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RESSOURCES LITHIQUES, PRODUCTIONS ET TRANSFERTS ENTRE ALPES ET MÉDITERRANÉE

ACTES DE LA SÉANCE
DE LA SOCIÉTÉ PRÉHISTORIQUE FRANÇAISE
NICE
28-29 MARS 2013

Textes publiés sous la direction de
Antonin Tomasso, Didier Binder, Gabriele Martino,
Guillaume Porraz, Patrick Simon et Nicolas Naudinot

Société préhistorique française
www.prehistoire.org

2016

ISBN : 2-913745-64-4 (en ligne)
ISSN : 2263-3847

SÉANCES DE LA SOCIÉTÉ PRÉHISTORIQUE FRANÇAISE
5

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Société préhistorique française
Paris
2016

Les « Séances de la Société préhistorique française » sont des publications en ligne disponibles sur :

www.prehistoire.org

Illustration de couverture : Carole Cheval, artcheograph.fr.

Responsables des réunions scientifiques de la SPF :
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Société préhistorique française
(reconnue d'utilité publique, décret du 28 juillet 1910). Grand Prix de l'Archéologie 1982.
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Publié avec le concours du ministère de la Culture et de la Communication (sous-direction de l'Archéologie),
du Centre national de la recherche scientifique,
de l'université Nice - Sophia Antipolis,
de l'UMR 7264 « Cultures et environnements, Préhistoire, Antiquité, Moyen Âge (CEPAM) », Nice - Sophia Antipolis
et de la Maison des sciences de l'homme et de la société Sud-Est), Nice.

Dépôt légal : 2e trimestre 2016

ISSN : 2263-3847 – ISBN : 2-913745-64-4 (en ligne)

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ISSN : 2263-3847 – ISBN : 2-913745-2-913745-64-4

Southern Alpine (Trento Plateau) and Northern Apennine flints: Ages, Distribution and Petrography

Stéfano Bertola

Abstract: The sedimentary successions on the south-eastern side of the Alps (Trento plateau, Southern Alps) and on the northern Apennines side are described and compared, with particular focus on the distribution of flints. The aim was to identify the potential they represented in prehistoric times for the people who settled in or passed by these two areas separated by the Po plain. These two areas present similar but also distinctive features, substantially deriving from their respective palaeogeographic positions along the margins of the Adria microplate and from the structural evolution of the Alps and the Apennine Mountains. Flints and radiolarites are rocks that are typical of deep marine environments. The studies therefore focused on such formations. The Trento plateau is the northernmost margin of the Adria plate. The Permian-Triassic sedimentary successions, overlying the crystalline basement, are essentially composed of continental, alluvial, evaporitic and shallow water marine carbonate facies. During the Ladinian stage there was an initial differentiation of the platform into basins in which the Buchenstein/Livinnallongo cherty limestone deposits were intercalated between vulcanite and tuff deposits. This formation mainly outcrops in the Dolomites, where these quite characteristic flints have been collected and used. During the Jurassic stage a drastic environmental change followed the breakup of the Pangaea leading to the opening of the Piemont-Liguria Ocean. The Southern Alps and part of the northern Apennine series (Umbria-Marches; Tuscany) belonged to the Adria passive margin that faulted and were subjected to subsidence into pelagic deposits from the Liassic stage on. Pelagic limestones were deposited in the whole area during the Dogger-Upper Cretaceous interval: flint-bearing radiolarites and limestones were deposited on continental slopes as well as in oceanic domains. The Adria margin was articulated in platforms, submarine plateaus and basins. The series that outcrop above a large raised submarine block (Trento plateau, Southern Alps) are described. The pelagic deposition above the Trento plateau was affected by erosions (sea bottom currents) and condensation compared to adjacent deeper areas (Lombard and Belluno basins). On the other hand the rifted block protected the sea bottoms from terrigenous inputs and made possible the deposit of undisturbed cherty limestones. The westernmost margin of the Apennine-Adriatic paleomargin has been overthrust by the Ligurids that were deposited originally farther west, near the continental slope and in the Piemont-Ligurian oceanic domain. Subduction of most of the oceanic crust and covers occurred during the eoalpine (Late Cretaceous) and mesoalpine (Eocene) tectonic phases. The rotation of the Corsica-Sardinia Block started during the Oligocene/Miocene and played an important role for the general structural setting of the Apennine Range. The Ligurids occupy a large part of the northern Apennines slopes; the easternmost area is dominated by the flintless Umbria-Marche siliciclastic foredeep successions. The Ligurids have been traditionally subdivided into internal (mainly outcropping on the Ligurian side) and external Ligurids (mainly outcropping on the Emilian side). The internal Ligurids are remnants of the oceanic crust (Piemont-Ligurian Ocean) and the connected covers. The external Ligurids (northern Apennines side) were deposited between the internal Ligurids and the Adria paleomargin. Here thick, monotonous siliciclastic and almost flintless (except for the Mount Sporno flints) successions were deposited during the Upper Cretaceous-Eocene interval. The basal complexes of the series are comprised of olistoliths /olistostromes showing analogies with both the internal Ligurids (western external Ligurids, WEL) and the Adriatic slope/marginal continental successions (eastern external Ligurids, EEL). These olistoliths/olistostromes have sometimes an impressive size (up to several kilometres), and contain well preserved sedimentary flint-bearing successions that were exploited locally. The 'internal Ligurids-like' successions have been known for a long time and they are very peculiar on the Apennine slope, often being associated with ophiolites, whereas the 'Adria margin/slope-like' successions are less well known and less frequent. A few large outcrops are distributed on the medium Apennine side (eastern external Ligurids, EEL) and they contain sedimentary cherty successions comparable to more internal portions of the Adria margin (mainly in Tuscany and Southern Alps successions). In particular the Triassic-Jurassic cherty limestones, the Aphtycus limestone and the Maiolica series contain high-quality flints exhibiting particular features, unknown for the internal Ligurids and the western external Ligurids (WEL). The quality and the dimensions of the flints are comparable to the outcrops identified in the Southern Alps. These outcrops certainly represented important procurement sources in prehistoric times and should be considered before taking into account more distant flint provenances for the Apennine sites. The Epiligurids were deposited above the tectonised Ligurids during the Eocene-Messinian period, in satellite basins trapped over the growing chain. Only the Antognola formation (Miocene) contains flints that are abundant locally (Bologna, Modena). These flints were exploited in historic times and are known as 'phtanite'. In the Apennine foothills the Imola Sands were deposited during the Early Pleistocene in a marginal marine (littoral) environment containing horizons of well-rounded marine conglomerates including mainly flint. These conglomerates, widely exploited in the area since the Lower Palaeolithic, were transported by the sea shore currents from the Romagna and Marches areas and include flints cropping out in these areas. This work mainly focuses on the description of the geologic framework of the cherty formations as well as on flint distributions and occurrences. Detailed petrographic descriptions (microfacies) combined with an assessment of the knapping suitabilities of the flints are ongoing and will be subjected to further studies in cooperation with the Ferrara University.

Keywords: Trento plateau, northern Apennines, flint, ages, distribution.

Résumé : Les successions sédimentaires du versant sud-oriental des Alpes (plateau de Trente, Alpes du sud) et du versant septentrional des Apennins sont décrites et comparées avec une attention particulière pour la distribution des silex. L'enjeu est d'identifier le potentiel de ces formations pour les populations qui gravitaient entre ces deux domaines séparés par la plaine du Pô. Les deux zones présentent des similitudes mais aussi des traits distinctifs, découlant essentiellement de leurs positions paléogéographiques relatives le long des marges de la microplaque adriatique et de l'évolution structurale des chaînes alpines et des Apennins. Les silex et les radiolarites sont des roches généralement associées à des milieux marins. Les recherches sont donc axées sur ces formations. Le plateau de Trente constitue la marge nord de la plaque adriatique. Sur le socle cristallin, les successions sédimentaires du Permien-Trias comprennent principalement des faciès continentaux alluviaux, évaporitiques et des carbonates marins de milieux peu profonds. Dans le Ladinien apparaît une différenciation entre la plateforme et le bassin où le calcaire Buchenstein/Livinnallongo, riche en silex, se dépose, intercalé entre des tufs et des volcanites. Cette formation se rencontre principalement dans les Dolomites, où ces silex, caractéristiques, ont été collectés et utilisés. Des dépôts de calcaires pélagiques intéressent toute la zone pour la période Dogger-Crétacé supérieur : les radiolarites et les calcaires à silex se déposent à la fois sur les pentes des domaines continentaux et océaniques. La marge adriatique associe des plateformes, des plateaux sous-marins et des bassins. La marge ouest de la paléomarge adriatique apenninique a été chevauchée par les Ligurides, originellement plus à l'ouest, près de la pente continentale et dans le domaine océanique Liguro-Piémontais. Les Ligurides occupent une grande partie du versant nord des Apennins. Dans la zone orientale, on rencontre principalement les successions silicoclastiques (sans silex) d'avant fosse Ombrie-Marches. Les Ligurides ont été traditionnellement divisées entre une zone interne (située principalement dans la pente ligure) et une zone externe (située principalement dans la pente émilienne). Les Ligurides internes représentent des restes de croûte océanique (océan Liguro-Piémontais) et des couvertures connexes. Les Ligurides externes déposées entre les Ligurides internes et la marge adriatique sont composées d'une succession de dépôts silicoclastiques épais et monotones, presque sans silex dans l'intervalle Crétacé-Éocène supérieur (sauf les silex du Monte Sporno). Le complexe à la base de la série comprend des olistolites/olistostromes présentant des analogies à la fois avec les Ligurides internes (Ligurides externes occidentales, WEL) et avec les successions adriatiques pente/marge continentale (Ligurides externes orientales, EEL). Ces olistolithes/olistostromes sont parfois massifs (d'extension kilométrique), et contiennent des successions sédimentaires à silex bien conservées et, localement exploitées. Quelques affleurements larges, répartis dans la pente moyenne des Apennins (Ligurides externes orientales, EEL), contiennent des successions de calcaires riches en silex comparables à des zones plus internes de la marge adriatique (Toscane principalement et successions sud-alpines). Ces affleurements représentaient des sources d'approvisionnement potentiellement importantes pendant la Préhistoire et il serait intéressant d'y porter plus d'attention avant de proposer une provenance plus lointaine pour les matières premières reconnues dans les sites des Apennins. Les Epiligurides ont été déposées pendant la période Eocène-Messénie, dans les petits bassins satellites piégés sur la chaîne en croissance. Seule la formation Antognola (Miocène) contient des silex, localement abondants (Bologne, Modène), historiquement exploités et connus comme « phtanites ». Dans les contreforts des Apennins, les sables Imola, déposés au cours du Pléistocène inférieur dans un environnement marin (littoral), contiennent des horizons de conglomérats marins bien arrondis et principalement siliceux. Ces conglomérats, largement exploités dans la région depuis le Paléolithique inférieur, ont été transportés par les courants littoraux et contiennent des silex des zones Romagne et Marches.

Mots-clés : plateau de Trente, Apennins du Nord, silex, âge, distribution.

This work describes and compares the sedimentary successions outcropping on the south-eastern side of the Alps (Trento plateau, Southern Alps) and on the northern Apennines side. The two areas present similar but also distinctive features, substantially deriving from their relative palaeogeographical positions along the margins of the Adria microplate and from the structural evolution of the Alpine and Apennines chains. The focus is on the description of the flint-bearing formations included in the sedimentary successions and more particularly on their significance and potential value for the prehistoric populations who settled in or passed by these two areas separated by the Po plain..

SHORT PALAEOGEOGRAPHICAL INTRODUCTION OF THE AREA UNDER STUDY

During the Late Triassic most of the emerged lands made up a supercontinent (Pangaea) surrounded by a single ocean (Panthalassa). In the Mediterranean area, a wide gulf (Tethys gulf) stretched westward (Haas et al., 1995; Gaetani, 2000). The continental shelf, as well as the future Adria microplate that was a part of it, were periodically flooded by the ocean and many tidal flats developed in tropical conditions (Carulli et al., 1998; Ciarrapica, 1990). At the end of the Triassic the Pangea began to break apart and during the Jurassic the African and European blocks separated. Between the Adria and Europe a new ocean was born: the Piemont-Ligurian ocean (Winterer and Bosellini, 1981; Bertotti et al., 1993; Schettino and Turco, 2009). Since this time three different domains have evolved: the thinned European continental margin, the Piemont-Ligurian oceanic domain and the extended African (Adria) continental margin. Many areas were covered by a deep sea. Pelagic sediments were deposited not only in the ocean but also along the continental slopes. From the Middle/Late Cretaceous on the European and African plates began to converge and the oceanic domain in between started to shrink (Schmid et al., 1996; Schettino and Turco, 2011). Most of the oceanic crust subducted underneath the Adria plate, the remnants of which, still visible today, were obducted or exhumed within subduction channels. Extensive terrigenous imputs (flysch deposits) started to sediment during the Late Cretaceous. Some areas in between were uplifted and thus exposed to neritic conditions at the beginning of the Tertiary (Bosellini, 1989). The rotation of the Sardinia-Corsica block started in the Oligocene/Miocene and played an important role in the general structural setting of the Apennine chain (Carmignani et al., 2004; Cerrina Feroni et al., 2004). The north-east oriented thrusts created an arcuate chain progressively moving towards the north-east. The deep adjacent northwestern-southeastern-oriented foredeeps were progressively filled by huge flysch deposits coming from the north. The area that was most distant from both growing chains, represented by the Umbria-Marches basin, remained quite undisturbed: here pelagic sedimentation lasted until the Miocene era without significant terrigenous imputs.

GEOLOGICAL OVERVIEW

The Alpine and Apennines chains originated basically from collisional processes between the European and African (Adria) plates, which started during the Late Cretaceous and are still active. The main structural units of the Alps have been subdivided on the basis of their palaeogeographical origin (Dal Piaz et al., 2003; here fig. 1). To the north are the units deposited on the continental margin of the European plate (Jura, Dauphinois-Helvetic). They are separated by the contiguous ones belonging to the Piemont-Ligurian oceanic domain (Penninic), only partly visible and often cut off from their original substratum. The southernmost units (Austroalpine, Southalpine, and

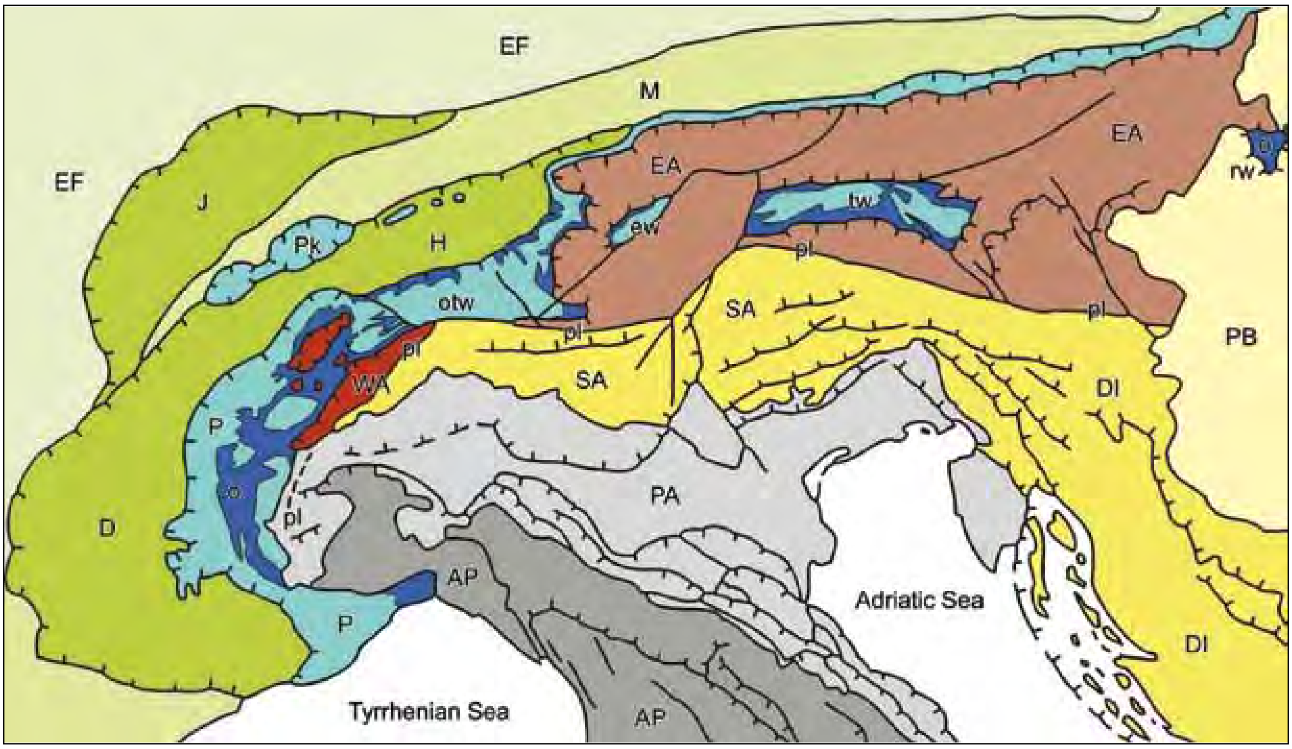

Fig. 1 – Structural map of the Alps (after Dal Piaz et al., 2003). M (Molasse): external sedimentary basin; JDH (Jura, Dauphinois, Helvetic): deformed but stable zones belonging to European plate; P (Penninic, light blue): subducted and exhumed continental nappes;. O (Ophiolites, dark-blue): subducted and exhumed oceanic nappes; EA (Eastern Alps): African plate continental nappes; SA, DI (Southern Alps, Dinarids): deformed Adria plate; PA: Adriatic undeformed plate; AP: Appennines. pl: Periadriatic line.

Fig. 1 – Carte structurale des Alpes (d'après Dal Piaz et al., 2003). M (Molasse): bassin sédimentaire externe ; JDH. (Jura, Dauphinois, Helvétique): zone de la plaque européenne, déformée mais stable ; P (Apenninique, bleu ciel) : nappe continentale subductée et exhumée ; O (Ophiolites, bleu foncé) : nappe océanique subductée et exhumée ; EA (Alpes orientales) : plaque africaine. SA, DI (Alpes du sud et Dinarides) : plaque adriatique déformée ; PA : plaque adriatique non déformée ; AP : Apennins ; Pl : ligne péri-adriatique.

Dinarids) were deposited on the African continental margin that was quite articulated (Schmid et al., 2008; Schettino and Turco, 2011). In this work we will consider the Southalpine, which belonged to the Adria microplate. Similarly the Apennines chain, from east to west, is subdivided into units belonging to the Adria paleomargins (Umbria-Marches and Tuscan successions): fragments of obducted units belonging to the Piemont-Ligurian ocean (Ligurids) and units deposited near or on the European margin (cropping out only in the westernmost sector of the chain).

SOUTHERN ALPS (TRENTO PLATEAU)

The Southern Alps belong entirely to the African paleomargin; more particularly they constituted the northernmost sector of the Adria microplate (fig. 2). This margin, formed during the Jurassic, first evolved as a passive margin and since the Upper Cretaceous as an active margin (Doglioni and Bosellini, 1987). The Jurassic rifting and subsequent continental drift caused a drastic change of the depositional environment. Within a few thousand years the neritic sedimentation (tidal flats) became predominantly pelagic (Winterer and Bosellini, 1981; Bertotti et al., 1993). The margins of the Adria had an irregular profile being cut by numerous extensional faults (Bosellini, 2004): these faults delimited uplifted *(horsts)* and lowered blocks *(graben)*. During the Lias the sedimentation was neritic in the horsts and pelagic in the graben. From the Dogger the carbonate platforms sank and became underwater plateaus (Bosellini and Winterer, 1975). The sedimentation became uniformly pelagic, except for the more internal continental areas where neritic sedimentation continued until the end of the Cretaceous, and was then followed by the thick siliciclastic flysch successions. The bathymetric differences between the plateaus and the basins were almost completely levelled during the Cretaceous, with the sedimentation of the pelagic Maiolica and Scaglia formations. The palaeogeographical units, reactivated several times by tectonics, strongly influenced the regional sedimentation throughout the Jurassic, Cretaceous and Eocene (Doglioni and Bosellini, 1987; Castellarin et al., 2006). Since the Middle/Late Cretaceous the European and African plates started to converge and the interposed vast basinal areas were reduced by subduction. Flysch sediments generally deposited in the basins close to the growing Alpine chain, while in raised and protected areas (ex. Trento plateau) undisturbed pelagic sedimentation continued. During the Middle Eocene/Oligocene interval, the tectonic regional uplift favoured the development of neritic environments. Above the roots of the Trento plateau grew the Lessini shelf (Bosellini, 1989; Luciani, 1989). Platforms alternating with circumscribed basins with pelagic or hemipelagic deposition and intercalated with volcanites (basaltic breccias, tuffites) developed. Starting with the Oligocene (Chattian), the southern Alpine foredeep was gradually filled by clastic deposits carried by huge turbidite systems arising from the erosion of the growing Alps to the north. These massive turbidite systems even filled the northern Apennines foredeep (Di Giulio et al., 2001).

Depositional environment of the biosiliceous sediments: old seas

Flints and radiolarites are characteristic deposits of relatively deep basinal environments. Most of them formed at the bottom of old seas and our attention therefore focused on such sediments. In the Trento plateau area, above the Variscan crystalline basement, the Permian and Triassic sedimentary covers are mainly clastic (continental) or were deposited in shallow water (Tethys gulf: tidal flats, evaporates; Bosellini, 1996; Bosellini et al., 2003). During the Middle Triassic a gradual rise in the sea level favoured the development of coral reefs and adjacent basins with predominant pelagic sedimentation. In these ancient seas, the presence of radiolarians and siliceous sponges is documented by blackish or greenish flint beds and nodules alternating with mudstones of the Ladinian Buchenstein (Livinallongo) formation. They represent the oldest flints included in the post-Variscan Southern Alps sedimentary succession. The Buchenstein formation has a wide distribution in both the Southalpine and the Austroalpine. It widely outcrops in the Dolomites where the strong uplift (Alpine orogeny) caused the erosion of the post-Triassic rocks. The Dolomites were part of the Trento plateau (northern sector): in this area the siliceous resources are represented almost exclusively by the Buchenstein flints. There are only a few remnants of Jurassic and Cretaceous covers, rarely including flints (Lukeneder, 2011). Between the Late Triassic and the Early Jurassic the entire Southern Alps were covered by a vast lagoon environment in which many tidal flats developed. The repetitive thin laminated peritidal limestone sequences do not contain any flint. In the Late Jurassic, with the opening of the Piemont-Ligurian ocean, most of the Southalpine sank several hundreds metres below sea level and the sedimentation became clearly pelagic. The sector considered here was a raised block during the Lias (Trento platform) with neritic sedimentation, bordered by oolitic and bioclastic bars connected to the adjacent basins (in the east: Belluno basin; in the west: Lombard basin; Winterer and Bosellini, 1981; Bosellini et al., 1981; Barbujani et al., 1986). From the Dogger the Trento platform collapsed and became a submerged plateau. Between the Late Jurassic and the Late Cretaceous a pelagic succession of cherty limestone sedimented—often compacted on the plateaus (Rosso Ammonitico-Maiolica-Scaglia)—directly above the neritic rocks. The progressive closing of the Piemont-Ligurian ocean halted this trend when the thick series of pelagites was interrupted by the first siliciclastic turbiditic imputs (flysch). These deposits, stemming from the erosion of the forming Alps to the north, have since the Late Cretaceous been widespread

Fig. 2 – The western margin of the Trento Plateau (dashed line) and its sedimentary covers. The indicated places correspond to the main flint-bearing sequences.
Fig. 2 – Bordure occidentale du plateau de Trente (ligne pointillée) et couvertures sédimentaires. Les localités indiquées correspondent aux principales séquences livrant des silex.

in areas adjacent to the Trento plateau (Lombard flysch; Doglioni and Bosellini, 1987; Castellarin et al., 2006). The Trento plateau, however, had to be in a slightly elevated position with respect to the adjacent areas, as it had not been reached by these initial detritic pulses, and the sedimentation remained frankly pelagic until the Eocene in the Scaglia facies. In the Trento plateau area the Scaglia Rossa sedimentation is generally interrupted by obvious erosion surfaces (Massari and Medizza, 1973). These hardgrounds have been related to a general uplift that brought some areas to neritic conditions. During the Eocene the depositional environment was fairly diversified, with neritic platforms and adjacent basins (Luciani, 1989). The clearly pelagic deposition occurred more particularly west of the Ballino line (Lake Garda), in areas corresponding to the previous Lombard basin, while the Lessini shelf developed above the Trento plateau. Along the slopes transitional hemipelagic formations were deposited, often with re-sedimentation stemming from the platforms. Strong volcanic activity manifested in the area between the Paleocene and the Oligocene (Venetian eruptive cycle), adding volcaniclastic apports in the basins. In the Baldo and Bondone chain V. Luciani (Luciani, 1989) recognised four depositional sequences (E1 to E4) in the Early Eocene/Oligocene interval. I will briefly describe the first one (Torbole, E1) as some of its formations contain flints. The author used the terms Torbole limestone for the neritic limestone, Malcesine and Chiusole limestones (platform to basin transition, slopes) and Scaglia Cinerea (pelagites). On the new geological map 1:50,000 (Avanzini et al., 2010) the Scaglia Cinerea has been renamed Ponte Pià formation. Cherts are distributed in the basins and along the slopes. These formations outcrop with lateral continuity and with considerable thicknesses in the western and central part of the previous Trento plateau (Baldo, Bondone, Western Lessini), whereas they are underrepresented or absent in the eastern sector of the same area. From the Middle Eocene on,

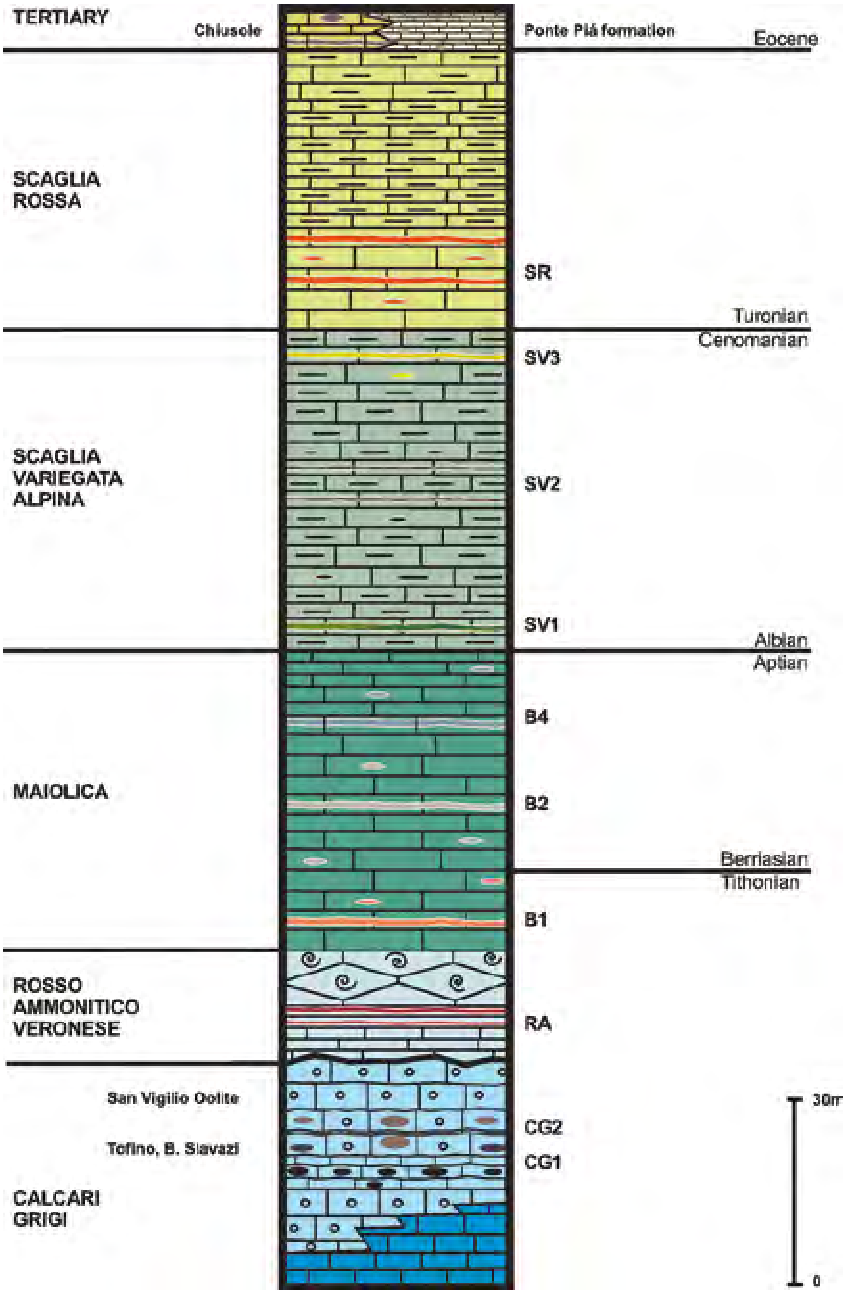

Fig. 3 – Simplified stratigraphic column of the Jurassic/Eocene series cropping in the Lessini-Baldo area. The different flint types (Bertola, 2001), distributed over the defined horizons are named with abbreviations on the right of the column.
Fig. 3 – Colonne stratigraphique simplifiée de la séquence Jurassique/Éocène dans l'aire Lessini - Baldo. Les différents types de silex (Bertola, 2001), distribués dans les horizons définis sont nommés avec les abréviations à droite.

from north to south, extensive deposits of siliciclastic flysch and alpine molasse started to emerge that do not contain cherts except for reworked clasts of older formations.

Stratigraphy of the flint-bearing formations

Buchenstein (Livinallongo) formation (Triassic, Ladinian; 0–200 m)

These are thin-bedded pelagic limestones alternating with green tuffites and volcanic ash layers (so called 'pietra verde'; fig. 3). These series were deposited in small basins adjacent to Middle Triassic reefs (Sciliar dolomite). The formation outcrops, with similar features, from Lake Como (Lombard basin) to Cadore (Belluno dolomites). It reaches thicknesses of about 200 metres and is usually subdivided into three units (Neri et al., 2007): slaty limestone *(Plattenkalke),* nodular limestone *(Knollenkalke),* and banded limestone (*Bänderkalke*). Flints are distributed throughout the formation, but are more frequent in the first two units. The Plattenkalke are slaty limestones with planar contacts, up to 20–30 cm thick. The silicification, rarely pervasive, frequently affects a few of the horizons. In most cases these are silicified limestones, ranging in colour from grey to green to black. Exceptionally very fine crystalline flints, green to grey, may be present. The overlying Knollenkalke are nodular limestones with wavy bedding. The calcareous beds are hard and compact, and often include small glassy grey flint nodules and thin layers, often diaclased. Flint textures made up of mudstones or wackestones with radiolarians, pelagic bivalves, calcispheres, sponge spicules and volcanoclastic clasts and minerals in different proportions depending on the palaeogeographical positions in the paleobasins.

Tofino formation, part of the Bocchetta Slavazi formation (Jurassic, Toarcian/Early Bajocian; 0–70 m)

Following a revised stratigraphy (Casolari and Picotti, 1997; Picotti, 2003) the Tofino formation was subdivided into four units, dated between the Hettanghian and the Bajocian. It is mainly a slope/basin formation, deposited at the transition between the Trento platform and the adjacent Lombard basin. The youngest unit (part of the Bocchetta Slavazi formation) corresponds to the former Tenno formation (Castellarin, 1972). This unit, often eteropic with the San Vigilio oolites, sedimented on the western slope of the Trento platform (Western Lessini, Baldo and Bondone) and belongs, to all effects, to the sedimentary sequence of the Trento Platform. The other units, all distributed west of Lake Garda, belong to the Lombard basin succession from a palaeogeological point of view and will not be discussed here. They are bedded (5–50 cm) marly limestones alternated with resedimented biocalcarenites, often associated with slumpings, stemming from the Trento platform. The marly limestones are grey to brown wakestones or packstones including brachiopods (rynconellida), peloids, bioclasts, intraclasts, sponge spicules and radiolarians. Calcarenites generally follow up. These are yellow to brown oolitic/encrinitic wackestones to grainstones, in layers up to 70 cm, with laminations and cross laminations alternating with biomicrites rich in radiolarians and sponge spicules (Barbujani et al., 1986). Chert is locally frequent in both litofacies, with the same textures but silicified (Bertola, 2001). These are primarily brown to black nodules, even of large size (diameters up to 40 cm), often not fully silicified and with rough surfaces. This flint is quite hard to flake but the rather large and complete nodules make it possible to detach large products.

San Vigilio oolite formation (Jurassic, Late Toarcian/Aalenian; 0–200 m)

The distribution of this formation runs in parallel to the Tofino unit, belonging to the Bocchetta formation. These are well-sorted, white to brown calcarenites (grainstones), including ooliths and echinoderm fragments, occurring in thick beds (0.5 to 3 m). These were high-energy sandbars that bordered the inner Trento platform lagoon from the adjacent Lombard basin. Similar or corresponding deposits are not present at the eastern edge of the Trento platform, where a clear erosion surface is visible on the 'glauconitic encrinites', coeval to the Tofino formation, part of the Bocchetta Slavazi formation. White to brown, poorly silicified flint nodules are locally present in the calcarenites in particular at the base of the formation (Barbujani et al., 1986) in some features similar to the Tofino formation ones, but they are completely unusable for flaking.

Ammonitico Rosso Veronese formation (Jurassic, Bajocian/Tithonian; 15–30 m)

Consequent to the submerging of the Trento platform this pelagic formation had sedimented in the entire area. It generally follows a clear erosion surface on top of a heterogeneous substratum belonging to the Calcari Grigi limestone. The authors subdivided this formation into three units (Clari et al., 1984 et 2006; Sarti, 1986; Pavia et al., 1987; Martire, 1992 and 1996). Detailed studies demonstrated that the deposit was strongly influenced by an articulated substratum. The lower unit (Bajocian/Callovian; 10 m) is flintless and comprised of reddish micritic limestones with pelagic bivalves (Bositra) and protoglobigerinids, followed by pink to yellow small nodular limestones with ammonites. The flint-bearing middle unit (Callovian/Oxfordian; 0–10 m) is a lithofacies characterised by thin-bedded (5–20 cm), red to brown platy micritic limestones (mudstones to packstones). The limestones regularly alternate with brown to dark-red flint layers (continental radiolarites), in proportions up to 35% of the whole (Bosellini and Dal Cin, 1968; Clari et al., 1990; Bertola, 2001 and 2011). These epicontinental radiolarites are widespread along the Adria paleoslopes and are partly coeval with the deeper Penninic (Piemont-Ligurian) oceanic radiolarites (Monte

Alpe Cherts, Apennines, see below). Sponge spicules, radiolarians and pelagic bivalves are common in the siliceous facies and belemnites, aptychi, echinoderms, brachiopods as well as Globuligerina cf. Oxfordiana in the limestones (Clari et al., 1984). Ammonites are generally missing. This unit is absent in the central sector of the Trento plateau because of a sedimentary gap while it is common on its slopes. The upper unit (Kimmeridgian/Tithonian; 15 m) generally exhibits quite homogeneous lithologic features and similar thicknesses. It is constituted by red to pink, well-bedded micritic limestones with a characteristic nodular aspect. The fauna is comprised of radiolarians, pelagic crinoids (Saccocoma), aptychi, ammonites, belemnites, fish teeth and tintinnids in the upper part. A hardground surface separates it from the other units. Chert nodules may be locally present in the lower part of this unit: they are dark-red, sometimes with light grey patches, usually small, irregular and diaclased. The transition to the subsequent Maiolica formation is gradual, evidenced by well-bedded (5–30 cm), pink to yellow micritic limestones with planar or stylolithic joints (Tithonian; Grandesso, 1977). This transitional unit, about 5 to 10 metres thick and often slightly dolomised, may contain pink to light-red fine cristalline flint nodules, which are often diaclased.

Maiolica formation (Tithonian/Aptian; 5–150 m)

The Maiolica formation is a common litofacies throughout the Mediterranean area (Wieczorek, 1988). In the Southalpine correlations have been made between the alpine and the apenninic sections (Faraoni et al., 1996 and 1997). It is composed of lithified calcareous and siliceous pelagic muds accumulated during the maximum opening of the Piemont-Liguria ocean. The Maiolica formation (also called Biancone) is formed by thin-layered (5–25 cm), white, ivory or pink mudstones with calcareous nannoplankton, planktic foraminifers and radiolarians. The limestones have a characteristic conchoidal fracture; the stylolithic joints are very common, highlighted by thin green clay seams. In distinct stratigraphic horizons (Berriasian/Valanginian; Late Valanginian; Late Hauterivian/Barremian; Early Aptian (Bersezio et al., 2002) the limestones alternate with dark marls and shales rich in organic matter (black shales). This formation was deposited above a still uneven and complex substrate that strongly influenced both thicknesses and depositional features (Bosellini et al., 1978; Weissert, 1981). Gaps, slumps and breccias are frequent especially along the paleoslopes: the most obvious ones are visible near the western edge of the Trento plateau (Clari and Pavia, 1987). Chert nodules, lenses and layers are very common, with varying colours primarily depending on the stratigraphic position and the deposition areas. In the Trento plateau area generally reddish to grey colours characterise the flints of the lower formation, followed by grey and dark-grey colours towards the top (Bertola, 2001; Bertola and Cusinato 2004). The degree of silicification of the poor marly and fine-grained limestones is quite high. Where the outcrops are not very tectonised, the flint nodules and layers are quite intact. These flints were particularly exploited for their very high quality (fine crystalline, homogeneous) and their availability. In the inner Trento plateau the series are more compacted (Lukeneder, 2011) compared to the paleoslopes and bottoms, where re-sedimentation is common. In areas in which the circulating waters were well-oxygenated, for example at the western border of the Trento plateau, both the rocks and the flints often exhibit reddish to yellowish brown or pinkish grey colours. In less oxygenated environments (bottom basins with restricted water circulation, bathymetric oxygen minimum zones, oceanic anoxic events) flints and sediments have dark-grey or blackish grey colours. The thickness of the formation varies: near the western margin of the Trento plateau it is greatly reduced and increases irregularly to the east (Bosellini, 1973; Weissert, 1981). The formation reaches a maximum thickness of 150 m in the Trento plateau and up to 330 m in the Belluno basin area, near Feltre (Channel and Grandesso, 1987). The plastic and easily erodible Maiolica formation often constitutes the bedrock of the Venetian Prealps, giving sweet and convex morphologies (Sauro, 1973).

Scaglia Variegata Alpina formation (Aptian/Turonian; 15–70 m)

This pelagic formation, first introduced by M. Claps and D. Masetti (Claps and Masetti, 1994), follows in stratigraphic continuity the Maiolica formation. It shows its typical features (marly limestones alternating with clay and marl interlayers) in the western Trento Plateau, whilst in the eastern Southalpine it was not separated from the Maiolica formation. It shows analogies and is partly correlated with the Marne a Fucoidi and Scaglia Bianca in the Umbria-Marches Apennines. The change of sedimentation from the Maiolica to the Scaglia has been interpreted as a consequence of changed global oceanographic conditions (De Boer, 1982). During the Middle Cretaceous the continental margins began to converge and the basins started to reduce. In specific sectors (Trentino) compressional tectonics generated a new structural setting of the local basins, orienting them mainly in a north-northwest/south-southeast direction (Bosellini et al., 1978). The authors (Claps and Masetti, 1994) also supposed that the palaeogeography of the bedrock played an important role in the vertical distribution of the Cretaceous facies (Maiolica, Scaglia Variegata Alpina and Scaglia Rossa formations) that are at least partly coeval in the Trento area. The formation consists of white to grey, thin-bedded micritic marly limestones alternating with centimetre-thick to decimetre-thick grey green clays and marls. These latter can reach a greater thickness than the limestones, especially in the western sector of the southern Lessini shelf. There are also black marl horizons (anoxic shales) with teeth and fish scales and pyrite and marcassite mineralisations, especially as regards the Selli (Aptian) and Bonarelli

(Cenomanian) horizons (OAE 1 and 2). The limestones are also speckled by bioturbations and contain planktic foraminifera and radiolarians. Cherts are distributed in distinct stratigraphic horizons, invariably in the limestones. These are silicified mudstones to wackestones with radiolarians and planktic foraminifers (planomalina, rotalipora, praeglobotruncana, helvetoglobotruncana, among other things; Bertola, 2001; Bertola and Cusinato, 2004). In the basal marly limestones, locally abundant, grey to green flint layers, up to 20 cm thick are generally present. These flints are suitable for knapping, although they are not fully silicified because of the clay content. Most of the formation (thick middle part) contains thin (centimetre scale) and discontinuous stripes and small isolated grey to black flint nodules, often brecciated and diaclased, almost unsuitable for flaking. The uppermost unit (Upper Cenomanian; 15 m) shows particular features. The environment became more oxygenated and sedimented high calcareous limestones and marl beds, with white to red to violet colours, expecially at the western margin of the Trento plateau (Lehner, 1987). They alternate with very characteristic green to yellow flint beds, (layers up to 20 cm; subordinate nodules), which are very homogeneous and of excellent quality. Their occurrence is variable: in some areas (Non Valley) they are very abundant whereas they are completely missing in others (Bertola, 2011).

Scaglia Rossa formation (Turonian/Early Eocene; 70–130 m)

The pelagic succession continues without interruption above the Scaglia Variegata Alpina with the Scaglia Rossa formation. This formation is regarded as a hemipelagic formation which was formed a few hundred meters below sea level during the convergence of the continental plates. The environment changed to more oxygenated waters, and the terrigenous imputs became more and more frequent towards the top. These are pink to red micritic marly limestones rich in planktic foraminifers (globotruncanids), with radiolarians and rare macrofossils (echinids, bivalves, fish remains). The red colour is due to the fine dispersion of iron oxides and hydroxides (hematite and limonite). The thicknesses vary from a few to more than one hundred metres: the compacted series generally overlie the Trento plateau that also exhibits important erosion surfaces (hardgrounds; Massari and Medizza, 1973; Luciani, 1989). The cretaceous Scaglia Rossa formation can be subdivided into two units (Massari et al., 1976):

1) The lower unit extends from the Turonian to the Early Campanian and is characterised by quite constant thicknesses (40–50 m). It consists of up to 30-cm-thick, bedded, pseudonodular micritic limestones, with thin reddish clay interbeds. There is a distinct geographic variability of flint frequencies, characteristics and knapping abilities (Bertola, 2001 and 2011; Bertola and Cusinato, 2004; Wierer and Bertola, this volume). Both the layers and the nodules are reddish brown to yellowish brown. The cherts may be locally abundant, but usually they are not frequent and may also be absent in many areas. They seem to be more frequent along the paleoslopes, showing also different features (chert beds rather than nodules, lighter colours, less calcareous inclusions). In the inner Trento plateau areas cherts often outcrop as isolated dark-red nodules (sometimes with bitumen), and with many calcareous inclusions that often interfere with flaking. This would demonstrate the persistence of a fairly articulated substratum.

2) The upper unit includes the Late Campanian/Maastrichtian interval. These are marly red, thin-layered (flaser bedding) limestones, generally devoid of cherts. The terrigeneous imputs (‘criptoflysh’) gradually become higher from the bottom to the top. The thicknesses vary because of two stratigraphic gaps, highlighted locally by hardgrounds, located at the base and at the top of the unit respectively. The Cretaceous/Tertiary boundary is invariably characterised by a regional gap, the width of which is larger in areas with compact sedimentation. In many areas of the Trento plateau the sedimentation of the Scaglia Rossa formation persists until the Early Eocene (Luciani, 1989) but cherts are generally absent or sporadic. The absence of Middle and Late Eocene cherts in the alpine Scaglia Rossa formation is the key to distinguishing these outcrops from the Apenninic (Umbria-Marches) ones in which the deposition of the pelagic Scaglia formations (Scaglia rossa, variegata, cinerea) continued until the Oligocene/Miocene (Bertola, 2012).

Chiusole formation (Early Eocene; 0–100 m)

The Chiusole formation consists of two main alternating litofacies. The normal sedimentation is constituted by platy micritic limestones with radiolarians and planktic foraminifers that are well-bedded (10–30 cm) and separated by thin clay interlayers. Towards the top of the formation in particular, this unit is intercalated by bioclastic calcarenites and breccias with nummulites, discocyclinas, red algae, echinoderms and molluscs (Arni and Lanterno, 1973; Sarti, 1980; Luciani, 1989). Grey to brown chert layers are quite frequent, distributed in the pelagic micrites and especially in the resedimented (mainly brown) calcarenites (Wierer and Bertola, this volume). The transition to the Scaglia Rossa formation is clear and marked by hardgrounds.

Ponte Pià formation (Early/Middle Eocene; 0–100 m)

This formation corresponds to the formerly named ‘Scaglia Grigia’ or ‘Scaglia Cinerea’ formation (Luciani, 1989). It consists of white to light grey, platy, micritic marly limestones, with planktic microfossils (globigerinids and radiolarians), alternating with laminated grey to blue marls, more frequent in the upper part. Tuffitic and glauconitic intercalations are common. Coarser re-sedimentations of neritic provenance (calciturbidites with discocyclinas and nummulites) are locally intercalated in the series. The cherts are quite common. In the pelagites these are thin and discontinuous, grey to olive-green-coloured, silicified layers, almost unsuitable for flaking. Exceptional isolated nodules up to 10 cm large, with a very fine texture and very suitable for knapping, are rarely present. The unit is eterophic to the Chiusole formation as well as to the Torbole and Malcesine limestones.

Cherts rheology and flaking attitudes

The previously described cherts have specific features, which mainly derive from the characteristics of the 'source rock' and from their depositional environment. These are invariably cherts deriving from diagenetic replacement processes of limestones. Most of them are included in pelagites or hemipelagites (Buchenstein, Ammonitico Rosso, Maiolica, Scaglia Variegata Alpina, Scaglia Rossa, Ponte Pià formation), others occur in calcarenitic formations distributed between platforms and basins or in neritic environments (Tofino formation, Chiusole formation). The first generally have a wide distribution whereas the second are confined to small areas. The pelagites have been almost completely transformed to silicified mudstones and wackestones. For the calcarenites the silicification was never complete, and their texture and composition are more heterogeneous. On the basis of their rheology and/or their deformation history, it is possible to group the formations into two main categories (Alvarez et al., 1978; Zampieri, 1990): 1) Formations characterised by a weak cleavage (Tofino formation, Ammonitico Rosso formation, Chiusole formation); 2) Formations characterised by a moderate to strong cleavage (Buchenstein, Maiolica, Scaglia Variegata Alpina, Scaglia Rossa, Ponte Pià formations). The first are characterised by a rigid response, the second have a more 'plastic' behaviour. The cherts integrity is indeed linked to the formations rheology. Generally the following observations can be made: 1) Cherts included in calcarenites (Tofino formation, Chiusole formation) are almost always intact; 2) Cherts included in the pelagites (Buchenstein, Ammonitico Rosso, Maiolica, Scaglia Variegata Alpina, Scaglia Rossa, Ponte Pià formation) are often involved in foldings and are diaclased. Indeed, during prehistoric times the cherts much sought after for flaking were those included in the pelagites because of their high degree of silicification and their homogeneity. Among these the Cretaceous formations (Maiolica, Scaglia Variegata Alpina and Scaglia Rossa) were more extensively exploited, including for their abundance in the geologic sections and their large geographical distribution. On the other hand these cherts are often tectonised and occur as quite small, several-centimetre-wide blocks, divided by fractures. The calcarenitic cherts have a much less elastic behaviour, but are less disturbed by tectonics, and are often intact in the outcrops. This fact played an important role mainly when large blanks (flakes, blades) were sought (Bertola, 2001).

NORTHERN APENNINES

The Mesozoic (post-Sinemurian) evolution of the Northern Apennines is very similar to that of the Southalpine (fig. 4). Both areas constituted a portion of the passive continental margin of the African (Adria) continental block and were located a few kilometres apart from each other. The two areas underwent similar tectonic evolution, with differences regarding the geometry and extension of the faulting due to different stratigraphic successions (Santantonio and Carminati, 2011). In both areas the continental margin was cut by north-south or north-northeast/south-southwest-trending tension faults and was articulated in platforms, seamounts and adjacent basins. The most important palaeogeographical elements from east to west were: the Lazio-Abruzzi platform, the Umbria-Marches basin and the Tuscan basin. The northwestern Adria continental margin is in the present day mainly buried under post-collisional formations. Portions of its Middle Triassic to Middle Cretaceous sedimentary successions are preserved somewhere as tectonic slices in the so-called 'basal complexes' of the external Ligurids series. The collisional and post-collisional evolution of the Northern Apennines is characterised by specific features (Carminati and Doglioni, 2004).

Geological overview

The Northern Apennines are a thrust-and-fold belt belonging to the Alpine orogenic system. The basal Canetolo and Tuscan-Umbrian continental units are overthrust by the Ligurid units. The Canetolo and Tuscan-Umbrian units constituted the western domains of the Adria margin. The Ligurids have been interpreted as units that sedimented on the oceanic (Piedmont-Ligurian ocean) and on the transitional domains, interposed between the European and Adria plates. The Ligurids are generally divided into the internal Ligurids and the external Ligurids (Elter et al., 1966). In the internal Ligurids the 'ophiolite succession' is the base of the sedimentary cover, which includes pelagic, trench and lower slope deposits ranging in age from the Late Jurassic to the Paleocene (Marroni et al., 1992 and 1998). In the external Ligurids the mafic and ultramafic rocks occur only as slide blocks in the Santonian/Early Campanian sedimentary melanges (Abbate et al., 1980). These sedimentary melanges, known as 'basal complexes', are widespread in the Emilian Apennines, mainly in the Taro, Aveto, Trebbia and Ceno valleys. They contain varying amounts of pebbly sandstones and mudstones with intercalations of coarse-grained lithoarenites. Large slideblocks ('olistoliths') are common and locally prevailing. Among them, ultramafic rocks and basalts of the mantle are frequent, but blocks of gabbro and pelagic sediments also occur (Marroni et al., 1998; Marroni and Pandolfi, 2007). In the large slide blocks the primary relationships between the different lithologies, in particular between plutonic rocks, basalts and radiolarites, are sometimes preserved (Pagani et al., 1972). The sedimentary melanges generally grade upward to the Late Campanian/Maastrichtian Helminthoid flysch, represented by a thick, monotonous sequence of calcareous turbidites. In the easternmost external Ligurids the mafic and ultramafic rocks are absent or very rare (Marroni et al., 1998, 2001 and 2010). These sequences include Early to Late Cretaceous pelagic, mainly siliciclastic deposits (Palombini shale, Ostia-Scabiazza sandstone and Salti del Diavolo conglomerates) topped by the Late Campanian/Maastrichtian helminthoid flysch (Marroni et al. 1992, 2001 and 2010). Tectonic slices of sedimentary series between the Middle Triassic and the Middle Cretaceous are recognisable in some places at the base of the pelagic sequences. These have been interpreted as remnants of the thinned continental crust belonging to the northwestern domains of the Adria continental margin (Marroni et al., 2001; Marroni and Pandolfi, 2007). One hypothesis is that the sedimentary melanges were deposited near or along the transitional slope between the ocean basin and the Adria continental margin (Elter, 1975; Zanzucchi, 1980). This domain experienced compressive/transpressive tectonics in the Late Cretaceous, which resulted in a sharp inception of tectonic-controlled sedimentation with the occurrence of large amounts of sedimentary melanges deposited along the western margin of the Adria plate (Marroni et al., 2010). On the accretionary prism, formed during the oceanic crust subduction and the subsequent continental collision, small satellite marine basins formed, trapped in the Apennines-forming chain. These basinal sequences, dated from the Middle Eocene to the Messinian, are known as Epiligurids. These are syntectonic units that had shifted progressively from west to east, pushed by the rotation of the Sardinia-Corsica continental block. At the same time a huge elongated north-south-oriented foredeep basin formed at the foot of the growing Apennines. This foredeep progressively shifted from west to east and was filled by different basinal terrigeneous (flysch) formations.

Internal Ligurids (IL)

The internal Ligurids (IL) outcropp on the Ligurian side of the Apennines and are generally thrust over the external Ligurids (fig.5). They have been divided into several units, but their stratigraphy is quite similar. Generally the Jurassic ophiolite sequence lies at the bottom, followed by the Middle Jurassic to Paleocene sedimentary covers. The cherts are included in the Late Jurassic/Middle Cretaceous interval, represented by pelagic formations deposited in a deep environment, far from siliciclastic continental imputs, during the greatest expansion of the Piemont-Liguria ocean. The sedimentary covers with cherts will be briefly described below.

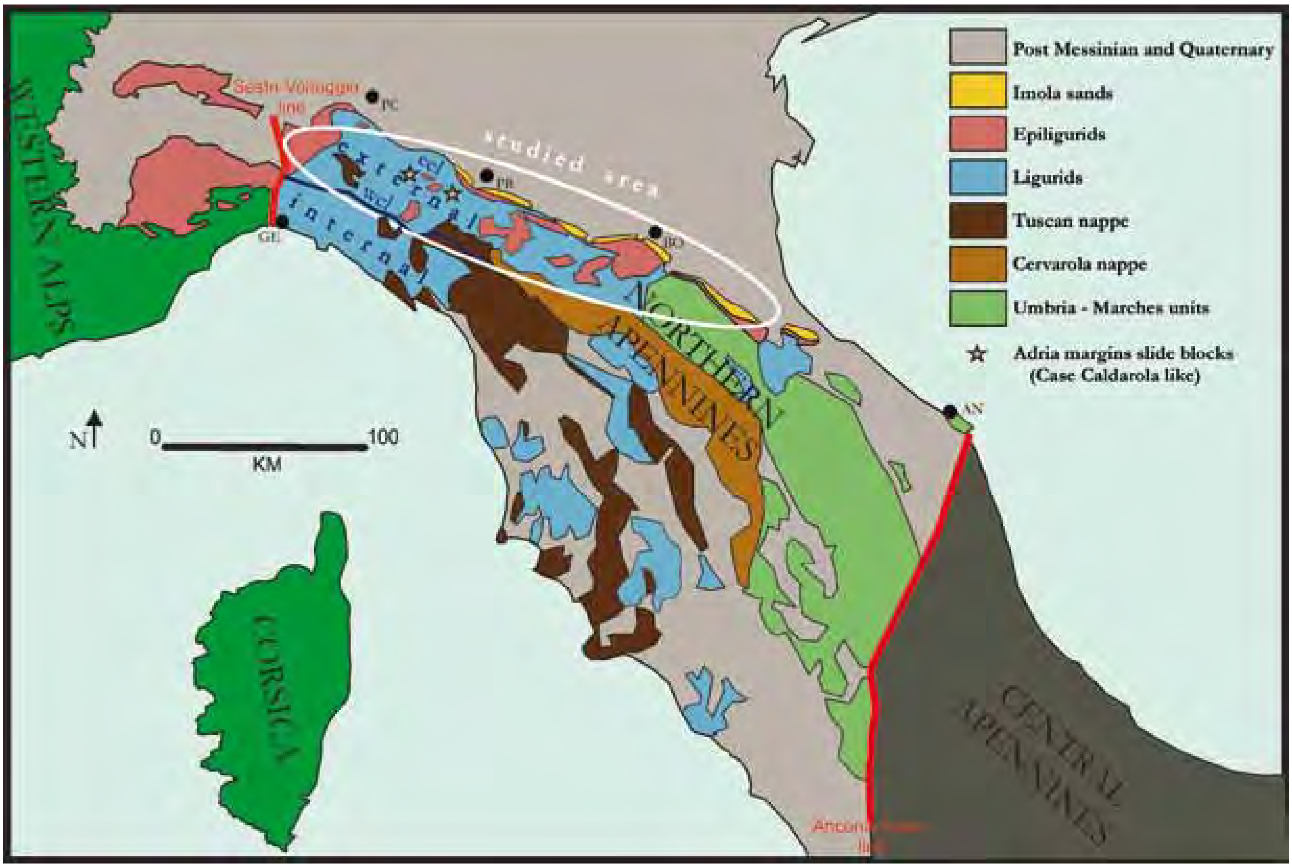

Fig. 4 – Schematic geologic map of the Northern Apennines with the area under study highlighted in white.
Fig. 4 – Carte géologique schématique des Apennins septentrionaux. Les zones étudiées sont indiquées en blanc.

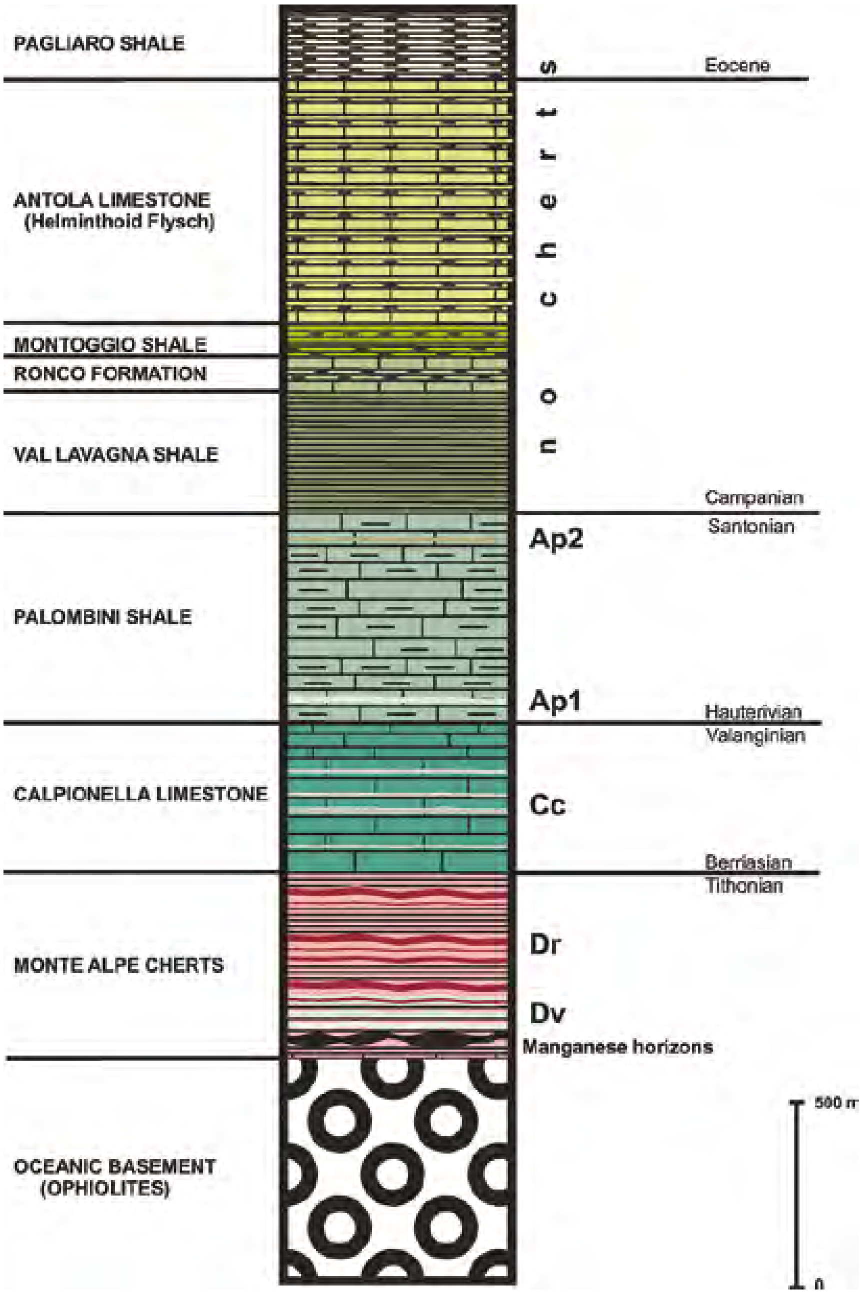

Fig. 5 – Simplified stratigraphic column of the internal Ligurids. The flint-bearing horizons are highlighted and named with abbreviations on the right of the column (Dv: green radiolarites; Dr: red radiolarites; Cc: Calpionella limestone cherts; Ap1 and Ap2: Palombini shale cherts).

Fig. 5 – Colonne stratigraphique simplifiée des Ligurides internes. Les horizons à silex sont indiqués et nommés avec les abréviations à droite (Dv : radiolarites vertes ; Dr : radiolarites rouges ; Cc : silex des calcaires à calpionelles ; Ap1 et Ap2 : silex des schistes à Palombini).

Stratigraphy of the flint-bearing formations

Monte Alpe flints (Callovian/Tithonian; 0–200 m)

The Monte Alpe cherts are a succession of predominantly siliceous pelitic shales, alternating with radiolarian-rich chert beds (radiolarites), directly deposited above the oceanic crust and below the CCD (carbonate compensation depth) (Conti et al., 1985). The flint colours vary from white (rare) to green and red (most abundant). Generally the white and green colours occur at the base of the sequence, followed by the red ones the latter colour may be the only represented in the sequences. The shales are invariably red, foliated and often contain manganese dots or patches. In some cases the concentrations of this element are so abundant that they were extracted as mineral ore (Braunite) in historic times. In Prehistoric times the radiolarian cherts were the most available and exploited raw material in the Northwestern Apennines (between

Liguria and Emilia), including because of the lack or the scarcity of other rocks suitable for knapping. But these cherts were not only a number-two choice: in some outcrops the quality of the radiolarian beds was rather good and they were widely exploited from the Middle Paleolithic on (Negrino and Starnini, 2006 et 2010). Mining activities have been identified in many places from the Upper Palaeolithic on (Campana and Maggi, 2002; Negrino et al., in press a and b).

Calpionella limestone (Berriasian/Valanginian; 0–50 m)

This formation consists of ivory- to white-coloured, bedded pelagic mudstones (including radiolarians, sponge spicules and calpionellids), deposited above the CCD. The limestone layers (up to 30 cm thick) are hard and compact, with conchoidal fracture and stylolithes, separated by thin green to grey shale interlayers. The thickness of this formation is variable and in some areas it may also be missing: the Palombini shales sedimented directly onto the Monte Alpe flints. The strata, in some place dolomitised, alternate with thin chert layers, up to 5 cm thick. Cherts may be locally frequent, but often they are rare or missing. Their colours vary from grey to light brown, often with not fully silicified laminations or stripes. In most cases they are unsuitable for flaking because they are too thin and/or diaclased. The formation, like the Monte Alpe cherts, accumulated above the oceanic crust and is similar to (coccolith-bearing) and partly coeval to the Maiolica formation, distributed across the Adria continental margins (Perilli, 1997; Perilli and Nannini, 1997). The main differences between the two formations are that the Maiolica sedimented during a greater time interval (Tithonian/Aptian), with greater thicknesses and with greater frequencies, variabilities and dimensions of the chert layers and nodules.

Palombini shales (Berriasian/Albian; 50–300 m)

The Palombini shales follow the Calpionella limestone, but they differ through a more terrigenous silty and marly content due to distal turbidites imputs in the bottoms. This is constituted of predominantly grey to green claystones alternating with laminated siltstones, marls and fine grey to white limestones (up to 30% of the whole formation, sometimes silicified). The limestones consist of fine crystalline mudstones (with radiolarians and calpionellids), often turning to wakestones and packstones at the base of the strata. The coarser layers contain bioclasts, ooliths, algae, detritical micas and intraclasts (Decandia and Elter, 1972; Cobianchi and Villa, 1992). This formation is widespread in the Apennines, in both the internal and external Ligurids series. It generally constitutes the base of the external Ligurids, which are tectonically cut as a result of this weak formation. Slightly silicified horizons (invariably in the limestones) are distributed both at the base and at the top of the formation. Well silicified chert layers or nodules are rare. The silicified horizons vary from light green (poorly silicified) to light brown (better silicified).

External Ligurids (EL)

The external Ligurids outcrop on the Emilian side of the Apennines and differ from the internal Ligurids in that they are detached from their original basement, generally as a result of the Palombini shales. They were possibly deposited in an area between the oceanic Ligurian domain (internal Ligurids) and the continental domain (Adria). Recently they were divided into two subunits: the western units (WEL) and the eastern units (EEL; Marroni et al. 2001 and 2010; Marroni and Pandolfi, 2007). In the basal complexes of the external Ligurids there are often slide blocks (olistoliths) originating from both the western oceanic and the eastern continental domains. These olistoliths are important for the palaeogeographical reconstruction of the area.

The western units (WEL)

The western units (WEL) contain significant slide blocks of ophiolites (olistoliths), the stratigraphy of which is similar to that of the internal Ligurids (fig. 6). They mainly outcrop in the upper part of the Emilian slope, close to the internal Ligurids and separated from these latter by the Ottone - Levanto - Carrara line, following more or less the crest line. The sedimentary formations involved in the slide blocks are represented by the Monte Alpe cherts—Calpionella limestone—Palombini shales succession that represents the covers of the ophiolites (Decandia and Elter, 1972). Despite gravitational transport many of these outcrops are not intensively affected by diaclases. In the Ceno valley near the village of Bardi (Parma) there is a large outcrop of this type. Even if the stratigraphy is inverted, the particularly silicified layers of the Monte Alpe cherts are quite undisturbed, and they have been intensively exploited since the Middle Palaeolithic (Negrino et al. in press a). Comparable huge slide blocks are included in the so-called 'basal complexes', constituted by clast-supported breccias and coarse-grained turbidite-derived rudites and arenites (Marroni et al., 2010) known as sedimentary mélanges. The basal complexes are generally followed by flysch formations (helminthoid flysch, Late Cretaceous/Eocene interval) deposited during and after the main tectonic (eoalpine and mesoalpine) phases, when the Piemont-Ligurian oceanic crust was subducted and the Adria continental margin deformed. These rhythmically alternating successions of limestones, marlstones, siltstones and claystones generally do not contain cherts.

The eastern units (EEL)

The eastern units (EEL) mainly outcrop on the middle and lower Emilian side (fig. 7). In the basal complexes of these units there are a few ophiolite remnants—deriving from the western oceanic domain—compared to more frequent

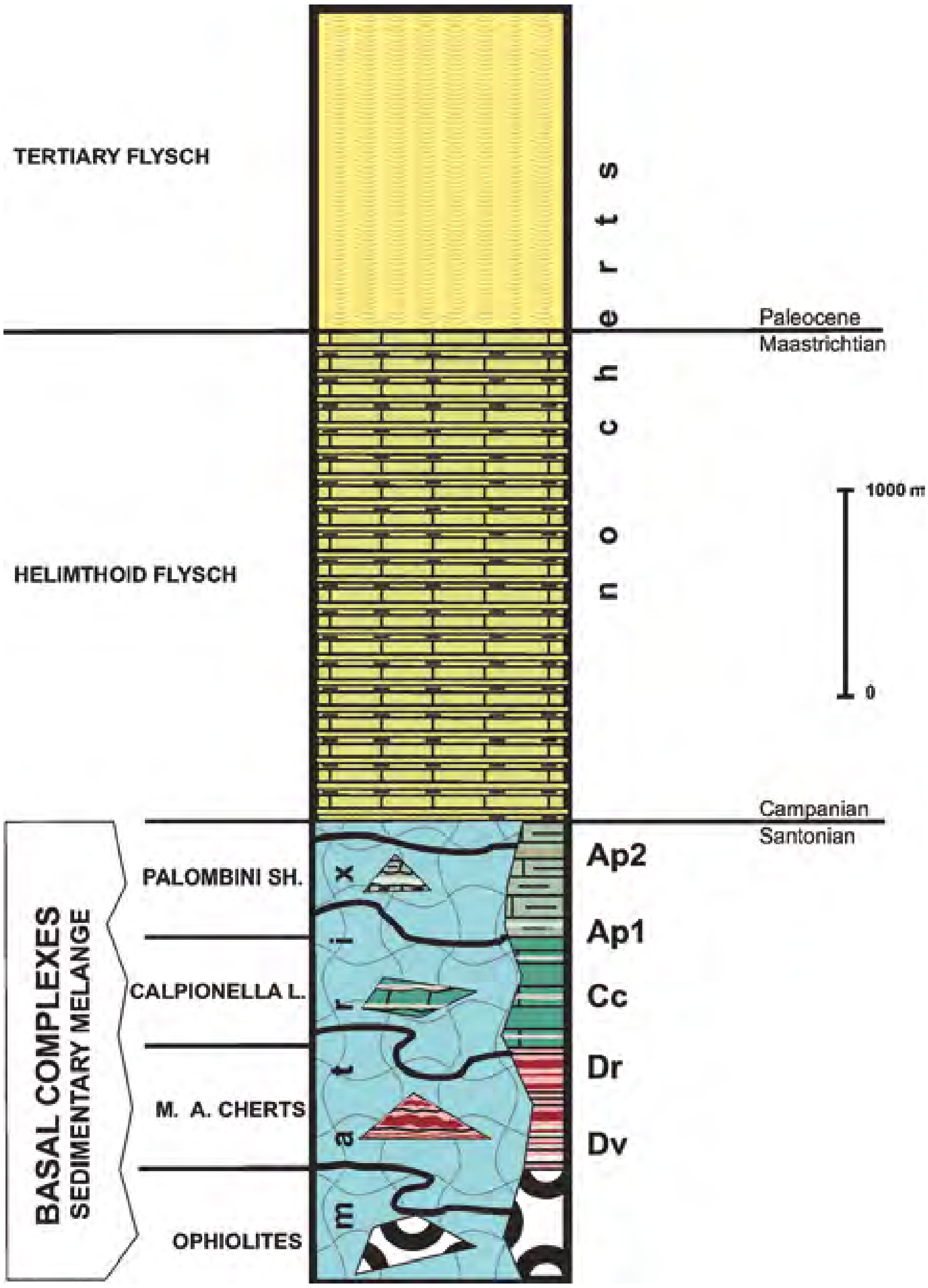

Fig. 6 – Simplified stratigraphic column of the western external Ligurids (WEL). The basal complexes contain sedimentary mélanges stemming from the Piedmont-Ligurian ocean domain and comparable to the internal Ligurids (Dv: green radiolarites; Dr: red radiolarites; Cc: Calpionella limestone cherts; Ap1 and Ap2: Palombini shale cherts).
Fig. 6 – Colonne stratigraphique simplifiée des Ligurides occidentales externes (WEL). Les complexes de base contiennent divers sédiments provenant de l'océan Liguro-Piémontais et comparables au domaine des Ligurides internes (Dv : radiolarites vertes ; Dr : radiolarites rouges ; Cc : silex des calcaires à calpionelles ; Ap1 et Ap2 : silex des schistes à Palombini).

continental slide blocks—deriving from the eastern continental Adria margin (Marroni et al., 2001 and 2010). Many of them are small fragments, but in some cases they are large enough to enable a stratigraphic reconstruction of the series. One of the most representative successions of the EEL is the Cassio unit, where the complete transition from the basal complex to the Tertiary flysch is visible. There are Middle to Late Triassic dolomitic limestones, cherty limestones (Lias), marls (Dogger/Malm) transitional to radiolarian flints (Malm), aptycus-bearing red marls (Malm) and white pelagic limestones (Maiolica). These series, very similar to the Tuscan and Southern Alps successions, are interpreted as remnants of continental blocks tectonically transported in a transitional area between the continental margin (Adria) and the oceanic domain (Piemont-Ligurian). Spots of these outcrops are distributed across the middle Apennines between the Pavia, Piacenza and Parma provinces and they represented siginificant potential procurement sources in a general context that is extremely poor in flints. A fairly big slide block of this type

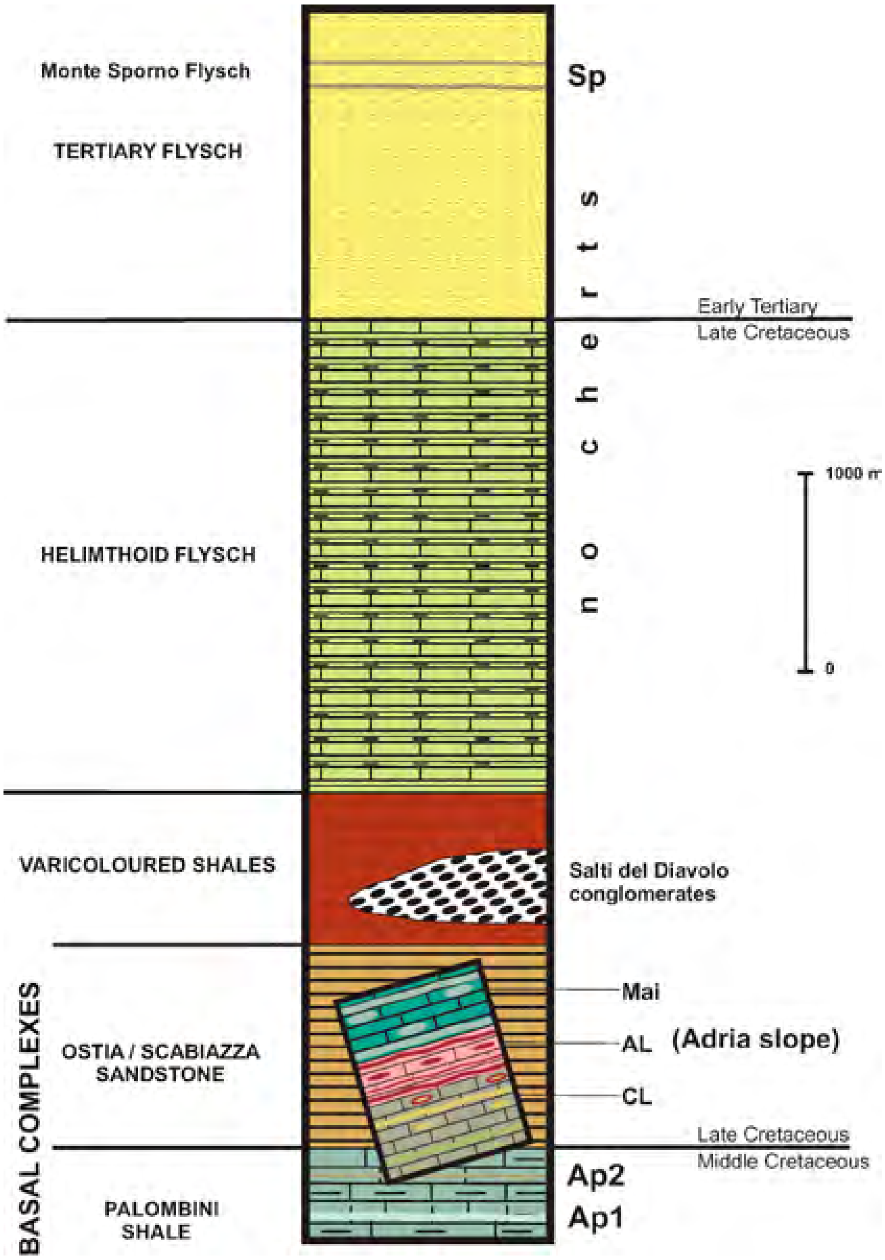

Fig. 7 – Simplified stratigraphic column of the eastern external Ligurids (EEL). The basal complexes contain sedimentary mélanges stemming from the Adriatic margins (east) and comparable to the Tuscan and Southern Alps series. (Ap1 and Ap2= Palombini shales cherts; CL= Triassic to Jurassic cherty limestones; AL= Aphtycus limestone chert; Mai= Maiolica chert; Sp= M. Sporno flysch chert).

Fig. 7 – Colonne stratigraphique simplifiée des Ligurides orientales externes (EEL). Les complexes de base contiennent divers sédiments provenant des marges adriatiques (est) et comparables aux séries toscanes et sud-alpines (Ap1 et Ap2 = silex des schistes à Palombini, CL= Calcaires siliceux Trias à Jurassique, AL= silex des calcaires aptytiques, Mai= silex de la Maiolica, Sp= silex des flyschs du Mont Sporno).

(Case Caldarola complex) is enclosed in the Scabiazza sandstones near Bobbio (Trebbia valley, Piacenza; Vercesi and Cobianchi, 1998). The subsequent hemipelagic 'variocoloured shales' (Cenomanian/Late Campanian) are interbedded with characteristic conglomerate horizons (Salti del Diavolo Conglomerate). This conglomerate includes intrusive, volcanic, metamorphic, sedimentary and siliceous (radiolarian flints and cherty limestones) pebbles. They originated from the subaerial erosion and submarine transport of the Adria sedimentary covers and metamorphic basement in uplifted and exposed areas farther north. The cherts can be attributed to similar successions, as discussed above. The pebbles, up to 10 × 5 × 5 cm, are big enough to be exploited, even if the erosion and the transport have in many cases compromised their integrity. Finally, similarly to the WEL, the thick helmintoid flysch successions generally do not contain cherts, but there are a few exceptions. Well-silicified horizons are seldom present in the Tertiary flysch of the Sporno unit, outcropping on the lower slope of the Apennines between the Piacenza and

Parma provinces (Di Dio et al., 2005). In these series the silicified layers often correspond to calcareous turbidites of neritic provenance, with many bioclasts. The cherts hues vary from light brown to grey.

Epiligurids

The Epiligurids were deposited above the tectonised Ligurid units, in all cases separated by unconformities. Today, because of erosion, they are preserved only in the external Ligurids. They represent the most recent and highest units in the Northern Apennines chain. The stratigraphic sequence can be related to a single marine succession, dated between the Middle Eocene and the Messinian (Papani and Vernia, 1994). The sedimentation started in the Middle Eocene with emipelagic marls (Monte Piano formation) alternating with sandstones (Loiano Sandstones). They are followed by the Ranzano formation (Late Eocene/Early Oligocene), constituted of thick (up to 1,000 m) siliciclastic turbidites. The Antognola formation (Late Oligocene/Early Miocene) follows. It is formed by slope marls, mainly alternating with turbidites and, in the upper part, with volcanic imputs. Volcanism favoured a general enrichment in silica (silicified marls) of the upper Antognola layers. In some areas (between the Modena and Bologna provinces) the silicified horizons are particularly abundant; most of the cherts are included in detritic slopes or in torrent pebbles. These are silicified marls, sandstones and siltstones; some of them are clearly turbidites with evident laminations. They contain fine detritus, many sponge spicules and radiolarians and scarce planktic foraminifers of Miocene age. The colours of the cherts vary from dark grey to light grey or reddish grey. The textures may be more or less fine, but detritical particles are invariably present. They are almost always layers, even thick (up to 30 cm). This raw material is locally known as ‘phtanite’, but this denomination (inherited from the past) should be revised. In another area (Reggio Emilia province, outcrops near the Carpineti village) poor-quality cherts, overall nodules, but also layers can be identified in the upper Antognola formation. Sometimes the nodules are very large (up to 40 cm diameter). They have a resinous aspect and are always full of fractures: because of its appearance it is also known locally as ‘chalcedony’ chert. It was very rarely exploited. Under the microscope no sedimentary structures, radiolarians or other microfossils are recognisable; the source of the silica is probably volcanic. Close to the Apennines foothill contemporaneous rhyodacitic cinerites (completely unsuitable for flaking) including radiolarians and diatoms were deposited in small basins (Contignaco formation, Early Miocene). The subsequent Bismantova formation (Middle Miocene) attests a general shallowing of the basin, documented by mainly neritic limestones (bioclastic calcarenites) and slope deposits. This trend continued with the deposition of the Termina Marls (slope deposits, Tortonian) and ended with the Messinian salinity crisis that led to the deposition of limestones and gypsum (Gessoso-Solfifera formation). After the Messinian crisis the sea level slowly increased. This is attested by transitional facies between land and sea, such as continental conglomerates and sandstones, silty clays and micritic laminated limestones (Colombacci formation, Late Messinian).

Plio-Pleistocene marine/continental facies

In the Pliocene/Early Pleistocene interval the Adriatic sea repeatedly transgressed on the Po plain. At least four transgressive/regressive cycles have been identified (Benini et al., 2009). The Argille Azzurre formation is constituted mainly by clay and silty clay, locally with conglomerate interbeds, widely sedimented in the area, attesting to a marine environment (Amorosi et al., 1998a). The deposition took place in the Po plain and in the Apennines foothills where littoral facies are preserved locally. In the Apennines near Bologna transitional facies between the continent and the sea are documented by the Monte Adone formation (Middle/Late Pliocene; sandstones, fluvial conglomerates, mudstones). The fluvial conglomerates (fan deltas) are mainly constituted by Ligurids limestones (Martelli et al., 2009); cherts are subordinated or absent. A transitional environment between the alluvial plain, lagoons, shallow marine sands and conglomerates is represented by the Imola Sands formation (Early and Middle Pleistocene; Amorosi et al., 1998b). This formation is widely distributed along a discontinuos stripe (1–2 km wide) at the foothill of the entire Northern Apennines, gradually eterophic to the Argille Azzurre (open sea facies, Po plain). The conglomerate horizons at the base of the formation (a few metres thick) have been interpreted as marine regressive. These well-rounded conglomerates may reach considerable dimensions (20 × 10 × 5 cm) even if they are usually smaller. They are mainly constituted by cherts (secondarily by limestones and quarzites). These cherts (aged between the Jurassic and the Miocene) were transported by the sea shoreline currents from the Umbria-Marches and Romagna areas (Veggiani, 1965). Most of them are silicified Tertiary calcarenites, sometimes including macrofossils. These cherts most probably derive from the erosion of the Val Marecchia Nappe (Romagna). Other lithofacies are clearly attributable to the Umbria-Marches succession (Maiolica, Scaglia, Bisciaro). The Imola Sands conglomerates represented an important source of raw material in the Apennines during prehistory. Indeed these pebbles are fine crystalline and very homogeneous cherts, a characteristic that is rare or absent from a large part of the Northern Apennines slope. Moreover, these samples are quite easy to collect, as they are relatively abundant and distributed in accessible areas. These cherts were exploited and selected among other poor-quality raw material (so called ‘phtanites’) from the Lower Paleolithic as shown by the pebble industries discovered in Emilia and Romagna (Lenzi and Nenzioni, 1996; Peretto et al. 1998). They were exploited for Levallois production during the Middle Paleolithic whereas they were exploited mainly for bladelet production during the Mesolithic.

DISCUSSION AND COMPARISON

As introduced above, the Southalpine and the Northern Apennines post-Jurassic sedimentary successions were deposited in the same sedimentary basin but in different palaeogeographical domains. The Southalpine (in this case the Trento plateau) is a sector of the faulted margin of the Adria plate and the Northern Apennines series (Ligurids) formed on the Piemont-Ligurian oceanic domain (internal Ligurids; WEL) and on the transitional areas with the rifted Adria paleomargin (EEL). The main difference concerns the environmental depositional depth, above a faulted continental slope (Southalpine) and on the ocean bottoms (Ligurids). In Middle/Late Jurassic the Monte Alpe flints (radiolarites) sedimented directly above the oceanic crust and mainly below the CCD, but comparable litofacies were also deposited in less deep environments (above the CCD) on the rifted continental slopes. This produces two groups of Jurassic 'radiolarites': 1) Deposited above the oceanic crust, below the CCD, alternating with siliceous shales. 2) Deposited on the continental slopes, above or close to the CCD, enclosed or alternating with marls or limestones (Folk and McBride, 1978; McBride and Folk, 1979). In the Trento plateau the latter correspond to the middle, flint-bearing Ammonitico Rosso Veronese unit. In other sectors of the Adria paleomargins they are called Rosso ad Aptici (Lombard Basin), Diaspri (Tuscan Basin) or Diasprigni limestones (Umbria-Marches Basin). These epicontinental radiolarites are quite similar to the Monte Alpe flints and may be difficult to identify without a detailed analysis. They were exploited mainly in the areas close to the outcrops and were never transported over long distances as is the case for the Monte Alpe flints. Above these mainly radiolaritic Upper Jurassic facies the sedimentation changed and became clearly pelagic in the entire area with the deposition of the Calpionella limestone/Maiolica formations. The bloom of nannoplankton caused a sudden drop of the CCD; calcareous and siliceous oozes reached the bottoms and lithified in micritic cherty limestones. The Maiolica facies is widespread in Italy, from Trentino to Sicily, and is known locally by various denominations (Calpionella limestone, Biancone, Maiolica, Calcare rupestre, Lattimusa). It was deposited both on the Piemont-Ligurian oceanic domain, where it is known as Calpionella limestone, and on the continent slopes. We discussed above the lithologic features of the formation. Even if the lithofacies are very similar, there are differences with regard to the chert content. The Calpionella limestone contains mainly thin gray to brown chert layers, nodules are absent or rare. The cherts are also missing in many sections; in any case they are rarely present and mainly distributed in the lower part. In most cases the small dimensions and the presence of cracks make them unsuitable for flaking. The Maolica formation differs in that it has a much greater chert content, both layers and nodules, often with changing textural features in the stratigraphic column. Along the rifted Adria margins several more or less condensed facies have been identified, the condensed facies sedimented over submarine elevations such as the Trento plateau. The textural differences of the cherts stem from several factors, for example the oxygenation of the bottom waters, the silica supply, the clay fraction of the mother rock (more or less marly), and the early diagenesis of the mother rock on the submarine plateaus. Along the slopes (ex. Trento plateau/Lombard basin; Friuli platform/Belluno basin) huge slumps and resediments strongly affected the sedimentation of the Maiolica formation. Distal turbidites riched the bottoms of the basins, where the thicknesses reached several hundreds metres. The coarser resedimented layers were often the preferred silicified layers; probably because they were more permeable to the silica fluids. The Northern Apennines also host outcrops of the Maiolica formation. They are more accurately included in the 'basal complexes' of the EEL, in which olistholits belonging to the Adria margins collapsed into the Late Cretaceous sedimentary successions. In some cases huge blocks with long series from Triassic to Cretaceous have been identified. The Maiolica flints differ strongly from the Calpionella limestone cherts. These are big, grey to light green nodules and layers of exceptional quality, when they are not tectonised. The textures and the shapes are very similar to the Maiolica flints of the Trento plateau, but the colours are different. The Maiolica formation follows the Diasprigni limestone and Triassic to Jurassic cherty limestones; to some extent these series can be compared to the Tuscan succession (Tuscan basin). These outcrops represent fragments of series deposited on the thinned continental crust between the Piemont-Ligurian ocean and the Adria microplate. The evidence suggests that these spots were intensively exploited at least since the Upper Paleolithic. The Palombini shales, widely outcropping in the Apennines, contain only very few cherts, compared to the Scaglia Variegata Alpina. This is related to a more terrigeneous content of the Palombini shales. The Scaglia Rossa formation was not deposited in the Emilian Northern Apennines: here thick, almost flintless flysch successions formed between the Late Cretaceous and the Eocene. From the Eocene a new system of platforms and basins formed above the Trento Plateau. Cherts are quite common in the Early and Middle Eocene basinal formations. Comparable cherts, containing macroforaminifers, formed in the Inner Apennines (Tuscan Apennines). These formations were subsequently transported by gravitation to the northeastern Apennines (Val Marecchia Nappe). For reasons related to time and to the extent of the research the Marecchia fold will be not discussed in this paper. The Epiligurids are characteristic of the Northern Apennines as well as the Apennines foredeep successions: Oligocene to Miocene cherts do not occur in the Southalpine.

Acknowledgements: I would like to thank Federica Fontana and Davide Visentin (Ferrara University, Sezione di Scienze Preistoriche e Archeologiche) who helped me on several field trips. Many thanks to Didier Binder, Gabriele Martino, Nicolas Naudinot, Antonin Tomasso (congress organisers) for their invitation and their cordiality.

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