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Geoarchaeological investigations in Artanish Peninsula, Armenia: Testing a new geochemical prospecting method for archaeology

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Abstract

Within the framework of an Armenian–German research project, taking place between 2019 and 2021 on the Artanish Peninsula at Lake Sevan (Armenia), in addition to numerous (geo-) archaeological investigations, methods of geochemical prospection have been carried out. The ancient burial grounds of Artanish 23 and Artanish 29 have served as model sites to successfully test the well-known method of geochemical prospection and evaluation of metal deposits in geology (mineral sector). As a result, a new experimental archaeo-geochemical prospecting and evaluation method has been developed, which has been adapted for the exploration of archaeological monuments. It is planned to use this experimental method (which we consider new and important in archaeogeochemical investigation, but not a conclusive and comprehensive work per se), which has already proven its work capacity, in archaeological research, in the prospective areas of Armenia and other countries. In addition to these investigations, research on the transformations in the landscape of the ancient tombs related to Lake Sevan fluctuations has also been carried out. The anthropogenic impact of humans on the environment (geochemical halos formed in the soil on the surface of the tombs) has been studied, as well as the problem of the impact of geological environment on human life activities, that is, the relocation of the burial grounds to more elevated areas due to the rise in the lake level. Based on the results of geochemical sampling and high-resolution magnetometer surveys, excavations have been performed at the site. Here, we present the results of an experimental study exploring the potential of combined magnetometer prospection and chemical soil analyses to locate and characterize the burial ground of Artanish on Lake Sevan, Armenia. The results have demonstrated the capability of these analyses to detect the sites, outline hotspots and interpret the features identified in the magnetometer results.

KEYWORDS
Armenia, Caucasus, geochemical fieldwork, Lake Sevan, mapping

1 | INTRODUCTION

The present-day territory of the Republic of Armenia is covered by a dense network of archaeological sites. Although archaeological research in the country goes back to the 19th century, many issues have remained unresolved to this day. Even in the Soviet times, when there was a real boom in the field of archaeology in Armenia, and there were no financial constraints, scientific research covered no more than 5% of archaeological sites already known at that time. The number of sites revealed but unexplored in the post-Soviet years has since doubled. The financial capacities for science are not comparable to the number of archaeological sites waiting for their turn of exploration. There is a need for selective research. The task is not easy since archaeological sites are under the soil surface and it is impossible to visually select the priority ones as well as the unlooted and those that are richest in artefacts among them. From an archaeological point of view, solutions have to be found in a non-traditional way.

In this regard, the successful experience of adapting geochemical prosepcting methods of buried ('blind') ore bodies and deposits (better known as Mobile Metal Ion geochemistry [MMI]) for archaeological sites may become a reliable tool for selecting the direction of archaeological priority activities and the sites will be subjected to excavation (cf. Sylvester et al., 2017).

Geochemical-archaeological research started as early as the first decades of the 20th century (e.g., Arrhenius, 1931; 1934; Rimmington, 2000). Recently, more targeted and methodical works have been carried out in this direction in some countries (Bethell & Smith, 1989; Booth et al., 2017; Cook et al., 2005; Pringle et al., 2022; Stijn Oonk et al., 2012; Sylvester et al., 2017), and in this context, the research conducted on the Artanish Peninsula seems to open new perspectives (Figure 1).

This is especially true in the sense that so far the parameters of geochemical anomalies formed around and above (in the soil of) archaeological sites have only been used to determine the general geochemical description of archaeological sites.

Basically, we attempted to adapt and apply the modern geological-geochemical prospecting methods, that have proven their effectiveness in mineral geology (Oganesyan et al., 2017; Arutyunyan et al., 2017; Wolf & Kunze, 2014; Wolf et al., 2013; Grigoryan et al., 2009) for geochemical prospecting and assessment work of buried archaeological sites (e.g., burials and settlements). It is planned to transfer the successful experience of the archaeogeochemical work carried out on the Artanish Peninsula to the prospecting of archaeological sites in other areas, in order to receive quantitative and qualitative information to clarify the internal content of archaeological sites (e.g., metal objects, weapons, human and animal bones) only through soil sampling and interpretation of geochemical data obtained, without 'opening' the site. That is, the idea is to select from numerous buried sites the one that is worth investigating first and foremost through surface studies, leaving the rest for later, thus saving the available resources and time.

Unlike geophysical methods, which give a quantitative assessment of buried archaeological sites (dimensions, depth etc.) and have been successfully used in archaeological fieldwork for decades (Aspinall et al., 2009; Fassbinder, 2015; Herles & Fassbinder, 2015; Scollar et al., 1990), this method provides a qualitative assessment of the site. Primarily, it provides information on the chemical

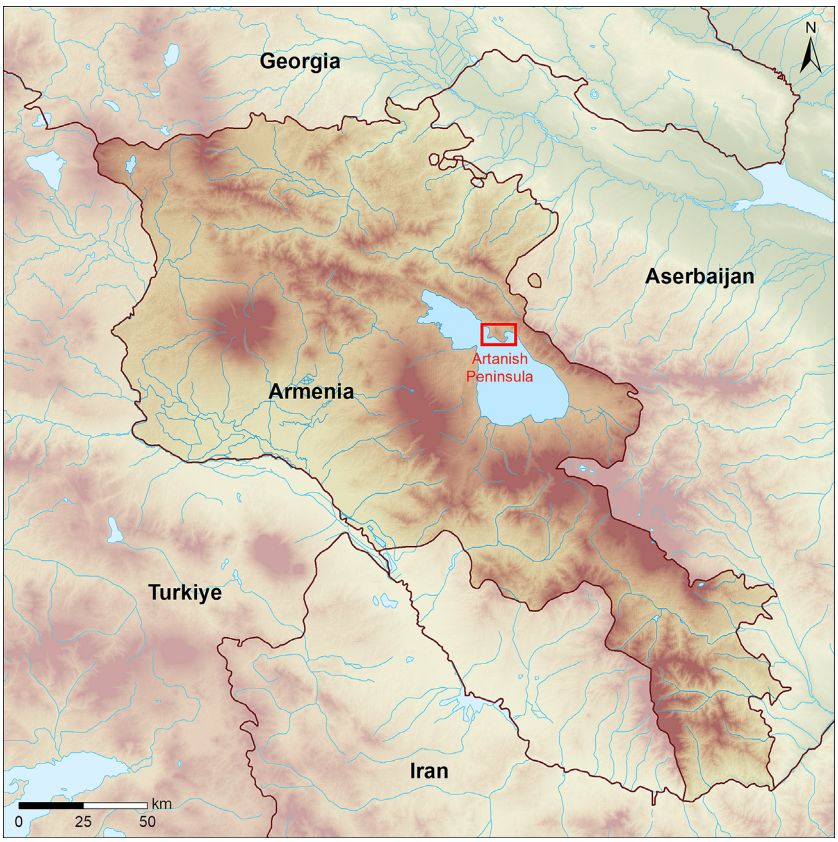

FIGURE 1 Location of the research area (Artanish Peninsula) in Armenia (Base map: SRTM by courtesy of the USGS and the NASA, public domain; water bodies and country borders: extracted from GADM, CC BY-NC-SA 3.0 US [made by A. Swieder, Halle/Saale]).

composition of deep anthropogenic material (up to 3 m deep in this study), that is, on the composition, type of alloys of buried metal objects and the presence of human and animal bones.

The present contribution demonstrates the positive results of geochemical surveys together with the problems of use of geological environment as well as geological dangers for human life.

FIGURE 2 The area of Artansh 23 (= Ar_23) with four burial mounds and 42 tombs with visible cromlechs (picture by drone made by S. Aghayan). The geochemical sampling points are marked in green.

2 | MATERIALS AND METHODS

2.1 | The essence of the problem

All metal objects which were produced and used by human beings, as well as human and animal bones, are more or less chemically active. Being buried, they interact with the aggressive environment and water rich in oxygen penetrating from the atmosphere, form chemical compounds and spread in soil, mainly due to surface tension forces (Mann et al., 2005), producing their own anthropogenic geochemical halos. The mechanism of formation of these halos is the same as that for secondary geochemical halos forming around ore bodies. The basic tracer elements for their assessment are copper (Cu), tin (Sn), arsenic (As), lead (Pb), zinc (Zn), silver (Ag), iron (Fe) and gold (Au), which form part of archaeological metal findings of the Bronze- (from the mid of the 4th millennium BCE to the end of the 2nd millennium BCE) and Iron- (from the end of 2nd millennium BCE to the mid of the 1st millennium BCE) Ages, as well as phosphorus (P) and calcium (Ca), which are the main components of the composition of human and animal bones. The geochemical halos formed by these elements provide

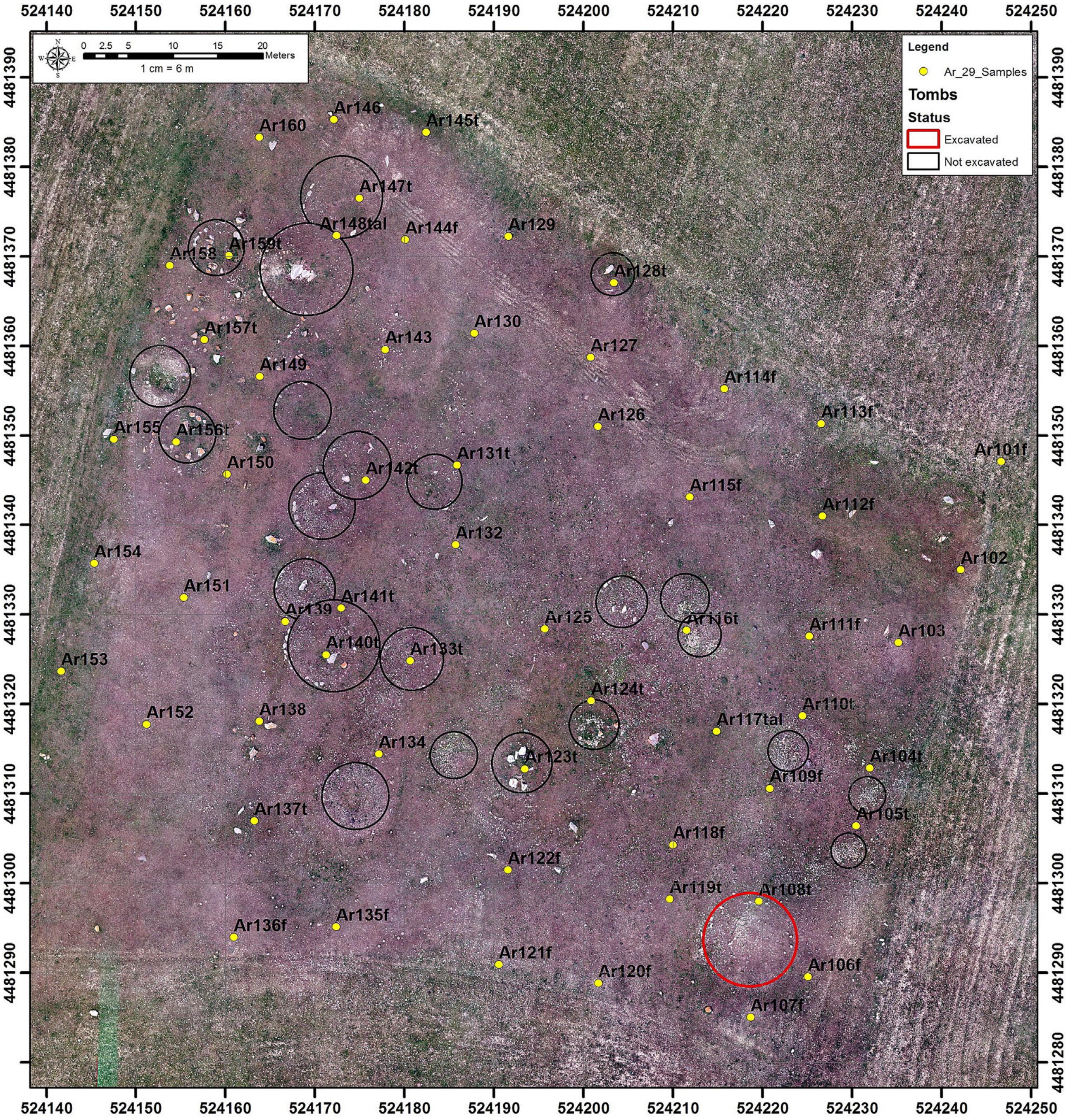

FIGURE 3 The area of Artanish 29 (= Ar_29) with 24 tombs with visible cromlechs (picture by drone made by S. Aghayan). The geochemical sampling points are marked in yellow.

quantitative and qualitative information about their anthropogenic source and, as shown by our investigations on the Artanish Peninsula, they are clearly reflected in soil on the surface of burials. After receiving the parameters of those anomalies (both mono-element and multi-element), we performed the following sequential steps: information classification, analysis, detection of regularities, identification of geochemical halos with a certain archaeological site, obtaining a reference geochemical model for geochemical prospecting by an already developed method in the other archaeological areas. More simply, we use the geochemical characteristics of an already explored site for prospecting and assessment of other similar archaeological sites buried under the ground.

2.2 | Implementation of the method: the research area

The eastern coast of Lake Sevan is famous for high density of archaeological sites (Biscione et al., 2002; Bobokhyan et al., 2017; Hmayakyan et al., 2008; Kunze et al., 2011, 2013; Mikaelyan, 1968). Alone on the small area of Artanish Peninsula, at the height of 1917–1945 m above mean sea level, more than 50 archaeological sites have been revealed by the Armenian–German archaeological expedition (Bobokhyan & Kunze, 2021), dating back from the Early Bronze Age to the Medieval period (fortresses, settlements, cemeteries and megaliths). From those sites, the burial grounds Artanish 23 and 29 have been selected for complex archaeogeological research. There are four burial mounds and 66 tombs with cromlechs (circle of stones around the tombs) in the area of these two cemeteries. The estimated dating is Early to Middle Iron Ages (ca. 1200–600 BCE). Since this kind of experimental research on the tombs had not been carried out previously, we needed cemeteries where, at depth and at the bottom of a few tombs, metallic artefacts would be guaranteed to be located. From the point of view of Armenian archaeologists, it was the region of the Artanish Peninsula that met all the conditions and was an ideal testing ground for our experimental geoarchaeological research. The selection of those cemeteries as an experimental 'polygon' was conditioned by the fact that there were at least a few tombs that had never been disturbed or looted. That fact is crucial during the investigation by secondary geochemical halos; otherwise, geochemical halos formed above and around the tombs will be disturbed, with identification and interpretation inseparable from the original archaeological signature. The tombs are located unevenly: within a distance of 0–30 m from each other (Figures 2 and 3). The objective of this study is to use geochemical exploration and to emphasize the most informative tombs for archaeological excavations.

2.3 | Archaeological sites and their geological environment

Geologically the area is adjacent to the central segment of Amasia-Sevan-Hakari ophiolitic zone. The rocks are represented by aleurolites, limestone conglomerates, sandstones, marls, tuff breccias of the Upper Cretaceous period, gabbros of the Middle Eocene and lacustrine as well as slope deposits of the Upper Pliocene-Pleistocene period (Galoyan et al., 2009).

The climate of the region is arid. The winter is moderately cold; windless weather with light frost prevails. Average annual temperature is 5.3°C, 15.5°C in the hottest month (August), and −5.5°C in the coldest month (January). Average humidity values range from 68% to 75%. The annual amount of atmospheric precipitation is 484 mm. Artanish 23 burial ground is placed in sediments with a mixture of lake sand gravel and clay particles. Artanish 29 burial site is in slope deluvial sediments, represented by loamy soils and carbonate rock gravel.

The construction material of the burial structures, according to our field observations and petrographic investigations, is fully integrated with the surrounding geological environment. The walls of the cells built in soil and the cromlech laid in circle are made of local stones—coarse-medium-grained gabbros, which are ultrabasic intrusive rocks, and the tomb cover is assembled by local marly limestones of oolitic structure.

It is noteworthy that the raw construction materials were aquired in close vicinity. The geological field investigations, together with the petrographic analysis of construction materials taken from the tombs and the outcrops of gabbros and marly limestones in the area of

FIGURE 4 The Artanish Peninsula. The arrows indicate the burial grounds Artanish 23 and Artanish 29, as well as the ancient mines of construction materials used for the tombs.

Artanish Peninsula, suggest that this material is of local origin. The ancient deposits of marly limestones, used for the tomb covers, are practically located next to the burial grounds, just 500 m from Artanish 23 and 200 m from Artanish 29 (Figure 4). Gabbros are widespread in the area of the Artanish Peninsula, as well as on the north-eastern shores of Lake Sevan and in the waterside areas. All these areas represented by gabbros were recorded and sampled by us. All the samples of gabbros, gabbro-diorites and diabases taken with a radius of 10 km have undergone petrographic analysis and have been compared with petrographic features of stones of the tomb structures. The large outcrop of gabbros of the south-western corner of the Peninsula was the only site, the mineralogical composition, granularity, texture and structure parameters of the stone of which coincided with the parameters of the stone of tomb walls and cromlech, and it was definitely used as a mine (Figures 4 and 5a–c).

2.4 | Fieldwork

2.4.1 | Geochemical fieldwork: assessment of geochemical haloes

Before starting fieldwork, we collected and studied the available geological and archaeological materials, and created a preliminary cartographic database. We conducted preliminary reconnaissance field observations in the area of the experimental sites Artanish 23 and Artanish 29 and around them. The sites where the burials were localized in lake sediments (Artanish 23) and the sites where burials were localized in the diluvium (Artanish 23) were determined. Geodetic measurements obtained the absolute heights of the two above mentioned sites. We choose the optimal directions and density of sampling points for geochemical survey. It was planned to conduct the survey in such a way that at least one sampling point would be inside each stone circle-tomb or located as closely as possible to the tombs. Given that the burials (at least those visible on the surface of the earth) were unevenly distributed, the task was technically difficult. Because of this, our profiles do not have perfect lines. Sampling directions were chosen in such a way as to 'close' the site area with the minimum number of samples (this also means minimum analysis-costs).

Geochemical fieldwork in Artanish was carried out with predetermined geochemical profiles, on the area of 24 000 m^2 for Artanish 23 and 7200 m^2 for Artanish 29 (Figures 2 and 3). Soil sampling was from a depth of 15–20 cm. The weight was 150–250 g, depending on humidity and degree of availability of gravel material. The total number of samples was 130.

All geochemical samples have a strict cartographic connection (coordinates in the system WGS 84), with large 1:1000 and 1:200 scale topographic and geological maps. GPS mobile localization systems and a drone equipped with a camera (DJI Air 2S with a 1-Inch CMOS Sensor-camera) were used to photograph the terrain panorama from above and to build the local geographic network. The cartographic material has been created in digital GIS format.

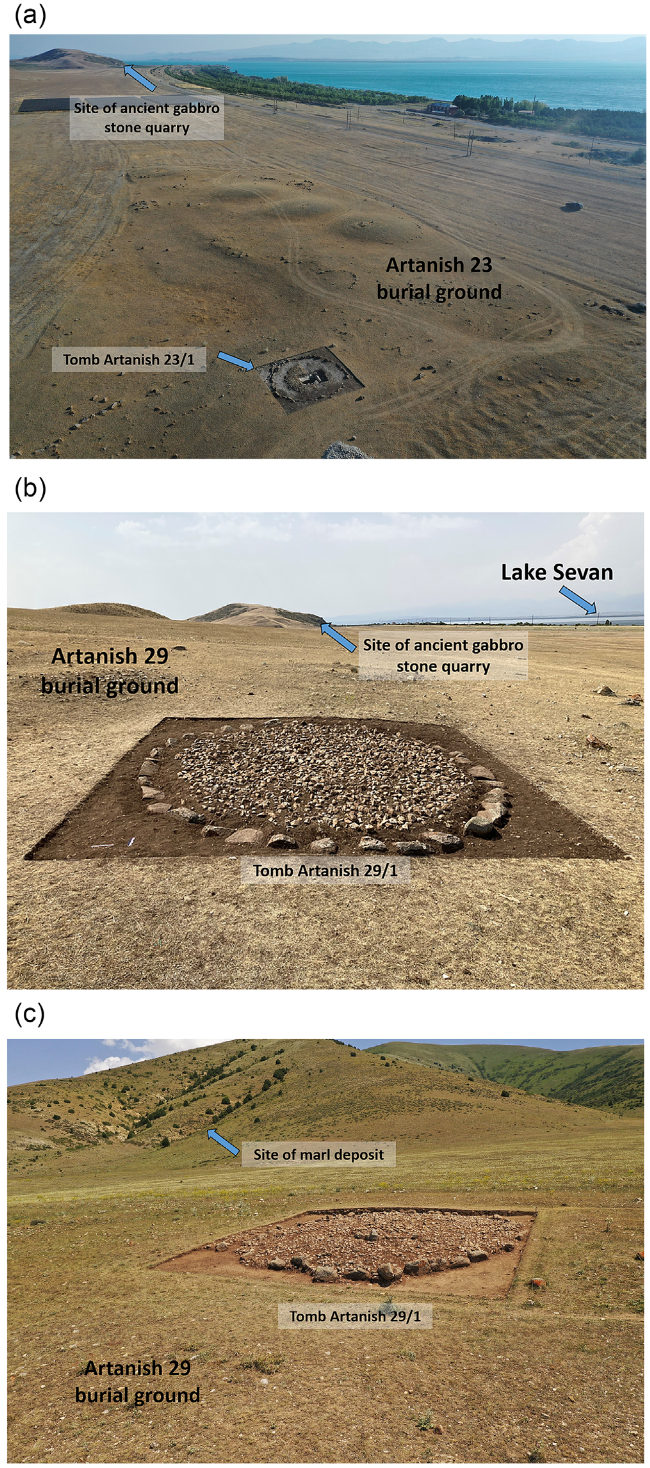

FIGURE 5 (a) Burial ground Artanish 23 with tomb 23/1 (picture by drone made by J. Abele). The ancient gabbro stone quarry is at a distance of 2.500 m. (b) Burial ground Artanish 29 with tomb 29/1 (picture made by Ushkiani-Project). The ancient gabbro stone quarry is at a distance of 1.500 m. (c) Burial ground Artanish 29 with tomb 29/1 and the ancient marl deposit (picture made by Ushkiani project).

The taken soil samples were dried, sieved and cleaned from the plant root residues and clastic material. Then, they were crushed to obtain the required size for spectral analysis (laboratory investigation

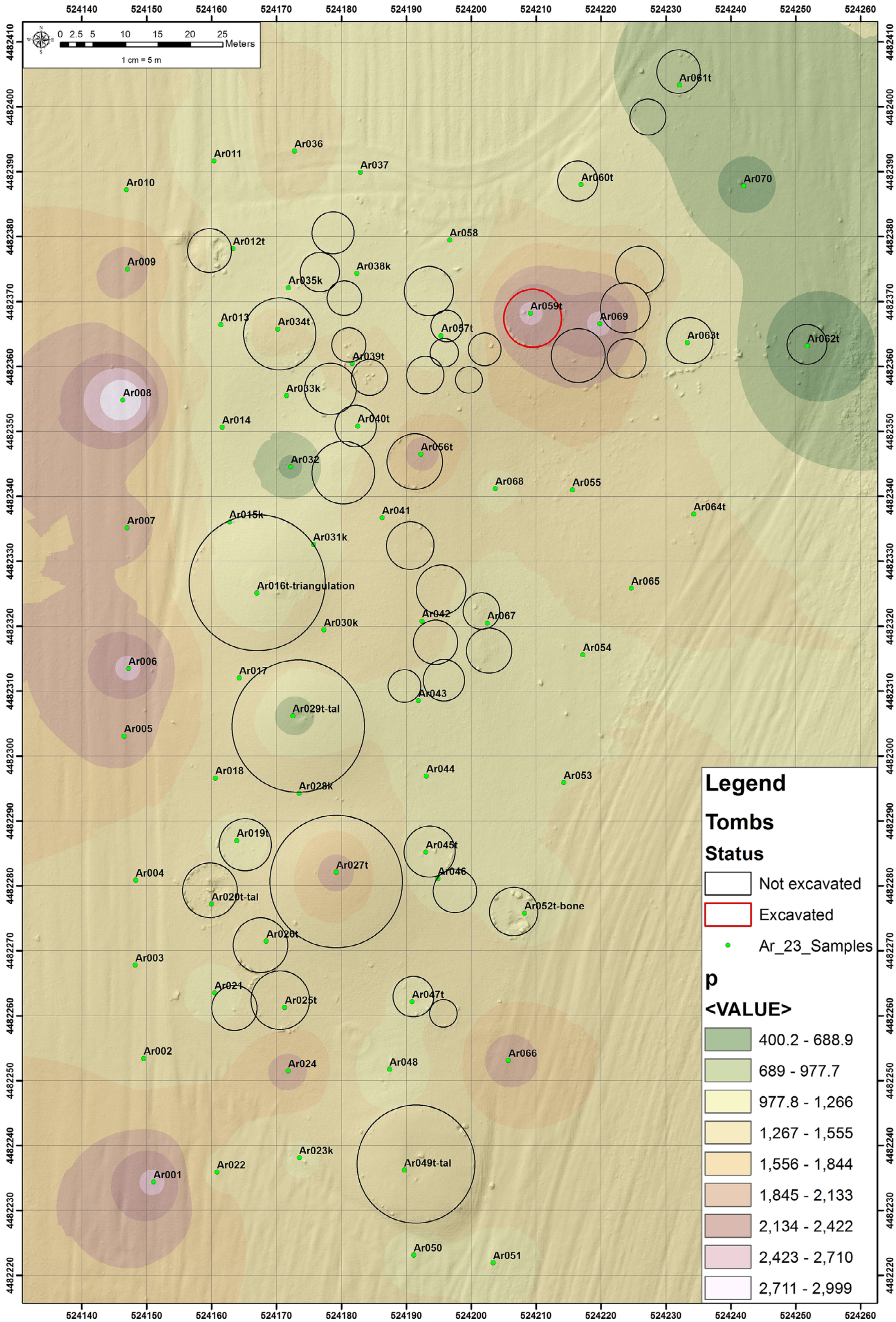

FIGURE 6 (a) Map of geochemical halos of phosphorus: Artanish 23 (made with ArcGIS 10.4 by D. Arakelyan). (b) Map of geochemical halos of phosphorus: Artanish 29 (made with ArcGIS 10.4 by D. Arakelyan).

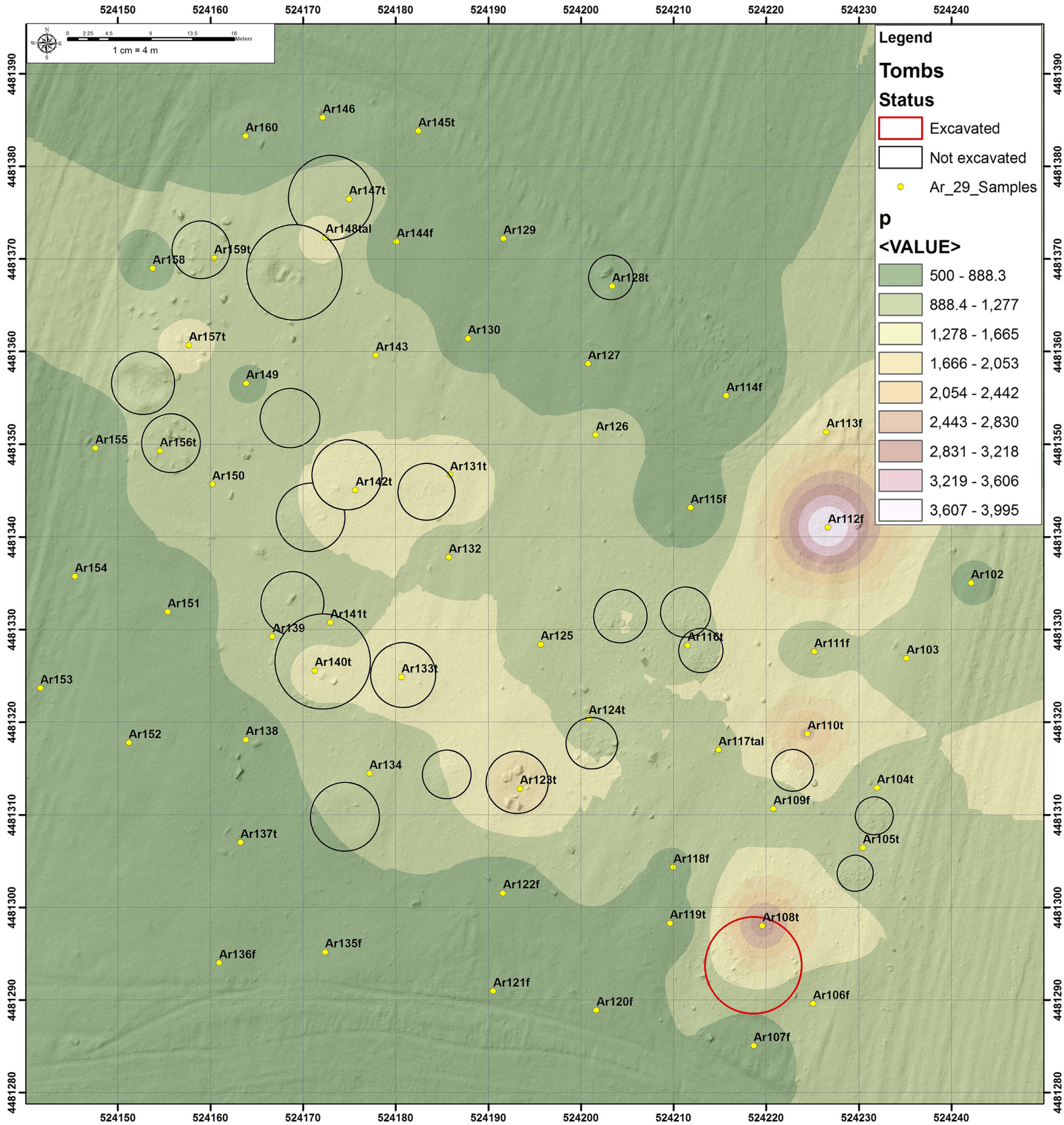

FIGURE 6 (Continued)

of 38 and more chemical elements). It is a method of approximate-quantitative spectral atomic emission determination of chemical elements in solid substances of mineral origin by the method of sample injection into a three-band arc discharge (I-MP/CKLPG-1-2018). The analysis was performed in a laboratory specially designated for geochemical prospecting and having international authority ('Alexandrov Experimental and Methodological Expedition', Alexandrov, Russia [Accreditation body for laboratories AAC 'Analytica'. 601650.]).

For the delineation of geochemical halos formed by tracer elements on the surface of soil over the archaeological sites, statistical parameters of their distribution within the background site were calculated. The edge sections of the sampled areas were used as a background site (determination of local geochemical background), where, according to visual observation data of archaeologists, there was no trace of archaeological site. Based on the results of spectral analyses, the most intensive and contrasting geochemical halos were built and delineated. Then, the chemical elements, which act as prospecting-assessment indicators for buried archaeological sites, were selected.

As a result of geochemical identification work mono-element and multiple-element geochemical maps were made. They made it possible

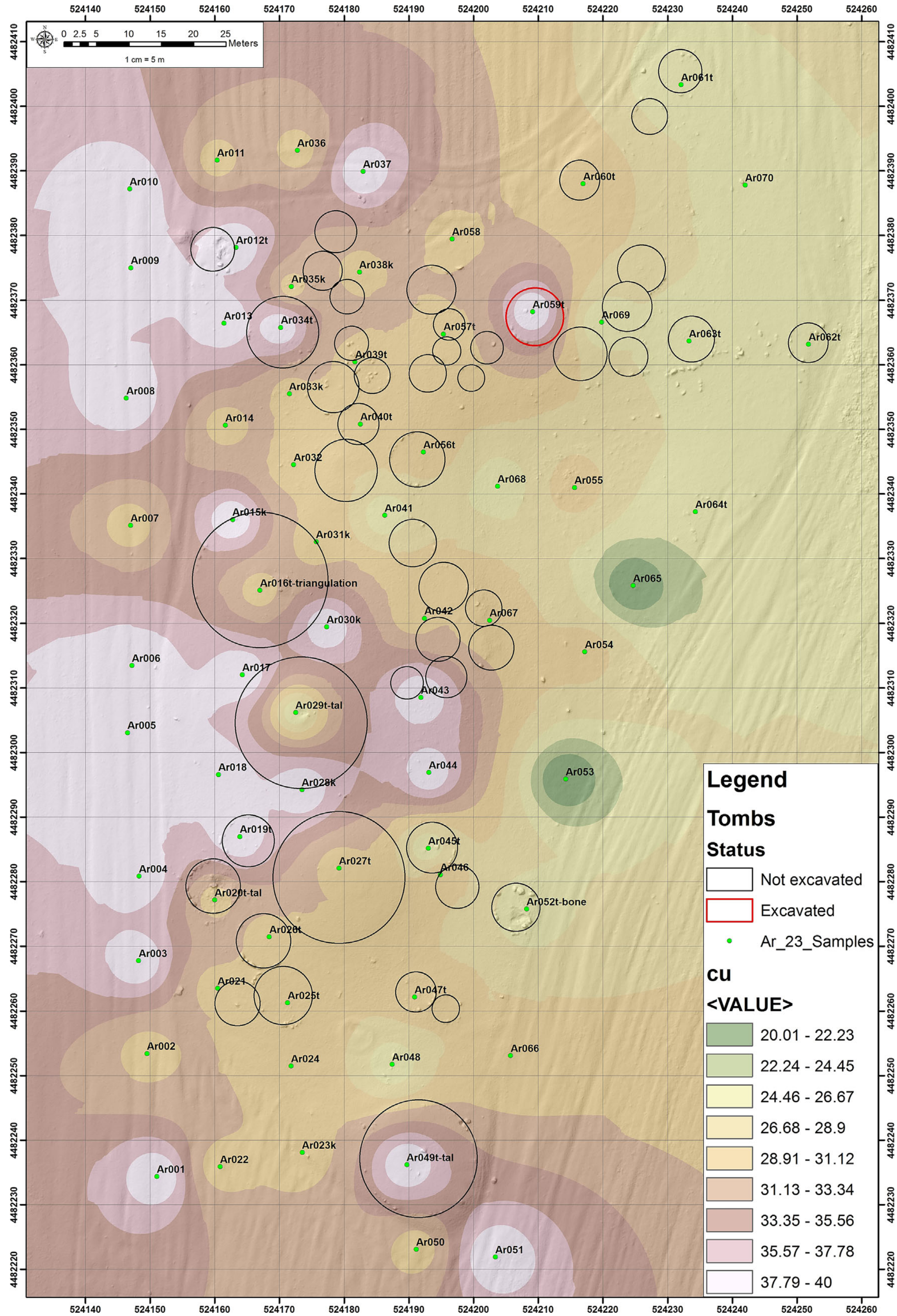

FIGURE 7 A map of geochemical halos of copper: Artanish 23 (made with ArcGIS 10.4 by D. Arakelyan). (b) Map of geochemical halos of copper: Artanish 29 (made with ArcGIS 10.4 by D. Arakelyan). (c) Map of geochemical halos of Lead: Artanish 23 (made with ArcGIS 10.4 by D. Arakelyan). (d) Map of geochemical halos of Lead: Artanish 29 (made with ArcGIS 10.4 by D. Arakelyan).

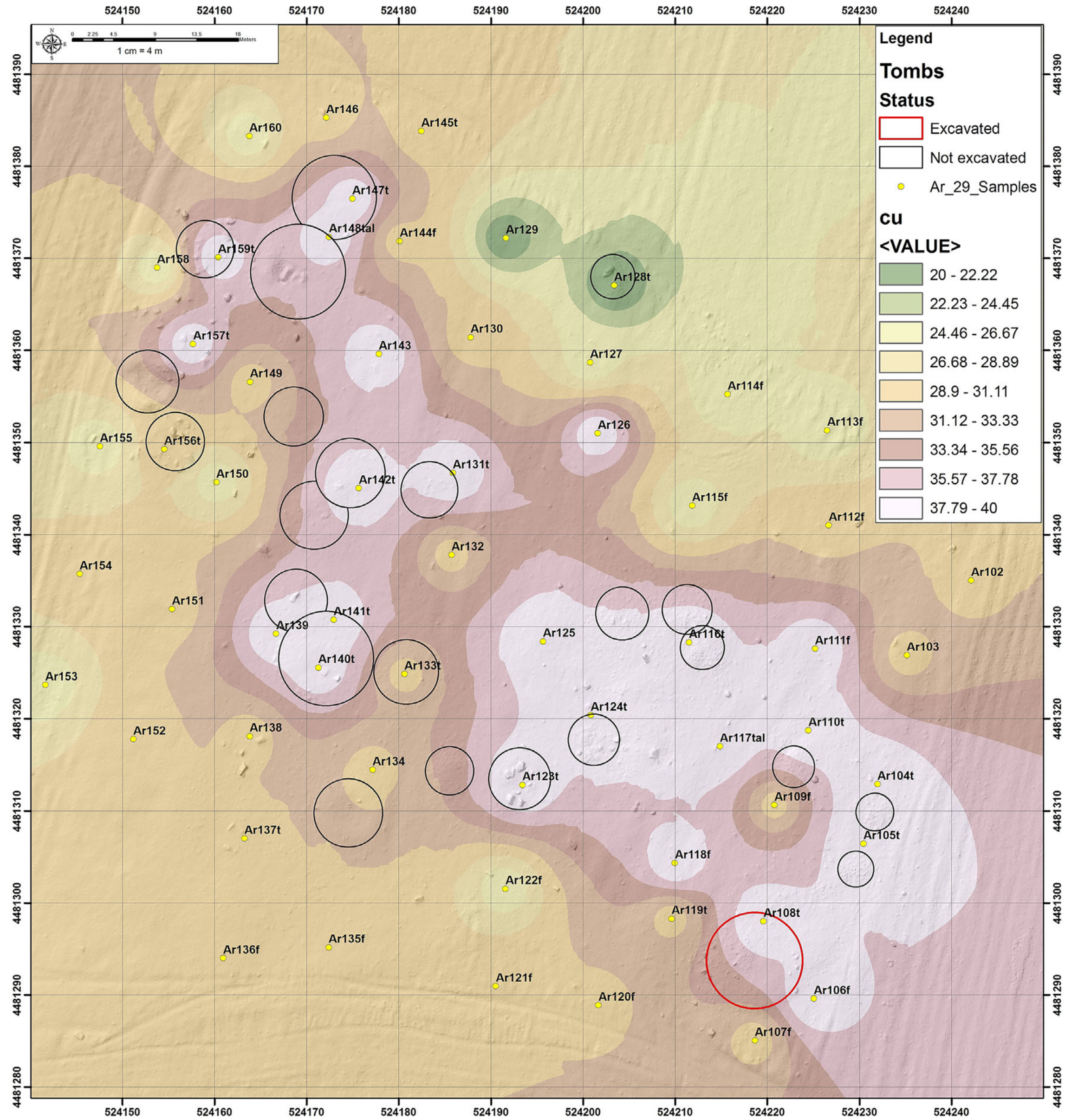

FIGURE 7 (Continued)

to adjust and delineate the boundaries of Artanish 23 and 29 and to localize and distinguish within these boundaries the sites having the most favourable (contrasting) geochemical anomalies for archaeological excavations. Twenty mono-element geochemical maps were drawn: Cu, Ag, B, Ba, Co, Cr, Ga, Li, Mn, Mo, Ni, P, Pb, Sn, Sr, Ti, V, Y, Zr and Zn. The information obtained is too extensive to be discussed in a single scientific paper, hence we focus here on only the information relevant for purely archaeological research of these particular sites.

2.4.2 | Magnetometer prospection

In Artanish 23, magnetometer surveys commenced by staking out a 40 × 40 m grid (cf. Figure 12). Magnetic measurements were recorded at 10 Hz sampling frequencey, along straight traverseswith traverse intervals of 1 m. We carried the two probes of each of the magnetometers we used (Scintrex Smartmag SM4G-special magnetometer and a Geometrics G-585 magnetometer) on a wooden stand around 30 cm above the ground. In order to avoid interference of the two magnetometer probes, the sensors are placed at a horizontal distance of 50 cm from each other. Therefore, we obtain a spatial resolution of 50 cm cross-line and around 12.5 cm in-line. We use the two sensors of each magnetometer as a special version of a variometer, the so-called 'duo-senso' configuration, instead of a gradiometer, to enhance the signal-to-noise ratio of the instruments (Fassbinder, 2023; Linford et al., 2007). In this configuration, the sensors of the Caesium vapour magnetometers measure the total intensity of the Earth's magnetic field. This setup is comparable to a differential configuration,

TABLE 1 Correlations of chemical elements in soil cover of Artanish 23.

	Cu	Zn	Pb	Ni	Co	Ag	Mn	Sn	P
Cu		0.37	0.35	0.03	−0.01	0.55	0.04	0.30	0.47
Zn			0.59	0.27	0.39	0.41	0.27	0.64	0.57
Pb				0.09	0.20	0.32	0.05	0.46	0.55
Ni					0.53	0.04	0.29	0.28	−0.11
Co						0.00	0.26	0.30	0.09
Ag							0.16	0.34	0.48
Mn								0.16	−0.07
Sn									0.50
P									

Note: The underlined red numbers indicate close spatial relationships (more than 50%) between pairs of chemical elements.

TABLE 2 Correlations of chemical elements in soil cover of Artanish 29.

	Cu	Zn	Pb	Ni	Co	Ag	Mn	Sn	P
Cu									
Zn	0.70								
Pb	0.49	0.60							
Ni	0.50	0.43	0.60						
Co	0.58	0.52	0.49	0.42					
Ag	0.57	0.49	0.51	0.56	0.63				
Mn	0.62	0.64	0.59	0.50	0.51	0.42			
Sn	0.54	0.44	0.37	0.32	0.28	0.47	0.35		
P	0.48	0.62	0.45	0.25	0.24	0.25	0.38	0.29	

Note: The underlined red numbers indicate close spatial relationships (more than 50%) between pairs of chemical elements.

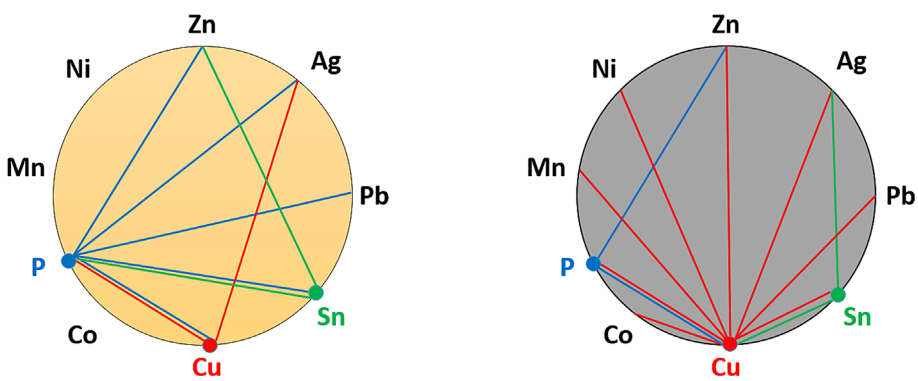

FIGURE 8 Relations between chemical elements according to spatial correlation data (the colours in the diagram were used solely for more expressiveness).

where the reference probe is set virtually to infinity. Thus, we measure the maximum intensity of the magnetic anomalies. The advantage is that the resulting magnetogram also includes information for greater depth (more than 1 m). The diurnal variations of the Earth's magnetic field, whose range may be identical to the magnetic anomalies caused by buried anthropologic remains, are removed in the post-processing (for details, see Hahn et al., 2022). As a complementary method, magnetic susceptibility measurements with the portable kappameter SM 30 (ZH instruments) were performed in situ soil samples and on excavated rocks of the burials and used as a reference for the interpretation of the magnetograms (Bondar et al., 2022; Hahn & Fassbinder, 2021; Hahn et al., 2021).

2.5 | Selection of 'working' chemical elements

The following fundamental priorities were essential in the selection process. First, the concentrations of chemical elements had to be significantly different from the geochemical background of the site. Secondly, those elements had to be necessarily present in the composition of the metal artefacts, which were revealed to be present in contemporary tombs of Sevan basin. These were mandatory, but not sufficient conditions.

The information about the chemical composition of metal artefacts was taken from the results of investigations of compositions of the artefacts obtained from excavations of sites Sotk 2 and Norabak

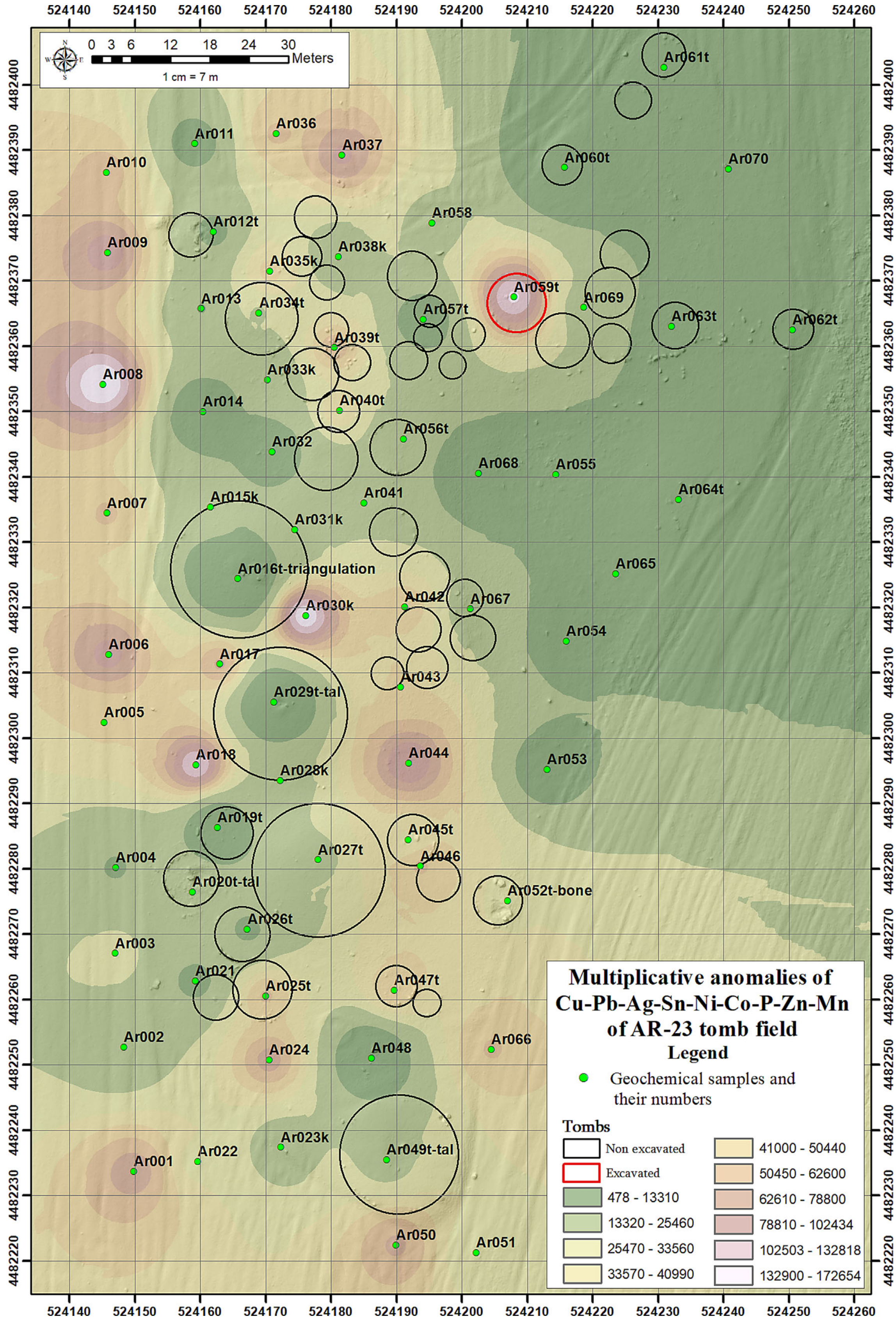

FIGURE 9 (a) Map of geochemical halos drawn by means of multiplicative coefficient: Artanish 23 (made with ArcGIS 10.4 by D. Arakelyan). (b) Map of geochemical halos drawn by means of multiplicative coefficient: Artanish 29 (made with ArcGIS 10.4 by D. Arakelyan).

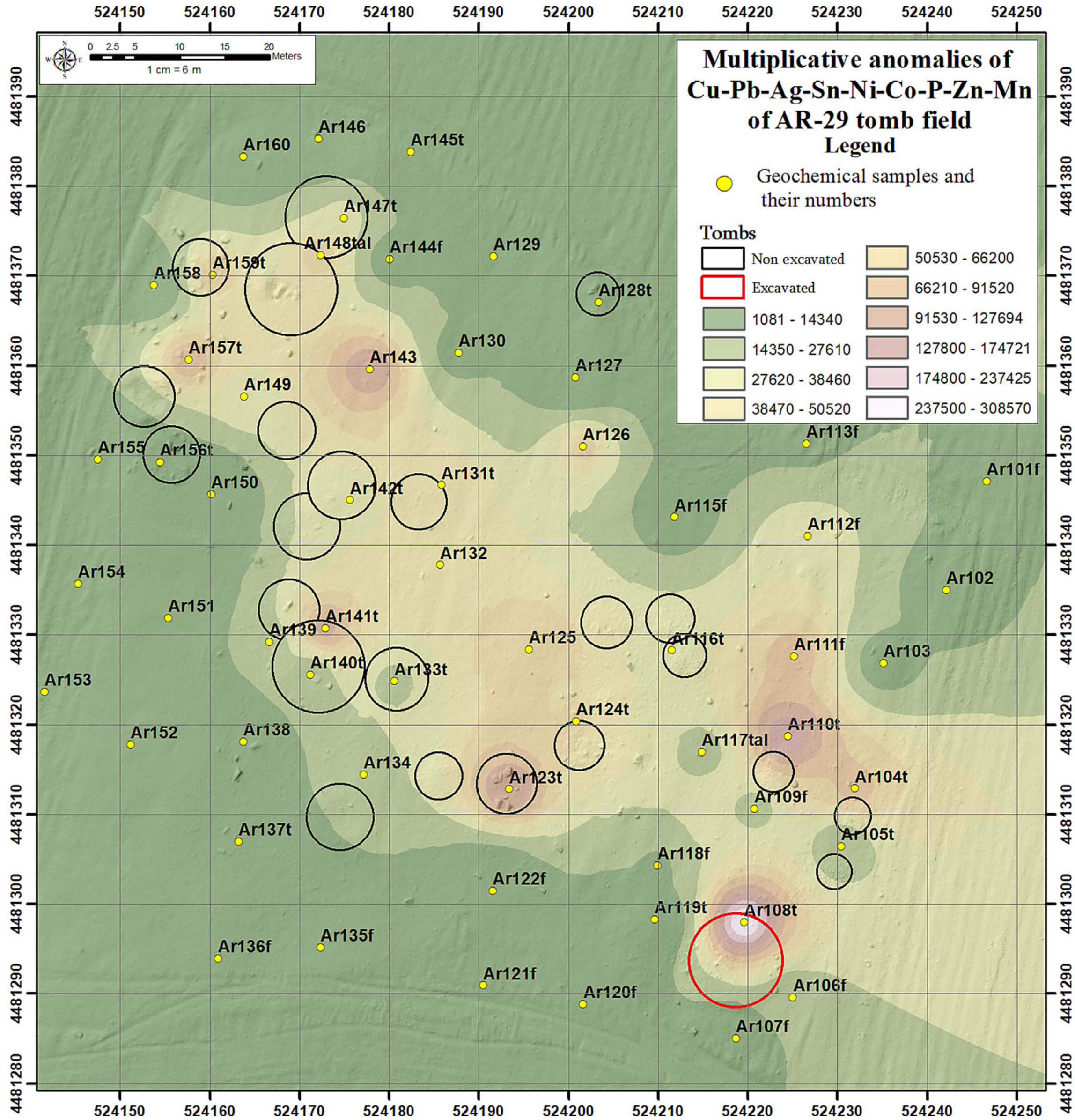

FIGURE 9 (Continued)

1 (Kunze et al., 2013), according to X-ray fluorescence (XRF) analyses. Based on these data, the subset 'working'elements (Cu, Ag, Co, Mn, Ni, Pb, Sn and Zn) were defined, being present both in our analyses and in the above-mentioned metal artefacts of the Bronze and Early Iron Ages.

Additionally, phosphorus (P) was selected as a component part of human and animal bones (Figure 6a,b). The latter, as our investigations have shown, acts as a reliable indicator for recording human bones at depth. The chemical elements not related to the natural environment of the area and human activity were omitted from this investigation. They do not correlate with anthropogenic and geological findings.

Based on the results of the analyses, the geochemical maps were made. For some elements, they simply 'give away' which tombs contained artefacts in their depth (Figures 6a,b and 7a–d).

The next important condition we have set is the calculation of spatial correlation of pairs of chemical elements. The purpose of this investigation is to validate the first and second conditions, based on the regularity of geochemical processes through statistical analysis. The correlation of chemical elements was performed for all pairs of 'working' elements, for both artefacts composition and their corresponding elements from soil composition. The pairs showing close correlation connections were singled out.

As demonstrated in Tables 1 and 2, the selected pairs of chemical elements both on Artanish 23 and on Artanish 29 show spatial correlation of nearly 50% (higher than 0.45 co-efficient) and over 50% (0.5 and higher—marked in red) in soil cover. The behaviour of phosphorus is particularly striking, showing a close spatial relation to the metal artefacts indicating an association with metallic artefacts with bones

FIGURE 10 Artanish 23/1 tomb.

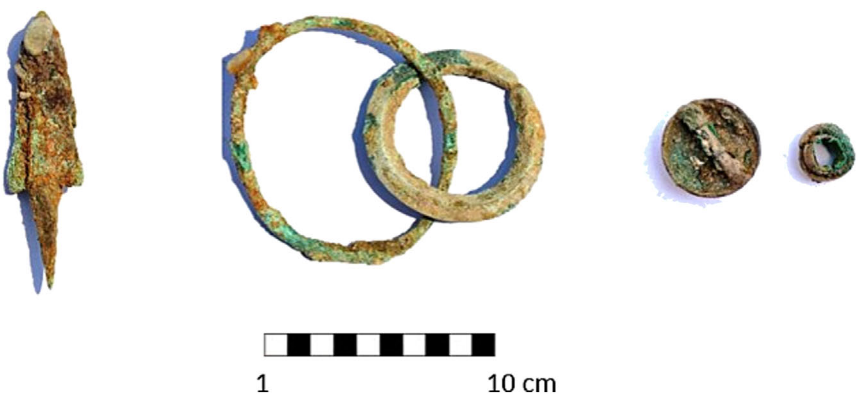

FIGURE 11 Bronze artefacts (from left to right: arrowhead, rings, buttons) from the tomb Artanish 23/1.

at depth. These facts directly suggest that the source of chemical elements is below, under the ground. A graphical representation of these correlations is shown in Figure 8.

As seen from the tables, the correlation analysis has confirmed the probability of our approach related to the methodology of the selection of 'working' chemical elements. To summarize, the conditions that we consider mandatory in the initial stage of geochemical exploration are as follows: (a) abnormally high concentrations, strongly deviating from the background, in soil cover above the tombs, (b) a significant and high concentration of elements from the composition of the artefacts, excavated from the same region, in the soil covering above the tombs, and (c) close spatial correlations of those elements.

2.6 | Indication according to geochemical maps with a multiplicative coefficient

Ensuring the full suitability of the selected chemical elements as prospecting-assessment indicators of buried archaeological sites, we made the final step to investigate abnormal elemental concentrations above the tombs by the multiplicative method (Figure 9a,b).

The purpose of this method is the final check and verification of the obtained mono-element maps, boosting the prominence of geochemical anomalies at a site. The recorded concentrations of all 'working' chemical elements were multiplied, including phosphorus. The data obtained in this way are more representative compared to the data obtained with mono-elements (Grigoryan et al., 2009). The multiplicative coefficient enables to suppress the incidental and weak signals, while strengthening those with greater prominence.

3 | RESULTS AND DISCUSSION

3.1 | Artanish cemeteries in context

Five abnormal fields in the area of the cemeteries strike the eye, of which the one in the north-eastern corner is recorded on arable land (cf. below). Three 'weaker' abnormal fields surround the third among the four big burial mounds, if we count from south to north (Figure 9a). There is no anomaly on the burial mound itself. Most likely, this is a misleading burial, as no traces of plunder of the main burial mound and on small tombs surrounding it were recorded by

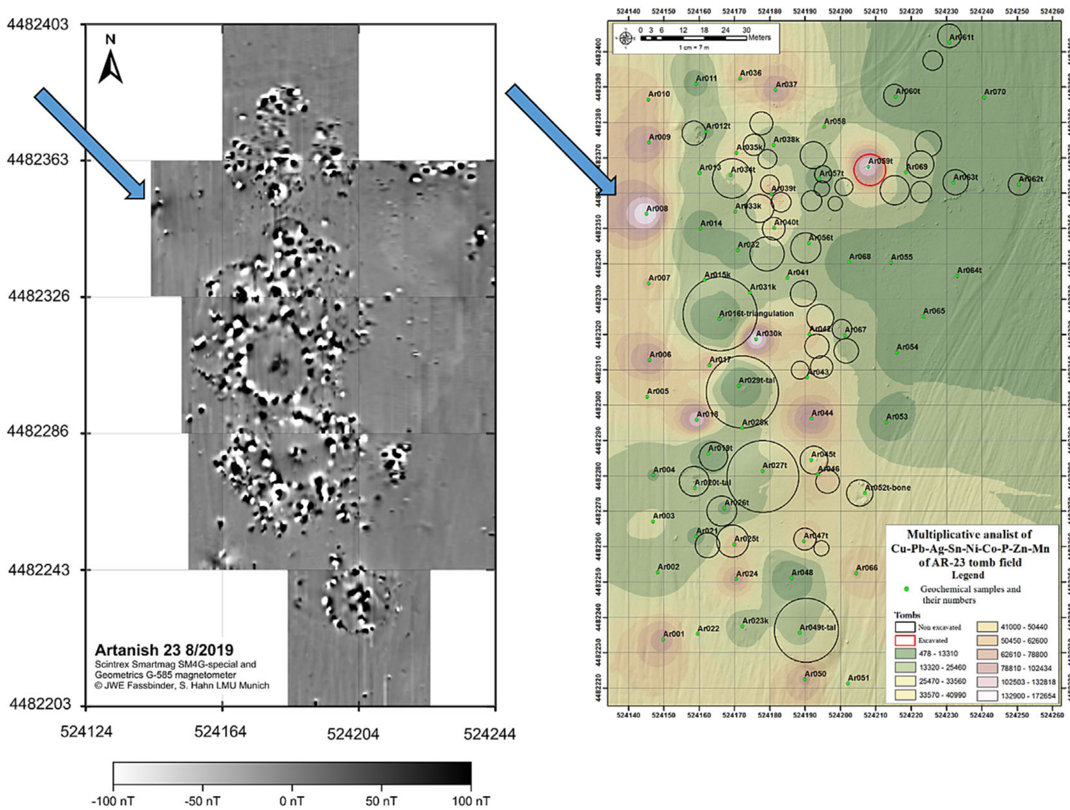

FIGURE 12 Magnetogram of underground structures below of soil surface (left), geochemical anomalies and cromlechs of the burials on the right, showed in the circle.

archaeologists. Later excavations of the tombs in 2020–2021, funded by the German Research Foundation (DFG), showed that they had been plundered. The most interesting one is the islet-anomaly located in the northern part (Figure 9a), which lies directly on the tomb (in a red circle). The tomb on this burial ground, just under this anomaly (Figures 5a and 10), was the first to be approved for excavation (Artanish 23/1).

The image is somewhat different on Artanish 29 (Figure 9b). The fields show a more blurred picture, except the one above the tomb located in the south-east (in a red circle). It is this tomb (Artanish 29/1) that has received the second approval for excavation.

The difference in the intensities of the anomalies in soil covers of burial grounds Artanish 23 and Artanish 29 is probably related to the higher levels of humidity on Artanish 23, and the burials being carried out in sandstone soils, because the high humidity is a barrier for the capillary movement in soils. So, this could significantly stop the process of forming anomalies on the soil surface. These are lacustrine sediments, which are not favourable for the formation of geochemical halos (Mann et al., 2005). The clarification of this issue is a subject of a separate study.

The first stage of archaeological excavations, carried out in 2019, confirmed the correctness of geochemical analyzes. There was a large amount of rich archaeological material in the tombs, namely pottery, metal objects and human bones (Figures 10 and 11).

The guidance for ore prospection by secondary geochemical haloes, replicated here, suggests that geochemical anomalies should not be recorded on the plundered tombs available in the fields. The plunder deprives the geochemical halo of a constant source of elemental nourishment at a depth, and elements are progressively leached out under the influence of the sun and atmospheric water. As such, they lose their definition over time. Indeed, geochemical survey has showed that contrasting anomalies no longer exist on the plundered tombs, although they are visually recorded by archaeologists (Artanish 23/2, 23/3, 23/4 and 23/5). This phenomenon is an additional argument in favour of the new method. Furthermore, no metal or phosphorus anomalies should have existed at all on the tombs with false burials. The 2021 excavations in Artanish 29/1 experimentally confirmed this approach. Ten of the twelve excavated tombs were looted.

Thus, in 2019, the tombs of Artanish 23/1 and Artanish 29/1 were excavated, which was proposed by the geochemical approach. The excavations confirmed the correctness of our geochemical model: rather rich archaeological material was found. In 2020 and 2021, tombs with negative geochemical conclusions were excavated: the excavations revealed looted tombs.

One tomb (Artanish 29/1) was considered a false burial from the geochemical point of view. The excavations made in 2021 did not reveal any artefact or ecofact. Absolutely no traces of plunder were

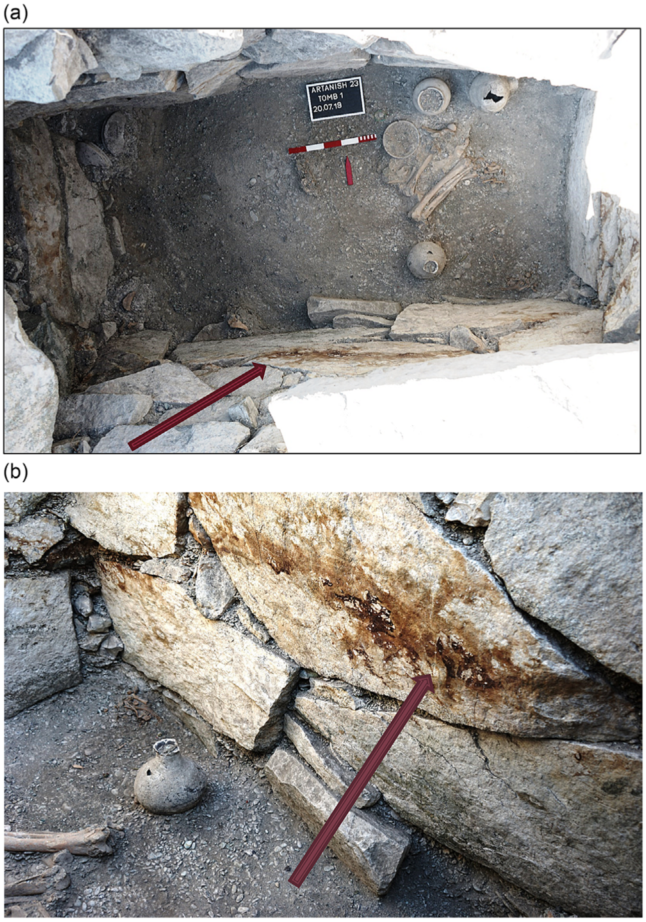

FIGURE 13 (a) Overview to tomb Artanish 23/1 after excavation with traces of moisture on the wall. (b) Detail section to tomb Artanish 23/1 with traces of moisture on the wall.

recorded. The tomb was filled with well-sorted, sieved and compacted soil, and then it was carefully closed by a shield of marly limestones.

The geochemical multiplicative anomaly of the north-western part of Artanish 23, located in the arable farmland, is of particular interest (Figure 9a, sampling point Ar 008). According to geochemical analysis, this anomaly is quite contrasting, and most likely indicates a burial with metal artefacts. Unfortunately, in the 20th century, agricultural activity in the area likely diminished the clarity of the geochemical halos through soil mixing, and dispersed them over a relatively large area. Besides, not a single stone was left in the field from the supposed former cromlech or cell and cover of the tomb, which would enable it to be spatially oriented in any way. In 2020, the magnetometric investigations carried out here showed the presence of the tomb under the 'arable lands' (Hahn et al., 2021; Figure 12).

3.2 | Historical fluctuations of Lake Sevan level

Another phenomenon has also been observed during the excavation of the tomb Artanish 23/1. At a depth of 1.5 m from the surface, 1916.5 m absolute elevation, traces of moisture were clearly visible on the wall (Figure 13a,b), demonstrating the level of Lake Sevan. Since it is impossible to make burials underwater, this level developed after the construction of the tomb, thus the Artanish 23 burials were made before the rise of Lake Sevan. With Artanish 29, being located hypsometrically higher (1925–1945 m) than Artanish 23 (1916–1917 m) (Figure 14), we suggested that the Artanish 29 tombs are younger than Artanish 23. The rise of Lake Sevan prompted the local population to move the burials to the Artanish 29, the lowest edge of which is at least 1–2 m higher than the highest historical level of Sevan (1919–1920 m).

To test this hypothesis, radiocarbon dating was conducted on the bones of the tombs Artanish 23/1 and Artanish 29/1. The bones of the former are dated 1051–921 BCE (Cal 2-sigma, MAMS 43487) and those from Artanish 29/1 date to 770–541 BCE (Cal 2-sigma, MAMS 43488), that is, at least 350 years younger. This supports our hypothesis for the timing of Lake Sevan fluctuations.

Various sources, including visual observations, and radiocarbon measurements, suggest that a rise of the Lake Sevan level took place between 900 and 800 BCE. This phenomenon eventually forced the Iron Age population to move burials (probably, also the settlements) to more elevated places.

In the most recent centuries, due to climatic, geological and anthropogenic factors, the lake level has made advance (transgression) and retreat (regression) of the coastline, affecting the coastal ecosystem, sedimentation processes and human life (Avagyan et al., 2021). Figure 15 demonstrates the schematic layouts of the main fluctuations of the lake level for the last 7000 years, based on the results of our works carried out on the Artanish Peninsula.

4 | CONCLUSIONS

The successful course of excavations on Artanish peninsula Iron Age cemeteries based on geochemical evidence provide us with grounds to consider the presented method of survey effective. Thus, taking into account the above mentioned, we recommend the use of this research method at other archaeological sites (ancient cemeteries, settlements etc.) especially for survey and prospecting of burial grounds, for the evaluation of burials without excavations, as well as for the rejection of robbed and fake graves. The following important provisions should be taken into consideration.

The main conclusions on geoarchaeological (geoarchaeochemical) surveys are as follows:

1. Although in recent years certain work on archeogeochemistry has been done in the archeogeochemical field, producing interesting and novel results, our research is the first adaption and application of the type of geochemical methods used in ore prospection for archaeological evaluation.
2. Such work requires the creation of a constantly updated statistical database. Moreover, it is desirable that in addition to geochemical data, the database includes both geological and geophysical

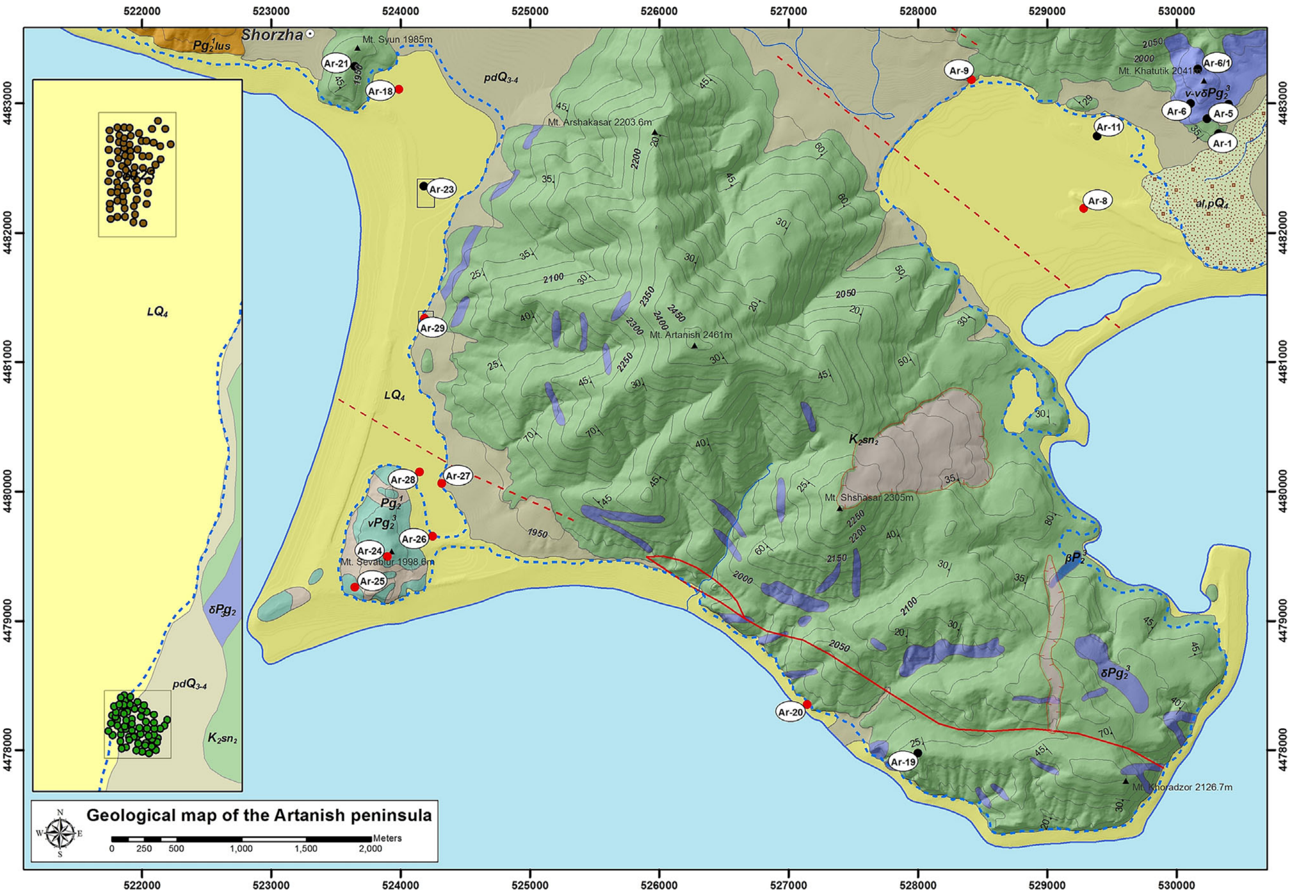

FIGURE 14 The localization of the burial grounds Artanish 23 (Ar-23) and Artanish 29 (Ar-29) near Lake Sevan with the points of geochemical sampling (on the left part) on the schematic geological map (made with ArcGIS 10.4 by D. Arakelyan).

evidence. For this purpose, it is necessary to combine complex data of a large number of archaeological sites located in various landscape-geological conditions.

3. Unlike geophysical methods, which give a semi-quantitative assessment of buried archaeological sites (dimensions, depth etc.), the geochemical method primarily provides the qualitative assessment of the chemical composition of deep anthropogenic material (up to 3 m depth in this study), namely, composition, type of alloys of buried metal objects, as well as the presence of bones. The used method for sample analysis was carried out with a multi-channel atomic emission with a MAES analyser. The results, in ppm, were treated with a multiplicative factor (see Section 2.6 and supplementary material).
4. The method, combined with archaeological visual observation, enables us to identify and verify the false, empty and plundered tombs, saving the time and financial resources of archaeologists.
5. The method facilitates the work for clarification and adjustment of the archaeological site boundaries, as well as the mapping process.
6. The successful experience of geochemical exploration of the burial grounds Artanish 23 and 29 enables the application of this prospecting-assessment method in other similar areas, where presumably or according to historical information, there are buried archaeological sites.

Conclusion on the impact of geological environment on human life and behaviour:

1. The contrast of geochemical halos on Artanish 23 site is weaker than on Artanish 29. This is due to the following:

a. The burials were implemented in the lacustrine sand-gravel rock mass, where the amount of clay mass is small, which in its turn is an obstacle for the formation of geochemical halos;
b. The area is partially waterlogged for at least 2800 years, hindering the full formation of geochemical halos.

2. This study reveals also that the Iron Age population in the habitat of Artanish Peninsula took full advantage of its geological environment. The stone used during erecting burials (gabbro rocks), as well as the material of the tomb cover (marly limestone) were extracted on site. The mines of those rocks exploited in ancient times are located at a distance of several hundred meters from the burial grounds.

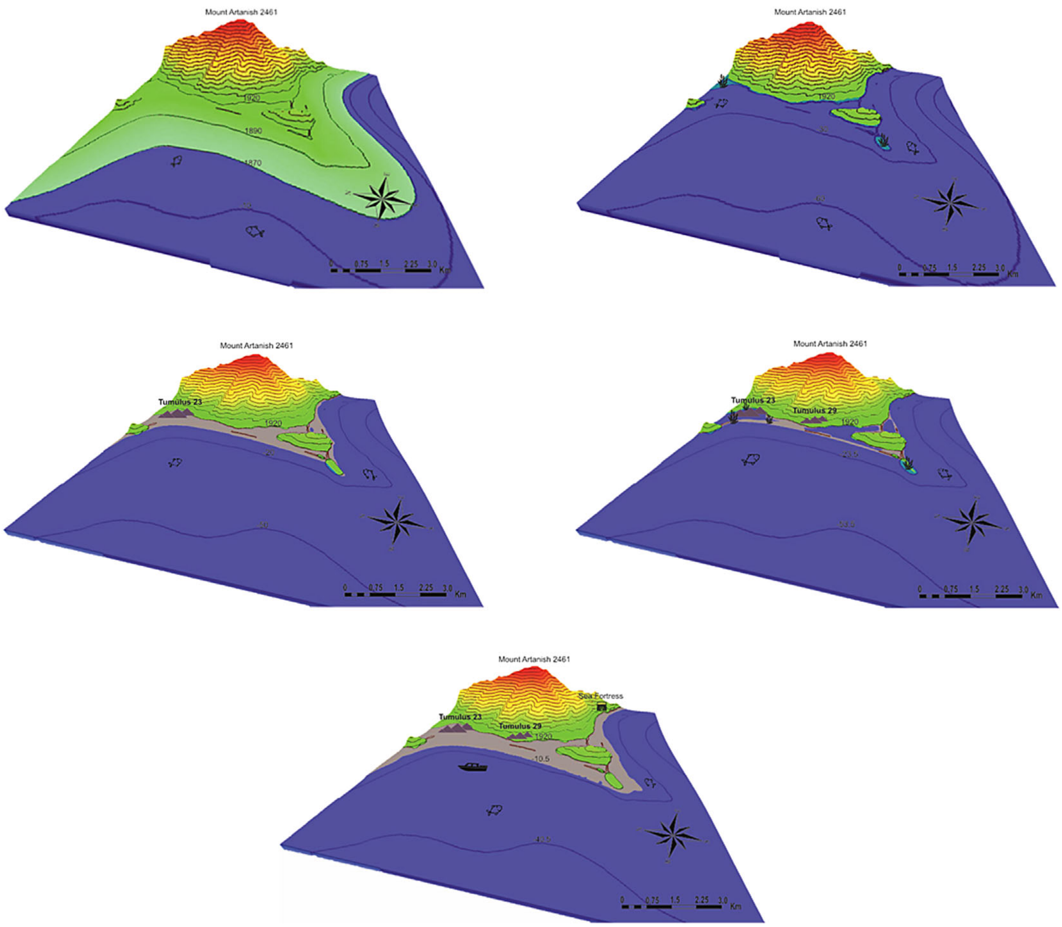

FIGURE 15 Reconstruction of Lake Sevan water level and the ancient environment. Elevations are visible on the isolines (made with ArcGIS 10.4 by D. Arakelyan).

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

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