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SYNTHESIS ON THE TURIN SUBSOIL STRATIGRAPHY AND HYDROGEOLOGY (NW ITALY)

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ABSTRACT**:** This work is a multidisciplinary synthesis of geological and hydrogeological researches on the subsoil of Turin and suburbs, summarizing the existing previous studies and also using new data specially collected, aimed at bringing together the different aspects of the subsoil in a single contribution.
The stratigraphic setting of the Turin Plain, as examined through numerous boreholes (wells, piezometers and geognostic drillings) shows an erosional surface essentially shaped on the fine Villafranchian succession and locally on the Pliocene and pre-Pliocene sediments, on which the Quaternary gravelly outwash and fluvial cover rests. This cover, which is mainly fed by the Dora Riparia River, is relatively thin (thickness between 5 and 57 m) and highly variable in terms of facies and cementation degreee. The most recent excavation activities are also taken into consideration, which locally allowed the direct observation of the shallow subsoil stratigraphy.
The geological literature reports that the setting of Turin subsoil is strictly conditioned by the Quaternary uplift of Turin Hill. The structural causes of this geological evolution and its relationship with seismicity are here summarized.
The stratigraphy of Turin subsoil is also connected to the recent deviation of the Po River, which flowed south of Turin Hill (through the southern slope of Turin Hill and the Poirino Plateau) during the Middle-Upper Pleistocene and only recently develops at the NW foot of Turin Hill. A new reading of this Po deviation as an overflow is made, based both on a re-examination of all the existing data and new collected data.
The hydrogeological features of the Turin subsoil are also reported, characterized by two superimposed main groundwater flow circuits, as well as the thermal regime of shallow groundwater and its geothermal potential. This work can help professional geologists for conducting geological, hydrogeological and geotechnical appraisals on Turin and suburbs. It can also be useful to researchers to reconstruct the geological and hydrogeological features of the Turin territory.

Keywords: subsoil stratigraphy, hydrogeology, fluvial deviation, Turin, Po Plain

1. INTRODUCTION

This paper is a multidisciplinary synthesis of the researches on the subsoil of Turin and suburbs, reporting both the numerous existing previous works on the stratigraphy and hydrogeology and new data specially collected, aimed at bringing together the different characteristics of the subsoil in a single contribution.

In detail, this work includes the revision of the recent geological studies and maps through the observation of some deep excavations for the construction of the subway (Line 1 of the Metro), the underground railway pass and the Intesa Sanpaolo skyscraper, and of new boreholes and outcrops.

The tectonic drivers of the recent geological evolution and its relationship with seismicity, strictly conditioned by the recent uplift of Turin Hill, are also reported. Moreover the relationship of the stratigraphy of Turin subsoil with the deviation of the Po River, which flowed south of Turin Hill (through the southern slope of Turin Hill and the Poirino Plateau) during the Middle-Upper Pleistocene and only recently develops at the NW foot of Turin Hill, is discussed. A new reading of this Po deviation as an overflow is made, based both on a re-examination of all the existing geological data and the use of borehole data (wells, piezometers and geognostic drillings) located along the Po River bed and into the Poirino Plateau.

A revision of the existing data on the hydrogeological setting is at last reported, as well as the thermal regime of shallow groundwater and its geothermic potential. This work can help professional geologists for their geological, hydrogeological and geotechnical appraisals. It can also be useful to researchers to reconstruct the geological and hydrogeological features of the Turin territory.

2. MORPHOLOGICAL SETTING

Turin and suburbs lie in the western sector of the Po Plain that here corresponds to a narrow band between the Western Alps and the Turin Hill. The city is built on the plain at the foot of the hill, where the Po River flows (Fig. 1). The suburbs display an asymmetric setting, west of the historical city.

The morphology of Turin reflects its geological

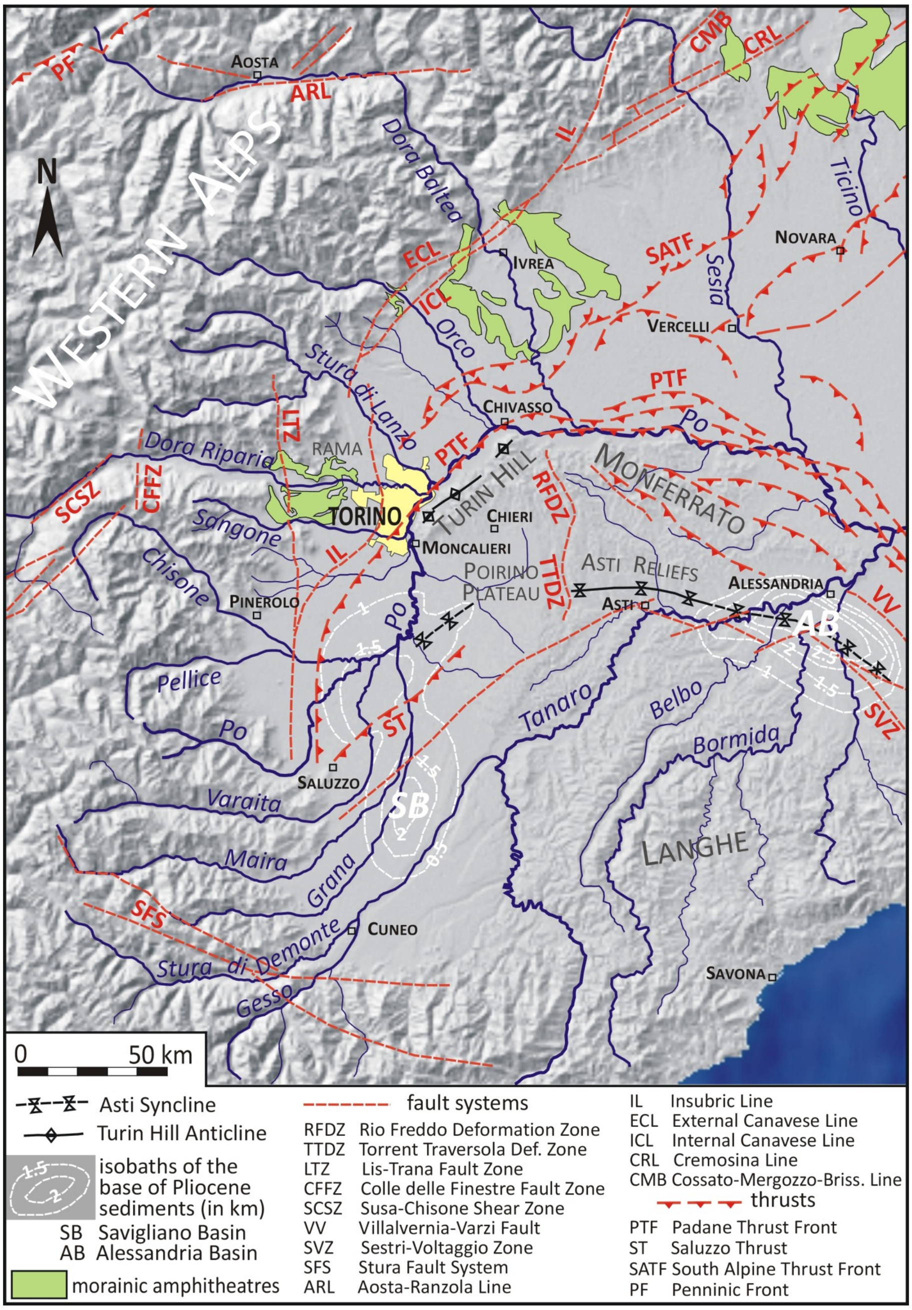


Fig. 1 - Location of Turin and suburbs (urban area in yellow) between the Western Alps and the Turin Hill, showing an asymmetric position along the Po River. The minor extension of the fluvial plain (approximately 17 km) is near Moncalieri. The Rivoli-Avigliana Morainic Amphitheatre (RAMA, west of Turin) is also mapped.

setting. In more detail, the city shows a prevalent flat morphology at elevations between 275 m and 230 m a.s.l., with a low slope towards the E corresponding to wide alluvial fans (Fig. 2). Turin is built on Upper Pleistocene outwash sediments forming the fans linked to the Alpine tributaries of the Po River: the Dora Riparia River flowing at the Susa Valley outlet downstream of the Rivoli-Avigliana Morainic Amphitheatre and subordinately the Stura di Lanzo and Sangone watercourses (Festa et al., 2009a) (Fig. 1). This sector is very flat and characterized only by local slope increases corresponding to fluvial scarps, that currently cut the Alpine alluvial fans.

The eastern edge of the city is instead built on lower (at elevation between 224-210 m a.s.l.) and narrow (with width up to 500 m) fluvial terraces along the two banks of the current Po River; the terraces gently dip towards the NE and are made of Holocene fluvial sediments of this watercourse.

The large extension of lateral fans formed by out-

Fig. 2 - Gently eastward sloping morphology of Turin, which has been built on the wide outwash fan supplied by the Susa Valley, drained by the Dora Riparia River, as seen from Turin Hill.

wash sediments connected to the Po tributaries, on which Turin and suburbs are built, suggests that these fans almost occupied the entire plain area, up to the foot of Turin Hill. The fluvial sediments linked to the Po River constitute only a narrow band along this current watercourse, which clearly cuts the lateral fans. This evident intersection between the fluvial Po sediments and the deposits of its tributaries is the result of an important fluvial deviation that affected the Po River in recent times (see section 5) (Carraro et al., 1995; Carraro, 2012).

Finally, the hilly part of the city (at elevation between 715 and 230 m a.s.l.) corresponds to the western and northwestern slopes of Turin Hill. It is prevalently built on terraced surfaces in which thin fluvial sediments directly rest on Tertiary marine successions (see section 4).

Fig. 3 - The hilly slope facing Turin shows flat surfaces, corresponding to a succession of fluvial terraces (arrows) shaped by the paleo Dora and paleo Stura rivers. Turin (240-230 m a.s.l.) is located in the plain, covered by fog. Monviso (3841 m) is the highest peak. The Superga church (S) (670 m a.s.l.) is located on the watershed of Turin Hill.

3. GEOLOGICAL SETTING

The features of Turin Plain, located near to the Turin Hill, suggest that it is connected with the hilly structure. In detail, the Turin Hill successions continue in the subsoil of Turin buried by Quaternary deposits. The Turin Hill is the surface expression of a NE-SW anticline formed during the Miocene (Festa et al., 2009b) at the top of the main Padane Thrust Front (*sensu* Pieri & Groppi, 1981). This antiformal ridge uplifted in the Quaternary, as indicated by the distribution of its terraced Quaternary fluvial succession that lies on its northern (Barbero et al., 2007), northwestern (Forno & Lucchesi, 2005) and southern sides (Forno & Lucchesi, 2016). The Turin Hill anticline axis plunges to the SW, below the Turin Plain, while to the east it is displaced by the Rio Freddo Deformation Zone (RFDZ),

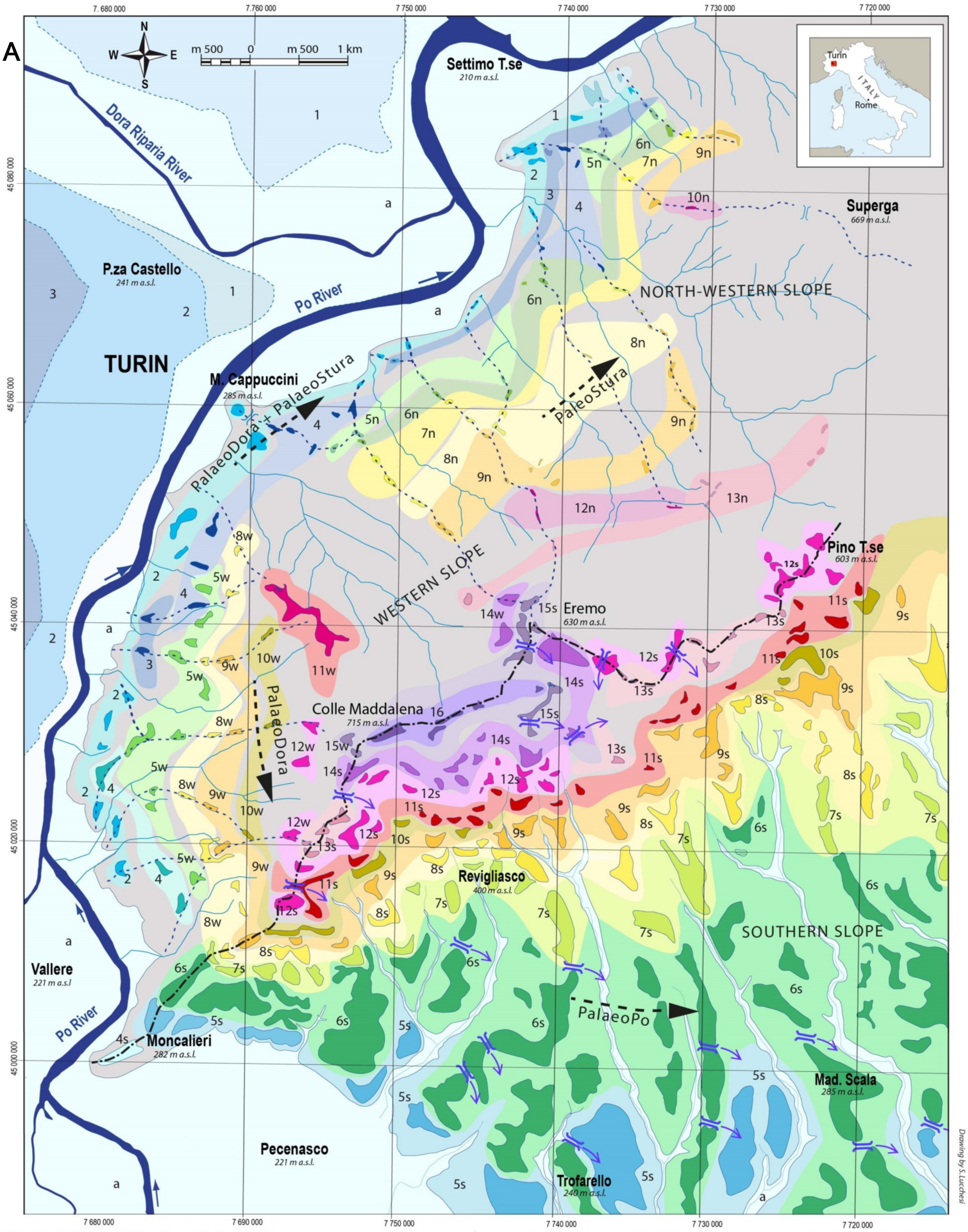
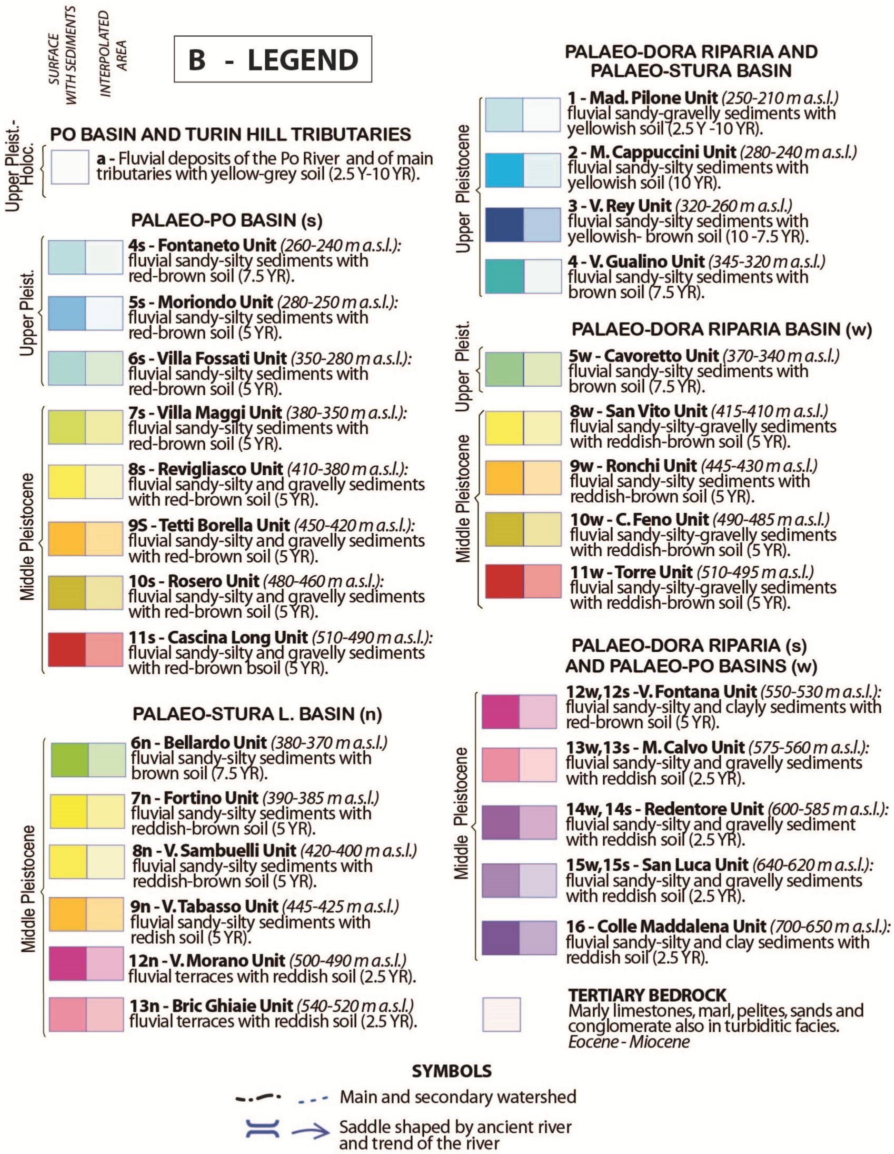


Fig. 4 - A) The fluvial terraces relating to the different time intervals are represented by the different colored bands. Ancient trend of the Dora Riparia and Stura di Lanzo rivers (paleo Dora and paleo Stura), showing opposite flow directions (towards the south and NE, respectively), are preserved on the western and northwestern slopes of Turin Hill for the high and more ancient terraces (Middle Pleistocene). The flow direction of these rivers is the same towards NE for the lower and more recent terraces (Upper Pleistocene). Ancient trends of Po River (paleo Po) are preserved in the southern slopes of Turin Hill, flowing towards the east. The more weathered oldest terraces are preserved near the hilly watershed and the more recent ones develop progressively to the northwest for paleo Dora and paleo Stura and to south for paleo Po. B) Legend of Fig. 4A in the front page (modified from Forno & Lucchesi, 2005; 2016).



which separates it from the adjoining Monferrato domain (Piana & Polino, 1995). Immediately southward, the Torrente Traversola Deformation Zone (TTDZ) cuts the Asti Syncline separating the Poirino Plateau from the Asti Reliefs (Gattiglio et al., 2015) (Fig. 1).

The stratigraphic succession that forms the Turin Hill bedrock is referred to the “Tertiary Piemonte Basin, TPB” (Gelati & Gnaccolini, 1982; Biella et al., 1997), a paleogeographic domain where an Oligocene to Messinian continuous sedimentary succession deposited. The sedimentary successions of the TPB can be well correlated through different geostructural domains of southern Piemonte, among which are the Turin Hill and the adjoining Monferrato Hill system. These mainly terrigenous successions (Dela Pierre et al., 2003; Festa et al., 2009a) were deposited in a syn-orogenic basin placed over the suture zone between the western Ligurian realm and the exhumed Eocene HP/LT metamorphic complexes of the Western and Ligurian Alps (Castellarin, 1994; Falletti et al., 1995; Piana & Polino, 1995; Piana, 2000; Mosca et al., 2010). Although strongly controlled by synorogenic tectonics, the TPB successions were deposited in a single upper Eocene-Miocene basin, affected by coeval tectono-depositional events marked by unconformities, which are physically traceable at a regional scale (Piana et al., 2017). These successions consist of two Late Eocene to Early Miocene terrigenous synthems (conglomerates, sandstones and marls) followed by a Burdigalian carbonate synthem and two other terrigenous synthems (Langhian to Tortonian) followed in their turn by Messinian evaporites.

The above described TPB units are covered by a Pliocene muddy-sandy succession that in Turin Hill crops out mostly in the southern flank of the anticline and which can be subdivided into three main lithostratigraphic units: from base to top, the Argille Azzurre Formation (from upper epibathyal to circalittoral marine clay), the Asti Sand (circalittoral and littoral marine sand)

Fig. 5 - The Superga ridge preserves three terraces (arrows at 670 m, 500 m and 350 m a.s.l.) high above the Turin Plain (average 230 m a.s.l.). This setting indicates that the paleo Stura flowed through an alluvial plain, progressively deformed and uplifted into the slope of Turin Hill.

Fig. 6 - The southern slope of the Turin Hill showing a flat surface in the foreground (arrows) represents the ancient trend of the Po River flowing towards the east. The higher sector of Turin Hill is on the top right on the picture.

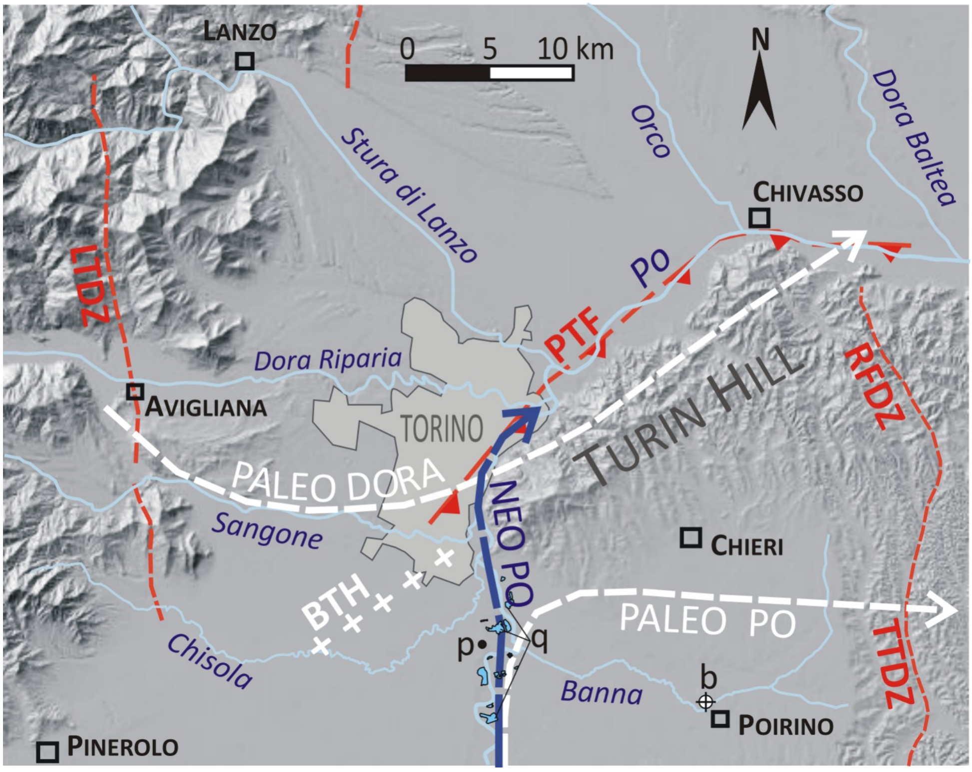


Fig. 7 - The fluvial succession mapped in Turin Hill proves that in the Upper Pleistocene the hydrographic pattern was formed by a paleo Dora River, that flowed on the western and northwestern slopes of Turin Hill, and a paleo Po River that flowed through its southern side (white arrows). The neo Po River develops during the late Upper Pleistocene, through an overflow phenomenon, flowing toward north (blue arrow). BTH: Buried Turin Hill; PTF: Padane Thrust Front; TTDZ: T. Traversola Deformation Zone; RFDZ: Rio Freddo Deformation Zone; LTDZ: Colle del Lys-Trana Deformation Zone. The peaty sediments connected to the paleo Po River and described in the Moncalieri-La Loggia quarries by Tropeano (1987) (**q**), observed in an ancient outcrop at la Loggia (**p**) (Fig. 9) and drilled in a recent borehole at Poirino (**b**) (Fig. 10) are also reported.

and the Villafranchian succession (deltaic and continental deposits). All these units crop out on the Turin Hill anticline and continue below the Turin Plain (Fig. 1).

4. GEOLOGICAL RECONSTRUCTION OF TURIN HILL

A reconstruction of the Quaternary geological succession of the neighbouring Turin Hill is necessary to understand the recent geological evolution that involves the Turin Plain. Flat surfaces are preserved on the northwestern and western slopes of Turin Hill, weakly sloping towards NW or W, corresponding to a succession of fifteen fluvial terraces (Fig. 3). This succession develops in a wide range of altitudes between approximately 700 m a.s.l. in the main watershed and 240 m on the lower terraces (Forno & Lucchesi, 2005). We can also clearly recognize these terraces in ancient iconography, before the urbanization of the hilly areas. Consequently, they are not anthropogenic, nor related to the recent urbanization of the hilly area.

Silty and sandy fluvial sediments form the different terraced surfaces, studied through geologic survey and well-log stratigraphy (Forno et al., 2002). The fluvial deposits are thin (2-8 m) and cover the Cenozoic (Eocene-Pliocene) marine succession of Turin Hill. The various soils (with hue color index of the B horizon variable from 2,5 YR to 10 YR) that developed on top of the different terraced fluvial sediments suggest to refer them to a relatively extended period of time that spans a large part of the Middle and Upper Pleistocene. Moreover, most of the fluvial terraces (from 15 to 4 units in Fig. 4) are discontinuously covered by the aeolian loess referred to the Last Glacial Maximum (LGM) (Forno, 1990); therefore, their age is older than 27.5-20 ka BP, according to the dating of the nearby Rivoli-Avigliana morainic amphitheatre (Ivy-Ochs et al., 2018). A few of them, without the loess cover, are instead more recent (post-LGM).

The correlation of various terraces at a higher altitude in Turin Hill (above 380 m a.s.l.) indicates the flow of an ancient path of the Dora Riparia River towards the S (paleo Dora) through the current western slope (11w-5w units in Fig. 4) and an ancient path towards the NE of the Stura di Lanzo (paleo Stura) through the current northwestern slope (from 13n to 6n units in Fig. 4) (Forno & Lucchesi, 2005). Data on the heavy minerals of the fluvial sediments forming the sequence of terraces indicates a provenance from the ancient basins of the Dora Riparia and Stura di Lanzo, respectively, confirming this morphological setting (Vezzoli et al., 2010).

The correlation of the fluvial terraces at lower altitudes of Turin Hill (below 380 m) indicates that a single river (paleo Dora + paleo Stura) flowing towards the NE subsequently developed along the current western and north-western slopes (from 4 to 1 units in Fig. 4), which is also confirmed by the composition of heavy minerals of sediments.

The elevation of these terraces, which are hanging with respect to the surrounding plain at up to several hundred metres (up to 450 m at Superga), suggests that they have been significantly raised and deformed by the recent geodynamic evolution of Turin Hill (Boano et al., 2004) (Fig. 5). This terraced succession is referred to ancient flat morphologies on which the Alpine fans leaned against the uplifting Turin Hill, before the recent definition of the current Po River (neo Po). A progressive incorporation of these terraces into the hillside due to the continuous uplifting of Turin Hill has been reconstructed, suggesting that they formed in the original alluvial plain and only later became part of the hill. Consequently, despite their proximity to the current Po River, these terraces are not linked to the paleo Po (Vezzoli et al., 2010).

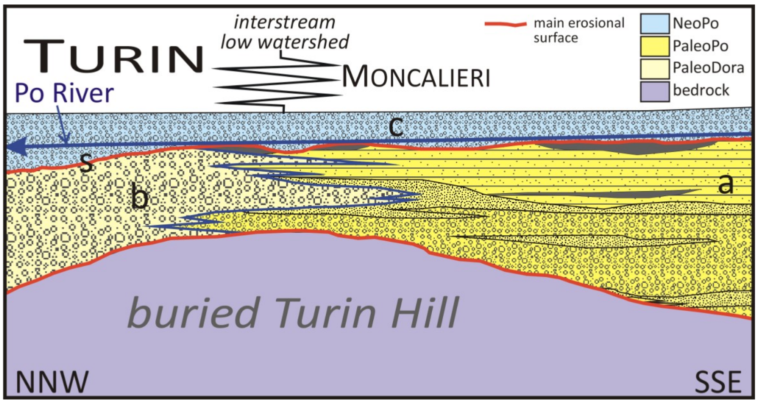


Fig. 8 - The alternating gravel and fine-grained sediments with peaty layers (black) deposited by the paleo Po River (**a**) during the Upper Pleistocene suggest the formation of marshes in the plain south of Turin. The gravel deposited by the paleo Dora River (**b**) indicates the aggradation of the Dora Riparia outwash fan. A low watershed developed between the two areas, currently buried. Subsequently, the shaping of an evident erosional surface (**s**) and the neo Po sediments (**c**) deposited in the late Upper Pleistocene indicate the formation of the current Po River through an outwash phenomenon.

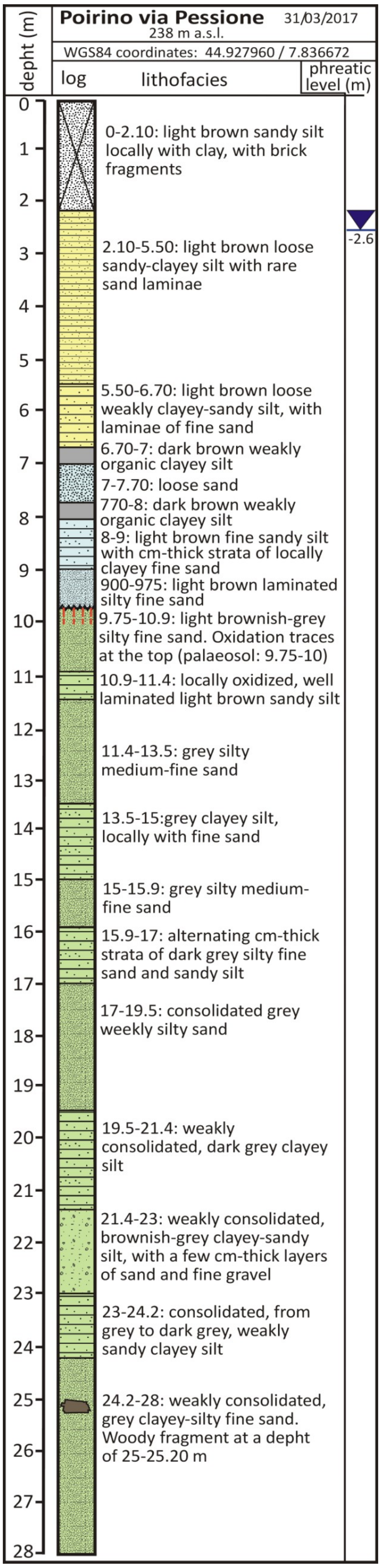
In contrast, the wide relicts of the fluvial Po Plain preserved on the southern slope of Turin Hill (Fig. 6) represent the main evidence that during the Pleistocene the paleo Po flowed eastward in this area (from 16 to 4s units in Fig. 4) and not in the current Po Plain north of Turin Hill (Forno & Lucchesi, 2016). These relicts preserved in the southern slope are mainly constituted by sandy silty sediments, with rare gravelly lenses, suggesting a deposition in a flat meandering river floodplain. The petrography of the fluvial pebbles (essentially formed by metamorphic rocks such as serpentinite, metagabbro, prasinite, eclogite, quartzite, and peridotite) is consistent with a paleo Po provenance and a flow

Fig. 9 - The peaty sediments (asterisk) connected to the paleo Po River are buried by the sandy silt deposited by the neo Po River (outcrop south of Turin along the ring road at La Loggia, near Cascina Revignano, now covered by walls).

n°	site altitude a.s.l.	lithostratigraphy	depht (m) quote (m a.s.l.)	radiocarbon age (^{14}C yr BP)	calibrated age[1] (calendar year BP)	ref.[2]
17	Ceretto Quarry (Carmagnola) q. 235 m a.s.l.	tree trunk in gravel and greyish sand	- 6-7 m q. 229 m	160 ± 50	288-59 y BP (1662-1891 AD)	e,f
		tree trunk in gravel and greyish sand	- 6-7 m q. 228 m	480 ± 50	561-451 y BP (1389-1499 AD)	f
16	Zucca and Pasta Quarry (La Loggia) q. 225 m a.s.l.	tree trunk in alluvial gravel and grey sand	- 5 m q. 220 m	290 ±30	457-349 y BP (1493-1601 AD)	c,f
15	Molinello Quarry (Moncalieri) q. 223 m a.s.l.	tree trunk of *Salix* in alluvial sand	- 3 m q. 220 m	900 ±70	930-692 y BP (1020-1258 AD)	a,c
		tree trunk in alluvial gravel and grey sand	- 4-5 m q. 219 m	1700 ±75	1745-1476 y BP (205-474 AD)	f
14	Fallé Quarry (Casalgrasso) q. 240 m a.s.l.	gravel and grey sand	- 6-7 m q. 233 m	3150 ± 50	3466-3232 y BP (1517-1283 BC)	f
13	Torino Quarry (Carignano) q. 227 m a.s.l.	coarse and medium sand with pebbles	- 4 m q. 223 m	4365 ± 80	5144-4826 y BP (3195-2877 BC)	f
12	Provana Quarry (Carmagnola) q. 230 m a.s.l.	gravel and greyish sand	- 4.5 m q. 225.5 m	4460 ± 60	5298-4955 y BP (3349-3006 BC)	f
11	Po-Pellice rivers confluence (Faule) q. 244 m a.s.l.	gravel and greyish sand	- 3.5 m q. 240.5 m	5180 ± 70	6121-5841 y BP (4172-3892 BC)	f
10	Fontane Quarry (Pancalieri) q. 243 m a.s.l.	oak trunk rest in yellowish-grey sand and gravel	- 8 m q. 235 m	5855 ±75	6808-6482 y BP (4859-4533 BC)	b,f
9	T. Banna outcrop (Villastellone) q.226 m a.s.l.	gravel and grey sand	- 5 m q. 221 m	11955 ± 140	14.1-13.5 y BP	f
8	Po-Banna rivers confluence q.216 m a.s.l.	big floated trunks in fluvial gravels, lying beneath recent overflow silts	- 1 m ? q. 215 m ?	12000 ± ?	about 14.5-13.5 ky BP	e,f
7	Candiolo excavation q. 237 m a.s.l.	peaty layer below clayey silt and sand	- 2.5 m q. 234.5 m	24300 ±200	28.8-27.9 ky BP	a,b,d
6	Vinovo borehole q. 232 m a.s.l.	peaty layer in clayey silt	- 10 m q. 222 m	26270 ±400	31.1-29.6 ky BP	a,b,d
5	Fontane Quarry (Pancalieri) q. 243 m a.s.l.	grey clayey silt	- 7 m q. 236 m	27450 ±900	33.5-29.7 ky BP	f
4	Ronchi well (Trofarello) q. 225 m a.s.l.	trunk remains in grey clayey silt lying above gravel	- 12 m q. 213 m	30660 ±1290	37.6 - 31.7 ky BP	b,d,f
3	C. Resca well (Trofarello) q. 228 m a.s.l.	blue-grey clayey silt and fine sand	- 13 m q. 215 m	33960 ±1735	41.7 - 34.7 ky BP	f
		peat in blue-grey clay with silt	- 20 m q. 208 m	30370 ±1605	38.0 - 31.2 ky BP	d,f
2	T. Chisola outcrop at Tetti Caglieri (Vinovo) q. 228 m a.s.l.	reworked trunk remains in blue-grey clayey silt and medium to fine sand	-4 m q. 224 m	> 44 ky		c,f
1	Molinello Quarry (Moncalieri) q. 223 m a.s.l.	woody macrorests in sand and gravel at the base of the Quaternary sequence	ca. 20-25 m q. 198-202 m	> 44 ky		c,d, e,f

1. References: a: Charrier & Peretti, 1977; b: Tropeano & Cerchio, 1984; c: Tropeano, 1986; d: Tropeano,1987; e: Tropeano & Cerchio, 1987; f: Tropeano & Olive, 1989.
2. ^{14}C ages was re-calibrated using Calib Rev 7.0.4 and IntCal 13.14c calibration dataset (Reimer et al., 2013) with a 2σ range

Tab.1 - Radiocarbon ages for the fluvial succession of the paleo Po (1-9) and the neo Po (10-17). Twenty dating were provided by woody remains and peaty layers coming from seventeen different sites (nine quarries, three boreholes, one dig and four natural outcrops) of the plain south of Turin. Conventional ages (see references in the table) are all calibrated or re-calibrated and listed in chronological order.



direction towards east, south of Turin Hill (Compagnoni & Forno, 1992). The more ancient fluvial terraces, which preserve well developed soils, are placed in the northern sector near the current watershed at 715-500 m a.s.l., and the more recent elements, which show poorly developed soils, are towards the south in the Poirino Plateau at 280-240 m a.s.l. (Fig. 4).

The scarce weathering of the more recent deposits (color 10 YR 4/6 of the B horizon) suggests that the paleo Po flowing through the southern slope of Turin Hill and the Poirino Plateau can be referred to a large part of the Upper Pleistocene, confirming the recent setting of the Po in the current position.

5. THE TURIN PLAIN AS RESULT OF FLUVIAL DEVIATION

The distribution of the fluvial terraces on the slopes of Turin Hill proves that the watercourses progressively migrated during the Middle and Upper Pleistocene, towards the NW for the paleo Dora and towards the S for the paleo Po, moving away from the hilly watershed (Fig. 7). This shifting of the two rivers was promoted by the progressive tectonic evolution of Turin Hill (see section 7).

The proximity of the paleo Po bed with the paleo Dora one suggests that a low and thin watershed separated the two rivers, connected both to the buried SW continuation of Turin Hill in the subsoil (BTH in Fig. 7) and the aggradation of the proglacial fan of the Rivoli-Avigliana Amphitheatre in the Turin Plain during the acmes of the glaciations.

The fine-grained sediments with peaty layers with minor gravel, sedimented by the paleo Po (a in Fig. 8), that are encountered in some boreholes and are also visible in quarries (Moncalieri-La Loggia, q in Fig. 7), record the formation of marshes in the plain south of Turin (Fig. 9). This evidence suggests a difficult flow of the paleo Po towards the east that was essentially caused by the uplift of the Poirino Plateau linked to evolution of the T. Traversola Deformation Zone (TTDZ) (Fig. 1) (Gattiglio et al., 2015).

A recent geognostic borehole observed near Poirino, south of Turin Hill (Fig. 10), evidences thin levels of grey sediments, with a peaty component, to divide the paleo Po sediments (6.70-9.75 m) on respect to the overlaying sediments connected to the Banna River (above 6.70 m), that currently develops in the Poirino Plateau. These levels furtherly highlight the formation of marshes.

The scanty weathering and the fossil remains of “Wurmian” mammals found in the sediments of the paleo Po River including *Mammuthus primigenius* (La Loggia), *Megaloceros giganteus* (La Loggia, Escosa Quarry), and *Bison priscus* (Moncalieri, Molinello

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Fig. 10 - Log of a Poirino geognostic drilling (Via Pessione). The thin organic sediments between 8.00 and 6.70 m are connected with the developing of marches to divide the paleo Po River sediments (light blue, between 9.75 and 6.70 m) from the Banna River sediments (yellow, above 6.70 m). The Villafranchian succession is observed in the lower stretch of the log (green, under 9.75 m) (modified from a Citiemme log).

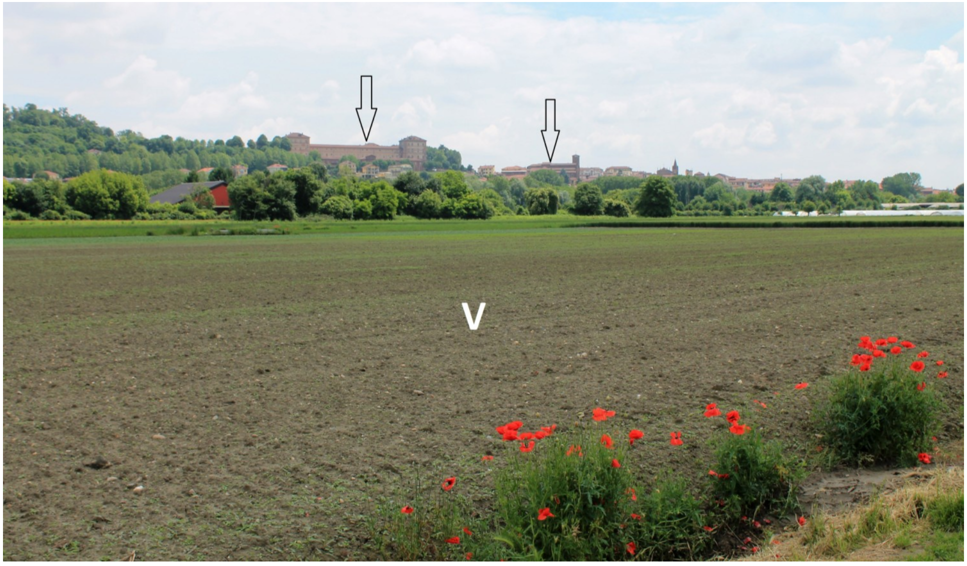


Fig. 11 - The more extended terrace in the foreground (Vallere Terrace, v), connected to the neo Po, is entrenched between the paleo Dora Riparia fluvial terraces (Moncalieri Castle Terrace and Moncalieri Church Terrace, arrows) and the paleo Dora alluvial fan of Turin (on the right outside the photo).

Quarry) (Tropeano, 1987) and the more ancient radiocarbon data of peaty layers (from >44 ka to 27.9 ka cal BP, 1-7 in Tab. 1) indicates that the ancient trend of the Po River (paleo Po) persisted until the late Upper Pleistocene.

Subsequently, the progressive paleo Po deposition buried the low watershed separating the paleo Po sediments (a in Fig. 8) from the paleo Dora ones (b in Fig. 8), and the first river consequently experienced a lateral spillover with deviation towards the north, forming the neo Po (c in Fig. 8). The current Po probably invaded the band shaped by the paleo Dora River, giving rise to

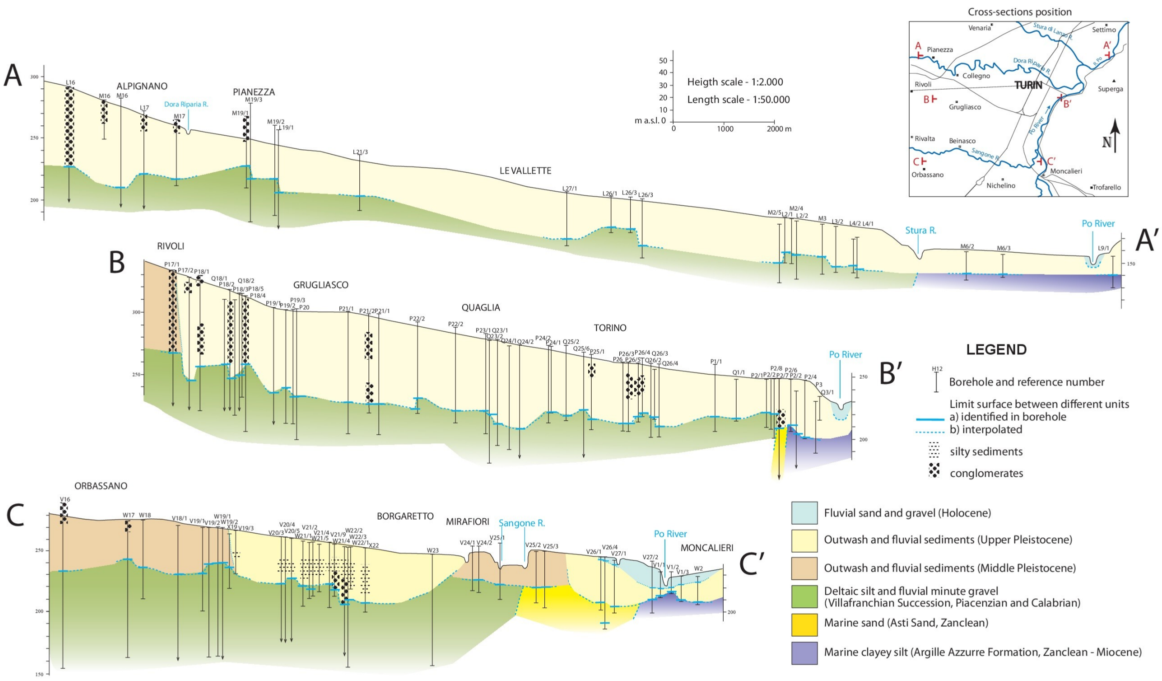


Fig. 12 - Geological cross section of the subsoil of Turin. In most of the Turin Plain the outwash sediments of PaleoDora Riparia River cover the Villafranchian succession. At the foot of the Turin Hill the fluvial sediments of the current Po River lie on the Miocene and Pliocene marine sediments (modified from Lucchesi, 2001).

an overflow phenomenon. This event could only have taken place after the end of the aggradation of the Dora Riparia proglacial fan, i.e. likely not before the early Lateglacial. Consequently to this overflow event, during the Lateglacial the Po River eroded the paleo Po and the paleo Dora successions forming an evident erosional surface (s in Fig. 8).

The radiometric ages referred to the neo Po River sediments are from 6.8 ka cal BP (10 in Tab. 1) to a series of historical ages (15 -17 in Tab. 1). The observation that the neo Po did not shape a new bed necessarily modifies the interpretation of this phenomenon, here indicated as overflow and, instead, reported as a diversion in the previous geological literature (Carraro et al., 1995).

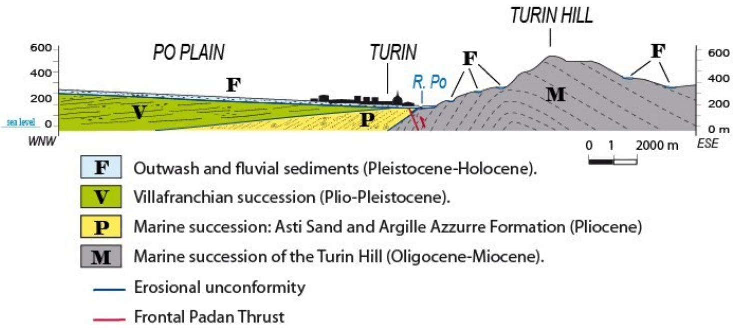


Fig. 13 - The outwash sediments of the PaleoDora Riparia River, referred to Middle-Upper Pleistocene, rest on a wide erosional surface shaped on the Villafranchian succession and locally on the Asti Sand or Argille Azzurre Formation (modified from Forno & Lucchesi, 2014).

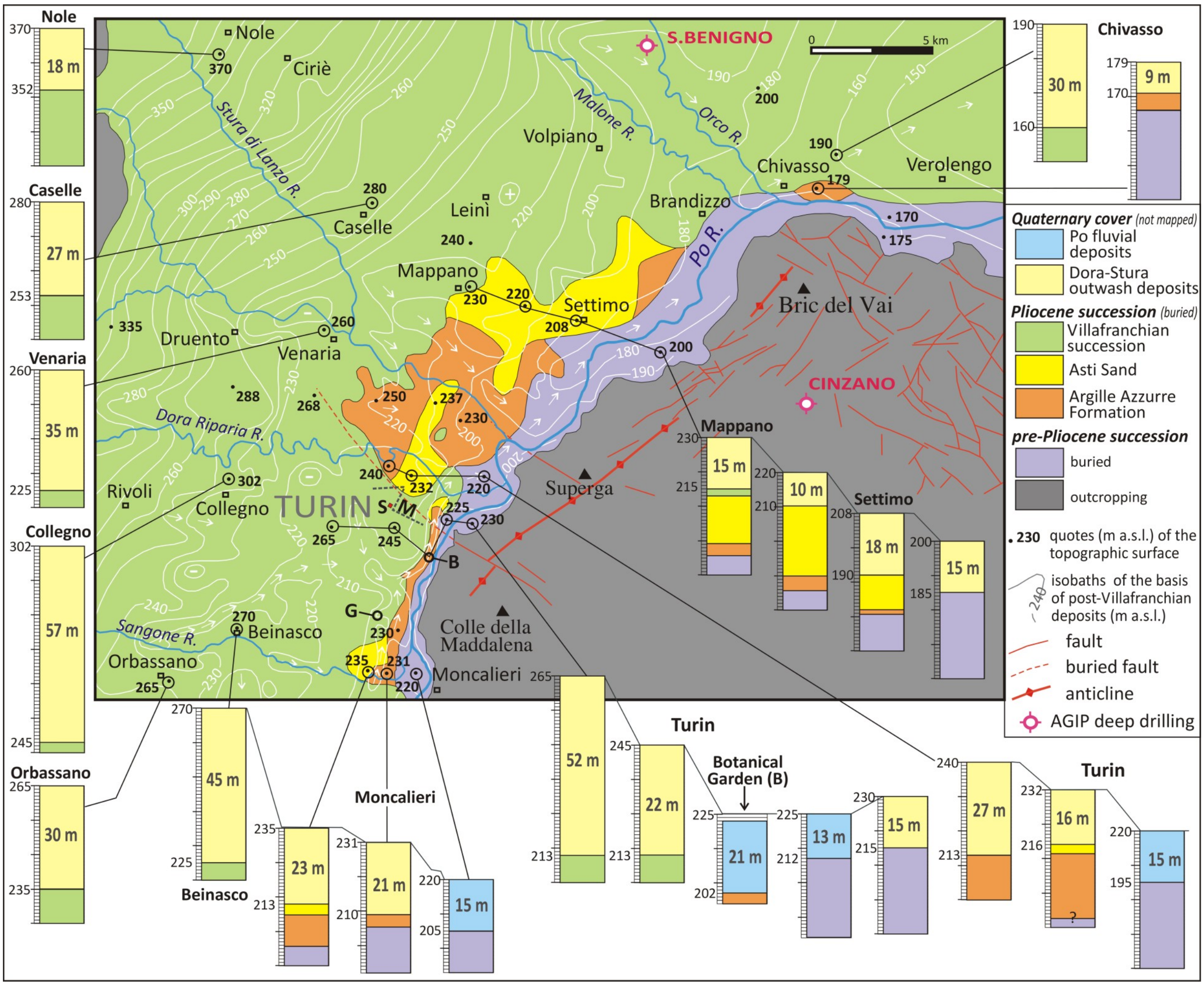


Fig. 14 - The thin outwash sediments, in the subsoil of Turin and suburbs, generally rest on the Villafranchian succession. Locally, at the foot of the Turin Hill, they rest directly on the Pliocene or Miocene marine succession, to form an erosional buried surface. The black and white numbers respectively indicate the topographic quote and the quote of the base of the outwash sediments. The logs of the boreholes evidence the thickness of outwash and fluvial sediments from a minimum of 5 metres (Moncalieri) to a maximum of 57 m (Collegno). Location of subway (M: Line 1 of the Metro, dotted grey line; see Fig. 15) and Intesa Sanpaolo skyscraper excavations (S: red square; see Fig. 16), outcrop of Giordano Bruno Street (G; see Fig. 17) and Botanic Garden borehole (B; see Fig. 18) are reported (modified from Festa et al., 2009b).

The Vallere Terrace, on the left side of the Po River near Moncalieri approximately 4 m above the current river bed, represents the evidence of the first path of the neo Po. This recent terrace appears entrenched into the terraces connected to the paleo Dora River (Fig. 11). The very weak weathering of the sediments connected to the current Po River suggests that this phenomenon occurred in the late Pleistocene/Holocene. In detail, the neo Po deepened the paleo Dora outwash fan (below the Moncalieri Castle and the Moncalieri Church terraces) also depositing the sand of the Vallere Terrace (Fig. 11). Some other lower terraces formed along the Po River, hanging only 2-3 metres over the current riverbed, also suggesting that the current watercourse is characterized by fluvial deepening consequent the new basic level (Carraro & Lucchesi, 2004).

6. STRATIGRAPHY OF THE SHALLOW SUBSOIL

The recent deviation of the Po River at the foot of Turin Hill, along the Padane Thrust Front (PTF) (Fig. 7), influences the stratigraphy of the shallow subsoil of Turin and suburbs (section 5). The stratigraphic reconstruction is based on local outcrops (anthropic excavations or river incisions) and a large number of borehole logs (wells, piezometers and geognostic drillings) carried out during the last decades. They are available in archives of the Regional Environmental Protection Agency (ARPA) and of the Earth Sciences Department of Turin University (Lucchesi, 2001) as well as in the CARG Project database (Festa et al., 2009b) (Fig. 12).

The shallowest subsoil of Turin and suburbs is mainly constituted by thin outwash sediments referred to the paleo Dora with the contribution of the paleo Stura (Middle and Upper Pleistocene), that cover the Villafranchian succession (Piacenzian and Calabrian). The northeastern sector of the city (between Turin and Settimo Torinese) shows instead outwash sediments, with thickness of 10-27 m, that rest on the marine succession (Asti Sand or Argille Azzurre Formation) (Fig. 13).

The Villafranchian succession is essentially formed by alternating silt and fine gravel, referred to the Lower Complex (Piacenzian), that are related to a deltaic environment (Forno et al., 2015). These sediments appear as overconsolidated and are very fractured (Forno et al., 2009). The gravelly and silty sediments referred to the Upper Complex (Calabrian) and related to a fluvial environment are instead only locally preserved.

The erosional surface that divides the Villafranchian succession from the outwash Pleistocene sediments, with regional extent, is likely the result of many erosional episodes carried out by the Alpine watercourses that have determined the almost total removal of the Upper Complex of the Villafranchian Succession (Fig. 12) (Lucchesi, 2001; Forno et al., 2009).

The overlying Pleistocene outwash sediments show a reduced thickness, generally between 57 m, at the western Alpine foot, and 9 m below Turin, at the eastern edge of the plain (Fig. 14). The maximum thickness along the Dora Riparia River (57 m at Collegno and 45 m at Beinasco) suggests a main supply from this basin, connected to the proglacial system of the Rivoli-Avigliana Amphitheatre (Fig. 1). These sediments are characterized by sandy gravel with minor lenses of silty sand and clayey silt (Fig. 15).

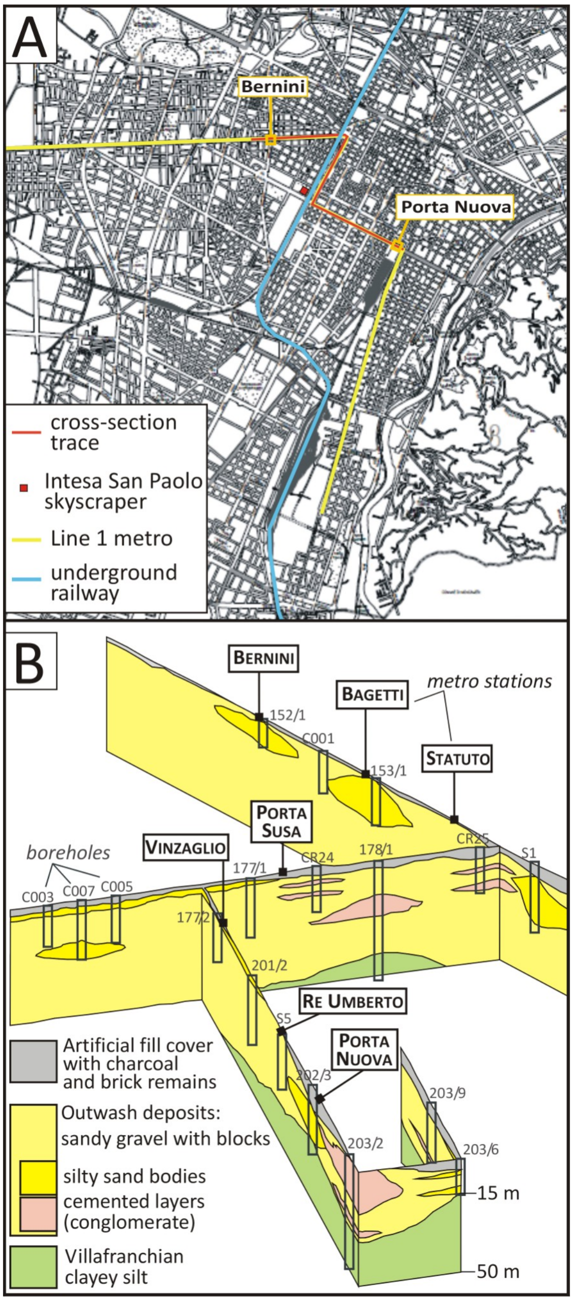


Fig. 15 - A) Main recent excavations in the subsoil of Turin: 1) subway (Line 1 of the Metro, 15 km); 2) underground railway pass (12 km); 3) Intesa Sanpaolo skyscraper. B) Cross section along the subway involving the variously cemented Dora Riparia River outwash sediments (modified from a Geodata sketch).

Several remarkable excavations have been carried out in the shallow subsoil of Turin. The ancient extensive tunnels of the Cittadella fortress have involved the subsoil of the center of Turin in the past (beginning of 18th century AD) and are still partly visible. The sub-

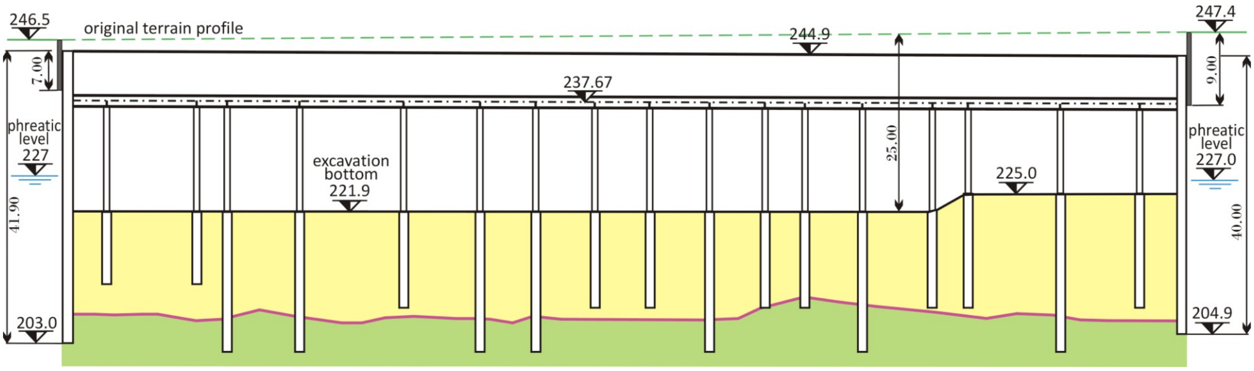


Fig. 16 - Cross section of the excavation of the Intesa Sanpaolo skyscraper (S in Fig. 14) essentially involving the outwash sandy gravelly sediments (yellow), with a boulder level, that lie on the silty Villafranchian succession (green). Altitude is referred as m a.s.l.

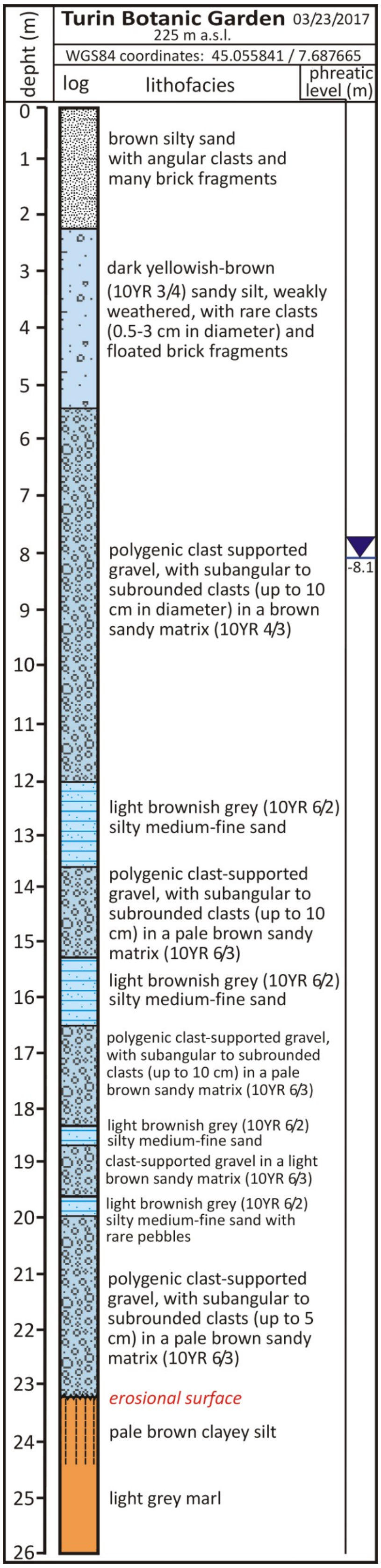
way (Line 1 of the Metro), the underground railway pass and a local deep excavation to build the foundations of the Intesa Sanpaolo skyscraper have been realized in the last decades. These excavations essentially involve the gravelly surficial outwash sediments, locally intercepting the underlying Villafranchian succession (Pelizza, 2010; 2014). The excavation activity was strictly conditioned both by the heterogeneity of the outwash sediments, formed in detail by alternating sandy gravel with boulders and silty sand, and by their degree of cementation. This cementation appears particularly remarkable along the Dora Riparia bed, suggesting a carbonatic contribution by this river supplied by a cathment basin rich in carbonatic rocks. More specifically, the approximately 20 m deep excavation of the subway in the northern sector of the Turin subsoil encountered a strong variability of cementation of gravel layers (Fig. 15) (De Rienzo et al., 2009). The excavation involved the Villafranchian succession only on the southern stretch (between the Porta Susa and Porta Nuova stations). The excavation of the underground railway pass in the southeastern sector of the Turin subsoil, instead, sustained problems essentially caused by a very shallow water table, as also evidenced by the hydrogeological reconstruction (see Fig. 22c).

The last excavation (Intesa Sanpaolo skyscraper), which was over 40 m deep, involves the alternating essentially gravelly and sandy outwash sediments, intercepting the top of the underlying clayey Villafranchian succession (Fig. 16). Boulders of considerable size (approximately 1 m in diameter) were found within the outwash deposits, also forming a level (32-33 m of depth) probably connected with glacial route phenomena. Moreover, a 15 m deep building excavation within the city of Turin (G in Fig. 14) showed a sequence formed by sandy gravelly outwash sediments, with a cover of silty sand (Fig. 17). The petrography of the pebbles (essentially metamorphic rocks such as serpentinite, metagabbro, prasinite, peridotite, amphibolite, quartzite, gneiss, graphitic schist and micaschist with rare marble and calcschist) indicates a feed by the paleo Dora (Col Giansesco Unit, in Festa et al., 2009b). These sediments show a scarce weathering (Fig. 17), evidenced by fresh pebbles and yellowish brown colour of soil (10 YR 5/6 of the B horizon), suggesting that they refer to the late Upper Pleistocene.

Fig. 17 - An approximately 15 m deep recent building excavation within Turin (Giordano Bruno Street, G in Fig. 14) shows the sequence formed by gravelly and sandy outwash sediments, supplied by the Dora Riparia River during the Upper Pleistocene.

Thin fluvial sediments referred to the neo Po (thickness between 13 and 21 m) are present only in the eastern sector of the city at the foot of Turin Hill, where they directly rest on a buried erosional surface molded in the Pliocene or pre-Pliocene marine succession by the fluvial erosion (Forno & Lucchesi, 2014) (Fig. 12; see green in Fig. 22a). A recent geophysical survey confirms the weak depth (3-20 m) of the marine sediments along the current Po River bed (Sambuelli et al., 2017).

In detail, the recently specially drilled 26 m deep piezometer in the Botanic Garden lying on a terrace at the left of the Po River (B in Fig. 14), shows a 21 m tick body of fluvial deposits consisting of alternating sandy gravel and silty sand linked to the neo Po (Fig. 18). The clasts of the gravel layers are centimetric to decimetric in size, characterized by high roundness and essentially formed by quartzite and conglomeratic quartzite (“anagenite” Auct.), serpentinite, prasinite, peridotite, gneiss, marble, dolomitic marble, and meta-pegmatite, according to the present Po basin also with the contribution of the paleo Tanaro River as tributary. Consequently, the known overflow of the Tanaro River (from the ancient northward flow to join the paleo Po River south of Turin, to the present flow towards NE across



the Asti Reliefs; Carraro et al., 1995) only occurred later than the Po River overflow. The sand layers are essentially constituted by fine sand, with intercalations of silt. The fluvial sequence of the neo Po shows absence of weathering with fresh pebbles and pale brown color of the matrix (10YR 6/3 of the B horizon), suggesting a late Upper Pleistocene or Holocene age, younger than the paleo Po sediments south of Turin containing peaty layers dated 38-28 ka cal BP (see section 4). The presence of Pliocene sediments at the base of the borehole implied a local revision of the map of Turin (Fig. 14), originally reporting the Miocene succession in the sector near the Po River (Festa et al., 2009b).

7. RECENT TECTONIC EVOLUTION

Since the Middle Miocene, the N-verging Padane Thrust Front (PTF in Fig. 1) developed and the TPB consequently evolved as a wide thrust top basin (Mosca et al., 2010), causing the folding of the Turin Hill and its tilting and overthrusting (together with the adjoining Monferrato domain) onto the Turin Plain foredeep, which lasted until the late Pliocene. In this time span, at the rear of the PTF, a new N-verging thrust (Saluzzo Thrust, Bigi et al., 1990, Mosca et al., 2010) displaced the TPB succession, while two major depocenters (the Savigliano and the Alessandria subsiding basins) developed south of the Turin Plain, where some NE-SW to E-W and N-S normal and strike-slip faults also evolved (Boano & Forno, 1999; Festa et al., 2009b). Seismotectonic analyses do not show clear evidence of current activity for the PTF at the edge of Monferrato and Turin Hill (Perrone et al., 2013). These data confirm the gradual reduction of shortening rates, as evidenced by GPS data (Devoti et al., 2011), from the eastern to the western Po Plain. Nevertheless, the eastward decrease of the shortening rates along the PTF, does not necessarily imply a complete deactivation of the PTF, but rather it could suggest its quiescence (Michetti et al., 2012).

Evidence of current tectonic mobility are reported, for the Turin area, by Morelli et al. (2011) and Perrone et al. (2013) on the basis of statistical analysis of PS-InSAR data (Fig. 19), suggesting present differential crustal movements of the inner part of the Cottian Alps with respect to the buried Turin Hill western prolongation but, conversely, reporting scarce vertical movements across the PTF. If poor uplifting rates of the buried Turin Hill are inferred not only for Present, but also for the late Pleistocene and Holocene, the Po overflow along N-S direction in the Turin Plain could more easily be justified, as previously discussed in section 5. These rates appear in contrast with the relevant uplifting rates recorded at the eastern termination of the Turin Hill-Monferrato system, as reported by Arca & Beretta (1985).

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Fig. 18 - The log of the recently drilled borehole of Botanic Garden of the Turin University (B in Fig. 14) shows the alternating gravelly and sandy Po River sediments (21 m thick) that cover the clayey silt and marl of the Pliocene Succession (Argille Azzurre Formation). A 2-m thick anthropogenic body is observed at the top of the stratigraphic succession.

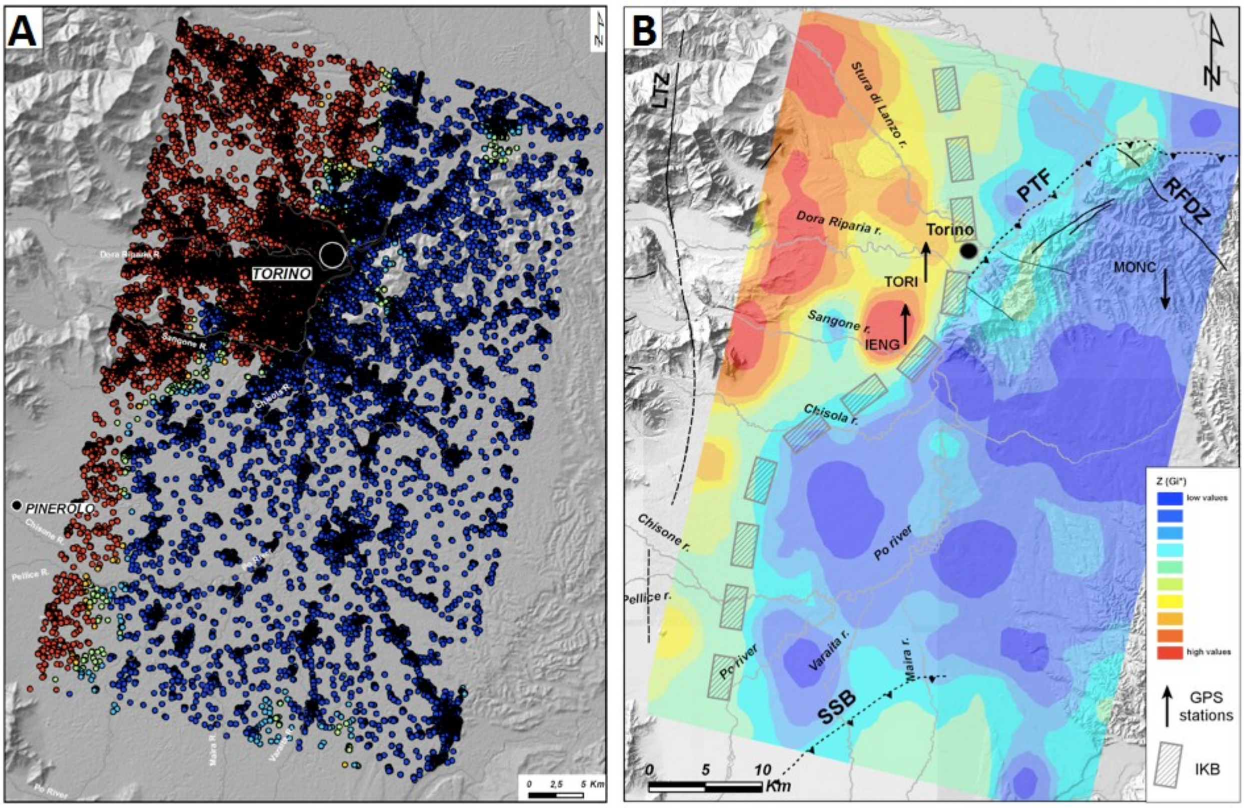

Fig. 19 - Distribution and statistical Hot-Spot analysis of PS-InSAR data related to the Turin area. A) PS spatial distribution that represents the spatial variability of PS-InSAR velocity. Hot-Spot was calculated with d=5 km; red and blue points represent respectively high and low Z (Gi)* values in relation to the expected values; B) Iso-kinematic map based on PS-InSAR data distribution expressed in high (red) and low (blue) values of Z (Gi)*. Grey dashed line represents the Iso-kinematic boundary (see Morelli et al., 2011 for further explanation) (from Perrone et al., 2013).

8. SEISMIC ACTIVITY

Despite Turin being assigned to the 4th seismic zone, the lowest in the national seismic classification, the seismic potential of the city of Turin is commonly associated with two main districts: the Northern Cottian Alps and the Borbera-Grue (North-Western Apennines) seismic zones (Fubelli et al., 2018). These zones are connected northwards to Vallese and converge southwards to Cuneese areas. The related earthquake epicentres appear to have a great dispersion towards the French Alpine side along the southern Piedmont reliefs. The regional seismic network annually detects hundreds of earthquakes with epicentres located in the Piedmont (e.g., the Susa Valley, Lanzo Valley and Langhe) or in surrounding areas. Generally, the population does not perceive them. Next to epicentral areas, there are about ten perceived earthquakes per year. On average, one event per year can possibly cause some significant effects, even at longer distances, where they would be generally slight. The last significant earthquake occurred on 25 July 2011 near the Sangone Valley and Chisola Valley (4.4 Mw).

More than one hundred historical earthquakes, with estimated moment magnitude between 4.5 and 6 occurred during the last millennium (Pignone et al., 2013) (Fig. 20). The data appears to be underestimated due to: i) the lack of details in the available historical catalogues and ii) the almost complete absence of information concerning the seismogenic sources responsible for the main events occurred in the two areas: the 1808 Pinerolo (Mw 5.64) and the 1828 Tortona (Mw 5.72) earthquakes. Greater magnitude earthquakes, that are able to produce appreciable effects even in Turin, have occurred relatively close to the borders of the Piedmont; in particular, the event of February 23, 1887, near the western Ligurian coast was less than 50 km from the Piedmont border and had an estimated magnitude of 7.0 Mw.

9. HYDROGEOLOGY OF THE SUBSOIL

The stratigraphy of the Turin subsoil influences its hydrogeology. Five hydrogeological complexes superimposed on top of each other can be identified in the Turin shallow subsoil (Fig. 21) (Bove et al., 2005; De Luca et al., 2014; De Luca & Ossella, 2014). The Complex of marine pre-Pliocene deposits of Turin Hill (Eocene-Pliocene) located at the base of the sedimentary succession comprises clay, marl, silt, limestone, sandstone and chalk (Festa et al., 2009a). They are generally compact rocks, constituting a basically impermeable me-

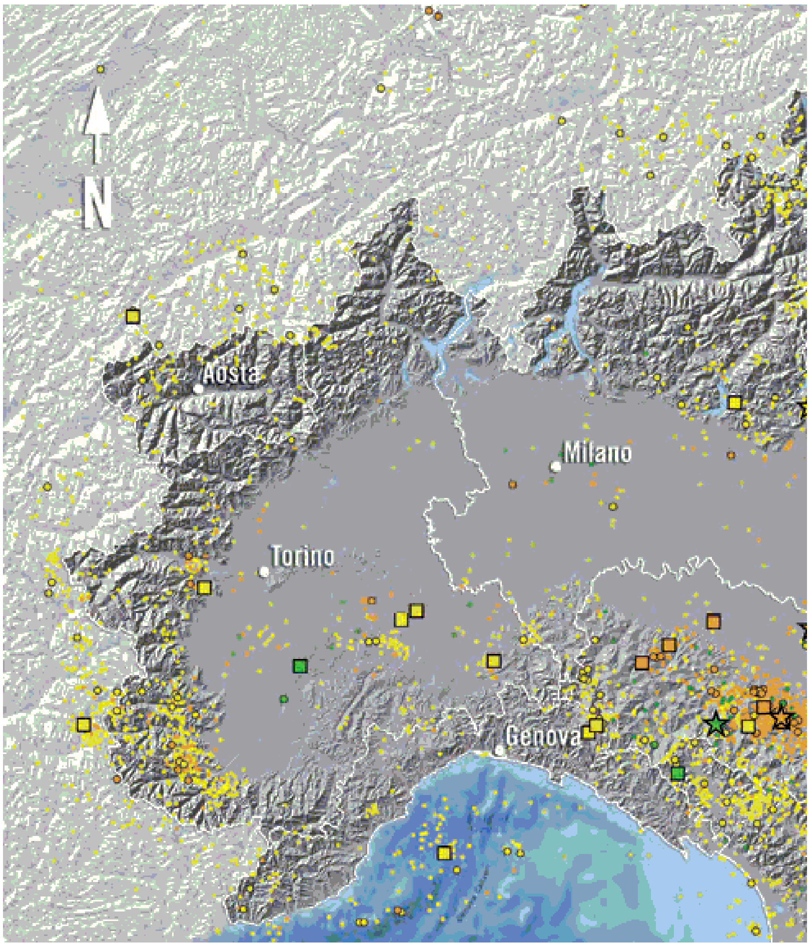

Fig. 20 - A focus on the Piedmont region extracted from the seismicity map of Italy, related to 2000-2012 period (from Pignone et al., 2013).

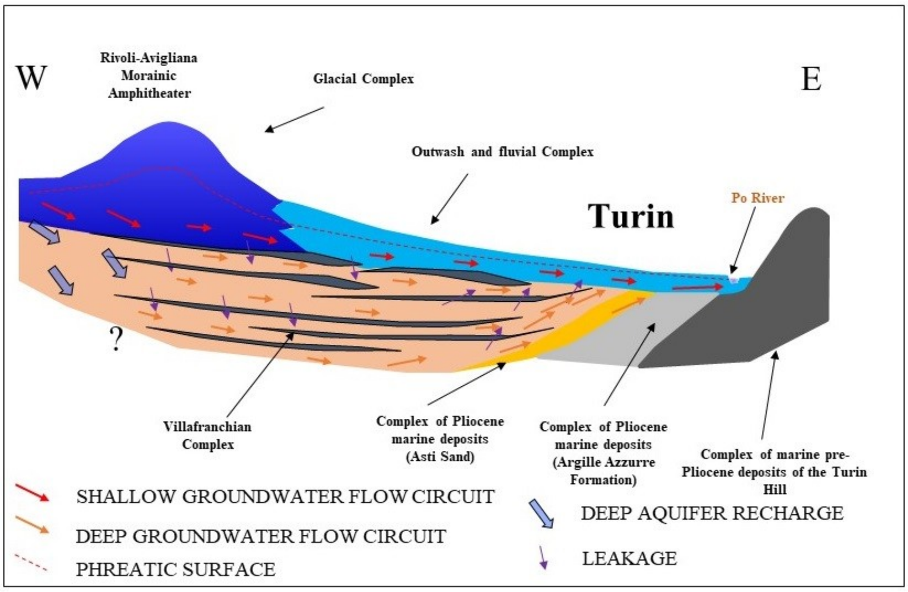

Fig. 21 - Conceptual hydrogeological model of the Turin area, showing deep aquifers, conditioned by the buried hilly structure, and a surficial aquifer both flowing from the Alps towards east.

dium, or are locally permeable by fractures (De Luca et al., 2015).

Two facies can be recognized in the overlying Complex of Pliocene marine deposits: the Argille Azzurre Formation consists of scarcely permeable silt and clay, while the Asti Sand hosts moderate productive aquifers, even if the frequent presence of a fine matrix can limit productivity.

The Villafranchian Complex (Piacenzian and Calabrian) constitutes the substrate of the Middle -Upper Pleistocene cover in most of the area. It consists of alternating sandy gravel (locally, it is possible to identify levels of predominant sand or predominant gravel) and silty clay and sometimes peaty silt. The alternating coarse permeable deposits with impermeable or semipermeable fine deposits generates a multi-aquifer system in which confined or semiconfined aquifers are located in coarse-grained levels, separated by low permeability levels. This multilayered aquifer represents the most exploited groundwater system of the Turin area, in particular for human consumption, but also subordinately for industrial uses.

The glacial Complex (Middle-Upper Pleistocene) exclusively forms the Rivoli-Avigliana Morainic Amphitheatre. These sediments have extremely heterogeneous grain size and appear on the whole to be scarcely permeable. Indeed, the abundant fine-grained matrix reduces the permeability, allowing the development of generally unconfined small aquifers.

The outwash and fluvial Complex (Middle Pleistocene-Holocene) consists of gravel and sandy gravel with boulders, with coarser texture towards the west (Castagna et al., 2015a; 2015b). The base of this hydrogeological complex has a higher slope in the western part of the studied area (near the Alpine edge), while the slope progressively decreases in the eastern area. Some depressions in the base, e.g., in the area between Alpignano, Rivoli and Rivalta-Orbassano, could be related to paleochannels and this morphology influences the groundwater flow (Fig. 22a). A shallow unconfined aquifer is hosted in this complex and is characterized by high productivity, but scarce quality mostly due to industrial contamination in town and agricultural pollutants in rural areas (Lasagna et al., 2015; 2016b; Lasagna & De Luca, 2017; Martinelli et al., 2018). Groundwater flow in the shallow aquifer is directed towards the east, towards the current Po River which represents the main gaining element of the whole Turin Plain (Fig. 22b) (Lasagna et al., 2016a). The piezometric lines range from a maximum of 360 a.s.l. m in the west (Rivoli) to a minimum of 205 a.s.l. m in the northeast (near the Po River). The depth of the water table ranges between 50 metres in the Perialpine sector and 5 m in the sector closest to Turin Hill and the areas surrounding the main

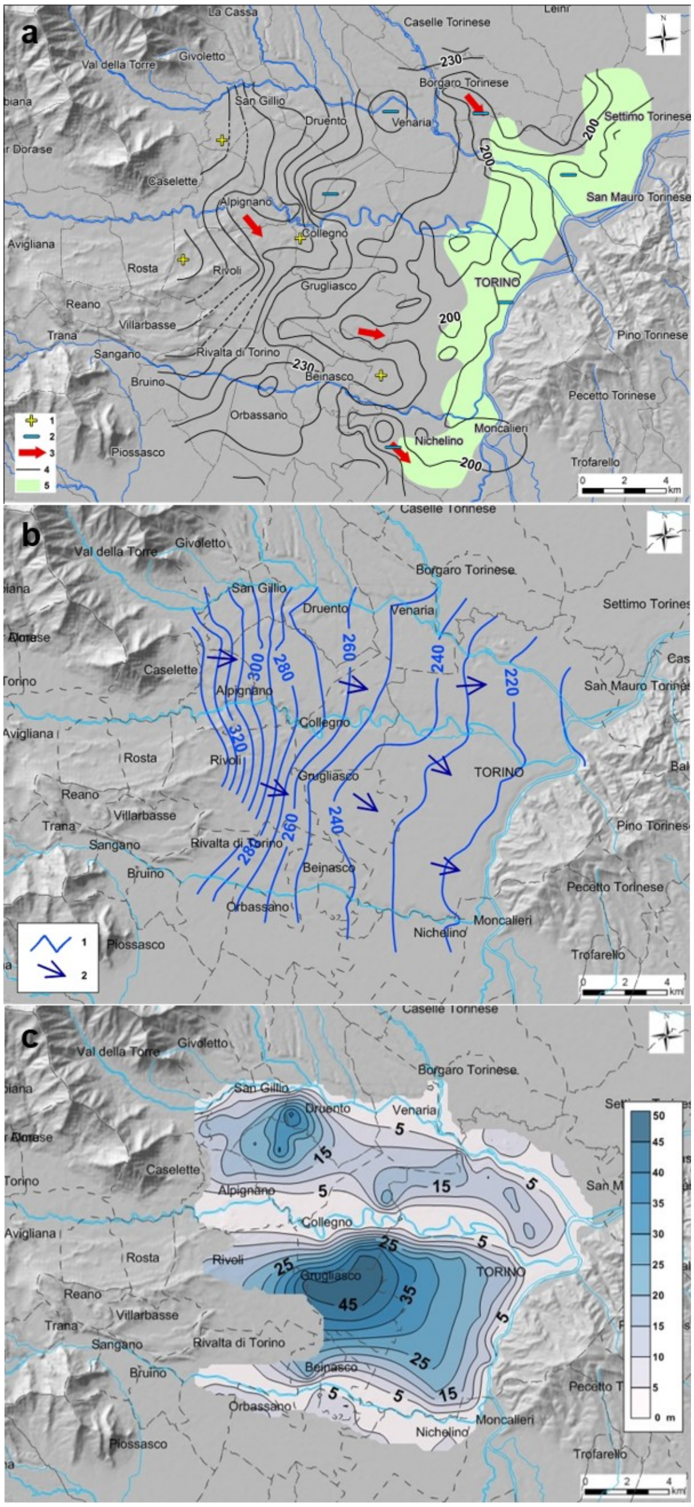

Fig. 22 - a) Map of the base of the outwash and fluvial Complex (1-highest altitude zones; 2-lowest altitude zone; 3- paleochannels; 4- contour lines of the Complex base in a.s.l. m; 5- buried erosional surface); b) Piezometric map of the shallow unconfined aquifer (January 2000) (1-isopiezometric lines in a.s.l. m; 2-flow lines); c) Map of depths to the groundwater table (January 2000).

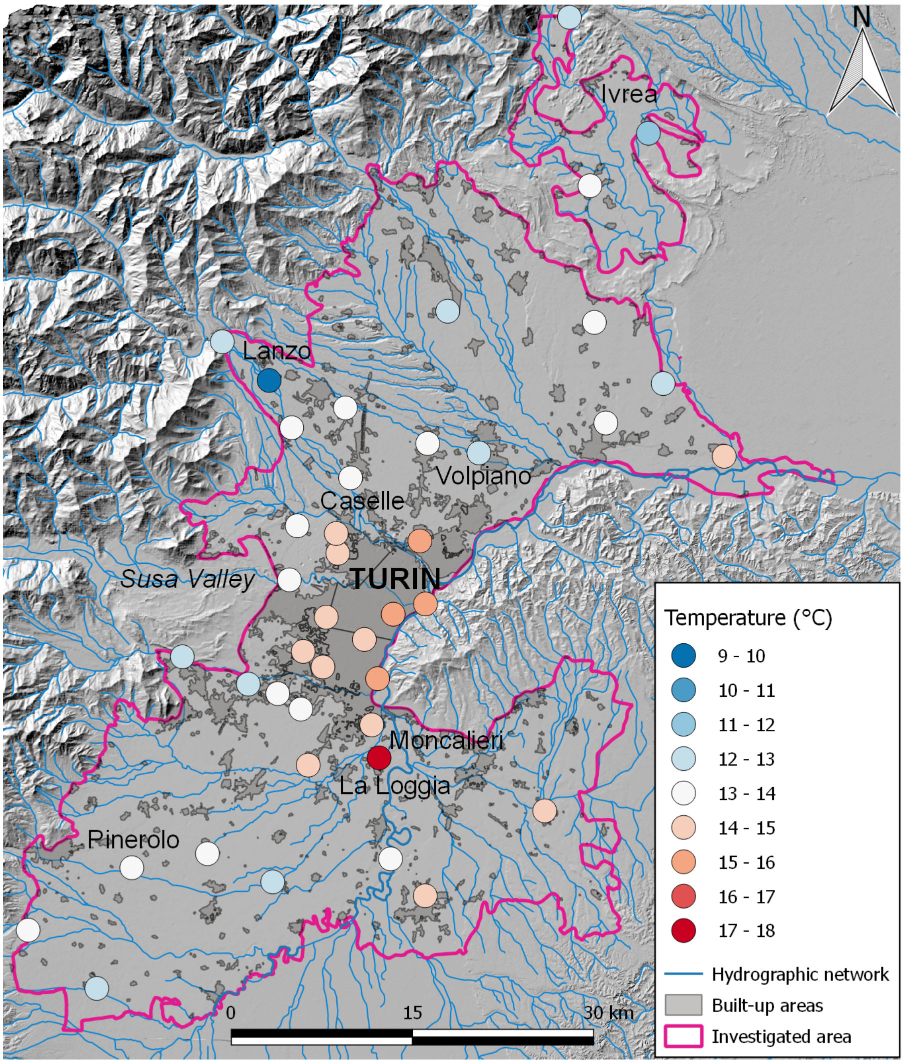

Fig. 23 - Groundwater temperature values of shallow aquifer in Turin area (spring 2014).

rivers (Fig. 22c) (Debernardi et al., 2008).

The hydrogeological conceptual model has been developed on the basis of the stratigraphic reconstruction and the hydrogeological features of the complexes. It describes two main groundwater flow circuits: a shallow flow system and a deep flow system (Fig. 21). The shallow flow system is close to the topographic surface. Groundwater flows in the shallow unconfined aquifer and it is hosted by the outwash and fluvial Complex. The deep flow system is located at greater depth. Deep groundwater flows in the Villafranchian Complex and in the Complex of Pliocene marine deposits. These aquifers can present different degrees of groundwater confinement according to the presence of impermeable or semipermeable layers.

The groundwater recharge of deep aquifers occurs in the foothill sector, in which a highest percentage of coarse deposits is identified than in the surrounding areas. This area can be described as an undifferentiated aquifer. Moving eastwards, the fine-grained levels gradually increase and thicken; this produces a growing confinement of groundwater in the interposed coarse layers.

10. THERMAL REGIME OF SHALLOW GROUNDWATER

Concerning the geothermal applications, the groundwater temperatures of shallow aquifer can be assumed to be relatively constant throughout the year if compared to the wider seasonal air oscillation recorded in a medium temperate climate of continental Europe. The thermal features of the shallow aquifer, in combination with the high productivity and the legal protection of deeper aquifers contributes to create favourable conditions for the large-scale diffusion of groundwater-coupled heat pumps (GWHPs).

The study of the thermal regime of shallow groundwater in the Turin Plain is of primary importance to define the potential exploitation with geothermal heat pumps (GSHPs) in an area where the large heating/cooling demand has driven a new interest in GSHPs.

Studies carried out in 2014 and 2016 (Barbero et al., 2016; Bucci et al., 2017) revealed that the strongest vertical variability of groundwater temperature is found within 10-20 m below ground surface. In spring, deeper temperatures are higher than shallow temperatures, while in autumn the trend is reversed. These variations are connected with the heating and cooling cycles of the ground surface due to seasonal air temperature fluctuations propagating into the aquifer. The groundwater temperature below the zone of seasonal effect, averaged from spring and autumn values extracted from Bucci et al. (2017), is 14.1 °C. The seasonal variations in the upper portion of the aquifer reach 8 °C and are inversely proportional to groundwater table depth. Indeed, the seasonal amplitude reduction with increasing depths means that the vadose zone plays a major role in damping the oscillations, according to similar studies by Burns et al. (2016).

The temperature increases from the foothill sectors close to the Alps towards the central Po Plain are driven by the progressive warming along the flow path (Fig. 23). In the city of Turin's aquifer temperatures are 0.6 ÷1.6 °C higher than in rural sectors. This groundwater warming is linked to the urban heat island effect, which is mainly driven by the typical artificial land use (i.e., Benz et al., 2015). Sparse warmer outliers (16-20 °C) are in some cases connected to documented point heat sources, such as GSHP systems, industrial districts and landfills. For instance, groundwater in some wells 10 km south of Turin city (25 to 30-m deep) is overheated by heat transported from the polluted sector, where exothermic reactions caused by organic matter degradation likely occur (the site has methane burners), and by the asphalted road that, according to previous studies (i.e., Taylor & Stefan, 2009), can increase temperatures up to 3 to 4 °C.

11. GEOTHERMIC USE OF THE SUBSOIL

Geothermal heat pumps represent an interesting technology that is expected to contribute significantly to the reduction of primary energy use for heating and cooling, in particular in urban contexts such as in Turin. The replacement of conventional heating systems such as boilers, with heat pump systems allows the delocalization of emissions of micropollutants from urban centres to the sites in which thermal power stations are operating. This also enhances emission monitoring and control.

In 2017, Turin has had high levels of CO_2 emissions dangerous to human health, and for several days the limits have been exceeded with respect to those allowed by law. The use of distributed production systems based on the use of renewable sources then also reduces CO_2 emissions (Lo Russo et al., 2011).

Urban areas such as Turin have environmental features that may influence the development of low-enthalpy geothermal systems and the choice of the most suitable type of system to be installed (Lo Russo & Taddia, 2009; Baccino et al., 2010). In this general context, the increasing implementation in several areas of the Turin urban city of the open-loop groundwater heat pump technology (a particular technology of geothermal heat pumps that disharge into the aquifer for cooling and heating buildings) could potentially cause, even in the short term, a significant environmental impact associated with thermal interference with groundwater, particularly in the shallow aquifers.

The discharge of water at different temperatures compared to baseline values (warmer in summer and colder in winter) poses several problems in relation to the potential functionality of many existing groundwater uses (drinking water wells, agricultural and industrial aims). In addition, cases may occur of interference between systems, especially in the densely urbanized places. This means that the alteration of the temperature of the groundwater determined by a plant may affect the installations located downstream, with significant alterations to the performances of the systems themselves. In particular, compared to countryside areas or urban areas with small population densities, there are potential issues that need to be considered in the analysis:

a) extensive use of the subsoil;
b) contamination of groundwater;
c) interference between facilities;
d) authorization procedures and legal constraints;
e) competition with alternative energy systems.

In particular the Turin territory is well suited to the analysis of issues related to the impact of heat pumps on groundwater. In this area there is a significant number of installations of medium and large size groundwater heat pumps and this number is still increasing. Among these installations, it is possible to mention the Politecnico di Torino, the Egyptian Museum, the Palace of the Province, the Intesa Sanpaolo skyscraper and future installation of the skyscraper of Regional Government "Regione Piemonte".

Some of these installations are very close to each other and there are potential interference problems. In the case of open-loop heat pumps, water re-injected in the aquifer after its use is characterized by a different temperature than that in the undisturbed aquifer. This thermal disturbance propagates through the groundwater and may affect the temperature of water withdrawals operated by downstream installations. Heat pump efficiency depends on the inlet temperature of water, and therefore there may be unforeseen changes in performances, which often leads to primary energy requirements larger than the initial expectations.

12. CONCLUSION

A multidisciplinary synthesis of the geological and hydrogeological researches on the subsoil of Turin and suburbs is reported, direct to bringing together the different features of subsoil in a single contribution and favouring a more complete view. This work develops partly through the re-examination of the previous geological literature and partly thank to data specially collected (excavations, wells, piezometers and geognostic drillings).

The most of the city and suburbs show a flat morphology at altitudes between 275 m and 230 m a.s.l., with a low slope towards the east, corresponding to the wide outwash fan essentially supplied by the Dora Riparia Basin. The logs of the numerous boreholes drilled in its shallow subsoil report as the outwash sediments, referred to Middle-Upper Pleistocene, generally cover an erosional surface essentially shaped on the Villafranchian succession, referred to Piacenzian and Calabrian. This cover is relatively thin, with thickness between 9 and 57 m. The outwash sediments rest, instead, on the marine succession (Asti Sand or Argille Azzurre Formation) in the northeastern sector of this area (between Torino and Settimo Torinese), where they show thickness of 10-27 m. These sediments are sandy gravel with minor lenses of sandy silt, essentially referred to the Dora Riparia Basin with the contribution of the Stura di Lanzo Basin.

Narrow terraces gently sloping towards NE are located only along the current Po River, entrenched in the Dora Riparia alluvial fan. These terraces are formed by the Po River sediments, with thickness of 13-21 m, that cover an erosional surface essentially shaped on the Miocene-Pliocene marine succession.

The new excavations for the building of the Intesa Sanpaolo skyscraper and the construction of the subway (Line 1 of the Metro) and underground railway pass as well as a new borehole near the Po River promote a more detailed knowledge of the surficial outwash sediments, allowing to distinguish different sedimentary facies (i.e. specifying the location of sandy silty lenses). They are characterized by a various degree of cementation, that results particularly remarkable along the current Dora Riparia River, supplied by a carbonatic basin. Boulders of considerable size (approximately 1 m in diameter) were locally found within these outwash deposits during the excavation for the Intesa Sanpaolo skyscraper, referred to glacial route phenomena.

The setting of Turin subsoil is also connected to the recent deviation of the Po River, that now develops at the NW foot of Turin Hill and instead, during the Middle and Upper Pleistocene, flowed south of Turin Hill (through the southern slope of Turin Hill and the Poirino Plateau). A new reading of this Po deviation as an overflow is made, partly based on a re-examination of all the existing data and particularly the observation that the new river develops along an ancient course of the paleo Dora and not represents a new fluvial bed. Between the new collected data, the observation of peaty sediments along the more recent course of the paleo Po in the Poirino Plateau (late Upper Pleistocene) reported by a geognostic borehole stratigraphy, is used to defining a difficult flow of the paleo Po towards the east, before the overflow.

The recent geological literature reports that the setting of Turin subsoil is strictly influenced by the recent uplift of Turin Hill. The Quaternary different terraced surfaces preserved on the Turin Hill slopes suggest a strong uplift of the hill and of its continuation in the shallow subsoil, that conditioned the flow of the Po River south of Turin Hill. This paper summarizes the structural causes of this recent geological evolution and its relationship with seismicity. The Turin sector is assigned to the 4th seismic zone, the lowest in the national seismic classification. In detail, the seismic potential of the city of Turin is associated with two main districts, represented by the Northern Cottian Alps and the Borbera-Grue (North-Western Apennines) seismic zones.

The Turin and suburbs subsoil shows two groundwater flow circuits corresponding to multi-layered deep aquifers, hosted in the Villafranchian succession and in the Pliocene marine deposits, and surficial aquifers, essentially flowing in the outwash cover. Both the circuits flow from the Alps edge towards east, where the current Po River represents the main gaining element of the whole Turin Plain. In detail, the deep aquifers represent the most exploited groundwater system of the Turin area, in particular for human consumption. The shallow aquifers, beside characterized by high productivity, show instead scarce quality due to industrial contamination in town and agricultural pollutants in rural areas.

The aquifer temperature of the Turin subsoil increases from the sectors close to the Alps towards the central Po Plain, showing a progressive warming along the flow path. In the city of Turin aquifer temperatures are 0.6 ÷1.6 °C higher than in rural sectors. This groundwater warming is linked to the urban heat island effect, which is mainly driven by the typical artificial land use. Unusual warmer outliers (16-20 °C) are essentially connected to point heat sources, such as GSHP systems, industrial districts and landfills.

The Turin territory is well suited to the analysis of the impact of heat pumps on groundwater. A significant number of installations of medium and large size groundwater heat pumps develops and this number is still increasing. Among these installations, it is possible to mention the Politecnico di Torino, the Egyptian Museum, the Palace of the Province, the Intesa Sanpaolo skyscraper and the future installation of the skyscraper of Regional Government “Regione Piemonte”.

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