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Long-term tracing in karstic aquifer reservoir for drinking water: the example of chain "Peaks of the Musi Mountain" (Western Julian Fore-Alps)

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Abstract

The chain of the Musi Mt (1,869.4 m) is one of the most important karst massifs of the Western Julian Fore-Alps (Italy). On the northern slope, the Barmàn spring is located; on the southern slope the Voidizza Springs and the Torre Springs are located. Almost the whole feeding basin of the above-mentioned springs is placed in a protected area, managed by "Ente Parco Naturale delle Prealpi Giulie". Therefore, the zone is an important example of an area having high vulnerability due to karst and it is strategic for the water supply for an important part of Friuli. Two tracing tests were carried out injecting Uranine into the Pahor Abyss on the northern slope. From these tests it results that the waters of the karst area drain in the Uragano Cave and in the underlying Barman Spring. Only during heavy low water, when the underground watershed of the massif lowers, is it possible to observe traces of Uranine in the Torre Springs, since the most northern underground regions of the massif are drained. The tracer test was supported by a chemical-physical study of the underground waters of the massif, and the analysis of the stable isotopes ($\delta^{18}O$, δD) were carried out.

Key Words: Karst hydrogeology, Tracer test, Uranine, Musi Mt, Western Julian Fore-Alps, NE Italy.

1. Introduction

The hydrogeological studies carried out on the basin of karst massif of the Musi Mount consisted in hydrological measurements, chemical analyses of undergorund waters and tracing tests (Anselmi et. al., 1997; Anselmi and Semeraro, 2003; Brun and Semeraro, 2004; Iacuzzi and Vaia, 1975; Semeraro, 2005). In particular, in the area two tracing tests were performed injecting Uranine into the caves of the Musi cirque located on the northern slope. The tests were both qualitative: water samples were analysed and detector bags were collected at the springs. The present investigation describes a qualitative tracing test with Uranine. The tracer was again injected into a cave of the Musi cirque, but this time some flourometer probes that monitored the waters for a long period were positioned at the two main springs of the karst massif. Morevover, during this period many chemical and isotope analyses were carried out on the sampled waters, with the purpose of obtaining a better picture of the geochemical characteristics of the aquifer. The aquifer of Musi Mount is captured at the Springs of Torre (southern slope) with an average quantity of 16.98 L/s, of which 10.45 L/s for drinkable water utilisation and 6.53 L/s for hydroelectric usage. In total an average of 1,467 m^3 per day, which shows the importance of this aquifer for the community of eastern Friuli region (Italy). Most of the mountain area is protected since the territory is managed by "Ente Parco Naturale Prealpi Giulie".

2. Geological and Karstological Setting

The chain of the Peaks of Musi Mt (height 1869.4 m) is located in the western Julian Fore-Alps and bordered northwards by Uccea stream (Isonzo River basin), Carnizza stream and Barmàn stream (Resia stream basin), and southwards by Voidizza and Mea streams (Torre stream basin).

The chain is formed by mainly Triassic and Jurassic dolomitic and calcareous rocks and by Quaternary deposits. The southern slope is made up of Dolomia Principale (Norian-Rhaethian). In the northern slope, Dachstein Limestones (Rhaethian) and Lias-Dogger oolithic and cherty limestones outcrop. The whole area is an east-west oriented, north-dipping uniclinal. The uniclinal is closed to the south by the east-west "M. Brancot-Caporetto-Circhina line" passing by the Torre Valley. (Fig.1).

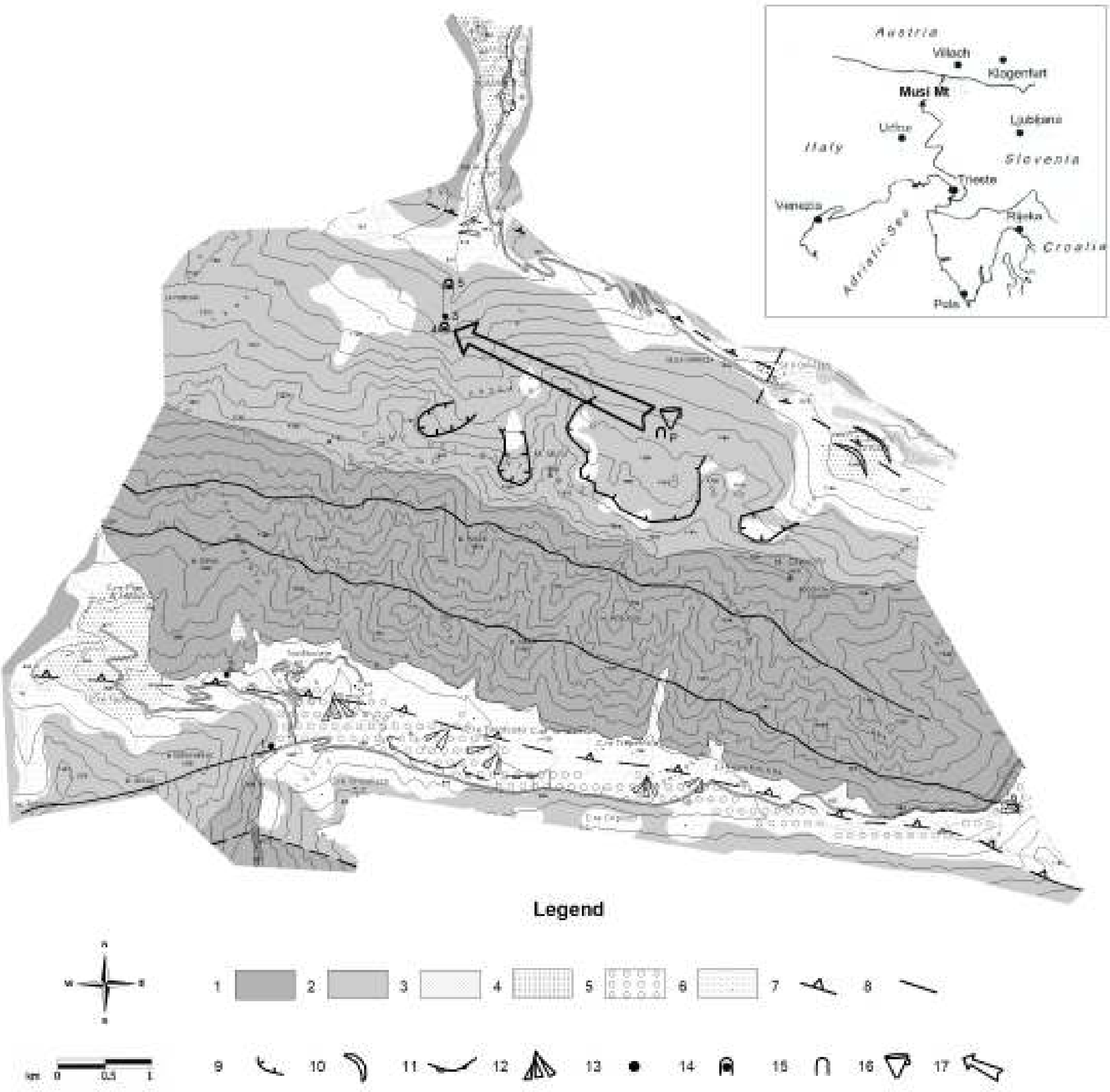

Fig 1 Hydrogeologic map of the area “Peaks of the Musi Mountains”. Legend: 1 = dolomites (prevailing) (Triassic); 2 = limestones and dolomitic limestones (Triassic), limestones, cherty limestones, oolitic limestones, dolomitic limestones (Jurassic); 3 = marly-arenaceous Flysch (Cretaceous); 4 = morain, till, fluvio-glacial deposits (Quaternary); 5 = alluvial deposits (Quaternary); 6 = landslide, talus, colluvial deposits (Quaternary); 7 = reverse fault; 8 = fault; 9 = glacial cirque; 10 = morenic arc; 11 = terrace; 12 = alluvial fan; 13 = main spring: [1] Springs of Torre Stream (T); [2], Springs left of Voidizza Stream, [3] Fontanon di Barman springs (B); 14 = cave-spring: [4] Grotta dell’Uragano (U), [5] Grotta di Barmàn (Ba); 15 = cave Abisso “R. Pahor” (P); 16: injection point of Uranine dye; 17: pathflow of the tracer

Along the northern slope, Quaternary deposits are represented by talus, while Würm moraines are present in S. Anna di Carnizza and in Lischiazze (Barmàn stream valley). Along the southern slope, Würm moraines are present in the Voidizza stream valley, and are probably buried below the alluvium in the Mea stream valley.

Large karst phenomena are concentrated in the northern slope limestones as the Dachstein Limestones, the transitional grey limestones and the oolithic limestones constituting the Musi cirque (Anselmi and Semeraro, 1997). It is a structural plateau, presenting cirques, glaciokarst dells and gullies. In the southern slope, stream trenches in dolomitic rocks are present. In the Musi cirque, with an area of about 5.5 km^2, 230 caves have been explored. The largest cave of the cirque is “Roberto Pahor” Abyss, (altitude 1425 m a.s.l., 495 m deep, 1091.5 m length). Formed by many passages, it is made up of pits and canyons; some passages are fossil, other are hydrologically active; some parts show a 45° inclined feature, related to the geostructural arrangement. To the west of the cirque, at the footwall of the southern slope, in the Barmàn gully, “Grotta dell’Uragano” develops. In the “Grotta dell’Uragano” (altitude 796 m a.s.l., 743 m length, +133 m height), paleoflow passages to the top and semi-flooded galleries near the bottom are present. On the bottom a perennial stream flows.

3. The Vadose and Phreatic Karstic Zones

In the Musi cirque, vadose shafts and canyons, partially derived from phreatic tubes, characterize the percolation zone (Anselmi and Semeraro, 2003; Semeraro, 2005). Deep corrosion pits are associated to them. This zone is actually in an evolutionary stage, especially in deep areas of the massif where percolation is kept by drainages. Vadose water trickle formed gorge system connected with shafts. These are phenomena that repeatedly occurred always equal. Small phreatic conduits originated these shafts. The dispersed percolation caused the formation of the deep corrosion pits.

The northern area of Musi chain is characterized by large conduits, with a saturated zone extremely reduced (or not present during the seasonal lacking of recharge), with a principal drainage system towards the “Grotta dell’Uragano” stream (Brun and Semeraro, 2004). The southern area – almost unknown – should be probably characterized by phreatic conduits (perhaps a network of lenticular tubes in Dolomia Principale Formation), slowly discharging, as perennial springs they recharge the saturated zone store, as resulting by hydrograph and recession curve of Springs to the left of Voidizza and Torre Springs. Hydrological and chemical data of spring point out the existence of a inhomogeneous karst system, divided into two parts.

4. Karst Hydrogeology

The rocky mass forming the chain of the Musi characterized by dolomites, dolomitic limestones and limestones differerently karstified, constituted the karst aquifer. Porous aquifer are represented by the Mea stream alluvium and by the Voidizza stream moraines.

In this area the isohyets are over 3000 mm/year. On the high altitudes of the Musi, rainfalls over 3500 mm/year are estimated, with a relatively low evapotranspiration (Er) calculated at 14.2%. Since the dripping basin of the plateau of the Musi has an area of ~5.5 km² an average theoretical flow of 0.5 m²/s/day will be obtained, which is lower in winter and dry summer periods.

In the southern slope the Torre Springs (529-532 m a.s.l., discharge Q_{avg} 1,8 m³/s) are supplied by Mea stream porous aquifer and by the water percolating from the Musi chain; but a contribution from water percolating in the Sorochiplàs and Postòncicco Mts limestone ridge placed south is possible. The Springs to the left of Voidizza stream (653 m a.s.l., discharge Q_{avg} 10-11 L/s) drain the groundwater of dolomitic aquifer. In the northern slope, the “Fontanon di Barmàn” (Barmàn Spring) (760 m a.s.l., discharge $Q \geq 1,5$ m³/s) connected with the perennial stream of the “Grotta dell’Uragano” (discharge $Q_{avg} \geq 50$ L/s) is fed by waters percolating from the western area of the slope (Poscala) as well as by Musi cirque. The link of “Grotta dell’Uragano” and Barmàn Spring, was observed by Brun and Semeraro (2004) using Tinopal CBS-X for specific tracer test.

The hypothesis of an underground watershed of karst aquifer of Musi Mt that migrated towards the north with respect to the hydrography proposed by Iacuzzi and Vaia (1975). This hypothesis was confirmed by Anselmi et al. (1997) by Uranine tracer test. Only in dry periods would they flow also towards the most depressed point of the aquifer that is the Torre Springs. Normally, the underground waters of northern slope drain towards the Barmàn gully (Anselmi and Semeraro, 2003). The “Grotta dell’Uragano”, in the Barmàn gully, is the terminal part of the northern passages, i.e. large karst conduits representing a principal drainage.

Torre Springs could probably be fed by stored base-flow, coming from a calcareous and dolomitic reservoir of the karst system, as suggested by low temperature and Mg/Ca ratio ranging between 0.48 and 0.32 (Semeraro, 2005); however, the large part of waters comes from the outflows of the Musi Valley porous aquifer (Droli, 1993). Near the spring area, the thickness of the porous aquifer (gravel) is about 70 m, interbedded with lacustrine loam and clays (about 30 m thick) forming an aquiclude, probably separating two different aquifers (one unconfined and one confined) (Droli, 1993; Droli et al., 1988).

5. Tracer test and geochemical survey

The long term tracing was carried out according to the techniques used at present (Käss W. eds., 1998) by injecting 1 kg of Uranine (Fluorescein sodic salt: $C_{20}H_{10}Na_2O_5$), previously diluted, into an upper gallery of R. Pahor Abyss, at the depth of about 100 metres and at the height of about 1,325 m a. s.l. on the 11th October 2005 at 1.20 p.m. The flow of the vadose drainage was minimum, about 0.2 L/s, however it was sufficient to drain the tracer. In order to perform the *in continum* Uranine monitoring two flourometer probes were positioned: one at the Barman Spring and the other at the mixer between the 21 drainages and the capture well of the Torre Springs. They are GGUN-Fl fluorometers supplied with FL02 and FL 20 probes by which it was possible to determine, quite accurately, an interval of Uranine concentrations ranging between 10^{-6} and 10^{-4} g/L. As for the calibration curves of the probes, standard solutions at different concentrations covering the range of instrument sensitivity were used. All the spring waters had been sampled many times in order to determine the “white” of natural flourescence.

For the whole duration of the survey, from the 4th Octobert 2005 to the 13th January 2006 many water samples were collected and detector bags were positioned for further checks of Uranine possible flow. Moreover, a chemical-physical and isotope study of the underground waters of the massif was carried out, considering hydrogeological surveys in alpine environment and the local data known (ARPA Friuli Venezia Giulia, 2006; Gat and Gonfiantini Eds., 1981; Hoefs, 1997; Jeannin, 1998; Kilchmann et al., 2004), using flow (Q) and chemical-physical measurements *in situ*, laboratory chemical analyses not only of the common parameters of the waters but also of the minor components (Tot. hardness, TDS_{180}, Alk. $CaHCO_3^-$, K^+, Na^+,

Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, NO_3^{-}, NH_4^{+}, B, SiO_2, Li^{+}, Rb^{+}, Sr^{2+}, Cd, Co, tot. Cr, Ni, Pb, Mn, Fe, Cu, As, Zn) as well as light stable isotope analyses ($\delta^{18}O$, δD) were carried. All the analyses were performed at the Chemical and Isotope Geochemical Centre of Geokarst Engineering by means of Atomic Absorption Spectrophotometer

The sampled points are: Barmàn Spring and Barmàn Cave (at different intervals) on the northern slope and the main of the Voidizza Springs (Voidizza Spring) and Torre Springs on the southern slope. The waters of the Torre Springs were collected at the capture of "CAFC Consorzio Acquedotti Friuli Centrale, Udine" and more precisely: a) at the mixer of the 21 horizontal drainages, b) at the drainage n. 1 (westwards), c) at the drainage n. 12 (eastwards) and d) at the capture well.

Correlations with rainfalls were carried out using the weather stations of "Prato di Resia" placed northwards (at 492 m a.s.l.) and of Musi (at 523 m a.s.l.) on the southern slope that is characterised by average rainfalls. Uranine was injected just after a rainy period that lasted from 3rd to 8th October with a total of 30.3 mm on the average. Subsequently, up to the end of Uranine monitoring on 30th October, a short rainy period occurred from 21st to 26th October with a total of only 6.1 mm that does not seem to have affected the test (Fig.2).

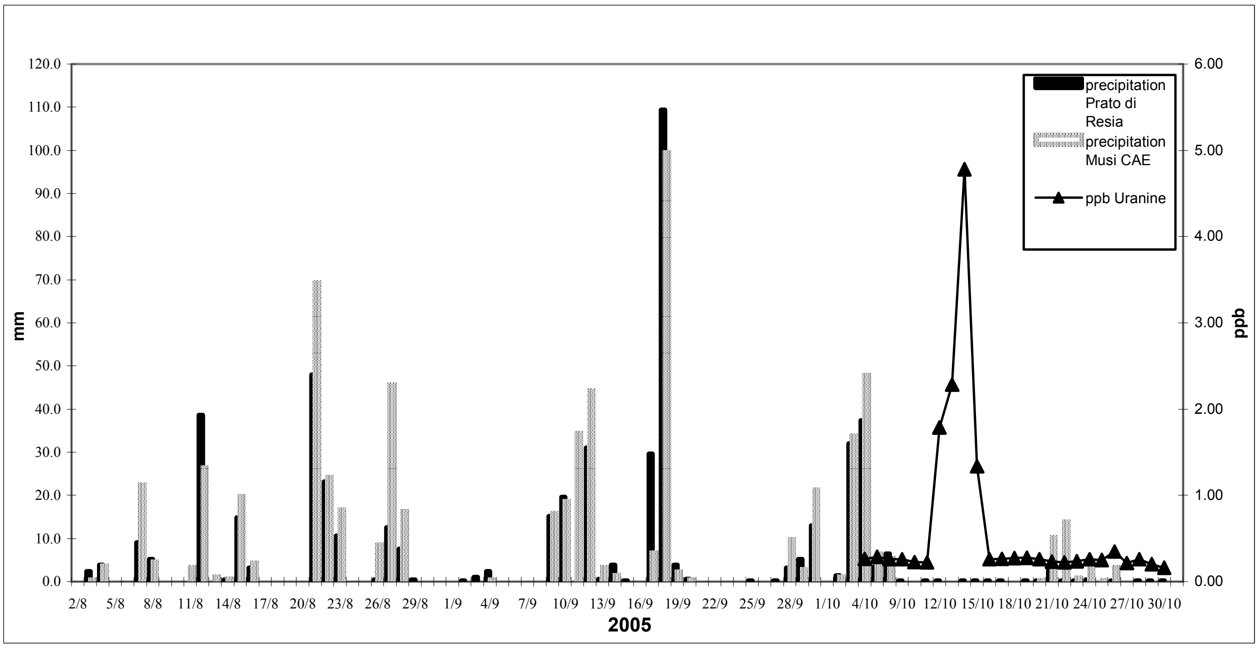

Fig.2. Correlation between precipitation from August to October 2005 and the Uranine breakthtrough curve monitoring by fluorometer probe at the Barmàn stream.

6. Results

The period before the injection of the tracer was characterised by a flood, due to the heavy above-mentioned rainfall, which affected the whole karst aquifer. During the survey of the 4th October, the Barmàn stream flowing below the spring, had a flow of 1.5-2 m^3/s; while the underlying Barmàn Cave discharges a flow of about 15L/s from the entrance (occasional behaviour). The Torre (Springs) and the Voidizza Springs/Streams also presented flood flows, which, however, were not measured.

Uranine was detected at the Barmàn Spring after 12.26 hours from injection into Pahor Abyss, with an apparent distance of about 1,500 metres, obtaining a theoretical velocity of 120 m/h (3.3 cm /s). The very rapid breakthrough curve (the tracer vanishes in only three days) and the obtained theoretical velocity confirm that it is a high mountain system that immediately reacts to impulses. If the obtained link is in accordance with what had been already verified during the former tests (Anselmi et al., 1997; Anselmi and Semeraro, 2003) with the present investigation the hypothesis of the flowing of the tracer in very short times was confirmed. It is, evidentely, a network of large karst conduits. In no other checked spring Uranine was detected. The fact confirms that only during heavy low waters is it possible to establish a link between the Musi cirque and the Torre Springs (Anselmi et al., 1997).

The measurments *in situ* and the laboratory chemical analyses gave interesting data on this period.

The temperature of the Voidizza Spring is always the highest of the all measured waters (between 8.1 and 13.0 °C), confirming that it is a little deep circuit. The temperatures of the Torre Springs range between 7.5 and 9.0°C while that of the Barmàn Spring ranges between 4.8 and 8.3 °C, thus showing a higher variability.

$E.C._{20°C}$ of the Barmàn Spring (between µS/cm 128.7 and µS/cm 188.0) is almost always constantly lower than $E.C._{20°C}$ of the Torre and Voidizza Springs on the southern slope (between µS/cm 139.9 and µS/cm 228.0). The datum indirectly indicates that the Barmàn Spring is linked to very rapid water flow with respect to the other two.

Ca^{2+} and Mg^{2+} are absolutely predominant in all the waters. At the Barmàn Spring and at the springs placed on the southern slope the values of Ca^{2+} are similar (between 30 and 31.8 mg/L), whereas at the Barmàn Spring Mg^{2+} is always lower (around 4.9 mg/L) than that of the springs located on the southern slope (between 9.0 and 16.2 mg/L). This datum confirms, for the southern slope, the existence of higher dolomitic aquifer (in particular for the Voidizza Spring) with respect to the one of the northern slope.

Among the minor components, never studied up to now, it is possible to observe Cu and Fe at the Torre and Voidizza Springs. (At present it is possible only to signal them since a deeper study is required). Whereas the presence of Sr in water appears remarkable (between 13.9 and 18.3 µg/L); Sr is found in the whole aquifer, indeed it was detected at the Barmàn, Torre and Voidizza Springs.

SO_4^{2-} and NO_3^- show low and constant levels in all the waters, respectively between 5.1 and 6.1 mg/L of SO_4^{2-} and between 2.0 and 5.9 mg/L of NO_3^-.

Silica in water is generally low: concentrations of SiO_2 between 0.2 and 0.4 mg/L were detected at the springs placed on the southern slope, whereas at the Barmàn Spring and Barmàn Cave silica is pratically absent.

The isotope data of Musi waters are important. During the period considered $\delta^{18}O$ of the spring of Barmàn was always lower (between -9.0‰ and - 9.1‰) than that of the springs of the southern slope (between -8.0‰ and -8.7‰) showing, with respect to the latter, a feeding coming from higher areas of the basin. δD of the Barmàn Spring ranges between -55‰ and - 63‰, while δD of the Torre and Voidizza Sptings ranges between -54.2‰ and -60.0‰.

The long-term tracing as well as the chemical-physical and isotope data show the high vulnerability of the aquifers of the area which are: the karst jointed one made up of limestone and dolomia and the porous one (high Torre valley) made up of moraines , floods and calcareous paleoslides.

In particular, the calcareous aquifer presents an exceptionally high permeability.

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