Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 29, issue 2 / 2023, pp. 75-81

ROCKMASS FRACTURE ANALYSIS AT CĂRPINIȘ TRAVERTINE QUARRY USING GROUND PENETRATING RADAR AND GEOPHYSICAL METHODS

Camelia MADEAR[1*], *Laurentiu ASIMOPOLOS*[2], *Natalia ASIMOPOLOS*[3], *Gelu MADEAR*[4]

[1]University of Petrosani, Petrosani, Romania, cameliamadear@upet.ro
[2]Geological Institute of Romania, Bucharest, Romania, laurentiu.asimopolos@igr.ro
[3]Geological Institute of Romania, Bucharest, Romania, natalia.asimopolos@igr.ro
[4]ECO-ROCCA Engineering, Petrosani, Romania, gelu.madear@eco-rocca.ro

DOI: 10.2478/minrv-2023-0017

Abstract: *Travertines are susceptible to fracturing/ cracking, making it difficult to extract large uncracked blocks of significant commercial value. In our study, we used the GPR – Ground Penetrating Radar and other geophysical methods (resistivity and seismic methods) to evaluate the degree of fracturing. Following the interpretation of the longitudinal and transversal GPR profiles, corroborated with the resistivities minima, led us to identify fractures and highly fracturing areas in the Carpinis quarry. In addition, using these combined methodologies and corroborating geophysical, geological, tectonic and geomorphological information creates the premises for an effective investigation of Carpinis quarry, which assists with optimising the mining process.*
Keywords: *travertine quarry, ground penetration radar, rock cracking, resistivity method, electric tomography, seismic method*

1. Introduction

The geomorphological and geological conditions specific to the travertine quarry in Carpinis led to an advanced degree of fracturing of the rock mass. Thus, on the plateau northwest of Carpinis, the Quaternary travertine formations were formed by the precipitation of geothermal waters rich in $CaCO_3$. The thermal springs that appeared at the intersection of the faults or along the faults, without a uniform distribution and with variable flows, led over time to the formation of travertine deposits. Therefore, travertine is a sedimentary rock formed by the precipitation of hydrothermal solutions.

These deposits vary in thickness, degree of compactness and colour. The vacuoles' density, size and spatial arrangement give the textural appearance of travertine. Sometimes travertine can look like breccia or weathered wood.

The travertine is extracted in the quarry from the hills to the right of the Mures Valley, near Simeria, the village of Carpinis, Hunedoara County.

Together with Geoagiu travertine deposits, these constitute Romania's only travertine mineral resources.

The travertine rock mass is susceptible to fracturing, making extracting large, uncracked blocks difficult.

Several methods can be used to evaluate the fractures/ cracks in the Carpinis travertine quarry, including visual inspection (a simple and accessible method) and geophysical methods, such as:

- Ground Penetration Radar (GPR);
- seismic and/ or resistivity method,

which can be used to detect underground cracks and estimate their depth.

These methods can be more effective than visual inspection because they allow the evaluation of fractures at greater depths without using other intrusive methods in the quarry.

* Corresponding author: Camelia Madear, Lect.eng. Ph.D, University of Petrosani, Petrosani, Romania, Contact details: University of Petrosani, 20 University Street, cameliamadear@upet.ro

vol. 29, issue 2 / 2023
pp. 75-81

2. Geology of Carpinis Quarry

The travertine deposit from the Carpinis quarry (Fig. 1) is located in the central part of Hunedoara County, in the Carpinis village, on the border limit with Bampotoc village. From an administrative point of view, the village of Carpinis belongs to the city of Simeria.

Figure 1. Carpinis Travertine Quarry, Romania

Access to the deposit is on the paved road from the right bank of the Mures River, then on the paved road that passes through the village of Carpinis - Fig. 2

From a geographical point of view, the Carpinis area belongs to the southern extremity of the Metaliferi Mountains, to the interference of the Mures depression and Hateg - Orastie depression.

These lines separate the Metaliferi Mountains and the Zarandului Mountains to the north and Poiana Rusca to the southwest. The area is hilly. Several hills with heights of 300 – 600 m are being developed. The area being exploited has a hilly aspect with 130 – 150 m unevenness due to slow geological processes of erosion and sedimentation.

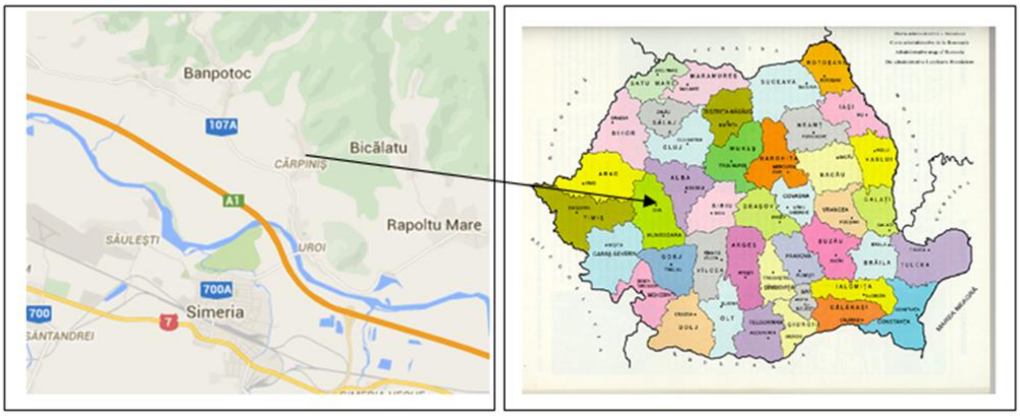

Figure 2. Carpinis Quarry Location

From a geological point of view, the territory of Hunedoara County has a complex structure as follows:

- crystalline and granitoid formations, conglomerates, sandstones and marls in the Southern Carpathians;
- metamorphic rocks in the Sureanu and Glodeanu Mountains as well as the rustic part of the Poiana Rusca massif;
- sandstones, clays, limestones, and marls in the Sureanu Mountains and the Petrosani Basin.

In terms of the region's geology, the geological composition of the area includes crystalline formations, sedimentary and eruptive rocks.

The crystalline formations represent, by stratigraphic position and degree of metamorphism, the continuation of the epimetamorphic series of the Poiana Rusca Mountains.

vol. 29, issue 2 / 2023
pp. 75-81

During the sedimentation in the Rapolt area, an east-west oriented coral barrier was formed, which greatly influenced the character of the sedimentation near the reef, depositing carbonate, and terrigenous material to the north and south, the initial magmatism was manifested, from which the tuffs and tuffites intrusions were formed.

This material was metamorphosed regionally, and the resulting rocks can be separated into four complexes:

- carbonate;
- carbonate-quartz;
- phyllites-conglomeratic;
- porphyritic.

The carbonate complex consists of massive, stratified limestones, sometimes schistose, dolomitic limestones, dolomite-calcareous dolomites, schistose or stratified dolomites, ankerite or ankerite dolomites.

In the Rapolt area, the complex has maximum development, forming the anticline symbioses and gradually thinning towards the west. The massive, stratified limestones are fine-grained, massive, and compact and become schistose near the phyllites.

At Bampotoc, they are greyish and comprise blocks of dolomite and dolomitic limestones, predominantly greyish and with a fine granoblastic structure, ruby texture, containing mainly calcite, dolomite, sericite, chlorite, less frequently feldspar, apatite, magnetite and pyrite.

Schistose dolomites are finely granular, lying on top and containing dolomite, calcite, sericite, chlorite, ankerite and less frequently bleached, siderite, rhodochrosite, quartz and pyrite.

The complex of phyllites-conglomeratic rocks - develops south and northwest of the anticline in the Rapoltel, Bobalna, and Varmaga areas and comprises sericite-chlorite, sericite-graphite, graphite, sericite-chlorite with muscovite, epidotic-actinolite, black, purple phyllite, micro conglomerates, conglomerates, weakly metamorphosed rocks.

The porphyritic rock complex has a large development in the western part of the area and was formed by metamorphosis in the conditions of green schists of granites, dacite rhyolites and accompanying pyroclastic products, the argument in support of these hypotheses being the presence of deposits with dykes, neks, silts, lava flows. The silvery-white porphyritic rocks have a blasto-porphyritic structure and a silty texture, sometimes weakly massive.

The mineral springs in the Bampotoc Valley then it was kaolinised and carbonated due to the circulation of hot waters, rich in CO_2 and had a varied mineralogical composition, predominantly: quartz, sericite, feldspar, pyrite, plagioclase, orthoclase, microcline, calcite, apatite, tourmaline and garnets.

The chlorite-sericite porphyrites occur only to the north, are ribbed and banded, and in the mass, there are individual orthosite or quartz-feldspar with concordant or discordant orthoclase.

The feldspathic rocks were formed by an old alkaline metamorphism followed by a newer alkaline-potassic one. Pegmatites - resulted from alkaline magmatism when pegmatitic, quartz-feldspathic phyllodes were formed, sometimes with biotite.

Research has established the age of the phyllites complex as Lower Carboniferous and the age of the basic tuffaceous systems complex as Devonian, the lower complexes being older.

The sedimentation of most of the formations occurred in the Lower Palaeozoic, some being even older, and the folding and metamorphism during the Hercynian movements.

Sedimentary formations - until the Lower Cretaceous, the crystalline island of Rapolt was exuded, the first transgression beginning in the Lower Cretaceous when a volcanogenic-sedimentary formation was formed, consisting of pyroxene andesites, grey limestones, sandstones and marls.

3. Geophysical Investigation at Carpinis Quarry

From the vast specialised bibliography in the field of geophysical methods, we selected as the source of information in our study [1], [2], [3] and [4], which represent almost exhaustive courses at the level of the years of their appearance. Many fundamental problems of geophysics have been deepened and developed in [5], [6], [7] and [9].

For the GPR method, we used [8], [10], [11] and [14]. At the same time, we used the PRISM2 software manual contained in [13], while the integrated geophysical study [12] represents an example to be followed in the corroboration of geophysical data.

All these cited bibliographic notes represent the source of information studied for the brief methodological presentations here.

vol. 29, issue 2 / 2023
pp. 75-81

3.1. Ground Penetration Radar

GPR is a geophysical, non-intrusive method of investigating the underground that uses radar pulses to image the subsurface discontinuities of resistivities. It uses electromagnetic waves to detect natural discontinuities and other features of soil or rock below the surface.

GPR uses a transmitter that generates electromagnetic waves of a certain frequency and a receiver antenna that receives the reflected waves from different rock layers. GPR uses electromagnetic radiation in the microwave band (UHF/VHF frequencies; the range 100 MHz to 2.6 GHz) of the radio spectrum and detects the reflected signals from subsurface structures that can have applications in a variety of media, including rock, soil and pavements.

These signals are then digitally processed to create an image of the subsurface that can be used to identify discontinuities and other rock features.

The available software that allows analysing GPR data and identifying natural discontinuities in marble blocks is PRISM 2. This software can plan the cutting direction of marble blocks to minimise the risk of breaking or cracking the blocks and maximise the yield of marble quarrying.

Our study used GPR to detect changes in travertine properties, voids and cracks at the Carpinis quarry.

3.2. Resistivity Method

The equipment used in our study, the Super Sting R8/IP+64 system, is produced by the American company Advanced Geosciences, Inc, Austin, Texas and uses a pulsating direct current for emission with a pulse duration equal to the pause duration.

Compensation of the natural potential is done automatically throughout the measurement. The resistivity is calculated by entering the device's coordinates, and the system generates images of resistivity and induced polarisation using the Earth Imager software. The acquisition system has eight channels and is used with multi-electrode passive leads. It uses a pulsed direct current for emission with the pulse's duration equal to the pauses. Compensation of the natural potential is done automatically throughout the measurement.

The resistivity is calculated by entering the coordinates of the device. Noise attenuation is at least 100 dB at frequencies higher than 20 Hz and at least 120 dB at frequencies 16, 20, 50, and 60 Hz from the transmission line, ensuring a clean signal.

Earth Imager inversion software is a program that interprets the recorded resistivity data (the inversion process) and produces images in the form of cross-sections that reflect the geological structure of the subsurface. The inversion of the resistivity data is a combination of forward simulation and inverse simulation, with the final result being the production of the structural model of the basement (the image of the basement obtained based on the resistivity data measured on the surface of the land).

First, a direct simulation or modelling is performed (virtual prospecting, an application from model to data, from cause to effect) on a model built based on some a priori, general information (distribution of apparent resistivity in the basement, electrode configuration) or assumed (the average resistivity of a sector, the user's hypothesis or the structure of the basement), obtaining a set of synthetic data.

Direct modelling (direct solution) is obtained by solving the equation with partial derivatives in the spectral domain.

3.3 Seismic Method

Seismic measurements were performed with the 24-channel Geode-Seismograph system and SeisImager software.

The Geode Exploration Seismograph is the most popular engineering seismograph in the world. The Geode is a versatile and flexible seismograph, small and lightweight enough to be packed in a suitcase yet easily expandable for full-scale 2D and 3D surveys via our intelligently designed distributed architecture.

Use the Geode for reflection, refraction, MASW/MAM, tomography surveys and more niche use cases such as earthquakes, quarry blasts, or heavy equipment monitoring.

The Geode can also easily handle marine profiling and continuous recording.

4. Experimental results obtained at the Carpinis quarry

Fig. 3 shows three transversal profiles spaced at 1m, located in detail (red colour), from the investigated perimeter.

All profiles were processed and interpreted with Prism 2 software, following the steps from the software methodology.

Following the interpretation, we highlighted the distribution of the main cracks and areas of cracks in the test area investigated in the Carpinis quarry.

Resistivity is a physical property of a material that measures how much the material resists electrical flow, which depends on many factors such as crystal structure, chemical composition, degree of hydration, temperature and pressure. Resistivity is measured in ohms per meter (Ω/m). Resistivity values for marble, travertine and andesite can vary depending on certain conditions and specific compositions.

The image from Fig. 4 shows two sections of resistivities on the performed electrometric profiles. The profiles are 31 m long and are equidistant at 5 m. The dotted line shows the correspondence between the resistivity maxima and minima on the two profiles. The areas of minimum, outlined in blue, represent fractures and fissures in the quarry rock mass.

Also, the areas of increased gradient (quick transitions from minimum-blue to maximum-red) highlight the change in the rock mass's geological and micro tectonic characteristics.

Due to the weak grip between the geophones and the hard rock, the recorded data had a very large dispersion, which can constitute a large source of errors.

The source of production of elastic waves is a 10 kg hammer operated manually at predetermined distances from the ends of the seismic profile (0 m, 6 m, 11 m and 22 m). In order to try to improve the reception of the geophones, other earth and water were brought to each reception point.

A seismic profile from this geophysical investigation is presented in Fig. 5

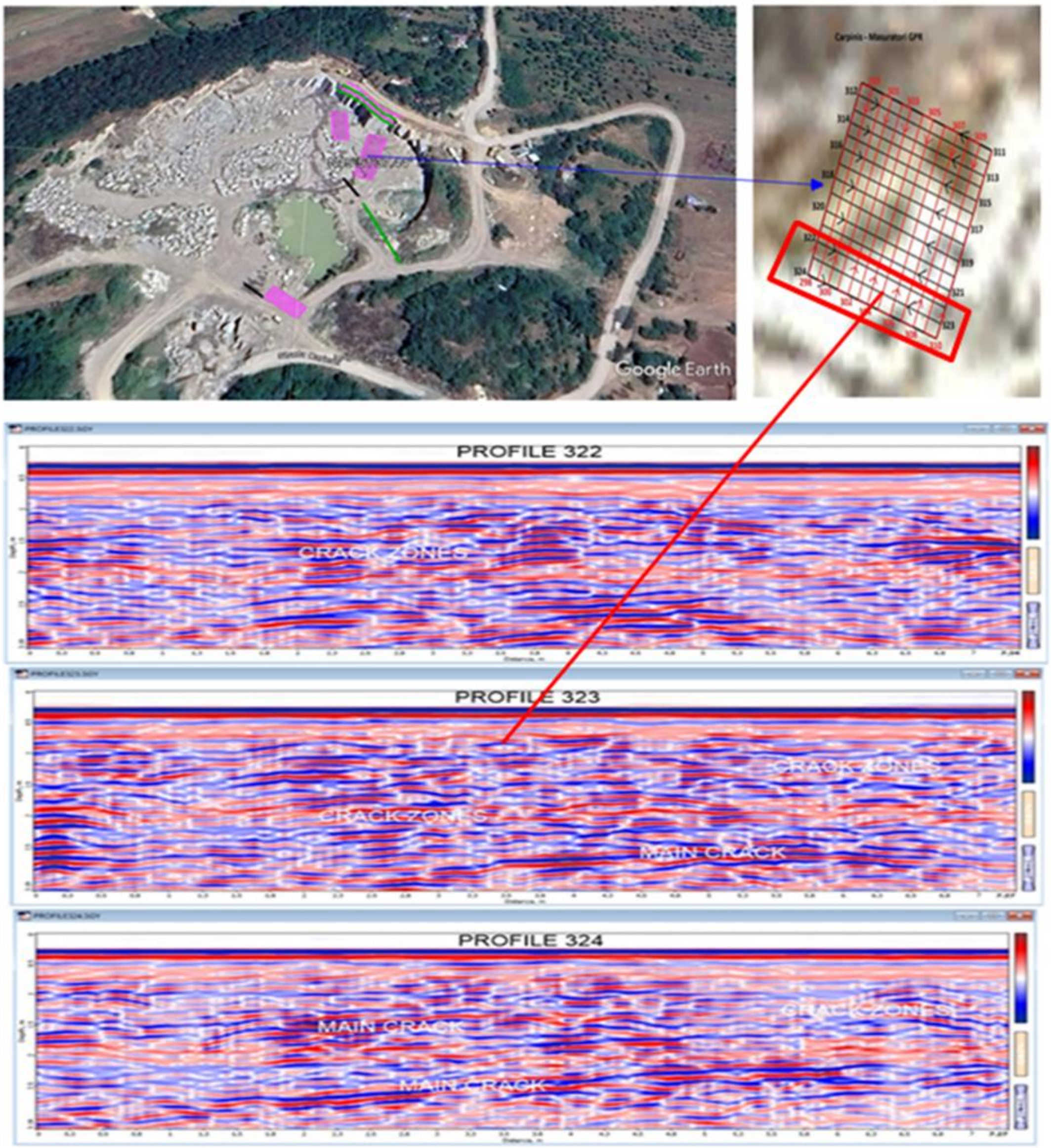

Figure 3. Carpinis Quarry and location of geophysical measurement profiles in Google Earth (pink-GPR; green–electrometry; black-seismic); Detail of GPR measurements – site 1, Radargrams of transversal profiles 322-324

vol. 29, issue 2 / 2023
pp. 75-81

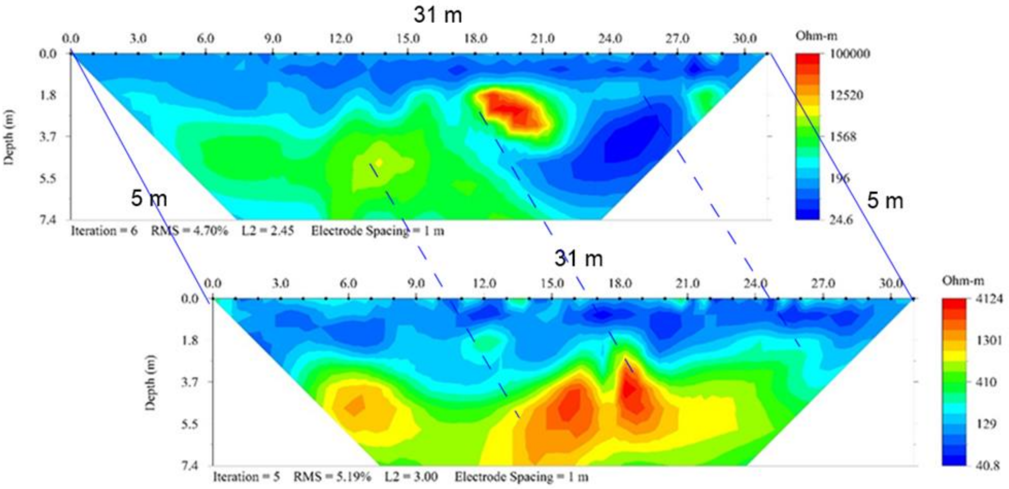

Figure 4. Two resistivity profiles 31m long and equidistant at 5m

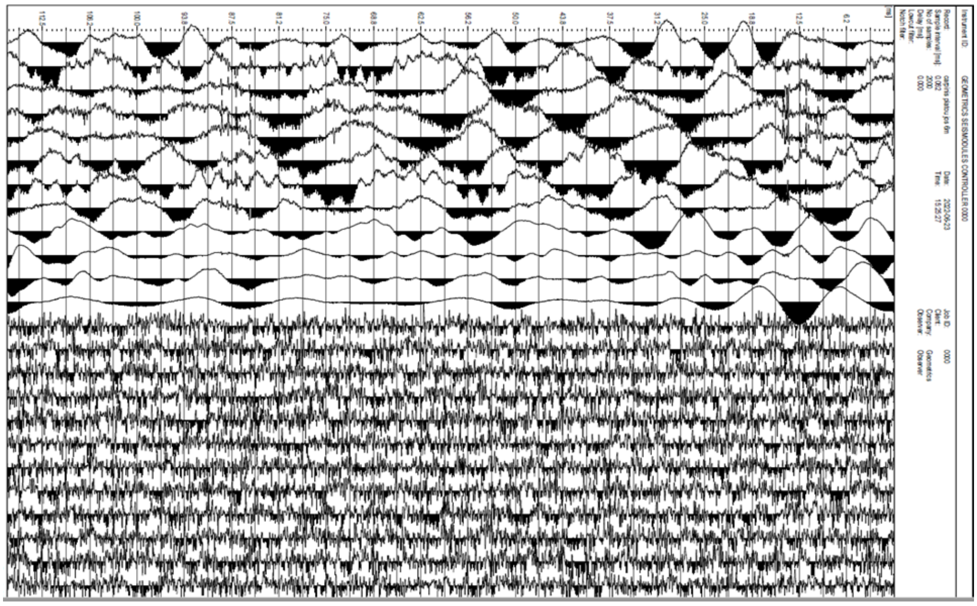
Figure 5. Image on seismic profile at Carpinis Quarry

5. Conclusions

GPR reflection profiles are created as radar antennas move along the ground surface, transmitting waves into the ground. A sequential stacking of many reflections consisting of reflected waves from different depths in the rock mass is then produced. In the GPR method, all two-dimensional reflection profiles (longitudinally and transversally) are re-sampled in depths and relative amplitudes of reflected waves located at those depths. Then, they are plotted, interpolated and gridded to produce a defined number of cracks in the stone.

These images can be used in data fusion analyses, where depth slices are directly compared to maps from other geophysical methods. However, these methods can directly compare several GPR reflection profiles to geophysical (electrometry, magnetic, seismic) profiles and others adjoining it.

After performing the electrometric resistivity tomography, we can draw the following conclusions:

- resistivity maximum may represent unaltered areas without fluid-circulated fractures. We can consider electronic conductivity between particles;
- the resistivity minimum may represent altered areas with fluid-circulated fractures. We can consider an electrolytic conductivity between particles. These considerations are qualitative. The electrometric resistivity data must be corroborated with direct investigative information for a quantitative determination.

Superimposing the various results from GPR, resistivity and seismic methods, a clear indication of the highly fractured areas could be established. Therefore, areas with reduced fracturing were recommended for mining the travertine blocks with higher commercial value.

Acknowledgements

The authors wish to acknowledge UEFISCDI for financing the project "AI-COSTSQO - Artificial Intelligence and Combined Survey Techniques for Stone Quarries Optimization", which was co-funded by the Horizon 2020 Programme of the European Union through ERA-MIN 3 Project Framework. Also, the authors wish to express their gratitude to MARMOSIM SA and the managerial and technical team for supporting in-situ investigations and the help provided during the fieldwork.

References

[1] **Constantinescu L.**, 1965
Prospectiuni Geofizice, Vol. 2, Ed. Tehnica

[2] **Georgescu P.**, 1982
Prospectiuni electrice, Editura Universitatii Bucuresti

[3] **Kaufmam A.A., Eaton P. A.**, 2001
Methods in Geochemistry and Geophysics 33, The Theory of Inductive Prospecting, Academic Press, Elsevier, ISBN: 9780444503107

[4] **Kaufmam A.A.**, 1994
Geophysical Field Theory and Method Part B Electromagnetic Fields I, United Kingdom Edition published by Academic Press Limited

[5] **Lowrie W.**, 2007
Fundamentals of Geophysics, Published in the United States of America by Cambridge University Press, New York

[6] **Zhdanov M.S.**, 2009
Methods in Geochemistry and Geophysics, 43 *Geophysical Electromagnetic Theory and Methods*, Elsevier Radarweg 29, PO Box 211, 1000 AE Amsterdam, The Netherlands

[7] **Campana S., Piro S.**, 2009
Seeing the unseen: geophysics and landscape archaeology, CRC Press, Netherlands. ISBN 978-0-415-44721-8

[8] **Conyers L.B.**, 2016
Ground-penetrating radar for geoarchaeology, Wiley-Blackwell Publishers, London

[9] **Conyers, L.B.**, 2018
Medieval Site in Ireland, Ground-penetrating Radar and Magnetometry for Buried Landscape Analysis, SpringerBriefs in Geography, Cham: Springer International Publishing. pp. 75–90. doi:10.1007/978-3-319-70890-4_7. ISBN 978-3-319-70890-4. Retrieved 24 June 2021

[10] **Gaffney V., Patterson H., Piro S., Goodman D., Nishimura Y.**, 2004
Multimethodological approach to study and characterise Forum Novum (Vescovio Central Italy). Archaeological Prospection 11:201–212

[11] **Goodman D., Piro S.**, 2009
*Ground penetrating radar (GPR) surveys at Aiali (*Grosseto). In: Campana S., Piro S. (eds) Seeing the unseen. Geophysics and landscape archaeology, Taylor and Francis, London, pp 297–302. ISBN 978-0-415-44721-8

[12] **Kelly T.B.; Angel M.N., O'Connor D.E., Huff C.C., Morris L., Wach G.D.**, 2021
A novel approach to 3D modelling ground-penetrating radar (GPR) data – a case study of a cemetery and applications for criminal investigation, Forensic Science International. 325: 110882, DOI:10.1016/j.forsciint.2021.110882. ISSN 0379-0738

[13] **Piro S., Goodman D., Nishimura Y.**, 2003
The study and characterisation of Emperor Traiano's villa using high-resolution integrated geophysical surveys. Archaeological Prospection 10:1–25

[14] **Radar System Inc.**, 2022
Prism 2 (Version 2.7x) User's Manual – Riga, LV-1012, Latvia, web: www.radsys.lv

[15] **Srivastav A., Nguyen P., McConnell M., Loparo K.N., Mandal S.**, 2020
A Highly Digital Multiantenna Ground-Penetrating Radar System", IEEE Transactions on Instrumentation and Measurement. 69: 7422–7436. doi:10.1109/TIM.2020.2984415. S2CID 216338273