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Surface corrosion of an Alpine karren field: recent measures at Innerbergli (Siebenhengste, Switzerland)

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Abstract:
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29 year old rock paintings in the Alpine karren field of Innerbergli (Siebenhengste, Switzerland) prevented the underlying rock from corrosion, while the surface nearby was corroded. Measurement of the steps indicates an average recent corrosion rate of 0.014 (±0.007) mm/a. This denudation rate is very similar to those observed in other comparable places and with other means.

Keywords: recent corrosion rate, limestone denudation rate, micrometer measurement, rock paintings, Innerbergli, Siebenhengste, Switzerland.

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INTRODUCTION

Carbonate denudation measurements were done for different climatic and geomorphologic settings. Most of the time, corrosion measurements rely on either limestone tablets that corrode (Gams, 1981; Plan, 2005), or on glacially altered surfaces that corroded since the last glaciation (Bögli, 1978; Maire, 1999), or on hydrogeochemical calculations (e.g. Gunn, 1981). Only rarely in-situ micrometer measurements (e.g. High & Hanna, 1970, Spate et al., 1985) have been published - most of the time just because of time constraints.

To enhance data availability and material for comparison, it was decided to publish this numerical contribution to recent in-situ karst denudation rates. They were made possible because of speleological work 29 years before the measurement.

SITE DESCRIPTION

The Innerbergli is one of many karrenfields within the area of Siebenhengste-Hohgant, north of Lake Thun, Switzerland (Fig. 1). Innerbergli is comparatively small, only 0.5 km^2, but of exceptional beauty, not only because of its surroundings of overgrown sandstone, which makes a stark contrast with the barren limestones, but also because almost every karren form that may exist is present there - and as such it is a field laboratory for karstologists studying the surface morphology of karst. Such a karstification has also its expression underground - Innerbergli is one of the areas with the highest cave density of Switzerland, with 100 caves (the longest one 28 km) and more than 400 small objects (to 10 m depth) concentrated on that small area. Caves in such a density can only be explored if there are sectors made, which then are prospected systematically. Such sectors were made in 1976 by the late Philippe Rouiller, who then in 1977 painted the sector limits directly on the rock with yellow paint. The colour being resistant to weathering, the underlying rock was no more attacked by corrosion, while the surrounding rocks continued to be eaten away by precipitation and percolation. The relief now present between the colour-covered rock and the surroundings gives a direct amount of the corrosion over the last 29 years. The limestone on which the marks were painted is called "Schrattenkalk sensu stricto" by Jeannin (1989); it is a very pure, rudist-rich member of the Lower Cretaceous Urgonian facies.

Innerbergli is situated in the first range of northern forealps, the so called Helvetic domain, at 1650 to 1920 m a.s.l. The climate is temperate, with an average precipitation of 1670 mm (Atlas of Switzerland 2.0), of which about half used to fall as snow before the presently active climate change. Snow cover was on average between mid-November to beginning May (due to the exposition of the Innerbergli to the South). The mean annual temperature averages 2.3°C.

The ablation of the rock is necessarily from corrosion and not from erosion, because on the respective surface, there is neither stream flow of water nor

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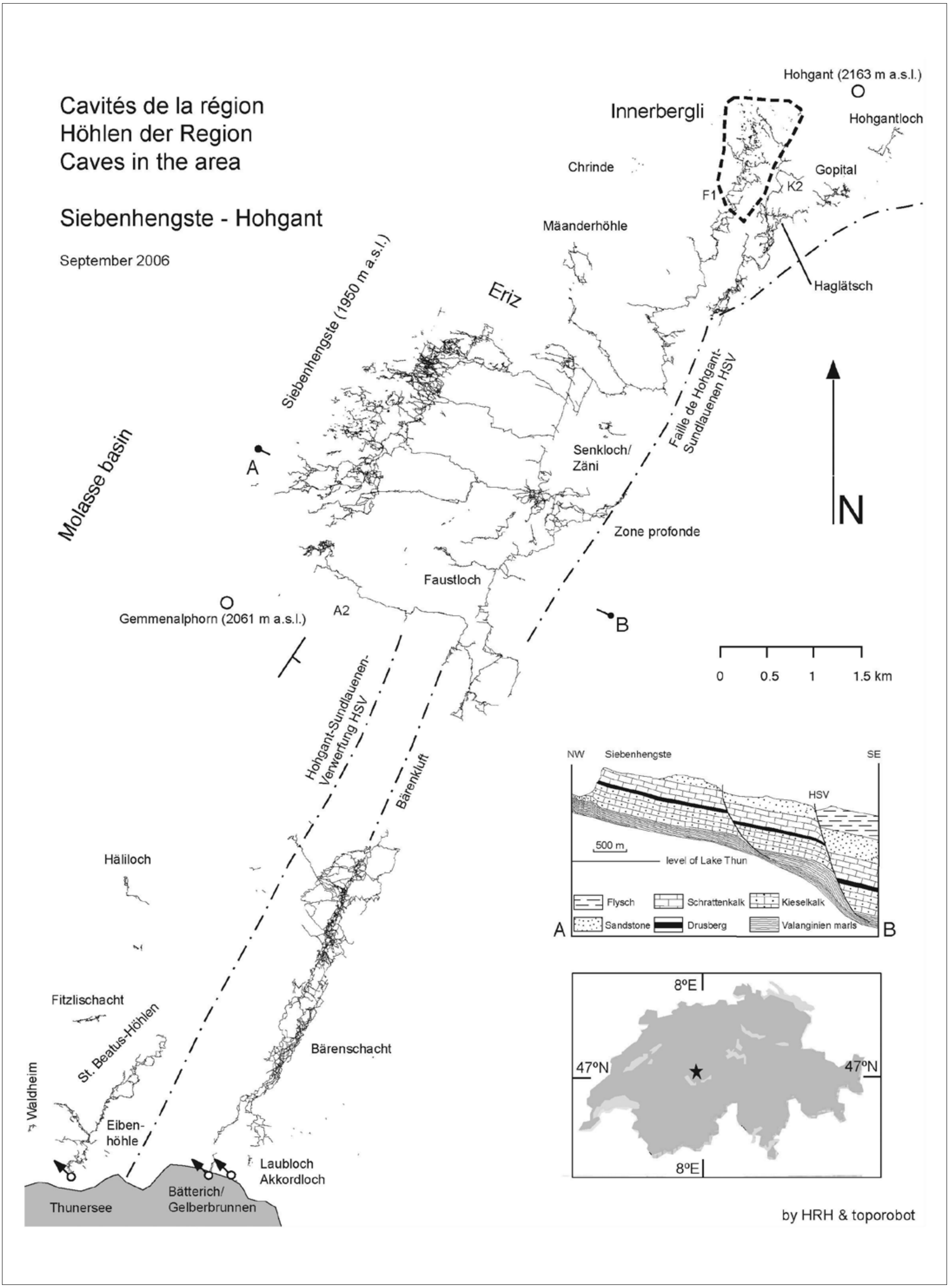

Fig. 1. Overview of the cave area of the Siebenhengste. The two insets show the location within Switzerland and a tectonic cross-section. The Innerbergli site is in the North of the cave area, indicated by the dashed line.

possibility for other eroding agents (such as large masses of gliding snow, or slope processes). This is also consistent with the preservation of the colour, which would not resist to mechanical erosion (Fig. 2).

METHOD

Relief difference was measured by a mechanical tripod micrometer (property of University of Fribourg, Switzerland). This type of micrometer is normally used on three points fixed within the rock. This is not possible in our setting here, since the micrometer has to be moved to measure first the site with colour and then the site without. This movement evidently induces errors due to the non-exact positioning of the micrometer. We tried to compensate for that by moving it only a very small distance (often 0.5 mm) within places with similar relief, and by measuring the same relief at multiple points to minimize the error by statistical methods.

Thickness of paint was another issue. The elastic nature of the colour permitted to take it off the rock in some rare places, so that the rock thickness before and after removal could be measured (Fig. 3). In addition, the colour chips obtained were measured in the field by the micrometer. Statistical calculations revealed that the colour thickness was 0.149 mm (± 0.030 mm). In the following calculations, only the limestone values without colour were used.

RESULTS

The obtained results vary quite a bit, from 0.254 mm to 0.556 mm total corrosion (see Table 1 and Fig. 4), which makes 0.0088 to 0.0192 mm per year. This variation could be due to exposition of the limestone surface (horizontal, inclined, or vertical) and to the presence or absence of vegetation in the immediate vicinity of the paintings. However, this explanation is not sufficient, because the lowermost value was found on a horizontal surface with no vegetation nearby, whereas another place with the second-highest corrosion had exactly the same disposition. We think that microclimate, thus the amount of available water, and the exposition, are the main factors for the differences.

The overall average for the Innerbergli is 0.014 ± 0.007 mm of corrosion per year.

DISCUSSION

A comparison with literature should indicate whether the above results correspond, in the order of magnitude, to other measured values. It is very difficult to get meaningful comparisons, because many measurements were done by means other than micrometers, and thus they represent averages over longer time periods, or total ablation including areas covered by soil (in the case of hydrogeochemical measurements). A non-complete overview of data is presented in Table 2.

Bögli (1971) calculated the karst denudation in Muotatal (Switzerland) by hydrochemical means. He stated that in the bare karren field, 0.071 mm/a are denuded, of which 0.014 mm/a should occur at the

Fig. 2. One of the painted letters indicating caving sectors. Approximate size of letter G is 7 cm.

Fig. 3. Close-up photograph of the paintings. The downweathering of the bare limestone surface is easily visible. Approximate size of letter G is 7 cm.

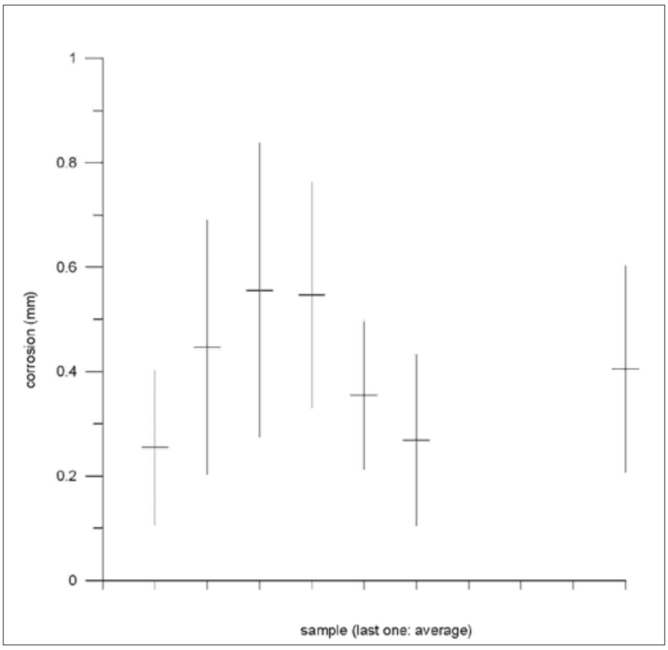

Fig. 4. Graph of the average downweathering for the last 29 years. The overall average value for all measured sites is shown at the right. As also seen in Table 1, the range of values is quite high.

Measured point	Coordinates (Swiss grid)			Number of measurements	Results (mm)	Deviation (mm)
	x	y	z			
D-L-200	633692	181227	1762	6	0.255	0.147
G-D-H-200	633633	181316	1773	11	0.447	0.243
A-F-G	633396	181327	1794	13	0.556	0.281
I-J-200	633593	181563	1850	10	0.547	0.215
A-E-F	633431	181164	1769	10	0.355	0.141
D-F-G	633626	181259	1784	11	0.269	0.163
Paint thickness				5	0.149	0.030
Average value				61	0.405	0.198
Average per year				61	0.014	0.007

Table 1. Measured values and their deviation. The values are net corrosion; the colour thickness is subtracted

Measured point	Site	karst type	altitude (m a.s.l.)	annual rainfall (mm)	method used	rate (mm/a)	source
arctic	Spitsbergen, Norway	bare karst			vein protruding	0	Akerman (1983)
	Svalbard, Norway	bare karst			hydrochemistry	0.004-0.035	Krawczyk (2008)
	Svartisen, Norway	bare karst	200	2600	hydrochemistry	0.03	Lauritzen (1990)
	Alaska	bare karst		1750-2540	micrometer	0.04	Allred (2004)
	Alaska	forested karst		1750-2540	micrometer	0.03	Allred (2004)
alpine	Silberen, Switzerland	bare karst	2200	2400	hydrochemistry	0.01	Bögli (1971)
	Bödmeren, Switzerland	forested karst	1300	2100	hydrochemistry	0.08	Bögli (1971)
	Innerbergli, Switzerland	bare karst	1800	1670	micrometer	0.01	Häuselmann, this volume
	Kanin, Italy	bare karst	2000	2800	micrometer	0.01-0.035	Forti (1984)
	Kanin, Slovenia	bare karst	2200	3500	micrometer	0.017-0.1	Kunaver (1979)
	Steinernes Meer, Austria	bare karst	2000	2200	micrometer	0.03	Pavuza (unpublished)
	Hochschwab, Austria	bare karst	2000	2150	carbonate tablet	0.01	Plan (2005)
	Hochschwab, Austria	covered karst	2000	2150	carbonate tablet	0.013-0.04	Plan (2005)
	Vercors, France	covered karst	1060	1640	carbonate tablet	0.02	Gams (1985)
mediterranean	Classical karst, Italy	covered karst	300	1440	micrometer	0.01-0.041	Forti (1984)
	Classical karst, Italy	bare karst	300	1350	micrometer	0.03	Cucchi et al. (1987)
	Classical karst, Italy	bare karst	300	1350	micrometer	0.02	Cucchi et al. (1995)
	NSW, Australia			950	micrometer	0.0-0.02	Spate et al. (1985)
tropic	Patagonia, Chile	bare karst	200	7300	vein protruding	0.06	Maire (1999)
	Puerto Rico	covered karst	323	1690	carbonate tablet	0.01	Gams (1985)
mixed areas	Friuli-Venezia, Italy	mixed	mixed	mixed	micrometer	0.01-0.04	Cucchi et al. (1994)

Table 2. Table of different values found in literature. The values are in general quite comparable to ours.

surface, and 0.057 mm/a underground. The altitude of measurement at Bögli (1971) is slightly higher, as is the precipitation (2400 mm/a). However, his determined value is exactly ours. Bögli further stated that covered karst resulted not only in higher denudation rate, but also in much higher surface removal (as opposed to corrosion within the caves beneath). Unfortunately, we do not have measurements of forested karst areas.

An overview of karst denudation rates presented in Bögli (1978) gives rates that vary from 0.017 (Spitsbergen) to 0.091 mm/a (forested karst Muotatal). These values are calculated for total denudation, of which 20 (bare karst) to 90 % (covered karst) should occur at the surface. Most of the values presented in Bögli, however, are within areas where covered karst predominates, so these values cannot be compared to ours.

Cucchi & Forti (1994, after Ford & Williams, 2007) measured, with the help of a micrometer, more than 50 sites in northern Italy, and got an average surface lowering rate of 0.02 mm/a, so quite comparable to ours. Spate et al. (1985) measured limestone surfaces in Australia and got an average value of 0.007±0.011 mm/a. This value is half the one of Innerbergli, but the precipitation on that Australian site is also about half. On the contrast, Allred (2004) found 0.03 to 0.04 mm/a in rainy parts (1800-2500 mm/a) of Alaska. These values are significantly higher than ours even if taking into account the effect of rainfall.

In general, the measured values at Innerbergli are in the same magnitude as other measurements. Although more difficult to measure because of the conditions (non-fixed micrometer), they represent average values for the last 29 years and may therefore be of interest to the scientific community.

The average value of corrosion at Innerbergli, 0.014 mm/a, equals 1.2×10^{-9} moles/m^2 x sec.

This value is 100 to 1000 times smaller than the one given by Kaufmann & Dreybrodt (2007). However, their value is for rapid corrosion during rainfall, whereas our value is averaged over the whole year (with and without rainfall). To allow a direct comparison, we would have to know how many seconds per year it is raining at Innerbergli. Alternatively, taking above numbers, we could also conclude that the season without flowing water is 100 to 1000 times longer than the one with flowing water. The findings of Kaufmann & Dreybrodt (2007), however, are very important and might actually explain why a plot of total rainfall and corrosion rate (as it was tried on the base of Table 2) does not yield a straight line: if the time during which rain is falling is more important than the actual rainwater quantity, then regions with few constant rain (Alaska, Ireland) would have potentially higher corrosion rates than areas with rare torrential rains. This would be an interesting point to investigate in the future.

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