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PRELIMINARY HYDROGEOLOGICAL INVESTIGATIONS ON CAMPO DI BONIS (JULIAN PREALPS): RESULTS OF THREE PRE-TRACER TESTS

ABSTRACT

The Campo di Bonis in the Julian Prealps is a large karst depression characterized by a hydrography affluent of the Natisone river and, at the same time, an internal hydrography coming from springs which is captured in sinkholes. From a geomorphological point of view this depression can be classified as an "open polje". It develops in the Flysch del Grivò (Upper Paleocene-Lower Eocene), an alternation of siliciclastic and hybrid turbidites interbedded by karstified carbonate strata and megabeds. The peculiarity of the phenomenon and the completely unknown subterranean hydrogeology led to the planning a study on the groundwater circulation. In this area, between the years 2018 and 2019, three pre-tracer tests were carried out, using charcoal bags, in order to preliminarily identify the possible outputs of the water captured in Campo di Bonis. Two fluorescent dyes, uranine and Tinopal CBS-X, were used by perform fluorometric analyzing of eluates extracted from charcoal. The three pre-tests were necessary to discriminate the possible outputs of the vast area enclosed between the Cornappo stream, the Gorgons stream, the Podjama-Namlen stream and the Bianco stream-Natisone river. Only after the third pre-test were the outputs of the waters captured in the two main sinkhole are discovered, which correspond, the first to the spring below the Grotta sopra il Rio Boncic located in the left bank of the stream east of the open polje, the second to the spring below the Risorgiva Liskovac located on the right bank of the stream west of the open polje.

Keywords: Karst hydrogeology, Tracer test, Speleogenesis, Julian Prealps, Northeastern Italy.

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RIASSUNTO

Il Campo di Bonis nelle Prealpi Giulie è una depressione carsica di grandi dimensioni caratterizzata da un'idrografia superficiale affluente del Fiume Natisone e, contemporaneamente, un'idrografia interna alimentata da sorgenti che viene assorbita dal sottosuolo carsico in inghiottitoi. Geomorfologicamente questa depressione può essere classificata come un "polje aperto". Essa si sviluppa nel Flysch del Grivò (Paleocene sup.-Eocene inf.), un'alternanza di torbiditi silicoclastiche ibride intercalate da strati e megastrati carbonatici incarsiti. La particolarità del fenomeno e l'idrogeologia ipogea completamente sconosciuta, hanno indotto a progettare uno studio sulla circolazione delle acque sotterranee. Nell'area, tra gli anni 2018 e 2019, sono stati eseguiti tre pre-test di tracciamento, impiegando fluocaptori, allo scopo individuare preliminarmente i possibili output delle acque inghiottite nel Campo di Bonis. Sono stati usati due traccianti, uranina e Tinopal CBS-X, analizzando in fluorimetria campioni d'acqua e gli eluati estratti dai carboni attivi. I tre pre-test si sono resi necessari per discriminare l'ipotetica vasta area dei possibili output che era racchiusa tra il Torrente Cornappo, il Rio Gorgons, il Rio Podjama-Namlen e il Rio Bianco-Fiume Natisone. Soltanto dopo il terzo pre-test si sono scoperti gli output delle acque assorbite dai due principali inghiottitoi, che corrispondono, il primo alla sorgente sottostante la Grotta sopra il Rio Boncic situata in sinistra del torrente omonimo a est della polje aperto, il secondo alla sorgente sottostante la Risorgiva Liskovac situata in destra del torrente omonimo a ovest del polje aperto.

Parole chiave: Idrogeologia carsica, Test di tracciamento, Speleogenesi, Prealpi Giulie, Italia nord-orientale.

Introduction

The southern area of the Julian Prealps is characterized by Flysch dating from the Upper Cretaceous to the Middle Eocene. The Flysch del Grivò develops within this succession and is characterized by turbidites and carbonate strata or banks within which subterranean karst phenomena develop.

Fig. 1 – Geographical setting.

Campo di Bonis (Municipality of Taipana) is located in this area of the Flysch del Grivò and is a particular large karst depression with an internal hydrography coming from springs that is captured by sinkholes and suffosion dolines in the karstic horizons, and at the same time with a tributary hydrography of the Natisone river (Fig. 1). The underground hydrogeology of Campo Bonis is completely unknown and therefore we have planned a study of karst phenomena, in particular on groundwater through multi-tracer tests. We performed three pre-tracer tests in order to be able to preliminarily discriminate the possible outputs of water captured in the karst depression, considering that it is a vast area with karst springs present in the valleys that surround it, some used by aqueducts. Only with the third pre-test was it possible to identify the outputs of the karst system with relative certainty and therefore to be able to design a definitive tracer test.

The research was carried out by the Centro Ricerche Carsiche "C. Seppenhofer" (Gorizia, Italy) with equipment from the Laboratory for Speleology and Fluorometric Techniques (Farra d'Isonzo, Italy).

In this note only the synthetic and main results are presented since a future multi-tracer test is being planned, combined with physical-chemical monitoring, in order to obtain semi-quantitative data on karst hydrogeology. A conclusive multi-tracer test is currently being performed and interpreted, to be implemented using field instrumentation and laboratory analyses, combined with continuous monitoring of the physico-chemical parameters at the springs, in order to obtain more detailed hydrological data.

Campo di Bonis: An ancient polje

Fig. 2 – View of Campo di Bonis from NW to SE.

The Campo di Bonis is a large depression developed to SE-NW with irregular contour and axes of about 2 x 2 km and about 35,000 m^2 south of the Gran Monte chain, open on the SE edge by a narrow canyon due to the regressive erosion of the Boncic stream (Fig. 2). If not for this opening, probably morphologically recent, it would be a closed depression, where the sub-flat bottom, around 680 –690 m a.s.l., is karstic. The watershed that delimits the basin has the highest altitude at Mt Uorsig at SW, altitude 985 m a.s.l. The erosion threshold of the Boncic stream is at SE at about 675 m a.s.l. At 2 kilometers from this threshold the Boncic stream flows into the Bianco stream at 445 m a.s.l., the Bianco stream, after about 1 km, then flows into the Natisone river at altitude 415 m a.s.l.

FERUGLIO (1929), discussing the erosion of these pre-alpine valleys, hypothesizes that it was discontinuous and not uniform; in this regard he cites a phase of stasis corresponding to the terraces located between 300–400 meters above today's valley bottoms, including the Campo di Bonis, assuming a Pliocene age since the moraines and quaternary alluvium lower than by several hundred meters. MARINELLI (1897) cited, briefly, the Campo di Bonis as a "flat region" formed mainly by limestone strata of the Eocene, with small and funnel-shaped dolines. More generally, MARINELLI (1912) and BRAGATO & MARINELLI (1912) indicated the Campo di Bonis as attributable to the karst phenomena: a "plateau whose undulating surface is here and there sprinkled with karst sinkholes". Other authors hypothesize a possible ancient "glacial lake" (GHERDOL, 2010). Only recently, as a result of speleological research, has also been ascertained its endoreic function as a karst basin (TAVAGNUTTI, 2012a).

According to modern terminology (GRACIA *et al.*, 2003) Campo di Bonis can be defined as an “open polje”. However, the concept of open polje is not new, it had been previously introduced by BONACCI (1987) who distinguished “upstream-open polje”, “downstream-open polje” and “upstream and downstream-open polje”. In the case of Campo di Bonis the closed basin was captured to the SE by the regressive erosion of the Boncic stream, and for this reason defining it as an “open polje” is justified. The evidence of the capture is evident: i) the rapid lowering of the watershed on the SE front, ii) the steep and short escarpment that leads from the terrace to the stream, iii) the reverse “herringbone” hydrography tributary to the first part of the Boncic stream. The entire hydrographic pattern of the Boncic stream clearly reflects the tectonic elements conditioning of the area, as well as the open polje. The considerable difference between the maximum altitude of the ridge that surrounds it and that of the average altitude of the bottom, which is 300 meters, would, according to GAMS (2005), be an index of such processes, defining this type of basin as real cryptodepressions. The scarcity of eluvial-colluvial deposits (however, there are no glacial deposits) could instead be attributed precisely to its opening in correspondence with the SE slope, which would have drastically disfavoured the accumulation phenomena, having triggered the drainage into the Boncic stream. The opening of the endorheic Campo di Bonis basin, considering the knickpoint at an altitude of 675 m a.s.l. reflecting the different conditions and hydrographic processes evolution (BULL, 2007), is certainly the cause of a rapid lowering and rejuvenation of the local base level. The Boncic stream, which deepens rapidly, becoming a narrow and recessed gorge, has knickpoints connected to the variation of the lithologies, where the carbonate banks form waterfalls.

Perhaps these phenomena can be associated with the past activity of the Barcis-Staro Selo line, one of the most important south-vergent Neoalpine thrust in the Julian Prealps, which involves the magnetic basement probably causing its raising to a depth of about 7.9 km (CATI *et al.*, 1987). However, it is worth noting that, in the recent period, no evidence of seismogenic activity can be observed in correspondence to this thrust (POLI *et al.*, 2002). In this regard is should also be remembered that there is the lot evidence of neotectonic initially recognized, e.g. along the Nimis fault (CARTON *et al.*, 1978) south of the Campo di Bonis, today are also interpreted as selective erosions (BARTOLINI, 2004) (passive control exerted by the geologic structure on surface morphology).

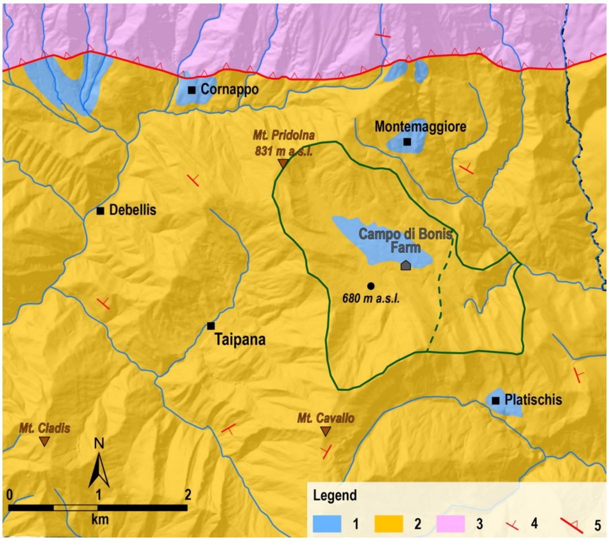

Fig. 3 – Simplified geological map of the area. Legend: 1 = Main Dolomite (Norian-Rhaetian), 2 = Flysch del Grivò (Thanetian-Ypresian p.p.), 3 = Cemented or incoherent Quaternary deposits, 4 = Dip and strike of strata (dip angle 10°- 45°), 5 = Thrust (Barcis-Staro Selo line). Solid and dashed green color line: present and ancient eroded watershed of Campo di Bonis hydrographic basin.

Geology and hydrogeology

The Campo di Bonis area is characterized, to the north, by the Gran Monte chain consisting mainly of the Main Dolomite (Norian-Rhaetian) overthrust the Flysch del Grivò (Thanetian-Ypresian p.p.) (Tunis & Venturini, 1987) along the E-W Barcis-Staro Selo line (Carulli, ed., 2006; Zanferrari, ed., 2013, Zanferrari *et al.*, eds., 2013). Along the Barcis-Staro Selo line the Main Dolomite present a large fractured and cataclastic band. In the open polje area the Flysch del Grivò is stratigraphically located at the top of the Flysch di Masarolis (Middle Paleocene) (Pirini *et al.*, 1986) and the Flysch di Calla (Lower-Middle Paleocene) (Tunis & Venturini, 1987; Ponton, 2008). In the Flysch del Grivò, also in the area, there are two carbonate megabeds, the Megabed of Mt Joanaz north of Campo di Bonis (Feruglio, 1925, 1929) (MS according to Feruglio) dated lower Ilerdian and the Megabed of Vernasso at south (Gnaccolini, 1968) (MS 11 according to Feruglio) dated lower Cuisian. The area is characterized not only by megabeds but also by siliciclastic, carbonate and hybrid turbidites, massive calcarenites and conglomerates. It is structurally complex, affected by important tectonic deformations, some reported up to the border of the same (Marchesini *et al.*, 2021) but which probably cross it. Quaternary deposits are generally thin (Mocchiutti, 2012) and of little interest for the purposes of this study.

We are carrying out a detailed geological survey since information on the area is very scarce, therefore we present only a simplified geological map (Fig. 3) where the two megabeds are not reported as they are simply included in the Flysch del Grivò lithologies.

From a hydrogeological point of view, siliciclastic turbidites are not very permeable, but only rarely constitute aquicludes, usually aquitards thanks to the intense fracturing, sometimes with very low karstification where the carbonate component is higher as in some sandstones (Mocchiutti & Maddaleni, 2005), while the thicknesses of laminated marls are saturated with water and can slowly give it up to the carbonate strata. Carbonate lithologies are always karstified. In these carbonate bodies a subterranean water circulation is established which can also give rise to impressive hypogean networks. The most significant karst macro-phenomenon of the area is the Campo di Bonis which is characterized by springs and sinkholes.

Objectives and methodology of the three pre-tracer tests

The three pre-tracer tests had the purpose of preliminarily discriminating the possible outputs of karst system. In consideration of the hypothetical short distance from the injection points to a possible output of the system corresponding to a karst cave-spring which supplies the Taipana village aqueduct (maximum within 1,800 meters), we have planned tests using very low quantities of tracer substances, i.e. uranine and Tinopal CBS-X, which in any case, from the preliminary calculations and estimates based on the input and output flow rates as well as taking into account the uncertainty of an experimental trace, could be reliable for instrumentally recognizing their eventual recovery.

The injection points, which correspond to the sinkholes [A] and [B], and the sampling points used during the three pre-tracer tests are in Fig 4. The sampling points identified with abbreviation, number and altitude m a.s.l. (Alt), are as follows. [CH-1] Cornappo stream Alt 442 m, [CM-2] Cornappo stream Alt 350 m, [GP-3] Gorgons/Bieli Patok stream Alt 380 m, [GS-4] Gorgon stream Alt 334 m, [LG-5] Liskovac stream before the Gorgons stream confluence Alt 400 m, [PN-6] Podjama/Namlen stream Alt 388 m, [NR-7] Natisone river Alt 384 m, [BF-8] Waterfall on the Boncic stream Alt 645 m; [BN-9]

Bianco stream at the Nero stream confluence Alt 417 m, [GL-10] Lower spring of Gorgons stream Alt 477 m, [GH-11] High spring of Gorgons stream Alt 495 m, [LS-12] Spring of Risorgiva Liskovaz Alt 570, [BS-13] Spring of Boncic stream Alt 669 m, [CB-14] Spring of Grotta sopra il Rio Boncic Alt 664 m, [LT-15] Liskovac upstream of Taipana Alt 508 m, [BB-16] Boncic stream at the Bianco stream confluence Alt 445 m, [BW-17] Bianco upstream of the Boncic stream confluence Alt 443 m, [SW-18] Spring in right bank of Bianco stream Alt 446 m, [SP-19] High Podjama/Namlen stream Alt 625 m.

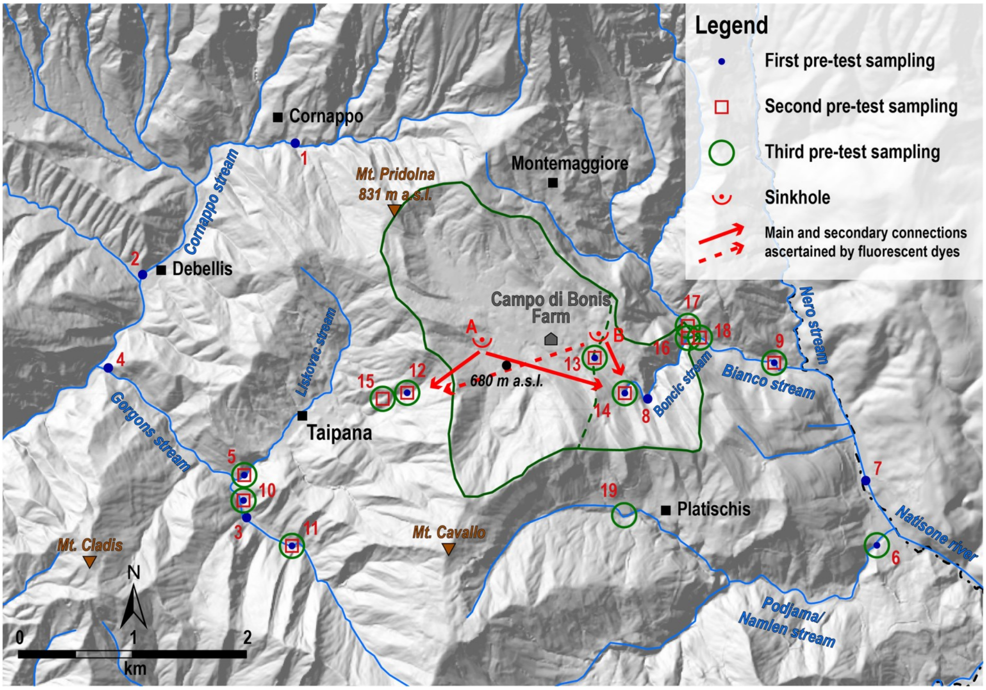

Fig. 4 – Control points in pre-tracer tests (see abbreviations/numbers in the text). Fluorescent dyes injection points A and B (description in the text). Solid and dashed green color line: present and ancient eroded watershed of Campo di Bonis hydrographic basin.

Since these were preliminary tracer tests, the technique of charcoal bags alone was opted for. The analyzes were performed in fluorometry with a GGUN-FL24 instrument (Geomagnetic Group Université de Neuchâtel / Albillia Co.). The extraction of the eluates from the activated charcoal dye receptors was performed according to a standard methodology developed by the Laboratory for Speleology and Fluorometric Techniques. First pre-tracer test "blank" charcoals were not sampled, while they were sampled from second and third pre-tracer tests. Interesting is the comparison between the "blank" eluates (B) at 83 days (third pre-test) and 32 days (second pre-test) in the springs [GL-10, GH-11, LS-12, BS-13, CB-14, SW-18] (Figs. 5 and 6), knowing that there is always a natural background in the water and the detention limits are much higher than those of fluorescent dyes. It has been experimentally proven that natural waters frequently carry, albeit in modest concentrations, organic and inorganic substances (chlorophyll, etc.) which can be fixed by activated carbon and also interfere with the subsequent fluorometric analysis. Even with charcoals immersed in different hydrological conditions, a higher background (accumulation) is almost always observed for the charcoals immersed for the longest period both for uranine and for Tinopal CBS-X. This was considered in the data interpretation.

For uranine B-83 we have respectively average (M_a) 2.11 and median (μe) 2.21 while for B-32 M_a 1.51 and μe 1.17, for Tinopal CBS-X B-83 we have respectively M_a 4.98 and μe 5.5, while for B-32 M_a 3.91 and μe 4.15.

The two injected fluorescent dyes are widely used in tracer tests without creating toxicological problems (Behrens *et al.*, 2001, Gombert *et al.*, 2017). From a technical point of view, Tinopal CBS-X has greater problems of use than uranine (Licha *et al.*, 2013). The methodology of use of the three tracers, adopted in the present multi-tracer tests, has been widely tested (Schudel *et al.*, 2002; Benischke *et al.*, 2007; Goldscheider & Drew, 2007; Benischke, 2021) and allows good operation and reliability some data.

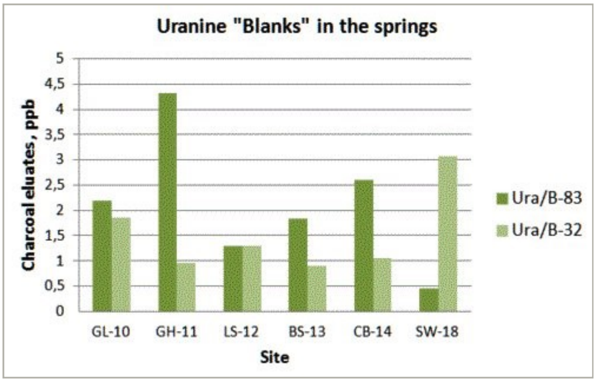

Fig. 5 – Histogram of uranine "blanks" eluates concentrations in the charcoals immersed in water in the third pre-tracer tests and second pre-tracer test for 83 and 32 days respectively [Ura/B-83] [Ura/B-32].

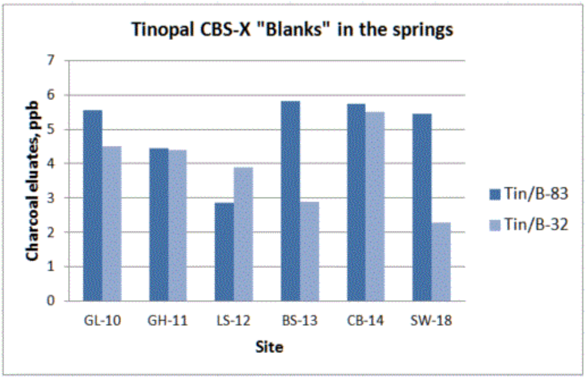

Fig. 6 – Histogram of Tinopal CBS-X "blanks" eluates concentrations in the charcoals immersed in water in the third pre-tracer tests and second pre-tracer test for 83 and 32 days respectively [Tin/B-83] [Tin/B-32].

First pre-tracer test

The first pre-tracer test was performed by simultaneously and premixed injecting 50 g of uranine and 150 g of Tinopal CBS-X into sinkhole [A] of Campo di Bonis, on March 9, 2018, which received a flow rate of 4 L/s. The bottom of the open polje still had large patches of snow. Said sinkhole is located in the central part of the Campo di Bonis at altitude 684 m a.s.l. (A in Fig. 4). Only the technique of charcoal bags was adopted, which were placed in duplicate (one of which to be recovered only at the time of the last withdrawal). The charcoal bags were installed in 14 sites between watercourses sections and springs, shown in Fig. 4. [CH-1] Cornappo stream, [CM-2] Cornappo stream, [GP-3] Gorgons/Bieli Patok stream, GS-[4] Gorgon stream, [LG-5] Liskovac stream before the Gorgons stream confluence, [PN-6] Podjama/Namlen stream, [NR-7] Natisone river, [BF-8] Waterfall on the Boncic stream, [BN-9] Bianco stream at the Nero stream confluence, [GL -10] Lower spring of Gorgons stream, [GH-11] High spring of Gorgons stream, [LS-12] Spring of Risorgiva Liskovaz, [BS-13] Spring of Boncic stream, [CB-14] Spring of Grotta sopra il Rio Boncic. Dates of installation, withdrawals and relative replacement of char-

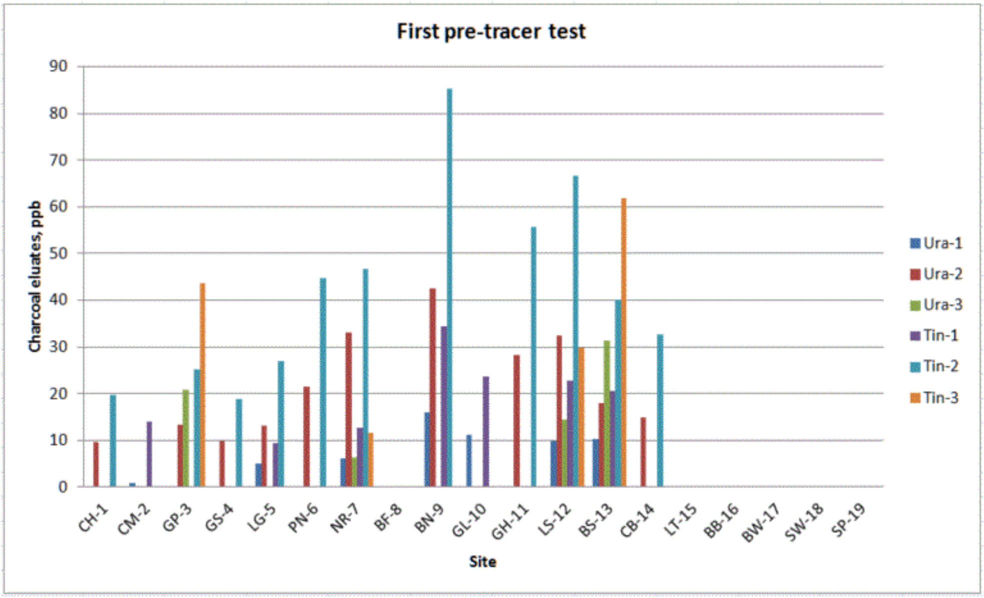

Fig. 7 – First pre-tracer test. Histograms of the concentrations of uranine and Tinopal CBS-X in the samplings performed (charcoals). No charcoal "blanks" were sampled. Missing histograms correspond to failed samples. Abbreviations, numbers and altitude of the control points are described in the text and in Fig 4.

coal bags, as follows. First installation in duplicate March 9, 2018, before injection. Subsequently, March 23, April 6, with charcoal bags in duplicate, for a total of 28 control days, and therefore for analytical purposes two time periods (1 and 2) each of 14 days and one, total (3) of 28 days. This first pre-tracer test was characterized by a period of intense and prolonged precipitations, almost 200 mm of rain at the Faedis weather station (158 m a.s.l.) located at the foot of the hilly area, but much more estimated at higher altitudes, such as those of Campo di Bonis, also causing snowfall and subsequent snowmelt. In fact, 416 mm of rain fell during the period at the reference of Musi weather station, 600 m a.s.l., quite representative given the altitude, located beyond the Gran Monte; in particular, rainfall of 165.2 mm was recorded on days 11-12 March 2018, 60.2 mm on days 15-16 March 2018, 127.8 mm on days 28-30-31 March 2018. Despite the precautions adopted some charcoal bags have been lost.

The fluorometric analysis of the eluates extracted from the charcoals (Fig. 7), for uranine (U_c) and Tinopal CBS-X (T_c), provided significant values for the [BS-13] Spring of Boncic stream with U_c(1) 10, 3 ppb, U_c(2) 18.0 ppb, U_c(3)31.3 ppb, T_c(1) 20.6 ppb T_c(2) 40.1 ppb, T_c(3) 61.8 ppb, for the [CB-14] Spring of Grotta sopra il Rio Boncic with U_c(2) 15.0 ppb, T_c(2) 32.6 ppb. Other significant values were found at the [BN-9] Bianco stream at the Nero stream confluence and from the [LS-12] Spring of the Risorgiva Liskovac with U_c(1)1 9.9 ppb, U_c(2) 32.5 ppb, U_c(3) 14.4 ppb, T_c(1) 22.8 ppb, T_c(2) 66.6 ppb, T_c(3) 28.9 ppb. Lower values are found at the [LG-5] Liskovac stream before the Gorgons stream confluence. The [GH-11] High spring of Gorgons stream provided doubtful values, while values of greater interest are at the [GL-10] Lower spring of the Gorgons stream. All the waters that affected the Cornappo stream gave negative results. In conclusion, from this first pre-tracer test there were possible outputs in the Boncic and Liskovac streams, taking into account the values of relative interest at the Bianco stream and the lower course of the Liskovac stream.

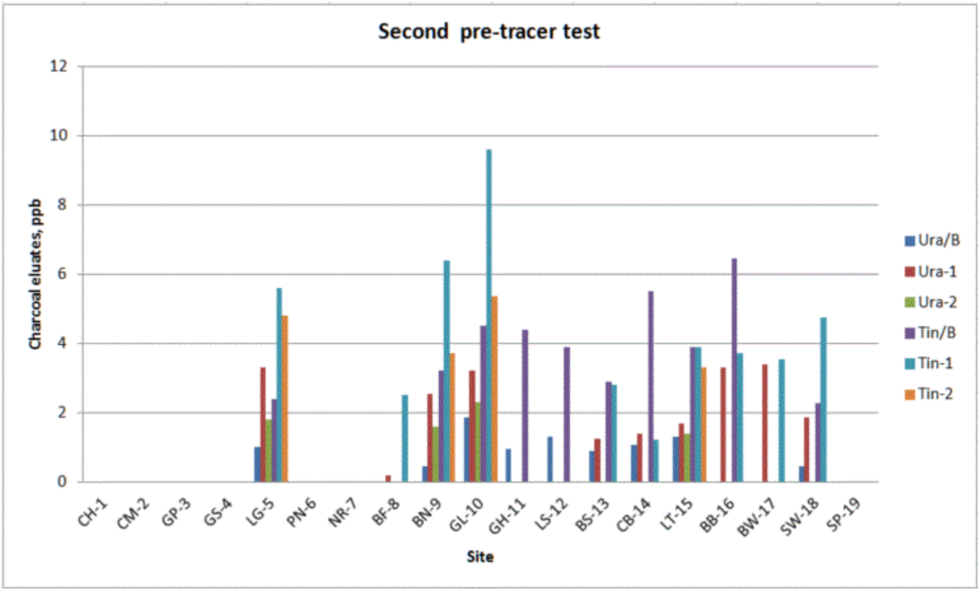

Fig. 8 – Second pre-tracer test. Histograms of the concentrations of uranine and Tinopal CBS-X in the samplings performed (charcoals). Missing histograms correspond to failed samples. Abbreviations, numbers and altitude of the control points are described in the text and in Fig 4.

Second pre-tracer test

The second pre-tracer test was performed by injecting, on February 9, 2019, 150 g of Tinopal CBS-X into the sinkhole [A] of the Campo di Bonis and 75 g of uranine into the sinkhole [B] of the Campo of Bonis (A and B in Fig. 4), premixed; the hydrography had very low flow rates. The sinkhole [B] is located in the south-eastern part of Campo di Bonis, in the transition area with the Boncic stream at 665 m a.s.l. Only the technique of charcoal bags was adopted, which were installed in duplicate (one of which to be recovered only at the last sampling). "Blank" charcoal bags were taken from each site and installed on December 4, 2018; this time for a period of 32 days of immersion (Ura/B, Tin/B). The charcoal bags have been installed in 11 sites, of which the previous ones [LG-5], [BN-9], [GL-10], [GH-11], [LS-12], [BS-13], [14], and the new sites (Fig. 4) [LT-15] Liskovac upstream of Taipana, [BB-16] Boncic stream at the Bianco stream confluence, [BW-17] Bianco upstream of the Boncic stream confluence, [SW-18] Spring in right bank of Bianco stream. Dates for installation, withdrawals and relative replacement of charcoal bags, as follows. First installation, February 8, 2019, before injection (Ura-1, Tin-1); subsequently: February 22, 2019 (Ura/2, Tin-2), for a total of 15 control days for analytical purposes. In the period, 54.8 mm of rain fell on the days 10-11 February 2019 (Musi weather station), and it was characterized by severe low water.

All charcoal bags have been recovered. We have a complete set of blanks for the period, except for site [BW-17]. For series (1) a complete sampling is available. For series

(2) sampling only for sites [LG-5], [GL-10], [GH-11], [LS-12], [LT-15]. The fluorometric analysis of the eluates extracted from the charcoals (Fig. 8), for uranine (U_c) and Tinopal CBS-X (T_c), provided values of interest only at the [GL-10] Lower spring of Gorgons stream with U_c 2.30 ppb and T_c 5.35 ppb and the [SW-18] Spring in right bank of Bianco stream with U_c 1.85 ppb and T_c 4.75 ppb. The test undoubtedly suffered from the severely dry period and it was estimated that a lowering, even differentiated, of the water table in the aquifers could have led to the temporary abandonment of the higher altitude water circuits outlined, albeit in the first hypothesis, during the first pre-tracer test, in favor of a migration of the water circuits towards outputs with lower altitudes.

Third pre-tracer test

Based on the results of the two pre-tracer tests presented, a third pre-tracer test was

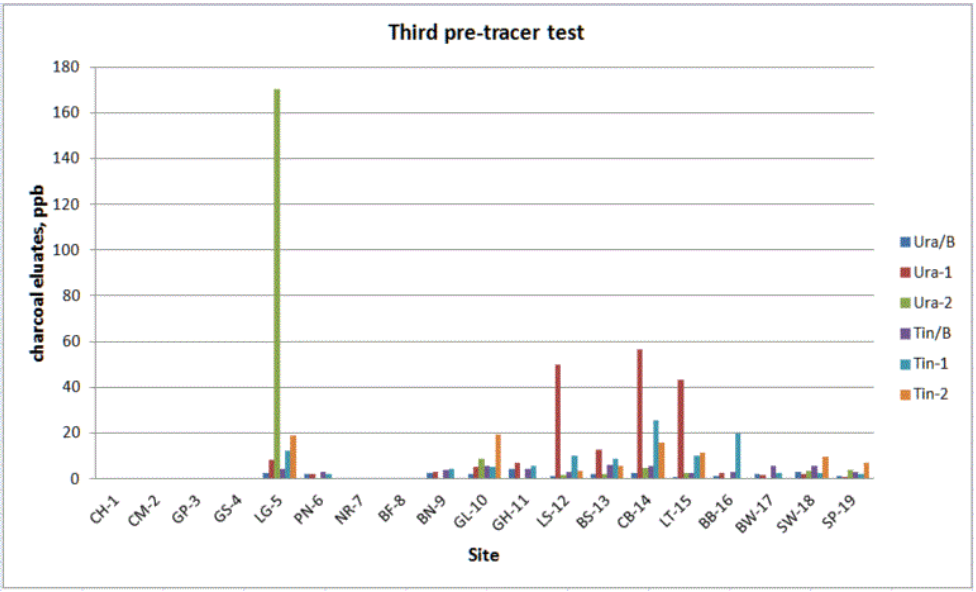

Fig. 9 – Third pre-tracer test. Histograms of the concentrations of uranine and Tinopal CBS-X in the samplings performed (charcoals). Missing histograms correspond to failed samples. Abbreviations, numbers and altitude of the control points are described in the text and in Fig 4.

planned. This test was carried out by injecting, on October 27, 2019, 300 g of uranine in the sinkhole [A] of the Campo di Bonis and 1,000 g of Tinopal CBS-X in the sinkhole [B] of the Campo di Bonis, premixed. Also in this test the technique of only charcoal bags was used. Previously, charcoal bags for the “blanks” (Ura/B, Tin/B) were installed on August 4, and on October 26, 2019, these were collected and replaced. The charcoal bags have been installed in duplicate for greater safety, one of which to be replaced at the next collection and the other with the last collection. November 1, 2019: Collection of charcoal bags and their replacement, November 23, 2019: Collection of charcoal bags. After the injection of the fluorescent dyes, the first series of charcoal bags (1) remained immersed for 5 days, the second series (2) for 22 days. The charcoal bags were installed in 12 sites

(Fig. 4), of which the previous [LG-5], [PN-6], [BN-9], [GH-11], [LS-12], [BS-13], [CB-14], [LT-15], [BB-16], [BW-17], [SW-18], and the new site [SP-19] High Podjama/ Namlen stream. During the period, after the injection of the two fluorescent dyes, initially there was little rain (Musi weather station), 8.4 mm from days 28 to 31 October 2019; while from days 2 to 23 November 2019 a total of 931.1 mm of rain fell almost without interruption. It follows that the first series of charcoal bags (1) was affected by flows practically in a regime not influenced by precipitation while the second series (2) was affected by a regime strongly influenced by precipitation.

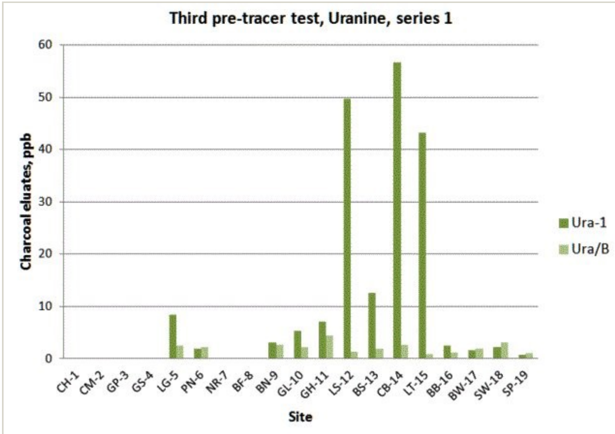

Fig. 10 – Third pre-tracer test. Uranine, comparison between sampling series no. 1 and the "blanks" (charcoals).

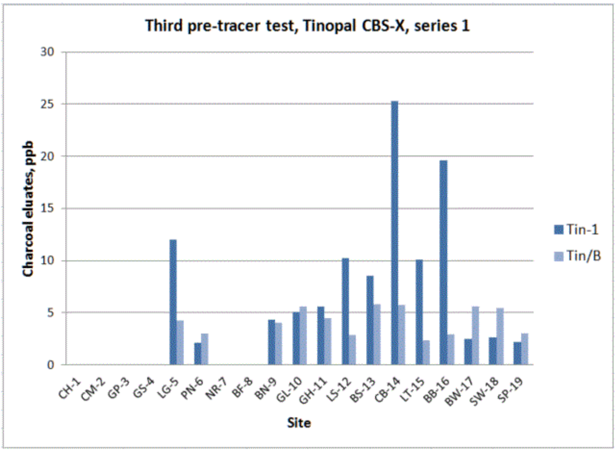

Fig. 11 – Third pre-tracer test. Tinopal CBS-X, comparison between sampling series no. 1 and the "blanks" (charcoals).

The fluorometric analysis of the eluates extracted from the activated charcoal dye receptors, for uranine (U_c) and Tinopal CBS-X (T_c), was congruent with the hydrological situation in which the test was carried out (Fig. 9). Indeed, the entire month of October was characterized by very low rainfall, for a monthly total of 232.2 mm. From the fluorometric analyzes it appears that the sampling cycle significantly traced corresponds to the short-term cycle (1) and incontrovertibly two main outputs have been identified. The uranine (Fig. 10) injected into the sinkhole [A] of Campo di Bonis is distributed, with similar concentrations, between the [LS-12] Spring of Risorgiva Liskovac with U_c 49.7 ppb and the [CB-14] Spring of the Grotta sopra il Rio Boncic with U_c 56.7 ppb, with apparent distances of 750 m and 1,000 m, respectively. The Tinopal CBS-X (Fig. 11) injected into the sinkhole [B] of Campo di Bonis is distributed mainly between the Spring of the [CB-14] Grotta sopra il Rio Boncic with T_c 25.3 ppb of Tinopal CBS-X and in a minor way in the [LS-12] Spring of Risorgiva Liskovac with T_c 10.2 ppb of Tinopal CBS-X, respectively with apparent distances of 550 m and 1,650 m. For the two cave-springs traced the values of the concentrations, both for uranine and for Tinopal CBS-X are congruent in the downstream samplings in the short period (1). For uranine there are interesting values in the Liskovac stream [LT-15 and LG-5] and also in the springs of Gorgons stream [GL-10 and GH-11]. For Tinopal CBS-X there are interesting values in the Boncic stream system [BS-13 and BB-16] and also traces in the Liskovac stream system [LG-5]. The fluorometric analysis of the charcoals involved in the second sampling cycle (2) would lead us to consider that the flows traced were "exhausted" within 5-6 days of the injecting, reasonably assuming rapid subterranean pathflows. In the longer period (2) one could hypothesize unknown springs in the Liskovac stream, given that high concentrations of uranine (170.23 ppb) (Fig. 12) have been measured at its outlet, point [LG-5], while upstream, both at the [LS-12] Liskovac spring and of the subsequent downstream near Taipana, point [LT-15], the concentration values were strongly attenuated (1.45 ppb and 2.68 ppb), almost comparable to those of the "blanks". Longer term (2) for Tinopal CBS-X there (Fig. 13) are traces in the Boncic/Bianco streams system [SW-18] and in the Liskovac/Gorgons streams system [LG-5 and GL -10]. Compared to the "blanks", the value of U_c 12.5 ppb and T_c 8.5 ppb at the Spring of Boncic stream [BS-13] over the short period (1) is interesting, which could indicate how this spring was affected by the flow traced in particular by uranine. This without considering the very strong dilution of the two fluorescent dyes due to the huge discharge caused by the November rainy period.

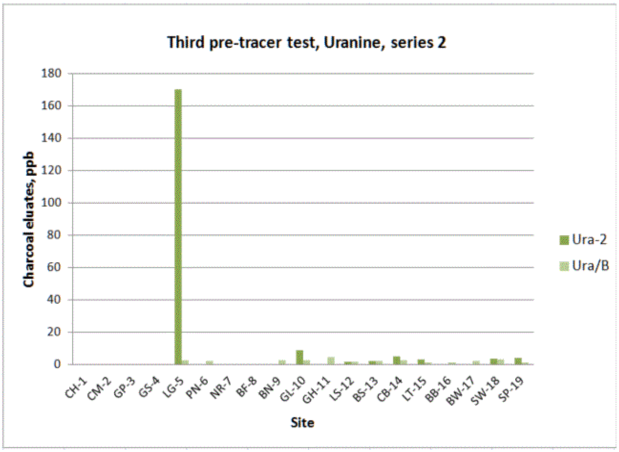

Fig. 12 – Third pre-tracer test. Uranine, comparison between sampling series no. 2 and the "blanks" (charcoals).

Discussion

The three pre-tracer tests involved checking a total of 19 sites. The analyzes on the eluates extracted from the activated charcoal dye receptors provide relative concentration data which are well comparable with the single sampled series since they are charcoals with a homogeneous immersion time in water but different adsorption where they are in contact with waters traced by different fluorescent dyes for different periods and concentrations in the time frame of the same series.

The fundamental data that result from these three pre-tracer tests is the diffluence of the waters that disappear in two of the major sinkholes [A] and [B] of Campo di Bonis and, for both, towards two different outputs which are represented by two hydrologically active caves (Tavagnutti, 2012b), the Risorgiva Liscovaz (5312/2949FR) [see LS-12] and the Grotta sopra il Rio Boncic (4603/2604FR) [see CB-14] where in both cases there is a spring immediately below the respective entrances. The two caves are represented by galleries largely genetically of the phreatic type (Fig. 14), with internal siphons (including hanging ones), which developed in correspondence with a carbonate bank and, at the state of knowledge, no exposed confinements of marly-arenaceous lithologies are known inside

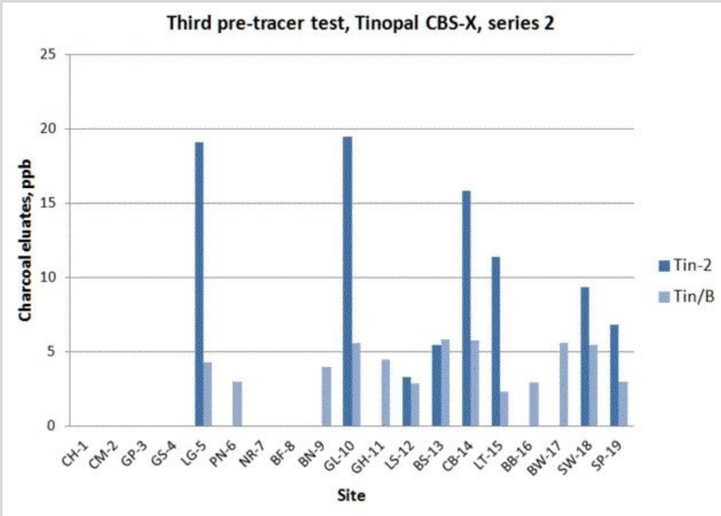

Fig. 13 – Third pre-tracer test. Tinopal CBS-X, comparison between sampling series no. 2 and the "blanks" (charcoals).

them. Their springsheds are assumed to be of no great extent. Generally, the [CB-14] Spring of the Grotta sopra il Rio Boncic has a flow rate about 1/3 lower than that of the [LS-12] Spring of the Risorgiva Liskovac. The two springs showed in periods of lower and medium discharge rates between 4 L/s and 15 L/s. The [BS-13] Spring of Boncic stream has a lower and medium flow rate between 3–4 L/s and 10–15 L/s while with flood flows they have been estimated up to about 30–40 L/s.

Chemical analyzes were carried out on the waters of the Campo di Bonis springs and the Risorgiva Liskovac (Comar, 2012; Valentinuz, 2018), while for the waters of the Grotta sopra il Rio Boncic there are no chemical data. From the comparison between the springs waters (*Sw*) and those of the Liskovac cave (*Lc*), different average values are observed, respectively, between the first and second, of Ca^{++} (*Sw*) 61–64 mg/L and (*Lc*) 52.7 mg/L,

Fig. 14 – Grotta sopra il Rio Boncic. It is formed by phreatic conduits, even doubled on the same joint, emerged by lowering of the water table, set on low-angle fractures which crossing a conglomerate and calciruditic-calcarenitic bank, below, a large rhombic network of tension fractures with sparry calcite created by differential corrosion.

Fig. 15 – Example of hypogean karstification in the Flysch del Grivò outcrop exhumed by erosion (Bianco stream). Carbonate strata (top) with pelitic-arenaceous levels at the bottom. The bed of the carbonate strata is affected by a dense network of planar and vertical karst channels developed in phreatic zone.

Mg^{++} (*Sw*) 2.7–3.6 mg/L and (*Lc*) 2.1 mg/L, SiO_2 (*Sw*) 4.9–6 mg/L and (*Lc*) 3.3–4.2 mg/L, HCO_3^- (*Sw*) 180–206 mg/L and (*Lc*) 163–177 mg/L, EC K_{25} (*Sw*) 228–259 µS/cm and (*Lc*) 208–248 µS/cm, suggesting inhomogeneity of the aquifers.

At present, in this area of the Flysch del Grivò the organization of the drainage network within the strata and carbonate banks is poorly known, and has only just begun to be understood with these preliminary studies. In some cases, a diffused water circulation developed in karst phreatic conditions can be observed. In other cases, inputs from dolines and sinkholes would form real karst conduits. In still others, in vadose conditions and when a sufficient hydraulic gradient has been reached with the deepening of the valleys, erosion of the proto-conduit in the carbonate strata can start up to the top of the lower marly-arenaceous strata and continue in depth (usually on plurimetric fractures with high persistence) reaching the carbonate layer at the bottom. The latter case, however, is a situation observed in the area only on outcrops exposed by torrential erosion and also on a small scale (not yet in caves) (Fig. 15). It is a partially known type of speleogenesis (Comar, 1998), with different aspects, mainly of a mechanics-erosive type. The numerous phenomena, ascertained, of plurimetric fractures with high persistence that normally intercept aquitard/aquiclude strata (hybrid siliciclastic turbidites) and aquiferous strata (carbonate) – i.e. multilayer structures important for connectivity (Gross & Eyal, 2007) – where small phreatic conduits, could also suggest, in the 3D distribution of soluble rocks, that in the past there have been recharge flows from the underlying layers, determining a speleogenesis, hitherto never suspected, of hypogenic origin sensu Klimchouk (2013) in confined conditions. Sometimes, on the other hand, there are tectonic contacts between the aquifers, which elide the interposed aquitards/aquicludes, which allow the network of karst conduits to redirect themselves.

The high persistence plurimetric fractures, which would constitute a connection network between aquitard/aquiclude and aquifer strata, sometimes show feeble dissolution

Fig. 16 – Example of high persistence plurimetric fractures constitute a connection network between aquitard/aquiclude and aquifer strata (marly-arenaceous layers and prevailing calcarenitic bank) where it is possible to observe dissolution phenomena (Bianco stream).

phenomena in correspondence of sandstone layers when crossing the siliciclastic turbidites (Fig. 16). According to traditional terminology, these would be pseudokarst phenomena, but in a recent debate of the term its use is preferred to morphologies rather than processes (Bella *et al.*, 2022). The term "pseudokarst" was used for the first time by Knebel (1906) and, currently, it assumes more of a practical meaning than a strictly scientific one, therefore, although it is a term considered "indefinite" it is simply convenient to be used in karst areas like this in study.

Recent geochemical and thin-section studies of siliciclastic rocks suggest that micas and iron around quartz grains may favor grain disintegration and subsequent removal by erosion (Fabri *et al.*, 2022). The Flysch del Grivò in the "Julian basin Flysch" is characterized by high percentages of SiO_2 (48.35 –58.79%), FeO (1.22–2.43%) as well as CaO ranging between 20.67–23.31% (De Min *et al.*, 2014), which suggest possible moderate solution and removal phenomena within fractures penetrated by aggressive groundwater. A congruent scenario characterizes the sandy and pelitic sediments in the caves of the Taipana area (Cancian, 2008; Cancian & Princivalle, 2008), originating from weathering and erosion of the Flysch del Grivò rocks, characterized by quartz and phyllosilicates (illite/muscovite) and some abundance of granules of heavy minerals such as limonite and goethite and secondarily hematite and limonitized pyrite.

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