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THE PLIOCENE AND EARLY PLEISTOCENE DRAINAGE NETWORK EVOLUTION IN THE MONFERRATO HILLS (PIEDMONT, NW ITALY)

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ABSTRACT: The drainage network in the Monferrato Hills is, in general, quite complex. However, in the western and eastern end of the Monferrato there are areas where the drainage is less complex. Morphological analysis suggests that the differences in drainage were mainly produced by captures that have affected the catchments of some streams.
Geological and geomorphological studies have shown that during the early Pliocene, a portion of the Monferrato, along with part of the Torino Hill, was an island in which there were some catchment basins draining towards the southern and northern sea.
The tectonic evolution caused the capture of rivers that have been dated from the Piacenzian onwards using stratigraphic and morphological data. The head of the Stura, Colobrio, Rotaldo and Grana valleys, that flowed southwards after the emersion of the island, were captured by headward erosion of streams draining towards the northern basin.
The post-Zanclean uplift of the western Monferrato, some gentle post-Zanclean anticlines lying south of the hills, the subsiding basin lying north and the tectonic structures transversal to the Monferrato thrust front, played a dynamic role in the evolution of the drainage.
On the contrary, the tectonic structures displacing the sediments that form the core of the Monferrato hills, active mainly before the Pliocene, influenced, mostly passively, the drainage network when the area emerged from the sea. In fact, the initial direction of the streams was conditioned by the different strike, dip and erodibility of the pre-Pliocene sediments.

Keywords: structurally-controlled drainage network, river capture, Pliocene, Pleistocene, Monferrato Hills, NW Italy

1. INTRODUCTION

The present paper deals with the Pliocene-Early Pleistocene evolution of the drainage network of the Monferrato Hills. Since the paper by Sacco (1889), it has been known that during the Pliocene the Monferrato was an island, and therefore the study of the present drainage network can highlight the structure of the drainage that developed on the just emerged island and the influence of the Pliocene and Pleistocene tectonic activity on its evolution.

The Monferrato and Torino Hills are the north-western termination of the Apennine chain, and are surrounded by the Savigliano and Alessandria basins, to the south, and by the Po basin to the north (Fig. 1). The post-Messinian geological and tectonic evolution of the hills can be considered fairly similar (Irace, 2009; Mosca et al., 2010).

The drainage network in the Monferrato and Torino Hills is formed by small streams, that are tributaries of the Po river north and SW of the hills, and of the Tanaro river south of the hills. In the Monferrato, the drainage is far more complex than in the Torino Hills.

The geological literature reports various hypotheses regarding the evolution of some portions of the drainage network (Biancotti & Franceschetti, 1979; Carraro et al., 1980; Giraudi, 1981; Carraro & Valpreda, 1991; Carraro et al., 1995; Dela Pierre et al., 2003b; Forno & Lucchesi, 2005; Vezzoli et al., 2010; Giraudi, 2015; Forno & Lucchesi, 2016): the picture that emerges from the morphology of the valleys, the presence of fluvial sediments of Alpine origin and the deformation of Plio-Pleistocene sediments and terraces is clear in indicating that the drainage is strongly influenced by the tectonic evolution connected with the activity of the Monferrato thrust front and some transverse strike slips or transtensive faults and deformation zones.

The aim of the present paper is to analyze and discuss the morphology of the valleys of the main streams of the Monferrato Hills in order to recognize the features that originated during the Pliocene and the evolution of the drainage network until the Early Pleistocene, and to hypothesize the forcing factors.

2. MATERIAL AND METHODS

In the present paper it is assumed that, as suggested by the results of the studies of Sacco (1889), Carraro et al. (1980) and Dela Pierre et al. (2003a,b), the hills bounded by Pliocene sediments of littoral facies indicate approximately the extent of the land surrounded by the sea during the Pliocene, in particular during the

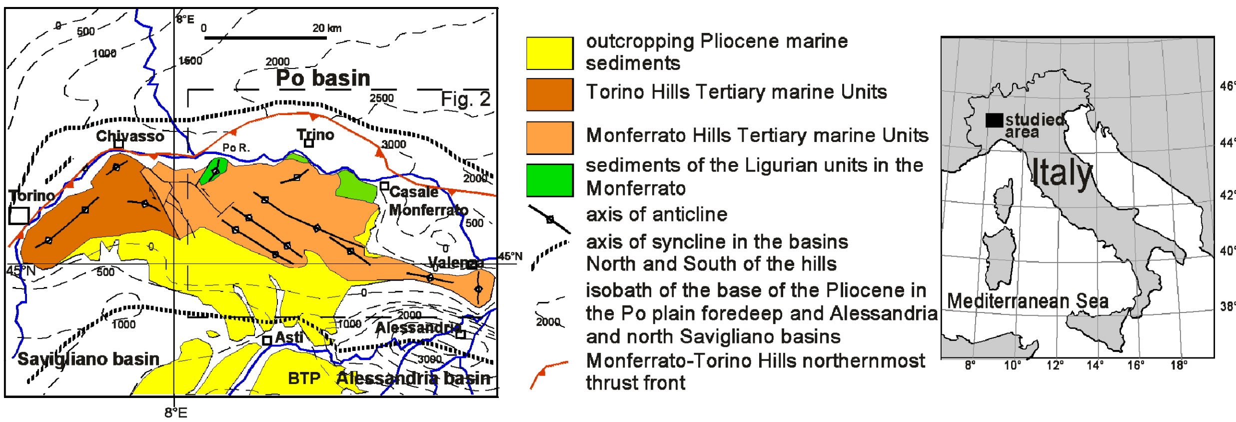

Fig. 1 - Geological sketch of the Monferrato and Torino hills and surrounding Pliocene basins, with location of the study area.

Zanclean. The stratigraphy and tectonic structures affecting the Monferrato Hills have been outlined because of their possible impact on the drainage evolution and some interpretations of peculiar geological and morphological features have been discussed.

The geology of the area drawn in Fig. 2 is based on the Geological Map of Italy at the scale of 1:100,000, Sheets 57, 58, 69 and 70 (Anfossi et al., 1969; Boni & Casnedi, 1969; Bonsignore et al., 1969; Bortolami et al., 1969; Braga & Ragni, 1969; Corsi et al., 1969; Montrasio et al., 1969). In fact, only part of the Monferrato lies in the Trino Sheet of the Geological Map of Italy at the scale 1: 50,000 (Dela Pierre et al., 2003a), which represents an advancement in both the cartography and the interpretation of the stratigraphic and tectonic evolution. However, some tectonic structures identified by Dela Pierre al. (2003a) and the Fontanetto Po, Trino, Salera Line, Giarole-Lu and Valenza deformation zones, evidenced by Giraudi (2014; 2015; 2016), have been included in Fig. 2.

The evolution of the drainage network of the Monferrato Hills was outlined using geomorphological analysis. Some morphological features have been used in order to identify areas in which the drainage network has the same characters. The presence of elbows of capture, mostly already reported in literature (Biancotti & Franceschetti, 1976; Carraro et al., 1995; Dela Pierre et al., 2003; Giraudi, 2015; 2016), and strong valley asymmetries have been taken into account in order to establish the most important drainage variations.

The drainage network has been interpreted in order to determine the approximate location of the Pliocene divide between basins draining to the south and to the north and in order to have some information on the Pliocene landscape that was later modified by the geological and geomorphological evolution.

3. GEOLOGICAL OUTLINE OF THE HILLS AND BURIED MONFERRATO

Detailed knowledge of the geological features of the Monferrato Hills is limited by the extensive vegetation cover and the scarcity of outcrops. Paradoxically, there are more detailed data on tectonic structures that affect the tertiary sediments covered by alluvial deposits of the Po Plain (the Buried Monferrato) thanks to the geophysical data and the extensive outcrops along the Po riverbed.

The geological structure of the Monferrato is outlined in Fig. 2.

3.1. The Monferrato hills

The current geological structure of the Monferrato Hills was determined by the Pliocene and Pleistocene northward migration along thrust fronts of Tertiary sedimentary units already deformed by earlier tectonic phases (Dela Pierre et al., 2003a,b; Galadini et al., 2012; Giraudi, 2014; 2015) and by an uplift that lasted, at least in some places, until the Late Pleistocene (Carraro et al., 1980; Carraro & Valpreda, 1991; Carraro et al., 1995; Michetti et al., 2012; Giraudi, 2014; 2015).

According to several authors (Costa, 2003; Giraudi, 2014; 2016), the thrust front is intersected by transverse strike slip or transtensive faults and deformation zones.

The thrust front, buried under Quaternary fluvial sediments, is located at a variable distance from the northern slope of the Monferrato and Torino Hills.

In general, the core of the Monferrato Hills consists of strongly deformed pre-Messinian sediments and is bounded to the south by gently folded Messinian and Pliocene sediments.

The new stratigraphic studies reported in Dela Pierre et al. (2003b) have led to the recognition of sediments of littoral facies, Pliocene (Zanclean) in age, and have demonstrated that, after the Zanclean, a marine regression began. The area surrounded by the Zanclean sediments corresponds, at least approximately, to the area not submerged by the sea during that period.

However in the Moncalvo area (Fig. 2) there are two small anticlines affecting Messinian and Pliocene sediments and the Pliocene that completely surround the Messinian core (Sacco, 1889). The post-Zanclean anticlines (Pieri & Groppi,1981; Cassano et al., 1986), create a unique case in Monferrato, where the Messinian sediments always surround unconformably the older marine formations.

Near San Salvatore, the marine sedimentary sequences do not contain the Ligurian Units, outcropping

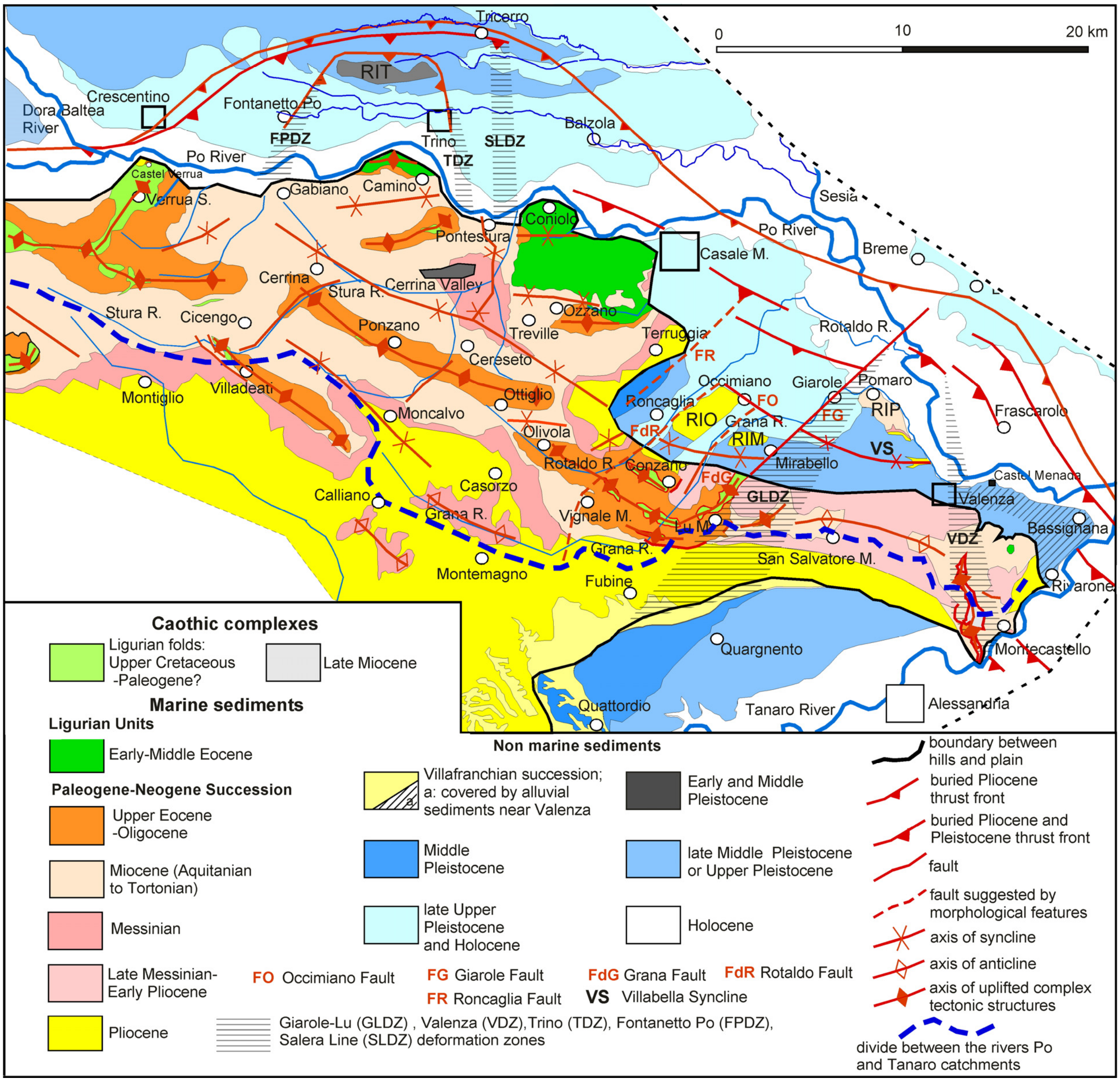

Fig. 2 - Geological map of the Monferrato Hills (modified from Anfossi et al., 1969; Boni and Casnedi, 1969; Bonsignore et al., 1969; Bortolami et al., 1969; Braga and Ragni, 1969; Corsi et al., 1969; Montrasio et al., 1969). Some faults are from Dela Pierre et al. (2003), while the Fontanetto Po, Trino, Salera Line, Giarole-Lu and Valenza deformation zone are from Giraudi (2014; 2015; 2016). RIT, RIO, RIM and RIP indicate the isolated hills of Trino, Occimano, Mirabello and Pomaro.

in other areas of the Monferrato (Fig. 2), and the anticline that forms the core of the hills consists of continental and marine Messinian and early Pliocene marine sediments. Elsewhere, except in the Moncalvo area, Messinian and Pliocene sediments outcrop just on the edge of the highest hills.

On the northern slope of the hills west of Casale Monferrato, near Verrua Savoia, there is just an isolated outcrop of Pliocene (Zanclean) sediments (Martinis, 1954, Zappi, 1960; Trenkwalder & Violanti, 2001; Bove Forgiot et al., 2005).

In the eastern Monferrato, between Casale Monferrato and Conzano, Pliocene marine littoral sediments are quite extensive and indicate the approximate boundary of the emerged land.

Regarding the tectonic features, it can be observed that the hills west of the Grana Valley consist of a series of uplifted complex structures and synclines oriented mainly NW-SE and WNW-ESE, although some structures lying in the northern portion of the area are oriented approximately W-E and, seldom, SW-NE and approximately N-S.

While many of the sediments that form the core of the Monferrato hills were already folded and faulted before the Pliocene, and partly emerged during the Zanclean, the area south of Moncalvo, where the anticlines with a Messinian core involving Pliocene littoral sediments are located, was deformed and uplifted later (Sacco, 1889; Pieri & Groppi, 1981; Cassano et al., 1986). According to Dela Pierre et al. (2003b), tectonic movements started during the sedimentation of the deposits of Villafranchian facies (Piacenzian in age) and caused the uplift of part of the area between Moncalvo and Asti.

Also the anticlines that involve Messinian and early Pliocene marine sediments forming the core of the highest hills near San Salvatore were produced by tectonics active during or after the Pliocene. According to ENEL (1984) these sediments lie on a thrust front and their displacement occurred after the lower-middle Pliocene.

Therefore, the deformation of the Pliocene marine sediments and the emersion of the areas near Moncalvo and San Salvatore probably took place at the same time after the Zanclean, while the sea was still present in the Alessandria and Po basins.

Because the emersion occurred later than in the core of the Monferrato, this area from now on will be called Neo-Monferrato.

In the lower Cerrina Valley (Fig. 2) there is a very peculiar syncline, whose axis runs first from NW to SE, then W-E and afterwards S-N. The stretch of the syncline oriented NW-SE might correspond to the continuation of the syncline having the same direction which extends from the area of Cereseto to Treville and Roncaglia. The syncline of the Cerrina valley was also active from the Early Pleistocene (or late Pliocene) to the Middle Pleistocene and (according to Giraudi, 2016) may correspond to a subsiding basin produced by the distension that occurred behind the thrust front (Fig. 2) located north of the Trino isolated hill (RIT in figures).

In correspondence with the Giarole-Lu Deformation Zone (GLDZ), some diapiric structures, with WNW-ESE oriented axes, are folded (Fig. 2), assuming a SW-NE trend. Between the San Salvatore area and the Pomaro isolated hill (RIP in figures), the folds assume a WNW-ESE direction and then, at the eastern end of the Monferrato, in correspondence with the Valenza Deformation Zone (VDZ), a direction approximately N-S.

The lithology of the Tertiary sediments of the Monferrato is predominantly marly and clayey, but the Pliocene marine sediments have sandy and calcarenitic facies, the Miocene ones contain interbedded calcarenitic horizons and sandstones, while very cemented conglomerates and sandstones are common in the Oligocene sediments. In particular, the latter, which generally form the highest hills, are the most resistant to erosion (Fig. 2).

In the core of the Monferrato Hills, continental sediments older than the Late Pleistocene are scarce and outcrop in a patchy fashion, with the exception of the Cerrina Valley. Some alluvial sediments, probably Pliocene in age, lie in the area east of the Colobrio Valley, at an elevation similar to the hilltop, many tens of metres above the lake sediments outcropping in the Cerrina Valley, dated at the Early Pleistocene sub-chron Olduvai (Giraudi, 2016). Characteristic of the lower Cerrina Valley (Fig. 2) is the presence of a significant amount of Early and Middle Pleistocene alluvial sediments, formed by clasts of Alpine origin, demonstrating the presence of a river flowing from the area sited NW of the valley head (Giraudi, 1981; Carraro et al., 1995; Giraudi et al., 2003; Dela Pierre et al., 2003a,b; Giraudi, 2016). The lithology of some patches of alluvial sediment suggest that the river continued SE of the valley reaching the Buried Monferrato lying north of the easternmost Monferrato Hills (ENEL, 1984; Carraro et al., 1995; Giraudi, 2015; 2016).

3.2. Buried Monferrato

The Buried Monferrato, located north of the hills between the hill slope and the thrust front, is mainly formed by the same pre-Pliocene marine sediments forming the hills, underlying Late Early Pleistocene to Holocene fluvial and glaciofluvial deposits of the Po plain (ENEL, 1984; Dela Pierre et al., 2003 a, b; Giraudi, 2014) which, normally, are less than 20 m thick. The marine sediments have been observed in a number of wells and boreholes drilled for oil exploration, or related to studies for a nuclear power plant, and water wells (ENEL, 1977; 1984; Pieri & Groppi, 1981; Cassano et al., 1986; Giraudi, 2014; 2016). Pliocene and Pleistocene (Gelasian) marine deposits of littoral facies have been found not only in the Po and the Alessandria basins at the top of a thick successions of older Pliocene sediments, but also in some places in the Buried Monferrato lying unconformably on older Pliocene neritic and pre-Pliocene marine sediments (Fig. 2). In general, in the Buried Monferrato, the Pliocene marine sediments lie near the thrust fronts, but north of the Eastern Monferrato they have been found between the hillside and the Pomaro isolated hill, i.e. in an area well south of the Monferrato thrust front (Pieri & Groppi, 1981; Cassano et al., 1986).

The tectonic structures affecting the Buried Monferrato, shown in Fig. 2, take into account mainly synclines, thrust fronts, faults and deformation zones active also during the Pleistocene and which fit better with borehole and well data already discussed in Giraudi (2016). In point of fact, such structures could have conditioned the Early Pleistocene drainage evolution on the Buried Monferrato. Therefore, some thrust fronts active before the Late Pliocene or of uncertain activity, assumed in geological literature (Montrasio et al., 1969; Pieri & Groppi, 1981; ENEL, 1984a; Cassano et al., 1986; Bigi et al., 1990; Michetti, et al., 2013; Giraudi, 2014; 2015; 2016) have not been drawn in the figure.

The area of the Buried Monferrato (Fig. 2) is affected by strike-slip or transpressive faults transverse to the front (Costa, 2003) both in the areas west and east of the Trino and Pomaro isolated hills.

According to recent studies (Giraudi, 2014; 2015; 2016) in places roughly corresponding to the transpressive faults reported by Costa (2003), but also in other areas, there are the Fontanetto Po (FPDZ), Trino (TDZ), Salera Line (SLDZ), Giarole-Lu (GLDZ) and Valenza (VDZ) deformation zones. The deformation zones, active during the Pliocene, Early and Middle Pleistocene, are transverse to the thrust fronts, and show left-slip west of the Trino and Pomaro isolated hills, and right-slip to the east.

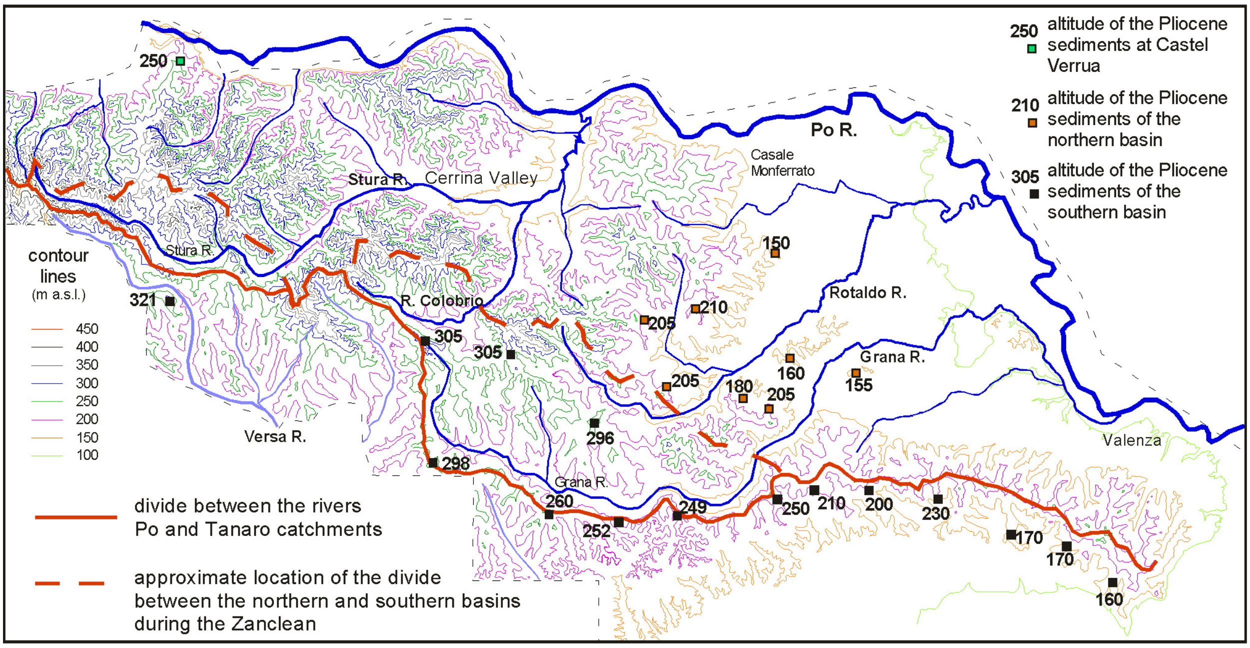

Fig. 3 - Elevations of the Monferrato Hills and of the surrounding plains, evidenced by 50 m contour lines, and elevation of the Pliocene littoral sediments north and south of the Po-Tanaro divide.

3.3. Connection between topography of the hills and tectonic structures

The connections between the topography and the geological structures seem very clear in the core of the hills. The map of Fig. 3 shows the elevations of the study area with 50 m contour lines. The maximum elevations, just below 500 m a.s.l., are reached towards the western end of the area. In the same area the height of the hills often exceeds 400 m a.s.l. The elevations decrease from NW to SE.

From a comparison between Fig. 2 and Fig. 3, it is evident that the maximum elevations coincide with the uplifted complex structures and the lower ones with the synclines. It is also easy to observe that the hills lying NE of the head of the Stura, Grana and Rotaldo valleys are, in general, higher than those lying SW and that, just after changing their direction from NW-SE and WNW-ESE towards NE, the same valleys lie on SW-NE trending faults and cut deeply through the uplifted structures oriented NW-SE (Fig. 2).

Making a comparison between the maximum heights of the hills and the portions where the Zanclean sediments of littoral facies are present, next to the divide between the Po and the Tanaro basins (Fig. 3), the difference is of about 100 m in both the Western Monferrato (400-440 m and 330 m respectively) and the Eastern Monferrato (250-260 m and 160 m). In Fig. 3 it can be observed also that east of Moncalvo, the Pliocene littoral sediments outcropping north of the Po-Tanaro divide sometimes reach elevations higher than the hills forming that divide, but do not reach the elevation of the northernmost hills.

4. PRELIMINARY DATA ON THE DRAINAGE NETWORK IN THE MONFERRATO AND TORINO HILLS

The Torino and Monferrato Hills are affected by a drainage network with different characteristics (Fig. 4A). All the streams on the northern slopes are tributaries of the Po river , while the streams that drain the southern slopes flow into two different basins: from the Torino Hills they flow mostly to the E-W trending river Banna, which is a tributary of the Po, while those draining the Monferrato flow to the W-E trending Tanaro river or the Triversa stream, its tributary.

North of the hills, the Po river and the small streams flow through the Buried Monferrato.

The drainage network in the hills is shown in Fig. 4A. It can be observed that the smaller streams flowing from the hills to the Po river are sometimes not drawn in the figures when they reach the alluvial plain. These streams are in fact connected with the network of irrigation ditches and therefore are difficult to follow and their shape and direction are wholly artificial.

In the context of Fig. 4A, various areas have been highlighted in which the drainage has common features.

Zone A: corresponds to the Torino Hills and the portion of Monferrato located W and SW of the confluence of the river Dora Baltea and the river Po. The drainage network in this zone has, in general, the following characteristics: the head of the basins of most streams begins at the divide between the northern and southern slopes of the hills, and the streams, with directions transverse to the divide, flow directly into the river Po (to the north) or into other streams roughly flowing E-W or W-E, tributaries of the main rivers (to the south). In zone A, the Po-Tanaro divide reaches its northernmost point.

To the north of the hills, the river Po runs close to the hillslope, on the Buried Monferrato, where tertiary sediments are predominantly pre-Pliocene. Studies conducted by Forno & Lucchesi (2005; 2016) in the Torino Hills indicate the presence of small remnants of terraces on the NW and N hillside. The terraces and the lithology of the alluvial sediments suggest that, in the period between the Middle Pleistocene and the present time, the drainage at the margin of the hills migrated towards N and NW.

Zone A1: corresponds to the eastern end of the Monferrato. Its drainage is similar to that of the Zone A, and the head of most basins reaches the divide between the northern and southern slopes of the hills, that is, the Po-Tanaro divide. The streams have a direction roughly transverse to the divide and flow directly into the Po and the Tanaro rivers.

Zone B: corresponds to most of the Monferrato Hills, except at its western and eastern ends. Starting from the western edge of Zone B, the Po-Tanaro divide heads southeast. Only the head of the valleys of three streams (Stura, Colobrio, Grana), pertaining to the Po basin, reaches the Po-Tanaro divide. At first, the streams run NW-SE or WNW-ESE, parallel to the divide, but at some point they abruptly change direction, flowing generally towards N and NE and reach the Po river. Other small streams lying at the northern slope of the hills flow directly into the Po river. In the Tanaro basin, several streams having catchments that reach the divide flow into the Versa, a tributary of the Tanaro, in the area where the stream runs NW-SE and therefore is parallel to the divide. On the Buried Monferrato, the streams are sub-parallel to each other.

Zone C: includes the hills between the town of Valenza and the Grana Valley. The head of the small catchment basins reaches the Po-Tanaro divide and the direction of the streams is generally transverse to that of the divide. In the hills the drainage pattern is similar to that of the A1 Zone, but on the Buried Monferrato the streams are sub-parallel to each other and do not drain directly into the Po but flow into other tributary streams of the Po. The streams of the southern slope of the hills drain directly into the Tanaro.

In Fig. 4B, it can be observed that the boundaries between the A, B, C and A1 zones correspond to or are located in the vicinity of some deformation zones: the Rio Freddo Deformation Zone between A and B, the Giarole-Lu Deformation Zone between B and C, and the Valenza Deformation Zone between C and A1. The A, A1, B and C zones correspond, roughly, to portions of the hills having different geological features.

The portion of the Monferrato Hills where the drainage is more complex (zones B and C) will be discussed and interpreted below.

5. THE DRAINAGE NETWORK IN THE MONFERRATO HILLS

The characteristics of the Monferrato drainage network have already been partially discussed in a number of papers. One of the major basins, that of the Stura stream, was studied by Biancotti & Franceschetti (1979). Also Dela Pierre et al. (2003b) discussed the characteristics of the drainage in part of the area covered by the present study, while in Giraudi (2015) some features of the drainage of the eastern Monferrato were taken into account. The studies made it possible to recognize some stream captures or diversions but only some of the variations that occurred in the Middle-Late Pleistocene have been chronologically framed (Carraro et al., 1980; Giraudi, 1981; Carraro & Valpreda, 1991; Carraro et al., 1995; Dela Pierre et al., 2003b; Giraudi, 2015; 2016).

5.1. Drainage network features

Most of the main streams in the Monferrato, north of the divide between the Po and the Tanaro, show a common trend (Fig. 5A): at the head of the valleys the streams flow NW-SE and NNW-ESE, then they turn toward NE or NNE. In the case of the Ponara stream, a tributary of the Rotaldo, at the head of the valley it flows from NNE to SSW, and then takes the same direction as the other streams.

A more detailed observation of the drainage network in the Monferrato Hills and the Buried Monferrato allows some areas with different features (Fig. 5B) to be identified.

Area 1: the heads of the main valleys are parallel to the divide between the Po and Tanaro catchments and their southern slopes correspond to the divide. In general, the prevailing direction of the streams is towards south-east and east. The tributary basins of the main valleys are mainly elongated in the directions from NW to SE and from N to S. The valleys of the main streams (Stura, Colobrio, Grana, Rotaldo) trending from NW and WNW to SE and ESE at the head, turn N and NE at the boundary of the area. Their basins are clearly asymmetric and the tributary basins facing the northern quadrants are much narrower than those facing the southern ones (Fig. 5A). The asymmetry of the slopes is very clear near the places where the change in direction of the streams occurs, that is in correspondence with elbows of capture of the upper Stura and Colobrio valleys reported in previous papers (Biancotti & Franceschetti, 1979; Dela Pierre et al.,2003b). The capture of the upper Stura valley, which originally drained towards the SW, was assumed by said Authors after the evaluation of morphological parameters, while that of the Colobrio is represented on a map without any discussion.

The capture of the valleys and the abrupt changes in direction occur in correspondence with faults trending mainly SW-NE, as reported in Dela Pierre et al (2003b).

Abrupt changes of direction occur also in the high Grana and Rotaldo valleys, in correspondence with SW-NE trending faults and of strong asymmetries of the valleys. The change of direction of the valleys, from NW-SE to SW-NE, takes place in an area formed by Pliocene sediments in the Alessandria basin. Those sediments reach elevations higher then the hills forming the divide between the Po and Tanaro rivers but lower than that of the hills lying to the north

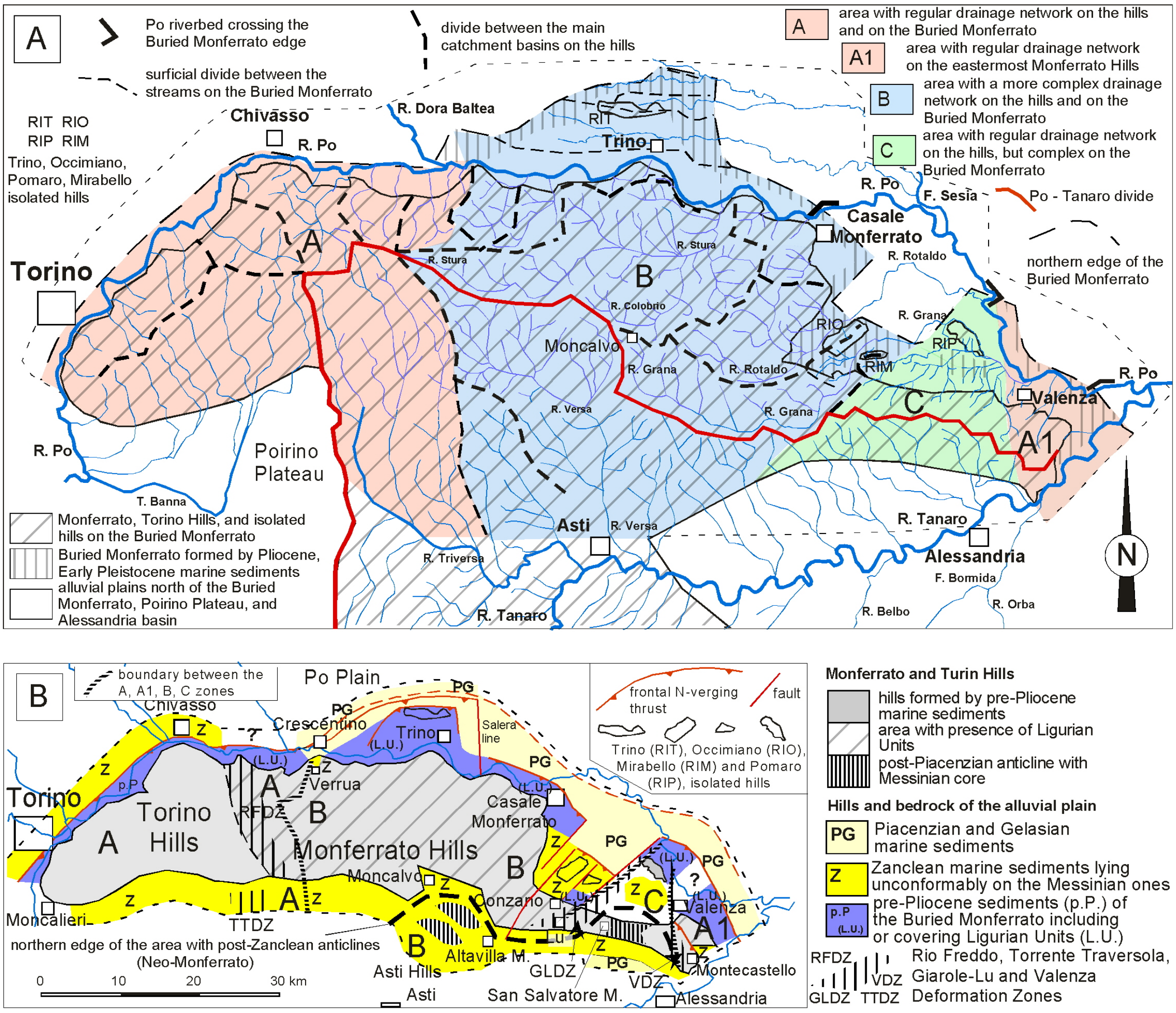

Fig. 4 - A: morphological outline of the Monferrato and Torino Hills and the Buried Monferrato drainage network, showing areas with different drainage patterns. B: geological outline of the main tectonic structures and sediments forming the Monferrato and Torino Hills and the Buried Monferrato.

(Fig, 3). Other sharp variations in the direction of the Stura and Grana valleys (Fig. 5A) are present in correspondence with stretches of valley having characteristics very similar to the elbows of capture evidenced in literature

Area (1): it is located south of the Po-Tanaro divide (Fig. 5B) and corresponds to the catchment of the Versa stream, mostly developed on Pliocene marine sediments, draining towards south or south-east, and was studied by Carraro & Valpreda (1991). In Area (1) the drainage is more complex than in the other catchments draining south (Fig. 4A, 5A): the Versa stream flows from NW to SE, running parallel to the divide, then turns eastwards, then southwards, and then, once again, flows from NW to SE. The heads of some smaller catchments in this area do not reach the divide between the Po and the Tanaro. All the other basins lying south of the divide have a drainage system similar to that of the A Zone (Fig. 4A): in fact the heads of all the basins begin at the divide between the northern and southern slopes of the hills, and the streams flow in directions transverse to the divide.

Area 2: this includes part of the Stura, Rotaldo and Grana catchments (Fig. 5B) where the main streams flow, in general, from SW to NE. The Stura stream direction of flow is more complex: it first flows from SW to NE, then W - E, and finally forms an elbow and starts heading NNE.

The main and secondary streams flow in many different directions (Fig. 5A;B).

The tributaries of the Stura stream drain both SE-SSE and NE-NNE, i.e. towards the axis of the lower Stura valley (Cerrina Valley). In this area, while the slopes of the main valley are quite symmetrical (Fig. 6A), the slopes of the small valleys of the secondary streams can be asymmetrical. The small valleys often have slopes facing west much more extensive than those facing east or vice versa. In Area 2, also the

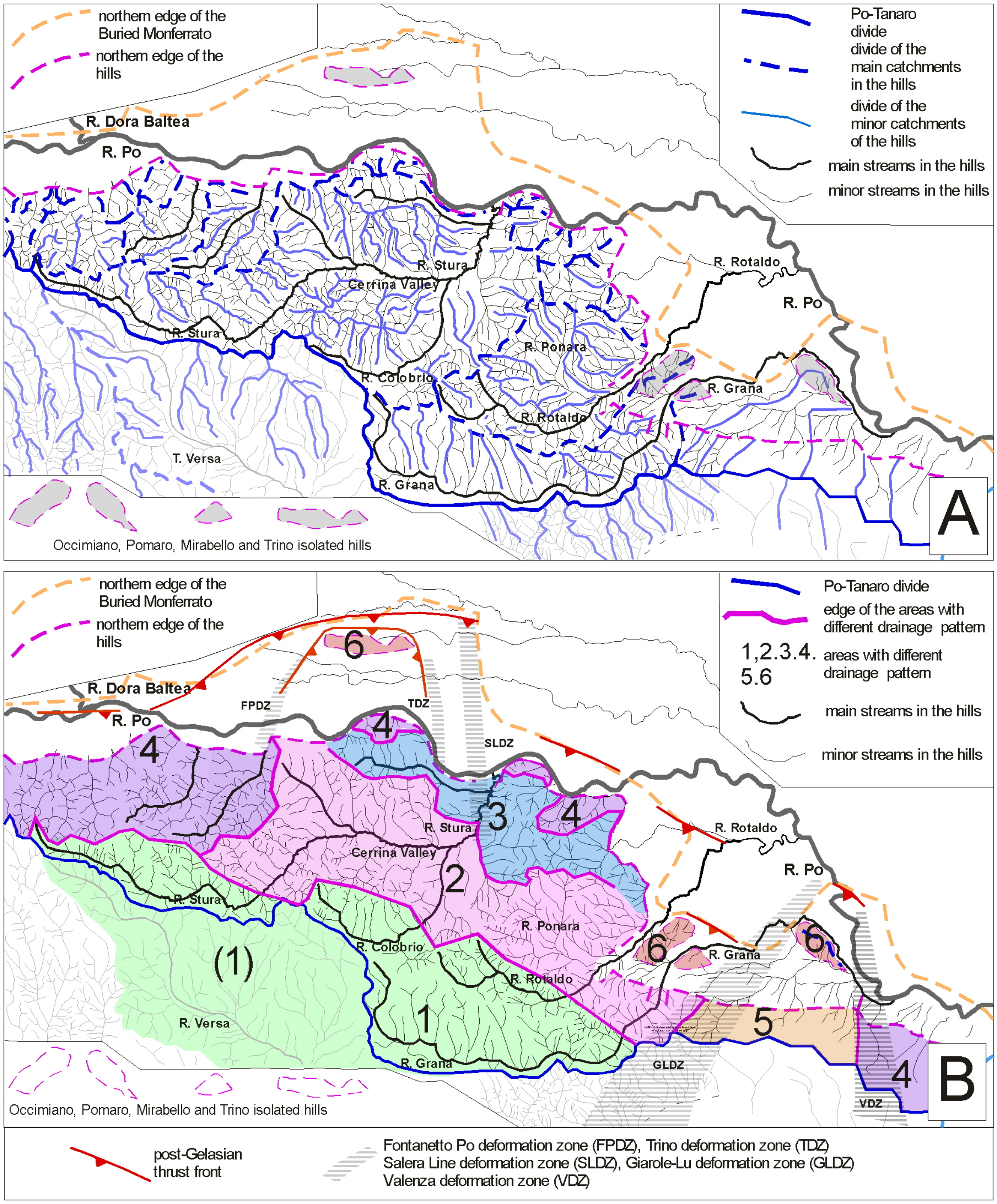

Fig. 5 - Drainage network and areas with a different drainage pattern in the Monferrato Hills and the Buried Monferrato. A: drainage network and catchment basins. B: areas with different drainage patterns.

Rotaldo and Grana streams flow from SW to NE (Fig. 5A). On the left side of the lower catchment of the Rotaldo stream, the direction of the tributary streams is from WNW to ESE. The tributaries of the Ponara stream flow mainly from WNW to ESE but some flow from WSW to ENE. In the south-eastern portion of

Area 2, the secondary streams flow mainly NW-SE and SE-NW into the Rotaldo and Grana streams. Both the mouth of the Rotaldo valley and the catchments of some secondary streams are very asymmetric (Fig. 6A), with slopes facing the western quadrants much less extensive than those facing east. In a few cases the slopes facing the southern quadrants are much narrower than those facing north. A divide separates the major catchments forming Area 2: the basin of the Stura (to the west) and the portion of the Rotaldo basin west of the stream (to the east). However, until the Middle Pleistocene, the Stura basin and a portion of the Rotaldo basin were part of a single catchment crossed by a river from its north-western edge to the south-eastern one (ENEL, 1984; Carraro et al., 1995; Dela Pierre et al., 2003b; Giraudi, 2015; 2016).

Area 3: here the Stura flows from SSW to NNE, but the main streams of this area run approximately W-E and E-W and their tributaries flow from NW, N, S, SW, and SE (Fig. 5B). Fig. 6A shows that the valley slopes are usually asymmetrical and that generally the sides facing north are narrower than those facing south. In only two cases are the slopes facing east much more extensive than those facing west (Fig. 6A). In the final stretch of the Cerrina Valley, where the Stura runs SSW-NNE, this kind of asymmetry is in correspondence with a northward elbow of capture of a river, mentioned above, which until the Middle Pleistocene drained SE towards the Rotaldo valley, as evidenced before.

Area 4: here the streams drain mainly towards N, NNE and NE and flow directly into the river Po. Only in the eastern area are there any asymmetries in the valleys (Fig. 6A), with slopes facing the eastern quadrants far larger than the opposite ones.

Also in this area, in two cases out of three, the asymmetry is in correspondence with the elbow of capture of a stream flowing towards NNE but draining originally towards ESE (Carraro et al., 1995; Dela Pierre et al., 2003b; Giraudi, 2015; 2016).

- **Area 5:** the streams here flow into small valleys in a NNE direction, but when they reach the plain, they do not flow directly into the river Po, but into a series of secondary streams, tributaries of the river. In this area there are asymmetries in the basins (Fig. 6A): the slopes facing south are far less extensive than the opposite ones.

Area 6: isolated hills with radial drainage that cannot be represented at the scale of the figures.

6. DISCUSSION

The hypotheses of captures and changes in the drainage network reported in previous papers were based in one case (Cerrina Valley) on the lithological composition of the alluvial sediments, and in the other cases (Stura and Colobrio valleys) on morphological features, mainly the presence of elbows of capture.

The presence of a different drainage in the lower Cerrina Valley is indicated by the presence of a significant amount of Early and Middle Pleistocene alluvial sediments (Fig. 2), formed by clasts of Alpine origin. These sediments demonstrate the presence of a river flowing from the area sited NW of the valley head (Giraudi, 1981; Carraro et al., 1995; Giraudi et al., 2003; Dela Pierre et al., 2003a,b; Giraudi, 2016). The river continued SE of the Cerrina Valley (Fig. 6A) reaching the Eastern Monferrato Hills and probably the Buried Monferrato north of the hills, as suggested by the lithology of some patches of alluvial sediment found in terraces and in boreholes (ENEL, 1984; Carraro et al.,1995; Giraudi, 2015; 2016). The old drainage network, mainly elongated in a NW-SE direction, and running in drainage Area 2, was strongly modified around 600 ka ago.

The capture of the upper Stura and Colobrio valleys which, according to Biancotti and Franceschetti (1976) and Dela Pierre et al (2003b), in origin drained towards SW, was assumed from the presence of an elbow of capture. Before capture, the divide between the catchments flowing towards the Savigliano-Alessandia and Po basins was near the northern divide of the upper Stura and Colobrio valleys (Fig. 6A). The presence of Pliocene sediments in a small portion of the catchment testifies that part of the head of the present Colobrio valley was covered by the Pliocene Sea in the Alessandria basin. After emersion, as a consequence of the Zanclean regression, the Colobrio excavated its bed in the newly emerged marine sediments in a SE direction. Later, the stream was captured towards the NE.

In the same figure, it can be observed that in correspondence with the elbows of capture of the Cerrina, Stura and Colobrio valleys there is pronounced asymmetry of the slopes and therefore also the asymmetry could be linked to the morphological evolution that contributed to or followed the captures.

The captures and the abrupt change in direction occur in correspondence with faults (Fig. 6A) trending mainly SW-NE reported in Dela Pierre et al (2003b).

Abrupt changes of direction occur also in the high Grana and Rotaldo valleys, in correspondence with SW-NE trending faults and of strong asymmetries of the valleys (Fig. 6A; B). Having the same geological and morphological characteristics as the Stura and Colobrio valley elbows of capture, it can be assumed therefore that also the Rotaldo and Grana valley elbows were due to captures (Fig. 6A; B).

The elbows of capture of the Grana and Rotaldo valleys occur in an area formed also by Pliocene sediments of the Alessandria basin that reach elevations higher than the hills forming the divide between the Po and Tanaro rivers but lower than that of the hills lying just north (Fig. 3). It follows that, before the capture and until a period following the post-Zanclean regression, the Rotaldo and Grana streams flowed towards the Alessandria basin and the divide was roughly in correspondence with the hills forming the northern divide of the head of the Rotaldo valley.

It can be observed also that the Stura, Colobrio, Grana and Rotaldo streams show the same trend, both in areas 1 and 2, and therefore a common evolution can be assumed.

The former divide between the basins draining

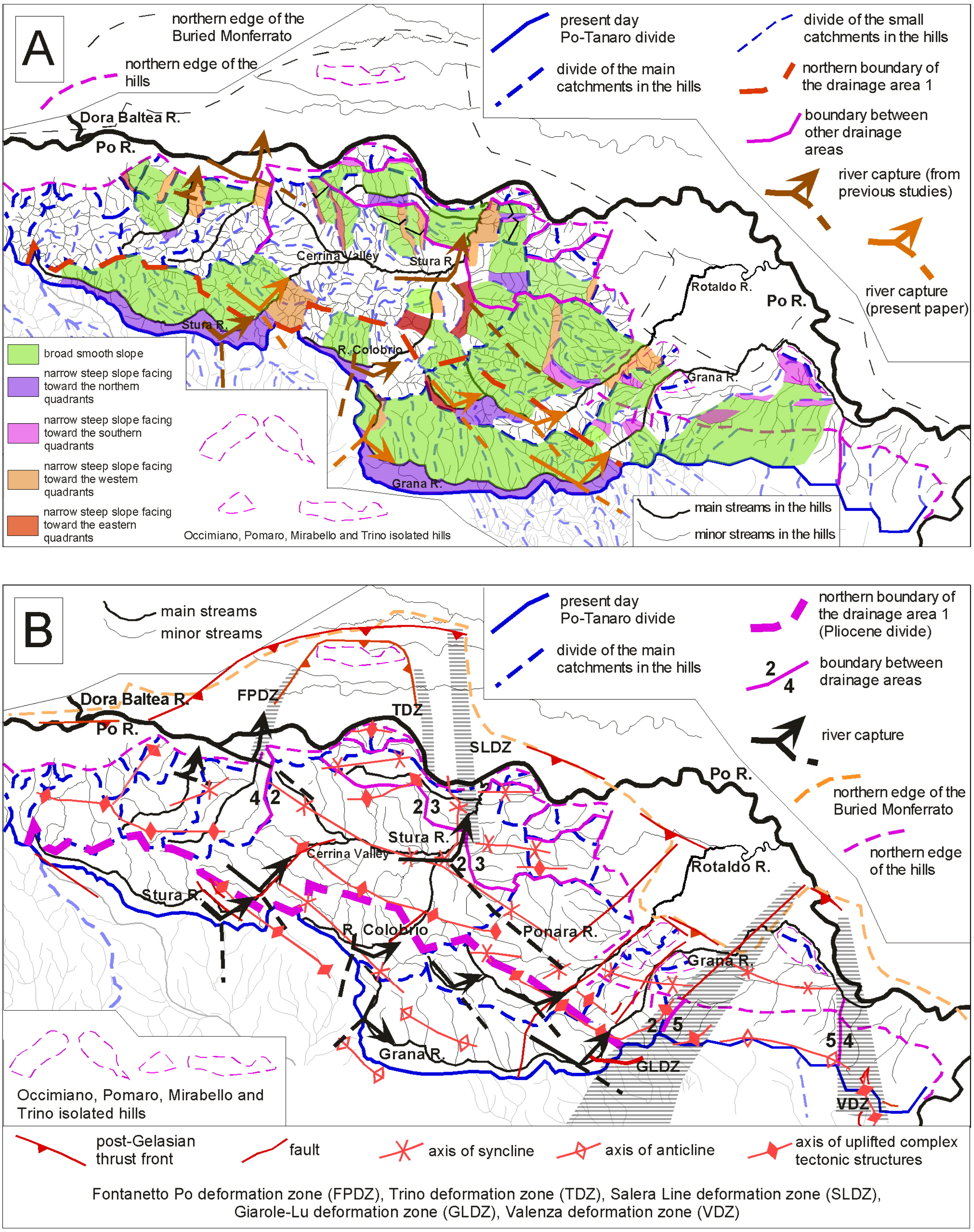

Fig. 6 - Asymmetry of the valleys and elbows of capture (6A) and relations between the drainage network and major tectonic features (6B).

towards the Alessandria and the Po basins was near the boundary between areas 1 and 2.

Other sharp variations in the direction of the Stura and Grana valleys (Fig. 6A) are present in correspondence with stretches of valley having characteristics very similar to the elbows of capture evidenced in literature and discussed before. It is likely that said elbows were produced by other captures.

6.1. Structural and lithological forcing in the drainage network

In Fig. 4B, it can be observed that both in the Monferrato and Torino Hills the boundaries between zones A, B, C and A1 correspond to or are located in the vicinity of some deformation zones: the Rio Freddo Deformation Zone between A and B, the Giarole-Lu Deformation Zone between B and C, and the Valenza Deformation Zone between C and A1.

Tectonics probably played a role in determining the drainage evolution in the Monferrato Hills as observed by previous Authors (Biancotti & Franceschetti, 1979; Carraro et al., 1980; Giraudi, 1981; Carraro & Valpreda, 1991; Carraro et al., 1995; Dela Pierre et al., 2003b; Forno & Lucchesi, 2005; Vezzoli et al., 2010; Giraudi, 2015; Forno & Lucchesi, 2016).

The comparison between the morphology of the valleys, the position of the elbows of capture and the tectonic structures (Fig. 6B) suggests the following considerations:

- the widest valleys correspond to synclines active also during the Late Miocene and sometimes during the Pleistocene;
- the highest ridges are located in the western hills and in general coincide with the presence of coarse cemented sediments involved in complex uplifted structures active before the Pliocene;
- changes in direction of the valleys and elbows of capture towards the north mostly occur in correspondence with faults trending SW-NE and deformation zones (FPDZ; SLDZ; GLDZ; VDZ) trending SW-NE, WSW-ENE, and N-S, active also during and after the Pliocene.

The tectonic structures and the lithology also affect the boundaries between the areas in which the drainage network shows different characteristics:

- the boundary between Areas 1 and 2 mostly coincides with ridges formed by strongly cemented sediments present in complex uplifted structures;
- the boundary between Areas 2 and 3 corresponds to the transition between hills with pre-Pliocene tectonic structures trending from NW to SE and hills where W-E trending structures prevail;
- the boundary between Areas 2 and 4 lies in the southern extension of the Fontanetto Po Deformation Zone active also during the Pleistocene;
- part of the boundary between Areas 2 and 3 lies in the southern extension of the Trino and Salera Line Deformation Zones, active also during the Pleistocene;
- the boundary between Areas 2 and 5 coincides with the Giarole-Lu Deformation Zone active until the Pleistocene;
- the boundary between Areas 5 and 4 is in correspondence with the Valenza Deformation Zone active also during the Pleistocene.

Comparing between the maximum heights of the hills and the elevation reached by the Zanclean sediments of littoral facies, next to the divide between the Po and the Tanaro basins (Fig. 3), the difference that can be seen is of about 100 m in both the Western Monferrato (400-440 m and 330 m respectively) and the Eastern Monferrato (250-260 m and 160 m). It may be concluded that most of the differences in the maximum heights of the hills were due to a differential uplift that occurred after the Zanclean, and that the western portion of the study area underwent a greater uplift, estimated at about 150-170 m.

The structural and lithological influence on the drainage network seems therefore real. However in the core of the Monferrato Hills, the directions of the streams, not affected by SW-NE trending faults, follow the trend of the main tectonic structures active before the Pliocene. It can be hypothesized that, when the core of the Monferrato emerged from the sea, the initial NW-SE and WNW-ESE orientation of the streams was conditioned by the different strike, dip and erodibility of the already deformed pre-Pliocene sediments, and therefore the influence of the older tectonic structures was mostly passive.

The flow towards SE or ESE of the streams was also affected by the stronger post-Zanclean uplift of the western Monferrato Hills.

7. THE PLIOCENE DRAINAGE NETWORK AND ITS EVOLUTION

The pre-Zanclean emersion of the Monferrato core formed mainly by Tertiary marine sediments, already strongly deformed, and the clear structural forcing on the drainage network, allow speculation about the original drainage.

Fig. 7A shows the possible drainage network on the just emerged lands, before the capture to the north of the main streams. The drainage must have been conditioned by the pre-Pliocene tectonic structures and by lithology, with the valley bottoms in correspondence with synclines or formations consisting of softer sediments easy to erode, and the top of the ridges and the main divides lying on strongly cemented sediments forming the uplifted structures. The boundary between Areas 1 and 2, lying near the elbows of capture of the main streams and in correspondence with the highest hills formed by strongly cemented uplifted sediments, was probably the divide between the Zanclean catchment basins draining towards the Saluzzo-Alessandria and the Po marine basins.

This hypothesis is corroborated by the presence of Zanclean sediments of the southern basin north of the present-day Po-Tanaro divide.

It can be observed that the head of the Grana valley, cut into Zanclean marine sediments (Fig. 2), was still below the sea during the early Pliocene and emerged only during the post-Zanclean regression (Fig. 7A). During the regression, the Colobrio, Grana and

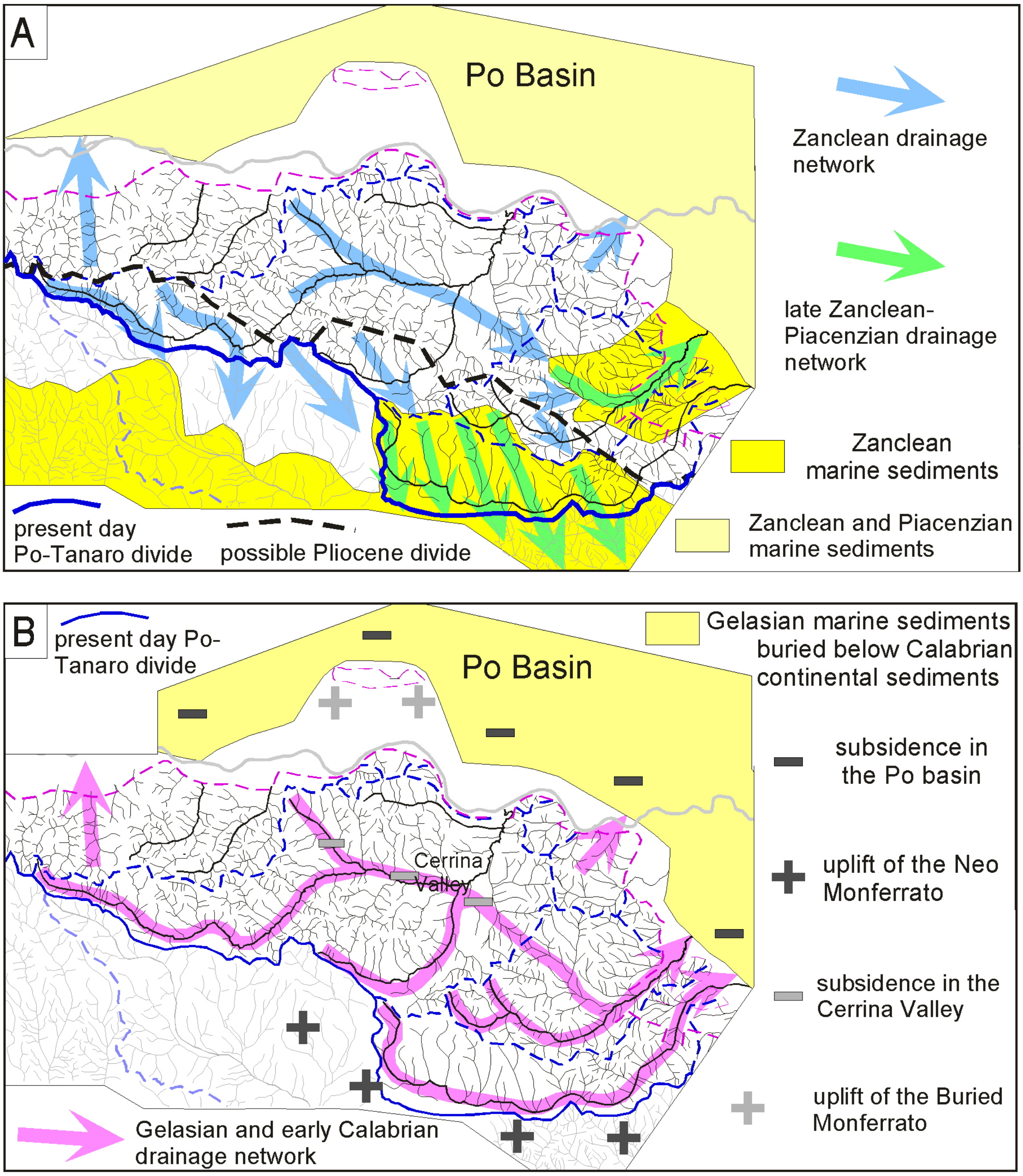

Fig. 7 - The Pliocene and Gelasian drainage evolution (A) and uplifted and subsiding areas (B).

Rotaldo streams, already existing during the Pliocene, excavated their beds in the newly emerged marine sediments.

South of the hills the streams drained mainly NNW -SSE, that is towards the Saluzzo-Alessandria basin while east of the hills they drained to the east and NE into the Po basin.

The capture of the high Colobrio, Grana and Rotaldo valleys was probably due to the withdrawal of the heads of streams draining towards the northern basin, in correspondence with faults cutting through the uplifted structures forming the earlier divide. The headward erosion of the stream flowing to the north and the capture of streams flowing towards the south can be explained considering the known geological evolution of the Monferrato.

The flow of the streams towards the southern basin may have been hindered by the uplift of the Neo-

Monferrato with respect to the northern hillslope. This interpretation is supported by the comparison between the elevation of the Pliocene sediments of the southern and northern basins (Fig. 3). According to the Geological Map of Italy at the scale 1: 100,000, Sheets 57, 58, 69, 70 (Anfossi et al., 1969; Boni & Casnedi, 1969; Bonsignore et al., 1969; Braga & Ragni, 1969; Corsi et al., 1969; Montrasio et al., 1969), the Pliocene sediments of the southern basin reach elevations between 290 and 250 m a.s.l. between the Colobrio and Grana valleys, while those of the northern basin lie between 205 and 150 m a.s.l. In the same period, the headward erosion of the streams flowing northwards was increased by the lowering of the base level due to the subsidence of the northern basin which, until the Gelasian, was still covered by the sea (ENEL, 1977; 1984; Pieri & Groppi, 1981; Cassano et al., 1986; Violanti & Sassone, 2008; Giraudi, 2014; 2016). The subsidence lasted at least until the Middle Pleistocene (Giraudi, 2015; 2016).

The uplift of the Neo-Monferrato and the subsidence of the northern basin could have favoured also the headward erosion of the streams and the capture of the high Stura valley. However, also the subsidence of the Cerrina valley, which acted as a local base level of the Stura and Colobrio streams, could have played an important role.

The subsidence of the Cerrina valley (Giraudi, 2016) started before the sub-chron Olduvai (age 1.9-1.7 MA). During the Olduvai, the sedimentation started as lacustrine silty clay, followed, during the Jaramillo subchron and the early Matujama chron, by the sedimentation of alluvial deposits consisting mainly of clasts of Alpine origin. It can be ruled out that the headward erosion and lake sedimentation were coeval. In fact it is supposed that during the phases of headward erosion the streams had to carry downstream many clasts consisting of marine sediments outcropping in their catchments. But the lacustrine sediments have an extremely fine grain size and no coarse alluvial sediments of local origin, interfingered with lacustrine sediments, have been observed. The alluvial deposits (dated from about 1 to 0.7 MA), contain few clasts of local origin, and it is unlikely that they were contemporary with the phases of headward erosion of the streams. A younger age of the captures is ruled out by the stratigraphy, lithology and grain size of the later alluvial sediments and by the morphological features.

We can assume, therefore, that the erosion phase, to which the capture of the heads of the Stura and Colobrio valleys was connected, was mostly completed during the Gelasian, before the Olduvai sub-chron.

To sum up, the headward erosion that led to the capture of the valleys draining towards the southern basin during the Zanclean and the following regression started with the Piacenzian uplift of the Neo-Monferrato and ended, probably, before the Olduvai sub-chron.

Although some important captures and diversions occurred later, during the Middle and late Pleistocene (Giraudi, 1983; Carraro et al., 1995; Dela Pierre et al., 2003; Giraudi, 2015; 2016), the Middle Pliocene-Early Pleistocene captures shaped the most evident anomalies in the Monferrato drainage network.

8. CONCLUSIONS

During the Pliocene, a portion of the Monferrato emerged as an island on which a drainage network developed.

Analysis of the morphological and stratigraphic data has made it possible to reach a comprehensive interpretation of the drainage evolution in the Monferrato from the Pliocene to the Early Pleistocene.

The heads of the basins of the Stura, Colobrio, Rotaldo and Grana streams drained southwards, towards the Savigliano and Alessandria synclines. The flow towards the south of those streams, that followed the post-Zanclean regression, was hindered by the Piacenzian uplift of the Neo-Monferrato, south of the core of the hills.

The headward erosion of the streams draining towards the Po basin, that produced the capture of the heads of said streams, possibly started during the Zanclean regression and was strengthened by the subsidence of the northern basin, occupied by the sea until the Gelasian. The headward erosion was favoured also by the presence of tectonic structures (faults and deformation zones) cutting into the Pliocene divide.

According to the stratigraphic data, it can be assumed that the capture of the high valleys of the Stura, Colobrio, Rotaldo and Grana streams occurred between the Piacenzian and before the Early Pleistocene Olduvai chron.

The correlation between the development of the hydrographic network and tectonic structures, assumed by previous Authors, is confirmed and even strengthened by the relations between the drainage and the tectonic structures recognized in more recent investigations.

Tectonic structures played different roles. The gentle post-Zanclean anticlines that form the Neo-Monferrato, the Pleistocene subsidence of the northern basin and the deformation zones transverse to the Monferrato front, played a dynamic role in the evolution of the drainage network.

Conversely, the complex uplifted structures that form the core of the Monferrato Hills, active mainly before the Pliocene, influenced, generally passively, the drainage network when the Monferrato emerged from the sea, the initial direction of the streams being conditioned by the different strike, dip and erodibility of the pre-Pliocene sediments.

REFERENCES

Anfossi G., Bruno G.M., Casnedi R., Mosna S., Motta E., Perotto G., Zezza F. (1969) - Foglio 70, Alessandria, della Carta Geologica d'Italia alla scala 1:100,000. II Ed., Servizio Geologico d'Italia, Roma.

ARPA Piemonte (2014) - Banca dati geotecnica. Available at: http://webgis.arpa.piemonte.it/flxview/GeoViewerRiskNat/index.aspx

Biancotti A., Franceschetti B. (1979) - Analisi dell'ambiente fisico del bacino del Torrente Stura del Monferrato. In: Studi dell'IRES sui piani di si-

stemazione idrogeologica. Parte prima: La Stura del Monferrato. Editrice Nova, Torino: 51-101.
Bigi G., Cosentino D., Parotto M., Sartori R., Scandone P. (1990) - Structural Model of Italy, Consiglio Nazionale delle Ricerche (CNR), Progetto Finalizzato Geodinamica, Quaderni de "La Ricerca Scientifica", 114 (3), 1:500.000 scale, Firenze, SELCA.
Boni A., Casnedi R. (1969) - Note illustrative della Carta Geologica d'Italia alla scala 1:100.000, Fogli 69 e 70, Asti-Alessandria. Servizio Geologico d'Italia, Roma.
Bonsignore G., Bortolami G.C., Elter G., Montrasio A., Petrucci F., Ragni U., Sacchi R., Sturani C., Zanella E. (1969) - Note illustrative della Carta Geologica d'Italia, Fogli 56 e 57 (Torino e Vercelli). Servizio Geologico d'Italia, Roma.
Bortolami G., Crema G.C., Malaroda R., Petrucci F., Sacchi R., Sturani C., Tagliavini S., Venzo S. (1969) - F. 56 "Torino" della Carta Geologica d'Italia alla scala 1:100.000. Seconda Edizione. Servizio Geologico d'Italia, Roma.
Bove Forgiot L., Trenkwalder S., Violanti D. (2005) - Le associazioni plioceniche a foraminiferi ed ostracodi di Verrua Savoia (Piemonte, Italia NW): analisi biostratigrafia e paleo ambientale. Rendiconti della Società Paleontologica Italiana, 2, 9-27.
Braga G.P., Ragni U. (1969) - Note illustrative della Carta Geologica d'Italia alla scala 1:100.000 Fogli 44 e 58, Novara e Mortara. Servizio Geologico d'Italia, 56 pp.
Carraro F. (1996) - Revisione del Villafranchiano nell'area-tipo di Villafranca d'Asti. Il Quaternario, 9 (1), 5-120.
Carraro F., Forno M.G., Ricci B. (1980) - Ricostruzione preliminare dell'evoluzione plio-pleistocenica dell'area corrispondente ai rilievi delle Langhe, del Monferrato e della Collina di Torino. Contributi alla realizzazione della Carta Neotettonica d'Italia. CNR - Progetto Finalizzato Geodinamica- Sottoprogetto "Neotettonica". Pubblicazione n. 356, 315 -330.
Carraro F., Valpreda E. (1991) - The Middle-Upper Quaternary of the Asti Basin. Il Quaternario, 4: 151-172, Roma.
Carraro F., Collo G., Forno M.G., Giardino M., Maraga F., Perotto A., Tropeano D. (1995) - L'evoluzione del reticolato idrografico del Piemonte Centrale in relazione alla mobilità quaternaria In: Polino R. & Sacchi R. (Eds.), Atti del Convegno: Rapporti Alpi-Appennino. Acc. Naz. Sci. Sc. Doc, 14, 445-461.
Carraro F. (2012) - Geologia del Quaternario. L'evoluzione geologica degli ambienti superficiali. 393 pp. D. Flaccovio Editore, Palermo, Italy.
Casnedi R. (1975) - Segnalazione di una successione stratigrafica compresa tra il Langhiano e il Pliocene Inferiore a NW di Valenza (Monferrato Orientale). Rendiconti Scientifici Istituto Lombardo, A 109, 178-184.
Corsi M., Gatto G.O., Gatto P. (1969) - Foglio 58, Mortara, della Carta Geologica d'Italia alla scala 1:100,000. II Ed., Servizio Geologico d'Italia, Roma.
Cassano E., Anelli L., Fichera R., Cappelli V. (1986) - Pianura Padana: interpretazione integrata di dati geofisici e geologici. 73° Congresso della Società Geologica Italiana. 1-27.
Costa M. (2003) - The buried Apenninic arcs of the Po Plain and Northern Adriatic Sea (Italy): a new model. Boll. Soc. Geol. It., 122, 3-23.
Dela Pierre F., Michailov V., Polino R. (1995) - The tectonosedimentary evolution of the tertiary basins in the Western Po Plain: kinematics inferred from subsidence curves. In: Polino R. & Sacchi R. (Eds.), Atti del Convegno: Rapporti Alpi-Appennino. Acc. Naz.Sci.Sc.Doc, 14, 129-146.
Dela Pierre F., Piana F., Boano P., Fioraso G., Forno M.G., Polino R. Clari P. (2003a) - Carta Geologica d'Italia alla scala 1:50.000, Foglio 157 "Trino", APAT, Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici - Dipartimento Difesa del Suolo, Roma.
Dela Pierre F., Piana F., Fioraso G., Boano P., Bicchi E., Forno M.G., Violanti D., Balestro G., Clari P., d'Atri A., De Luca D., Morelli M., Ruffini R. (2003b) - Note Illustrative della Carta Geologica d'Italia alla scala 1:50,000, Foglio 157 Trino. APAT, Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici- Dipartimento Difesa del Suolo, Roma, 147 pp.
Devoti R., Esposito A., Pietrantonio G., Pisani A.R., Riguzzi F. (2011) -Evidence of large scale deformation patterns from GPS data in the Italian subduction boundary. Earth and Planetary Science Letters, 311, 230-241.
ENEL (1984a) - Rapporto per la localizzazione di una Centrale Elettronucleare nella Regione Piemonte. Area Po 1. ENEL Direzione delle Costruzioni, Roma. XIX volumes, unpublished.
ENEL (1984b) - Rapporto per la localizzazione di una Centrale Elettronucleare nella Regione Piemonte. Area Po 2. ENEL Direzione delle Costruzioni, Roma. XIX volumes, unpublished.
Festa A., Boano P., Irace A., Lucchesi S., Forno M.G., Dela Pierre F., Fioraso G., Piana F. (2009b) - Note Illustrative della Carta Geologica d'Italia alla scala 1:50,000, Foglio 156 Torino Est. APAT, Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici- Dipartimento Difesa del Suolo, Roma, 143 pp.
Forno M.G., Lucchesi S. (2005) - La successione fluviale terrazzata pleistocenica dei versanti occidentale e nordoccidentale della Collina di Torino. Il Quaternario, 18 (2), 123-134.
Forno M.G., Lucchesi S. (2016) - Relicts of the Pleistocene Po Plain on the Western and Southern slope of Turin Hill (NW Italy). Journal of Maps, 12 (2), 394-306.
Galadini F., Falcucci E., Galli P., Giaccio B., Gori S., Messina P., Moro M., Saroli M., Scardia G., Sposato A. (2012) - Time intervals to assess active and capable faults for engineering practices in Italy. Engineering Geology, 139-140, 50-65.
Gattiglio M., Forno M.G., Comina C., Doglione A., Violanti D., Barbero D. (2015) - The involving of the Plio-Pleistocene succession in the T. Traver-

sola Deformation Zone (NW Italy). Alpine and Mediterranean Quaternary, 18(1).

Gibbard P. L., Head M. J., Walker M. J. C. and the Subcommission on Quaternary Stratigraphy (2010) - Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma. Journal of Quaternary Science, 25, 96-102.

Giraudi C. (1981) - Presenza di depositi medio-pleistocenici intensamente deformati in Val Cerrina (Monferrato Settentrionale). Geogr. Fis. Din. Quat., 4, 69-74.

Giraudi C., Mottura A., Sala B., Siori M.S., Bormioli D. (2003) - The Castagnone Site (Cerrina Valley, Monferrato Hills, NW Italy): Early Pleistocene sedimentary record and biochronology. Rivista Italiana di Paleontologia e Stratigrafia,109 (3), 517-526.

Giraudi C. (2014) - Quaternary studies as a tool to validate seismic hazard potential of tectonic structures: the case of the Monferrato thrust front (Vercelli Plain, NW Italy). Alpine and Mediterranean Quaternary, 27(1),5-28.

Giraudi C. (2015a) - Quaternary evolution of the plain between Casale Monferrato and Valenza: implications for the tectonics of the Monferrato thrust front (Piedmont, NW Italy). Alpine and Mediterranean Quaternary, 28 (1), 71-92.

Giraudi C. (2016) - The evolution of the northernmost Apennine front (Piedmont, Italy): Plio-Pleistocene sedimentation and deformation in the Po basin and Monferrato hills. Alpine and Mediterranean Quaternary, 29(1), 45-65.

GSQP- Gruppo di Studio del Quaternario Padano (1976). Studio interdisciplinare del "Rilievo Isolato" di Trino (Bassa Pianura Vercellese, Piemonte), Quaderno n.3, Litografia Massaza e Sinchetto, Torino.

Irace A., Clemente P., Natalicchio M., Ossella L., Trenkwalder S., De Luca D.A., Mosca P., Piana F., Polino R., Violanti D. (2009) - Geologia e idrostratigrafia profonda della Pianura Padana Occidentale. 110 pp, 61 allegati. La Nuova Lito, Firenze.

Livio F., Ferrario M.F., Frigerio C., Michetti A.M. Zerboni A., Bonadeo L., Fioraso G., Irace A., Brunamonte F. (2015) - Late pleistocene reverse surface faulting at the Pecetto di Valenza site (AL- Northern Italy): preliminary results. Conference of the GNGTS, sessione 1.1, 45-50.

Martinis B. (1954) - Ricerche stratigrafiche e paleontologiche sul Pliocene piemontese. Rivista Italiana di Paleontologia e Stratigrafia, 60, 45-114 and 125-194.

Michetti A. M., Giardina F., Livio F., Mueller K., Serva L., Sileo G., Vittori E., Devoti R., Riguzzi F., Carcano C., Rogledi S., Bonadeo L., Brunamonte F., Fioraso G. (2012) - Active compressional tectonics, Quaternary capable faults, and the seismic landscape of the Po Plain (northern Italy). Annals of Geophysics, 55, 5, 969-1001.

Montrasio A., Ragni U., Bonsignore G., Borgo A., Zanella E., Crema G., Medioli F., Petrucci F. (1969) - Foglio 57, Vercelli, della Carta Geologica d'Italia alla scala 1:100,000. II Ed., Servizio Geologico d'Italia, Roma.

Mosca P., Polino R., Rogledi S., Rossi M. (2010) - New data for the kinematic interpretation of the Alps-Apennines junction (Northwestern Italy. International Journal of Earth Sciences, 99 (4), 833-849.

Piana F., Polino R. (1994) - La zona transpressiva di Rio Freddo e l'evoluzione convergente del Monferrato e della Collina di Torino. Atti Ticinesi di Scienze della Terra, serie speciale, 1, 167-180.

Piana F., Polino R. (1995) - Tertiary structural relationships between Alps and Apennines - The critical Torino Hill and Monferrato area, Northwestern Italy. Terra Nova, 7 (2), 138-143.

Pieri M., Groppi G. (1981) - Subsurface geological structure of the Po Plain, Italy. Quad. CNR. Prog. Fin. Geodinamica, Roma, 1-13.

Sacco F. (1889) - Il bacino Terziario e Quaternario del Piemonte. Atti Società Italiana di Scienze Naturali, 31-32, 135-281, 289-398, 331-390.

Siori M.S., Sala B. (2007) - The mammal fauna from the late Early Biharian sito of Castagnone (Northern Monferrato, Piedmont, NW Italy). Geobios, 40, 207 -217.

Trenkwalder S., Violanti D. (2001) - Il Pliocene di Verrua Savoia (Piemonte, Italia Settentrionale):sintesi dei nuovi dati biostratigrafici e Paleoambientali. Giornale di Geologia, 62 supplemento, 77-82.

Vezzoli G., Forno M.G., Ando S., et al. (2010) - Tracing the drainage change in the Po basin from provenance of Quaternary sediments (Collina di Torino, Italy). Quaternary International, 222 (1-2), 64-71.

Violanti D., Sassone P. (2008) - Il Pliocene del sottosuolo di Casale Monferrato (Piemonte, Italia Nord-Occidentale): dati preliminari. Atti Museo Civico di Storia Naturale Trieste, 53 (supplemento), 233-264.

Zappi L. (1961) - Il Pliocene di Castel Verrua. Atti Società Italiana di Scienze Naturali, Museo Civico di Storia Naturale Milano, 100, 73-204.

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