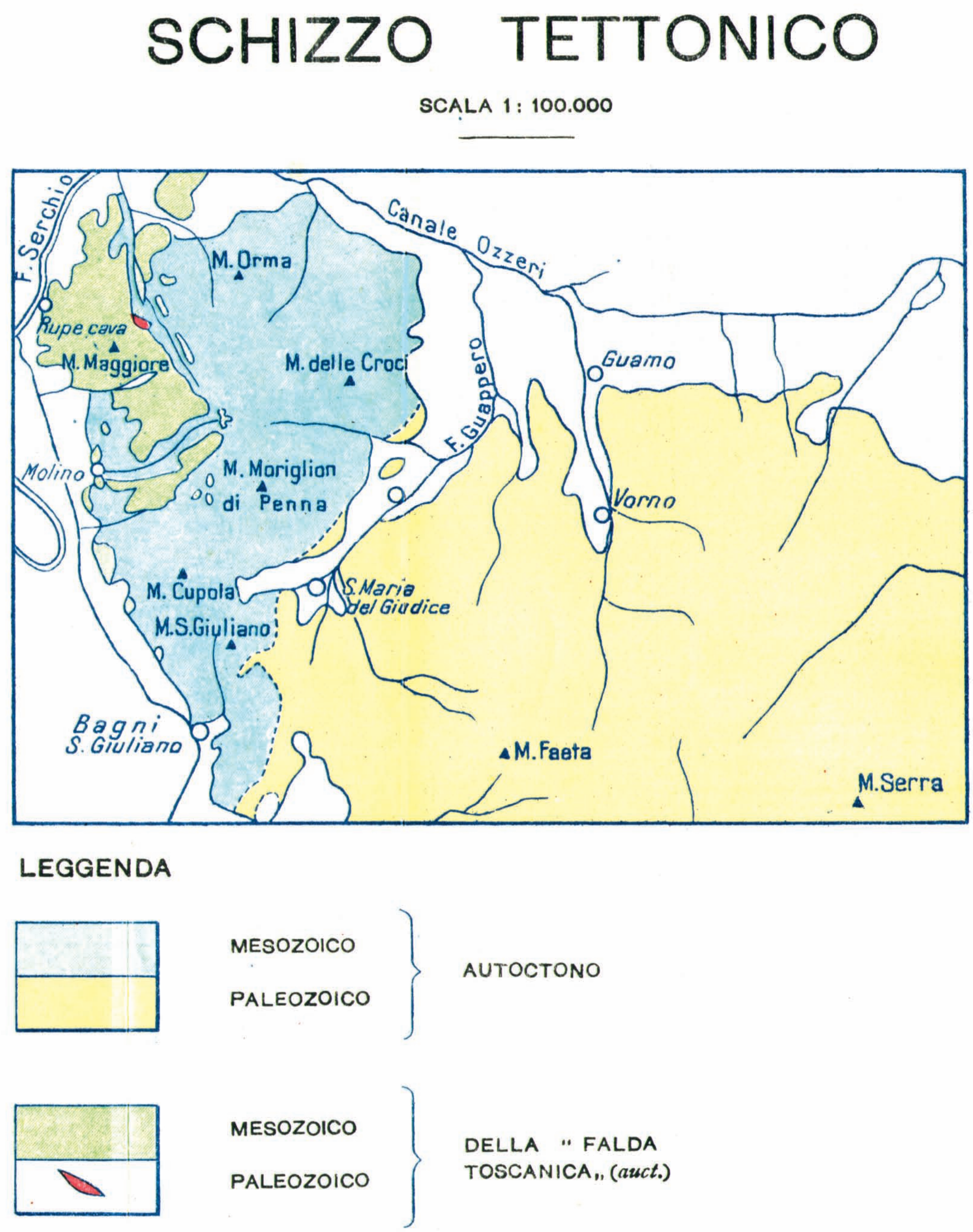

Fig. 5 - Tectonic setting of the M. Pisano, from Ippolito (1950).

of essentially disjunctive tectonics in the single ridge, with fault stacks converging below, thereby creating a moderate amount of crustal shortening transverse to the mountain chain; and where the gravitational effects seen in landslides and large superficial rock slides, or in small scale folding of semi-incoherent rock parcels (poorly cemented sandstones, limestone or siliceous muds), was all secondary to the uplift; and with the correlated isostatic changes."

The Nappe theory began to advance in the Italian literature only at beginning of the 1940s. C. E. Burckhardt, F. Ippolito and A. Spicher, under the supervision of A. Rittmann, began a geological survey of the M. Pisano and the Apuan Alps for the *Centro Ricerche Geominerarie* of the I.R.I. The publication of the complete study was delayed, due to the war, until 1948 and 1950, with A. Rittmann and F. Ippolito as authors. A geological map of the M. Pisano, scale 1:25,000, and a tectonic sketch are presented in a memoir of Ippolito (1950). The sketch shows Mesozoic and Palaeozoic rocks which are assigned to the "Autochthon," and Mesozoic and Palaeozoic rocks which are assigned to the "Tuscan Nappe, (*Falda toscanica* (auct.))" (Figure 5).

Four stratigraphic columns are attached to the publication addressing the Apuan Alps (Ippolito,

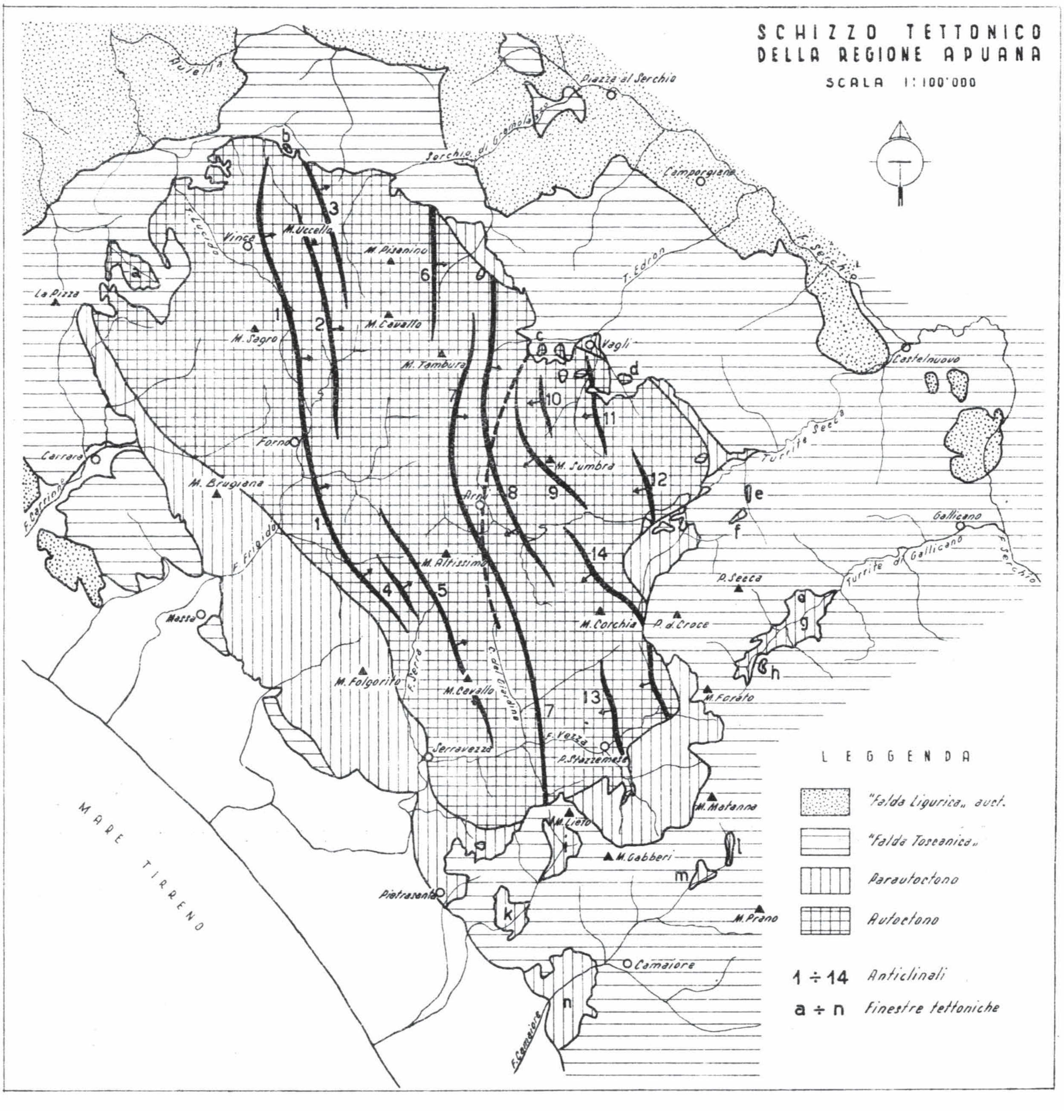

Fig. 6 - Tectonic sketch of the Apuan Alps, from Ippolito (1950).

1950): one for the "*Falda toscanica*" west (Carrara Region); one for the "*Falda toscanica*" east (Pania della Croce Region); one for the "*Autoctono*" west (Carrara Region), and one for the "*Autoctono*" east (Monte Corchia Region). This publication also contains a "Tectonic sketch of the Apuan Region (*Schizzo tettonico della Regione Apuana*)," 1:100,000 scale, in which four units are identified: "*Falda Ligurica* auct.," "*Falda Toscanica,*" "*Parautoctono,*" and the "*Autoctono*." (Figure 6).

Ippolito's two memoirs are striking for the modernity and clarity with which they address the important ideas in Tuscan geology. These concepts would form the basis of significant research, analyses, and syntheses, in the succeeding decades.

These concepts include: the identification of the regional extension of the Tuscan Nappe and the age of its emplacement; an analysis of the structural geometry of the Apuan Autochthon; the recognition of brittle faulting after nappe emplacement in the Apuan Alps and M. Pisano; the recognition that elisions within the Tuscan Nappe, which the author correctly interpreted as tectonic in nature, and which successive authors beginning from Signorini (1949) called the "*serie ridotta* (reduced series)."

In the 1960s, research addressed the stratigraphy of the Tuscan Nappe, its regional extension, the frontal overthrust, tectonic transport direction, and unconformities and discontinuities evident in the internal sections. Memoirs, from this time period, by Trevisan (1962), Giannini *et al.* (1962) and Baldacci *et al.* (1967), contain many ideas of regional relevance. Trevisan identified the front of the Tuscan Nappe as the large overturned fold that emplaces the Macigno fm. onto the Cervarola Sandstones. He also described in some successions in the Tuscan Nappe some characteristic discordant structures, "*où les terrains plus plastiques jouent le role de lubrifians.*" Giannini *et al.* (1962) conducted a detailed examination of the Tuscan Nappe for its entire extent through the Northern Apennines: they also traced the front as following a structural alignment in M. Orsaro - Val di Lima - Montecatini T. - Monti del Chianti - Monte Cetona. However, Giannini *et al.* remained uncertain

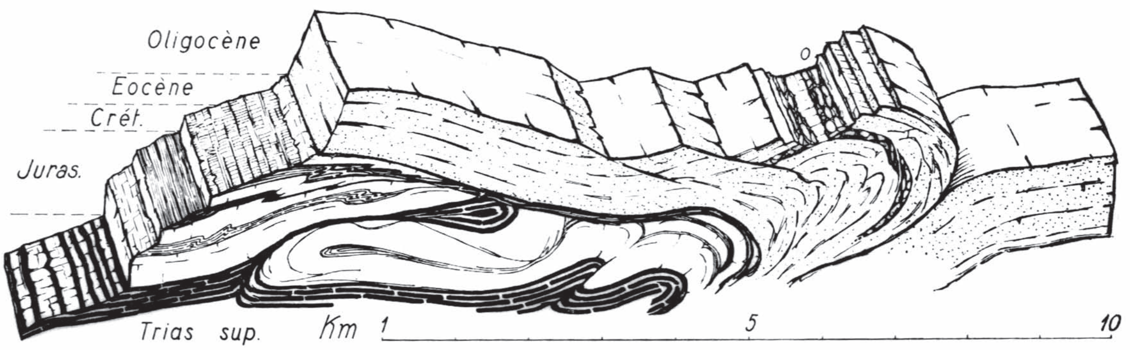

Fig. 7 - Structural discontinuities in the Tuscan Nappe, from Trevisan (1962).

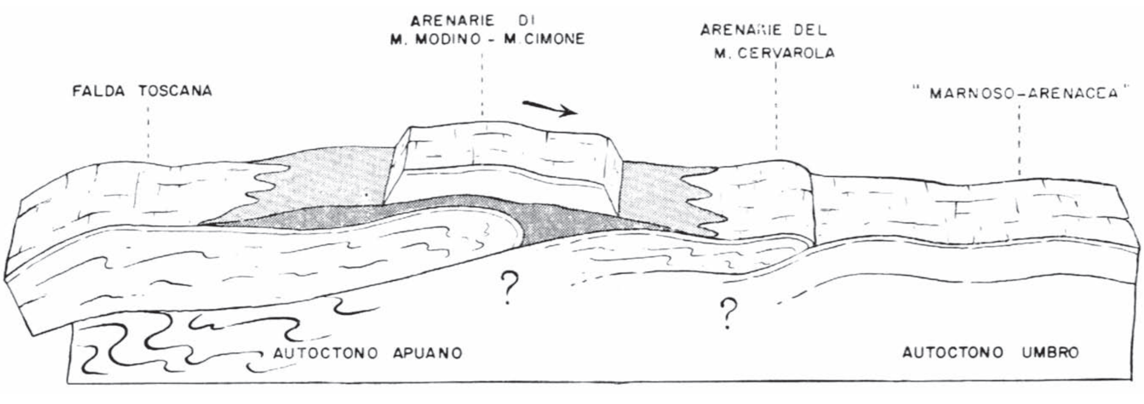

Fig. 8 - Tectonic relationships between the Tuscan Nappe and the "autochthonous" successions, both Apuan and Umbrian, according to Giannini *et al*. (1962).

of the genetic and tectonic significance of the Cervarola Sandstones (Figure 8).
Baldacci *et al.* (1967) believed that the Tuscan Nappe was emplaced in two phases: "the first at the Oligocene-Miocene boundary, when the front of the principal unit was defined. This front is still recognizable in some parts of the Monte Orsaro - Val di Lima structure. The second phase occurred in the Tortonian, when the principal unit and the underlying formation (the external unit) were clearly emplaced. This created a new front, east of the older front." This last sub-unit "is composed of parts of the Cervarola Complex l.s., and this terrain formed the original stratigraphic cover of the Autochthon. This cover was then removed, as it is said, at the level of the Scaglia fm. and then slid ahead until it was overthrust onto the Umbrian series." (Figure 9).
The relationship between the Apuan Autochthon and the Tuscan Nappe was then re-examined by Carmignani, Giglia and Kligfield in the 1970s. They conducted a detailed structural analyses of the Apuan metamorphic unit (Carmignani *et al.*, 1978; 1981). This study showed that the Oligocene-Miocene tectonics were poly-phased and synmetamorphic. During their D_1 phase, the metamorphic unit constituted a shear zone whose upper limit is the contact with the Tuscan Nappe, and whose lower limit (which does not outcrop) is the more external zone (Umbrian? substratum) which is presumably overthrust by the Apuan metamorphics (Carmignani & Giglia, 1984)." In a successive phase, likely in the Early Miocene, the D_1 structure was re-folded into an ellipsoidal dome, an antiformal stack, and then extensional processes commenced in the upper levels of the crust. The extensional events continued into the Neogene and the Pleistocene, resulting in the exposure of the Apuan's "core complex" (Carmignani *et al.*, 1994) (Figure 10).
Beginning at the end of the 1950s, and for all the 1960s, much attention was given to the Ligurian cover, theretofore it had not been detailed as was generically referred to as the "scaly clays (*argille scagliose*)." This new interest was fuelled by microfossil studies, and in particular by the application of "microfacies" analyses to the more coherent lithotypes. The microfossil and microfacies analyses produced more precise chronological references. The state-of-knowledge of the "scaly clays (*argille scagliose*)" was revealed to be almost nil during a 1956 Società Geologica Italiana conference that was actually dedicated to their study ("*Le argille scagliose ed i terreni in facies di flysch nell'Appennino*," (The scaly clays and their terrain in the Apennine flysch facies), presided over by F. Ippolito). Merla and Trevisan presented the first data coming from research in the Northern Apennines, which showed that one could "recognize several series still in stratigraphic order" within the allochthon's disorderly mass. Merla (1957) identified four successions near Florence, each exceeding one thousand meters in thickness. The successions were: "1) the Monte Senario - Monte Giovi Series (from polychrome schists to sandstones

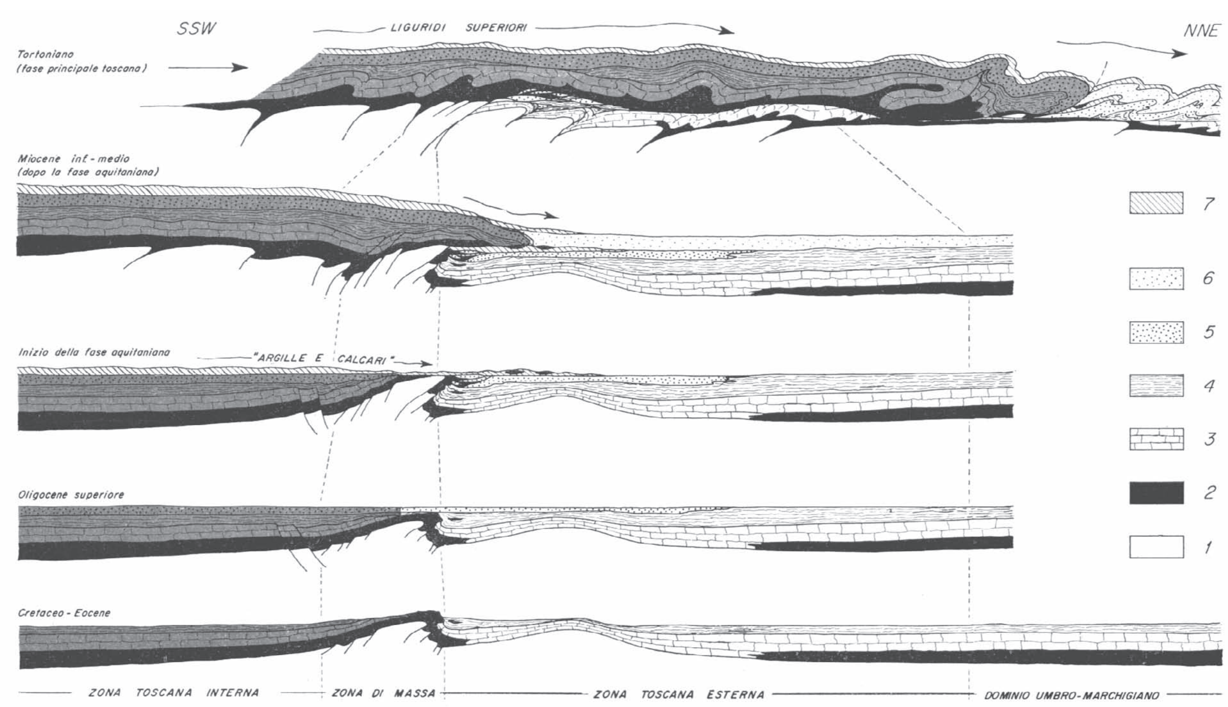

Fig. 9 - Diagram of the evolving paleogeography and tectonics in the Tuscan Domain, from Baldacci et al. (1967).

equivalent to *Macigno fm.*; Cretaceous-Eocene-Oligocene); 2) Vallina series (Pietraforte - Alberese; Cretaceous-Eocene); 3) Monghidoro Series (marly limestones - sandstone; ?Cretaceous - ?Paleogene); 4) Monte Morello Series (Alberese; Eocene). And a fifth series, very disordered, which comprised in the following order: ophiolites, radiolarites, Calpionelle limestones (Tithonian-Early Cretaceous)."

Trevisan (1957) recognized that "the allochthonous complex of "scaly clays" became increasingly heterogeneous, both in materials composition, and structural arrangement" as one proceeded from the Tyrrhenian to the Adriatic sector, in the Northern Apennines. He also proposed a succession for the "Scaly Clay" complex, and indicated the possible lateral relationships with the Tuscan Series. The idea of emplacement of the "Scaly clay" is shared by the conference participants, as concisely expressed by Facca during Beneo's talk (1957): "The new tectonic theory, as applied to the Apennines, also introduces the concept of gravitative tectonics for the Apennine's geology. Thanks to the new Tuscan school of thought, we will finally not have any more references to tectonic nappes in the scaly clays, and the absurd "push from behind (*spinta da tergo*)" which was to have thrust the Apennines over the scaly clay complex, in a type of *tapis roulant* that carried the uprooted limestone mountains." Several studies dedicated specifically to the stratigraphy and tectonics of the allochthonous cover, were published in the 1950s. Elter & Schwab (1959) identified three tectonic complexes in the region of Carro-Zeri – Pontremoli (Figure 11): "The first was probably part of the Apuan cover and comprises a series similar to that usually identified in Tuscany.

In the upper part of the sandstone (Macigno fm.) however one observes intercalations of "scaly clay" terrain. These intercalations were thought to be submarine slides, their provenance would be the allochthon's front, in motion. The intercalations were then deposited in the Macigno's sedimentary basin, while the basin was still being formed.

The formations which overthrust the Tuscan Complex had up to then been considered to belong to a single "scaly clay" covering. In reality, they belong to two distinct and overthrusted stratigraphic series. The lower series is characterized by the presence of Helmintoid

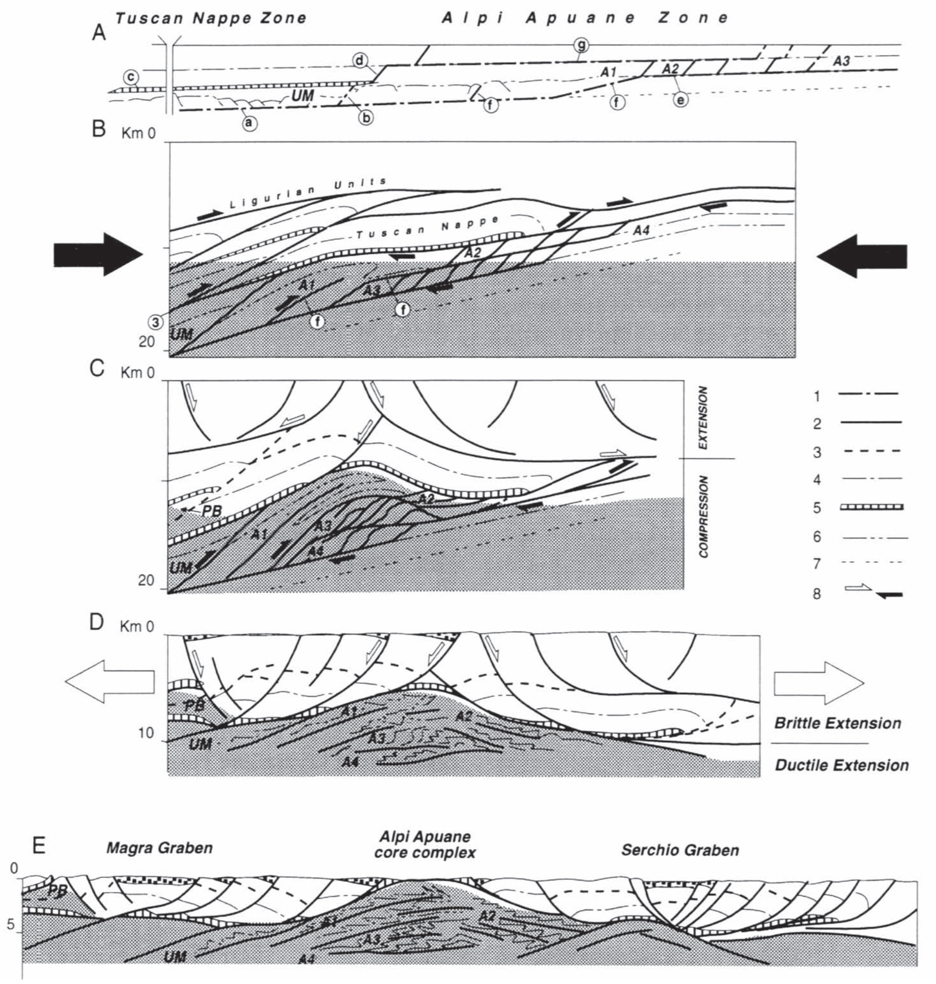

Fig. 10 – Tectonic evolution of the Apuan Alps during the compressional (Late Oligocene – Early Miocene) and extensional (Middle-Late Miocene - Late Pleistocene) regimes, according to reconstructions of Carmignani & Kligfield (1990). From Carmignani *et al*. (1994).

marls (Alberese); and the upper by the so-called “Upper sandstone (*arenaria superiore*).” P. Elter (1960), in a synthesis of the northwest Apuan Alp identified, “several complexes, one overthrust upon another. In each complex, the sediments at the base are older than those which compose the top of the underlying complex. Two of these complexes have already been identified. The first is composed of the so-called “Apuan overthrust serie (*raddoppio apuano*)”, or Tuscan Nappe, and contains para-autochthonous slices at its base; it is thrusted over the autochthon’s sandstone (or the Pseudomacigno fm. of earlier authors) with Triassic terrain. The second complex is called the “scaly clay complex” Elter identified “three terrain series which are partially coeval” in this second complex. The series are, from bottom to top: 1) “The Alberese cover, composed of a Cretaceous-Eocene series, and characterized by the “Alberese” formation”; 2) “The scaly clay ophiolitic covering and the upper sandstone, which constitutes the Jurassic-Oligocene series”; 3) “the Helmintoid flysch covering, apparently composed of one Cretaceous-age formation (Figure 12).” These successions’ significance is, “because this series was tectonically overthrust, and it is observed across a vast area, even south of the study zone, we must not consider it a single slice, but rather a regional Nappe cover (Elter, 1960).”

The 1960s saw many innovative interpretations of the geology in Tuscany, and also the extraordinary development of cartography. The *Legge Sullo* (Legge n°68 of February 2, 1960) created initiatives to complete and remapping much of the Geological Map of Italy, producing the 1:100,000 scale map sheets. This initiative provided impetus to the efforts to address the various problematics of the Northern Apennine geology, and it stimulated the confrontation amongst the various research institutions which were studying this part of the mountain chain (especially the Universities of Genoa, Florence, Parma, Pavia, and Pisa). The maps produced were not only those of the Italian Geological Survey, but also the many geological sheets at larger scales (especially 1:250,000) which covered the more important stratigraphic and structural regions. The Italian and foreign (especially from the Berlin school) researchers concentrated on clarifying the relationships amongst the several tectonic units (Tuscan and especially Ligurian) found overthrust in the chain, and the definition of the litho- and chronostratigraphy. The intense scientific research culminated with the publication of several syntheses addressing the Northern Apennine geology, along with the regional-scale maps. We can see that the legends ofthese geological maps reflect a rather uniform vision of the Apennine’s structural setting, despite a few differences in presentation. However, Reutter (1968) makes it apparent that the German authors did have different ideas. The numerous tectonic units which are overthrust in the Apennines have been assigned to four paleogeographic zones: the Ligurian, the Emilian, the Tuscan, and the Umbrian-Marches zones. Within these zones one can find: four Ligurian units (the *Liguridi* I-IIIa); five Emilian units (the *Emilianidi* I-V); two Tuscan units (*Toscanidi* I-II); and one Umbrian-

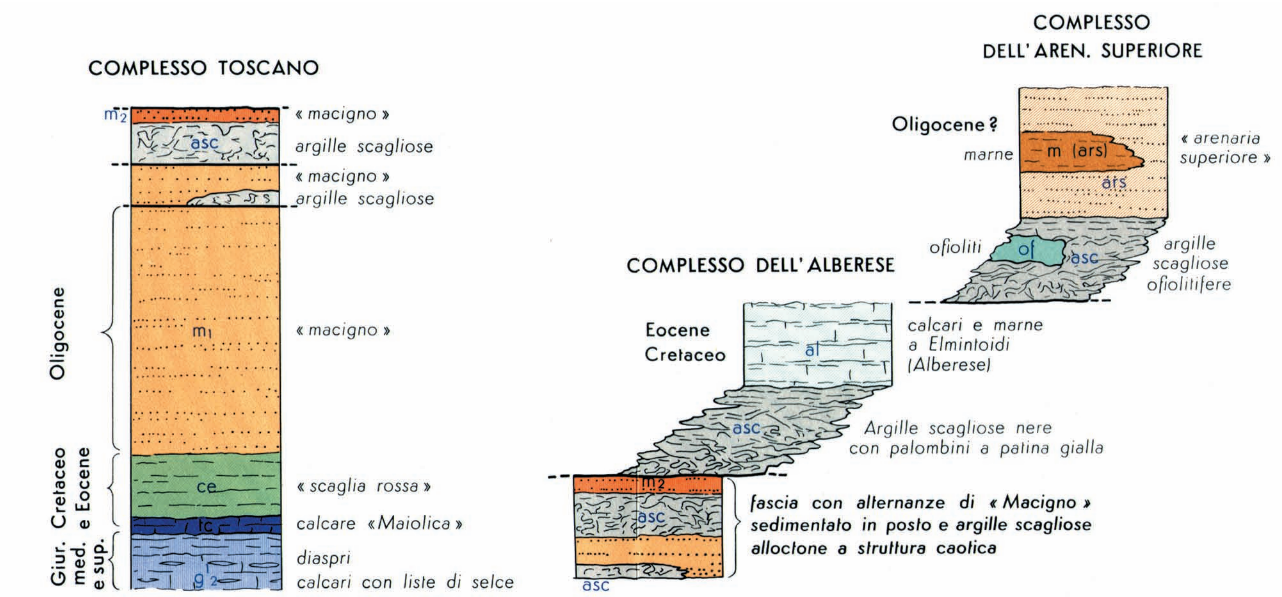

Fig. 11 - Relationships between the "Tuscan complex" and the "Scaly clay cover" successions, near the vicinity of Carro - Zeri - Pontremoli, from Elter & Schwab (1959).

Marches unit. Three additional small units have been identified, although their paleogeography is uncertain (Figure 14).

A new and important synthesis of the Northern Apennine geology was published in *Sedimentary Geology*, in 1970; it was edited by Florence geologists (Sestini, Ed., 1970). A geological map at 1:500,000 scale was attached (Bortolotti *et al.*, 1969). The map's legend was unusual for it was composed according to the geosynclinal theories elaborated by Aubouin (Aubouin, 1961; 1965). The lithostratigraphic units have been assembled into miogeosynclinal, eugeosynclinal, lategeosynclinal (*tardogeosinclinal*), and postgeosynclinal assemblages. The miogeosynclinal assemblage comprises all the formations in the Tuscan and Umbrian-Marches successions, the metamorphics, and the non-metamorphics, ordered by age from the Palaeozoic to the Messinian. The eugeosynclinal assemblage is divided into groups and supergroups formations, from the bottom these are: the Canetolo Complex (Paleogene), the Calvana Supergroup (Late Cretaceous superiore - Middle Eocene), the Elba Flysch (Late Cretaceous), the Sambro Group (Late Cretaceous - Paleocene), the Vara Supergroup (Late Jurassic - Paleocene), the Baganza Group (Late Cretaceous - Paleocene), and the Trebbia Supergroup (Late Jurassic - Middle Eocene). The late geosynclinal sequence includes the Eocene-Miocene Tuscan Epiligurian succession, the Umbrian-Marches succession, and the Po gypsiferous-sulphurous Formation. Finally, the postgeosynclinal assemblage includes the lacustrine and marine sediments dating from the Late Miocene to Pleistocene in Tuscany and in Lazio (the Neoautochthonous Auctt.), and the Plio-Pleistocene sediments in Emilia and the Marche regions.

Aubuoin's theories of the eugeosynclinal and miogeosynclinal systems were short-lived. The first studies showing ocean floor spreading, and transform faults, were published at the beginning of the 1960s. The explosion of publications addressing the "new global tectonics" commenced in 1968 (see Ranalli, 1995). The first hypotheses addressing the setting of the "greenstones (*rocce verdi,* ophiolites)" of the Northern Apennine ophiolitic allochthonous complexes, within the newer plate tectonic framework, were produced by Decandia & Elter (1969; 1972). The ophiolites were not evaluated as eugeosynclinal (*sensu* Aubouin) elements, but as oceanic crust elements which had been revealed due to the breaking and spreading away from the continental crust. Other studies followed in the 1970s (Figure 17). Elter & Raggi (1965), and Elter (1972), are responsible for the division of the Ligurian oceanic and the adjoining Tuscan-Umbrian continental margin (of the Late Cretaceous) areas into paleogeographic zones. A division that occurred before the orogenic phases, which then developed tectonic units, with the subsequent overthrusting and construction of the Apennines (Figure 16). The paleogeographic zone model was adopted, with alterations of varying degree, by many authors in the decade following. Some more recent geological maps and their legends still showed the influence of this model (Giannini et al., 1971; Giannini

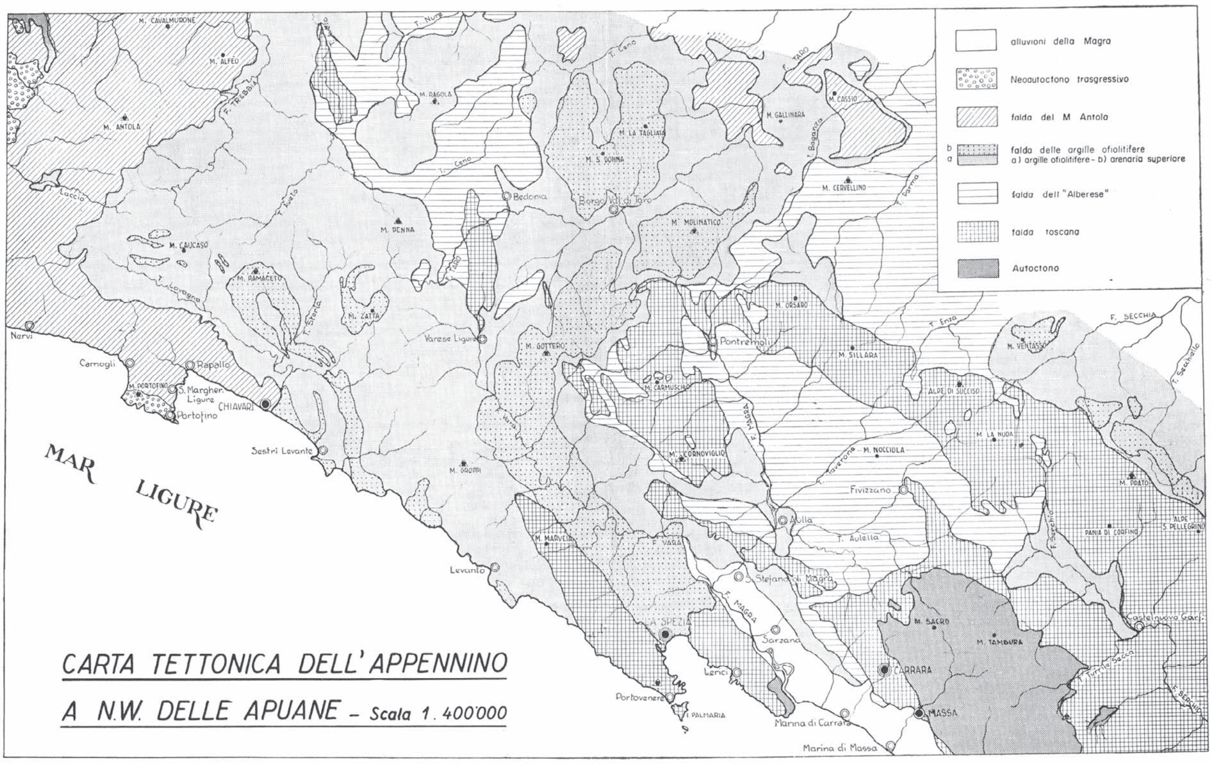

Fig. 12 - Tectonic map of the Northern Apennines, from Elter (1960).

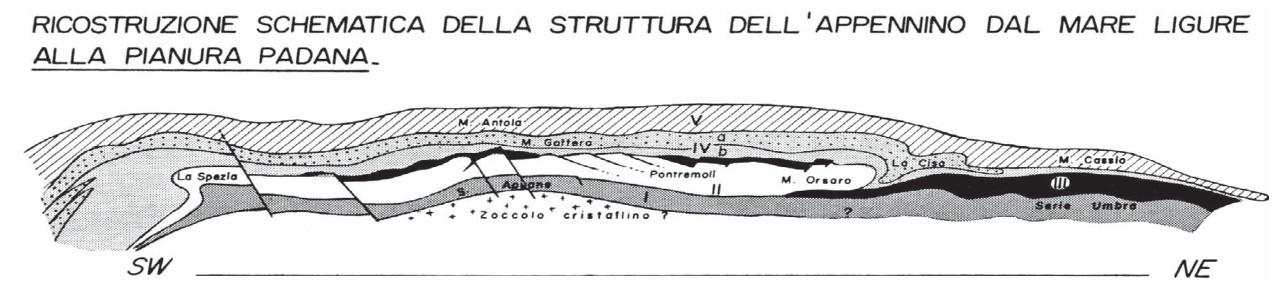

Fig. 13 – Schematic reconstruction of the Apennine structure, from the Ligurian Sea to the Po Plain. Symbols: I - Autochthon; II - Tuscan Nappe; III – Alberese Nappe; IV - Ophiolitic Nappe, a: Upper sandstone; b: Basal clayey complex; V - Helmintoid Flysch Nappe. From P. Elter (1960).

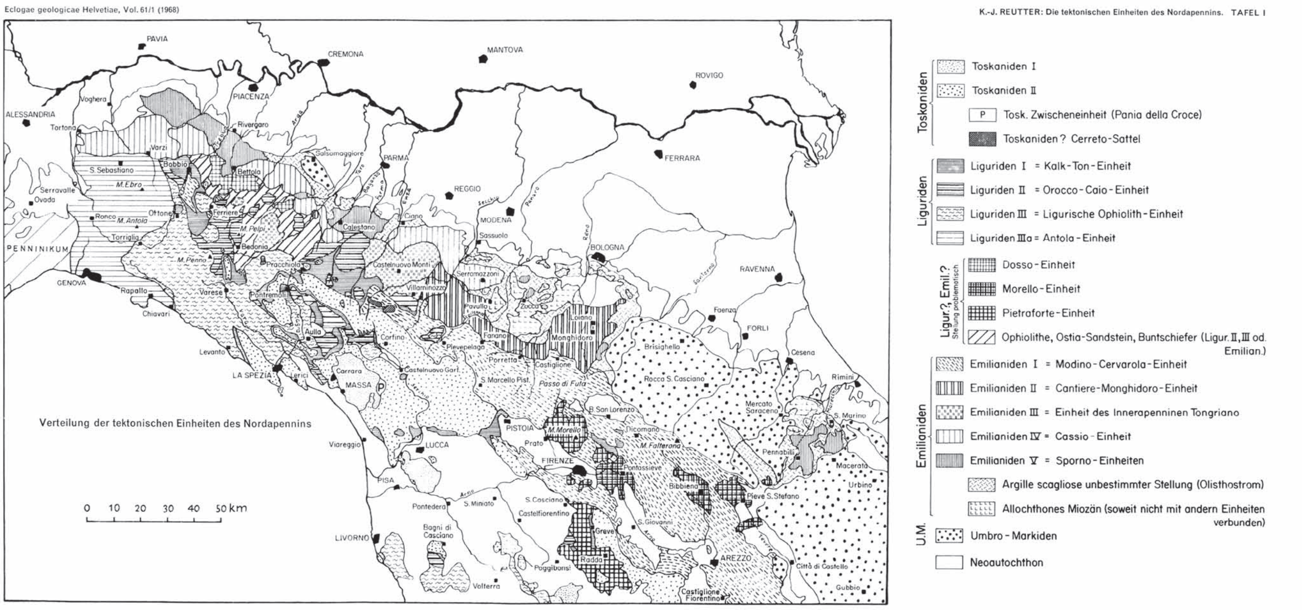

Fig. 14 – Tectonic units of the Northern Apennines, from Reutter (1968).

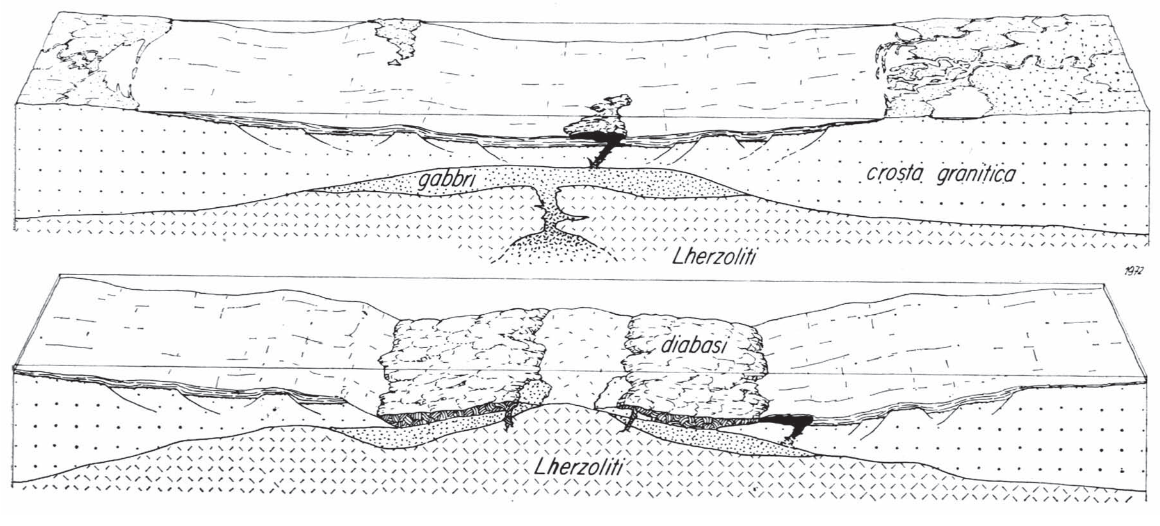

Fig. 15 – Evolution of the Ligurian Basin: above, Trias - Dogger; below, in the Malm, after separation of the continental crust, according to Elter & Decandia (1969; 1972). From Elter (1972).

& Lazzarotto,1975; Boccaletti & Coli, 1982).

In the 1970s, the Italian Geological Survey finished production of the Geological Map of Italy, II Edition, scale of 1:100,000. It then began to elaborate a project for a new Geological Map, at a scale of 1:50,000. Eleven map sheets were produced, one of which was in Tuscany: the map sheet "F°332-Scansano." However, the initiative to produce a new geological and geothematic map of Italy, began when the laws n. 67 (1988) and n. 305 (1989) were enacted: this is known as the *Progetto C.A.R.G.* The first map sheets made for Tuscany, apart from those sheets bordering the Emilia-Romagna region, were: sheet F° 285 - Volterra, sheet F° 295 – Pomarance, and sheet F° 306 - Massa Marittima. These maps were directed by geologists at the University of Siena. The legends were compiled according to Criteria 4, of Vai & Castellarin (1992). They state that the legend must be composed of lithostratigraphic units which are "grouped together to compose larger tectonic units, and these in turn should correlated to the larger facies domain."

The construction of the Volterra, Pomarance and Massa Marittima 1:50,000 maps was a long and complex process. These three map sheets cover much of the "Colline metallifere," these metaliferous hills are part of the collisional chain, that is the Paleoapennines, which were folded during the Early Miocene. All of the geological problematics related to a collisional chain, are found within these hills. The deformational events are recognizable, as diverse tectonic settings, in the pre-, syn- and post-collisional phases. The formations which were involved in pre- and syn-collisional structural deformation have been grouped into tectonic units, arranged in order of their geometric relationships in the field (Figure 17). Those units which have been affected only by post-collisional deformation, have instead been arranged in accordance to their stratigraphic emplacement. A tectonic unit is a groups of formations delimited at the top and bottom by thrust faults. The tectonic setting of the unit is highly variable: it varies from chaotic, to a high degree of organization in which a single tectonic unit's internal structure is still visible. Thus the tectonic unit may be divided into units of superior and inferior rank: the former are represented by entire paleogeographic domains, the latter are represented by several paleogeographic zones. Both belong to the same domain, and comprise sections which may overlap at least partially. Similarly, primary and secondary thrust faults have been identified: both are labelled "often reactivated as normal faults (*spesso riattivati come faglie dirette*)," and indicate the frequent occurrence of tectonic inversion.

The Ligurian and Tuscan cover, in this area, have been strongly laminated. Large, thick elisions of the sedimentary successions are observed, and even the direct superimposing of the Polombini Clay Ophiolitic Unit upon either the Tuscan Nappe Triassic Evaporites or even upon the metamorphic basement.

This structural situation is frequently referred to as the "*serie ridotta* (reduced series)," for the Northern Apennines. At the same time, several of the Italian regional authorities had also begun the production of Regional Geological Maps, the maps had small scales and were to be a knowledge base for regional management. Emilia-Romagna was the first region to make and utilize a map with a scale of 1:10,000. This cartographic project synthesized within one geological map the small scale structures, and the data accumulated during the twenty years of research.

The Geological-Structural Map of the Emilia-Romagna Apennines, 1:250,000 scale, was constructed. A tectonic model of the Northern Apennines, 1:500,000 scale, was also made and accompanied by its Illustrated Notes (Cerrina Feroni *et al.*, 2002). However, this map was not just for applied purposes, but instead presented a truly scientific synthesis of the Northern Apennines, along with ground-breaking interpretations of their structure (which had already begun to be addressed by other researchers (Cerrina Feroni *et al.*, 2002)). Two sectors were identified for this part of the mountain range: a western or Ligurian-Tyrrhenian sector, and an eastern or Po-Adriatic sector; these sectors were separated by a boundary identified as "*sistema transpressivo destro* (right transpressive system)."

The authors stated that "the Legend for the Geological-Structural Map is therefore organized on the basis

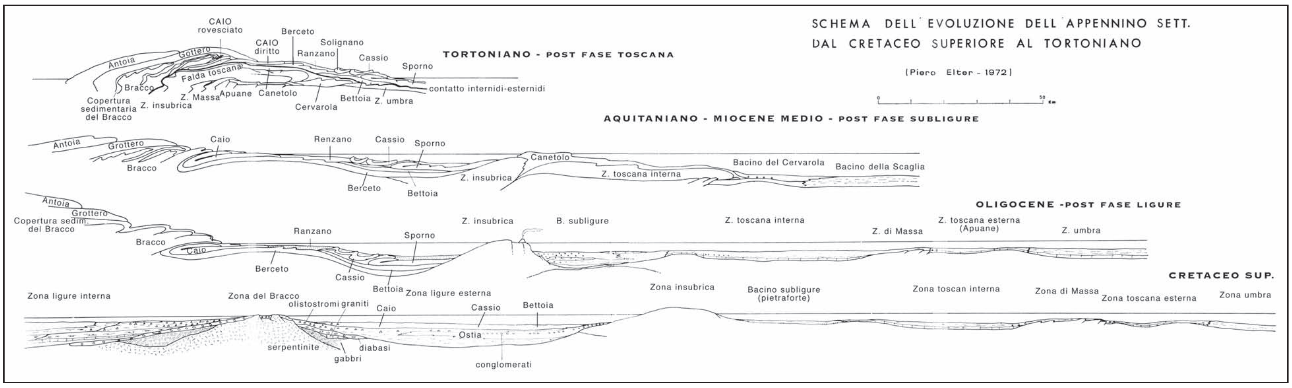

Fig. 16 - Tectonic evolution of the Northern Apennines, from the Late Cretaceous to the Tortonian, from Elter (1972).

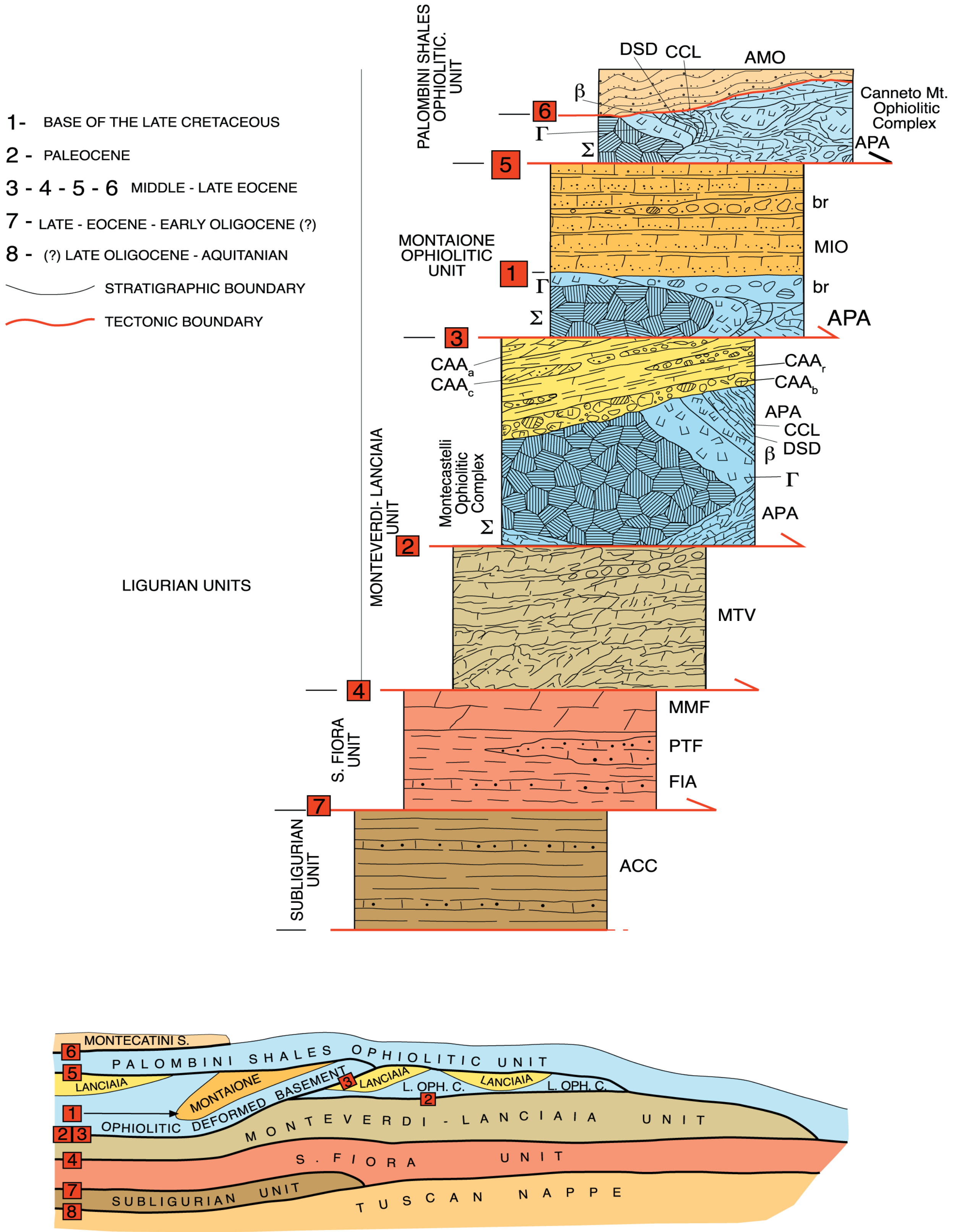

Fig. 17 - Structural relationships among Ligurides, Subligurian units and Tuscan Nappe of the Cecina Valley. Moreover, timing of deformational events is showed with numbers. Key: Γ, Σ, β: Ophiolites (respectively gabbro, serpentinite and basalt, Middle Jurassic in age); DSD: Cherts (Late Jurassic); CCL: Calpionella Limestones (Early Cretaceous); APA: Palombini Shales Fm. (Early Cretaceous); br: ophiolitic breccia; CAA: Lanciaia Fm. (Early-Middle Eocene) (lithofacies are represented with small letters); AMO: Montecatini Sandstones (Late Cretaceous-Early Paleocene); MIO: Montaione Flysch (Late Cretaceous); MTV: Monteverdi M.mo Fm. (Late Cretaceous - Early Paleocene); MMF: Monte Morello Fm. (Paleocene - Middle Eocene); PTF: Pietraforte Fm. (Late Cretaceous); FIA: S. Fiora Fm. (Late Cretaceous - Paleocene); ACC: Canetolo Fm. (Paleocene - Middle Eocene). Modified from Costantini *et alii*, 1995

of these two sectors. Therefore, we distinguish the structural units, the unconformable stratigraphic sections of the thrust top basins (*bacini episuturali)*, and the Oligocene-Miocene foredeep successions belonging to the western sector, from those belonging to the eastern sector (Figure 18).

In 2000, the Tuscan Region authority, along with many other Italian regions, followed the example of Emilia-Romagna and began production of a small-scale map. The Tuscan region established joint programs with the Universities of Florence, Pisa and Siena, along with the C.N.R. (I.G.G.), for the production of regional geological maps, at a scale of 1:10,000. A Geological Scientific Committee for Tuscany (*Comitato Scientifico Geologico Toscano*, CSGT) was established, and more recently a Regional Geological Service. The map, now in production, will be a scientific document with essential relevance to the region's projects.

THE NEW GEOLOGICAL MAP, ORGANIZATION OF THE LEGEND.

Compiling the Geological Map of Tuscany at a scale of 1:250,000, is a first and preliminary attempt to create a document which unifies and synthesizes the information from the small-scale maps (that is the *Carta Geologica Regionale*, 1:10,000 scale) and from the Progetto CARG of the Italian Geological Survey. The 1: 10,000 maps presently exist for approximately 60% of the region, and some of the cross-sections constructed are still preliminary. Not all areas were actually surveyed: the most recent published geological maps (1:25,000 and 1:10,000 scales) and Geological Map of Italy sheets (1:100,000) were utilized for the draft. The map is provisional, and it is based on documents from diverse scientific frameworks. Therefore, we did not introduce any new hypotheses concerning the Northern Apennines structural.

The Legend for the Geological Map of Tuscany has been organized into: a) Tectonic Units originating from different paleogeographic domains, which were deformed and emplaced during the Tertiary collisional phase (Early Miocene) related to the Apennine Orogeny, after the Ligurian Ocean closure (Paleocene-Eocene); b) sediments deposited after the main Tertiary tectonic phases.

Fig. 18 – Tectonic setting of the Northern Apennines, from Cerrina Feroni et al. (2002).

Each tectonic unit corresponds either to a single domain, or to part of a domain. The domains are based on the paleogeography of the Apulian southern margin, and the adjacent Ligurian ocean domain, in the Cretaceous. Some tectonic units have been grouped together if the following conditions were met: they are of minor extent, they originate from the same paleogeographic domain, and they are separated by relatively minor overthrusts on the original maps. A palinspastic reconstruction, oriented W-E in present day coordinates, evidences the following domains (the tectonic units with minor extension, incorporated within the domains, are shown in parentheses):

Ligurian Domain: we retain the classical subdivision of an internal Ligurian Zone, which is characterized by a deep sea succession deposited on oceanic crust (Ophiolitic Unit, or Gottero Unit); an external Ligurian Zone characterized by several Helmintoid Flysch and their related "basal complexes" which were likely deposited upon oceanic crust, or mantle, near the continental margin (Helmintoid Flysch Unit, Antola Unit, Caio Unit, Ottone Unit, Monteverdi M.mo Unit, Montaione Unit, Morello Unit, S. Fiora Unit, Cassio Unit, etc.)

Subligurian Domain (Limestone and Clay Unit, Canetolo Unit);

Tuscan Domain; we distinguish a succession exhibiting little or no metamorphism (Tuscan Nappe), and a succession with green schist facies metamorphism ("Apuan Autochthon," Massa Unit, S. Maria del Giudice Unit and M. Serra Unit, Monticiano-Roccastrada Unit);

Umbrian-Marches Domain (limited outcrops of the Marnoso-Arenacea fm. And overlaying marls).

Separate tectonic units have been maintained for the "*Successioni incertae sedis* (Uncertain position successions)" and the "*Successione oceanica con metamorfismo di alta pressione* (Oceanic successions with high pressure metamorphism)." The first mentioned unit essentially comprises the "*Pseudoverrucano*" succession, which outcrops in southern Tuscany. Its paleogeographic context remains equivocal, and therefore we retain it as a singular unit. The second has been maintained as a distinct tectonic unit: it comprises lithotypes of varying provenance (from the Ligurian and also possibly the Tuscan successions), incorporated into tectonic mélange and shear zones, that experienced high pressure metamorphism related to the Tertiary collisional phases of the Northern Apennines (Cala Piatti Unit, Cala Grande Unit, M. Argentario, Gorgonia Metamorphic Units, etc.)

Other sedimentary successions are distinguished in the legend. These successions, on the Tyrrhenian side of the Northern Apennines, have been deposited on the tectonic units, unconformably, after the tectonic unit was emplaced. The successions are separated by regional unconformities. From top to bottom they are:

1. Pliocene to Quaternary, continental and coastal deposits;
2. Pliocene to Quaternary marine deposits;
3. Messinian lacustrine and lagoonal, evaporitic and pre-evaporitic, deposits;
4. Messinian pre-evaporitic, marine deposits
5. Early Turolian lacustrine deposits;
6. Epiligurian Deposits

Finally, some lithostratigraphic units have been grouped together, for ease of presentation at map scale as the magmatic intrusive and subvolcanic rocks, effusive and pyroclastic rocks linked to Neogene magmatism, and the Quaternary cover.

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