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Reconstruction of a segment of the world's heritage Hadrian's Villa tunnels network by integrated GPR, magnetic-paleomagnetic, and electric resistivity prospections

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The UNESCO world's heritage Hadrian's Villa lies over the Quaternary Colli Albani Volcanic District, near Rome. The substratum is composed by a complex succession of volcano [U+F02D] sedimentary units that are characterized by irregular geometry, variable thickness, lateral facies variations, and heterogeneous alteration. The outcrop lithology in the survey area is represented by the Pozzolanelle Unit (Villa Senni Formation), an ignimbrite tuff massive deposit characterized by an ash matrix abundant in iron oxide [U+F02D] rich scoria clasts and leucite crystals. A combined magnetic–radar survey was performed in 2017–2018 in the area surrounding the Hadrian's Villa Plutonium. The main goal was to detect buried buildings and outline the local structure of the underground system of tunnels that links different zones of the villa. While several buried structures were revealed around the exposed part of this monumental building, the most interesting finding is represented by a complex system of interconnected tunnels of different size. The radar survey was performed using a GSSI SIR 4000 system equipped with a 200 MHz antenna, which in principle should have allowed sufficient penetration for investigating the system of tunnels that were dug in the tuff units underlying the Plutonium–Inferi complex. However, the soil of this area includes abundant clays that formed by weathering of the volcanic substratum. In moist conditions, these clays display strong electric conductivity, thereby the maximum depth of penetration did not exceed 2 m. Total field magnetic data were collected using a Geometrics G–858 cesium vapor magnetometer. These data are associated with high [U+F02D] amplitude magnetic anomalies, due to the highly magnetic bedrock and strong magnetization contrasts between topsoil infill of cavities and the surrounding tuff. The integrated use of GPR and magnetic data allowed complementary but not directly correlative analyses of the materials preserved in the ground but the two method's results complemented each other in determining the properties of the ground. The GPR and magnetic analyses were supplemented by electric resistivity 2D ERT tomography profiles, which were acquired to confirm the presence of holes and tunnels. Finally, nine cores were sampled from the bedrock beneath the Plutonium area. The samples were analyzed at the ISMAR–CNR Paleomagnetic Lab of Bologna with the objective of determining the NRM magnetization of the substratum. The results of the paleomagnetic analysis explain the strong magnetic anomalies observed around the Plutonium, with magnitudes up to ∼2200 nT. The collected dataset was used in the reconstruction of the geometric arrangement of the buried structures through forward modelling of the magnetic anomalies, while the integration with GPR data allowed a characterization of the physical nature of the sources of the observed anomalies in three dimensions.