4.5. Călugări ebb and flow spring

Călugari ebb and flow spring is located in the South-Eastern end of Vaşcău karst plateau, on the left side of Vulpilor brook, a tributary of Topliţa stream in the watershed of Crişu Alb river, in the area of Izbuc Monastery. It emerges from Anisian dolomites, in the neighbourhood of underlying Werfenian sandstones.

In 1863, the Austrian geographer A. SCHMIDL published "Das Bihar Gebirge an der Grenze von Ungarn und Siebenburgen" in Vienna, a first inclusive morphology and speleology study of a area on the Romanian territory. This is the work that introduces Călugări spring in the world geographical literature as an ebb and flow spring (intermittent spring). The author presents both the results based on personal observations made at its location, accompanied by a splendid watercolour image of the source (photo 1), as well as the results of previous observations made by VASARHELYI (1822), MEDVE (1823), WASTLER (1859) and CSAPLOVICS (1861).

J. VASARHELYI is known as the first researcher of this spring, being the source of its name in hungarian, that is "Dagado forras", or "the rising spring". In 1822, he says that "local people use the water as a healing force; it fills the reservoir in 2 minutes 30 seconds up to 1.5 feet (equivalent of 50 buckets). After that, the water went back fast, and it returned and went back again in 16 minutes. For one hour there was no water."

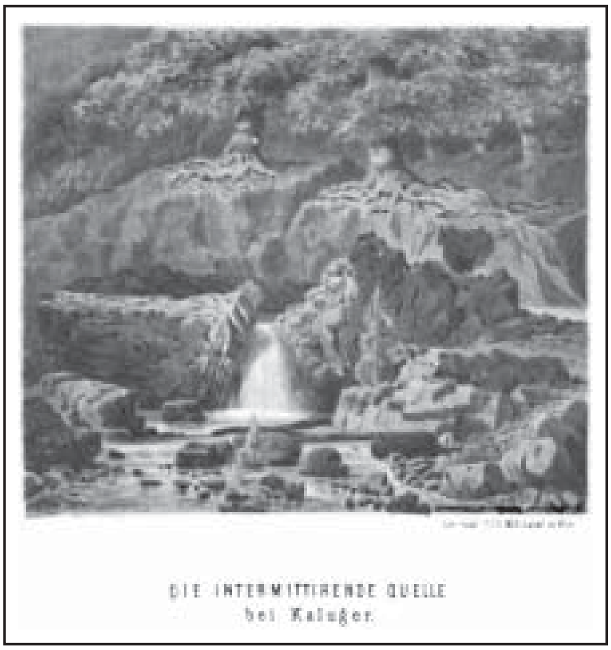


Photo 1. Ebb and flow spring at Calugari in flowing period, aquarelle in A. Schmidl's book "Das Bihar Gebirge an der Grenze von Ungarn und Siebenburgen" (Vienna, 1863).

CSAPLOVICS (1861) says that "the emergence of water in Călugari spring is preceded by loud noise. The water comes every hour or every half of hour, and while raining, event more often than that."

On 3 September 1858, Prof WASTLER notes detailed observations on the timing of eruptions, concluding that the duration of one cycle is 17'55'', while the raising of water in the reservoir from the beginning to its retraction lasts 2'16''. 4'50'' represents the time from the moment of rising to the end of the retraction, and the reservoir stays empty for 13'5''. In 1860, in autumn, he finds the spring waterless.

A. SCHMIDL had 29 observations over 24 hours in 1861, remarking the alternation of a strong eruption with a weak one. The water raised with 1 Fuss and 9 Zoll in the reservoir. He points out that the spring has a winter break in between September-March.

G. PETHO publishes "The rising spring" in 1896, in which he provides a detailed description of the flow, and comments on the feeding source and compares his own observations with those of his predecessors. On 14 August 1892, one hour and 28.5 minutes following a last eruption, "there is a shush in the evacuation tube. The water comes. In its underground route, it pushes and suddenly evacuates the air in the evacuation tube. A few moments later, the water rises up at 62 cm in two minutes. From that moment, the level goes down slowly, part of the water is drained in the riverbed on the exterior side of the reservoir, and a small fall appears, while on the other side about a third goes back in the spring. In 16.5 minutes a whole cycle takes place."

A. MIHUŢIA presents a sketch of the spring in 1904 (Fig. 1), and his observations on 14-15 July and 12 August 1901 alongside those of his predecessors. "The spring mostly emerges in early summer, in mid-summer its rise is less often, and in autumn even less often. The connection with the rainfalls is clear, respectively the amount of underground water and the amount of spring water." The author points out, as Petho did in 1869, the presence of a second source

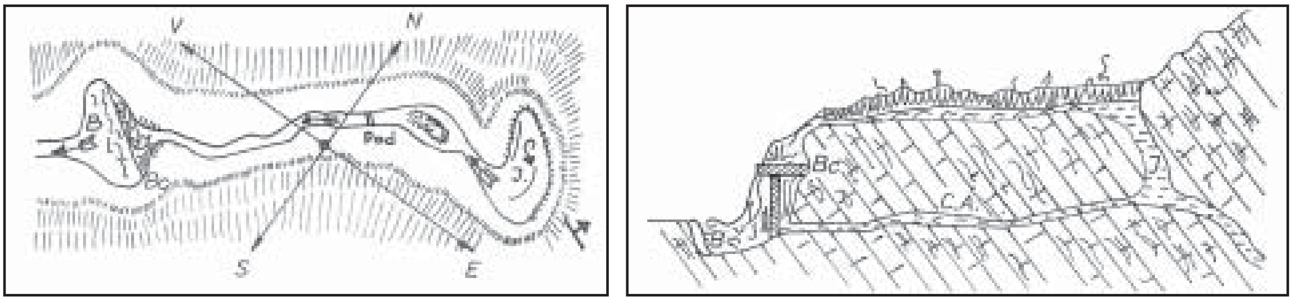


Figure 1. Sketch and cross section in the area of the of the spring (A. MIHUȚIA, 1904).

placed under the fall (Figure 1, to the right), a source by which the water of the same aquifer is discharged.

I. AL. MAXIM, in 1942, proposes a template of the spring functioning based on the siphoning principle and the observations performed on the spring run by PETHO (the 14th and 15th of August 1892) and, partially, by SCHMIDL (1st of September 1861), observations that he generalizes. From these data, MAXIM found out "a grouping of the flows , i.e.: a) after two flows succeeding at short intervals, there is no flow but after a long pause; b) the long pause between the two flows is interspersed by another flow; and the second short flow oscillates in time". This functioning of the ebb and flow spring is explained by the presence of a "double siphoning", that means it has two grottos of water storage: one smaller, down, and one bigger, up (Fig. 2).

I. Al. Maxim also remarks that the secondary source under the fall, a source draining most of the spring water and affecting its operation, "was carefully plugged by the monks, so that the flow of water keeps going the same way."

Besides the up-mentioned researchers, K. SIEGMETH (1899), also wrote about the ebb and flow spring.

After the period of their visit to the spring, the authors mentioned either the existence of oscillations of the spring water and the laps of time between them, or the immobility of the water surface at its bottom. The observations are made in very short intervals of time, usually in summer, the published data being very non-homogenous. But they provide important information regarding the periods in which the spring was active.

Călugări ebb and flow spring (Fig. 3 and photo 2) comes from a 50 cm circular gallery located at the bottom of a irregular pool, rather rectangular (3.6 × 1.8 m), named by I. Al. MAXIM "Puţul de Piatră" (the Stone Pit). The pool, excavated by dissolution in dolomites, is 1 m deep, and its bottom, continuously ascending, goes on with a stone ditch, being 8.5 long in total. In the middle of the ditch, the slope turns rough, with a threshold located at 90 cm over the access of water (Fig. 4).

The water in the Stone Pit is discharged in a concrete pool shaped like a quarter of a circle, with

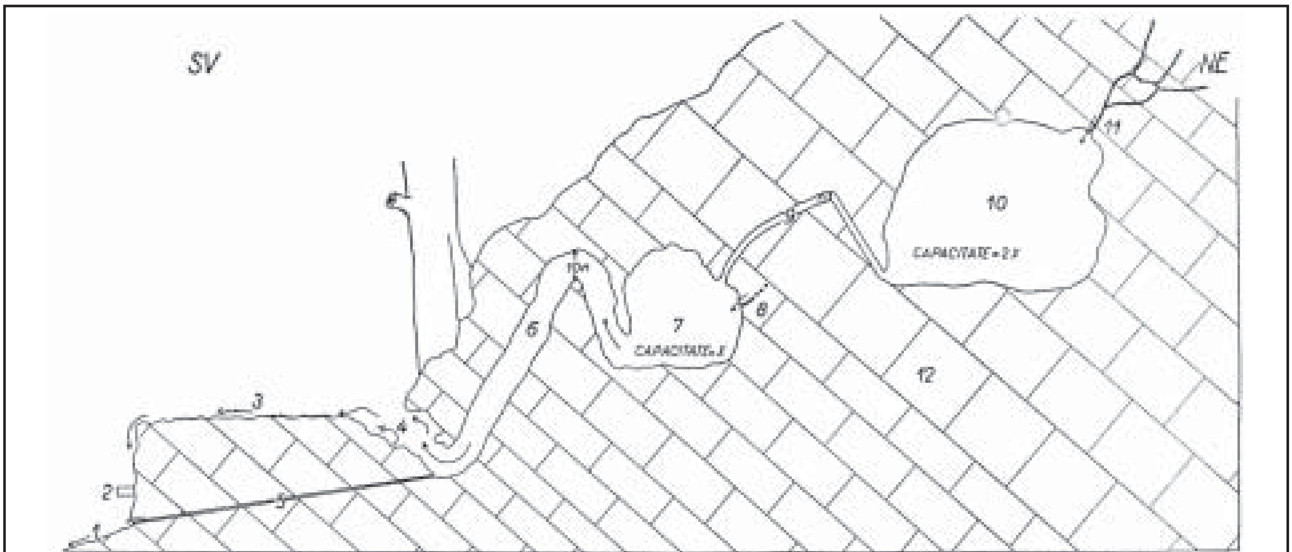


Figure 2. Principle of Călugări spring's work after I. Al. MAXIM, 1942.

4.4 m radius (¼ pool). In the concrete on the bottom of the ¼ pool, there is a hole where the water go out at high oscillations in Stone Pit (source A in Fig. 4). Other two parasite sources of a similar regime come in the ¼ pool on its Western side. A parasite and constant sources comes at the South-Eastern exterior corner and under the floor of ¼ pool.

Topographic survey were done in the area of the spring. The elevation marks presented in the text are relative altitude, being in relation with the bottom of ¼ pool, near "A" source in Fig. 4, seen as "0 m" relative altitude.

A staff gauge (100-210 cm) was put in the Stone Pit, its bottom being at -0.2 m relative altitude. The observations in Stone Pit, were irregular, based on monthly direct observations or with a shifting water level recorders (1:1 scale and 7 cm/hour paper speed). In between October 1989-November 1991, a water level recorder of 1:10 scale and 24 cm/day speed was installed. The debit of the source was almost constantly measured via a triangular weir (α = 90°C) with a water level recorder (1:5 scale and 24 cm/day speed), installed at Vulpilor brook 20 m downstream the spring. Vulpilor valley are mostly dry throughout the year.

Systematic hydrologic records, started in October 1986, and outlined that over one year, water oscillations in Stone Pit occurred in various ways (Fig. 5).

When the rainfalls were important, mostly between December and June, the water in the Stone Pit has high oscillations, of 60-80 cm amplitude, and of 9-15 minutes with about 1:7.3 ratio between the duration of water level rise and decrease, with overflows past a threshold. A clear invariance of high oscillations over long durations was remarked (Fig. 6).

Eruptions are preceded by the activation of parasite sources close to the Stone Pit and the loud evacuation of the air in underground holes. The level of the water goes up fast in the Stone Pit, over the threshold (0.64 cm relative altitude) and is discharged in the ¼ pool as a small fall. Once the maximum level is reached, the water goes down slowly, and once the threshold is reached the exterior flow stops, and the water in the Stone Pit goes back in through the access pipe and is evacuated outside by parasite sources.

Fig. 7, left, presents the shapes of high oscillations observed in various times, while Fig. 7 right indicates the debit of the source during those oscillations.

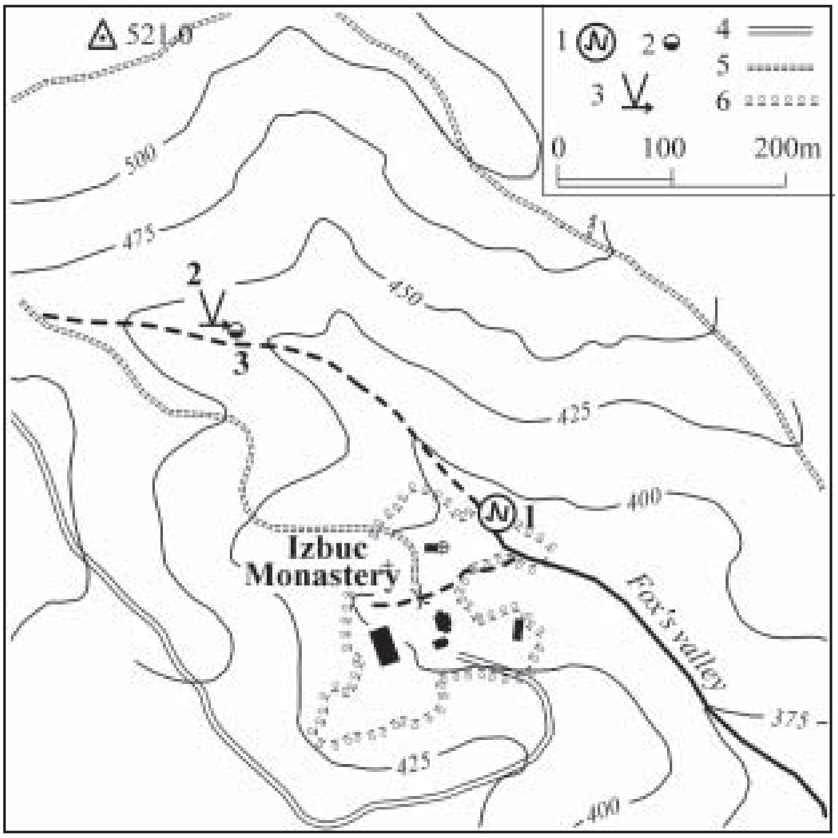


Figure 3. Site of the spring.
1 - Călugări ebb and flow spring;
2 - pothole;
3 - temporary spring;
4 - road;
5 - foot path;
6 - Izbuc Monastery area.

Photo 2. Călugări ebb and flow spring in flowing period.

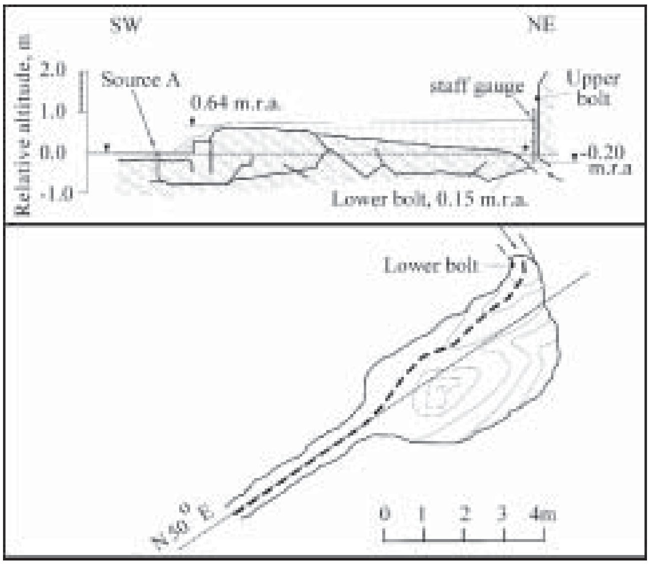


Figure 4. The Stone Pit. Cross section and sketch.

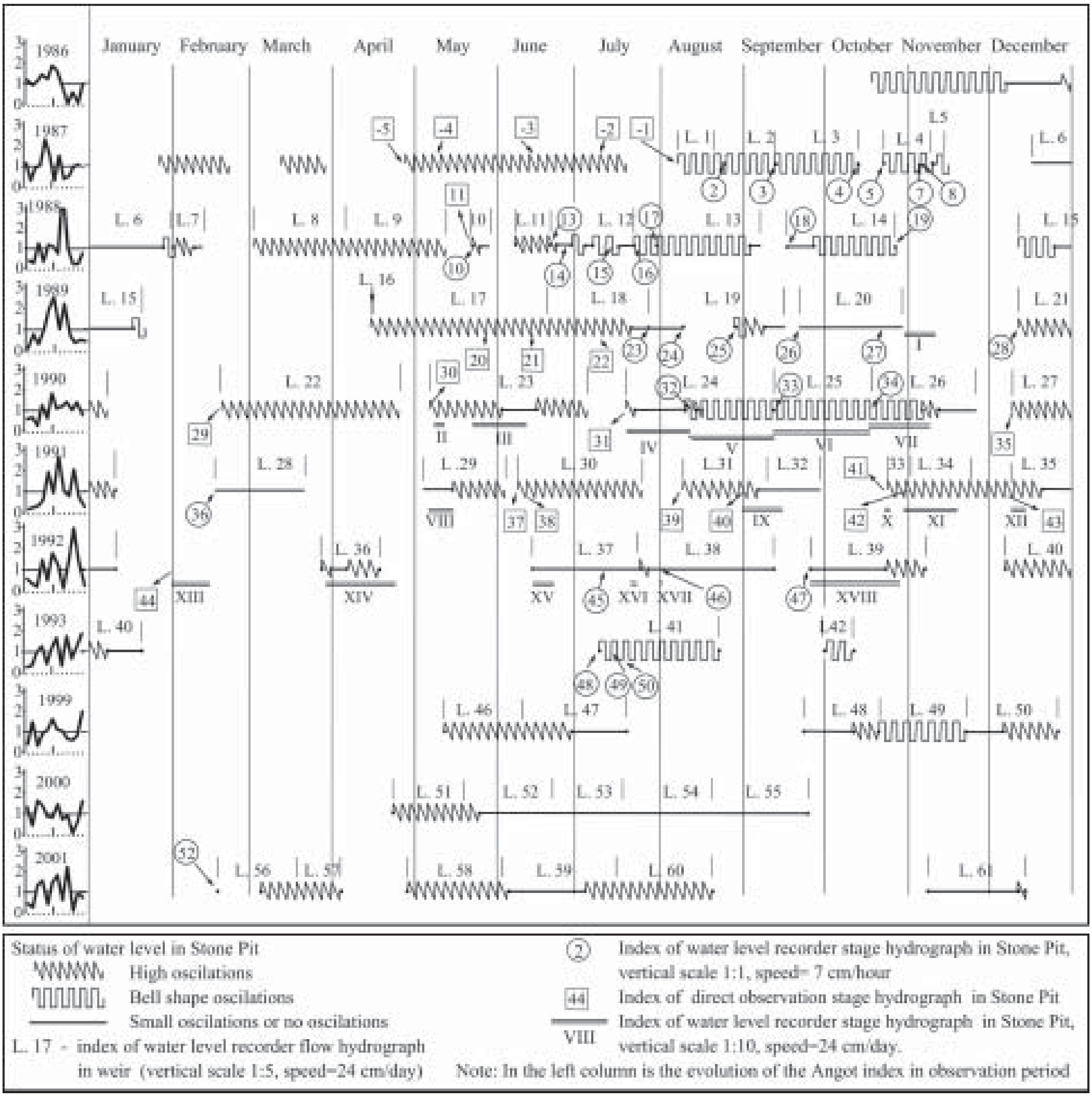


Figure 5. Observations performed at Călugări ebb and flow spring.

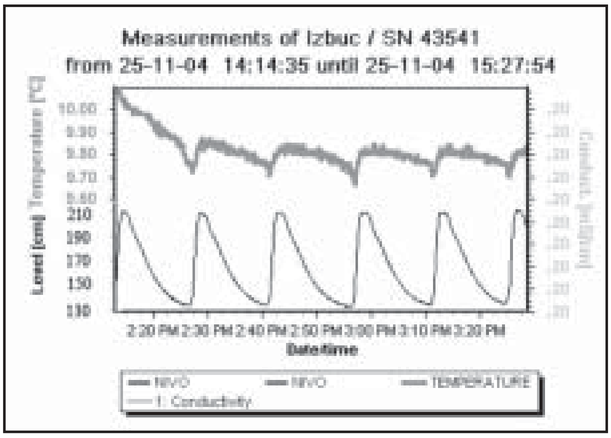


Figure 6. Water level and temperature evolution in Stone Pit during high oscillations.

The source is discharged over the threshold at medium debits of the system higher than 2.5-3.0 l/s. There were cases though when higher oscillations were noted for 1.7 l/s. The highest mean debit recorded, evacuated from the Stone Pit and the parasite sources, was 10.2 l/s, with an absolute maxim in the peak of the discharge of 33 l/s. The highest observed level, over 30 cm over the threshold, matched a maximum debit of 33 l/s. The average debit of permanent parasite sources varies between 1-5 l/s.

The height of the high oscillations goes along the medium debit of the eruption (Fig. 8). The relationship between a discharged volume of the source during the rise of the level (V1) and the decrease (V2) is of 1:3.5 (Fig. 9).

The relation between the mean discharge of the source and the duration of a high oscillation (T) is not relatively noticeable. During a time of no rainfalls, while the daily average debit goes down, the duration of the oscillations increases and this is even more noticeable at the end of high oscillations, when the duration of the oscillations, T, goes up considerably sometimes (Fig. 10).

While the flow rate decreases below cca 2.5-3.0 l/s, the amplitude of high oscillations goes down to 30-40 cm, which corresponds to 130-170 on the staff gauge, they stop abruptly (Fig. 11), the level of the water continuing to have small oscillations (Fig. 12, 13), with a 1.5 - 3 minutes ebb and flow period and with their amplitudes progressively decreasing from 8 cm to complete vanishing, together with their rarefy (Fig. 14, 15).

Further on, the spring regime exhibits a new expression, with **bell shaped oscillations** lasting about one hour and reaching 30 cm maximum

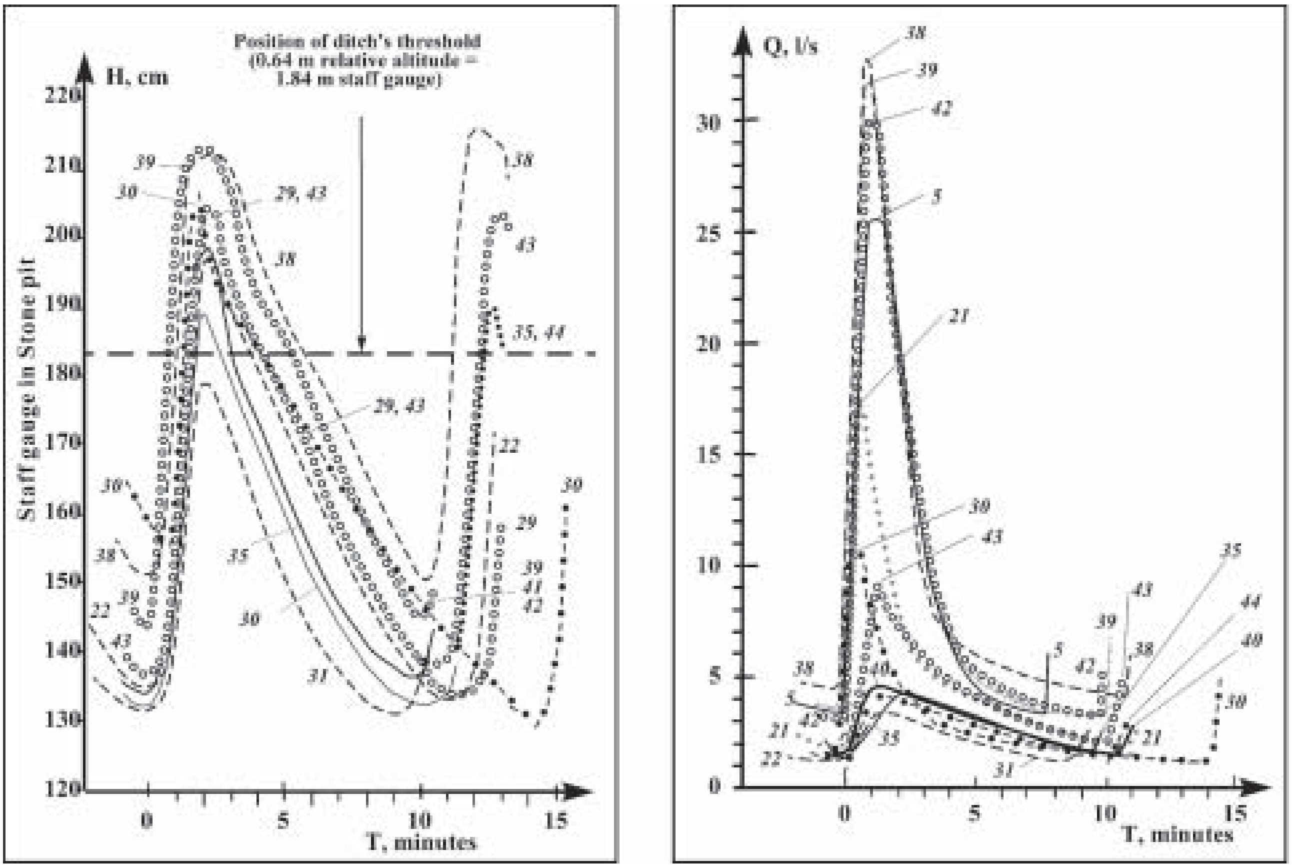


Figure 7. The shapes of high oscillations observed in Stone Pit (left) and evolution of the spring's discharge during those oscillations.

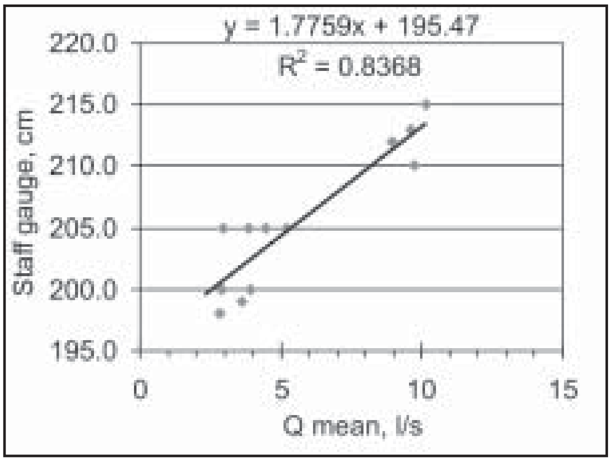


Figure 8. The amplitude of high oscilations increase with mean water discharge.

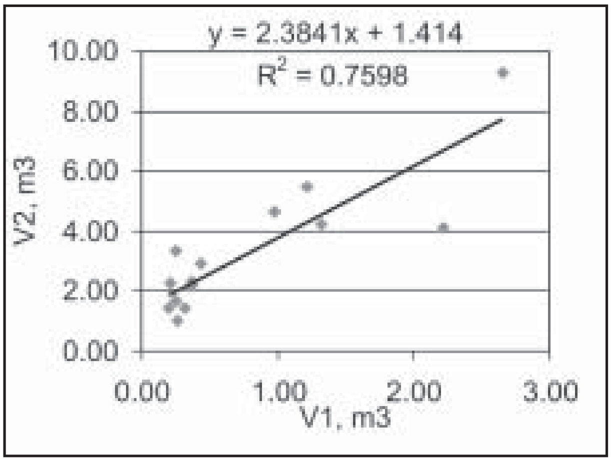


Figure 9. Relation beetwen water volumes discharged by the spring during the rise and decrease of the debit.

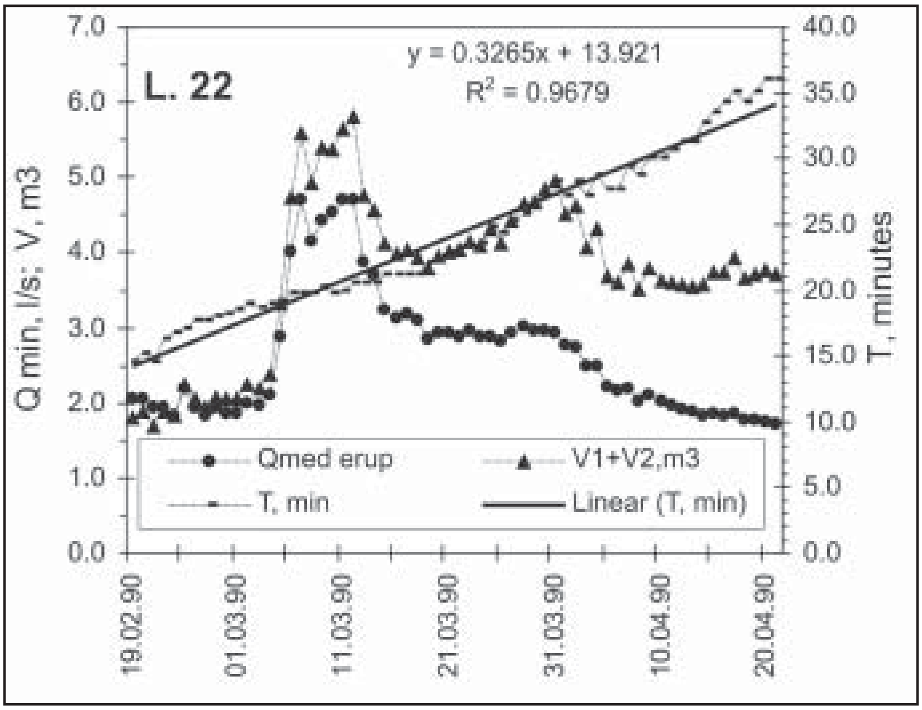


Figure 10. Results of processing the weir water level recorder flow hydrograph no. 22.

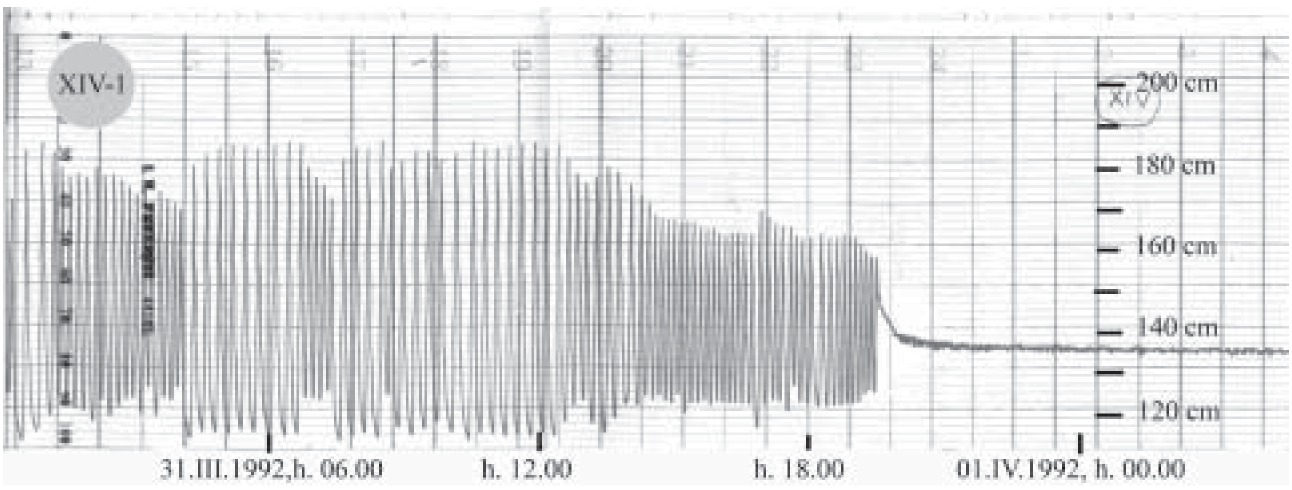


Figure 11. Stop of the high oscillations.

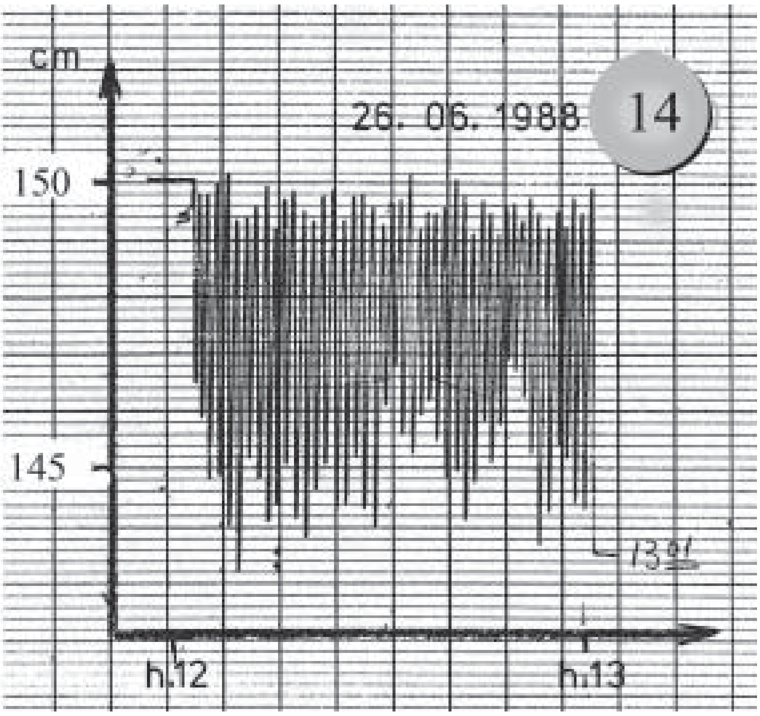


Figure 12

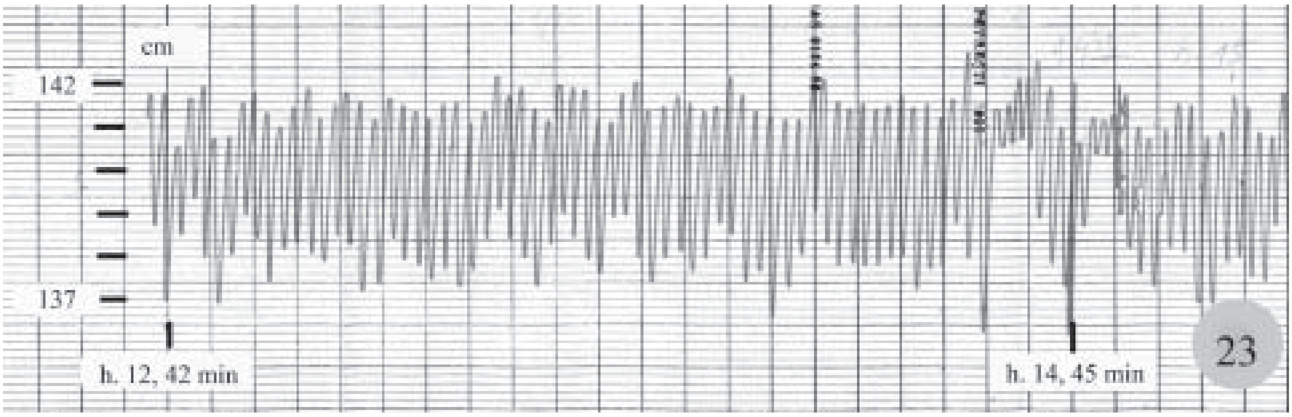


Figure 13

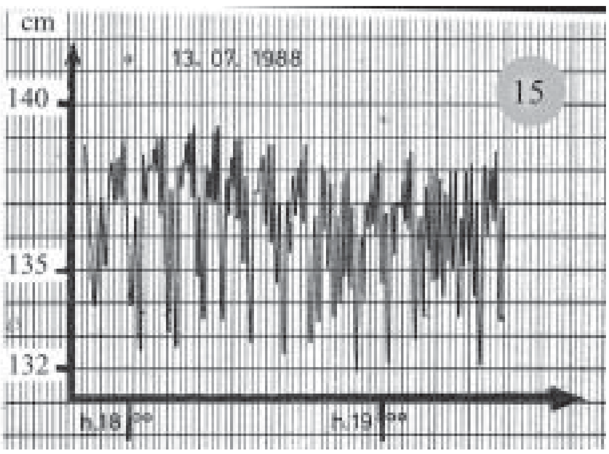


Figure 14

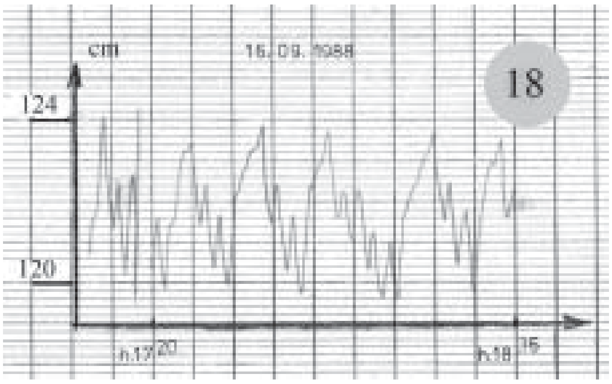


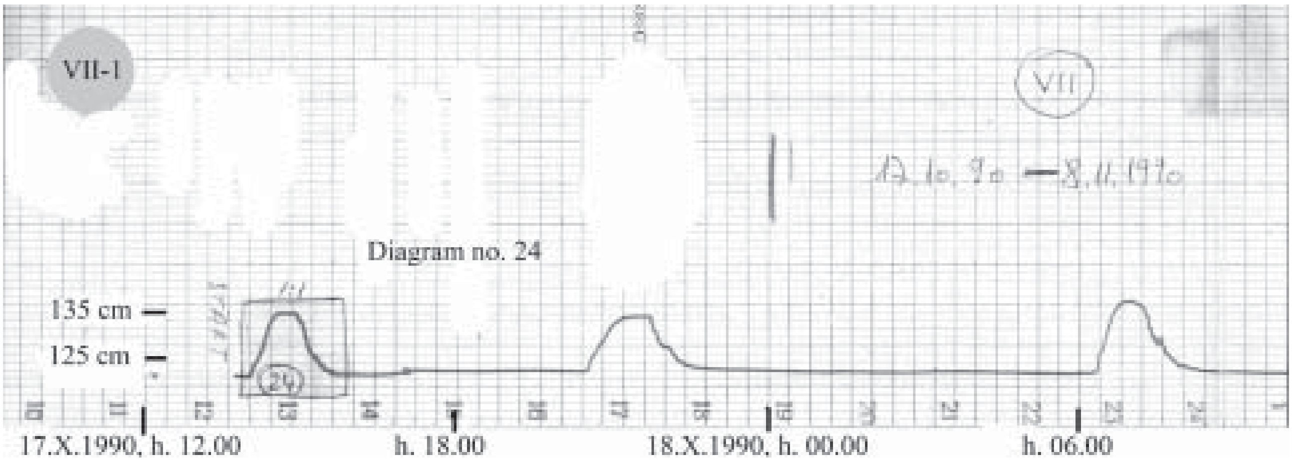
Figure 15

Figures 12, 13, 14 and 15. Different shapes of small oscillations.

amplitude (Fig. 16). In time, the interval between bell shaped oscillations increasingly large periods, ranging from 2 hours up to two oscillations or less once a day (Fig. 17), when the water level have only small oscillations.

The uneven distribution of rainfalls influences the operation of the spring, often altering the succession of oscillations previously remarked (Fig. 18 and 19).

Wet or dry character of a month within a year is illustrated by Angot index value (MARIA CRISTEA, 2004). The left column of Figure 5 present the evolution of Angot index during the years of observations at Ştei weather station, not-



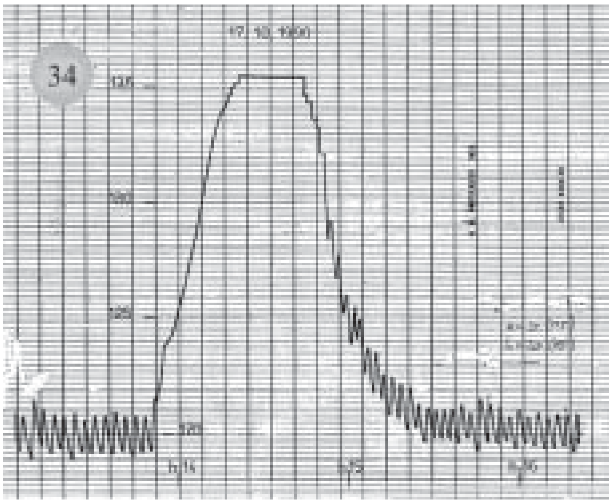


Figure 16 a & b. Sequence of bell shaped oscillations of water level observed in Stone Pit (1:10, 24 cm/day, above) and details of a bell shaped oscillation (1:1, 3.5 cm/hour, right).

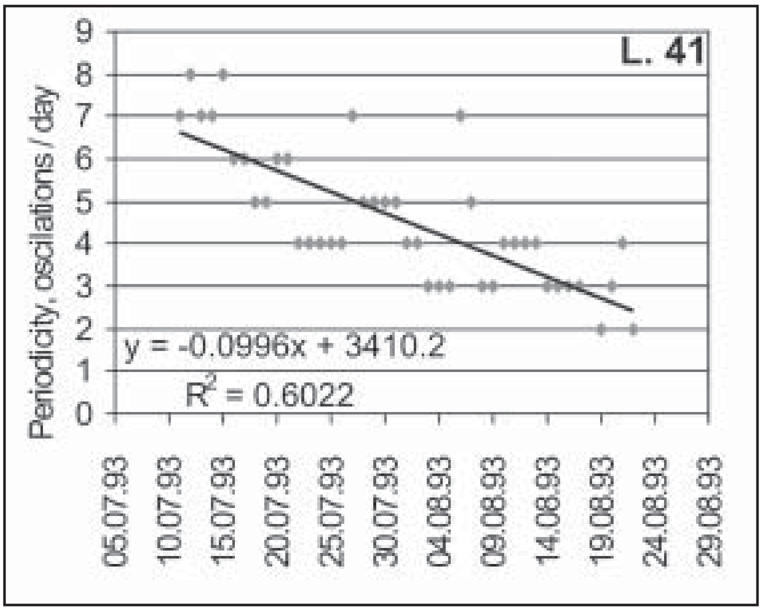


Figure 17. Rest period of bell shaped oscillations increase in time.

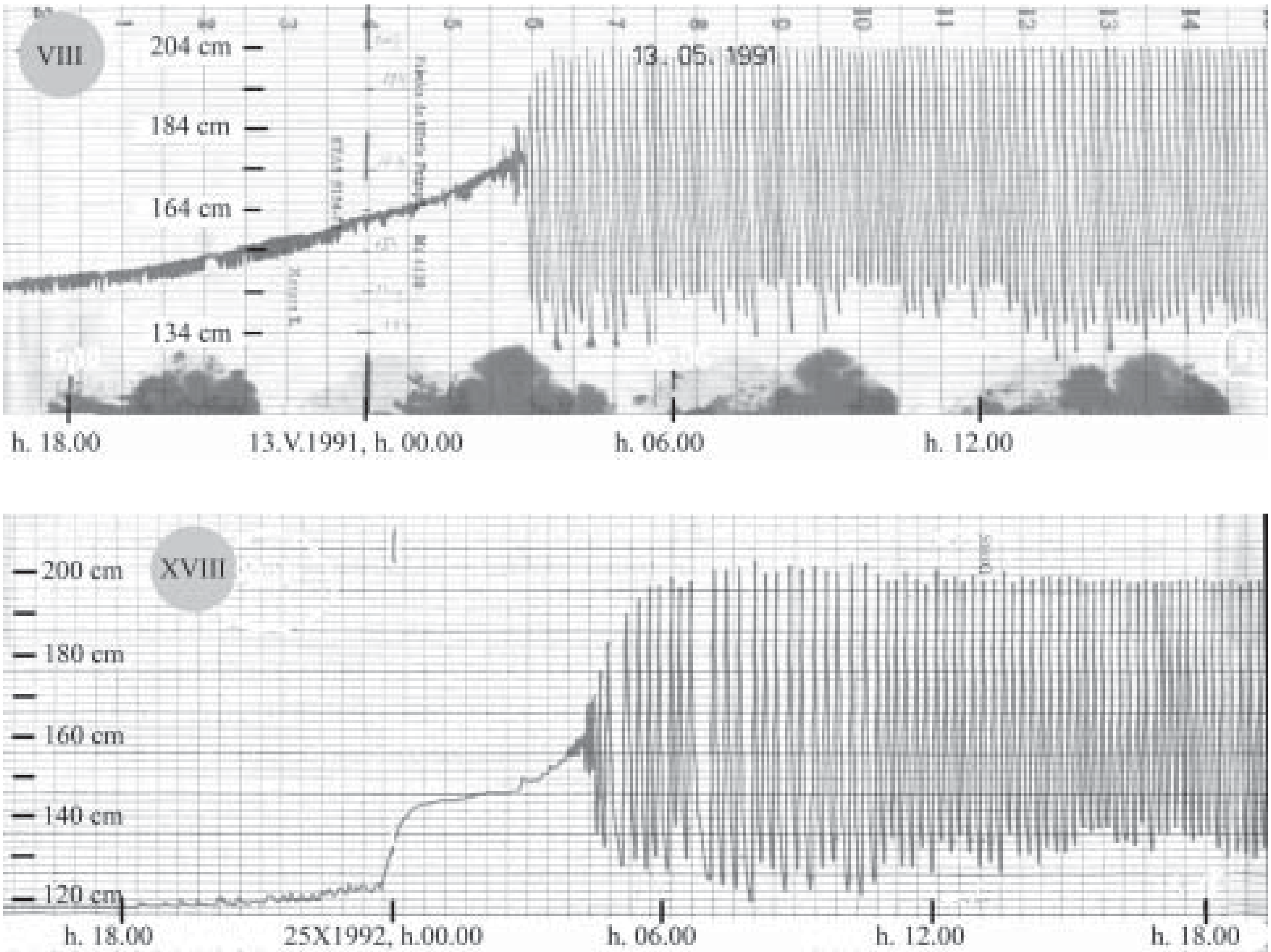


Figure 18. Different ways to start high oscillations.

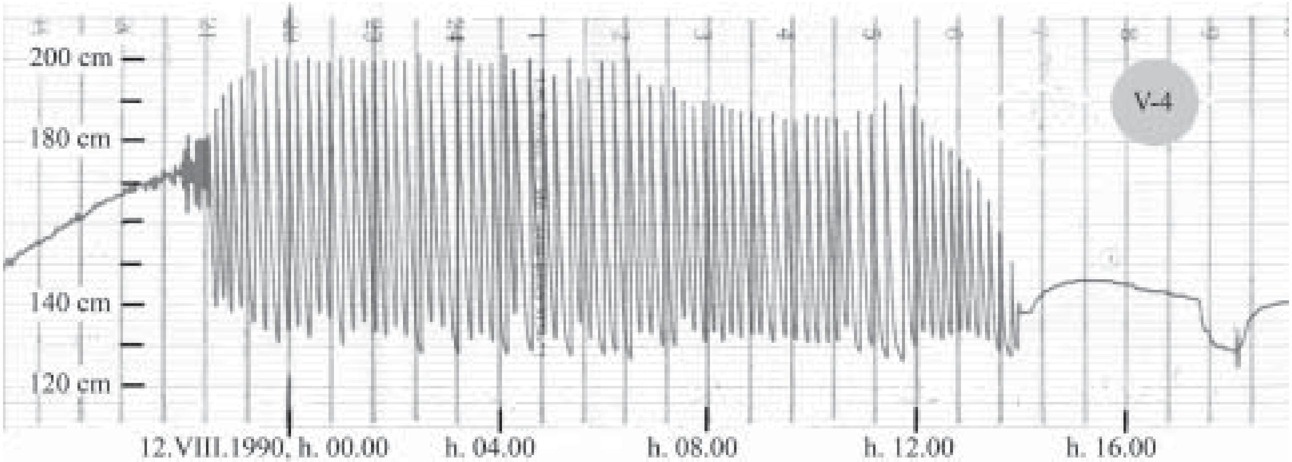


Figure 19. Framed high oscillation between small and bell shaped oscillations.

ing presence of high oscillations in Stone Pit in the rainy periods and their absence in the drought.

In spring 1985, following serious rainfalls, a 3 m diameter land collapse took place on the left side of Vulpilor brook 315 m upstream the ebb and flow spring, in the diluvia deposits with black dolomites blocks, having at the bottom a narrow descending gallery of 10.5 m long, build of the same deposits. The gallery, explored by the author in 21.10.1987, ends in the top of a karst hole with a lake 4 m below, whose surface oscillates. In 10.12.1988, GH. BRIJAN in Ştei survey the lake in pothole (Fig. 20). The observations showed that the level of water in the lake has oscillations of a similar regularity as the ebb and flow spring. The hydrological connection of those two points was proved by a fluoresceine test undertaken at 06.11.1987

The oscillations of the level of water were occasional recorded, first by sight, on a staff gauge and then on a 1:1 water level recorder for short time, and finally based on air tube method with a rubber tube. The access in the hole was difficult and dangerous. Meanwhile, the access gallery in the underground lake was slowly clogged, and in 1995 it turned unreachable.

In between 20-21 October 1990, during the bell oscillations at Stone pit, the level of the lake varied with 28 cm (water level recorder, Fig. 21). Meanwhile the debit of the ebb and flow spring varied between 0.32 and 1.51 l/s. The average volume of water evacuated from the underground lake during one eruption being 5.6 m^3, corresponding to a surface of the underground lake of about 20 m^2 (L. 26).

In Fig. 22 the recordings taken simultaneously at Stone Pit and the lake at the pothole in Vulpilor brook (air tube method) are presented on 13 July 1993. The level of the water in the pothole rises with 35 cm in 2 hours and 28 minutes, then it goes down, reaching the initial point after 1 hour and 08 minutes. If the water from the lake go direct to the Stone Pit, it travels the underground pipe between the pothole and Stone Pit (315 m) in 17 minutes and 12 seconds, with a mean speed of 0.3 m/s.

For high oscillations of water level in the Stone Pit, the level of the water in the lake of the cave has low oscillations, about 2 cm, within the error margin of the measurement. The maximum observed level of the water in the lake was 37.6 m relative altitude, when the water in the Stone Pit had high oscillations, and the overflow source (Fig. 20, a) had a debit of about 5 l/s and one could hear an underground fall.

The rare observations on the oscillations of the lake in the pothole are not sufficient to state if the lake represents a siphon mechanism or its more a appendix of the karst system. It is also to be mentioned that during the bell shaped oscillations into the Stone Pit, the oscillations of the water

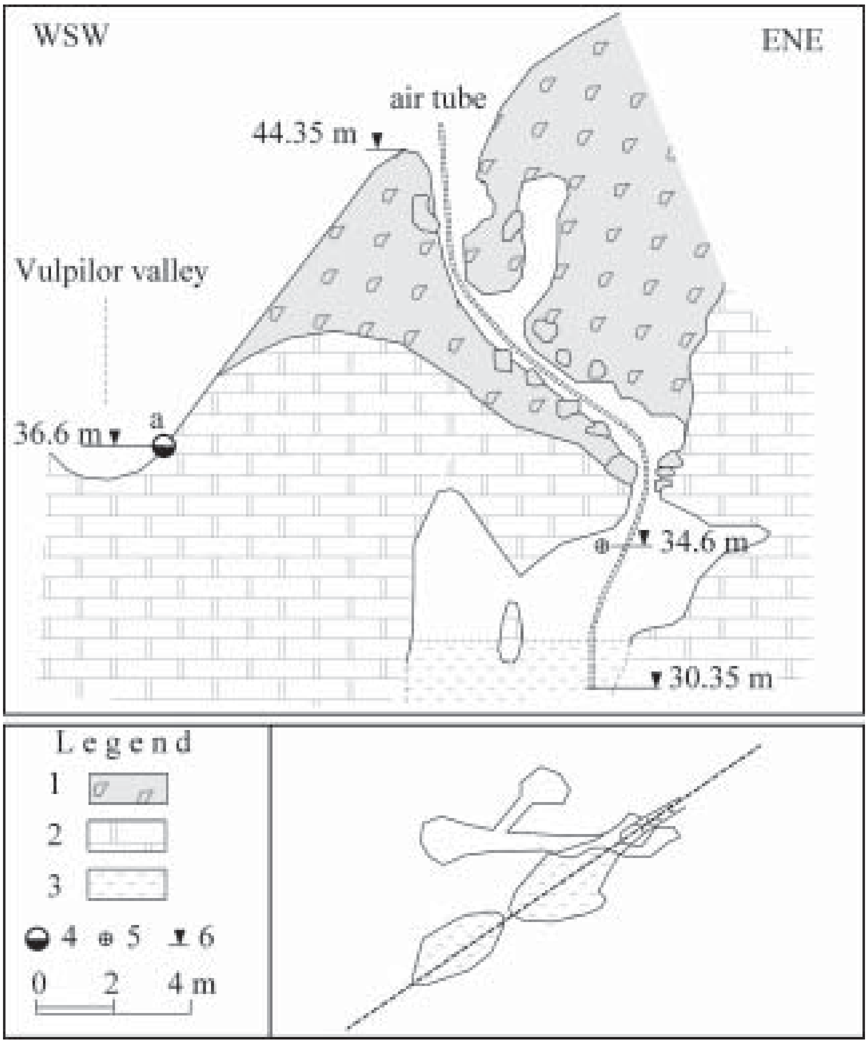


Figure 20. Pothole in Vulpilor brook.

Legend:

1. clay with blocks of dolomites;
2. dolomites;
3. underground lake;
4. temporary spring;
5. bolt;
6. mark with relative altitude

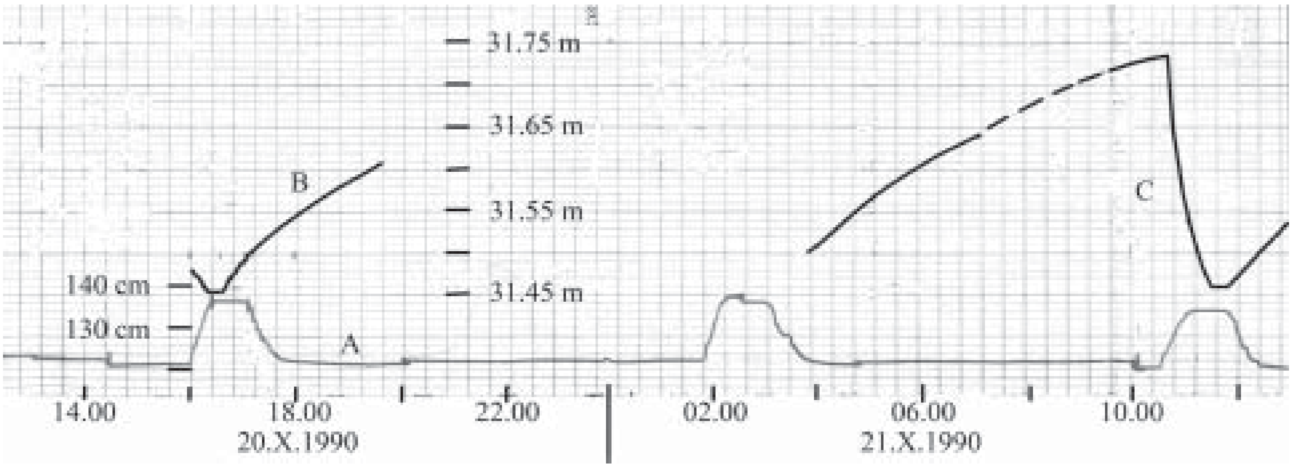


Figure 21. Oscilation of water level in Stone Pit (A) and in underground lake of pothole in Vulpilor brook (B and C).

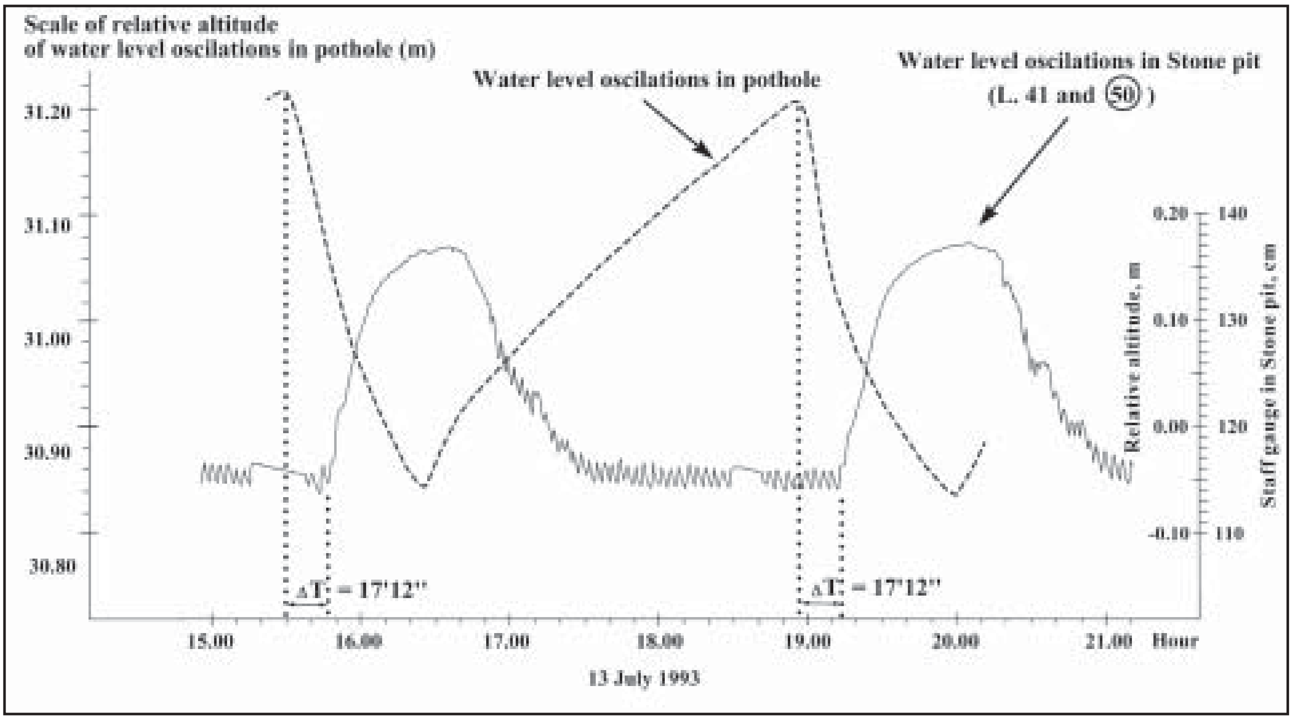


Figure 22. Simultaneous measurements of water level oscillations in Stone Pit and in underground lake in pothole in Vulpilor brook.

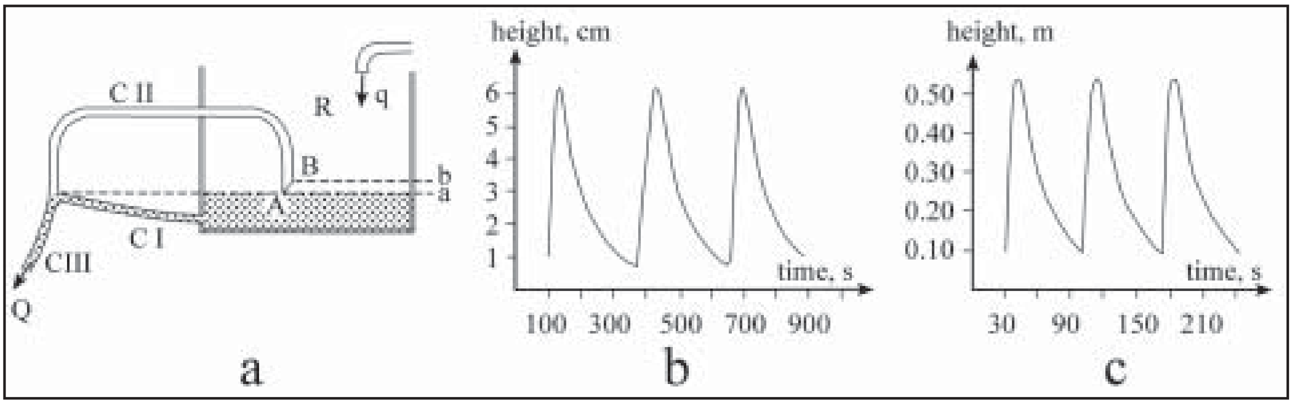


Figure 23. A. MANGIN's low scale model (a) gets oscillations of the water level (b), identical with those noted for Fontestorbes source (c).

level into the underground lake took place in different elevations.

The connection between the siphon mechanism and the Stone Pit is done by an underground flow directed on a karst pipe, with no connection to the flooded zone of the karst aquifer. The flow through the underground pipe has a free level, proved by the losses or the sources coming in the talweg of Valea Vulpilor in various times of the year. We also mention that no periodical debit variations were noticed at the overflow source "a" in Fig. 20, (no. 3 in Fig. 3).

We think the Stone Pit acts like a water stilling basin for hydro technical projects, and the oscillations of the water level are caused by the variation of the water speed into the Stone Pit. To the variation of the water speed into the Stone Pit (caused by the change from the rapid movement into the karst gallery, to the slow movement into the Stone Pit) it is associated a pressure wave that generates the movement of the water surface in Stone Pit (hydraulic jump). The variation of inflow discharge produced by siphoning mechanism are mirrored in the amplitude of hydraulic jump (by means of associated discharge wave).

In 1689 J. V. Valvasor describing spring Lintvern near Vrhnika, for the first time explained the function of intermittent spring by siphon (R. PODOBNIK, 1987). After about three hundred years, the explanation of the functioning of ebb and flow springs was approached by many researchers, among whom I. Al. MAXIM (1941), A. MANGIN (1969 a), P. HABIC (1970), A. JEANBLANC, G. SCHNEIDER (1981), J.-P. FABRE (1983), R. PODOBNIK (1987), LAZAREVIC R. (1991).

A. MANGIN (1969 a, 1969 b) notes detailed observations at Fontestorbes (Belesta-Arige, France) and published resulted data accompanied by a low scale model, which explains the mechanism of a ebb and flow source. Fonterstorbes acts as intermittent spring only in between 0.6-1.8 m^3/s debits, the duration of one oscillation varying between 48-75 minutes.

With the help of a low scale model (Fig. 23, a), A. MANGIN gets oscillations of the water at a low scale (Fig. 23, b), identical with those noted for Fonterstorbes source (Fig. 23, c).

The low scale model is made of a reservoir R connected to two pipes, a siphon CII and an almost horizontal one CI, which join in point C to result an evacuation pipe CIII. The reservoir is fed with a q debit, the debit evacuated through CIII being Q.

When reservoir R is full, the water obstructs the gap of air CII in B. The debit at CIII rises, Q>q, causing the emptying of the reservoir up to point A. At that moment, the activation of the air intake leads to a higher loss of the load and the reduction of Q evacuated debit which turns lower than q and the level rises in the reservoir up to the full obstruction of air gap CII. At that moment the loss of load disappears, while debit Q rises and the phenomenon restarts.

PODOBNIK R. (1987) using a model consisting of a long plastic tube of 12.3 m and a diameter of 43 mm, placed in different positions, obtained similar stage hydrograph as those of ebb and flow springs.

Starting from hydraulic intake air bases in siphons (CASTELEYN J. A. et al., 1977) and from three ebb and flow sources hydrographs flashing in the former Yugoslavia, BONACCI O. & BOJANIC D. (1991) suggest a mathematical working model of ebb and flow springs (springs called rhythmic by authors) consists of two reservoirs joined by a siphon. With the proposed model the authors have obtained identical simulated to those observed hydrographs and were possible to define the real dimensions of the siphoning mechanism.

Research on models performed by MANGIN A. (1967), PODOBNIK R. (1987) and BONACCI O. & BOJANIC D. (1991) showed that simulated hydrographs can be obtained identical to these observed at intermittent sources with very different patterns of combining pipelines, tanks and siphons, and stressing the complexity and diversity of these natural phenomena.

Călugări spring is a permanent karst source with a complex type of functioning. The high oscillations are similar to those at Fonterstorbes and may be explained based on the model proposed by A. MANGIN. They do not stop at maximum debits as the Fonterstorbes source does, but high debits are evacuated through the overflow source ("a" in Fig. 20).

Bell-shaped oscillations noticed in the Stone Pit may be explained by the way a simple siphon works, which is supported by their shape and the continuous reduction as the debits gets low.

Low series of oscillations noticed between the high and the bell ones are generated by debit perturbations between those two types of oscillations.

The water at Călugări is a Ca-HCO3 one, with a medium mineralization of about 300 mg/l (Ca^{++} = 40.1 mg/l, Mg^{++} = 18.2 mg/l).

We hope that future observations and further interpretation of collected data to bring new clarifications for Călugări ebb and flow spring.

Acknowledgements

I would like to express my gratitude to father Ioan Grebenea, abbot of Izbuc Monastery during research period, for his understanding and accepting to note observations and the warmth shown during all my visits.

I would also like to thank to speleologist G. BRIJAN in Ştei, for his help to explore the pothole in Valea Vulpilor and undertaking parallel hydrological observations to the Stone Pit.

I will thank A. Schneider in Oradea for the translations from German and Hungarian of the reference papers on Călugări spring.

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