HYDROARCHAEOLOGY AND PUBLIC HEALTH: RESULTS OF CHEMICAL TESTING OF WATER SOURCES IN THE *TERRITORIUM* OF *TROPAEUM TRAIANI*–ADAMCLISI

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Abstract: As part of the research program of the territory of the roman city of *Tropaeum Traiani*, in 2005, water samples were taken from Abrud, Adamclisi, Cucuruz, Şipotele and Zorile, but only the first two mentioned were subjected to the analyzes. The sample from Abrud comes from the Roman aqueduct, and the one from Adamclisi from the Turkish well, where, around the surface of the place, Roman pottery appears. Water from other sources, about which there was no information that would have been used in Roman times, was not analyzed.

The results of the tests performed both on site and in the laboratory, indicate very high values for water hardness, for all analyzed samples. Indeed, the area of Adamclisi, like the western Dobrudja, up to the Danube, is located on a loess level with a high percentage of carbonates (20–27%), compared to the rest of the area.

The chemical analysis clearly shows that the water in the Turkish well from Adamclisi is carbonated. The water from Zorile, Abrud and Şipotele contains a relatively high level of carbonates, which is close to that admitted for consumption and household needs. It is quite possible that the relatively low level of mineral carbonates in the water sources from Şipotele and Abrud made the Romans build the aqueducts, the one from Şipotele to *Tropaeum Traiani* and the one from Abrud, which was going in an unknown direction.

The most interesting sources of water are Zorile and Cucuruz. The latter is a village, currently abandoned, because the population was forced to move during communism, where water has the lowest level of nitrates in the chemical composition. This is due to the abandonment of the village and the lack of mechanized agriculture.

The water from Zorile and Cucuruz contains the lowest level of dissolved minerals, which makes these springs the safest source in the area for drinking water.

Keywords: *Tropaeum Traiani*, *territorium*, water sources, chemical analyzes, aqueducts

HYDROARCHAEOLOGY PROGRAM

Hydro-archaeological surveys, conducted between 2004 and 2006, have been investigating Roman-period aqueduct lines surrounding *Tropaeum Traiani* within a 25-km radius of this Roman city. A major aim of this research is to

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identify remains of aqueducts in the *territorium* of *Tropaeum Traiani*, as well as to document Turkish-period water pipes and fountains, abandoned fountains, and fountains in use during the 20th-century to the present time. The long-term research goals include understanding the ecological and economic roles of rural communities that supported *Tropaeum Traiani* during its five-century occupation (2nd–6th centuries AD); study of the urban-rural interdependency during both the apex and decline of Roman imperial hegemony; and tracking of underground aqueduct systems which not only supplied water to *Tropaeum Traiani* but possibly to Roman plantation-style farms.

Within the *territorium* of *Tropaeum Traiani*, there are numerous locations where subterranean aquifers (water-bearing formations) rise close enough to the surface that they were easily recognized and exploited in antiquity. In both the 2004 and 2005 seasons, we solicited information on communal wells and fountains known to have been used by local inhabitants and conducted surface surveys at each of these locations for any signs of archaeological remains. At the sites of Abrud, Adamclisi-well, Cucuruz, Şipotele, and Zorile[1] (fig. 1), substantial Roman-period remains have been found through surface surveys and/or prior excavations. Remains of Roman aqueducts have been found at Adamclisi-well, Şipotele[2] and Abrud. At Abrud, water still flows through the Roman aqueduct and is used today by local herdsmen for their animals. Most of these sources were also exploited during the Ottoman period, at which time communal fountains were built under Turkish administration of Dobrudja.

In 2005, water samples from Abrud, Adamclisi-well, Cucuruz, Şipotele, and Zorile were collected for chemical analysis. Only water flowing from 1) Roman aqueducts and 2) Turkish fountains with Roman pottery found in surface surveys were tested. Water from 20th-century piping and pumping systems and from historical fountains with no evidence of Roman-era exploitation were not tested because it could not be readily verified whether these water sources were used in antiquity.

[1] All villages are part of the Constanţa County: Abrud (comm. Adamclisi), Cucuruz (village that no longer exists, being integrated into Urluia village, comm. Adamclisi), Şipotele (comm. Deleni), Zorile (comm. Adamclisi).

[2] Ştefan 1972.

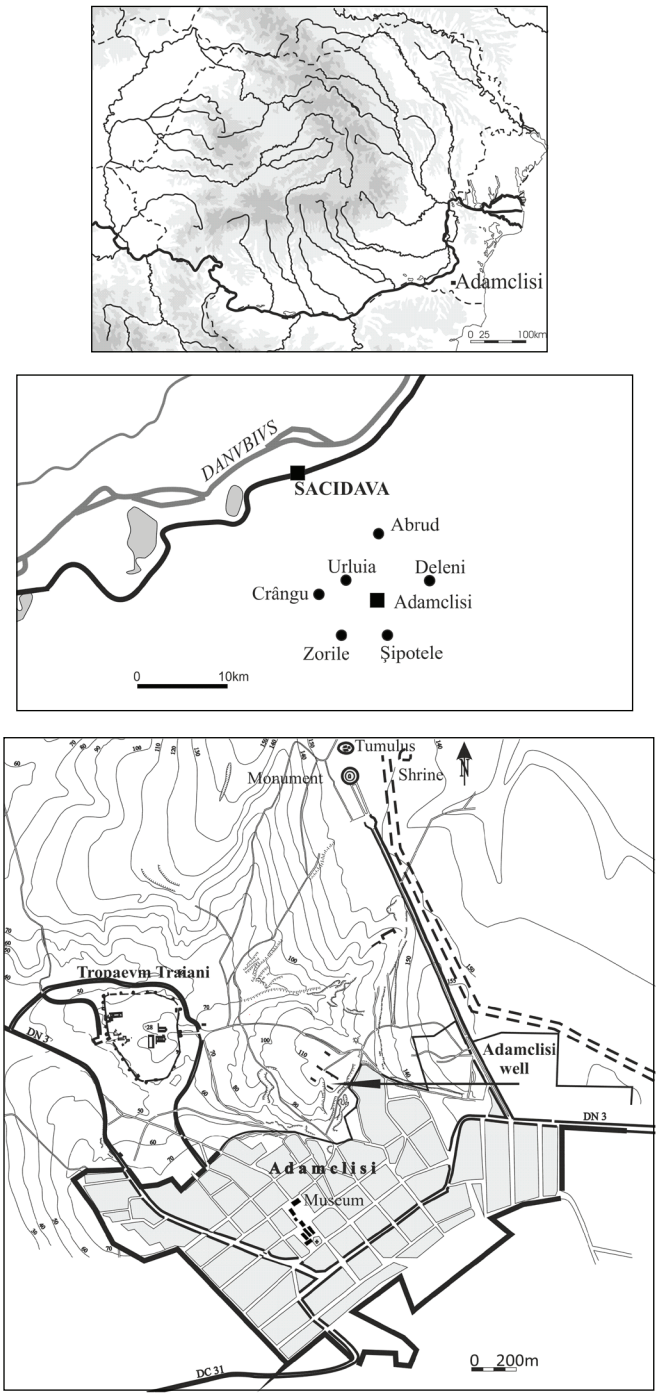

Fig. 1. Location of sampling sites related to *Tropaeum Traiani*–Adamclisi.

CHEMICAL ANALYSIS OF WATER SOURCES EXPLOITED IN ANTIQUITY

Specifications of chemical testing procedures in the field

Six, *preliminary* chemical tests were performed in the field: pH, total hardness, nitrite, total nitrate, chloride, and total alkalinity. The tests were done with colorimetric water-quality test strips manufactured by Industrial Test Systems (US) and WaterWorks (US). Chemical strips are easily transported and excellent for field testing directly at the water source. However, these results were *semi-quantitative only*, giving range values for each color on the test strip.

Chemical Test	Abrud	Adamclisi – well (west basin)	Adamclisi – well (east basin)	Adamclisi – well (Turkish pipe)	Cucuruz	Şipotele	Zorile
pH	8.0	8.5	8.5	8.5	8.0	8.5	8.5
Total Hardness as $CaCO_3$ (ppm)*	250	425+	425+	425+	120	250	250
Nitrite as N (ppm)	0	0.15	0.15	0	0	0	0
Total Nitrate as N (ppm)	5	50+	50+	50+	0.5	50	5
Chloride (ppm)	100	500	500	500	250	250	250
Total Alkalinity (ppm)	240	240	240	360	360	360	360

Table 1. Results of field tests of water sources in the *territorium* of *Tropaeum Traiani* (*One part per million (ppm) is equal to one milligram per litre (mg/L)).

For the initial, field testing, six of the most common water tests were performed in order to obtain a base-line chemical profile of each source, even though some of the tests are not relevant to the ecosystem of the Roman period (Table 1). Total nitrate level, for instance, is the result of mechanized agricultural practices in communist-era Romania. Nitrates, from continuous use of industrial fertilizers, migrate through the soils and contaminate subterranean aquifers. In the Adamclisi area, the nitrate content of the historical water sources was so high that it was beyond the colorimetric scale of our tests (indicated with + after the highest reading). However, total hardness and total alkalinity are indeed relevant to ancient hydrology, independent of modern interference with the landscape, and result from groundwater in contact with the carbonate rock formations. Although the results in Table 1 are semi-quantitative only, these quick and efficient field tests were valuable for determining that more precise testing in a laboratory would have significant merit (Table 2).

Specifications of chemical testing procedures in the laboratory: Water samples were collected from the same, above-named sources in the *territorium* of *Tropaeum Traiani* for more precise analyses in the laboratory. Samples of 500 ml were taken

directly from flowing water (not collecting basins, nor still water) into new, previously unopened plastic bottles (received sterilized and sealed from the manufacturer). Water samples were maintained in the same collecting bottles, couriered in person, and never opened during transportation. Glass laboratory equipment was sterilized and hot air dried after each test to avoid cross-contamination of water samples. Samples were assigned random numbers for blind testing. All tests were conducted by the author in the Archaeometry Laboratory of the Museum Studies Program, San Francisco State University.

Three chemical assays were performed for chlorides, alkalinity, and total hardness - the most relevant for ancient water systems for the region and time period under study. A series of water quality testing chemicals and equipment developed by the Hach Company (US) for the aquaculture industry was used for this hydro-archaeology program:

1) Reagents used to measure chlorides present in the water samples: chloride indicator powder (potassium chromate); silver nitrate solution.

2) Reagents used to measure alkalinity: bromcresol green-methyl red indicator powder; phenolphthalein indicator solution; sulfuric acid standard solution. Both phenolphthalein alkalinity and total alkalinity (methyl orange) were measured. Total alkalinity includes all carbonates, bicarbonates, and hydroxides.

3) Reagents used to measure total hardness: hardness buffer solution (aminomethylpropanid, acetic acid); hardness test solution (calmagite, hydroxylamine hydrochloride, isopropanol, propylene glycol); hardness titrant reagent (EDTA).

Chemical Test	Abrud	Adamclisi-well (west basin)	Adamclisi-well (east basin)	Adamclisi-well (Turkish pipe)	Cucuruz	Şipotele	Zorile
Total Hardness as $CaCO_3$ (mg//L)	256	1060	957	1094	222	376	222
Chloride (mg/L)	150	330	330	330	120	240	180
Total Alkalinity (mg/L)	171	239	239	239	273	273	324

Table 2. Results of laboratory tests of water samples from the *territorium* of *Tropaeum Traiani* (All results have an error factor: ± 17 mg/L (1 gpg)).

Explanation of general water chemistry

Total Hardness: Calcium and magnesium, from dissolved limestone and dolomite rock minerals, are the most abundant alkaline earth metals found in natural waters. Hardness is defined as the characteristic of water that represents the total concentration of calcium and magnesium expressed as their calcium carbonate equivalent. Other divalent ions also contribute to hardness, but their effects are usually negligible in natural waters. The ideal range for domestic purposes is 150-200 ppm. If total hardness is very high, then the groundwater source is a carbonate aquifer.

Total Alkalinity: Alkalinity is the capacity to neutralize acid and refers to the amount of bases in water. The presence of carbonates, bicarbonates, and hydroxides is the most common cause of alkalinity in natural waters. Sources producing alkalinity are primarily dissolved limestone or dolomite minerals (carbonates and bicarbonates) from soil or rock minerals. Alkalinity and hardness are usually similar in values because they derive from the same dissolved minerals. If alkalinity is much higher than total hardness, then the water is also naturally high in sodium. If alkalinity is much lower than total hardness, then the water may be contaminated with chlorides, nitrates, and sulfates.

Chloride: Chloride is a salt compound resulting from the combination of chlorine and a metal. Some common chlorides include sodium chloride (NaCl), potassium chloride (KCl), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$). Sodium chloride may impart a salty taste in water at 250 ppm; however, calcium or magnesium chlorides are not usually detected by taste until levels of 1000 ppm are reached. The US Environmental Protection Agency (EPA) recommends a maximum chloride level of 250 ppm. Chlorides present in water may result from agricultural runoff or rocks containing chlorides that have dissolved in the aquifer.

pH: The pH of water is a measure of the hydrogen ion (acid) concentration on a scale of 0 (very acidic) to 14 (very basic), with pH 7 being the neutral point. The pH value represents the instantaneous hydrogen ion activity rather than the buffering capacity or total reserve as in acidity or alkalinity tests. The pH of most natural waters ranges from 4 to 9 and is greatly influenced by the present of carbon dioxide, carbonates, bicarbonates, or acid rain.

Nitrite: Nitrite (NO_2) occurs as an intermediate stage in the biological decomposition of compounds containing organic nitrogen. Nitrite is an unstable form of nitrogen and is not often found in surface waters because in aerobic conditions they are readily oxidized to nitrates. Levels of nitrites greater than natural residual amounts can be acutely toxic to humans and animals and water supplies containing more than 0.5 ppm require treatment. Sources of nitrites in rural areas are typically fertilizers and animal waste.

Nitrate: Nitrate refers to the univalent radical NO_3 or a compound containing it, especially calcium nitrate, sodium nitrate or potassium nitrate in fertilizer. Nearly all metal nitrates are soluble in water. Therefore, nitrates are the most frequent groundwater pollutants in rural areas. The origin of nitrate in groundwater is primarily from fertilizers

and manure spreading operations. Fertilizer nitrogen not taken up by plants, volatilized, or carried away by surface, runoff ends up in the groundwater in the form of nitrate.

PUBLIC HEALTH ISSUES AND FUTURE RESEARCH

Of particular concern to this research were the levels (bi-)carbonates and dissolved minerals in the water sources during antiquity. Therefore, the results for total hardness and total alkalinity are the most significant for our archaeological research. Of all the chemical contaminants in water, only the (bi-)carbonates could have been easily recognized by ancient peoples.

Adamclisi – well, the water source closest to the ancient city of *Tropaeum Traiani*, has two Turkish fountain basins and an exposed pipe, all of which have water flowing and today still used by herds of livestock. In times of need, this water source has also been used for consumption, irrigation, and hygiene by the present-day village population, who are aware of the water-quality problems. High levels of carbonates and minerals make it very difficult to wash oneself and one's clothing, stunt the growth of chemically-sensitive fruits and vegetables, and in very high quantities cause human and animal sickness.

Test results show extraordinarily high values for total hardness of all the sources tested. The zone surrounding Adamclisi and indeed all of western Dobrudja, flanking the right bank of the Danube, is situated on a loess horizon with the highest percentage of carbonates (20–27%) in comparison with the rest of the province[3]. Based on the chemical analyses, it is clear that the water source at Adamclisi – well is a carbonate (limestone, karst) aquifer[4]. It is for this reason that we believe that the Roman administration created extensive aqueducts throughout the *territorium*. Building the city of *Tropaeum Traiani* next to this source of water, with toxicity recognizable in ancient times, is confounding and contrary to all reason, especially since the Romans were astute managers of water supplies. It is therefore all the more likely that this city was emplaced by Trajan purely for commemorative and military motives, and the landscape hydrology was engineered (at great expense!) to meet the emperor's objectives.

Zorile, Abrud, and Şipotele show moderately high levels of dissolved carbonate minerals, just above the ideal range for human consumption and domestic uses. The lower level of dissolved carbonate minerals at Abrud and Şipotele most likely induced the Romans to construct an extensive aqueduct from Şipotele to *Tropaeum Traiani*[5] and another aqueduct at Abrud (to a currently unknown destination).

However, the most interesting water sources are at Zorile and Cucuruz – both geographically the closest communities to Adamclisi. Cucuruz, a village whose population was forcibly removed and relocated during the early years of the communist

[3] Conea 1970, p. 56.
[4] Hanshaw, Back 1979.
[5] Ştefan 1972.

era, has the lowest level of nitrates in the water as a result of village abandonment and lack of 20th-century industrialized farming. For both Zorile and Cucuruz, the most important natural characteristic of the water is the lowest level of dissolved minerals (total hardness), which makes these sources the safest drinking water (of those tested) in the region. Since Roman-period remains were found during a surface survey in 2004, it is surmised that these water sources were exploited heavily in antiquity. It is for this reason that these areas will be more intensely surveyed in future field campaigns.

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CALITATEA APEI ŞI SĂNĂTATEA PUBLICĂ. REZULTATELE ANALIZELOR CHIMICE ALE APELOR DIN *TERRITORIUM*-UL ORAŞULUI ROMAN *TROPAEUM TRAIANI*–ADAMCLISI

REZUMAT

În cadrul programului de cercetare a teritoriului oraşului roman *Tropaeum Traiani*, în anul 2005 au fost luate probe de apă de la Abrud, Adamclisi – Cişmeaua turcească, Cucuruz, Şipotele şi Zorile, dar au fost supuse analizelor doar primele două menţionate. Proba de la Abrud provine de la apeductul roman, iar cea de la Adamclisi din cişmeaua turcească unde, în jur, chiar la suprafaţa locului, apare ceramică romană. Apa din alte surse, despre care nu existau informaţii că ar fi fost folosite în epocă romană, nu a fost analizată.

Rezultatele testelor, efectuate atât la faţa locului, cât şi în laborator, indică valori foarte ridicate pentru duritatea apei, pentru toate probele analizate. Într-adevăr, zona comunei Adamclisi, ca şi toată Dobrogea vestică, până la Dunăre, se află situată pe un nivel de loess cu un procent ridicat de carbonaţi (20–27%), în comparaţie cu restul zonei.

Analiza chimică demonstrează clar că apa din cişmeaua turcească de la Adamclisi este una carbonatată. Apa de la Zorile, Abrud şi Şipote conţine un nivel relativ ridicat de carbonaţi, dar care se apropie de cel admis pentru consum şi nevoi casnice. Este foarte posibil ca nivelul relativ coborât de carbonaţi minerali în sursele de apă de la Şipote şi Abrud să-i fi făcut pe romani să construiască apeductele, cel de la Şipote, spre *Tropaeum Traiani* şi pe cel de la Abrud, orientat spre o direcţie încă necunoscută.

Cele mai interesante surse de apă sunt cele de la Zorile şi Cucuruz. Aceasta din urmă provine dintr-un sat, în prezent părăsit (deoarece populaţia a fost mutată forţat în timpul epocii comuniste), unde apa prezintă cel mai scăzut nivel de nitraţi în compoziţia chimică. Aceasta se datorează abandonării satului şi lipsei agriculturii mecanizate.

Apa de la Zorile şi Cucuruz conţine cel mai scăzut nivel de minerale dizolvate, ceea ce face ca aceste izvoare să fie cele mai sigure din zonă în privinţa apei de băut.

Cuvinte-cheie: *Tropaeum Traiani*, *territorium*, surse de apă, analize chimice, apeducte

EXPLICAŢIA FIGURILOR

Fig. 1. Localizarea punctelor de eşantionare raportate la *Tropaeum Traiani*–Adamclisi.

Table 1. Rezultatele testărilor pe teren a surselor de apă din teritoriul *Tropaeum Traiani* (*O parte la milion (ppm) este egală cu un miligram pe litru (mg/L)).

Table 2. Rezultatele testărilor de laborator a surselor de apă din teritoriul *Tropaeum Traiani* (toate rezultatele au o marjă de eroare de ± 17 mg/L (1 gpg)).