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Geosciences on a changing planet: learning from the past, exploring the future

88° Congresso della Società Geologica Italiana

Napoli 7-9 Settembre 2016

Abstract book

Edited by

D. Calcaterra, S. Mazzoli, F.M. Petti, B. Carmina & A. Zuccari

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UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

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Three-dimensional electrical and seismic tomography for assessing the state of conservation of a masonry wall

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Keywords: electrical resistivity tomography, seismic tomography, masonry wall, rising damp.

Geophysical non-destructive testing has been applied worldwide during last decades for understanding the inner geometry, the constructive materials and the degree of conservation of ancient buildings affected by the ravages of time, human interventions or natural phenomena (e.g. Polymenakos et al. 2005; Tsokas et al., 2013).

The integrated approach presented in this work encompasses the use of Electrical Resistivity Tomography (ERT) and seismic tomography aiming to assess the current state of conservation of a Roman masonry building, named "Casa di Diana", located at the Ostia Antica archaeological site (Rome, Italy).

Three-dimensional ERT and seismic tomography investigations were focused on an inner wall, made in opus caementicium, prone to both rising damp and cracking phenomena, in order to reconstruct a 3D model where anomalous zones would be highlighted. ERT dataset were inverted with the VEMI interface (De Donno & Cardarelli, 2015), while seismic tomography inversion was performed by means of the algorithm after Cardarelli & Cerreto (2002).

Results show that low resistivity and P-wave velocity values can be associated to the presence of the inner mortar, while higher values of both parameters were observed for the existence of the outer brick component. Overall, with reference to a previous work where a small-scale sample of a Roman masonry wall was analysed in the laboratory using seismic tomography (Cardarelli & de Nardis, 1999), the brick part seems to be in good conditions (optimal V_P=1400 m/s, recovered V_P=1300 m/s), while the low velocity values of the mortar (optimal V_P=500 m/s, recovered V_P=250 m/s) can potentially represent an anomaly due to degradation phenomena. Therefore this approach can be employed to reconstruct a 3D model of an archaeological wall in order to plan the recovery actions.

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Contribution of geophysical methods to the characterization of the subsoil at archaeological seismic sites: the case of Hierapolis (Turkey)

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Keywords: soil characterization, seismic site, GPR, ERT, reflection seismic surveys, surface wave analysis.

The characterization of the subsoil, particularly in active seismic zones, is fundamental to plan the activities and the tools to be adopted for heritage preservation. In this context, the use of geophysical measurements, considering their non-invasive approach, offers an essential contribution to localize the anomalies in the subsoil, identifying the most critical zones under the built heritage. We present an example of soil characterization in a seismic zone represented by the results of geophysical surveys carried out at the archeological site of Hierapolis (Turkey). The goal is to reconstruct the subsoil characteristics under a monumental building known as 'Terme-Chiesa' complex, exposed at serious seismic damages through many centuries. The Hierapolis archeological site is located on the complex Eastern normal faults system of the Denizli Graben (De Filippis et al., 2012). The site was interested by a dozen of large earthquakes in the last few centuries. The faults system that crosses the archeological site is considered "seismogenic", i.e. being capable of seismic magnitude > 6.0 (Hancock et al., 2000). The normal fault system, on the other hand, facilitates spontaneous thermal springs exploited since the Roman period, where the rising of hot carbonatic waters facilitated the deposit of thick travertine covers (Ozkul et al., 2013; Koralay & Kılınçarslan, 2015). This peculiar and complex geological context made the fortune of the ancient Hierapolis, worldwide known for its travertine quarries, but it should be carefully taken in account for seismic response. On the other hand, one should note that large travertine deposits, highly conductive in term of electrical properties, can affect geophysical results (e.g. Pola et al., 2014). For the characterization of the 'Terme-Chiesa' subsoil at Hierapolis, we used GPR and ERT measurements, reflection seismic surveys, surface wave analysis and passive seismic acquisitions. In the end, the subsoil characterization by geophysical measurements shows close correlations with structural damage evaluations and offers new tips in the field of built preservation.

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Research of crypts and/or cavities of the Bronze Age in the Hyblean carbonate soil by means of seismic tomography: a case study

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Keywords: Cava Ispica, bronze age, seismic tomography, cavities, Sicily.

The Hyblean plateau (South Eastern Sicily) consists of a platform carbonate interbedded with volcanic horizons, whose age ranges from the Cretaceous to the Pleistocene and is characterized by the presence of numerous incisions from waterways, known locally as "hollow". The most important is the “Cava Ispica” which crosses for about 13 km the municipalities of Modica, Ispica and Rosolini. It is a collection of archaeological evidence, ranging from prehistoric to medieval low, entirely cut into the rocks, which make this "hollow" one of the most representative historical places of Sicily pre-classical and late antiquity (Trigilia, 2011). The monuments that are within the perimeter of the Regional Archaeological Park have long been excavated, but many still remain below the current floor plans due to the amount of coves that characterizes this part of Modica territory. Non-invasive seismic surveys were carried out in the area between the catacomb of Larderia (IV-V century a.d.) and the area of the Gymnasium’s caves (III century b.c.) in order to identify the possible presence of anthropic cavities in the subsoil.

The strong contrast between the low velocity zones such as human cavities, and high seismic velocity waves of limestone rock formation that contains them, strongly favors the use of this geophysical technique (Cardarelli et al., 2010). As witnessed by the numerous excavations carried out in the area during the archaeological surveys the cavities are often filled by material of geological/anthropogenic source that has accumulated in hundreds of years, this means that there is not a sharp contrast between the rocky continuum and the empty.

The seismic refraction surveys processed using tomographic method have highlighted low seismic velocity (<400 m/sec) zones distributed evenly in both areas on the site "Gymnasium" and "Terrace", with constant depth of two meters from the surface. These areas represent evidence of the presence of man-made cavities. The size and the shape of cavities have been defined through the isovelocity surface having values of about 400 m/sec. On the basis of knowledge acquired the shapes and sizes of these areas are compatible with paleo-anthropic elements present in the site and visible on the surface, and it is therefore reasonable to expect similar deep structures.

The three-dimensional reconstruction doesn’t highlights a net and linear geometry, because, as is expected, can be filled largely by solids.

Although the lack of a net velocity contrast between the rock and the filled or partially filled cavities has made difficult to interpret the seismic lines acquired, the numerous informations deriving from surveys carried out are undoubtedly a useful planning tool for the purposes archaeological research.

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Geophysics applied to archaeology: multi-instrumental surveys for a Byzantine site recovery in Eastern Sicily

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Keywords: geoarcheology, multidisciplinary approach, multi-instrumental surveys.

In recent years the geophysical applications in archaeology allowed the archaeological research to program /optimize phases of archaeological excavation of any target, although today there isn't an universal method of geophysical survey for all types of contexts. This note presents the case-study results in an archaeological site in Ragusa province, obtained by investigations performed with multi-instrument and multidisciplinary approach (archaeology, geology, geophysics and topography), focused on the context characteristics and research objectives. The case-study is a late Roman – Byzantine site in C.da Selvaggio (Rg), marked by a small thermal bath and a Tardo-Antica church; geophysical surveys conducted here have had a dual purpose. The first, properly about research and study, verifying archaeological assumptions respect to a structure covered by a late medieval adamant pavement. The results of the geophysical surveys have enabled us to detect the presence of voids below the pavement that, when excavated, has been revealed as tombs; while the second, provided the certainty of the presence of buried structures (potential alignments of walls and roads) useful to program possible further excavations next the Frigidarium (part of the old small thermal bath) already identified.

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Integrated geological and geophysical methods to investigate the Palatine hill archaeological area (Rome, Italy)

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Keywords: Integrated subsurface model, Anthropic layer, ERT and GPR, Geohazard assessment, Palatine hill.

The Palatine hill archaeological area was investigated with the aim of assessing local geohazard levels. In particular, well-logs from continuous coring boreholes, Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) surveys were integrated in order to detect cavities, both in the geological units and in the anthropogenic layer.

Continuous coring boreholes were drilled on the Palatine hilltop, along the slopes, and in the alluvial valleys bordering the hill. All the boreholes crossed the anthropic layer, which ranges in thickness between 1 and 20 meters. Some of the boreholes drilled built structures with empty voids, or filled by anthropogenic material. Several boreholes also crossed a network of tunnels dug in the tuff rocks underlying the anthropic layer. These tunnels are often filled with unconsolidated, unsorted anthropogenic material.

For the GPR surveys, a GPR SIR3000 (GSSI) equipped with a 500 MHz bistatic antenna with constant offset, a 70 MHz monostatic antenna, and a 35 MHz monostatic antenna, was employed. A nominal microwave velocity of about 0.07 m ns-1 was determined from fitting hyperbolas to the raw field data and used to estimate the penetration depth from the GPR survey (up to approximately 15 meters). In order to obtain a planimetric image of all possible anomalous bodies, the time-slice representation technique was applied using all field profiles.

GPR survey was than constrained mainly using well-logs and archaeological stratigraphies. Low intensity reflectors are related to fine-grained geological and anthropogenic materials, while high-intensity reflectors are referred to empty voids and to masonry or foundation remains.

Resistivity field data were collected with a Syscal R2 resistivity meter coupled to a multielectrode acquisition system (48 electrodes), using different array configurations (Wenner-Schlumberger and Dipole-Dipole) and an electrode spacing ranging from 1 to 10 m, obtaining different investigation depth (from about 8 to 80 m).

The electrical images were successively compared and calibrated with data coming from geological, archaeological, well-logs and GPR surveys. As regards the archaeological layer, it shows an irregular lower boundary and variable resistivity values. Relatively high resistivity values (ρ>400 Ωm) are associated to voids and/or cemented conglomeratic walls, while low to moderate resistivity values (ρ Particular attention was paid to two areas of the hill, i.e., the Clivo Palatino and the so-called No Man's Land. Integration of information resulting from different prospecting techniques have allowed us to define an extremely complex subsoil setting, mainly due to the presence of cavities whose partial collapse has probably involved built structures already in historical times, as well documented by the archaeologists in this area of the hill.

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Integrated Geophysical Investigation of a Buried Roman Villa in Pompeii

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Keywords: Electric and Seismic Tomography, Magnetometric Survey, GPR, Rural Villa, Imperial Age.

In archaeological research non-invasive techniques are commonly used to characterize a site or part of it. Among them, geophysical surveying is a valuable, non-destructive tool for archaeologists in evaluating sites and guiding excavation programmes within already discovered sites.

In this paper we describe the results of an integrated geophysical survey carried out over a buried Roman Villa in Via Nolana, Pompeii. The area was partially unearthed in 1985 showing the remnants of a villa from the first Imperial Age. The excavation found also some frescos and traces of rural activities. The remnants were successively earthed again.

The survey included high-resolution Geoelectrical, Magnetometric, Seismic and Ground Penetrating Radar measurements. They were performed both over the known buried structures and in the unexplored area immediately adjacent to the remnants, with the aim of verifying the presence of other unearthed villa structures beyond the explored area.

Data processing included advanced filtering techniques, such as *Discrete Wavelet Transform* (DWT, Fedi & Florio, 2003), allowing an effective filtering of localized and directional noise. Furthermore, the use of multi-scale potential-field techniques such as *Enhanced Horizontal Derivative* (EHD; Fedi & Florio, 2001) and *Depth from Extreme Points* (DEXP; Fedi, 2007) allowed positioning the lateral edges of the buried structures and characterizing their shape and depth.

The results yielded by the different methods showed a rather good consistency in terms of position and size of the buried structures. Furthermore, the integration of the outcome of each geophysical technique reduced the intrinsic ambiguities of each method.

Our interpretation revealed the presence of remnants in the unearthed area, in continuation of the already discovered section of the villa, and highlighted preferential areas for future archaeological diggings.

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First outcomes on the study of a relict landslide at the Abakainon necropolis (NE Sicily)

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Keywords: Relict landslide, Abakainon, seismic tomography, necropolis.

The Greek colony of Abakainon was a founded in northeastern Sicily by Sicels, after having defeated the Sicani in 1100 BC (Oliva et al., 2012). Its strategic location made this settlement very desired, especially for military and trading purposes, leading to a succession of conquests by different people. Nowadays, the unearthed ruins of the necropolis are accessible to tourists at the village of Tripi, northern Sicily. Here several tombs appear partially collapsed or broken, probably due to a natural event. An archaeoseimological study was carried out by Bottari et al. (2013), who found that the necropolis was abandoned before the collapse, and that the destruction is likely to have occurred after an earthquake. In particular, from in situ morphological evidences they hypothesized that the necropolis was built on a relict landslide, which is likely to have been reactivated by the seismic event, leading to the destruction of the site.

This research aims to investigate on the landslides occurred in this area, looking for evidences of the relict landslide hypothesized by Bottari et al. (2013), by in situ geological and geophysical surveys. Several landslide bodies were surveyed in the area, along with widespread blocks fallen from rock cliffs. The main movements can be classified as rockfalls, debris flows and rotational or planar sliding and affect both the intensely weathered metamorphic basement and its sedimentary covers. With particular reference to the necropolis site, electric and seismic tomographies were performed looking for evidences of the main body of the relict landslide. Results highlight that the necropolis was built on a poor material from a geomechanical point of view, with P-wave velocity lower than 800 m/s and low resistance values, comparable to material mobilized by an old landslide. The lowest seismic velocities characterize the central sector of the site, which is likely to be the midmost portion of the main body of the relict landslide. Nevertheless, within the investigated depth (about 17 m) no sliding surface was detected; for this reason, further surveys will be soon performed.

Achieved results, although preliminary, validate the hypothesis that the Abakainon necropolis was built on a relict landslide body and that, after a shaking event, it was razed probably due to a site effect.

Bottari C., Barbano M.S., Pirrotta C., Azzaro R., Ristuccia G. & Gueli A. 2013. Archaeological evidence for a possible first century AD earthquake in the necropolis of Abakainon (NE Sicily). Quaternary International, 316, 190-199.

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Searching for the Antigonea theatre: A magnetic survey in an ancient Epirus city

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Keywords: Magnetic anomalies, Topographic correction, Greek theatre, Albania, Antigonea.

We report on two magnetic surveys performed in July and September 2015 at the ancient Hellenistic city of Antigonea, located in southern Albania. The main objective of the two surveys was to find the city theatre and determine possible sites of future excavations. We developed a new technique for dense collecting of magnetic data along difficult terrains, with minimization of the topographic effect. Evidence of a possible location of the theatre was found along the southern slope of the Jermë hill, just outside the city walls. Other interesting structures indicate the presence of many other buildings in this part of the Antigonea settlement.

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Magnetic and electromagnetic prospections at the Roman city of Urbs Salvia, central Italy

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Keywords: Magnetic anomalies; Urbs Salvia; Forum; Ground Penetrating Radar.

We report on a combined magnetic–GPR survey performed in 2015 and 2016 at the ancient Roman city of Urbs Salvia, located in central Italy. The main objective of this survey was to reconstruct the urban organization of the city forum and determine possible sites of future excavations. We found a complex pattern of buried structures, possibly resulting from the coexistence of republican and imperial artifacts and burned structures. A test excavation at the location where we detected a long linear structure characterized by strong magnetic signal revealed the presence of thermal baths. GPR data were acquired in the area adjacent to the theatre and in other areas characterized by high magnetic noise induced by metallic infrastructures (e.g., fences), which prevented a correct acquisition of archaeological anomalies. These data not only allowed to overcome the magnetic noise, but provided interesting 3D reconstructions of the buried structures.

SESSION S33

Metals in the Mediterranean area: Archaeology and current resources

CONVENERS AND CHAIRPERSONS

Maria Boni (Università di Napoli Federico II)
Nicola Mondillo (Università di Napoli Federico II)
Gilberto Artioli (Università di Padova)

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Prehistoric copper exploitation in the Alps

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Keywords: Copper metallurgy, Alps, Copper Age, Bronze Age, smelting slags, mining.

The research group at the University of Padova has developed a geochemical database for the Alpine copper mines that includes lead isotope data for most of the copper deposits in the Western Alps and Italian Eastern Alps, besides a number of other geochemical tracers for selected deposits. The database fills an existing gap in available reference data and provides valuable information for the geochemical interpretation of the mineral deposits. The database may be critically inquired to assess the provenance of the mineral source of slags and metal objects: The successful results obtained on provenancing a number of Copper Age and Bronze Age metal objects will be presented. The data clearly show the importance of the Alpine deposits in the production and circulation of copper metal in prehistoric and protohistoric times. The chemical and isotopic differences between Bronze Age copper ingots and coeval metal objects are discussed.

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"Critical" importance of the Silius vein system (SE Sardinia,Italy)

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Keywords: Fluorite, Rare Earth Elements, critical raw materials.

The late- to post-Hercynian geological evolution of Europe, as well as part of Northern Africa, is characterized by numerous hydrothermal mineralizing events, ranging in age from the end of the orogenic compression (Permian) to the onset of Tethys spreading (Triassic-Jurassic) (Muchez et al., 2005). The Silius vein system (SE Sardinia (Italy) is analogous to other late- to post-Hercynian mineral systems of this type in Europe. Silius consists of two main veins, characterized by several generations of fluorite, barite, carbonates and quartz (Boni et al., 2009). Silius is known for its barite-fluorite, but also galena mineralizations that have been exploited until lately. Distinct fluorspar resources still exist in the mine area. Gangue carbonates, consisting of calcite and ferroan dolomite, contain Rare Earth Elements (REE)-bearing minerals represented by minor xenotime, and especially by synchysite-(Ce) (Mondillo et al., 2016).

To check the effective amounts of REE in the Silius orebody, representative samples of the carbonate gangue have been collected in the underground mine. The values of LREE mainly, are in the range of 462-2071 ppm (951 ppm on average). The average volume of the carbonate gangue still in place is considered to be around 532,000 tons, to which may be added more 750,000 tons of carbonates discarded at the flotation plant. The corresponding total REE resource currently occurring at Silius may be about 1,220 tons.

The discovery of REE in the Silius mine opens interesting perspectives for the exploration of subeconomic REE concentrations in this deposits type, where REE could be recovered as by-product of the fluorite exploitation. REE geochemistry of carbonates in other post-Hercynian fluorite veins has been widely investigated in the Harz Mts (Germany), in the Valle de Tena (Spain) and in the El Hammam orebodies (Morocco). Even though REE occur in contents comparable to those observed at Silius, the above deposits are not considered economic for this type of commodity till now. Being both REE and fluorite critical raw materials for the European economy, the Silius and the other similar post-Hercynian F-mineralizations should be now reconsidered in their double significance: not only for their fluorspar content, but also for the possibly recoverable REEs contained in the carbonate gangue.

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Metallic artifacts (Bronze/Iron Age, Campania region, southern Italy) from the collection of the Paleontological Museum of the University of Naples Federico II: a first look

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Keywords: bronze, objects, Bronze/Iron Age, Striano, Sarno River plain, Campania, mineralogy.

Archaeological metallic objects coming from the Striano surroundings, a town located in the Sarno River plain (Campania region, southern Italy), are preserved in the Paleontological Museum (Centro Musei delle Scienze Naturali e Fisiche) of University of Naples Federico II. They belong to a vast collection of ceramics and metallic artifacts, found in 1930 and then given to the former Geological Museum of the Naples University (De Joanna, 1947). These objects are related to the proto-historic necropolis of Striano, that date back to the late Bronze Age up to the Iron Age ("Orientalizing" period; D'Ambrosio et al., 2009). These findings are very common in the whole Sarno River plain, situated in the south of the Somma-Vesuvius volcanic complex. Until today the archaeological research activity of the Sarno River plain was particularly focused on urban settlements like Pompeii, Nuceria and Stabiae, but all their hinterland represents a very important cultural landscape, characterized by continuous anthropogenic activity since the Middle Bronze Age (Seiler et al., 2010). The eruption of the Somma-Vesuvius AD 79 resulted in a nearly complete burial of the entire Sarno River plain, hence this unique situation of a sealed pre-AD 79 perfectly conserved archaeological findings and paleo-landscape enable detailed investigations of both the ancient remains of human activity in the plain and of the paleo-environment/topography (Seiler et al., 2010). The metallic objects consist of bronze spearheads and sheaths, and have never studied before. This work deals with a first mineralogical characterization of the bronze artifacts by means of X-ray powder diffraction (XRPD), metallographic optical microscopy and scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS). Preliminary mineralogical data show that they are mainly composed of Cu-Sn alloy, with Sn content ranging from 5 to 12 %. Inclusions of galena, native copper, lead and silver, as well as argentite are also detected in the alloy. Alteration minerals are mainly represented by cuprite, silicates, phosphates and sulfates. Microstructures are observed by optical microscopy and secondary/backscattered electrons imaging.

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Mineralogical and geochemical data on metallic artifacts from the National Archaeological Museum of the Agro Picentino – Pontecagnano (Salerno)

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Keywords: metallic objects, Pontecagnano museum, Bronze Age, Iron age, IV-V century.

Pontecagnano (SE of Salerno) archaeological site, the ancient town of Amina (renamed "Picentia" by the Romans) is the largest Etruscan outpost in the south (Camporeale, 2013; Cerchiai, 2013; Cuozzo, 2013). Archaeological investigations - started since the 1960s - certify the area has been inhabited as early as late Neolithic. At the beginning of the 3rd millennium BC the area was settled by peoples of Gaudo culture, probably immigrated from Anatolia. Gaudo population worked metals, as testified from copper daggers and other weapons excavated from more than 9.000 tombs in the area. The National Archaeological Museum of the Agro Picentino was instituted in 2007 and contains more than 8000 findings mainly related to tomb outfits (Tocco, 2007). The main Etruscan settlement was founded between the end of the X and beginning of IX century b.C. on the left side of the Picentino river. The period of its greatest development was the "Orientalizing" age (end of VIII-VII century b.C.), when great and wealthy aristocratic families (the so-called "Princes") took the power, as also testified by precious artifacts found in the Pontecagnano burials. Then, the settlement took urban connotations, becoming a frontier community. This work deals with mineralogical and geochemical characterization of various metallic artifacts spanning in age from early Eneolithic/Bronze Age to IV century b.C. by means of X-ray powder diffraction (XRPD), scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDS) and micro X-ray fluorescence m-XRF. The objects are of different types (fibulae, rings, earrings, spears, pins, ingots, slags, etc.), and are mainly composed of lead, copper, silver and bronze. The bronze artifacts are high-Sn (17.3 to 27.4 %, Sn), as expected by ancient alloys; lead and iron, as well as titanium and nickel to a lesser extent, can be also present as minor to trace components. The silver artifacts can contain small amounts of copper, iron and gold; in one case a copper object (91.4 % Cu) also shows other metallic components, as lead (4.8 %), bismuth (2.6 %) and iron (1.1 %). Interesting microstructures are also observed. Finally, the combined use of two spectroscopic techniques allowed us to verify the potential of m-XRF in archaeometallurgy sector in order to carry out non-destructive and non-invasive analyses.

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