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LANDSCAPE INFLUENCE ON THE DEVELOPMENT OF THE MEDIEVAL CITY-STATE OF SIENA, ITALY

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ABSTRACT: *Costantini A. & Martini I.P., Landscape influence on the development of the medieval city-state of Siena, Italy.* (IT ISSN 0394-3356, 2010)
This paper examines how the landscape has influenced the development of the medieval–early Renaissance city-state of Siena, Italy. Siena is a hill-top town with a historic ~2 km^2 wide core surrounded by ancient city walls. It still preserves the medieval urban plan and Gothic architecture, and its inhabitants keep ancient traditions alive. It is built on Pliocene, loosely cemented, calcareous, marine, porous sandstone that overlies impermeable marine calcareous silty clay. The town is limited on three sides by steep slopes indented by secondary deep, narrow, small valleys. The forth side to the north is a gently sloping terrain along the hilltop leading to distant highlands. This geomorphologic setting had been beneficial to the development of the town during mediaeval times because readily defendable and, being far from wet, unhealthy, malaria-infested lowlands, it was crossed by a major medieval pilgrimage route (Via Francigena) to Rome. However the hilltop location presented difficulties such as scarce availability of water and limited space to expand.
Siena tried valiantly to adapt to the demand of expanding population and international markets. Two major underground aqueducts were built for a total of about 25 km long tunnels, to bring water both to the centre of the walled town mainly for human consumption and to a major fountain (*fonte*) complex at the base of the hill that was the major medieval industrial site. However, water was never plentiful and became totally insufficient for the expanded mechanized industrialization of cloth-making that started in mid 14th century. Siena could not compete with other towns, like the neighbouring Florence, endowed with fluvial hydraulic power.
Like other hill-towns Siena also had the problem of limited space for its growing population inside city walls. Within the city the space was and still is maximized in two main ways. One is to level hilltops for constructions, such as the Cathedral, or cut terraces into the easily quarried soft sandstone for buildings. The other is to build retaining walls in the upper parts of the secondary, indenting, narrow valleys and partially filing their apex, as it was done during the last century to obtain the stadium and associated athletic facilities, or, in the medieval times, to build the famous Palazzo Pubblico (Town Hall) and its antecedent, sloping semi-arcuate (*Pecten-shell like*) public square.

RIASSUNTO: Costantini A.& Martini I.P., Influenza dell'ambiente sullo sviluppo della città medievale di Siena, Italia. (*IT ISSN 0394-3356, 2010)*
Questo articolo esamina l'influenza che la geologia e la geomorfologia hanno avuto sullo sviluppo della città-stato medievale di Siena. La città antica ha un'estensione di circa 2 km^2 ed il suo centro storico si sviluppa sul culmine di tre colline. L'impronta medievale della città è segnalata dall'architettura gotica, dalla planimetria e dalle sue mura. La città è costruita su arenarie calcaree di età pliocenica, poco cementate, porose, deposte principalmente in ambiente litorale, che poggiano su argille marine calcaree ed impermeabili. Le arenarie formano delle ripide scarpate (coste) che delimitano la città su tre lati. Solo verso nord è presente un crinale piu' dolce che raccorda la città in modo quasi pianeggiante con il resto del territorio. Questa situazione morfologica ha avvantaggiato la città durante il medioevo rendendola praticamente inespugnabile. La posizione collinare di Siena costituì, inoltre, un altro vantaggio proteggendola dalla malaria. Quando i tratti delle antiche strade romane, che correvano lungo le coste tirreniche ed nelle valli appenniniche interne che divennero infestate dalla malaria perchè impaludate, divennero impraticabili, i pellegrini che viaggiavano verso Roma e quelli che dalla città eterna si spostavano verso l'Europa, scelsero il percorso (Via Francigena) piu'salubre che passava per Siena. Il grande incremento nel numero di pellegrini che sostavano a Siena comportò aumento di ricchezza e di popolazione.
Dalla seconda metà del XIV secolo lo sviluppo della città fu però limitato dalla scarsità di acqua e di spazio disponibile per espandersi. L'aumento del fabbisogno idrico comportò l'escavazione di acquedotti sotterranei per un totale di circa 25 km. L'acqua ottenuta, tuttavia, non fu mai sufficiente per la città e l'industria tessile che stava crescendo, e dentro, la cinta muraria, non vi era spazio per allargare i complessi industriali. Siena non poté quindi piu' competere contro altre città, come Firenze, che potevano avvalersi della forza idraulica dei loro fiumi per sviluppare l'industria.
Siena utilizzò al massimo lo spazio che aveva dentro le mura spianando le colline e le asperità del terreno o accumulando riporti per ubicarvi palazzi e costruzioni. Ad interventi del genere si devono la realizzazione, nel Medioevo, della Piazza del Campo, del Palazzo Pubblico e della Piazza del Mercato. In tempi moderni la costruzione dello stadio comunale, ubicato all'interno di una delle valli che si insinuano fino al centro della città.
Il continuo impegno per utilizzare al meglio le caratteristiche morfologiche ed idrogeologiche del proprio territorio sviluppò nei Senesi fin dall'antichità, un uso parsimonioso e molteplice delle risorse naturali e dell'acqua in particolare (Siena la città con poca acqua sviluppò una vera e propria "cultura dell'acqua"). I Senesi, modificando solo in parte e senza deturparla la morfologia del luogo, riuscirono a costruire monumenti unici come il complesso del Duomo, e la famosa Piazza del Campo, la cui forma di conchiglia e' dovuta all'adattamento della piazza all'apice di una valle.

Keywords: Medieval city-state, underground aqueducts, development with nature, landscape limitations for city development, pilgrimage routes, Via Francigena.

Parole Chiave: Città-stato medievale, acquedotti sotterranei, sviluppo compatibile con la natura, limitazioni ambientali per lo sviluppo urbano, pellegrinaggio, Via Francigena.

1. INTRODUCTION

Geology and geomorphology affect human activities, and, conversely, humans often modify the environment to adapt it to their needs, differently in different time periods, (MARTINI *et al*., 2010). The objective of this paper is to analyze relationships between the landscape features (such as geology, geomorphology, climate, and hydrology) and the human activities, and how these contributed to the development of the city-state of Siena during the medieval to early-Renaissance times.

Siena is located in the central-north part of Italy, in the Tuscan Region, west of the Northern Apennines Mountains (Fig. 1). It is about 70 km from its perennial rival Florence, 130 km from Pisa/Leghorn the main Tyrrhenian harbour of the province, and 80 km from Grosseto the main centre of the Maremma that was one of the main granaries of ancient Siena along the Tyrrhenian Sea.

Siena was built along a hillcrest. Its historical centre is about 2 Km^2 wide. It is still surrounded by intact ancient city walls, and preserves much of the original medieval urban plan. The modern inhabitants maintain many of the ancient structures and traditions alive. One example is the subdivision of the city into 17 neighbourhoods (*contrade*). Their ancient rivalries are still played out in bareback horse races (called *Palio*) twice a year.

1.1. Environmental conditions

1.1.1. Geology

Siena is located at the NW margin of the Siena-Radicofani Basin. This is one of the basins of Tuscany that developed in NW–SE directed tectonic depressions delimited by major thrust and normal faults (Fig. 1) (MARTINI & SAGRI, 1993; BONINI & SANI, 2002). The SW flank of the basin is composed of Triassic–Miocene metamorphic and sedimentary rocks, the NE flank of Triassic–Oligocene sedimentary rocks, mostly sandstones. The partial filling of the basins consists of Pliocene offshore marine, calcareous, silty clays toward the centre with some intercalations of sandstones and conglomerates, and shallow marine sandstones, conglomerates and lagoonal silty deposits toward the margins. The sedimentary deposits underlying Siena are characterized by marine silty clays at the base, overlain by a series (up to seven in places) of shallowing upward parasequences formed mainly by calcareous, fossiliferous, marine shoreface sandstones, coastal conglomerates, and some lagoonal deposits (Fig. 2) (TERZUOLI, 1997; COSTANTINI & MARTINI, 2004).The sandstones are poorly cemented (the cement constitutes 5 % in volume of the rock), but sufficiently strong to be a good substrate for buildings and for stability of steep slopes. The conglomerates occur as two major facies. One is characterized by clasts-supported, internally poorly stratified deposits of medium sorted, well rounded clasts up to 15 cm in diameter. They are interpreted as fluvial channel deposits. The other is characterised by clasts-supported, weakly internally stratified deposits with well sorted, well rounded, flat clasts up to 10 cm in diameter. These are interpreted as beach deposits.

The substrate of Siena is cut by several normal faults oriented NW–SE and NE–SW. The faults are still active and they have been responsible for several earthquakes, most of low intensity (V–VI in the Mercalli scale: less than 5 in the Richter scale; CASTELLI & BERNARDINI, 2006). A series of these earthquakes that started on September 21 and terminated on December 29 of 1697 is famous because reported in the ancient town registers of Siena (*Bicherna*) (FUSAI, 1991). Some destructive earthquakes did occur as well, such as those that occurred in 1792 and 1798 (FIORINI, 1991). They damaged columns supporting the dome of the Cathedral (Duomo) (CA, Fig. 3), toppled the upper part of the bell tower of the church of S. Domenico (SD, Fig. 3), other private towers, and damaged several habitations particularly in the area of Fontebranda (FB, Fig. 3).

Siena benefitted from various geological resources. Among these, clays for ceramic products were obtained from the nearby basin floor (most of Siena is built of bricks), carbonates from the hills bounding the basin were used for some early towers and several palaces, sandstone from the near Apennines Mountains

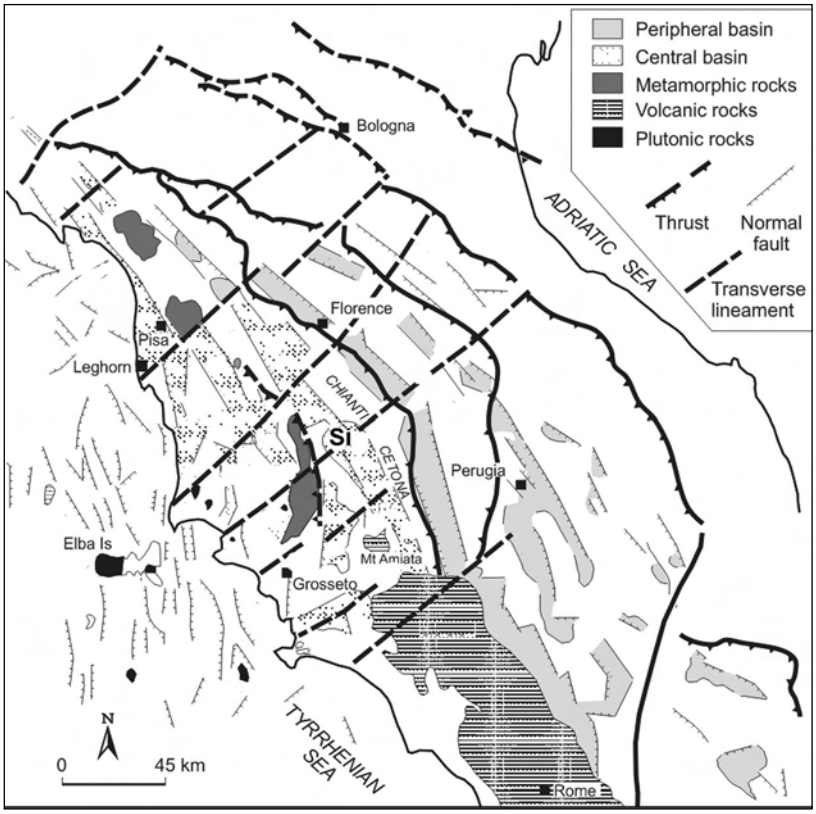


Fig. 1 - Generalized structural maps of the Northern Apennines. Major structural features and Neogene–Quaternary basins of the Northern Apennines (Si: Siena town and Siena-Radicofani Basin). (After PASCUCCI *et al*., 2007).

Mappa strutturale schematica dell'Appennino Settentrionale. Strutture principali e bacini neogenico-quaternari. (Si: città di Siena e bacino di Siena-Radicofani. (Modificata da PASCUCCI et al.*, 2007).*

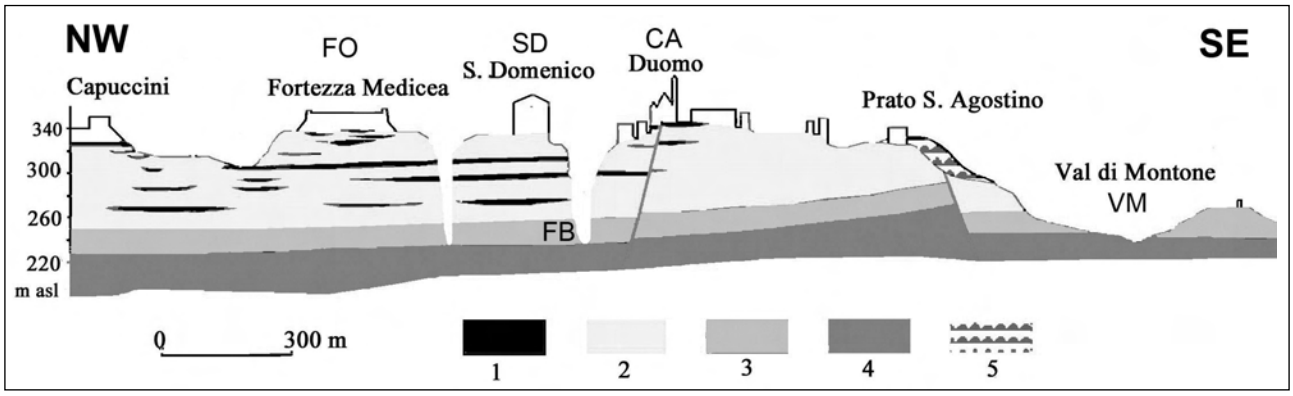


Fig. 2 - Schematic cross-section of the Pliocene deposits under Siena (1: marine silty clay; 2: sandstone; 3: basal argillaceous sandstone; 4: sandy conglomerate lenses; straight inclined line below the Cathedral (Duomo): normal fault; CA: Duomo (Cathedral); FB: Fontebranda; FO: Fortezza (Fort); SD: S. Domenico; VM: Val di Montone; see location of cross-section on Figure 3). (After LAZZAROTTO & PASCUCCI, 1998).

Sezione schematica dei depositi pliocenici sui quali poggia Siena (1: argille marine; 2: arenarie; 3: arenarie argillose basali; 4: lenti di conglomerati sabbiosi; linea inclinata sotto il duomo: faglia normale; FB: Fontebranda). Vedi traccia della sezione sulla Figura 3. (Modificata da LAZZAROTTO & PASCUCCI, 1998).

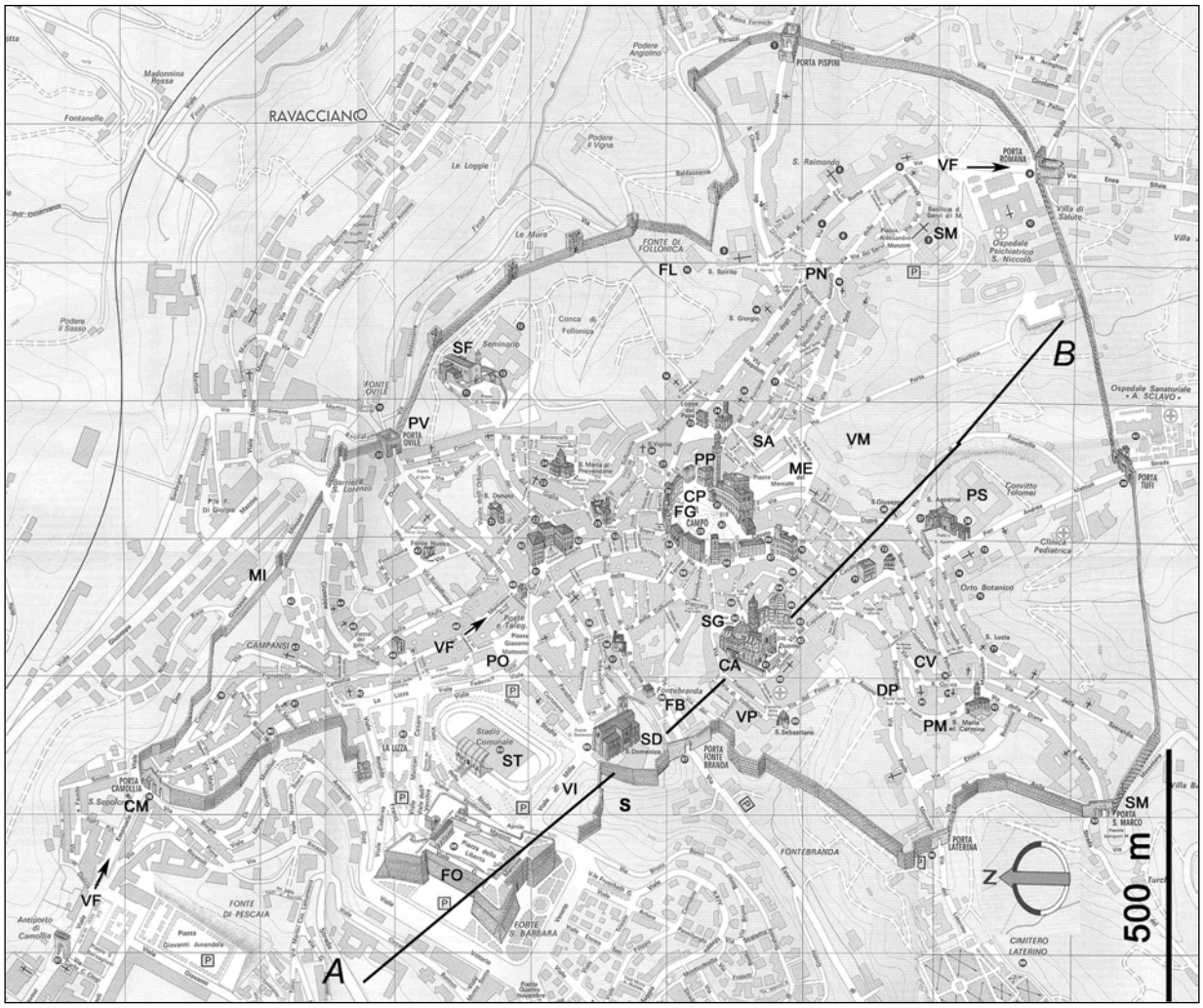


Fig. 3 - Map of Siena showing the city walls and sites mentioned in the text. (A–B Coss-section shown in Figure 2; CA: Duomo (Cathedral); CM: Camollia; CP: Il Campo (piazza); CV: Castelvecchio; DP: Due Porte; FB: Fontebranda; FG: Fonte Gaia; FL: Fonte di Follonica; FO: Fortezza (Fort) ; ME: Piazza del Mercato; MI: Viale G. Minzoni; PM: Pian dei Mantelini; PN: Ponte di Romana; PO: Piazza della Posta (Matteotti Square); PP: Palazzo Pubblico (Town Hall); PS: Prato di S. Agostino; PV: Porta Ovile; S: Rastrello Valley; SA: Salicotto; SD: S. Domenico; SF: S. Francesco; SG: Piazza S. Giovanni; SM: Porta S. Marco; ST: Stadio Comunale (Soccer field); VF: Via Francigena; VI: Viale dei Mille; VM: Val di Montone; VP: Vallepiatta street).

Mappa di Siena che mostra la cinta muraria ed i siti discussi nel testo. (A–B sezione mostrata in figura 2; CA: Duomo (Cathedral); CM: Camollia; CP: Il campo (piazza); CV: Castelvecchio; DP: Due Porte; FB: Fontebranda; FG: Fonte Gaia; FL: Fonte di Follonica; FO: Fortezza (Fort) ; ME: Piazza del Mercato; MI: Viale G. Minzoni; PM: Pian dei Mantelini; PN: Ponte di Romana; PO: Piazza della Posta (Matteotti Square); PP: Palazzo Pubblico (Town Hall); PS: Prato di S. Agostino; PV: Porta Ovile; S: Valle del Rastrello; SA: Salicotto; SD: S. Domenico; SF: S. Francesco; SG: Piazza S. Giovanni; SM: Porta S. Marco; ST: Stadio Comunale (Soccer field); VF: Via Francigena; VI: Viale dei Mille; VM: Val di Montone; VP: Via di Vallepiatta).

were and are still used for street paving, and other ornamental rocks have been used such as marble, travertine, some limestone, and metamorphosed volcanic rocks (Balestracci & Piccinni, 1977). Furthermore during the medieval times Siena extracted ore, including silver for its coin, and iron, from the Colline Metallifere, a chain of low hills located to the SW of Siena halfway to the Tyrrhenian Sea.

1.1.2. Geomorphology

Siena is located on an elongated hill that protrudes southeastward into the Siena Basin from the Chianti–Cetona highlands (Fig. 1). Consequently the ancient town is bounded by very steep slopes on three sides indented diagonally by narrow deep secondary valleys, and a gently northwestward grading hillcrest. This imparts a characteristic birdfoot (reversed Y) shape to the city-map (Fig. 4). During the medieval and early Renaissance times Siena was not expugnable from three flanks. The fourth flank was protected by extra fortifications and double city door (*antiporto*).

Ancient Siena, however, did not have a reliable sufficient supply of water. No permanent streams exist there. Two small seasonal creeks are present near the base of the hill and some springs with limited output are present at the boundary between the sandstone aquifer and the underlying impermeable clays. Therefore there never was sufficient water supply for the fast growing ancient city and its industries.

1.1.3. Climate and agriculture

Siena has a typical warm Mediterranean climate mitigated by moderate windy conditions. Maximum temperatures are registered in July and August with a monthly average of 28°C together with the least monthly precipitation of 28 and 30 mm respectively. Minimum temperatures are reached between December and February with monthly averages of 3°C to 4°C. Maximum monthly average precipitation is reached in November with about 112 mm, and, except for the summer, the monthly average ranges between 60 to 90 mm. This means that during the summer the clayish countryside of the Siena basin becomes dry and unproductive. During the spring and autumn, though, the precipitation is sufficient for a good production of cereals (mainly wheat) and grass. Very good-quality oil and wine are produced from the surrounding hills. During medieval times Siena could also obtain foodstuff from Maremma that was a very fertile area, although vexed by lethal malaria.

2. LANDSCAPE AND HUMANS: ADAPTION AND LIMITATIONS

The development of societies mostly depends on internal and external sociological, political and economic conditions, but, particularly in emerging entities, it is also greatly affected by the geology, morphology, climate and hydrology of the land; that is, the landscape. The landscape-influence differs from locality to locality, or in the same place from one time period to another as societies evolve and needs change.

2.1. Siena pre-medieval times

The peopling of Siena in antiquity is not well documented. Only a few pre-medieval archaeological sites have been found in some hills along the southwestern side of the basin (Fiorini, 1991), a possible Etruscan tomb has been documented near Siena, and some tunnels near springs at the base of the hill have bell-shaped roofs typical of Etruscan constructions.

The Roman occupation of the area is better documented, although Siena probably remained a colony of secondary importance. There are several archaeological finding in Siena among which a mosaic and a buried pavement that most likely was part of the floor of a street or a cistern. Some documents report cavity habitations cut into the sandy substrate (locally called *tufo*) near the main square of Siena (Il Campo: CP on Fig. 3) where there were numerous taverns (*tabernae*). Poorly preserved ruins of Roman baths (terme) have been found near Siena (Bargagli Petrucci, 1992). Furthermore the colony is mentioned in Roman maps as *Sena Julia*. The Roman occupation has fomented the legend that Siena was founded by the mythical sons (Aschius and Senius) of Remus (Remus was one the two founders of Rome). Like the father, they are belie-

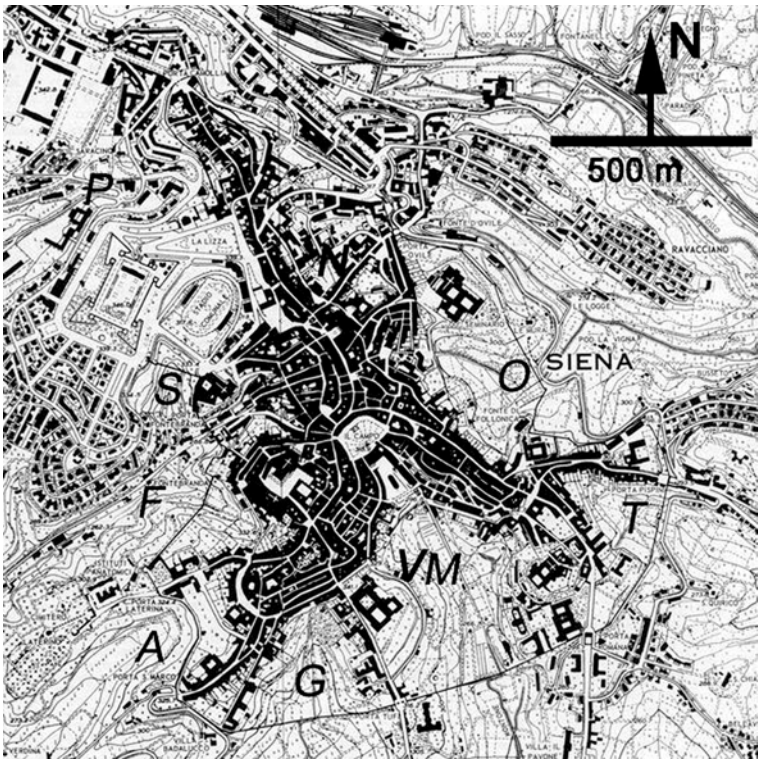


Fig. 4 - Schematic 1965 topographic map of Siena with indication of the secondary narrow valleys that indent the main Sienese hill. (A: S. Ansano; F: Fontebranda; G: Gavina; N: Fontenova; O: Follonica; P: Pescaia; S: Rastrello; T: Pispini; VM: Montone).

Carta topogafica del 1965 della zona di Siena che mostra le valli secondarie che risalgono fino al centro della città. (VM: Montone; G: Gavina; A: St Ansano; F: Fontebranda; S: Rastrello; P: Pescaia; N: Fontenova; O: Follonica; T: Pispini).

ved to have been nursed by a female wolf. It is also said that a statue of Venus was found near a spring. This suggests that Romans managed the small local springs trying to increase the outflows.

2.2. Siena during the medieval to early Renaissance times

Siena is essentially a medieval city. It was one of the first independent city-states (comune), and reached its best period during the XII–first half of the XIV century. The city developed through the agglomeration of early villages/castles located in adjacent slightly higher lands in the Siena area (Catelvecchio (CV)–Duomo:CA), Castel Montone (Castel Montorio–S. Maria dei Servi:MS) and Castello del Poggio Malavolti (~Camollia:CM) (Fig. 3) (FIORINI, 1991; LIBRO DELL'ISTRICE, 2004). As the city enlarged, several new wider city walls were built, eventually enclosing most of the bottom-valley fountains (*fonti*) including those of Fontebranda (FB) and Follonica (FL), and several agricultural fields (locally called *orti*) useful during sieges (Figs. 3, 5). As new walls were built, the remnants of the older ones became part of the cityscape and were incorporated in habitations. The city-walls were built differently according to the location: they were built at the top of steep, long slopes, such as at S. Francesco (SF)–Porta Ovile (PV), Viale Don Minzoni (VM), Porta S. Marco (SM) (Fig. 3). They, instead, covered the side of smaller scarps and built slightly higher for defence, such as just east of the Due Porte (DP) along Pian dei Mantellini (PM). One common way to build the walls was *a sacco*. That is, two brick walls were raised close to each other and the space between them was filled with loose, pressed gravel (Fig. 6). Reinforced buttresses were constructed to reinforce the walls where they cross fault zones.

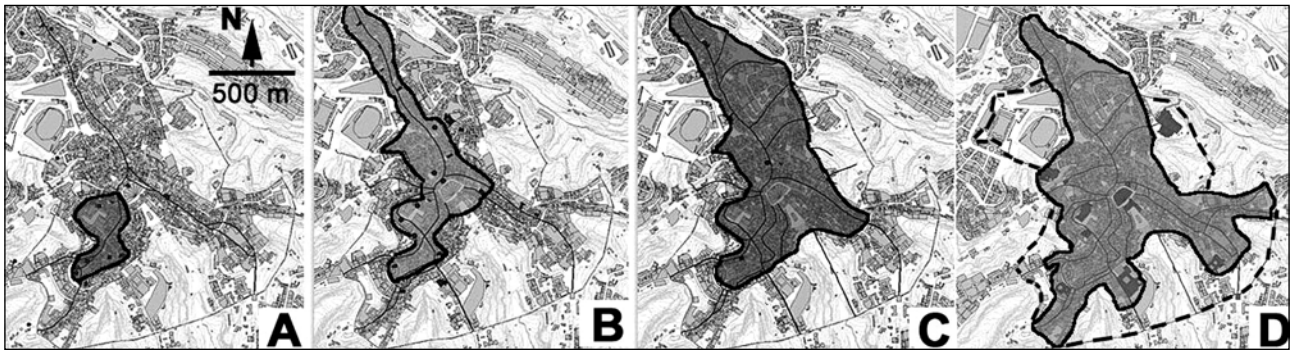


Fig. 5 - Maps showing the various city walls built at different times as the city was enlarging. (After BORTOLOTTI, 1988; Department of Archaeology of the University of Siena). (**A**) Early Medieval Age. (**B**) First half of 12th century. (**C**) Beginning of 13th century. (**D**) Solid line: half of 13th century, dashed line 15th century.

Mappe di Siena che mostrano i vari stadi di costruzione della cinta muraria (da mappe schematiche del Dipartimento di Archeologia dell'Università di Siena). (Modificate da BORTOLOTTI, 1988 e da mappe del Dipartimento di Archeologia dell'Univeristá di Siena). (***A***) *Etá Medievale.* (***B***) *Prima metà del XII secolo.* (***C***) *Inizio del XIII secolo.* (***D***) *Linea continua: metàl del XIII secolo, linea spezzata XV secolo).*

Fig. 6 - Typical construction "a sacco" of the city walls of Siena.

Costruzione tipica "a sacco" della cinta muraria di Siena.

2.2.1. Houses, palaces and towers

Many early habitations of Siena were caves excavated in the relatively soft sandstone substrate, and wooden buildings. These were progressively substituted, especially staring in the second half of the 13th century, by houses built with wood and bricks (Fig. 7). Some palaces, towers and churches were made of stones, mainly limestone. The use of the substrate as integral part of habitations lasted through the medieval times as shown by the walls of a house composed of remnant natural strata of conglomerates still visible in Piazza S. Giovanni (SG, Figs. 3, 8A). Ornamental stones like marble and serpentinites (weathered ophiolites) were used for churches and some monuments. Towers, originally made of stones and later of bricks, had the double function of status symbol (the higher the tower, the higher was the wealth and political status of the family) and defence (Fig. 8B). Later on, they were remodelled as habitations (*case-torri*).

Fig. 7 - Modern view of the Fontebranda street climbing toward the medieval houses of the city centre constructed with bricks.
In the background the tower of the Town Hall (called Torre del Mangia).

Fotografia recente della strada di Fontebranda che sale verso le case medievali del centro cittadino costruite in mattoni. La torre comunale del Mangia si intravvede all'orizzonte.

The use of bricks in Siena became eventually predominant for every construction because the clay resource was readily available nearby at low cost (Zdekauer, 1896/1980; Bortolotti, 1988). During early stages, the furnaces to make bricks were located within the city. However they were a continuous fire risk for the surrounding wooden houses and were eventually moved into the countryside. As the population grew, the habitations were built closer to each other along narrow steep streets within the limited space enclosed by the city walls. It has been estimated that in the first decades of the 14th century Siena reached a population of 50,000 people living in a 2 km^2 area (Bairock *et al*., 1988; Ginatempo & Sandri, 1990; Pirillo, 1994).

Siena is primarily characterized by a Gothic stile, modified in places by the development of the typical *arco Senese* that is a cuspate high gothic arc enclosing a lower round arc (Fig. 9). To preserve the medieval architectonic characteristics, recent restructuration (latest 1900s) of houses of entire neighbourhoods, such as the Salicotto (SA, Fig. 3), was made utilizing bricks in the same old fashion and similar architecture.

2.2.2. Eco-sociologic conditions promoting the expansion of the city-state

The city-state of Siena reached its golden developmental period toward the end of the 13th and the beginning of the 14th century under the Governo dei Nove (Government of the Nine: 1287–1355) when major buildings such as the Palazzo Pubblico (PP: Town Hall, Fig. 3) were completed, and some ambitious constructions were initiated but never completed, such a huge cathedral of which only an unfinished facade and some columns remain.

The development of the city-state was greatly influenced by the Via (route) Francigena (VF) used by pilgrims travelling from various parts of Europe toward Rome (Fig. 10). This was a route over the hills, which was preferred to the older Roman roads that crossed the coastal plains of the Tyrrhenian Sea (Via

Fig. 8 - Views of Siena. **(A)** Lower part of the Battistero and stairs leading up to the Cathedral square. Note conglomerate layer (arrow) enclosed in the wall of the houses to the left. (**B**) Ancient tower built with stones.).

Viste di Siena. (***A)*** *Parte basale del Battistero e scalinata che porta in alto a Piazza del Duomo. Nota lo strato di conglomerato (freccia) che è stato incluso nel muro di una casa.* (***B***) Antica torre costruita in pietra.

Aurelia) and inland valleys, such as the Val di Chiana (Via Cassia), infested by malaria. Siena catered well to pilgrims in several ways. It offered accommodation, health care, and, importantly, protection from profiteering hosts within the city and, within its territory, from the numerous brigands that preyed on the travellers along the route. It also offered money change (Siena at that time had its silver coin) and banking facilities so that the people could leave in safekeeping part of what they owned before adventuring toward the dangerous Roman area. The pilgrims brought wealth to the city directly and also by being good ambassadors when they returned to their states. Siena at that time was one of the most important traders in the European markets, particularly for wool cloth, and its banks served popes, cardinals and princes.

2.2.3. Geo-sociologic conditions hampering development and capability to compete

Environmental constraints, continuous competition and fighting internally and against the neighbouring rival Florence, unwise political and economic decisions, and the terrible tragedy of the pestilence bouts of the 14th century starting with the one of 1348 that reduced the population by 2/3 (to less than 20,000 people), weakened tremendously the city (Bowski, 1964, http://www.jstor.org/stable/2850126?seq=1; Pinto, 2002). Siena was not capable to rebound after the pestilence, adapt to the new world's conditions, and compete with

Fig. 9 - Gothic architecture in Siena: detail view of the Santa Maria della Scala Museum fronting the Cathedral square. This is a large building used as hospice for medieval pilgrims and as hospital until the last century. Note the typical arco senese above the now sealed doors (arrows).

Architettura gotica senese: dettaglio della facciata del complesso museale di Santa Maria della Scala (ex ospedale). Questo grosso edificio ha ospitato un ospedale per pellegrini nel medioevo ed ha svolto le funzioni di ospedale civile fino al 1980. Oggi è diventato il principale complesso museale senese. Nota il tipo arco senese sulle porte murate basali (frecce).

larger cities, like Florence, that, instead, experienced strong and fast demographic, economic and political development. The fortunes of Siena progressively decreased and the city-state was eventually defeated in 1555 by a Spanish-Florentine army, and became part of the Granducato di Toscana of the Medici of Florence in 1557. A Sienese republican government resisted in a nearby fortified small town until 1559 (http://en.wikipedia.org/wiki/Siena).

Low supply of water and insufficient accommodation space were two of the most important landscape features that limited the development of the city-state of Siena in the medieval and early-Renaissance times although that society tried valiantly to adapt and modify the existent conditions to its advantage.

2.2.3.1. Water in medieval Siena

The water supply from local bottom-valley springs was sufficient for the few early habitants of Siena, but as the city enlarged, more water was needed particularly starting in the 1100s. The output of the local springs was augmented by opening the contact between the aquitard and aquifuge layers enlarging local tunnels. As the demand for water increased further, two large underground aqueducts – Bottino Maestro di Fontebranda (FB) and that of Fonte Gaia (FG) – were built, the latter between 1334 and 1466 (BALESTRACCI *et al*., 1983; BALESTRACCI, 1984/85, 1993; KUCHER, 2005). These aqueducts consist of 25 km long tunnels (Fig. 11A). It was possible to readily excavate the tunnels with hand-tools of the time because the calcareous sandstone of the substrate is relatively soft, and naturally maintains vertical walls (Fig. 11B). Only locally, particularly where fault zones were crossed, brick reinforcing walls were needed. Occasionally along

Fig. 10 - Via Francigena: major medieval pilgrim route through north-central Italy toward Rome. The map shows slight variations along the Via Francigena as wells as the ancient Roman roads (Via Aurelia and Via Cassia) that crossed malaria-infested lowlands. (After FLETCHER 2000/2008).

Via Francigena: una strada di pellegrinagio importante attraverso l'Italia verso Roma. La mappa mostra i vari percorsi e la loro posizione rispetto alle antiche strade romane (Via Aurelia e Via Cassia) che attraversavano aree pianeggianti che nel tempo si impaludarono e furono infestate dalla malaria. (Modificata da FLETCHER 2000/2008).

the route, harder concretions were encountered, and the tunnels were slightly modified from the standard size of 0.80 m in width and 1.80 m in height. The tunnels were excavated primarily by experienced miners that had worked in the mineral mines of the Colline Metallifere. To accelerate constructions of the Bottino Mestro di Fonte Gaia two crews were used, one working from the aqueduct-end in the main town square (Piazza del Campo) backward and the other from just outside the city walls toward the centre. Some levelling errors were made and they are still recorded by the modifications made to the tunnels (higher and/or wider) at the points of encounter of the two crews (COSTANTINI & MARTINI, 2004).

The two underground aqueducts get water from various small springs on the nearby northwestern higher lands. These springs have developed at the contact between coastal calcareous argillaceous sandstone layers and silty, clayish lagoonal deposits of the margins of the Siena Basin (COSTANTINI & MARTINI, 2004). One of the aqueducts (Bottino Mestro di Fontebranda) carries the waters to the base of the Siena hill were there also is the original larger spring of the area (Fig. 11A). The other aqueduct (Bottino Maestro di Fonte Gaia) carries the water to the centre of town in the main square, in front of the Palazzo Pubblico and to other parts of the walled town (Fig. 11A; see http://www.italyguides.it/us/siena_italy/piazza_del_campo/fonte_gaia.htm for interactive detailed view and 360° moving panoramic about these and other Sienese localities). Originally the aqueducts supplied water only to public fountains (fonti). Later, starting in the 1500s, secondary tunnels were built under the city to carry water from the Bottino Maestro di Fonte Gaia to wells under palaces and religious buildings.

These were not the first underground aqueducts constructed in antiquity in the world. Similar underground canals were built mainly for irrigation in China (*karezes*, II sec. BC), in the Middle East (*qanats*; 1st millennium BC; KUCHER, 2005), in North Africa (the ancient fogarras) and, of course, the numerous Roman aqueducts. However the construction of the aqueduct of Siena was a great engineering feat for the times because of the hydraulic innovations implemented. With rudimentary tools the miners succeeded in maintaining a regular slope of 2‰ of the tunnel floors for the water to flow properly. Under the city they devised simple strategies, such as locally meandering the small canal (*gorello* on Fig. 11B) carrying the water within the tunnel, to slow and thus deepen the flow and go from the main aqueduct to secondary ones through small holes in a small barrier used to measure the amount of water to be paid by the users. Also large decantation pool (Fig. 11C) were built in 1338 near the entrance of the town to settle silt that had entered the system during particularly heavy precipitations, and also to allow for calcite to precipitate from the very hard waters before they were distributed to the public fountains and private wells.

Public fountains (*fonti*) were built at the end of the main aqueducts and in front of local tunnels dug to enlarge the outflow from springs at the base of the Siena hill. They were built for maximum use of the scanty water resource. Some fonti were monumental, such as the Fonte Gaia in Piazza del Campo (PC) (Figs. 3, 12), but they too were used, for a time, for public needs, such as washing interiors of animals sold in the market held in the main city square. Others, like Fontebranda (built first in 1198 and rebuilt in 1246), were complex establishments (Fig. 13). They consisted of a series of buildings and pools. The first pool was invariably for water for human consumption. In some fonti this was followed by a pool to raise fish, responding to religious diets of the time. In most others, the first pool was followed by others for animals to drink and be washed, then others for washing clothes; the waters were then canalized to run small mills, and finally to irrigate field outside the city walls. The Fontebranda complex had some of the pure water from the aqueduct also deviated into additional pools/cisterns to wash wool and manufacture wool cloth, and other water was used in the processing of slaughtered animals. So Siena, the city that always suffered from a limited amount of water instituted a 'culture of water' fostering conservation and maximum multiuse. Nevertheless water was never enough for the enlarging city and for the industry of cloth to satisfy the burgeoning European markets especially from the mid 14th century on.

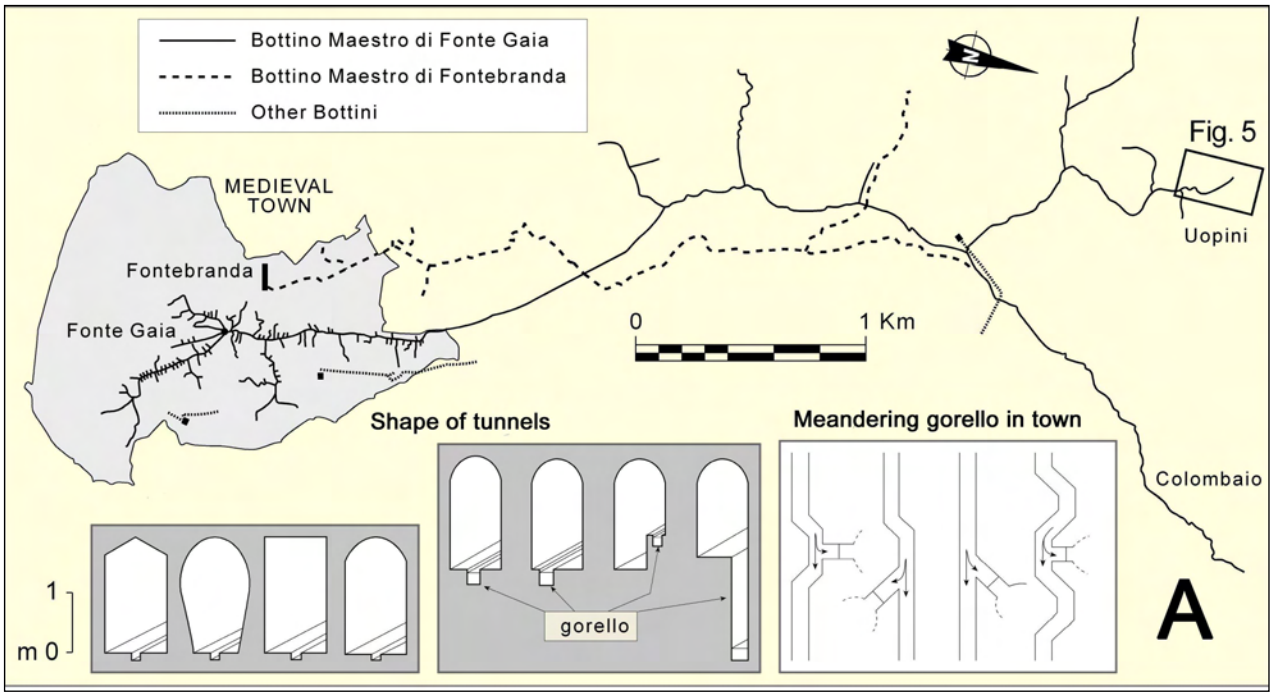
Nowadays the ancient underground aqueducts have been partly restructured and water is used mainly for irrigating city gardens. It cannot be used for human consumption because the source area is not protected against potential contaminations and the tunnels are not kept free of calcium carbonate incrustations and pollutants as they were during medieval times. Potable water is now obtained for Siena through modern aqueducts from the distant volcanic hills of Mt. Amiata located to the south (Fig. 1) and from deep wells dug near the centre of the basin.

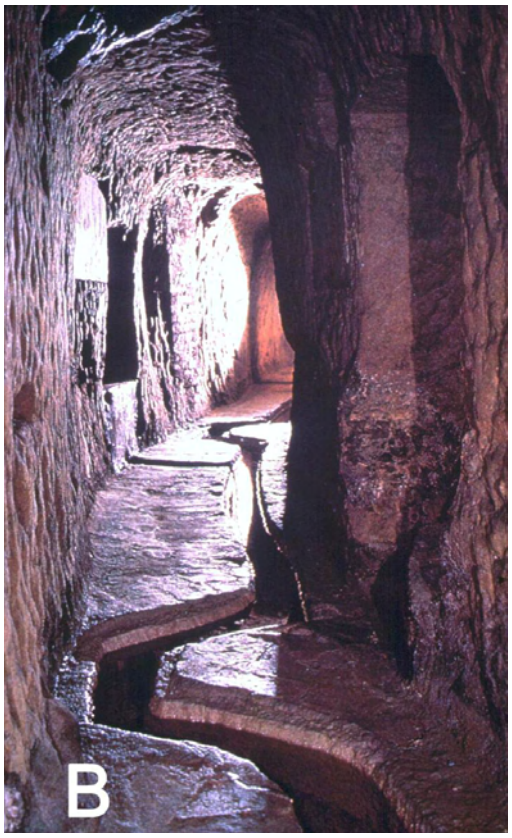
2.2.3.2. Building space within the medieval walled town

The overall original morphology of the Siena hill has been little changed throughout the ages, but some local areas within the city have been modified by either removing or adding rocks and sediments to generate flat surfaces to build edifices, squares, roads, or to develop cultivable fields inside the city walls.

There are several notable cases where considerable material has been removed from hilltops. One is the removal of about 5 m of sandstone down to a resistant conglomerate layer to build the Cathedral (Duomo) and the adjacent square (building started in 1226). Much more recently, in the first part of the 1900s, the small hill called Malavolti was levelled down to build the Matteotti Square (also called "Piazza della Posta" (PO, Fig. 3). Several metres of sandstone were removed as shown by the remnant high at the SW corner above which there is the church of the Contrada del Drago.

Terraces for construction of edifices have been and are still cut on the flanks of the hill. Notable is the cut on the northern side of the hills of the Cathedral made in 1317 to build the Battistero (Christening church) and its small adjacent square of (Piazza S. Giovanni: SG, Fig. 3). Of interest is the conglomerate that forms a wall of a house facing such a piazza. This conglomerate is the same that underlies the higher square of the Cathedral, except that it has been downfaulted 4.5 m below it (Fig. 8A). This fault was active in the past and created problems during the botched construction of





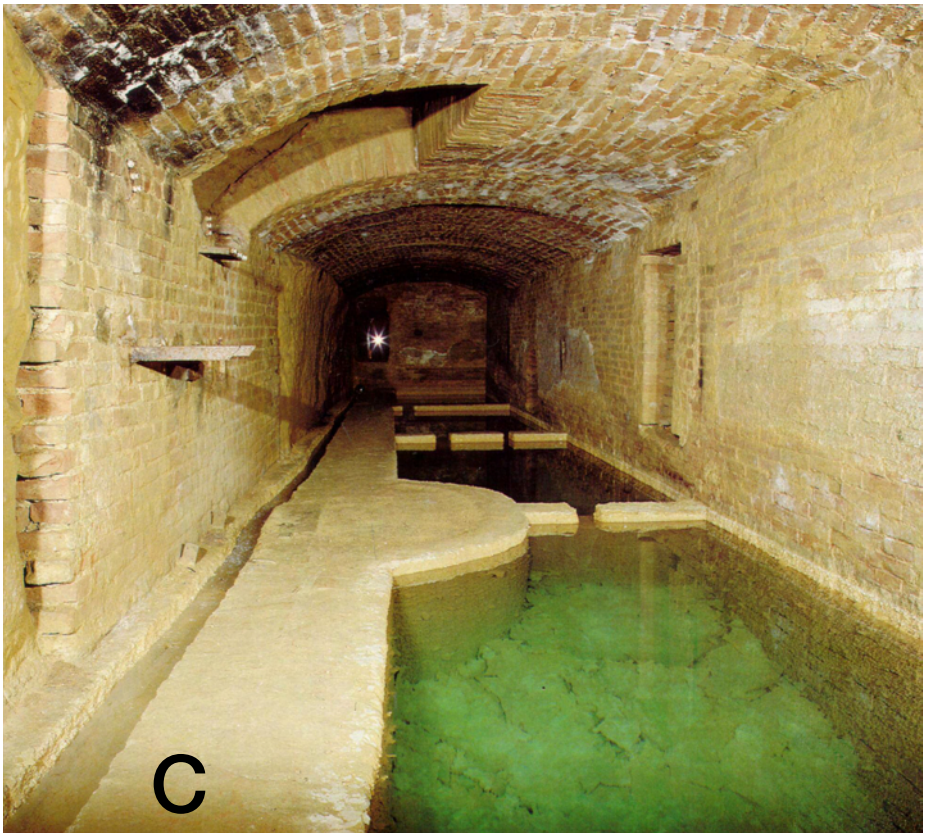


Fig. 11 - Medieval aqueducts (Bottini) of Siena. (**A**) Map of the main (maestro) Bottini as well as local shorter ones, and the various shapes of the tunnels. (**B**) Typical tunnel of the Bottini showing brick layered floor with a central small canal (*gorello)*. In his case, under the city, the gorello is forced to meander to reduce the slopeand deepen the flow to allow water to exit toward private tunnels and wells. (**C)** Large settling tanks built at the northern end of town for settling impurities and crystallization of calcite from hard waters. (From Balestracci D., 2004).

Aquedotti medievali (Bottini) di Siena. (***A***) *Mappa dei Bottini Mestri e secondari, e schemi delle varie forme dei cunicoli*. (***B***) *Cunicolo tipico dei Bottini pavimentato con mattoni e con un canaletto centrale (gorello). In questo caso il gorello è meandriforme per poter ridurre la pendenza, aumentare la profondita' del flusso ed invitare l'acqua ad andare verso i pozzi degli utenti.* (***C***) *Vasche di decantazione costruite all'entrata nord di Siena per far sedimentare l'eventuale materiale in sospensione ed abbassare il tenore in calcio delle acque calcaree dei Bottini*. *(Da Balestracci D., 2004).*

the larger Cathedral that was planned in the early 1300s, and has also played an import role in the strong late-1700s earthquakes that damaged many buildings and towers (FIORINI, 1991; CASTELLI & BERNARDINI, 2006).

Levelling of terrains was also achieved by dumping material on certain areas. A large artificial plateau is the Prato di S. Agostino (PS, Fig. 3) was formed by dumping on it the material removed to construct the Cathedral and its square. Of even greater impact is the modification made to construct both Viale dei Mille (VI) between the church of S. Domenico (SD) and the Fortezza (Fort, built in 1560 by the Medici of Florence; FO), and the famous sloping, shell-shaped square of the Campo (CP, Fig. 3).

(a) The Viale dei Mille (VI) and associate football (soccer) field (ST) required a causeway to be built across the relatively narrow but deep secondary Rastrello Valley (S, Figs. 3, 4, 14), and partial filling and levelling of the upper part of the valley. The start was the dumping of rubble generated by the destruction of buildings, including the toppled upper part of the bell tower of S. Domenico (SD), by the series of earthquakes of the late 1700s. The construction of the actual causeway was done starting toward the end of 1800s (Fig. 14A, B). Part of the upper valley was filled and levelled, and Viale dei Mille–football field complex was completed as it is today in mid 1930s (FIORINI, 1991).

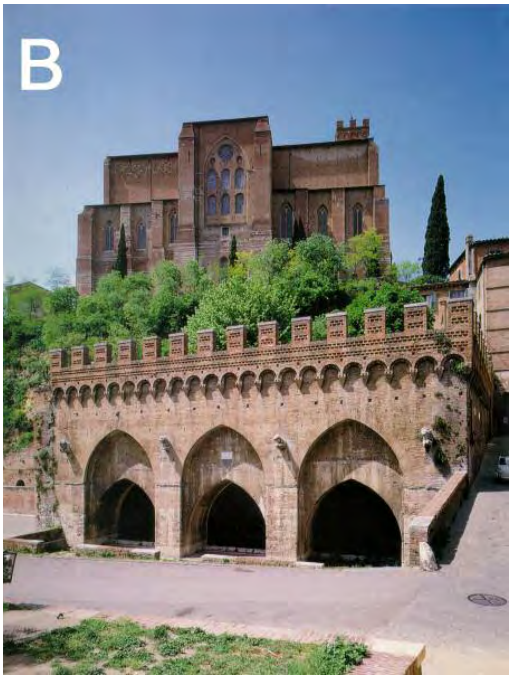
(b) An earlier impressive modification of another secondary valley-head (Val di Montone:VM, Figs. 3, 4, 15) led to the development of the complex of Piazza del Mercato (ME)-Palazzo Pubblico-Piazza del Campo (CP) (Figs. 3, 15). First a low retaining wall was build across the valley to reduce erosion, and, adding material, a terrace was constructed sufficiently large for Piazza del Mercato (ME, Fig. 3). A second retaining wall was later built in 1194 where the Palazzo Pubblico is now (the initial Town Hall was built in stages from 1284 to about 1310). The remaining upper part of the valley-head was rather irregular and in part dissected by rill erosion. Several modifications were made along the roads running along the hillcrest to divert rainwater away from the square onto the opposite flank toward Fontebranda. Later, the surface of the valley-head was smoothed out and finally in the early 1300s it was paved with bricks as it is today (http://en.wikipedia.org/wiki/Piazza_del_Campo). The semi-arcuate *Pecten*-shell shape of this most famous square thus reflects the smoothed out valley-head.

2.2.3.3. Roads

Like other medieval cities built on hills, Siena had, and still has, some difficulty in building good roads, except for the one running along the crest of the hill. This is the route locally followed by the Via Francigena as well. Except for that, the other roads of Siena were originally narrow, winding, steep, and dark within the city, being bordered by constructions with protruding upper floors. As the city grew, modifications were made mainly straightening and enlarging the roads and forcing removal of protruding constructions. Except for the principal ones, they remained unpaved until recent centuries. Secondary roads of Siena are still today rather narrows, very steep straight downhill, difficult to be used by modern transport. This has benefited the town helping in preserving its ancient character. The use of private cars is banded from most of the walled city. To satisfy modern people (local inhabitants and tourists) needs, parking facilities have been built either underground in a few places just inside the city walls, or at the foot of the hill. For the people to reach the

Fig. 12 - Partial view of the monumental Fonte Gaia in the Piazza del Campo at the centre of town.

Visione parziale di Fonte Gaia (monumentale) in Piazza del Campo al centro di Siena.



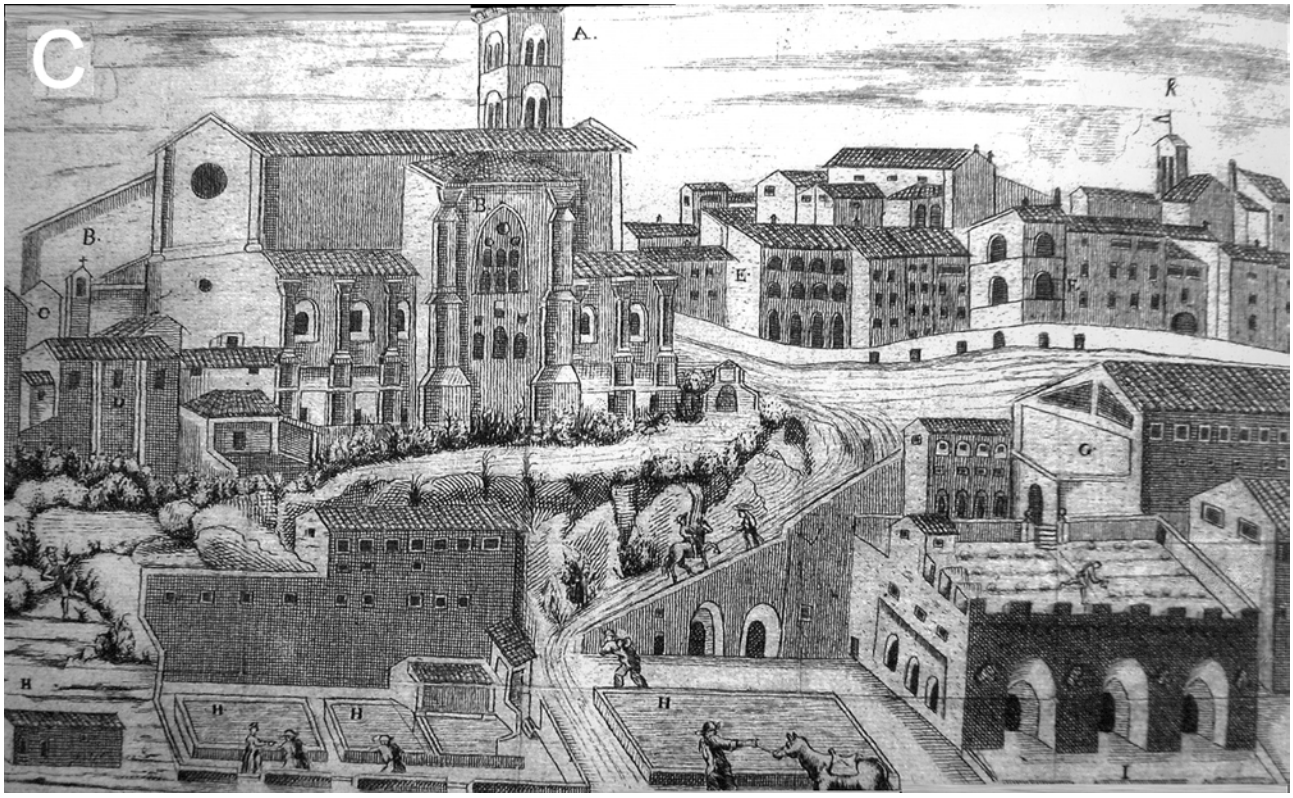


Fig. 13 - Fontebranda complex. (**A**) Narrow valley enclosed by medieval walls. The fonte is at the base of the cliff below the church of S. Domenico. (**B)** Main building of the fonte with water for human consumption. (**c)** Complex of Fontebranda showing arched building containing the main pool for potable water, and, sequentially to the left: drinking pool for animals, pool for washing clothes, pool for washing animals, and farther to the left and outside the walls, water was used for running mills, and finally to water the fields. Parallel to this, pools/cisterns (not visible in this figure) were used for washing wools, washing and tanning pelts, for butchering and so on. Note gardens on top of the main arched building. In previous times this top was used as tiratorio; that is, an area where to stretch and dry coloured wool-cloth. (From COSTANTINI & MARTINI, 2004).

*Complesso di Fontebranda. (**A)** Valle stretta di Fontebranda. La fonte è alla base della rupe di S. Domenico. (**B)** Edificio pricipale della fonte con la vasca di acqua potabile per usi umani. (**C)** Schema generale che mostra il parsimonioso utilizzo in cascata dell'acqua della fonte. L'edifico con archi è quello principale con acqua potabile. L'acqua in esubero della prima vasca passava alla seconda che serviva per abbeverare gli animali, poi alle vasche per lavare i panni ed infine nel guazzatoio che serviva per far rinfrescare e lavare gli animali. L'acqua veniva poi incanalata fuori le mura per far ruotare le macine di sei mulini ed infine per irrigare i campi. Altre vasche, non visibili qui, venivano riempite di acqua pulita ed utlizzate per lavare la lana ed il panno (principale industria medievale) e, fino a circa trenta anni fa, per macellare gli animali. Notare i giardini nel tetto dell'edificio principale della fonte. In tempi piu' antichi questo tetto veniva usato come tiratoio, cioe' dove si poteva stendere il panno di lana ad asciugarsi. (Da COSTANTINI & MARTINI, 2004).*

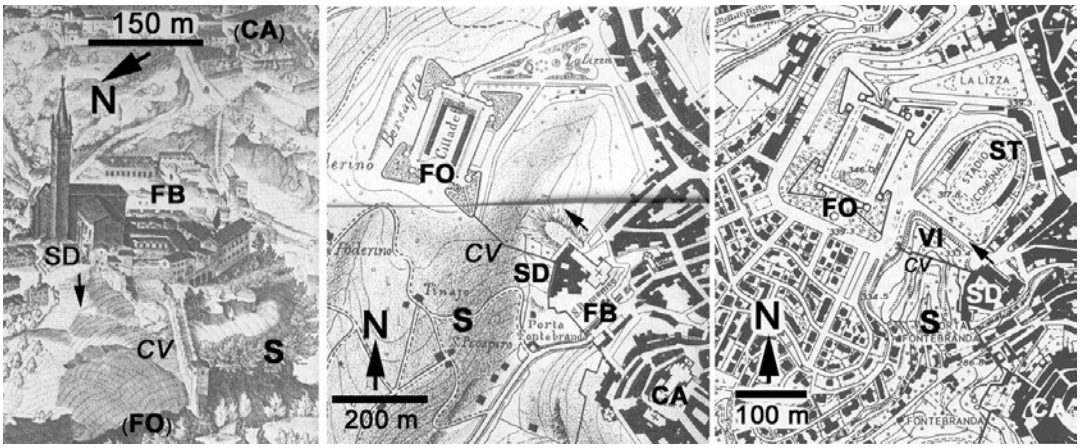


Fig. 14 - Maps showing the progressive enclosure of the apex of a small secondary valley (Rastrello Valley: S) indenting the main Sienese hill, and construction of a causeway and of the modern athletic complex (stadio). Note that the first map has opposite orientation to the other two. (Small arrow indicate the trend of the future causeway). (**A**) Detail of 1595 map by Vanni showing the head-valley part of the deep narrow Rastrello Valley (S) between S. Domenico (SD) and the Fortezza (FO), crossed by the city walls (*CV*). (**B)** 1860 map showing the same site (different orientation) with an incipient pile of refuses from the disruption of several towers and edifices by the late 1790s earthquakes, protruding (arrow) from S. Domenico into the Rastrello Valley, upslope from the city walls. (**C)** 1965 topomap showing completed causeway between S. Domenico e the Fortezza with the road (Viale dei Mille:VI) and the athletic complex (Stadio: ST, Fig. 3) on the partially filled and levelled head-valley part.

*Mappe che mostrano la progressiva chiusura della valle secondaria del Rastrello (**S**), e la costruzione di un terrapieno sul quale è stato realizzato il complesso sportivo (stadio comunale). Nota che l'orientazione della prima mappa a sinistra è diversa dalle altre due.* (***A***) *Dettaglio della mappa del Vanni (1595) che mostra la cima non modificata della valle del Rastrello fra S. Domenico (SD) e la Fortezza (FO), attraversata da un muro di cinta cittadino (CV).* (***B)*** *Mappa del 1860 che mostra un inizio di terrapieno che protrude (freccia) nella valle da S. Domenico. Questo terrapieno iniziale era formato dalle macerie causate dal terremoto del 1798.* (***C)*** *Carta topografica del 1965 che mostra il terrapieno completato con sopra il Viale dei Mille (VI) fra S. Domenico e la Fortezza, e parte dell'impianto sportivo (stadio) a NO del viale (ST, Fig. 3).*

ancient town on top of the hill, impressive movable stair facilities have been built, partly excavated along the hill flanks and hidden such that they are essentially invisible at the surface and do not deturpate the landscape.

3. DISCUSSION – A RESILIENT SOCIETY

Considering the interaction between space and water availability and changing societal needs through time, some interesting experiences have occurred in Siena. One is very recent (last decade) and relates to the building of a parking lot at the foot of the hill near Fontebranda. In doing so a large area was exposed at the contact between the impermeable marine clay and the overlying porous sand. The consequence was a relatively large flow of water, and remedies had to be implemented to protect the parking construction. One may say that finally the Sieneses had found the mythic underground stream, the "Diana", that they were unsuccessfully seeking since medieval times and for which they were derided by Dante in the Divine Comedy. Actually it is not a stream they found, they just opened a spring a bit wider and nowadays a small permanent rivulet flows from under the parking lot.

Another interesting adaptation during medieval times was dictated by the interaction between the need for defence, lack of water, and viability within the city. To start with, Siena had no water to fill the moat of the city walls, particularly along the vulnerable, flatter part of the hillcrest. So they filled parts of the moat with bundles of wood (*fascine*) to burn in case of attach (FIORINI, 1991). These fire-moats were called *carbonaie* (places where coal was generated or stored), for obvious reasons (FIORINI, 1991). Holmes were cultivated along the moats as source of wood. Once new walls were built the older carbonaie were abandoned. At first they were leased for cultivation and eventually they were levelled off and new city roads were built on them. Several roads of modern Siena have this origin, such as part of Viale Don Minzoni (MI), Pian dei Mantellini (PM) and possibly Via di Vallepiatta (VP) (*piatta*: flat in Italian, but most likely derived from Latin *platea*: large, wide; so Via Vallepiatta may indicate the road of the wide valley; FIORINI, 1991) (Fig. 3). Furthermore some topo-names still indicate the former existence of moats outside the older, abandoned city walls. One of such names is a locality called "Ponte" (PN, Fig. 3) inside modern Siena, which refers to a bridge that crossed the moat (now a levelled city road) in front of an ancient city-door (a partially preserved arc still marks the of ancient door of Porta S. Maurizio) (LUSINI, 1921).

Siena is just one of the many medieval hilltop city-states that had to cope with the limitations offered by the landscape as their population grew and globalization increased during the difficult, dangerous medieval–early Renaissance times. Siena like other towns of the region, such as Pisa and Lucca, flourished during early times but eventually had to surrender to the more powerful, better energy-endowed, rival Florence crossed by a relatively large river (Arno River). Through time, the Sienese society reacted to the limitations given by the landscape through maximization and conservation of available resources. After many centuries these early limitations to growth eventually turned out to be beneficial because ancient structures and even the overall urban plan has been preserved and nowadays they are great cultural and touristic assets.

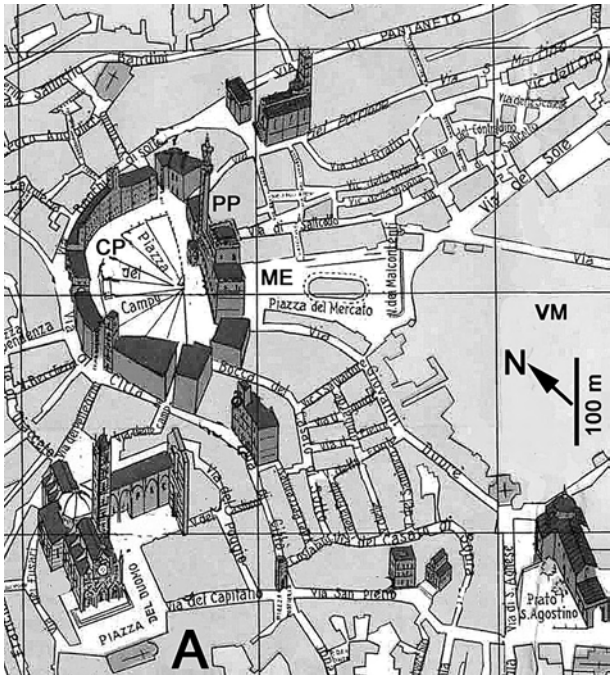


Fig. 15 - Piazza del Campo area. (**A**) Map showing modified headvalley part of the Montone Valley (VM) and constructions of the Mercato Square (ME), Town Hall (PP), and the Pecten-shell shaped main square (Piazza del Campo: CP). (**B**) Partial view of Piazza del Campo and of the Town Hall with its typical belltower.

*Zona di Piazza del Campo. (**A**) Mappa che mostra l'apice modificato della Valle di Montone (VM), Piazza del Mercato (ME), Palazzo Pubblico (PP), e la Piazza del Campo (CP) a forma di conchiglia che segue l'andamento della la testata della valle. (**B**) Vista parziale di Piazza del Campo ed il Palazzo Pubblico con la Torre del Mangia.*

4. CONCLUSIONS

(a) The overall medieval–early Renaissance development of Siena can be synthesized into three main periods. A first period (10th –11th centuries) was characterized by a rapid growth, followed by a second period of great wealth during the 12th –13th centuries, up to the apex of its maximum development at the end of the 13th century and first part of the 14th century under the Government of the Nine. It is during this last period that major monuments of Siena were built. Amborgio Lorenzetti in his fresco in the Palazzo Pubblico (1338/1339) left us a glimpse of Siena and its society of that period. Then followed a period of decadence starting in 1348 after the first bout of the Black Death, when some major projects, such as the new Cathedral, had to be abandoned, and Siena became uncompetitive in the European market. Siena lost its city-state independence to Spain and Florence in 1555/1557.

(b) Landscape conditions that favoured the early

development of Siena included an easily defensible location on the crest of a steep hill, and the development of a pilgrimage route (Via Francigena) from central Europe to Rome, which followed the hills rather than the older lowland tracks that had become infested by deadly malaria. The pilgrims were well treated by Siena and brought great wealth to the city, directly by visiting it, and indirectly as good ambassadors to their countries thus opening favourable markets throughout Europe.

(c) Adverse landscape conditions that contributed to the eventual loss of competitiveness of Siena in the enlarging European markets were the lack of sufficient water (no streams or large springs occur in the area) and space (on a relatively steep hill indented by small, narrow, deep secondary valleys) for further developing the city and the industry of cloth making.

(d) The society of Siena valiantly struggled to overcome the adversities by implementing regimes of conservation and multiuse of the available resources. Long (25 km total) underground aqueducts (the Bottini) were constructed, and the limited amount of water they carried was wisely used, and the city flourished. .

(e) The advent of the Back Death, starting in 1348, brought Siena to its knees as about 2/3 of the population died. Siena could not revitalize afterwards and could not compete with larger, more resilient cities like Florence that was endowed by hydropower from its river allowing it to develop an increasingly more efficient, stronger, and therefore more competitive industry. In addition to economics, political mistakes, and internal family feuds it may have endured, logistic limitations significantly contributed to Siena inability to successfully compete in the more industrialized world of the 1500–1600s centuries.

5. ACKNOWLEDGEMENTS

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