Drip-water monitoring in a superficial Alpine cave (Cogola di Giazzera, Trentino, NE Italy)

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Abstract
The two-year-long drip-water monitoring of ten stalactites at Cogola di Giazzera cave located on the Pasubio mountain (Trento Province, NE of Italy) reveals the predominant seasonal discharge of all the studied stalactites. The discharge, electrical conductivity and saturation state of the stalactite drips are directly controlled by the infiltration events and, as a whole, the longer is the time elapse from the infiltration event the lower is the drip-rate, and electrical conductivity of the water. This latter phenomenon is clearly related to prior calcite precipitation along the flow-path, both in the rock above the cave and within the cave itself along the feeding stalactites. In fact, the chemical analyses of two stalactite drips (G1 and G10) reveal a linear relationship between Ca content and calcite saturation state (R^2 = 0.74 for G1 and 0.67 for G10), an exponential correlation between drip rate and Ca content (R^2 = 0.59 for G1 and 0.85 for G10) and an exponential correlation between drip rate and calcite saturation state (R^2 = 0.41 for G1 and 0.47 for G10).

Riassunto
Il monitoraggio di due anni del drip-water di dieci stalattiti alla Cogola di Giazzera, situata sul Massiccio del Monte Pasubio (Provincia di Trento, Italia nord-orientale), rivela un dominante flusso stagionale per tutte le stalattiti studiate. Il flusso, la conducibilità elettrica e lo stato di saturazione dei drip di queste dieci stalattiti sono direttamente controllati dagli eventi di infiltrazione e, nel complesso, più è lungo il tempo di mancata infiltrazione, più è lento il drip-rate e più è bassa la conducibilità elettrica dell'acqua di stillicidio. Quest'ultimo aspetto è chiaramente collegato con la precipitazione di calcite lungo le fessure di scorrimento dell'acqua, sia attraverso la roccia soprastante la grotta sia all'interno della cavità stessa lungo i punti di alimentazione delle stalattiti. Infatti, le analisi chimiche dell'acqua di stillicidio di due stalattiti (G1 e G2) rivelano una relazione lineare tra il drip-rate e il contenuto di Ca (R^2 = 0.59 per la G1 e 0.85 per la G10) e una relazione esponenziale tra il drip-rate e lo stato di saturazione della calcite (R^2 = 0.41 per la G1 e 0.47 per la G10).

1. Introduction
Dripwater monitoring is more and more utilised for testing the present-day cave environment condition in order to calibrate the paleoclimate proxy-data extracted from speleothems (Borsato, 1995; Baker et al., 1995).
In the frame of the AQUAPAST project - which aim was to reconstruct past climate in Trentino region studing speleothems from different caves - was monitored chemical and physical parameters for five caves in Trentino. One of this monitored caves was Cogola di Giazzera that we are going to illustrate.

2. Cave site and environmental setting
Cogola di Giazzera is located on the Pasubio mountain in the Trento Province, NE of Italy (Longitude 11°05'50"; Latitude 45°51'11" N) at the elevation of 1025 m a.s.l. The cave is cut in fissured Lower Jurassic well-bedded limestones (Calcari Grigi formation), with a maximum rock overburden of 30 m (Fig.1). The cave opens on a slope with a south-west orientation covered by deciduous forest with brown-calcareous soil cover.

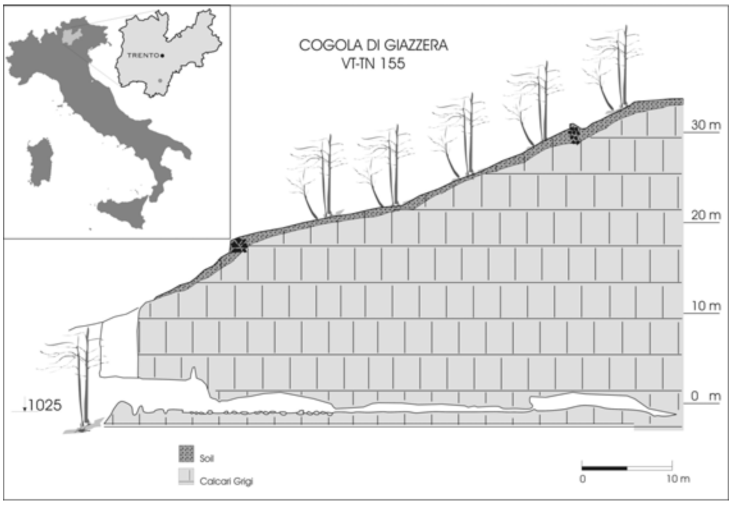

Fig.1. Location map and cross-section of Cogola di Giazzera cave.

The cave entrance is a big chamber at the end of which starts a gallery consisting in a single 20 m long chamber connected by a flat, narrow passage with the entrance chamber. A second very narrow passage lets to the last chamber of the cave where the monitoring program and the following palaeoclimatic study were carried out. The central area of the terminal chamber is decorated with hundreds of stalactites, stalactites and columns (Fig. 2), with several active morphologies and small pools.

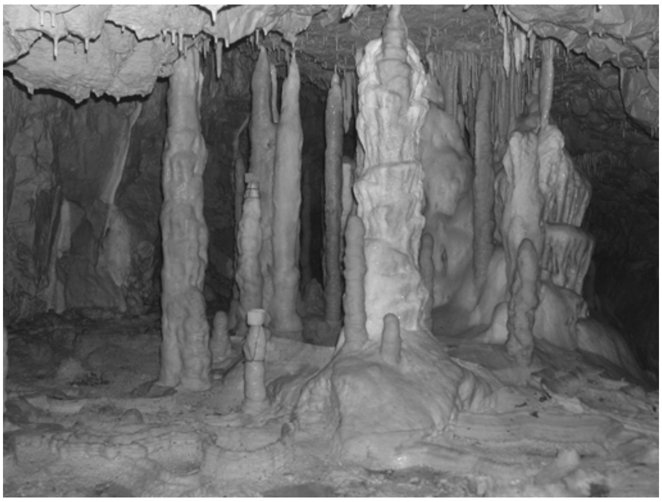

Fig. 2. Several stalagmites and columns in the terminal chamber.

The precipitation in the area (Terragnolo meteorological station, 800 m a.s.l.), is 1162 mm/year (average period 1923 to 1990) and show a bimodal distribution with a maximum between April and June and a second maximum in October-November. The mean annual air temperature at the cave site is about 8.8°C, while the mean monthly temperature is near zero from December to February, period during which the area is cover by snow. The theoretical infiltration, calculated using the Thornthwaite formula, show summer dryness from June to August and occasionally in September, whereas the highest values are recorded in November (110 mm), October (90 mm) and December (75 mm). The result is a strong seasonal signal that is recorded in the fabric of the active growing stalagmites that are mostly composed by dendritic texture.

3. Material and methods

The monitoring program started in 2002 and lasted for two years including a hydrogeological and microclimatic study of the cave. To realise that some instruments were installed in the terminal chamber and the cave was visited each month. We utilise a Logotronic temperature and electrical conductivity (EC) datalogger for the G1 stalactite drip (EC range: 1-2000 µS/cm, accuracy of ±1 µS/cm, resolution 0.1 µS/cm; temperature range: -5 to 100 °C, accuracy: ±0.2°C, resolution 0.01°C) and two Hanna Instruments datalogger for the air temperature (range: -10 to +40°C, resolution: ±0.1°C). Electrical conductivity, pH and temperature were checked monthly by a portable WTW Multivarn instrument that has similar technical characteristics of the Logotronic datalogger. All the EC measurements are corrected to the reference temperature of 20°C.

Inside the terminal chamber 10 stalactites (G1 to G10) with different drip-rates and response time were chosen for the monthly measure of the drip rate in order to investigate the hydrological behaviour and the lag-time of the aquifer with respect to the infiltration events. Two of the most regular drip points (G1 and G10) were chosen to collect water for chemical and isotopical analyses. Being that the water flux for each stalactite was quite slow (mean annual flow < 0.1 ml/min) we utilise 500 cc plastic bottles below each drip site to collect enough water for chemical analyses that were carried out at San Michele all'Adige laboratory. The chemical analyses include the ionic composition, pH, EC and alkalinity that allow to calculate the calcite saturation state. Moreover, below four other drips, were installed glass templates used to investigate the present-day calcite precipitation.

4. Results and discussion

4.1. Drip-water discharge

The two-years period records a different annual precipitation amount with 1793.8 mm during the 2002 and 730.6 mm during the 2003 (Terragnolo meteorological station). However, the strongest annual difference was the snow precipitation that, in the quarter from January to March varied from 176.2 mm in 2002 to 36.6 mm in 2003 (fig. 3 A).

The measured stalactite drips show a mean annual discharge between 0.6 and 0.006 ml/min (i.e. ~ 10^{-5} to 10^{-8} L s^{-1}), with a marked variability from one to the other and less pronounced intra-annual variability. Figure 2 B show the trend of five stalactites that represents the whole spectrum of the 10 monitored ones. The general feature of the two years monitoring is a clear seasonal trend, with drip-rate increase in late autumn following the November recharge and a progressively decrease, punctuated by episodic short-living increases, in spring and summer. The major difference from

2002 and 2003 is the strong recharge in late February 2002 due to the snow melting that is not present in 2003 due to the near-absence o snow precipitation in the winter.
Discharge of stalactites G1 and G2 are more constant during the year while G7, G9 and G10 display a greater variability and during some period (Jan to Feb 2002 and autumn 2003) they reduced strongly the discharge and some of them stopped. Nevertheless, as a whole the coefficient of variability of all the drips vary between 50 to 150%, with few intra-annual variability, and match the field of "seasonal drip" follow Smart and Friedrich, 1987 and Baker et al., 1999 definitions.

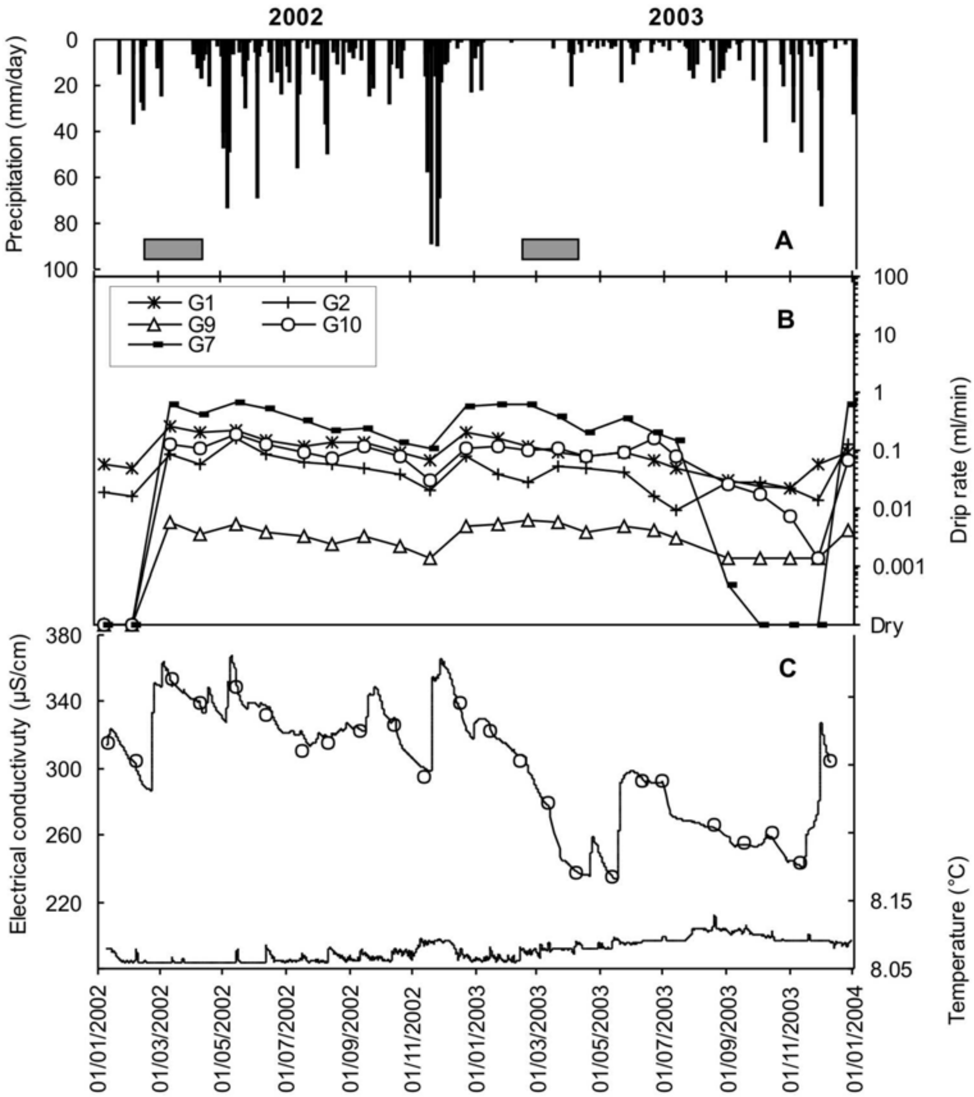

Fig. 3. Two-year long drip rates of five selected stalactites in Cogola di Giazzera main chamber (B) compared with the rainfall record at Terragnolo (A) and the electrical conductivity and temperature continuous monitoring of stalactite G1. The grey bars in (A) represent the snow-melt periods; the circles in (C) the periodic electrical conductivity measurements.

4.2. Electrical conductivity and temperature

The general trend of electrical conductivity measured on G1 drip-water (Fig. 3 C) is characterized by some abrupt increase in EC up to 70-90 µS/cm followed by gradual decreases. The more pronounced of these latter occurred in winter-spring 2003 when was reached the lowest value of 234 µS/cm. The strongest EC increases are due to precipitation events exceeding 20 mm (19.11.02, 19.05.03, 17.11.03, 29.11.03) or, only for 2002, to snow melting event (22.02.02). The lag-time between the EC rising and the mid-point of the rainfall events vary from 12 to 48 hours. These episodes triggered the drip-rate increase in all the monitored stalactites and the strongest drip-rate increases are recorded in the faster discharge stalactites G7 and G10 (cfr. Fig. 3 B and C). The general trend, therefore, is exactly the opposite of fast dripping stalactites monitored at Grotta di Ernesto, that open about 45 km NE from Cogola di Giazzera, were the strongest rainfalls were followed by abrupt EC drops of -20 to -50 µS/cm due to the fast infiltration of the low-mineralized water associated to the rainfall events (Borsato, 1997).
Figure 2 C visualize the water temperature: although the terminal chamber is near to the cave entrance, and the rock overburden is less than 25 m, the temperature is constant throughout the year with a mean value of 8.08°C. In the

graphic are visible some minor peaks that are connected with the monthly visits to the cave that usually last 2 hours. The cave needs one or two days to re-equilibrate its temperature.

4.3. Calcium content and saturation state

Figure 4 visualize the relationship between drip-rate, Ca content and calcite saturation (SIcc) of drip G1 and G10. For both stalactites there is a clear positive correlation between the three variables. In particular, we observe a linear relationship between Ca content and SIcc (R^2 = 0.74 for G1 and 0.67 for G10), and an exponential correlation between drip rate and Ca content (R^2 = 0.59 for G1 and 0.85 for G10). The exponential correlation between drip rate and SIcc (R^2 = 0.41 for G1 and 0.47 for G10) is weaker, due to some dispersion at low-SI values, but still striking.
These situation reflects the calcite precipitation inside the aquifer and along the flow-path in the cave (mostly along the feeding stalactite), that lower the Ca content and the SIcc during low-discharge periods.

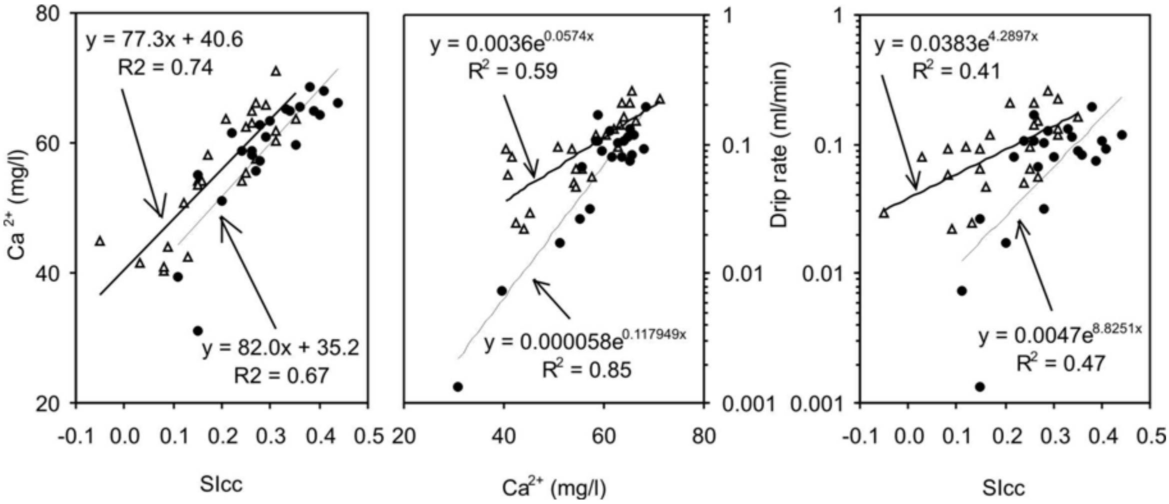

Fig. 4. Correlation between Ca content saturation state and drip-rate of stalactites G1 (triangles) and G10 (black circles) for 24 monthly measurements.

5. Conclusion

The two-year-long stalactite drip-water monitoring at Cogola di Giazzera reveals the predominant seasonal discharge of all the studied stalactites. The discharge, electrical conductivity and saturation state of the stalactite drips are directly controlled by the infiltration events and, as a whole, the longer is the time elapse from the infiltration event the lower is the drip-rate, Ca content, electrical conductivity and calcite saturation state of the water. This feature is clearly related to prior calcite precipitation along the flow-path, both in the rock above the cave and within the cave itself on the stalactite. This study testify the peculiarity of shallow caves in fissured aquifer with respect to karst hydrology, and the implication for palaeoclimatic reconstruction from speleothems. The cave show an enhance sensitivity that can record even sub-annual and monthly-long episodes, but is prone to possible discontinuous growth during drier periods.

Acknowledgements

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6. Bibliography

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