Groundwater drainage pattern of the Roman Forum, geological framing and physical chemical analysis by onsite measures, ion chromatography, UV-Vis spectrometry

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Introduction

The most important historical cities born near rivers. Just as examples we can cite the seven wells city Be'er Sheva, Jerusalem, Costantinopoli (also named Water-Tower Gate) Athens (birthplace of the deity Ninphs) and Corinth that born near the Gihon [2], Sulukulekap, Kallirroe and Peirene springs respectively.

Rome must be considered one of the most significant examples due to the presence of Tiber and its tributaries, that in the first millennium B.C. were much more numerous than the current, as well as for the numerous springs starting from the hills on which the city born. Many of them are up today lost but inside the city their approximate number would be 50.

The city is located on the alluvial plain at the lower course of the Tiber river hydrographic system. This graben-like depression is controlled by NE-SW trending faults and it is limited by: the Apennine NW-SE trending fold-and-thrust mountain chain to the NE; the Tyrrhenian sea to the SW; the volcanic provinces of the Colli Albani and Monti Sabatini, to the SE and the NW, respectively. The outcropping rocks ages range between the Pliocene and the Holocene. They are mostly represented by a sedimentary succession (marine to fluvio-lacustrine deposits) recording the progressive marine regression related to the Apennines uplift and a concurrent sea level drop. The uplifting was accompanied by an intense volcanic activity of both the Colli Albani and Sabatini provinces that strongly influenced the river path and the valley morphology evolution. At the end of the Colli Albani activity the Rome plain resulted as a plateau formed by the volcanic deposits. The Tiber and its tributaries then carved the paleo-topography to leave a network of valleys separating round-shaped reliefs (the famous seven hills among others).

Having Tiber and a particular hydrogeological system Romans have had a great availability of water sources [3]. The increase of citizens (someone talk about more then 1 million in the golden age) led to the need of more and more water; so, in 312 b.C. the first Roman's Aqueducts was constructed, because natural water springs were not enough anymore. When the Forum became the cultural and government centre of Rome the water sources inside it, as Iuturnae, Tullianum, Lacus Curtius, became sacred, visited by a lot of pilgrims. During the medieval period, some of these springs started to be used again, but only for a short period, while today just few of them are still accessible.

Experimental

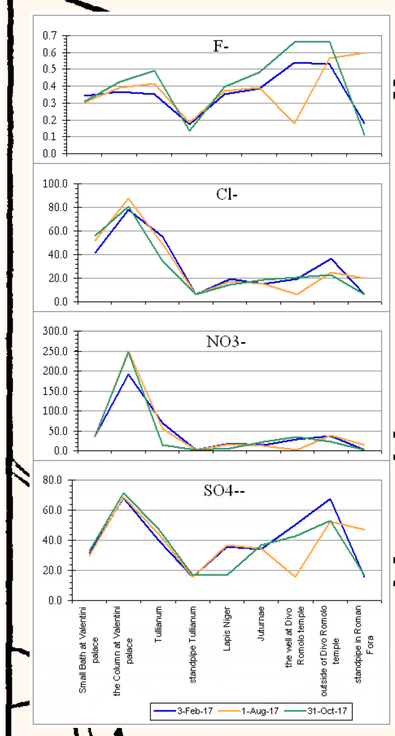
In 3 measurement campaigns, both performed in 2017, we measured in situ and collected samples from the seven sources in order to obtain their chemical-physical characterization. Temperature, pH, Conductivity, Li^{+}, K^{+}, Na^{+}, Mg^{+2}, Ca^{+2}, Sr^{+2}, F^{-}, Cl^{-}, Br^{-}, NO_3^{-}, PO_4^{-2}, SO_4^{-2}, $CH3COO^{-}$, $C_2O_4^{-2}$, HCO_3^{-} content, TOC, TIC, UV-Vis absorbance were measured in order to obtain some chemical index; samples from nearby standpipes were also analyzed for a comparison.

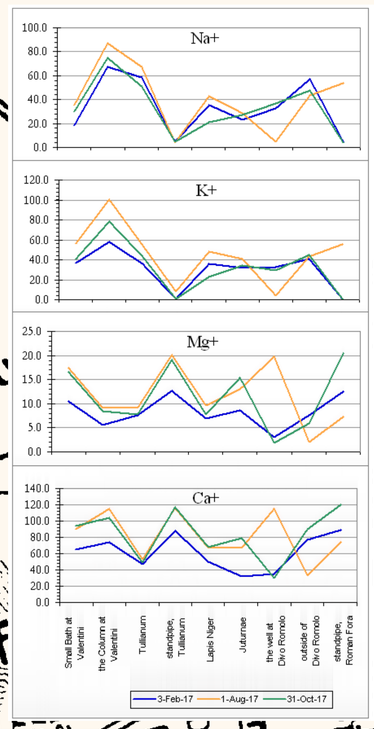
Anions and cations have been identified and quantified by ion chromatography. A Metrohm 761 (Metrohm, Swiss) IC equipped with Dionex (Thermo, USA) Ionpac AS14a and a Metrosep C4-250 columns were used for the analysis of anions [4] and cations [5] respectively using standard methods. Standard solutions coming from Merck and Sigma were used.

A Perkin Elmer (Perkin Elmer, USA) Spectrophotometer Lambda 16 UV-Vis, equipped with Helma QS, 2, 10, 50 mm cuvettes, has been used for the analysis of the Organic compounds and to evidence eventual colours of the waters.

Carbonate titration was performed with two Amel Instruments (Amel, Italy), a Digital Burette Model 233 and a pHmeter 338 equipped with Crison 12-02 pH electrode; an internal, unpublished, procedure with a continuous flux of N2 was adopted. Titrant was a Carlo Erba (Italy) Normex solution of HCl 0.1 M. All the other reagents, of analytical grade, come from Carlo Erba, from Merck and from Fluka. Common laboratory glassware was used.

For waters withdrawals 50 ml Falcons have been used while temperature, conductivity, pH and ORP, have been measured in situ with portable instruments from Vernier Instrument (Vernier, Canada), previously calibrated in laboratory.





In figures above the profile of anions and cations on an hypothetical vector starting from north-west to south-est. Interesting the opposite profile of F^{-} and Cl^{-}, the highest values of NO_3^{-}, SO_4^{-2}, Na^{+} and K^{+} on N-W. The profiles seem very similar for the 3 campaigns. Y axe in ppm.

Fig.1, Geological map of the Palatine hill and part of the study area: Roman Forum

Geological framing

The study area is located on a branch of the Rivo Labicola paleo-water stream that drained the surface water to the Tiber through the Palatino, Celio, and Oppio hills, and the Circus Maximus (Fig. 1). Four mixed sedimentary-volcanic depositional systems (Flaminia, Torrino, Quartaccio, and Fiume Tevere systems) are recognized in this area, separated by erosional/non depositional surfaces. The respective outcropping formations, from older to younger, are:

Flaminia system. The Santa Cecilia Formation (CIL) composed of alternating fluvial conglomerate, sand and silt beds with volcanoclastic component. Maximum thickness 40 m. Middle Pleistocene p.p.

Torrino System. The Fosso del Torrino formation (FTR) are fluvial to fluvial-lacustrine polygenic conglomerates, sands and silt dominated by volcanoclastic debris from reworking of the major ignimbrites from the Colli Albani and Sabatini Volcanoes whose activity is recorded in the area by the Pozzolane Rosse (RED) and Tufi Stratificati Varicolori di la Storta (LTT) formations, respectively. Calcareous silt and clay, and phytoclastic travertine are also present.

Quartaccio System: The Aurelia Dormation (AEL) is composed of conglomerates and sands with volcanoclastic component showing the occurrence of Travertine layers. In the upper part of the system the Villa Senni Formation (VSN) record the last large volume eruption from the Colli Albani. The radiometric ages in literature span from 357+/-2 ka to 338+/-8 ka.

Fiume Tevere System (SFT): silt, sands and clays sedimented in the alluvial plains of the Tiber river. Bore-hole data indicate the presence of peat and of a basal conglomerate level which may host a pressurized aquifer.

From the hydrogeologycal point of view [5] both the sedimentary and volcanic succession are characterized by alternating tight and highly-porous rocks. While some sedimentary deposit (conglomerates and sands) may show a high primary permeability in volcanic rocks the presence of a fracture system is needed to interconnect the numerous pores (secondary permeability). This architecture in the bedrock allow the formation of several, laterally-confined, aquifers at various depths that can locally intersect the topography to form water resurgence.

Conclusions

The uppermost water layer in the area is shallow and ranges between 5 and 10 meters in depth. The oldest proto-historic settlements have been found 12 m below the ground on the edge of the Via Sacra next to the Colosseum. This suggest that the studied water layer may represent the relic of a paleo surface water drainage.

In all sources no colour, that is one of the first requisite for drink water, were evidenced from the Visible spectra, Organic compounds, probably humic acids, absorbing around 300nm were detected so needing deepest investigation;

• Springs inside the Roman Forum show the lowest cations/anions total content in agreement with data from previous campaigns [3];

• A significant mixing with public water supply can be excluded due to the different "fingerprint" imparted by cations/anions chromatograms and Hardness values.

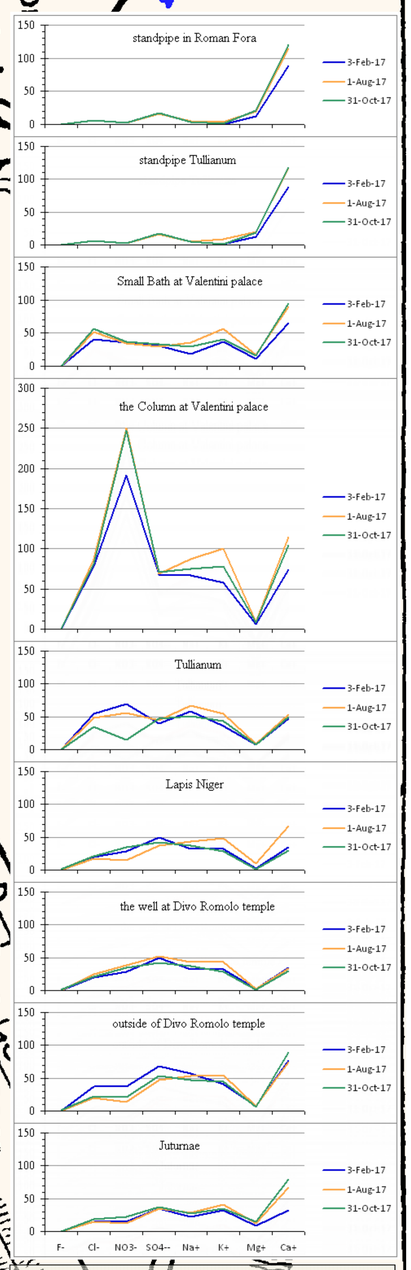
A plausible hypothesis could be that all the spring waters come from the same stratum and their different composition is due to the different kind of ground that they cross before emerging. To exclude the mixing with "Black Waters" or "Gray Waters" some mierobiological analisis are needed with more sampling campaigns.

Legend [1]:

Green dots: measured outcropping: 1) balneae of Palazzo Valentini 2), well recently excavated on Traiane temple, 3) basilica Ulpia (P. Funtinalis?), 4) Tullianum, 5) Lapis Niger, 6) Juturnae, 7-8) wells inside and outside Divo Romolo Temple

Blue dots: A) and B) standpipes (tap water)

Orange dots: estimated position in Romans era sources currently not accessible W) Acque Fontinalis (del Grillo?), X) Cisterns of Vittoriano, Y) Meta Sudans, Z) Lupercale



In figures above the profile ions for the sources. On the X axe the ions on the Y axe the concentration (ppm) using the same scale.

References

1) Meyers Konv-Lexicon, Map of Imperial Fourm, 1906, used here as background
2) R. Benami Amie, T. Grodek, A. Frumkin, Characterization of the hydrogeology of the sacred Gihon Spring, Jerusalem: a deteriorating urban karst spring, Hydrogeol. J., 18(6), 2010, 1465-1479
3) A. Corazza, L. Lombardi, Water and the city in antiquity, in La Geologia di Roma dal Centro Storico alla Periferia, Selca Ed., 2008, 189-220
4) ASTM D4327-11, Standard. Test Method for Anions in Water by Suppressed Ion Chromatography, ASTM International, West Conshohocken Ed., PA, 2011
5) ASTM D6919-09, Standard. Test Method for Determination of Dissolved Alkali and Alkaline Earth Cations and Ammonium in Water and Wastewater by Ion Chromatography, ASTM International, 2009

Accademia dei Lincei, XVIII Giornata Mondiale Dell'Acqua, Convegno: La Previsione Idrogeologica Sulla Risorsa Acqua, 22 march 2018, Via Della Lungara, 230, Rome, Italy

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