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CO_2-DRIVEN COLD WATER GEYSERING WELL IN TRANSYLVANIA - BĂILE CHIRUI

BOGLÁRKA CZELLECZ[1*], Z. PÁL[2], D. PETREA[1], Á. SZÁSZ[3], L. PALCSU[4]

ABSTRACT. – Co_2-Driven Cold Water Geysering Well in Transylvania - Băile Chirui. Cold water "geyser" or geysering well is the internationally used term of such phenomenon where cold water is erupting from a hydrogeological well due to CO_2 movement. Until now there have been reported 14 geysering wells all over the World (Glennon & Pfaff, 2004). Through this article we would like to add a "new" cold water "geyser" to the above mentioned list, the so called Chirui Geyser. Investigations on Chirui Geyser were carried out several times during 2007 – 2013. Compared with the others, Chirui Geyser has the longest erupting phase with its minimum 38 hours of activity. Switching from the active to the inactive phase or vice versa the values of different parameters of the water are also changing. There has been described an oscillating phase before the water falls back into the pipe. Such activity has not been reported at other cold water geysering wells. Chirui Geyser is located in a post-volcanic area where most probably CO_2 has a volcanic origin. In the South Harghita region there are several hydrogeological drillings that reached CO_2 rich mineral water aquifers. Many of them could possibly have geysering activity.

Keywords: *hydrogeologic drilling, geysering well, cold mineral water, CO_2 movement, South Harghita Moutains, Chirui Geyser*

1. INTRODUCTION

There have been described cold-water "geysers" (cold water geysering wells) all over the World; even so we can say that it is a rare phenomenon. Some examples are described in the USA, New Zeeland and Germany, while in Switzerland, France, Slovakia and Serbia the number of cold-water "geysers" is only one in each country. Articles appeared in the 19th century report some geysering wells driven by CO_2 in Hungary and Transylvania as well, but they were influenced and reconstructed because of the mineral water usage.

The geysering well phenomenon does not have a large bibliography. A few internationally accessible articles are published in the second part of the 20th century (Rinehart, 1974, 1976, 1980; Baer and Rigby, 1978; Campbell and Baer, 1978; Mayo et al.,

[1] *Babeș-Bolyai University, Faculty of Geography, Cluj-Napoca, Romania (*correspondence: boglarka.czellecz@ubbcluj.ro; czelleczke@yahoo.com)*
[2] *Corund-Praid Conservation Stewardship, Corund, Romania*
[3] *National Mineral Water Society, Baraolt, Romania*
[4] *Institute of Nuclear Research of the Hungarian Academy of Sciences, Hertelendi Laboratory of Environmental Studies, Debrecen, Hungary*

1991), more researches focusing on this topic were published after the year of 2000 (Waltham, 2001; Nurkamal et al., 2001; Lu and Watson, 2002; Glennon and Pfaff, 2004; Evans et al, 2004; Shipton et al., 2004; Lu and Watson, 2005; Lu et al., 2005; Gouveia and Friedmann, 2006; Bissig et al., 2006; Assayag et al, 2009; Barth, 2012; Han et al., 2013; Watson, 2014; Ladd, 2014). Several scientists refer to this topic because of CO_2 leakage or sequestration and not because of the geysering activity (Wilkinson et al., 2007; Heath et al., 2009; Burnside, 2010; Kampman et al., 2013). We need to point out some articles from the second part of the 19th century published in former Hungary that describe and present geysering wells in the Pannonian Basin, now eastern Hungary, eastern Transylvania and southern and south-eastern Slovakia, as well as some laboratory experiments used for the exposition of the phenomenon (Zsigmondy, 1875; Lucz, 1884; Antolik, 1890, Emszt, 1911, *, 1914). Nowadays the most researched geysering wells are the Crystal Geyser in Green River, Utah, USA and the Geysers from New Zeeland.

Cold water geysering wells have a geyser like operation due to periodic eruptions of water from a certain point. The water temperature is low, eruptions are caused by CO_2 movement.

The CO_2 driven cold water geysering wells are hydrogeological drillings and can be characterized by succession of active and inactive phases. The eruption of the water is considered to be the active phase, while in the inactive phase the water remains in the drilling tube but it is moving upward inside the tube. Usually the active and inactive phase periods/duration are each identical. The longest active period (among described geysering wells) can be observed at Woodside Geyser (USA) and Tumbleweed Geyser (USA) and they last for about 1.5 hours (Glennon and Pfaff, 2004). The longest inactive phase is characteristic for the Herl'any Geyser (Slovakia) and it lasts for about 32-34 hours (Glennon and Pfaff, 2004; Dobra, 1997; Dobra et al., 2007).

Hereby we intend to describe a "new" geysering well, the so called Chirui Geyser, that has not been presented in an international article yet. Chirui Geyser was first mentioned during the EU Intensive Program Seminar "Geography of Water" held in Romania in 2010 (Czellecz and Pál, 2011). Data and information described in this article are included in the PhD thesis of the author Czellecz Boglárka.

2. GEOLOGICAL AND HYDROGEOLOGICAL BACKGROUND OF CHIRUI GEYSER

The Chirui Geyser is located on the western slopes of South Harghita Mountains, along the Chirui creek valley at an elevation of 736 m (N: $46^0$18.176; E: $25^0$35.198). The study area can be characterized by Upper Pannonian volcaniclastics, pyroclastic flow and fall deposits on the surface that have a total thickness of about 500 m (Fig. 1).

Harghita Mountains is considered to be the southernmost segment of the Carpathian Neogene-Quaternary volcanic arc where the youngest edifices are located in the South Harghita segment. The Chirui valley is located on the volcanic plateau between Vârghiș (Harghita Mădăraș peak) and Luci-Lazu edifices that produced volcanic activity between 5.5 – 3.6 Ma (Szakács and Seghedi, 1995). As a post-volcanic phenomenon the underground CO_2 flow is still active and can be identified through the numerous

CO_2 rich natural mineral water springs in this region. The underground CO_2 flow is a complex and rhythmic process that is not influenced by the outside temperature or atmospheric pressure. The amount of the gas at a certain point is a sum of many flow-rates each of them having their maximum and minimum level successively (Ariniei and Pricăjan, 1975).

The main factor that operates the cold water gerysering wells is the underground CO_2 movement. Depending on the geological background the source of CO_2 can be multiple; in our case it probably has a volcanic origin.

The Chirui Geyser was last drilled (previous operation described by local people) for state order within an investigation project for mineral water resources in 1999 (László et. al., 1999). It has a total depth of 150 m where intersects a geological fault (Fig. 1). The tube is equipped with three filters corresponding to the aquifer layers with potential influx of water (Fig. 3). The Chirui Geyser gives highly mineralized and CO_2 rich mineral water; other free gas release can be observed as well (Fig. 2).

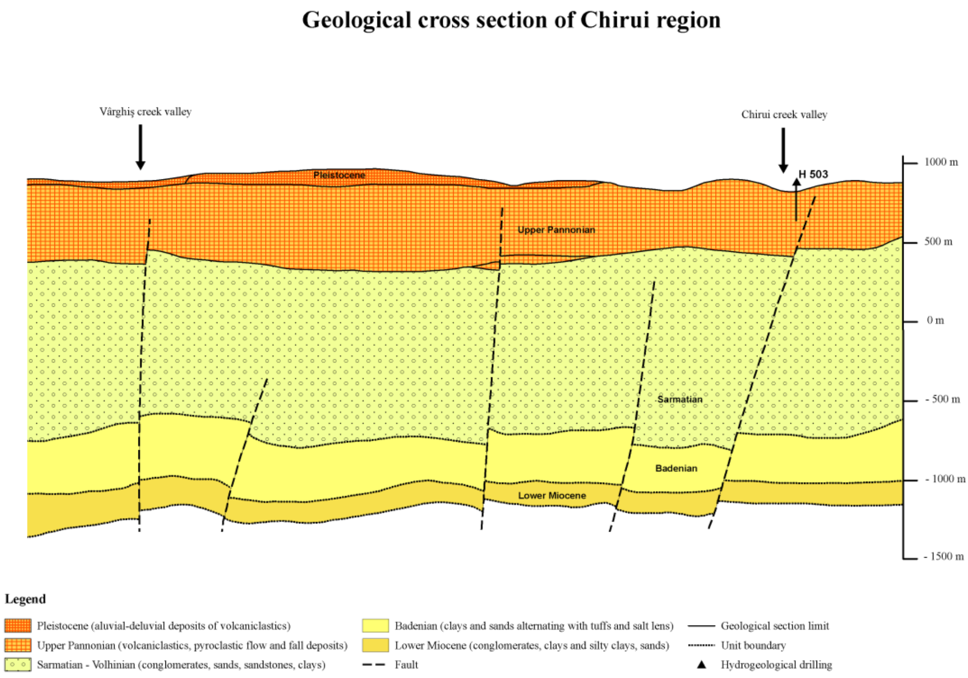

Fig. 1. Geological cross-section of Chirui Geyser surroundings
(Source: Geological map 1:50.000, L-35-64-A, sheet 79a, Băile Chirui, 1983)

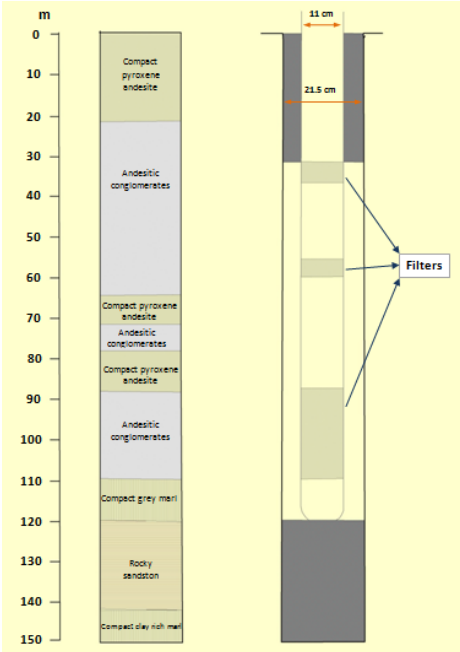

Fig. 2. Chirui Geyser in eruption phase (2015)
Fig. 3. Geological profile of the Chirui Geyser well (after László et al., 1999)

3. FIELD WORK MEASUREMENTS AND METHODS

In case of Chirui Geyser there are three possible aquifers for water influx into the system. Hydrostatic pressure deep down and CO_2 are the most important parameters that influence the operation of the "geyser". Analyzing the water quality is necessary to investigate the activation or deactivation of these aquifers and possible changes in the water physical and chemical characteristics during different phases.

During the first investigation period (2007-2009) there were measured the water temperature, water discharge, eruption level, electrical conductivity, pH, Total Dissolved Solids (TDS), CO_2 and HCO_3 content.

During the second investigation period (2013) we measured the water temperature, water discharge, electrical conductivity, pH, TDS and the hydrostatic pressure at different levels inside the drilling tube.

The water quality measurements were carried out using Thermo Orion Star multiparameter meter. Water discharge was measured manually using a 40 L keg. The hydrostatic pressure data were recorded at 10 m and 20 m deep using Dataqua DA-S-LTRB 118 electrode/equipment. The electrode was put in a few mm wide pierced pipe made of plastic that was introduced into the drilling tube. The aim of this method was to protect the electrode and to keep it fixed at the right depth.

During each investigation period the measurements were carried out in each hour, while the hydrostatic pressure data were recorded in each minute.

4. DESCRIPTION OF CHIRUI GEYSER PHENOMENON

During measurements carried out in the first investigation period, when there were no influencing acts in the “natural”, original operation of the “geyser,” we tried to define the duration of the active and inactive phases. Only one data set covers a full cycle (the period of time between two eruptions), while other, partial data sets are overlying to an active or inactive phase. The Chirui Geyser can be described as having an active (continuously erupting) phase of 38 hours and an inactive phase (water in the tube) of 13 hours. The full cycle duration is 51 hours (Fig. 4).

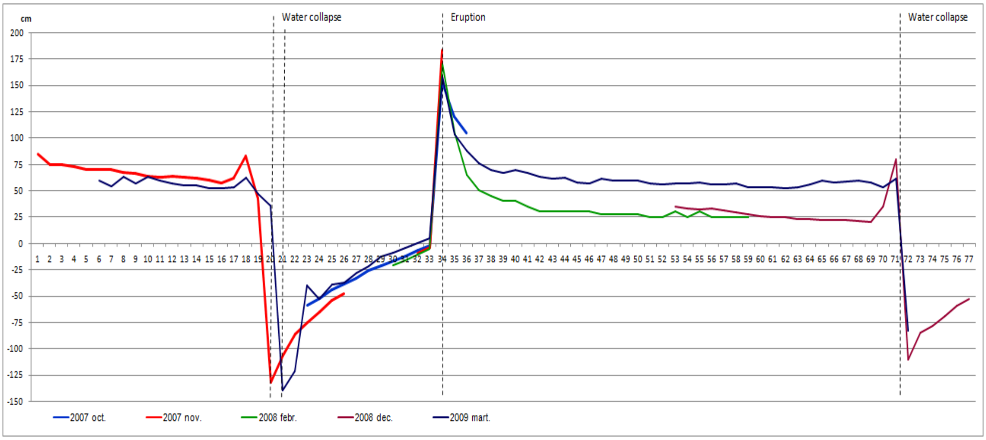

Fig. 4. The water level measured from the top of the pipe showing the full cycle of Chirui Geyser

The amount of CO_2 dissolved in the water and free gas movement are essential in the functioning of the “geyser”. Theories about the operation mechanism of the cold water geysering wells say that because of hydrostatic pressure changes inside the drilling tube (water column) dissolved CO_2 is released. Free gases form large sized bubbles that are moving upward taking the water molecules with them and finally causing the eruption (Lu et. al., 2005). Accordant with this theory in case of Chirui Geyser dissolved CO_2 content is decreasing when water starts to erupt and is increasing when the water falls back into the tube. Switching from one phase to the other causes a difference in the dissolved CO_2 content of about 450-600 mg/l (Fig. 5).

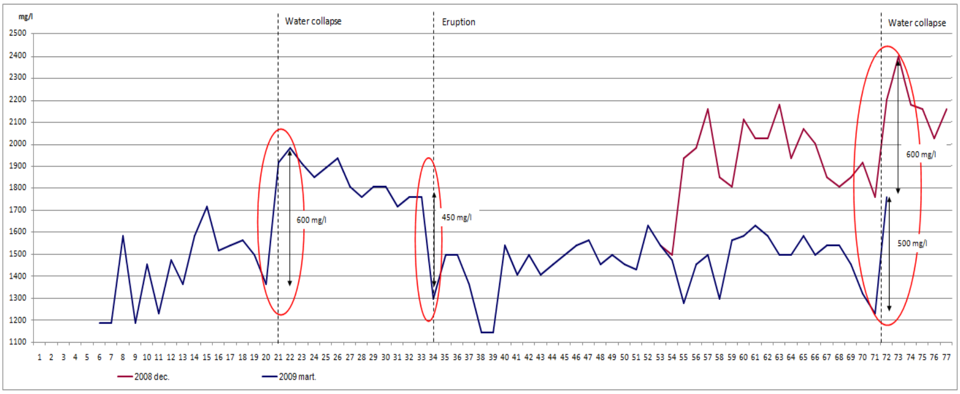

Fig. 5. Dissolved CO_2 content (mg/l) in the water at different phases of the Chirui Geyser

The hydrostatic pressure data set can be used for describing and analyzing the operation and a full cycle of Chirui Geyser. However, through interventions made inside the drilling tube for data collecting, the original mechanism of the „geyser" was influenced that caused a longer operation period.

In the inactive phase (called inactive because no water is coming out from the pipe) the water is moving upwards (increasing of the water level) inside the tube that can be associated with the increase of hydrostatic pressure. When water reaches the top of the pipe and flows out the hydrostatic pressure decreases suddenly and starts the eruption. This quick and significant decrease of the hydrostatic pressure values (approx. 0.35 bar difference) can be explained by appearance of many big sized CO_2 bubbles in the tube that push the water molecules upwards causing the eruption (Fig. 6).

In the first few hours the eruption level is the highest (approx. 150 cm), after that it stabilizes to a level of about 40 cm measured from the top of the pipe for many hours. A transition phase that can be characterized with the oscillation of the eruption level can be observed at the end of the active phase. These oscillations are reflected also by the changes of the hydrostatic pressure and water temperature values too (Fig. 6 and 7). As the moment of the water collapse is approaching the frequency of oscillations and the amplitude of eruption level are both increasing (Fig. 6 and 7).

The water falls back into the pipe very quickly (in a few minutes) to about 130 cm deep that causes a sudden increase of the hydrostatic pressure. From this moment the water level inside the tube starts to increase again that means the continuous increase of the hydrostatic pressure too.

The temperature of the water is also changing depending on the operation phase of the "geyser" (Fig. 6). During inactive phase lower temperatures can be observed (the lowest is 15.3^{o}C); while in the active erupting phase higher temperatures are characteristic (the highest is 17.5^{o}C). This trend and these temperatures of the water were observed during previous investigations too. In the inactive phase more CO_2 is dissolved in the water that correlates with the lower values of water temperature.

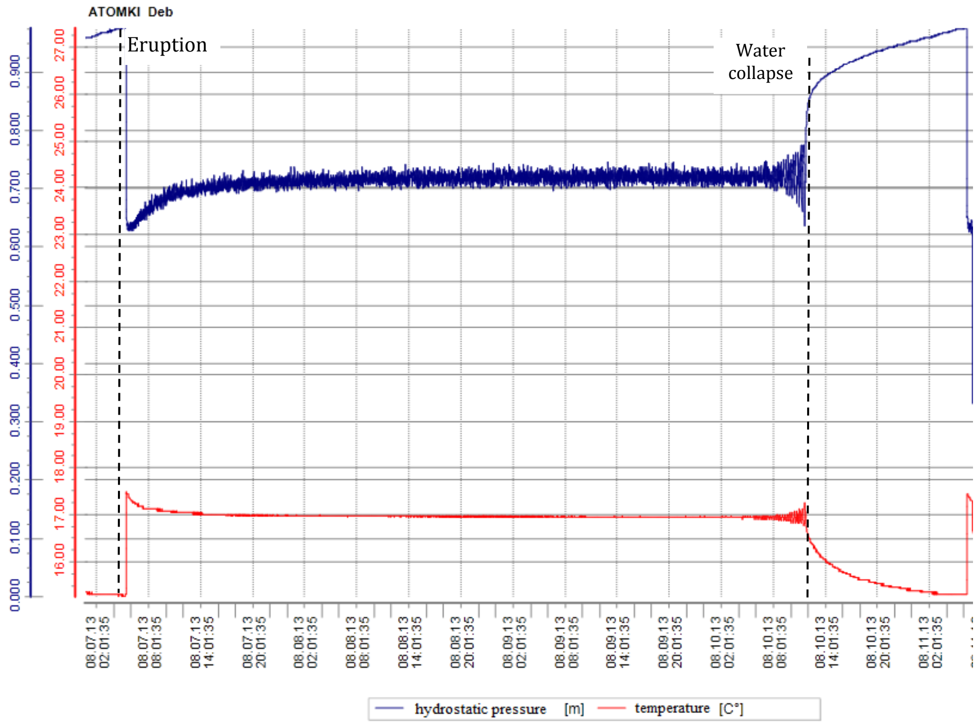

Fig. 6. Hydrostatic pressure (10 m deep) and water temperature changes in case of Chirui Geyser (August, 2013)

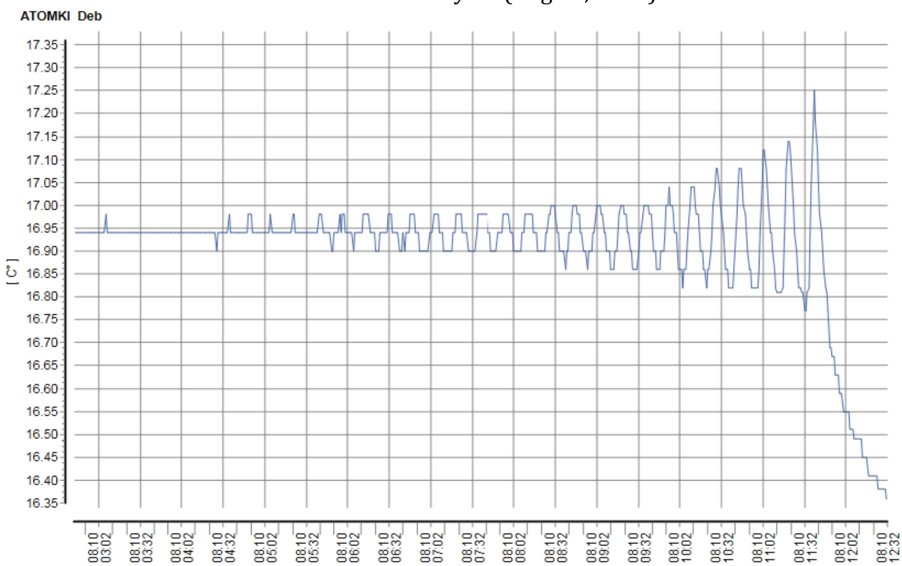

Fig. 7. Oscillation of water temperature values before collapse (August, 2013)

The values of electrical conductivity are not constant during the whole cycle; they are also changing and depend on the operation phase of the "geyser". The highest values are characteristic at the moment of the eruption, while the lowest values during the inactive phase. There were no identical values in none of the cases, but the trend and the amplitude of the changes in values are similar. So in case of the electrical conductivity data there is a difference of about 450 μS/cm between values measured in the inactive phase and the highest eruption phase. A difference of about 200-250 μS/cm was observed between the values recorded at the moment of the highest eruption and the constant, long lasting eruption phase. These observations were made during several measurements in the first investigation period. Analyzing the above mentioned data sets we can say that the Chirui Geyser has a constant water supply – during the inactive phase water is also moving inside the tube. Changes in electrical conductivity values at the eruption and water collapse can be explained by two possible events: (1) the activation or deactivation of a new aquifer that brings another type of water into the system, (2) the source of the water is the same but the HCO_3 content is higher or lower because of carbonic acid fractionation. More HCO_3 contributes to the increase of electrical conductivity. During field work in August, 2013 electrical conductivity was measured only in the active phase. In contrast with the previous statement, during measurements in 2013 a full cycle lasted for 97 hours (78 hours of activity and 19 hours of inactivity) probably because of interventions made inside the drilling tube. In this case the values of electrical conductivity show a periodic fluctuation in each 25 hours.

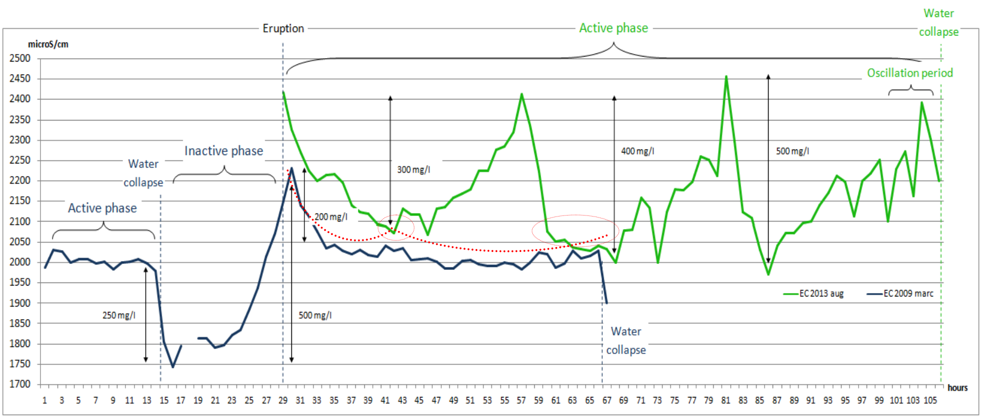

Fig. 8. Electrical conductivity values (μS/cm) of Chirui "Geyser" measured in 2009 and 2013

Data set that was recorded in 2013 (Fig 7) show that the amplitude of electrical conductivity fluctuation is getting higher as the active period evolves. The difference between peak and low values is increasing (300, 400, 500 μS/cm). In case of values measured in 2009 an obvious trend cannot be observed. Looking at the diagram carefully it can be identified a tiny fluctuation with a higher value event. This peak value was measured 12 hours after the eruption. The next higher value events happened 18-22-25 hours after the first one and can possibly refer to the oscillation phase before the water collapse. The short active phase in 2009 produced less and smaller fluctuations while the long lasting active phase in 2013 produced more and higher amplitude fluctuations. This hypothesis has to be demonstrated and confirmed by new measurements and observations.

The values of water discharge show that even if the length of a full cycle was different during the two investigations in 2009 and 2013 basically the "geyser's" functioning was similar in both of the cases. In 2009 we measured an average discharge of 6.48 l/s that means a total amount of 886.5 m^3 water during the active phase of 38 hours. In 2013 the "geyser" had an average discharge of 5.18 l/s and during 79 hours of activity produced a total amount of 1473.2 m3 water (Table 1). The highest discharge values are characteristic to the beginning of the active erupting phase, these are about 11-12 l/s.

Table 1.

The amount of water produced by Chirui Geyser during active phases in 2009 and 2013

	Active erupting phase (h)	**Average discharge (l/s)**	**Amount of water produced (m^3)**
Cycle 2013	79	5.18	1473.2
Cycle 2009	38	6.48	886.5
2013/2009 cycle rate	2.08	0.8	1.66

5. SUMMARY AND CONCLUSIONS

(1) In this article it was presented a hydrogeological phenomenon located in Băile Chirui, Transylvania that operates similar to the internationally so called "Cold water geysers".

(2) It can be described by the successiveness of active and inactive phases; eruption of water from the drilling tube is driven by physical and chemical lows, hydrostatic pressure and CO_2 dissolution/release.

(3) This phenomenon's operation shows a 51 hours periodicity with an active erupting phase of 38 hours and an inactive phase of 13 hours. A longer cycle can be observed when it is influenced by measurement equipment (the drilling tube's diameter is smaller).

(4) A full cycle can be divided into two main phases (active and inactive) and five part-phases: (1) the moment of eruption (highest eruption), (2) the long lasting stabile eruption phase, (3) the oscillation phase before collapse, (4) the moment of water collapse and (5) the inactive phase when water is inside the drilling tube.

(5) The drilling tube intersects a geological fault that facilitates CO_2 movement upward to the surface.

(6) Shifting from one main phase to the other implies some changes in the phenomenon's characteristics like increasing or decreasing of water temperature, electrical conductivity, hydrostatic pressure, CO_2 content, water discharge.

(7) Even if the full cycle is longer than usual, the main characteristics of the phenomenon are mainly identical. The amount of water produced is proportional to the duration of the active phase, only the source of it could be different.

(8) Similar properties and processes were identified and described in case of already known "cold water geysers" (ex. Crystal Geyser, USA and Herl'any Geyser, Slovakia) that allows us to say that the hydrogeological phenomenon located in Băile Chirui could be a CO_2 driven, cold water geysering well.

(9) New investigations have to be made at the Chirui Geyser – more parameters should be measured continuously during a full cycle to get closer in understanding the operation of this phenomenon.

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