

Tracer Tests History in the Alburni Massif (Southern Italy)

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Abstract. The Alburni Massif (Campania, southern Italy) is among the most important Italian karst areas, due to high number of caves (about 300), with several karst systems reaching depth of 500 m, and development of some kilometres. This remarkable karst is mainly related to three geological factors: presence of highly karstifiable and low-fractured Cretaceous and Tertiary limestones; peculiar morphological and structural conformation, with four main faults bounding the massif, forming a wide highplain with a variety of infiltration sites; presence of blind valleys and small catchments on flysch deposits, feeding the many swallets at the contact with the limestone rocks. The Alburni Massif represents an important hydrogeological structure, with a potential of about 10 mc/sec. Three basal spring systems are the main outcomes (Castelcivita, Tanagro and Pertosa) while other minor systems are located at higher elevation, as the Auso spring. The Castelcivita and Pertosa caves, located on the Alburni SW and NE foothills, respectively, are of particular importance also for the local economy, since Castelcivita became a show cave in 1930, followed two years later by Pertosa. Since 1950 many cavers have explored the Alburni Massif, due to the high potential of overall karstification, estimated in about 1 300m, and to the presence on its southern slope of the spectacular Auso spring. In this paper, the tracer tests carried out in the Massif are summarized, with the aim to update the available hydrogeological data, with particular regard to the most recent explorations and tests, carried out during the last 5 years, which brought significant new data to the overall knowledge of this remarkable karst area.

1. Introduction

The Alburni Massif (Campania, southern Italy) is among the most important Italian karst areas, due to high number of caves (about 300), with several karst systems reaching depth of 500 m, and development of some kilometres [1, 2]. This remarkable karst is mainly related to three geological factors: presence of highly karstifiable and (in average) low-fractured Cretaceous and Tertiary limestones; peculiar morphological and structural conformation, with four main faults bounding the massif, thus forming a wide highplain with a variety of infiltration sites [3]; presence on the highplain of blind valleys and small catchments on flysch deposits, which surface hydrology feeds the many swallets at the contact with the limestone rocks [4].

The Alburni Massif represents an important hydrogeological structure, well bounded on the four sides, with a potential of about 10 mc/sec. Three basal spring systems are the main outcomes (Castelcivita, Tanagro and Pertosa) while other minor systems are located at higher elevation, as the Auso spring [5, 6, 7].

The Castelcivita and Pertosa caves, located on the opposite foothills (respectively, SW and NE) of the Alburni Massifs, are of particular importance also from the touristic standpoint, and for the local



economy as well, since Castelvita became a show cave in 1930, followed two years later by Pertosa [8, 9].

Since 1950 many cavers have explored the Alburni Massif, due to the high potential of overall karstification, estimated in about 1300 m, and to the presence on the southern slope of the massif of a spectacular spring, the Auso, coming out at elevation of 260 m a.s.l. [10, 11, 12, and references therein] (figure 1).

In order to understand the link existing among the different karst system of the highplain, and their relationships with the basal springs, many tracer tests, and some geochemical analyses, have been in different times carried out by cavers, sometimes in connection with universities. The present article aims at summarizing the research so far done, which are often dispersed in the local caving bulletins, as an attempt to put together the pieces of the still quite complicated jigsaw puzzle represented by hydrogeology of the Alburni Massif. This will be performed also taking account of recent cave diving explorations that brought new light to the overall karst knowledge of the area.

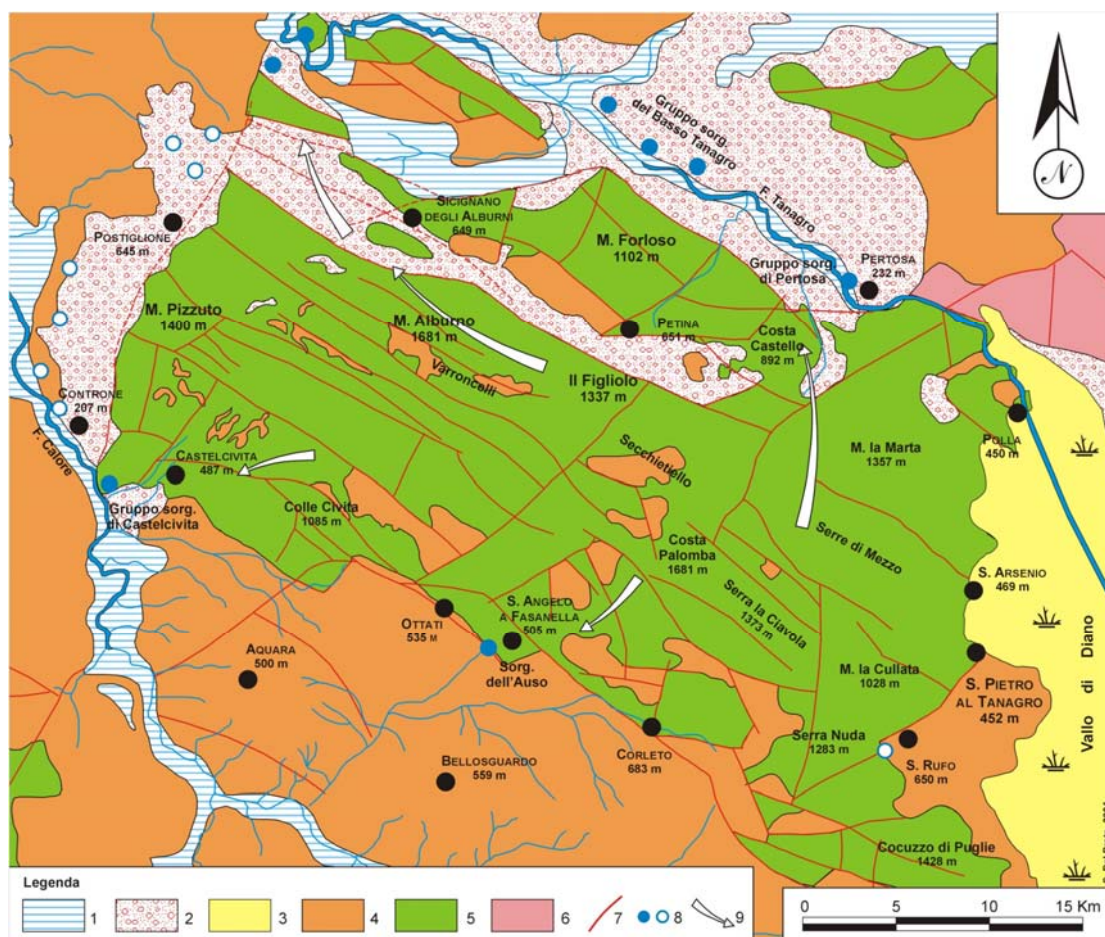


Figure 1. Hydrogeological map of Alburni Massif (modified, after [2]).

Key: 1) alluvial complex (medium to high permeability); 2) conglomerate debris complex (high permeability); 3) lacustrine complex (medium to low permeability); 4) flysch complex (very low permeability to impervious); 5) carbonate complex (high permeability); 6) calcareous-dolomitic complex (medium permeability); 7) fault; 8) spring; 9) main flow direction

2. Tracer test history

The spectacular Auso spring, near Ottati, is active throughout the year, reaching the highest discharge, greater than 10 mc/sec, on the occasion of intense rainstorm and periods of snow melt. The rapid

increase in discharge, combined to the spring location with respect to the other springs surrounding the massif, convinced since a long time cavers and scholars that Auso is the main underground collector channel, in great part still unexplored, of the central part of the Alburni Massif, in direct connection with the many swallow holes at high elevation.

The first scientific evidence of this hypothesis derives from a joint project between the grottos CAI Napoli and UGET Torino, in the late '80s, when a tracing test was carried out by using fluorescein: the test demonstrated the connection between the karst system of Inghiotto III di S. Maria and the Auso spring, located at a distance of some 5 km, with a relief energy of about 750 m [6, 13, 14]. In these studies, the main geochemical parameters of the springs, and a first hydrogeological profile of the massif, were also presented.

Other tracer tests were addressed to prove the links among the karst systems and the basal groups of springs. In detail, it was demonstrated the link between the Castelcivita Caves and the Auso spring, for a total development of more than 6 km [15]. Actually, this connection was already proved in 1957 when, during a period of intense rainfalls, 1 kg of fluorescein was introduced at the Castelcivita Caves (site *Cunicolo I CAI*) and after some tens of minutes the tracer was identified at the two resurgences of the Ausino Cave and the *Risorgenza del Mulino* springs [16]. Again in 1993, the CAI Napoli grotto, in collaboration with cave divers from CAI Foligno, carried out tracer tests in some flooded passages of the Castelcivita system [15], and confirmed the connection between this system, Ausino and some springs in the thalweg of the Calore River. The main conduit leading to the springs at the *Risorgenza del Mulino*, on the other hand, seemed not to be connected to Castelcivita, at least in no turbulence condition, as also indicated by the development of the cave, going in opposite direction. Further, the research performed during the first half of the 1990s presented water chemical data, and a detailed hydrogeological scheme of the water table along the Calore River.

In 1994-95 an automatic datalogger was installed in the karst system at Castelcivita, namely at *Risorgenza del Mulino*. The parameters of conductivity, as well as those related to temperature, indicated a deep circuit for the water at this spring, with temperature value of 16,5 °C; this was also confirmed by cave diving explorations by Bollati, who was able to go well down the sea level by diving into the conduit [15]. The same automatic datalogger recorded very rapid temperature changes following intense rainstorms on the Alburni highplain: the temperature changes were delayed 24 to 48 hours after the rainfalls, and highlighted in winter time a mixing of the cold water from the highplain with those warmer in the Castelcivita karst system, thus testifying a connection between the vertical systems and the basal water table [4].

Table 1. Communications among cave systems and springs, ascertained by means of tracing tests.

<i>Cave system</i>	<i>Spring</i>	<i>Transit time</i>	<i>Reliability</i>
Castelcivita	Calore River	Few hours	High
Castelcivita	Ausino	Few hours	High
Castelcivita	Mulino	Few hours	High in flood conditions
Fumo-Ing. III	Auso	Few days	High
Campitelli – Falco	Auso	Few days	High
Campitelli – Falco	Pertosa	Some days	Low
Campitelli – Falco	Tanagro River	Some days	Low
Capostarda - Poeta	Niedda	Few hours	High

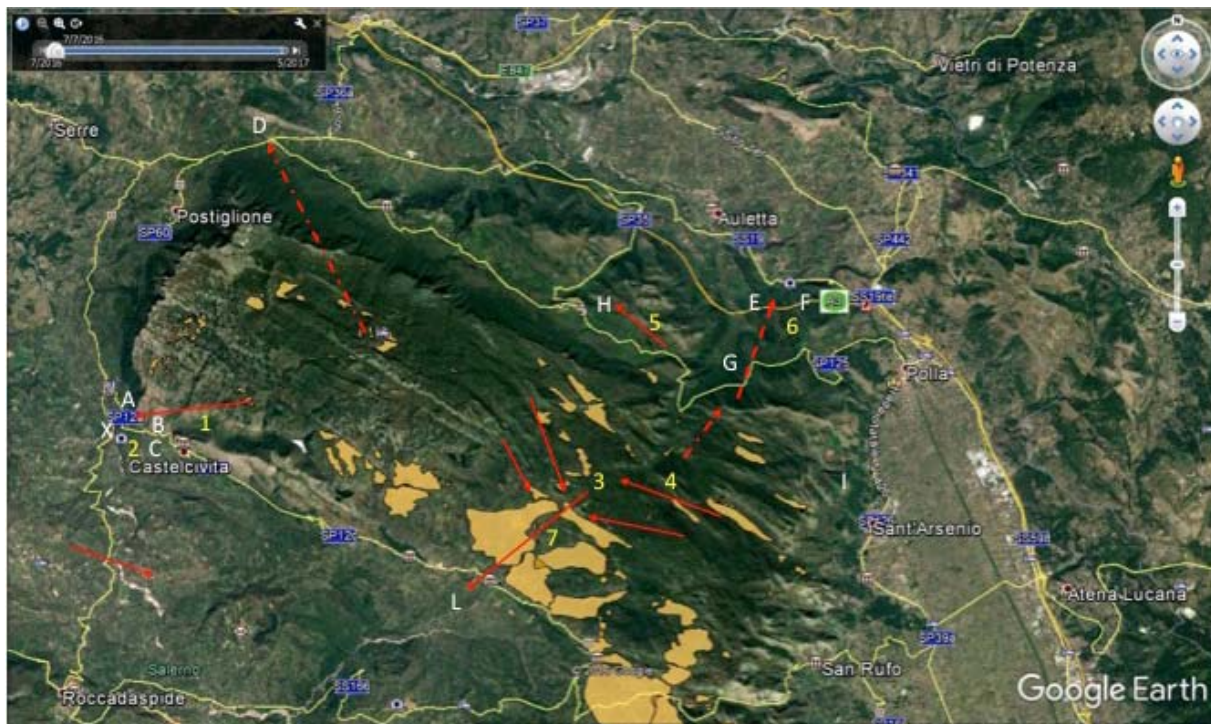


Figure 2. Map showing the results of the tracer tests in the Alburni Massif (after Google earth). Springs are identified by letters: A= Castelcivita, B= Ausino, C= Mulino, X= Calore River, D=lower Tanagro, E=Pertosa, F= Tanagro River, G= Acqua, H= Niedda, I= Secchio, L= Auso. Caves are identified by numbers: 1= Castelcivita, 2= Ausino, 3=Fumo-Inghiottitoio III, 4= Piani-Falco, 5=Poeta-Capostrada, 6=Pertosa, 7=Auso. Red solid lines indicate certain link, dashed red lines indicate presumed link. Flysch deposits in yellow colour

3. Recent developments

In the last 20 years, the exploration efforts by cavers in the Alburni Massif were concentrated on the search for new entrances to the karst systems in the highplain, and on enlarging some promising narrow passages that had been identified in the known caves. In particular, since 2010 several caving campaigns, which involved many grottos from different parts of Italy, resulted in interesting exploration results, and in the performance of further tracing tests.

In the northern sector of the massif, on the downthrown block of Petina, dye tracing with the use of fluorescein demonstrated the connection among some swallets (*Grotta Milano*, *Grava del Poeta*, *Inghiottitoio di Mastro Peppe*) and the nearby Niedda spring, located about 1 km downvalley [17, 18].

Later, also thanks to funding from the Cilento, Vallo di Diano and Monti Alburni National Park, other studies were carried out to prove the hydrogeological connection among the active swallow holes in *Piana dei Campitelli*, *Grotta del Falco*, and the nearby spring at *Grotta dell'Acqua* [17, 19]. The tests pointed out to a very complex hydrogeological scenario, since the fluorescein was detected, beside at *Grotta dell'Acqua*, also at the waterfall within the Pertosa Cave and at some springs in the Tanagro River. On the other hand, the test resulted negative at the sump within the same Pertosa Cave system.

In the same period, other grottos, following new diving explorations, carried out further tracer tests and confirmed the link between *Grotta del Falco*, the Pertosa Cave and the springs in the Tanagro River [20].

Of particular importance were the cave diving explorations by Luca Pedrali at *Grotta del Falco*, which proved the development of the cave system through one of the main tectonic lines of the Massif,

the Vallone Lontrano – Petina [for further details on the morphostructural setting, see 21, 22]. This resulted in transferring the water from this system to the central part of the Alburni Massif, toward *Grava del Fumo* and the S. Maria karst system, and, in turn, to the Auso spring. All of this was documented with tracing test carried out in April 2016 [23].

Eventually, Pastore et al. [24] present new geochemical data on the main springs of the Alburni Massif. Further, they remark the behaviour of the Vallone Lontrano - Petina tectonic line as an important draining structure, as actually previously hypothesized by Bellucci and co-workers [6].

4. Conclusions

The tracer tests carried out in the Alburni Massif, even though with temporal discontinuity, and by different teams, have brought to an increase in the hydrogeological knowledge of the area. Some points can be certainly identified: first, the link among the Castelvita system with the *Grotta dell'Ausino* and some springs in the Calore River thalweg. In the same area, on the other hand, the deep conduit at *Risorgenza del Mulino* seems to represent another circuit, which water mix with the previous one only on the occasion of significant floods following the main rainstorms. The Castelvita system represents one of the emergences of the basal water table, but also responds with a 24-48 h delay to the main rainfall in the highplain of the massif. The same happens at Pertosa, which system drains waters from the north-eastern sector of the highplain, namely from *Piana dei Campitelli* and *Grotta del Falco*. Part of this water should also feed some of the springs in the Tanagro River.

The area where data are still lacking is the NW sector of the massif, with the springs in the middle reach of the Tanagro River; there, more efforts are needed, in particular taking into account the high discharge, reaching about 6mc/s [7].

As concerns the Auso, this is certainly in communication with the central highplain, and the recent tests seem to widen the underground catchment, including also the sector of *Piana dei Campitelli* [24]. However, the recent tests were in some way contradictory, with the *Grotta del Falco* system flowing, according to some authors, toward the Tanagro River, whilst others believe the main direction is toward the Auso. These results need confirmation, since the two outflow areas are located on the opposite sides of the massif. At the same time, the possibility of a complex underground system, with dispersion of the groundwater network, cannot be excluded: during the dry seasons the karst conduits may act independently one from the others, but the situation might be quite different during floods.

In conclusion, notwithstanding the efforts and the many continuing explorations by cavers, hydrogeology of the Alburni Massif still has several dark points, which need further works.

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