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32nd INTERNATIONAL GEOLOGICAL CONGRESS

GEOSCIENCE FOR CULTURAL HERITAGE SAFEGUARD IN FLORENCE

Leader: P. Canuti

Associate Leaders: P. Malesani, P. Manetti

During-Congress **D04**

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Series Editors:
Luca Guerrieri, Irene Rischia and Leonello Serva (APAT, Roma)

English Desk-copy Editors:
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AUTHORS:
P. Canuti, R. Fanti, P. Malesani, E. Pecchioni
(Università di Firenze - Italy)

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Front Cover:
A view of Florence: Cupola del Brunelleschi and Torre di Arnolfo

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Introduction

The main objective of this proposal is to introduce the international scientific community to the main problems that the geosciences face, in the preservation of monuments and other cultural heritage sites.

Florence offers a wide spectrum of problems to be investigated using a multi-disciplinary approach, ranging from geotechnical engineering, engineering geology, structural geology, petrography, and mineralogy. The effects of weathering processes on monument preservation, and the problems concerning restoration work, are the main topics to be discussed in the visit to the historic center of the city. Slope instability conditions, associated with landslides and cliff failures, will be the aim of the tour of the San Miniato hillside, the instability of which was first recognized by Leonardo da Vinci.

Florence geologic setting

The plain of Florence is part of the Middle Valdarno basin, which is a still-active graben structure formed during the post Tortonian final phases of the Appenninic chain orogeny. The plain is made up of fluvial and lacustrine sediments, Pliocenic to Recent in age, which fills the structural depression and reaches a maximum thickness of 600m over the rocks of the substratum. Different types of deposits can be distinguished. The coarse terrains roughly following the Arno River are sands, pebbles, and gravels laid down during recent flood events of the river. Sandy pebbles and gravels also correspond to the alluvial fans of the tributary streams in the plain (the Mugnone stream, Terzolle stream and Greve River). The sediments reach a considerable thickness in the center of Florence representing the most important aquifer of the area, in terms of high permeability.

Sand, pebbles and gravel are generally overlain by a discontinuous silty flood layer, and/or by detrital sediment and removed materials from building demolition, and both layers are characterized by a thickness that varies by a few meters. In the remaining areas of the plain, silty and clayey deposits are widespread, sometimes with pebbles and gravels in a sandy matrix, forming thin lenses. A small area in the western sector is not affected by the alluvial sediments of the rivers (westwards from Peretola), and this area is made up of clays apparently of lacustrine-marshy origin. Finally, as regards the rocks forming the bottom of the lake , it is worth noting that they represent the same formations that outcrop in the hills around Florence. The main lithotypes are sandstones and marly limestones (Sillano Formation, Pietraforte Formation, and Monte Morello Formation) as well as quartzose-feldspatic sandstones (Macigno Formation - Pietra Serena). (Bencini et al., 1993).

Pietraforte is a sandstone belonging to the turbiditic formation present in the allocthonous complex of the External Liguridi, superposed on the Tuscan Series. The formation dates back to the Upper Cretaceous. Between Florence and Civitavecchia, it crops out in three areas (Florence, Amiata, and Tolfa mountains), presenting different thicknesses. Around Florence, Pietraforte is composed of great lenses of turbiditic materials mostly at the base of the Sillano Formation. Thickness varies from 100 to about 800m. From a lithological point of view, it is a regular alternation of grey sandstone layers and argillites (hemipelagites) with rare intercalations of marls and marly limestones(Bortolotti, 1962; Abbate and Bruni, 1987; Bruni et al., 1994).

Pietra Serena belongs to the sandstones of the Macigno Formation. It consists of beds of turbiditic sandstones separated by pelitic levels, which are the finest components of a single turbidity current. The Macigno constitutes the upper part of the Tuscan Nappe; it can be dated to the Upper Oligocene and stratigraphically overlies the Scisti Policromi. It has the greatest thickness along the alignment Mt. Orsaro - Chianti Mts. where it can reach 3000 m (Cipriani and Malesani, 1963; 1966; AA.VV., 1993).

Field itinerary
Morning, the Historical Center of Florence

The field itinerary around the historical center of Florence, will offer the possibility of observing the stone materials used for the construction of the main historical buildings and monuments, and to take into account their state of conservation.

The buildings situated in the center of Florence range in time from the Middle Ages, to the Renaissance, up to the nineteenth century and thus record the history of the town (Bargellini et al., 1970).

The main stone materials used historically in Florentine architecture are two kinds of sandstone: Pietraforte and Pietra Serena. Pietra Serena was mainly used for decorative purposes, while Pietraforte was mostly used during the Middle Ages in the construction of the bearing structures of buildings, and later as sheathing during the

Renaissance. Pietraforte is a turbiditic sandstone outcropping on the left side of the Arno River (e.g. Piazza Santa Felicita, Costa San Giorgio, Boboli etc.). These quarries were later built over in urban expansion, and new ones were opened further south (Monteripaldi, Florence). Pietra Serena is sandstone of the Macigno Formation; the most ancient quarries of Pietra Serena were probably located as far back as Roman-Etruscan times in the Fiesole ridge. Periods of greater development of quarrying of this stone can be dated back to between the 13th - 15th centuries, both periods linked to the urban growth of the city. In the 13th century, the quarrying activity took place in the area around Fiesole, (Valle del Mugnone, Monte Ceceri, Vincigliata, Settignano), while in the 15th century, new quarries were opened, for example to the west (Gonfolina and Carmignano) and to the south of Florence (Tavarnuzze), to meet the great demand for this material during the Renaissance. Nowadays, the quarrying of this stone around Florence has almost ceased, except for the quarry at Caprolo near Greve, 25 km south of Florence and at Ponte di Mezzo, near Lastra a Signa, about 20km west of Florence (Banchelli et al., 1997).
Various types of marbles, serpentinites, bricks and plasters were also used in building the monuments, in order to obtain special chromatic effects (Rodolico, 1953; AA.VV. 1993).

Stop 1:
The itinerary to visit the historical center of the city starts from the Cathedral of Santa Maria del Fiore (structurally completed in 1436) (Fig.1). The materials used for the original construction were, for the "red marbles" the marly limestones of San Giusto di Monterantoli (Cintoia in the Chianti mountains), as well as the marly limestones from Monsummano in Valdinievole (Pistoia), Carrara marbles for the "white", and serpentinite from Figline di Prato (Prato) for the "green" (AA.VV. 1987).
There is a difference in the case of the façade, which was built later (1887): the "green" of serpentinites wasextracted from Figline di Prato and usedalong with the "red", which came from several quarries, above all in the Grosseto area, at Villa Collemandina (Garfagnana-Lucca), and at Monsummano and in the Perugia area; while for the "white", after several visits to Carrara and Serravezza, an agreement was reached with G.B. Sancholle Henraux, who provided the marble from his quarries at Serravezza (Lucca) at cost price. On the façade, already two restorations have been carried out since then in order to counterract the bad decay of the marble with its typical accompanying black crusts. The condition of the sides of the Duomo are better: the Apuan marble used,is more durable because of its petrographical characteristics (Barsottelli et al., 1998; Bianchini et al., 1999).

Stop 2:
Is the S. Giovanni Baptistery, in front of the Cathedral (Fig. 2). It was realized in marble and serpentinite; it is octagonal in plan, with an extension to the west, and doors on the south, north, and east sides. The Baptistery is an ancient construction going back to 1056, but only in the middle of the XII century was it covered with Proconnesian marble and serpentinite from the Prato area (Rodolico 1953; AA.VV., 1993). On the Baptistery, several poorly judged restorations were carried out with waxes, and these are responsible for the yellowing of the white marble.

Stop 3:
In Calzaiuoli street it is possible to see the construction of the church of Orsanmichele (entirely built in Pietraforte), dedicated to the wheat market, which became in 1350 one of the most beautiful churches in the historical center. The church was restored in 1990.

Stop 4:
Piazza della Signoria is the next stop. It is one of the most beautiful squares in Florence and it hosts the Palazzo Vecchio (Fig. 3). Arnolfo di Cambio built the Palazzo Vecchio at the end of the 13th century, when it was given the name of "Palazzo dei Priori", and now it hosts the seat of the present City Hall. The main façade of the western side of the palace is mostly built in Pietraforte carved into little ashlars, with elements in common plaster, and corbels in Pietra Serena; the covered communicating corridor of the gallery is made of decorated plaster, with mullioned windows of white statuario marble, and the decorating elements above the main entrance door are of glazed earthenware. The façade on the northern side, standing on Via dei Gondi, is mainly built in Pietraforte with elements in both common and painted plaster; the mullioned windows are in some cases in statuario marble or in plaster, which imitates marble. The battlement placed below these windows, is built in a mixed material, consisting of limestone, earthenware, Pietraforte and Pietra Serena (Allegri and Cecchi, 1980).
On the Palazzo Vecchio several restorations have

been and are being carried out in order to restore the decorated portions in sandstone Pietra Serena and plaster.
The other mansions standing in the Piazza della Signoria, and especially those of medieval age, are mostly constructed in Pietraforte with portions decorated with Pietra Serena. The most degraded parts have either been replaced over the centuries, or rebuilt using mortars carved to imitate the stone (artificial Pietraforte or artificial Pietra Serena), or by using decorated plasters. Also the square shows visible examples of these types of operations. The less important buildings in the square are instead covered with common plasters (Jacorossi, 1972; Bargellini and Guarnieri, 1985).
Another outstanding monument of the Piazza della Signoria, is the Loggia dei Lanzi (14th century), an open-air gallery entirely built in Pietraforte, except for the balustrade on the roof, which is made of Pietra Serena, and the coats of arms which are in glazed earthenware and marble. It was restored at the end of the 1980s (Bellucci, 2001).
During the Florentine Republic, the sculptures of Marzocco (now inside Bargello Museum), Giuditta and Oloferne by Donatello (now the original is inside the Palazzo Vecchio, and the copy under the Loggia dei Lanzi) and the David by Michelangelo (now the original is at the Accademia Museum, and the copy in front of the Palazzo Vecchio), were collocated in the Piazza della Signoria. During the Medici dynasty, great novelties were introduced to decorate the square, such as the Fonte di Nettuno (“Neptune’s Fountain”), by Bartolommeo Ammannati, in marble and bronze, and the Monumento Equestre a Cosimo I (the equestrian statue to Cosimo I) by Giambologna, in bronze.
The pavement of the square has been constructed from different materials and colours throughout the centuries, starting from the original earthen soil to brickwork, to the Pietraforte and Pietra Serena of the 18th century, to paving slabs in great part replaced with Pietra di Firenzuola in the 1980s (Bonavia, 2001).

Stop 5:

On the south side of the Arno River there is the Palazzo Pitti, built according to a project by F. Brunnelleschi (1440) (Fig. 4).
Brunelleschi’s structure reflects his idea of how a Renaissance palace should look like: a cube equal in both height and depth, and covered with the typical Florentine stone Pietraforte carved into ashlars, which was quarried directly from the Boboli hill itself. The palace was originally built on three floors, with three entrance doors on the ground floor and seven windows on each side of the two upper floors. A balcony originally crossed the entire façade, linking up the windows, while a loggia was built beneath the roof to give it a finishing touch. The sloping frontage that forms the Palazzo Pitti, is closed on three sides by the circling wings of the Palace. The Palace and the sloping frontage have beenrestored in recent years, owing to the bad condition of the stone and its structural damage.
The garden of the Palazzo Pitti is called Boboli, and was built between 1550 and 1588 on the Boboli hill, between the Palazzo Pitti and the Forte Belvedere. It is said to be one of the most beautiful gardens in Italy. The project and the realization of the Italian-style garden was begun by Tribolo, then continued after his death in 1550 by Ammannati. The elaborate architecture of the Grotte was by Buontalenti, with its unusual mosaics and decorations (Costagliola, 2000). The Boboli Gardens reached their current size of 45,000 square meters in the seventeenth century, and they have always been considered as part of the palace itself.

Stop 6:

Coming back on the north side of the Arno River, it’s possible to see in Tornabuoni street, the Palazzo Strozzi. Filippo Strozzi began building his palace in 1489. The project, entrusted at first to Benedetto da Maiano, the architect preferred by Lorenzo il Magnifico, it was continued and completed by Simone del Pollaiolo. The palace remained in the Strozzi family continuously until 1937, when it was sold to the I.N.A. (National Insurance Institute). The I.N.A.carried out the restorations, and the palace was then acquired by the State in 1999. The palace, where prestigious institutions, such as the Gabinetto G. P. Viesseux and the Istituto Nazionale del Rinascimento, are located with their important libraries, hosts important art exhibitions on the first floor.. The Palazzo Strozzi is probably the best example of Renaissance private architecture; it shows a façade built with Florentine Pietraforte, carved as typical ashlars, and as an impressive cornice in the same stone material. Characteristic mullioned windows in Pietra Serena are present. The palace has harmonious interior spaces and follows a rigorous design (Gurrieri and Fabbri, 1995; Bellucci, 2001).

Figure 1 - Cathedral of S. Maria del Fiore

Figure 2 - S. Giovanni Baptistery

Stop 7:
A general view of the hill from Piazzale Michelangelo. According to an unverified chronicle, this area was uninhabited until 62 A.D., when a group of Christians, dispatched by St. Peter, settled and secretly built an oratory, nicknaming the hill Elisbots. More certain are the events concerning St. Miniato, the first evangelizer and Christian martyr in Florence. Victim of the persecutions of the Emperor Decius (249-251 A.D.), Miniato is thought to have been an Armenian prince: the legend narrates that, after his decapitation, he picked his head up, put it back on his neck and went to die in a cave on Monte alle Croci, where he had lived as a hermit, and where later the church, that nowadays bears his name, was built (Busignani and Bencini, 1974; Bargellini, 1980).

Figure 3 - View of Piazza della Signoria

Stop 8:
A look at the construction of what was originally a temple, one of the finest examples of pure Florentine Romanesque architecture, first started in 1018, thanks to Bishop Ildebrando, and continued until 1207 (Fig. 5). The façade was realized in white Carrara marble, and green Prato "marble"(serpentinite) (12th-13th centuries); the interior keeps an inestimable treasure of Renaissance masterpieces. In the 14th century, the contiguous Palazzo dei Vescovi (Bishops' Palace) was built,

The Afternoon: Piazzale Michelangelo and S. Miniato hill
The southern extremity of the historic center of Florence, on the hydrographical lefthand side of the Arno River, is bordered by a series of hills, known as the Colli Fiorentini, which afford an evocative panorama of the city, with all its artworks and monuments.
Monte alle Croci (also known as Mons Florentinus in the period of Roman Empire, and as San Miniato hill from the Middle Ages), represents the most famous of these gentle heights, due to its typically Florentine landscape, and its monuments of inestimable cultural, historic, and artistic value.

Figure 4 - View of Palazzo Pitti

and it was later converted into a monastery, with the addition of the cloister and other rooms, with frescoes by Paolo Uccello (15th century). The bell tower is situated opposite the cloisters: the original bell tower, probably contemporary with the church, was damaged by lightning in 1325 and 1413, and fell down in 1499 and the building of the present one was begun in 1524 (Gurrieri et al., 1988).

Figure 5 - Church of San Miniato al Monte

Stop 9:

In this period, this area was also the site of the construction of San Salvatore church and the San Francesco convent, an important Renaissance building which was completely rebuilt over a pre-existent little oratory (1419-1499) (Lapini, 1900; Bacci, 1960).

The façade of the church is both austere and graceful, and designed with alternating curved and triangular tympani; the interior shows signs of an attempt to get away from the influence of Brunelleschi (Fig. 6).

In 1527, while the San Miniato tower was under construction, the area became a strategic point for the military defense of Florence: after the expulsion of the Medici family, a republican government was established, and the attack of Charles V was looming. In order to prepare for the siege (Florence held out under siege for ten months during 1529), it was necessary to fortify the hill, and Michelangelo Buonarroti was commissioned to design the fortification, that was then rapidly built (Fanelli, 1973; Bargellini, 1980).

With some deviations from Michelangelo's original project, the bastions were built: they enclosed the basilica of San Miniato and the church of San Salvatore and steeply descended down to the Arno River.

The new defensive system integrated the big circle of pre-existing walls which had contained the city since 1333: the old wall lapped onto the hill, barely excluding it, and its construction was guided by the prediction of fast urban expansion, which in turn was cut short by the Black Death epidemic in 1348 (Bargellini, 1980).

After the 1529 engagements, the buildings of the area, damaged in different ways, were abandoned The San Miniato complex became a fortress (with some modifications to the bastions at the end of 16th century), and the monks left the hill (Fanelli, 1973; Gurrieri et al., 1988). Only in the San Francesco convent did the monastic life continue, even if in some solitude, as the area,at this point had been left out from town planning (Fig. 7).

Stop 10:

Until the 19th century, no new construction took place on the hill, when, in 1865, the construction of the monumental cemetery (called "Cimitero delle Porte Sante") started, immediately followed by the beginning of the city transformation works linked to

Figure 6 - The interior of San Salvatore al Monte: on the arch, some old restored cracks are evident.

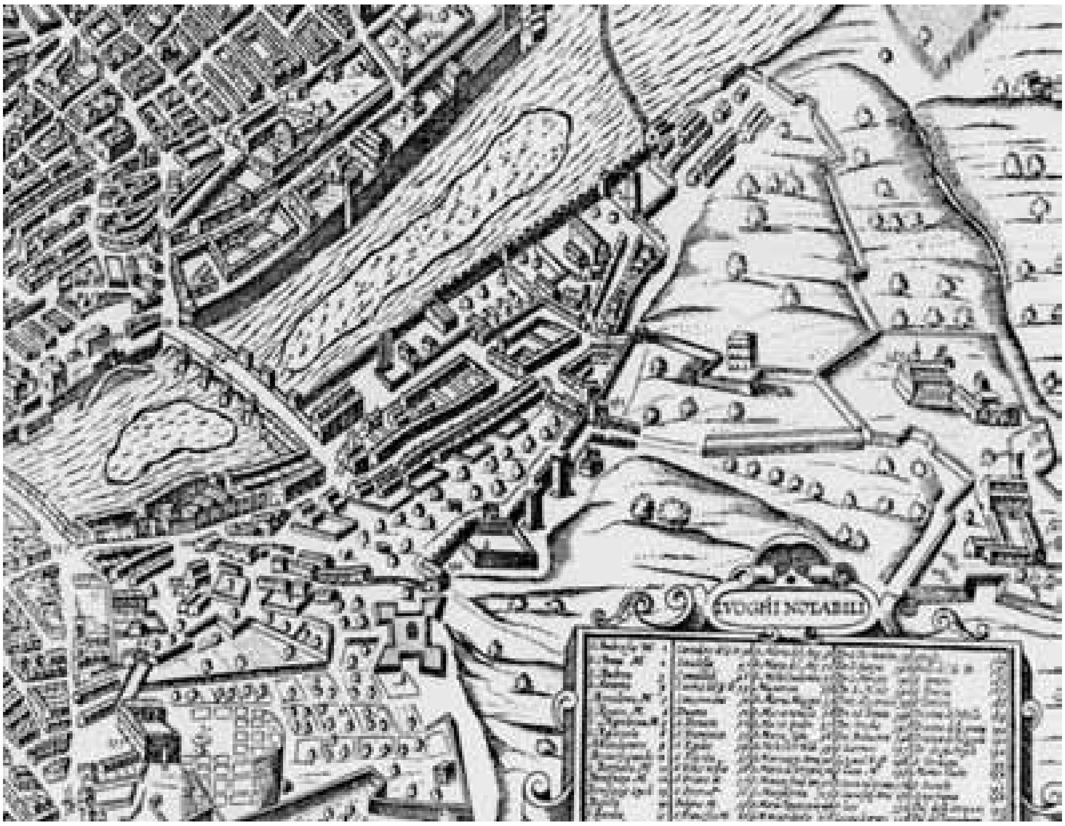

Figure 7 - Detail of a 17th century city map

Figure 8 - Monte alle Croci at the end of the 19th century

the appointment of Florence as capital of the Reign of Italy. Indeed, between 1865 and 1876, Monte alle Croci was involved in a radical town planning intervention, directed by the engineer, Giuseppe Poggi. On the hill, Poggi designed the theatrical Viale dei Colli, with its panoramic open squares, of which Piazzale Michelangelo is the most famous (Poggi, 1872; 1882; Bargellini, 1980).

Stop 11:

The implementation of the project led to a general modification of the slopes profile. Some excavations and fillings, involving impressive earth movements, were carried out, in order to build new drainage systems and canalizations, which supplied water for the waterfalls and fountains, and to construct a series of earth retaining structures along the boulevard and on the Rampe terraces.

A monumental staircase was built to reach the St. Miniato complex, and a big loggia was constructed between the new Piazzale Michelangelo and San Salvatore (Fig. 8).

Under the loggia, Poggi's project envisaged the creation of an open-air museum, containing Michelangelo's David and some other of his sculptures, but this was never carried out: later, only a bronze copy of his David was placed in the center of the Piazzale as is still seen today(Bargellini, 1980).

The last new construction works date from the first half of 20th century, with the restoration of the San Miniato complex (1906), the transformation of the old farms into villas, and the construction of some new elegant houses (1900-1920) There was also the realization of an athletic field (1936), and the repair of superficial damage caused by some engagements during the Second World War.

The evolution of instability and the course of mitigation works

Historical studies concerning the slope instability phenomena on Monte alle Croci are plentiful and detailed, because of the above mentioned strategic, military and religious importance of this place.

The unstable condition of the hill was already known in 1447, when Cosimo de' Medici forbade the friars of San Salvatore to enlarge the church, still under construction, because of the slope movements acting on the area (Pulinari, 1913; Bargellini, 1961).

At the end of the century, the validity of Cosimo's interdiction was confirmed by some considerable deformations in the San Salvatore complex: according to some chronicles, both the church and the convent were seriously damaged, with a delay in the conclusion of the construction (Mazzanti et alii, 1876), whilst according to others, the entire monastery fell down and, taking into consideration the difficulties to be had in trying to repair the original foundation, it was rebuilt closer to the church (Carocci, 1907).

In the same period, the San Miniato tower collapsed, and, to assess the causes of the general instability of the area, a committee was charged to study the hill conditions, and, among others, Leonardo da Vinci was also asked to participate(Gurrieri et al., 1988).

As causes of instability, the studies indicated: a) the geological composition of terrains–namely, the presence of beds of clayey marl, easily softened by water; b) the groundwater rise, in connection with intense and prolonged rainfall; c) the artificial undermining, due to the exploitation of a clay quarry located in the lower sector of northern slope.

However, no works were undertaken, and new damages to San Salvatore were recorded in 1530 and 1536: consequently, a little reservoir was dug near the convent to act as a drainage system (Bacci, 1960).

In 1547, during a catastrophic flood, a landslide occurred on an adjoining hill of Monte alle Croci, and several people died in Florence, thus shocking the city: the authorities temporarily prohibited any new building on the southern hills, and the tower of San Salvatore was lowered by about 15 m, this being based on the belief that the belfry load was responsible for the slope instability (Gurrieri et al., 1988).

During the following decades, new cracks in the convent walls compelled the friars of San Francesco to undertake extensive restoration work and, for a short period, to abandon the site. In 1652, a new landslide occurred on an undefined slope of Monte alle Croci, after a long period of heavy rainfalls; a technical board was given the task to study the causes and countermeasures (Bacci, 1960).

They agreed with the conclusions of the 1499 committee; when several tests proved the superficial origin of the waters, there was a general agreement on the mitigation strategies to be adopted for reducing landslide risk. These strategies can be summarized as follows: a) the building of a drainage system as a major restoration work (the plan of a very effective drainage systemrealized in 1652 is still available, although any evidence of the work has not been found on the ground); b) land-use policies, such as the suggestion of suitable agricultural practices or their constraint in some critical areas, and limitations in the construction of buildings; c) restoration of single buildings (such as underpinnings, substructions, and retaining walls) (Bacci, 1960).

At the end of the 17th century (1695), fresh damages occurred in the San Salvatore complex, and a new group of experts identified as triggering factors, the weak ground with a considerable water content under the building foundations, the high gradient of slope, and the change in land-use of the surrounding fields, which had been converted from woods into plantations.

The structures were reinforced with the construction of some buttresses and through the deepening of church's foundation by about 4 meters (Poggi, 1872). Some new damages are recorded in 1709, 1722, and 1758, and, consequently, some light restoration works

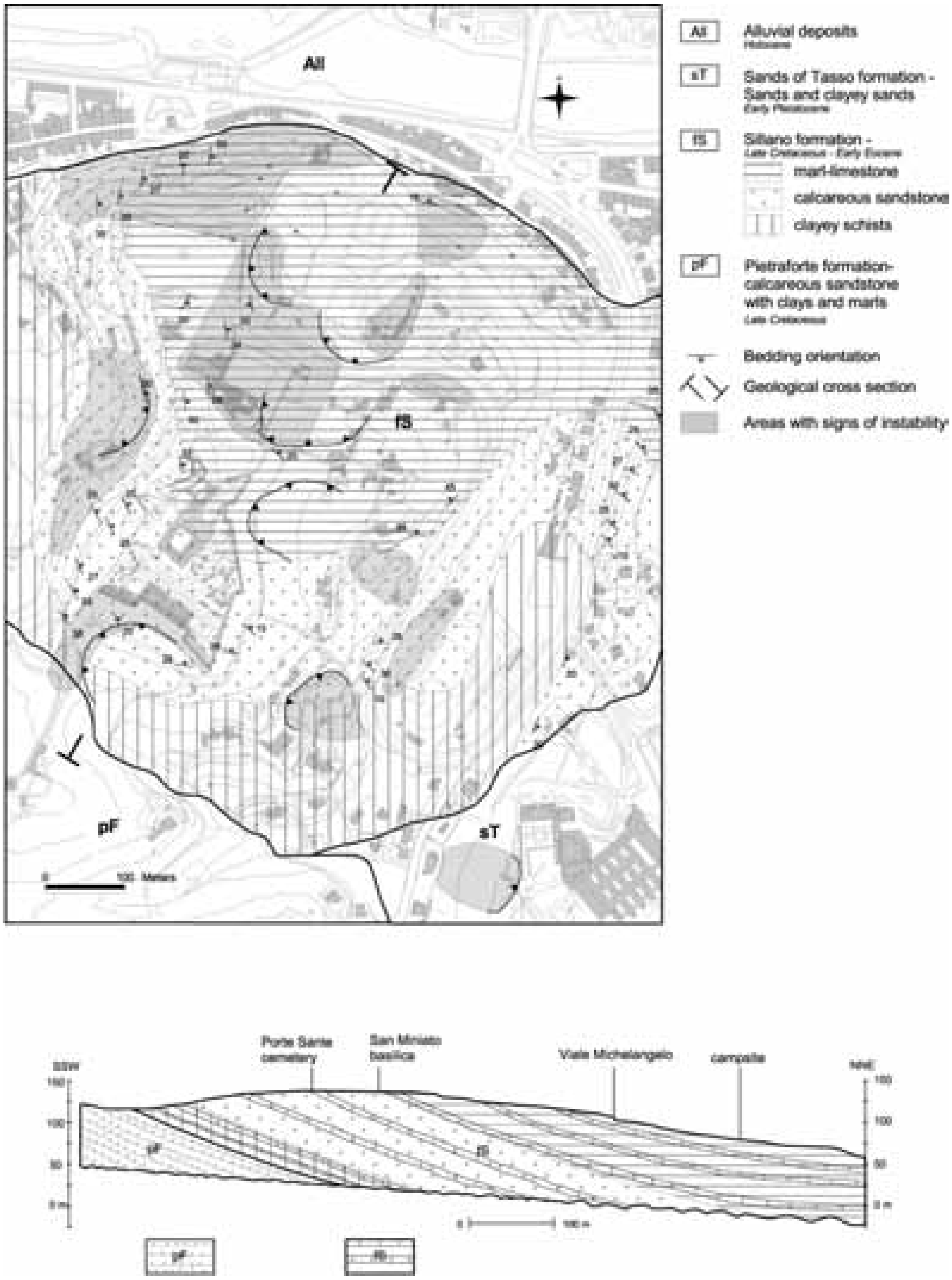

Figure 9 - Geologic and geomorphologic map of Monte alle Croci

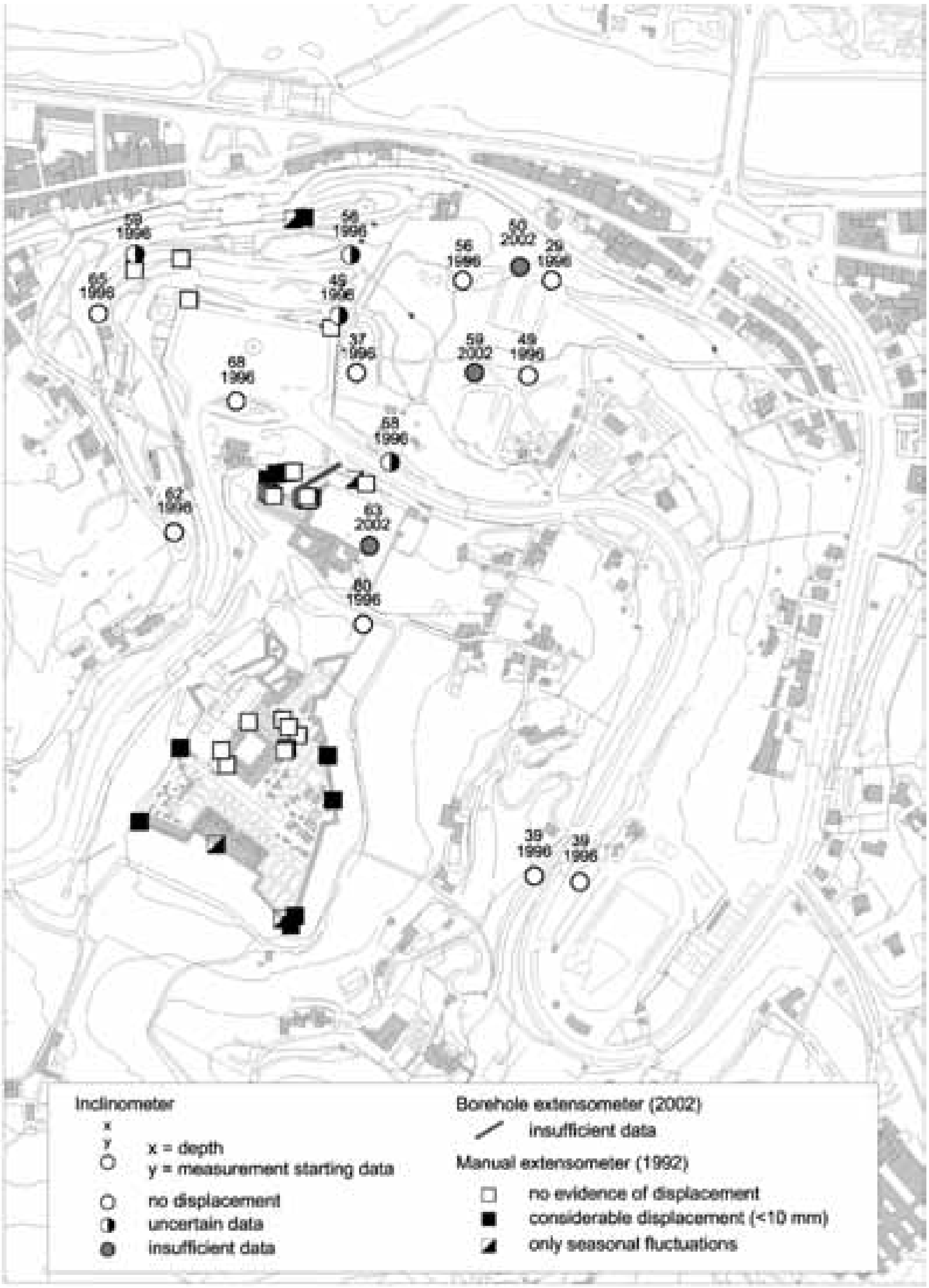

Figure 10 - Underground and superficial field surveys

were carried out in San Salvatore (Bacci, 1960).
The following reactivation of instability, in 1853, led the local authorities to constitute a new commission, in which G. Poggi was involved: they highlighted the role of the subsurface water regime and prescribed a lot of different interventions, which were never realized (Poggi, 1872).
Twelve years later, Poggi started his project, and, aware of the problems of the hill, he tried to establish a more stable layout: in spite of this, in 1878-79, after heavy rainfall, several cracks opened in the San Salvatore complex and the San Miniato bastions, especially in some of the newer structures, such as the loggia, the Piazzale Michelangelo retaining walls, and the buttress of the Rampe (Poggi, 1882; Giordano, 1884).
At once, the umpteenth commission was appointed: the experts, managed by F. Giordano, carried out a complete geological investigation, still admirable for its thoroughness and precision, condensed into some detailed stratigraphic logs, deduced from the excavation of five wells, from 15 to 33m in depth.
The inferred geological features were recognized as major factors in the instability triggered by earth movements during the main road works: however, the commission had many doubts about the presence of just one widescale,deep landslide, supposing the overlapping of some independent little mass movements, despite having conjectured a connection between the crack systems of San Salvatore complex and the Piazzale Michelangelo area.
Again, a careful drainage system was proposed as an adequate countermeasure, together with the building of new breast walls and some directions as to land use, as, for example, the banning of farming, and the restraint of new constructions; the reinforcement with chains of San Salvatore church was projected and realized in the following years (Giordano, 1884).
During the 20th century, some damage in the San Miniato complex was recorded, but it was linked to the indiscriminate digging in the cemetery of Porte Sante. There were episodes of slope instability in 1973 and 1989, with the occurrence of new cracks in the Piazzale Michelangelo and San Salvatore walls, and, in the case of the Piazzale, the development of a considerable sag.

Monte alle croci geological and geomorphological settings

The rocks outcropping at Monte alle Croci belong to an allochtonous formation of the Group of Calvana (Cretaceous-Lower Eocene), and are known as the Sillano formation (also named the Vallina formation), and are constituted of shales with interbeds of limestone, marls and sandstones: in the area, it is possible to distinguish three units, on the basis of the prevailing lithology (Fig. 9).
The rock layers are discontinuous and immersed in a clayey matrix, with a stratigraphical orientation of bedding parallel to slope, and dipping NE, with angles of between 20° and 30°. The Pietraforte formation, consisting of cemented sandstones, borders the southern sector of the area, and is partially overlapped by Pleistocene lacustrine sands (Sabbie del Tasso formation) (Focardi, 1991).
The main geomorphologic feature is the presence of slope instability, that, as described, has been affecting the hill for a long time. The recognition and delimitation of landslides is extremely difficult, due to the urbanization developments, over the last centuries, of the entire hill; the consequence of human settlement has resulted in a nearly complete obliteration of evidence of past and present displacements (Bertocci & D'Amato Avanzi, 1993; Bertocci et al., 1995).
The available documentation emphasizes the presence of several surfaces which are potentially subject to sliding (given the presence of soft clays, and strongly-fissured rocks) although clear failure surfaces have not still been defined (Giordano, 1884; Focardi, 1991; Bertocci et al., 1995).
According to some authors, slope instability is due to the presence of a generalized translational sliding of the entire hill, affecting the slope facing the Arno River, promoted by the orientation of bedding strata parallel to slope (Losacco, 1957). According to others, landsliding is due to independent phenomena (Bertocci et al., 1995; Agostini et al., 2002a; 2002b).
Given the lack of conclusive data, the most significant representation of available information is to be found along the boundary of some areas where signs of superficial instability are present.
The most important site, both in terms of its size, and in terms of the value of the involved or menaced buildings, is sited on the east side of Piazzale Michelangelo. This area is a wide valley, limited on the western flank by Michelangelo's bastions, and partially occupied by a camping site; it presents a large potential source area, which encompasses the zone of the San Salvatore church, and a portion of Piazzale Michelangelo.

Site investigation and monitoring

The most recent series of modern site investigations started with the works of the Giordano Commission in the 19th century, and continued during the 20th century with some drilling and structural deformation surveys. The most recent episodes of slope instability (in 1973 and 1989), induced the authorities to arrange an extensive campaign of underground and superficial field surveys, in order to understand better the geometry, geology, geotechnical properties, causes and possible evolution of phenomena in the area (Fig. 10).

Most of the instruments are still active, even if the results of field surveys carried out in the past are often difficult to understand, especially comparing data with superficial evidences. In particular, some inclinometric records are difficult to interpret correctly, due to a non-verticality of the tubes involved, and their imperfect cementation in the terrain (Agostini et al., 2002a; 2002b; Agostini and Fanti, 2003).

As a general rule, it can be stated that both inclinometers and extensometers have indicated good stability for the highest portion of the hill, where the Basilica of San Miniato is sited.

On many of the monitored buildings, some seasonal fluctuations have been measured; such fluctuations sometimes show large differences and, in some critical cases, a marked trend, such as in the wall of the San Salvatore church-square. In many cases, slope instability can very likely be associated to a lateral pressure of terrains on the structures, rather than to slope instability.

The data as a whole are interpretable as the result of a present condition of a general slope stability, that rules out the possibility that one or more deep landslides (slip surface > 5 m) with notable velocity, are active (of course, if inactive or extremely slow, they are undetectable through the inclinometers).

On the other hand, the existence of a set of superficial earth movements, like soil slip, is conjecturable: this can explain the framework of damages and cracks now observed.

It is very difficult to define the extent of these unstable areas, or their reciprocal relationships, and in this field, a very significant area is the Piazzale and the Rampe area below, where the Poggi project created an elaborate arrangement of filling material and excavation, with a steep gradient.

Nowadays, the area is considered the most critical, in terms of geomorphologic hazard and risk to the city's cultural heritage.

Looking at the situation as a whole, in order to establish the real dimensions of the superficial movements and, above all, to control the possible reactivation of bigger landslides, the continuation of the present monitoring survey is necessary. In particular, new and more revealing data are expected from the recent instruments, such as the deep inclinometers, surely well realized, and the sub-horizontal multi-basis bore-hole extensometer (Agostini et al., 2002a; 2002b).

Conclusions

Monuments and buildings sited on the hill of Monte alle Croci present damage of different degrees of severity (fissures, cracks, superficial displacements), part of which are due to mass movements.

As drawn from historical data, slope instability processes have occurred at different times, involving, in particular, the zone presently in use as a camping area, as well as the church of San Salvatore and the adjacent convent.

In the past, a large slope movement from south to north, affecting the entire hill, was hypothesized, but recent monitoring, and stratigraphical and geomorphological studies, have lead us to interpret the present instability phenomena as a series of independent and superficial slope movements distributed around the hill.

This cannot exclude the existence of one or more deep landslides, involving large parts of the hill, because, in the case of inactivity or very low velocity, the inclinometric survey, (moreover not completely reliable), is unable to detect them.

In order to control the evolution of the area, and, in particular, the possible reactivation of a general instability, the existing monitoring system, recently improved and integrated, will continue to be used.

However, at the present time, a higher risk is determined by the evolution without control of the little debris slips, since many deposits of filling material are distributed on the slopes, in particular in correspondence to monuments and other cultural heritage sites.

The great part of this filling material has poor geotechnical properties, and it is the result of Poggi's works, as the mutually unstable situation of the Piazzale and Rampe areas shows. For reason, an accurate monitoring and control is necessary in order to avoid the reoccurrence of events that, even if of very low magnitude, can determine a very high risk, due to the precarious balance of the site, a unique balcony on the art and history of Florence.

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field trip itinerary

FIELD TRIP MAP

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