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Tracer Test in the Vadose Zone of the Trebiciano Abyss near an Uncontrolled Landfill (the Karst of Trieste)*

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Abstract

The present study concerns the results of a tracer test in the vadose zone of the Trebiciano Abyss in the Karst of Trieste, at the bottom of which the Timavo underground river flows. Two tracers were used: Uranine and Tinopal CBS-X, separately introduced in two dolines above the abyss, through artificial spills of water, simulating heavy rainy events.

Inside the abyss, 350 m deep, four points were equipped in order to control and capture the percolation waters (S1, S2, S3, and S4), at different depths, where drainage is normally present. At each point daily sampling and flow measurements were carried out, at S2 at -250 m a fluorometer probe was also installed, to record the two tracers continuously. Refraction seismic survey characterized the epikarst, The Uranine was found at point S3 the same day as its injection, subsequently at point S2 (fluorometer probe recording). Tinopal CBS-X was found at point S2 the same day as its injection.

The tracing test also proved, unmistakably, that in just a few hours, after a strong rainfall or an accidental spill the release of pollutants on the karst surface, infiltrating underground, is transferred further than 300 m of depth, flowing directly in the base flow with no chance of being stopped.

Key Words: Karst Hydrogeology, Vadose waters, Tracer test, Uranine, Tinopal CBS-X, Trebiciano Abyss, Karst of Trieste, NE-Italy.

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1. Introduction

Within a programme of hydrogeological study on percolation waters of the Trebiciano Abyss on the Trieste Karst (Fig. 1) two dolines of the area were artificially traced in order to understand the drainage modalities of the vadose waters that flow in depth.

The test aimed at reconstructing a water flow model in a classic unsaturated karst area, draining towards a large aquifer showing high vulnerability. Very near the Trebiciano Abyss is the ex landfill of Trieste. This landfill, with no protection, was used from 1956 to 1972 and it is made up of 450,000 tons of material deposited on a surface of 120,000 m^2 of highly karstified limestones. Up to now the landfill has not been made safe. The test was projected to simulate the effect of a heavy rainy event, which in the area has a return period of four years, enabling to reproduce a theoretical case of drainage with pollutant release.

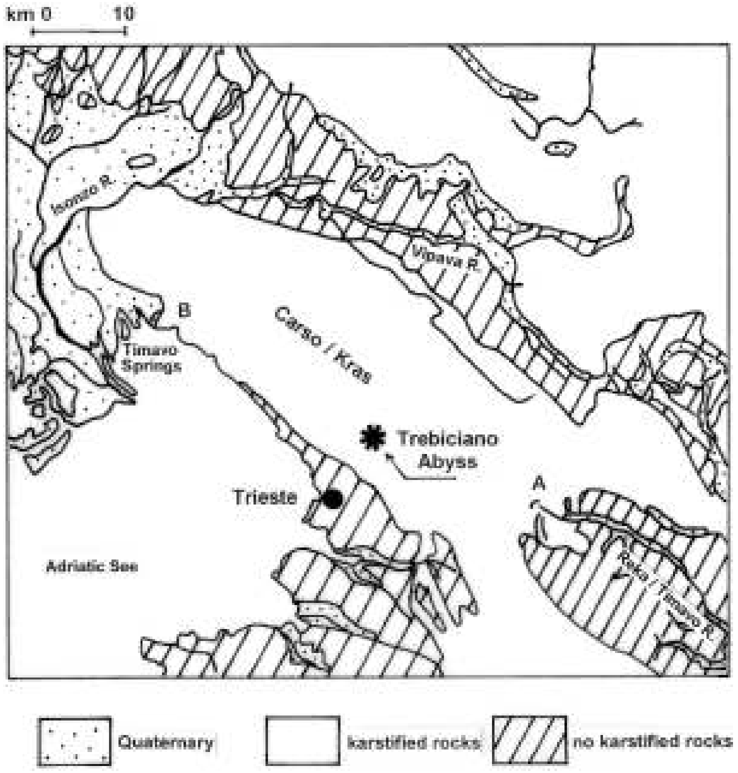

Fig. 1. Location map.

2. Hydrogeology in the Vadose Zone of the Trebiciano Abyss

The Trebiciano Abyss VG 17 opens on the Karst, on the side of a doline, at a height of 341 m a.s.l., in a highly karstified area having a high density of dolines (Fig. 2 and 3). The abyss, conditioned by lithologies and by the structural setting, develops in a sequence of carbonate rocks of the upper Cretaceous: from the entrance to the depth of about 185 m in limestone, then to the maximum depth in dolomitic rocks (Forti et al., 1979). At the depth of about 270 meters the systems of pits that characterize the abyss open onto the huge “Lindner Cavern”, on the bottom of which the underground Timavo river flows at an average height of 12-14 m a.s.l., in galleries under the sea level. The present depth reached in the abyss is of 350 m at -9 m a.s.l.

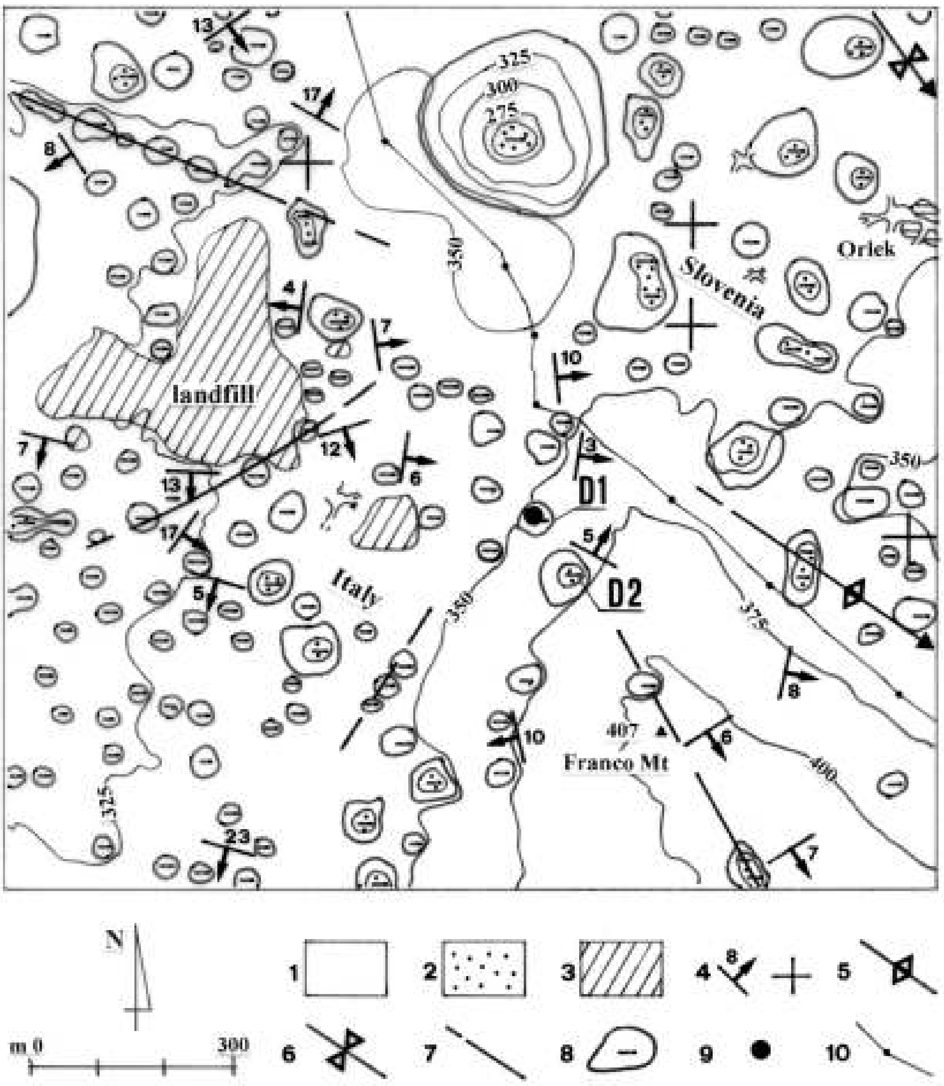

Fig. 2. Geological and geomorphological map of the Trebiciano Abyss area (by Jurkovšek et al. 1996 and Ballarin & Semeraro 1997, modified). 1: limestones; 2: “terra rossa” (red soil); 3: landfill; 4: strata; 5: anticline; 6: syncline; 7: fault; 8: dolina; 9: entrance of the Trebiciano Abyss; 10: border Italy-Slovenia.

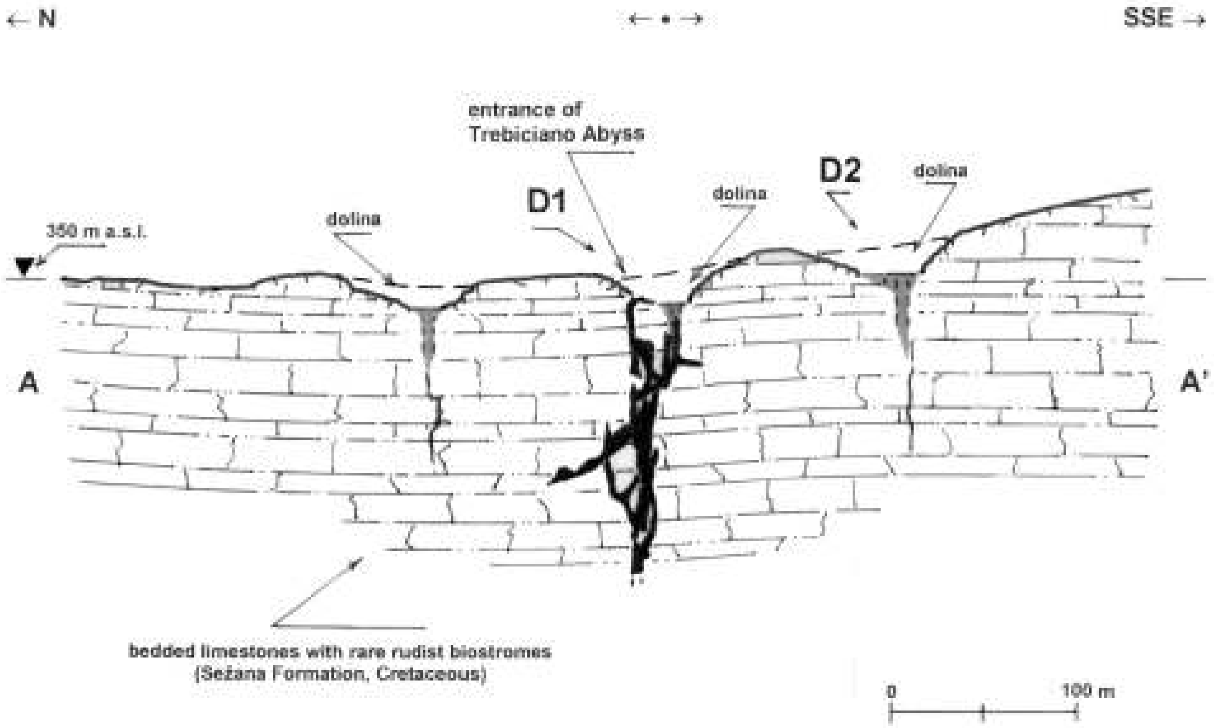

Fig. 3. Geological and seismic section (X-X') crossing the dolines [D1] and [D2]. The bottom of [Vp2] is the marker of epikarst.

The karstic hydrostructure of the vadose zone of the area is characterized by systems of pits, sometimes supposed to be near, that in depth collect the waters infiltrated through the surface, discharging them in the galleries and caverns in the epiphreatic area. This remarkable water activity along some pits of the deepest area of the Trebiciano Abyss has been already underlined (De Martini and Maucci, 1952; Crevatin and Dambrosi, 1977; Forti et al., 1979; Volpe, 1992). During the above-mentioned study programme, it was measured or estimated (Merlak et al., 2006) that some of these percolations, during heavy flow, can reach a flow of some L/sec. Then it is important to consider, though independent of the surface, the remarkable films of condensed water that develop inside the abyss especially in the period when it is crossed by big air volumes in temperature and hygroscopic unbalance with the walls. According to Volpe (1992), also the role of frost, dependant upon the outside meteoric conditions, should be considered. In the abyss the biggest known drainages of percolating water are placed in: pit at about -250 m ("waterfall pit"), in the pit of "the old path" that flows out at the roof of the "Lindner Cavern", then at least four drainages flowing from the roof of the "Lindner Cavern", of the "Timeus Lake" and of "Boegan Lake". Remarkably different hydrodynamic conditions characterize the dripping from concretions. Some of them, like those in the "fossil gallery" at -100 m, due to the regulatory reservoirs stored by the epikarst, have a flow higher than the above-mentioned big percolations in dry periods.

3. The Epikarst and the Drainage of Meteoric Water in the Vadose Zone

The epikarst is an enormous store of meteoric waters (Drogue, 1980; Williams, 1983, 1985; Bonacci, 1987; Klimchouk, 1995; Ford and Williams, 1996). During dry periods it discharges the waters stored and it can also release them very quickly during surplus due to a simple hydrostatic pressure.

In the epikarst remarkable corrosion phenomena occur. This fact is also due to the presence of soils, in fact an important quantity of dissolved solids (TDS) of infiltration waters that can be observed again in depth seems to derive from the activity of this area. Moreover, due to its characteristics, the epikarst is a privileged area for the origin of dolines and of drainage pits.

As for the Trieste Karst, on the basis of the numerous geophysical surveys (electrical, radar and especially seismic refraction surveys), suitable for an easy definition of micro-zones**,** carried out by Geokarst Engineering srl, it is possible to sum up the following situation. The thickness of the epikarst varies according to lithologies, but it usually consists of 1-5 m of "aerated" corresponding to the 1st seismic layer having [Vp_1] (seismic wave speed P) generally between 0.6-0.8 km/s, maximum 1 km/s; then a layer up to 5-10 m of a rock still full of open and karstified joints, that means that it is still affected by surface phenomena, corresponding to the 2nd seismic layer having [Vp_2] generally between 1 and 2.5-2.8 km/s, maximum 3 km/s. Then it is possible to observe the compact rock corresponding to the 3rd seismic layer, that is the marker of the bottom of the epikarst, generally having [Vp_3] between 3 and 4.5 km/s, maximum 5.5 km/s. In this scheme are numerous local variables, among them three are essential: a) sometime in very compact limestones stratified in thick layers, or massifs, the 1st and the 2nd seismic layers are undifferentiated and therefore replaced by a layer of rock that can reach 7-10 m generally having characteristics [Vp_2] b) in highly karstified limestones the aerated can reach 6-8 m of depth thanks to the big hanging joints that delimit big rock blocks; c) in massive stratified and jointed limestones the 1st seismic layer is usually thin and has low [Vp_1]. It is interesting to observe that [Vp_1] at about 0.5 km/s, or lower, characterize by broke up rock (or it can be subsoil), full of many pockets and joints full of red soil, whereas lower seismic speeds are peculiar to surface red soils. In correspondence with the dolines the stripe of the 1st and 2nd seismic layer deepens following the sinkhole. Many pits near the surface develop from master joints that drain a portion of the epikarst, or they correspond to the underground area of the dolines.

In order to understand the characteristics of the epikarst around the Trebiciano Abyss a series of refraction seismic surveys were carried out, by reconstructing a section crossing the dolines used for the tracer injection (Fig. 4).

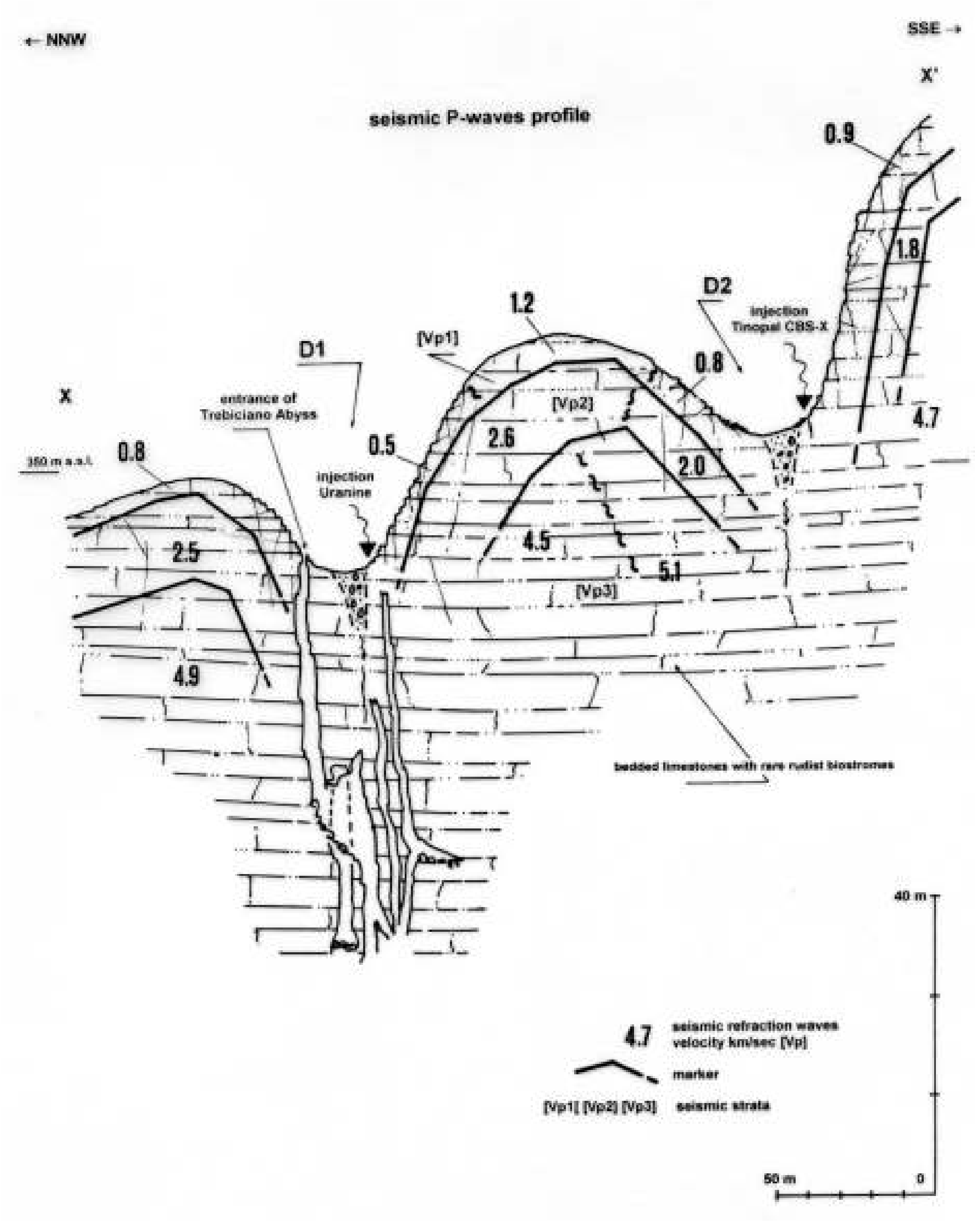

Fig. 4. Geological and seismic section (X-X') crossing the dolines [D1] and [D2]. The bottom of [Vp2] is the marker of epikarst. Trace in fig. 5.

The epikarst is made up of compact grey limestones with layers of a few decimeter, sometimes in layers of over one meter, showing well-spaced joints. Thus, there are: a 1st seismic layer whose thickness ranges from 1.50 to 4.80 m and [Vp_1] from 0.5 to 1 km/s (on the average 0.8-0.9 km/s); a 2nd seismic layer whose thickness ranges from 6 to 11 m and [Vp_2] from 1.8 to 2.6 km/s; and a 3rd seismic layer ("infinite") whose [Vp_3] ranges from 4.7 to 5.1 km/s and whose high seismic speeds are due to the compactness of these limestones. The epikarst reaches the top of the 3rd seismic layer and therefore it shows an average thickness from 7 to 14 m according to the geomorphological conditions, deepening near the slopes of the dolines.

The drainage of the water collected from the epikarst and from dolines in the underground, inside the vadose area crossed by karst cavities, is a very little known hydrogeologic phenomenon. By many direct surveys, mainly carried out in deep karst complexes, it seems that from the feeding area waters mainly follow active pathways recently developed, which very often cannot be passed through. This is the reason, widely shared, of the co-existence of active and fossil pathways in an underground karst in continuous development (Klimchouk et al. eds., 2000). The general situation of the Trieste Karst is similar. Here big water percolations can be observed only at a remarkable depth, only in determined caves, where pits and canyons showing "young" morphologies present a water activity dependant upon rainfalls. However, little is known about the real pathways of these waters inside a vadose area (or "unsaturated" area) that is permeable, above all, only because of draining selected canalizations. For this reason, these vadose waters could theoretically use also pathways different from the logical thought of "the shortest pathway". In order to understand these phenomena the technique of "natural tracers" was mainly employed, together with the study of the relations between the surface and deep waters through the analysis of the chemical-physical signal. Though valid, these methods present, due to the natural hydrodynamic and geochemical evolution of the waters first stored and then transferred in depth, an inevitable interpretative risk. A survey method for the direct verification of these phenomena is that of using tracing substances to inject on the surface and then to detect them in depth in the vadose or epiphreatic area. In the region of the Classic Karst, for example, this method was utilized in Postojnska Jama, in Planinska Jama and in the area of Pivka Jama (Kogovšek and Habič, 1980; Knez et al., 1995; Kogovšek, 1997) obtaining good results.

4. Site Characteristics and Techniques of Research

In the Trebiciano Abyss 4 sampling points (marked "S") corresponding to remarkable percolations and 3 checkpoints (marked "C") were considered (Fig. 5).

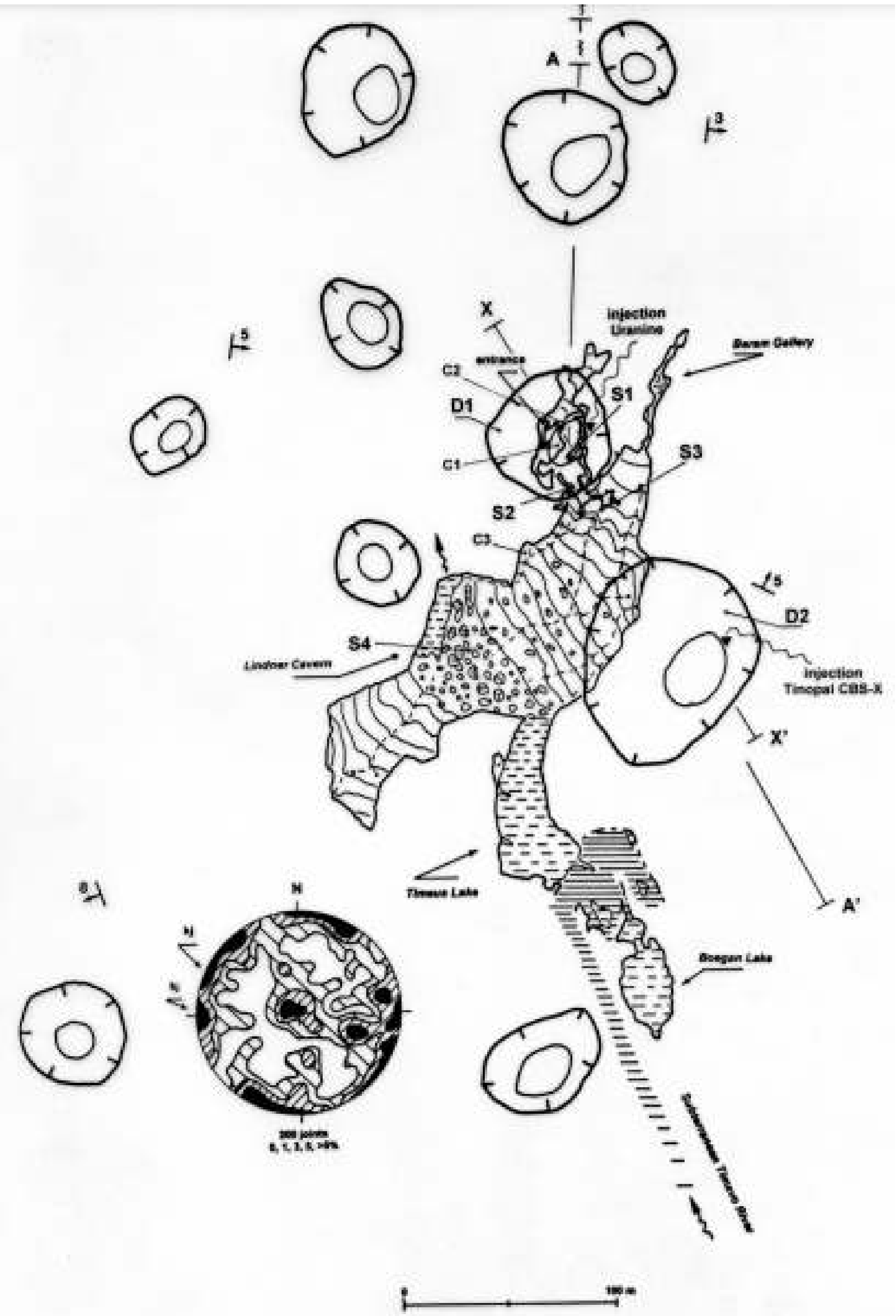

Fig. 5. Map of the area plant of the Trebiciano Abyss. Structural data: 200 joints poles in lower hemisphere equal-area Schmidt stereonets (by Forti et. al., 1979, modified). [D1,D2]: injection Uranine and Tinopal CBS-X points. [S2]: fluorometer probe monitoring [S1, S2, S3, S4]: sampling and detector bag points. [C1, C2, C3]:check points. Traces of cross sections A-A' and X-X'.

[S1] Percolation of the water captured at the base of the pit of 53 m at the depth of 161 m, by building a collecting work made up of a funnel of polyethylene occupying half of the section of the pit. The capture of the 80% of the waters that discharge in the pit was estimated. The percolation flows from the chimneys overlying the pit and it was estimated that in the rainy periods it is able to reach 0.5 L/s or a little more.

[S2] Percolation of the water captured at the entrance of the pit of 7.8 m at the depth of 250 m, by building a collecting work made up of a funnel of polyethylene occupying most of the section of the pit; the capture of almost all the waters is estimated. A pipe conveyed the waters in a meter to measure the flow. The percolation flows from the chimney overlying the pit and in rainy periods it can reach more than 1 L/s. It is one of the major percolations known in the abyss, indeed the pit is commonly known as “waterfall pit”.

[S3] Percolation of the water captured in the high part of the “Lindner Cavern” at the depth of about 275 m, positioning a polyethylene funnel on the basin made up of the water that falls from about 40 meters onto the sandy ground; the almost total capture of the waters is estimated. The percolation flows from a chimney, placed at the depth of 234 m, along the so-called “old pathway” (where the first explorers passed in the 19th century). The percolation, about which there are very few flow data, seems to be bigger than that of the “pit of the waterfall”.

[S4] Percolation of the water captured in the low part of the “Lindner Cavern” at the depth of about 315 m, by positioning a work similar to the former one on the small basin made up of the water falling from over 40 meters; the almost total capture of the waters is estimated. The percolation flows from a narrow chimney opening on the roof of the cavern, at the depth of about 260-270 meters. It shows a much less flow than that of the former point.

The points [S1], [S2], [S3] and [S4] were arranged in order to carry out an easy water sampling, to collocate detector bags guaranteeing a rapid downward flow and to measure the flow by volumetric method. In the point [S2] a fluorometer probe was also installed.

The points [C1], [C2] and [C3] are simply “sight” checkpoints, or there containers are used to facilitate observations. [C1] corresponds to the heavy and diffuse dripping of numerous stalactites in the “Cavern of Proteous” (artificial basins) at about -50 m. [C2] corresponds to a single area of perennial dripping of stalactites in the “bridge cavern” at about -78 m. [C3] corresponds to remarkable water percolation along the western wall of the “Lindner Cavern” at about -270-300 m.

As for the tracing test Uranine and Tinopal CBS-X were used.

The fluorometer analyses of the sampled waters and of the solutions extracted from active charcoal were carried out in the laboratories of Geokarst Engineering srl by means of a Fluorometer GGUN-FL produced by the "Equipe of Geomagnetism of the Department of Geology at the University of Neuchâtel (Switzerland)". The instrument is equipped with the following probes: FL02: probe for surface and laboratory waters, with a diameter of 160 mm, used for quick measurements; FL20: probe for the measurements in deep pits, with a diameter of 48 mm with a cable of 120 m. The calibration curves of the probes were obtained using standard solutions at different concentrations covering the sensitive range of the instrument. By means of the fluorometer probes used in this work, for the Uranine it was possible to determine a concentration interval ranging between 10^{-6} and 10^{-4} g/L accurately. As for the Tinopal CBS-X, it was possible to determine a concentration interval ranging between 10^{-5} and 10^{-2} accurately. The fluorometer probe FL20 installed at the point [S2] was programmed to measure alternately every 4 minutes, the Uranine and Tinopal CBS-X, for the whole experiment.

Moreover, detector bags were used. For the Uranine active charcoal of the "Laboratori B&B", having variable granules, was utilized; from laboratory tests it proved to be the most effective in absorption. In order to concentrate an optical bleach like Tinopal CBS-X cellulose fibre was employed, in this case some cotton previously controlled at Wood's lamp. For the extraction of the Uranine from the active charcoal an alcoholic solution of potassium hydroxide was used; the solution has been prepared by mixing equal parts of ethanol and KOHaq at 15%. The charcoal together with the alcoholic solution were put in the stirrer for one hour, filtered with membranes of cellulose acetate 0.45 μm and the elutes read by means of bench fluorometer. As for the Tinopal CBS-X that practically cannot be extracted, the check of the cottons was carried out using Wood's lamp.

As for the correlations with rainy events, it was possible to use the data of the weather station of Padriciano, in AREA Science Park, at a height of 370 m a.s.l. and 3 km far from the Trebiciano Abyss.

5.The Tracer Test

On 13/05/02 detector bags were positioned in the points [S1], [S2], [S3] and [S4] separately for Uranine and Tinopal CBS-X, as well as water samples were collected, for the verification of "whites" and the fluorometer probe was positioned at the point [S2]. This procedure was necessary to determine the base values of fluorescence in cave waters.

On 17/05/02 at 10.30 a.m. 800 g of Uranine were injected in the doline [D1] where the Trebiciano Abyss opens, under the rocks of the eastern wall, discharging 3.5 m^3 of water by means of a tank truck so as to facilitate the infiltration of the tracer in the ground. On 21/05/02 at 10.00 a.m. 2 kg of Tinopal CBS-X were injected in the doline [D2] placed at 120 m south-south-east, under the rocks of the eastern wall, using the above-mentioned procedure, discharging 2.5 m^3 of water. Also in this case the doline immediately absorbed the tracer. Both dolines are over 30 m deep, their stratification is sub-horizontal and limestones are crossed by big sub-vertical north-south and north-north-east/south-south-west joints (Fig.6).

At the points [S1], [S2], [S3] and [S4] the first collection of water samples and of detector bags took place the same evening of the first tracing test; during the two days that followed two daily (morning-evening) water collections were carried out. Then, a daily collection was carried out up to the 26/05/02, always regularly, finally a last one on 30/05/02. The fluorometer probe placed at the point [S2] was also dismantled the same day. During each investigation on the field the detector bags were collected and others were positioned. Finally, during each investigation on the field the flows were measured.

The choice of finishing the test on 30/05/02 was imposed by technical needs and practical reasons: it was not possible to support the hard work of speleologists beyond this limit. Having ascertained that return periods of the tracers were rapid, in the worst of the cases it could be foreseen to lose a part of the decreasing curve, therefore the interruption of the surveys would not alter the final result.

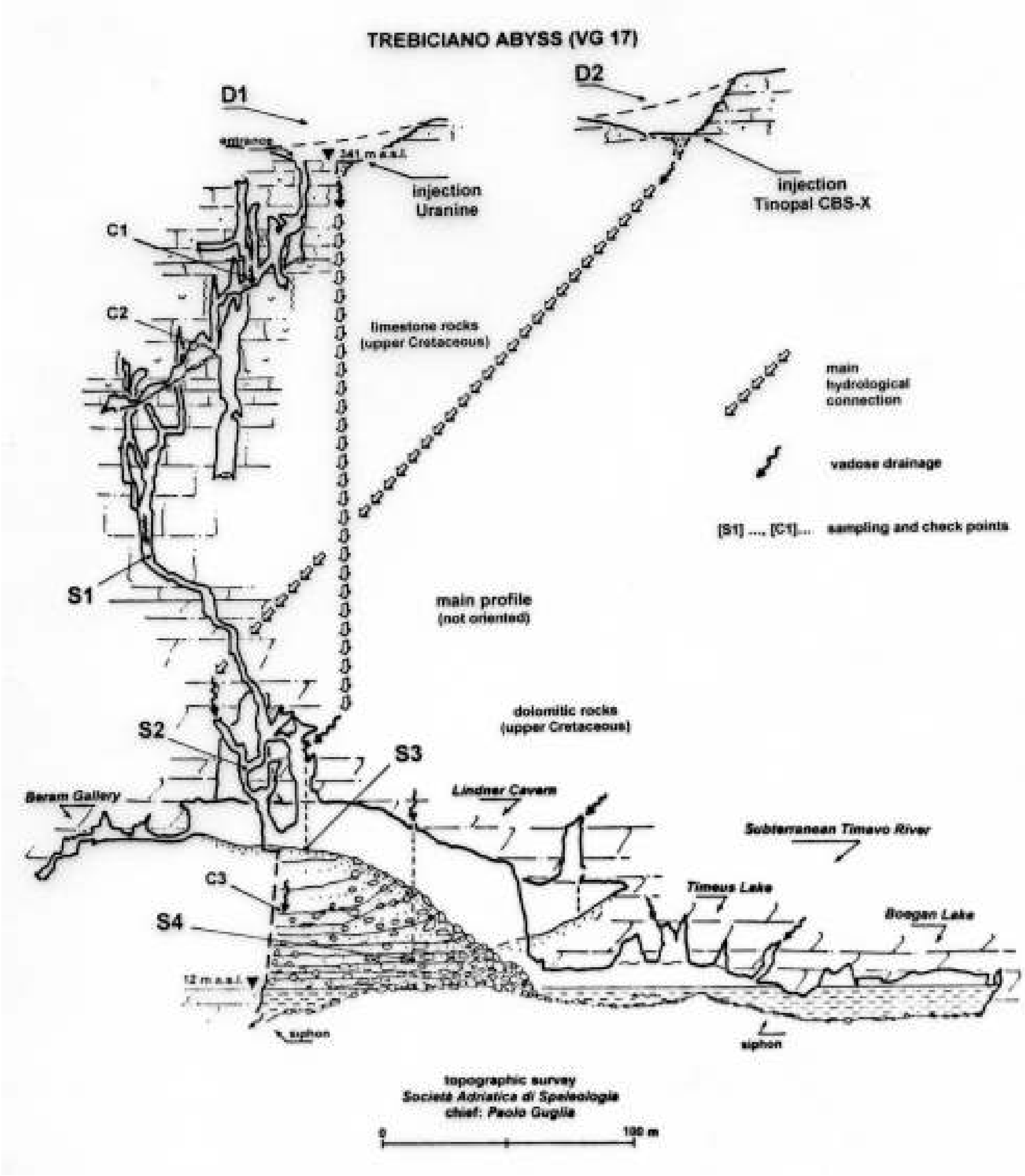

Fig. 6. Main section of the Trebiciano Abyss. Location of: injection points of tracers in the dolines [D1] and [D2]; monitoring, collecting and control points [S1, 2, 3, 4; C1, 2, 3]; results of the tracer test.

6. Results and Discussion

The main hydrological ascertained connections are in Fig.5. The Figg. 7, 8, 9, 10 and 11 show the results of the tracing tests; the graphics of the samplings show the dates 18 and 19/05/02 twice since during those days they were carried out in the morning and in the evening. Main and secondary pathways, ascertained by fluorometer probe, analyses or checks, are obviously relative since they do not exclude other unknown pathways in the same abyss, simply because not considered, or because towards other cavities, totally unknown, too.

Now, it is possible to sum up the results adding the following specifications. The times obtained with the fluorometer probe positioned in the point [S2] are accurate, whereas those obtained by the collections and by the detector bags are indicative since they both refer to a span of time up to the moment of the sampling.

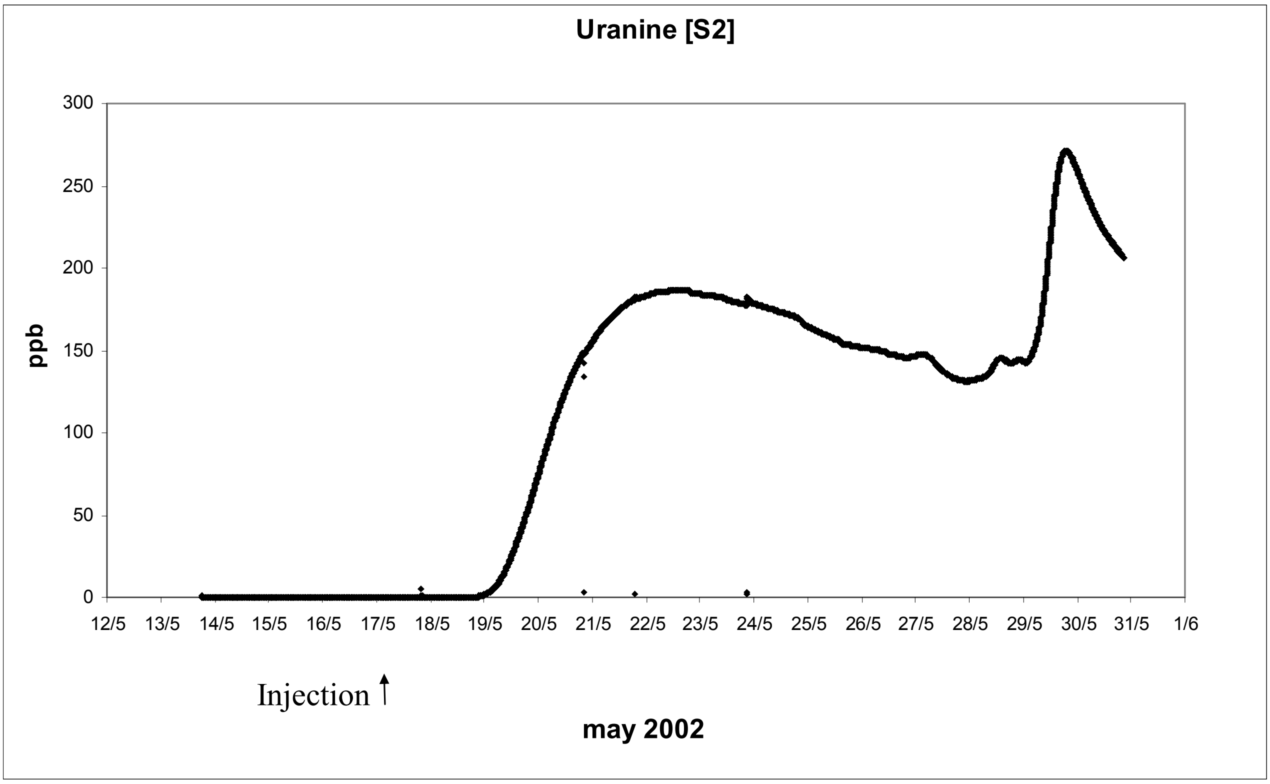

Fig. 7. Concentration curve of Uranine monitoring by fluorometer probe located in point [S2].

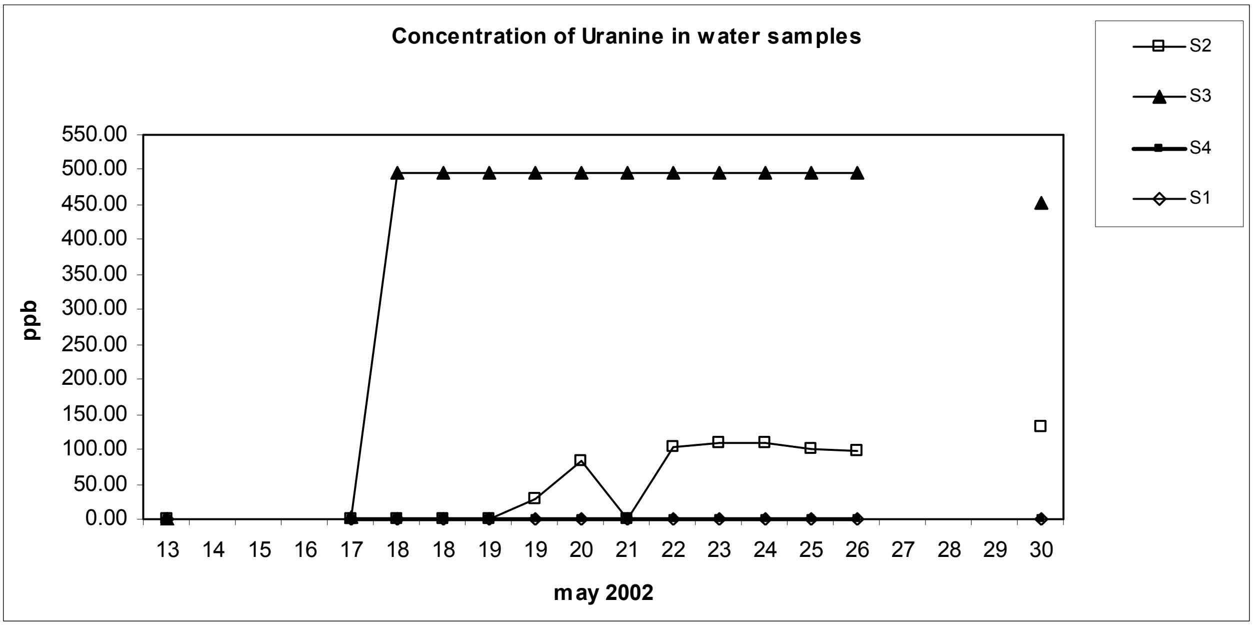

Fig. 8. Concentration of Uranine in water samples collected in the points [S1], [S2], [S3], and [S4].

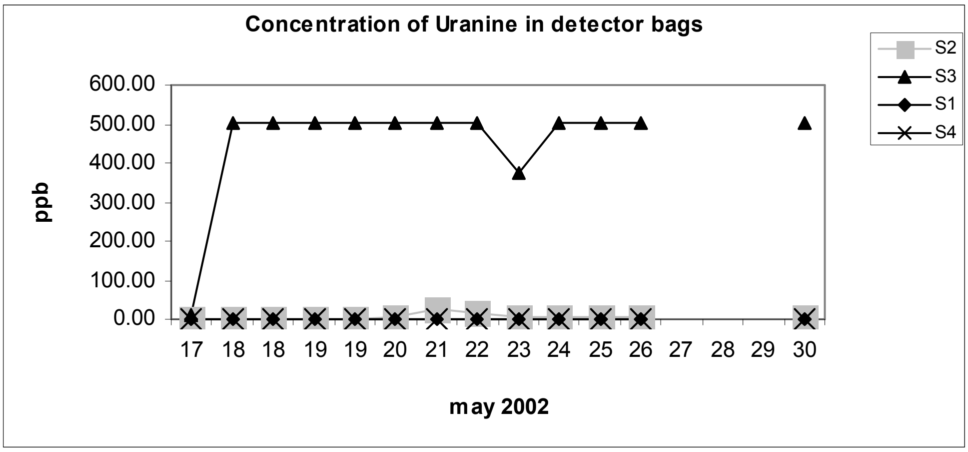

Fig. 9. Concentration of Uranine in detector bags collected in the points [S1], [S2], [S3], and [S4].

The Uranine, injected on 17/05/02 at 10.30 a.m. appeared at the point [S3] already during the taking carried out at 08.00 p.m. of the same day (Fig. 7). The concentration of Uranine is remarkable, therefore it is possible to suppose that it arrived before 9^h 30' were passed. On the same day at 05.00 p. m. at the point [C2] the percolation was traced by Uranine. The Uranine, then, appeared at the point [S2] on 19/05/02 at 01.44 p. m. (Fig. 7). Therefore, it is possible to suppose that probably the main pathway of the water drained from the doline where the abyss opens [D1] is along a system of unknown cavities, probably pits, which connect with the chimneys and pits of the "old pathway" that discharges in the high part of the "Lindner Cavern". Moreover, it is correct to think that the Uranine may reach the point [S3] also in a few hours. The system of cavities, also here probably pits, which instead connects the same doline [D1] with the "waterfall pit", at the point [S2], is clearly secondary for the present vadose drainage, since here the Uranine appeared after 51^h14' from the injection. All the collecting points [S2], [S3] and the check point [C2] that had been traced maintained the presence of Uranine up to the end of the test. The analyses on water samples (Fig. 8) showed concentrations around 100 ppb at the point [S2], whereas at the point [S3] ≥500 ppb were measured since this is the instrumental survey limit. This datum would confirm that the "old pathway" is probably the main link with the basin of the doline [D1]. The detector bags (Fig. 8) showed a good correlation with the collections.

The Tinopal CBS-X injected on 21/05/02 at 10.00 a. m. appeared at the point [S2] on the same day at 07.16 p. m., after 9^h 16', lasting up to the end of the test (Fig. 10). It was not surveyed in any other point of the abyss, as it results from the takings carried out (Fig. 11). Indeed, concentrations lower than 2 ppb are not significant since they may depend upon water base values, influenced by turbidity, pH, etc. The test on detector bags was negative: fact that confirms the difficulty in fixing the Tinopal CBS-X. Therefore, another system of unknown cavities exists, it connects the doline [D2] placed to south-south-east of the abyss with the “waterfall pit”, probably secondary, since very low concentrations were recorded.

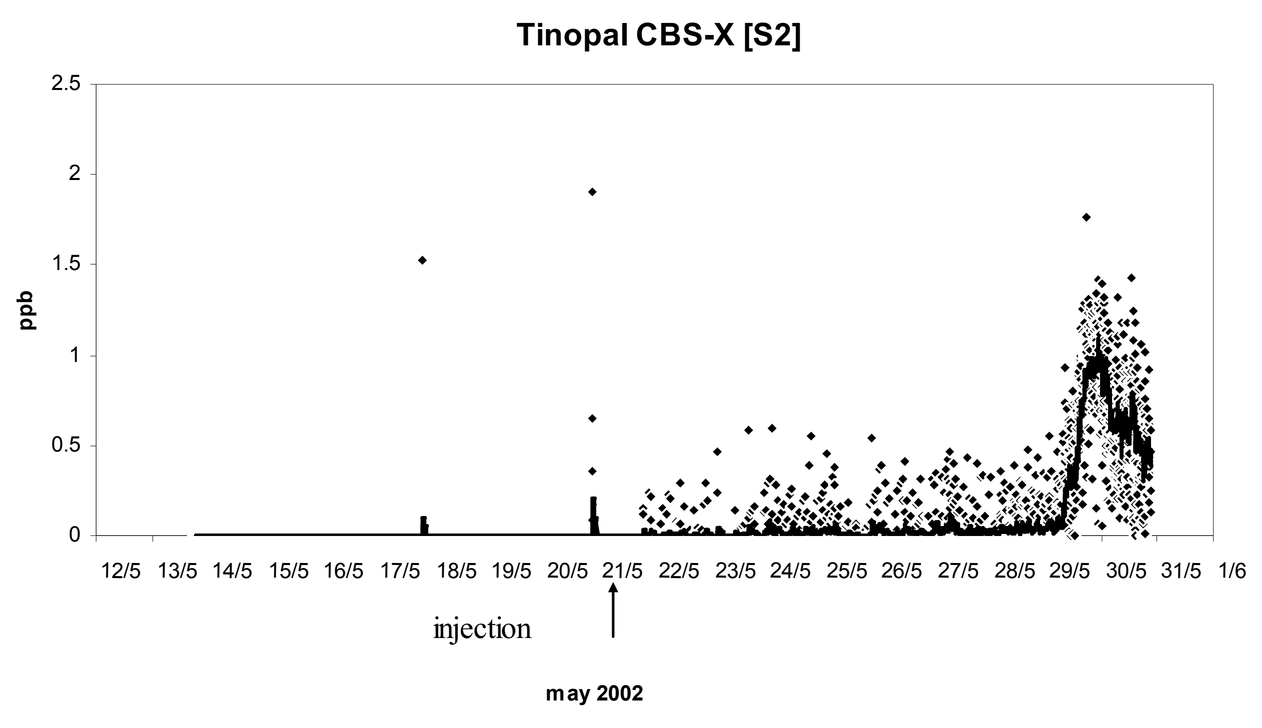

Fig. 10 Concentration of Tinopal CBS-X monitoring by fluorometer probe located at point [S2].

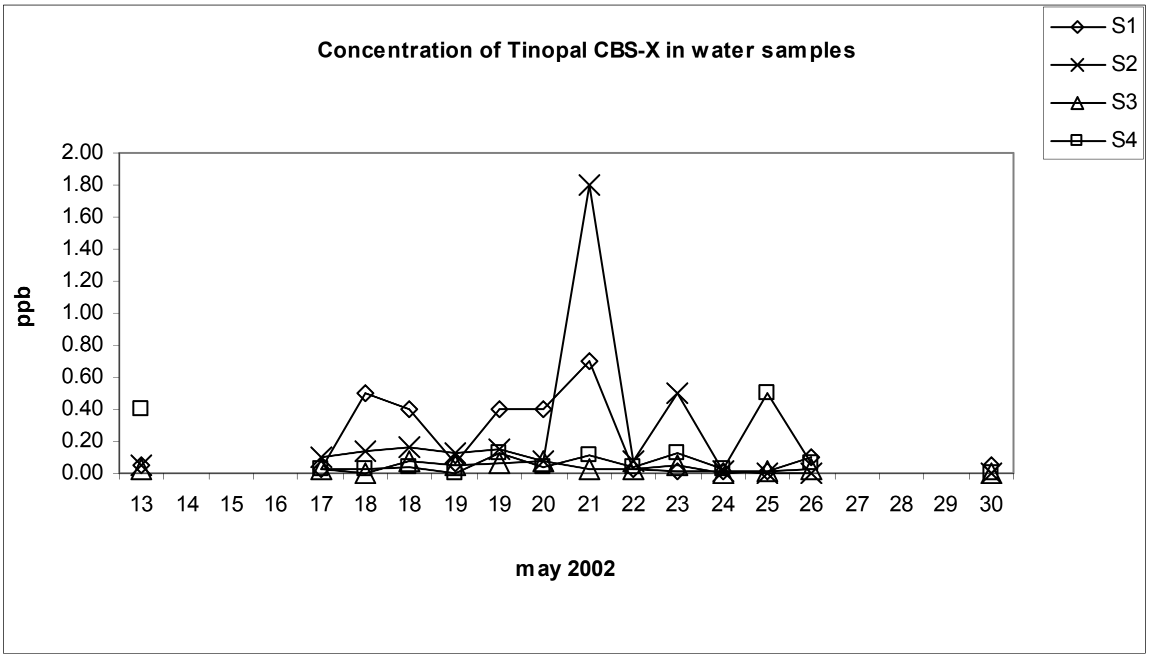

Fig. 11. Concentration of Tinopal CBS-X in water samples collected at the points [S1], [S2], [S3], and [S4].

The hypothesis that in both cases they are substantially systems of pits is not based essentially on the speeds of the two drainages caused by the in-flows, but on the evidence of karst of the area. The data obtained show that a vadose “scattered” circulation under the dolines and the epikarst does not exist but, essentially, there is a circulation that employs well-identified pathways, probably canalizations developed on the big sub-vertical above- mentioned joints. Moreover, it seems that the structure of the Trebiciano Abyss corresponds, as it had already been supposed (Forti et al., 1979), to systems of pits abandoned by the vadose drainage next to systems of pits that are active at present. Therefore, a type of evolution that might have been rapid, considering that theoretical studies (White, 2000) show how the development speed of pits (this does not mean that man can explore them) with water films that constantly flow along the walls may last thousands of years.

The beginning of the two concentration curves of Uranine and Tinopal CBS-X recorded at the point [S2] are basically different. For the Uranine the increase is relatively rapid, indeed in 75 ^{h} 12’ the peak of the curve is reached (almost 900 ppb of concentration), followed by slowly breakthrough. This leads to consider the existence of an inter-connected system of karstified joints; but this system has not developed into a pit yet. However, the same effect might be attributed to the storage in a filtering strata (detritus mixed clay-silt, perhaps the same epikarst etc.). For the Tinopal CBS-X the increase corresponds to a concentration curve relatively constant (on the average 0.2-0.4 ppb) for almost 164 ^{h} 44’, starting to rise on 28/05/02 at 04.00 p. m.; then on 29/05/02 at 09.08 a. m. it suddenly rose, reaching, on the average, almost 1.4 ppb, that is to say concentrations about 4-5 times higher, already on 29/05/02 after only 31^{h} 48’.

Obviously, all the results shown are to be considered relative. The traced waters might have flowed also in other points, both in the same Trebiciano Abyss in unchecked points as well as in unknown cavities peripheral the abyss. In the Trebiciano Abyss the rational principle of checking all the main percolation points was adopted (except for the drippings in the “fossil gallery”, which, however, are near point C2). Other known caves are too far from the dolines [D1] and [D2] and therefore were not taken into account.

In order to understand these phenomena it is necessary to correlate them with the rainfalls (Fig. 12). The last rainfall before the first injection occurred on the 8th and 12th of May with a total of 12.2 mm. During the test: on 19/05/02 15.6 mm were recorded; then on 14/05/02 7.6 mm and from 26/05/02 to 29/05/02 a total of 37.2 mm.

Therefore the tracing test was carried out in a non-stationary hydrological regime. However, since rain was scarce, it seems that there were not big interferences in the tracers, due to the infiltrated rain. Indeed, during the rainfalls the curve of Uranine decreases, while that of Tinopal CBS-X is stationary. Therefore, it is possible to suppose that these rainfalls were filling up the epikarst, which, however had already stored water masses, since both April (with 118.5 mm) and the beginning of May (with 17.1 mm) were characterized by average rainfalls. A theory to explain the peak that started on 28/05/02 at 04.00 p. m for the pathway of the waters traced by Tinopal CBS-X, once reached the point [S2], is that of the arrival of the water surplus of the epikarst in depth. It is necessary to remember that on 30/05/02 during the last sampling all the points [S1], [S2], [S3] and [S4] showed an increase in the flow higher than the average. The second peak of the Uranine: more than 250 ppb of concentration suddenly reached on 29/05/02 at 09.52 p.m., together with the peak of the Tinopal CBS-X may be connected with the rainfalls from 26/05/02 to 29/05/02.

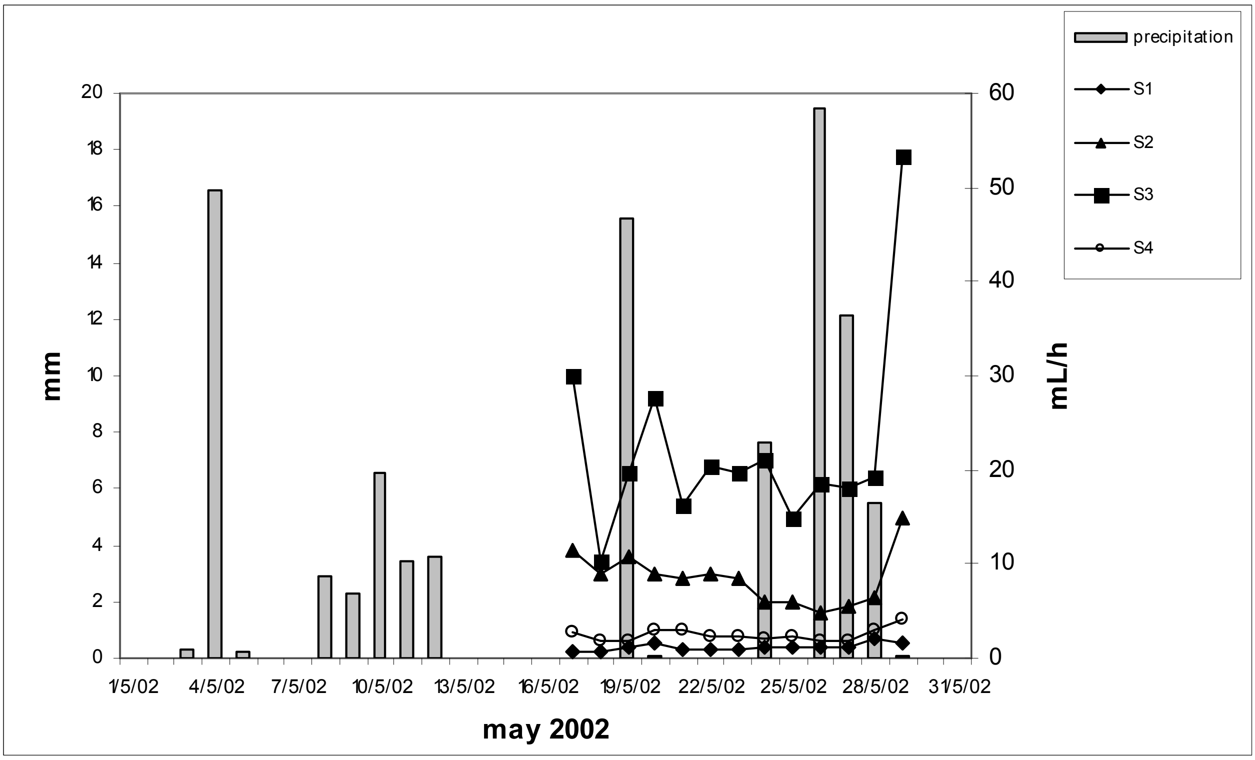

Fig. 12. Diagram of precipitations in May 2002 and flow of percolations in the points [S1], [S2], [S3] and [S4] during the test period (weather station of Padriciano AREA).

In order to understand better these phenomena it can be useful to elaborate simple hydrological models on the dolines in object. A heavy rainfall of 75 mm in 24 hours is a frequent event on the Karst. A rainy event of total 110-120 mm during 5 days is also quite normal (in the most rainy areas of the Karst it may rain 140 mm in 5 days). Moreover, it is necessary to remember that rainy events of 75 mm in 24 hours have a return period (T_{ra})

of 4 years, whereas rainfalls of 115 mm in 24 hours have a T_{ra} of 100 years (Colautti, 1976). A flow of 0.075 m^3/m^2 almost totally infiltrated in the underground during damp months corresponds to an event of 75 mm, for example. Since each of the two dolines [D1] and [D2] has a basin of about 4,500 m^2, an inflow of about 337 m^3 would be observed in each one. Therefore, the injection of 3.5 m^3 of water in the doline [D1] simply corresponds to the only volume of water of a rainy event, for example, of 75 mm on a surface of 45 m^2, this means to the plane bottom of red soil in the doline. The rainy contribution of 15.6 mm on 19/05/02 and the total 44.8 mm from 24/05/02 to 29/05/02, however, had little influence on the vadose hydrological regime of the abyss (on each of the doline: average theoretical 33.6 m^3/g of water probably partly stored in the epikarst). This fact would confirm that the evolution of the first parts of the curves of Uranine and Tinopal CBS-X can be ascribed to the artificial water spills, also in relation to the fact that the drainage occurs in a few hours. On this subject it is interesting to observe how on 06/05/02 all the checked points showed a scarce increase in the flow of percolations that were much lower than 10 L/h, except for the point [S3]. On 30/05/05, instead, all the flows had increased, on the average, (the point [S1] is sufficiently stationary), in particular the "waterfall pit" [S2] showed a percolation of 15 L/h, whereas the pits of the "old pathway" [S3] discharged a percolation of 53.4 L/h. With respect to the lowest measured ones the flow of the point [S2] had increased of 3.12 times, while that of the point [S3] of 5.23 times. The point [S3], with respect to the others, reacts to rainy contributions immediately, as it was punctually verified during all the rainfalls of that period. This datum confirms the direct connection between the doline [D1] and the pits of the "old pathway"; this cannot be said for the point [S3] where the event is modulated.

The simulated velocity of drainage can be calculated. In the connection between the doline [D1] and the point [S3], ascertained by the first peak of the Uranine, the velocity is of about 0.8 cm/s; while in the same connection with the second peak of the Uranine the velocity is of 0.1 cm/s. In the case of the connection between the doline [D2] and the point [S2], ascertained by Tinopal CBS-X, the velocity is of 0.7 cm/s. This velocity falls into the range of "rapid through-flow through most permeable conduits", between 0.5 and 2 cm/s, calculated by Kogovšek (1997). Bottrell and Atkinson (1992) and Kogovšek (1997) identified, using tracing techniques, three components in the storage waters of the unsaturated area: waters drained in a few days, 30-70 days, and 150-170 days. Obviously, these times are related to the hydrogeologic and karst conditions of tests and to the time required for them. The test on the Trebiciano Abyss, thank to its length, focused the only first component, the one characterizing the draining conduits. The other two components, those relative to "slower velocity" lower than 0.001 cm/s, respectively attributed to flows and drippings by the Authors, were not verified. According to our experience, the "slower velocities", which can be correlated with very low concentrations of fluorescent substances, surely exist but they should be object of very accurate studies, since the same background of fluorescence of percolation waters, which varies with turbidity and transported organic substances, can alter the interpretation of the instrumental datum.

As for the breakthrough curves recorded [S2], it is possible to observe that they are very different one from the other. This fact results from solubility and, in general, from the behaviours, very different one from the other, of the two substances in water. The curve of the Uranine is made up of linear concentration points, whereas that of the Tinopal CBS-X is made up of concentrations points rather scattered due to its less solubility. The data surveyed confirm what previous studies had already shown: that the concentration curve of the Tinopal CBS-X can be interpreted only as a whole.

The data of the tracing test confirm what had been previously supposed but never measured up to now. In a few hours, after a heavy rainfall or due to an accidental outflow, a release of pollutants on the Karst surface once infiltrated into the underground, is transferred to three hundred meters of depth, flowing directly in the base flow with no chance of being stopped.

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