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Main karst and caves of Switzerland

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ABSTRACT

This paper presents an overview of the main karst areas and cave systems in Switzerland. The first part encloses descriptions of the main geological units that hold karst and caves in the country and summarizes a brief history of research and protection of the cave environments. The second part presents three regions enclosing large cave systems. Two regions in the Alps enclose some of the largest limestone caves in Europe: Siebenhengste (Siebenhengste cave system with ~160 km and Bärenschacht with 70 km) and Bödmeren-Silberen (Hölloch cave system with 200 km and Silberen System with 39 km). These systems are also among the deepest with depths ranging between 880 and 1340 m. The third example is from the Jura Mountains (northern Switzerland).

Key-words: caves, Hölloch, karst, Siebenhengste, Switzerland.

El karst y las cuevas más importantes de Suiza

RESUMEN

Este trabajo presenta una visión general de las principales áreas kársticas y sistemas de cuevas en Suiza. La primera parte incluye descripciones de las principales unidades geológicas donde se desarrollan el karst y las cuevas en el país, y resume una breve historia de la investigación y protección de los entornos de la cueva. La segunda parte presenta tres regiones que incluyen sistemas de grandes cuevas. Dos regiones están en los Alpes e incluyen algunas de las cuevas más grandes, en roca caliza, de Europa: Siebenhengste (Siebenhengste Cave System con ~ 160 km y Bärenschacht con 70 km) y Bödmeren-Silberen (Hölloch Cave System con 200 km y el Silberen System con 39 km). Estos sistemas de cavidades también se encuentran entre los más profundos con profundidades que oscilan entre 880 y 1340 m. El tercer ejemplo es de la Jura Mountains en el norte de Suiza.

Palabras clave: cuevas, Hölloch, karst, Siebenhengste, Suiza.

VERSIÓN ABREVIADA EN CASTELLANO

Introducción

Suiza se extiende sobre una superficie de 41293 km² en el centro de Europa. Generalmente se definen tres territorios según su relieve: el 57% está ocupado por los Alpes, el 31% por la Meseta Suiza (Mitteland) y el 12% por las montañas del Jura. El flanco norte de los Alpes está formado por rocas sedimentarias de edad Mesozoica, incluyendo bandas de calizas intercaladas con margas, esquistos y areniscas. Los sistemas de cuevas más grandes en Suiza se han desarrollado en esta región ubicada entre 600 y 3000 m s.n.m. Las montañas Jura forman la parte noroeste de Suiza. Este relieve está formado por una serie de calizas y margas en el que se desarrolla la mayor región kárstica de Suiza. El relieve es moderado: entre 400 y 1700 m s.n.m. y está cubierto principalmente por bosques y pastos.

Áreas kársticas y espeleología

Áreas kársticas

El afloramiento de roca caliza, dolomía, yeso y carniolas cubren un área de casi 7900 km². El karst bien desarrollado, incluyendo karst activo y paleokarst que se extiende en profundidad sobre al menos unos 4000 km² (Figura 1). Las montañas del Jura están formadas por calizas del Jurásico (Dogger y Malm) y Cretácico inferior. La mayoría de las cuevas se encuentran en rocas calizas del Malm. La morfología kárstica superficial, el exokarst, se caracteriza por la abundancia de dolinas, valles secos y algunos campos de lapiaz parcialmente cubiertos. Se conocen grandes sistemas (>10 km) de cuevas horizontales (Grottes aux Fées, Milandre, etc.) así como varias cuevas verticales, algunas de estas alcanzando de 400 a 500 m de profundidad (Gouffre de Longirod, Nidlenloch, Petit Pré). En el sur de los Alpes, en Ticino y Engiadina (este de Suiza) las rocas karstificadas son calizas y dolomías de edad Triásico medio a Triásico superior, así como calizas del Lías. Los sistemas de cuevas más grandes en Suiza se desarrollan en la parte norte (externa) de los Alpes, en los Prealpes y unidades tectónicas Helvéticas. Dos series principales de rocas carbonatadas incluyen la mayoría de los sistemas de cuevas: la llamada «Caliza Urgoniana» (edad Barremiense, Cretácico inferior), así como la «caliza Titoniana» (Malm, Jurásico).

Cavidades

Se conocen casi 9000 cuevas en Suiza (a fecha de 2013; Näff 2013) con una longitud total de unos 1300 km. Las cuatro mayores cuevas del sistema acumulan una longitud de 460 km. Unas 160 cuevas presentan profundidades mayores a 150 m, 20 mayores a 500 m y sólo 2 tienen más de 1000 m. Dos regiones incluyen algunas de las cuevas en calizas más grandes de Europa: Siebenhengste (sistema de cuevas Siebenhengste con 160 km y Bärenschacht con 70 km) y Bödmeren-Silberen (sistema de cuevas Hölloch con 200 km y Sistema de Silberen con 39 km). Estos sistemas también se encuentran entre los más profundos con profundidades que oscilan entre 880 m y 1340 m. La Tabla 1 resume las características de las cuevas principales en Suiza. Se cuenta con la que es probablemente la cueva más alta de Europa, localizada en Jungfraujoch a una cota de 3482 m s.n.m. (Häuselmann, 2004b). La cueva tiene 108 m de largo y se ha desarrollado en una fina capa de caliza (~ 20m) intercalada dentro del granito de Jungfrau.

Organización de la exploración en las cuevas

La Sociedad Espeleológica suiza (SSS/SGH) fue fundada en 1939, y tiene en la actualidad unos 1.000 miembros. En el año 2000 SSS/SGH fundó el Instituto Suizo para la Espeleología y Estudios del Karst (SISKA) ubicado en La Chaux-de-Fonds, liderando la investigación científica, consultoría y acciones de la limpieza de cuevas. Con este instituto los espeleólogos adquirieron un estatus oficial entre autoridades, académicos, escuelas y público en general.

Protección de cuevas y biología

Todas las cuevas en Suiza están generalmente protegidas hasta un cierto grado. Decenas de cuevas contaminadas se limpian todos los años desde 2003 en el marco del servicio nacional no militar. La primera publicación de bioespeleología en Suiza data de 1861, pero las investigaciones florecieron en realidad entre 1920 y 1966. Durante este período de tiempo 180 estudios produjeron datos originales formando la base del inventario de la fauna de las cuevas suizas. Hasta 1966 cerca de 1300 cuevas habían sido exploradas en Suiza y se había investigado la bioespeleología de 341 (Strinati, 1966a, b), especialmente en las montañas del Jura y Ticino. Con posterioridad se colectaron datos bioespeleológicos de los Prealpes y de los Alpes calizos. La exhaustiva y significativa publicación titulada «Faune cavernicole de Suisse» (Fauna cavernícola de Suiza) por Pierre Strinati en 1966a,b representa una visión sintética del conocimiento bioespeolológico en Suiza en aquel momento. Bernasconi 2010 actualizó la síntesis anterior.

Breve descripción de los sistemas de cuevas seleccionadas

El sistema de cuevas Hölloch

Los sistemas de cuevas de Hölloch y de Silberen se desarrollan en Schrattenkalk (Barremiense-Aptiense, facies urgonianas, Cretácico inferior) de los Alpes calcáreos de Suiza Central. Campos de lapiaz espectaculares

se desarrollan en esta región (Silbern-Twärenen-Bödmeren; Charetalp). Con más de 200 km la cueva de Hölloch es la más grande de Suiza y de Europa occidental. El sistema Hölloch está casi conectado con el sistema de Silbere, que tiene 40 km de largo. La exploración de Hölloch comenzó en la década de 1880 y fue una de las tres cuevas más largas del mundo hasta la década de 1970. La cueva de Hölloch se desarrolla en la parte descendente del sistema hidrológico, principalmente dentro de la zona epifreática. La cuenca vertiente (32 km²) se encuentra entre 638 y 2349 m s.n.m. en un contexto con 2600 mm de precipitación anual, mucha nieve, pero ningún glaciar. La parte inferior de la cuenca está cubierta con bosque y la parte más alta con los pastos y pavimentos desnudos de roca caliza. Una gran parte de la cueva se inunda durante la temporada de lluvias. Entre 1999 y 2005 cuatro eventos de lluvia importantes produjeron inundaciones excepcionales de la cueva. En el otro extremo de la cueva, a 5.2 km del manantial, el agua ascendió 320 m sobre el nivel de aguas bajas. La parte superior de la cueva no se inunda, pero se generó principalmente dentro de la zona epifreática (secciones elípticas de los pasajes). Los pozos más recientes, cruzando los conductos epifreáticos antiguos se encuentran principalmente en la parte superior del sistema de cuevas.

El Sistema de cuevas de Siebenhengste

Con más de 160 km de pasajes conectados, el sistema de cuevas de Siebenhengste parece ser el segundo más grande en Europa occidental y uno de los más profundos (-1340 m). Bärenschacht con más de 70 km representa la parte más aguas abajo del sistema, pero no ha podido ser conectado hasta la fecha. La longitud total de cueva explorada en esta región es de más de 320 km (Figura 3). Estas cuevas se convierten en la «Border Chain» (la unidad tectónica más septentrional de los mantos Helvéticos) en la que las «Calizas Urgonianas» están altamente karstificadas. La cueva de Siebenhengste tiene 35 entradas. Algunas de ellas están típicamente seguidas de 150 a 200 m de pozos que cortan las calizas hasta su misma base. Muchas otras entradas conectan con el sistema principal a través de una compleja serie de meandros estrechos (cañones buzamiento abajo) hacia los pozos de profundidades variables. Este tipo alpino de cuevas corta o se une a pasajes freáticos fósiles (de sección elíptica), que se desarrollaron a diferentes profundidades a lo largo de la dirección de los estratos calizos. Muchos de los pasajes son bastante pequeños (de menos de 1 m de diámetro), pero los mayores alcanzan de 7 a 10 metros de diámetro. Este complejo laberinto de pasajes fósiles se drena por debajo por una serie de corrientes subterráneas paralelas, que fluyen buzamiento abajo. El conducto freático más antiguo, (~ 1900 m s.n.m.) tiene una antigüedad de 4.5 millones de años. En aquel tiempo el agua fluía del sudoeste al noreste. Los niveles de la cueva, ubicados por debajo de 1440 m, muestran claramente que la dirección del flujo cambio 180°, del noreste hacia el suroeste. Esto debe estar relacionado con un cambio en la posición del valle principal durante el Cuaternario y datado como 0.8 Ma (Häuselmann et al. 2006). El sistema hidrogeológico del manatial de Bätterich se extiende al noreste al menos 10 km más allá del sistema de cuevas de Siebenhengste hasta el masivo Schrattenfluh, donde pavimentos calizos maravillosos incluyen algunas cuevas importantes tales como Neuenburgerhöhle y Warzensystem. Bärenschacht se desarrolla directamente aguas arriba de la surgencia de Bätterich sobre una distancia de 4 km en línea recta. La cueva tiene solamente una entrada seguida de 900 m de pozos y meandros antes de alcanzar la red laberíntica principal de la cueva. La parte profunda de la cueva es un laberinto de pasajes elípticos (freáticos y epifreáticos) serpenteando arriba y abajo.

La Réseau des Grottes aux Fées de Vallorbe

Con más de 20 km de pasajes explorados (verano de 2014), este sistema de cuevas es el más grande en las montañas suizas del Jura. La cueva fue mencionada por primera vez en 1795, incluyendo una descripción de los primeros 200 m. En el año 2000 se amplió una fisura con una corriente de aire fuerte y la continuación de la cueva está siendo explorada desde 2004. La cueva se desarrolla en calizas del Malm (Jurásico) con suave buzamiento. La entrada de la cueva es un pasaje horizontal subfósil. Durante los eventos de inundaciones extremas se activa la entrada de la cueva y muchos pasajes en la cueva están inundados. El área de captación de agua es de 27 km². La cueva incluye varios tipos de pasajes, la mayoría de ellos se desarrollaron primero como pasajes freáticos o epifreáticos, que posteriormente pasaron a conductos vadosos. Algunas partes de la cueva son grandes conductos elípticos (15 a 20 m de diámetro). En 2008 se encontró una nueva entrada en la parte central de la cueva (Baume des Follatons), a través de una serie de pozos de 155 m.

Introduction

Switzerland extends over a surface area of 41 293 km² in the middle of Europe, on both sides of the central Alps. Three territories are usually defined according to its relief: 57% is occupied by the Alps, 31% by the Swiss Plateau (Mitteland) and 12% by the Jura Mountains. The Swiss lowest point is located at Lago Maggiore at an elevation of 193 m a.s.l. and the highest point at Dufourspitze in Mount Rosa Massif at 4634 m a.s.l.

Four main hydrographic systems drain water precipitated in Switzerland: the Rhine River, the Rhône River, the Ticino River feeding the Po River and the Inn River feeding the Danube River.

The northern flank of the Alps is formed by sedimentary rocks of Mesozoic age, including limestone bands interlayered with marls, schists and sandstones. The largest cave systems in Switzerland that have developed in this region are located between the Swiss Plateau and the high Alps. Valley bottoms typically lie between 600 and 1 000 m a.s.l. and summits between 1 800 and 3 000 m a.s.l.

The Swiss Plateau has a hilly landscape with an elevation ranging between 370 m a.s.l. and 1 000 m a.s.l. Rock in this region is Molasse, a series of sandstones and marls resulting from the erosion of the Alps.

The Jura Mountains form the northwestern part of Switzerland. This range is entirely made of a series of limestones and marls, building the largest karst region in Switzerland. The relief is moderate: between 400 and 1 700 m a.s.l., mainly covered by forests and pastures.

Karstic areas and speleology

Karst areas

Nearly 30% of the Swiss territory is underlain by more or less karstified rocks essentially formed during Mesozoic (Fig. 1). Outcropping limestone, dolomite, gypsum and cornieules cover an area of nearly 7900 km². Deep seated karst, including active and paleokarst features expand at depth over at least a further 4000 km², as evidenced by drilling investigations (Wildberger and Preiswerk, 1997).

The Jura Mountains are essentially formed by Limestone of Jurassic (Dogger and Malm) and Lower Cretaceous age. Most caves are found in Malm Limestone (Portlandien, Kimmeridgian and "Sequanian" or Oxfordian). Surface karst morphology is characterized by many dolines, dry valleys and some partly covered karrenfields. Large horizontal cave systems (> 10 km) are known (Grottes aux Fées, Milandre, etc.) as well as several vertical caves, some of them reaching 400 to 500 m in depth (Gouffre de Longirod, Nidlenloch, Petit Pré).

In southern Alps of Ticino and Engiadina (eastern Switzerland) karstified rocks are limestones and dolomites of Middle to Upper Triassic age, as well as Liassic limestones.

The largest cave systems in Switzerland develop in the northern (external) part of the Alps, in Prealps and Helvetic tectonic units. Two main carbonate rocks series enclose most of the cave-systems: the so-called "Urgonian Limestone" (Barremian age, Lower Creataceous), as well as the "Tithonian Limestone" (Malm, Jurassic). Limestone series of Dogger, Lias and Upper Trias are karstified, but enclose less significant cave systems.

Helvetic nappes form the so-called "High calcareous Alps", crossing Switzerland from Dents du Midi (south of Lake Geneva) to Säntis (south of Lake Constance), enclose the largest Swiss cave Systems (Siebenhengste and Hölloch) in their central part. The "Urgonian Limestone" is the main karstified formation in this range.

In western Switzerland the "High calcareous Alps" are made up of a pile of three major Helvetic nappes (Morcles, Diablerets,Wildhorn). They reach an elevation of 3200 m. a.s.l. and are partially covered by glaciers. Spectacular Karrenfields (limestone pavements) are found (Tsanfleuron, Lapis di Bou, Rawyl) as well as a series of large caves in Malm (Poteux cave) or in Cretaceous (Grand-Cor cave).

Further east, between Thun and Luzern, the "Border Chain" (the northernmost tectonic unit of

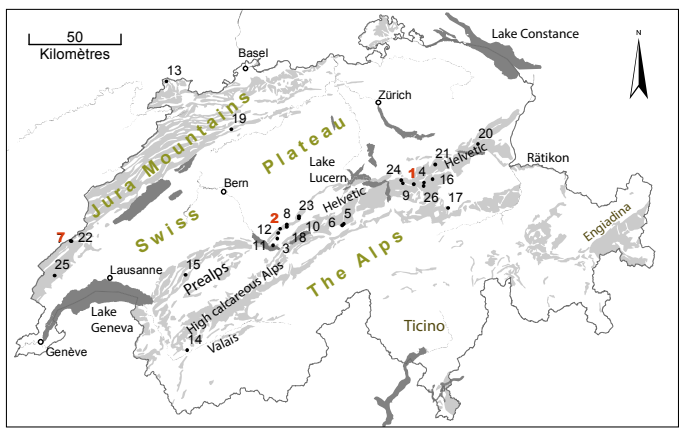

Figure 1. Karst regions of Switzerland (in grey) and main caves (Numbers refer to Table 1).
Figura 1. *Regiones kársticas de Suiza (en gris) y cuevas principales (los números se refieren a la tabla 1).*

the Helvetic nappes) is formed only by Cretaceous and Eocene rocks. The "Urgonian Limestone" (locally named "Schrattenkalk", meaning "Karrenfields Limestone") of this unit is highly karstified. Its lower limit is given by the impervious "Drusberg Marls" along which many cave streams develop. The large cave systems of the Siebenhengste-Hohgant-Schrattenfluh region (Siebenhengste cave system, Bärenschacht, Beatushöhle, Réseau des Lagopèdes, Neuenburgerhöhle, etc.) develop in this context. Spectacular karrenfields of Siebenhengste or Schrattenfluh are the visible parts of this exceptional karst system (Hof *et al.*, 1984; Jeannin *et al.,* 2000, Häuselmann, 2002, Jeannin and Häuselmann, 2005).

The calcareous Alps of Central Switzerland, around Lake Lucern, are mainly formed by two units: nappes of Drusberg (in the front) and Axen (in the back). Karst mainly develops in three limestone formations: "Seewerkalk" (Upper Cretaceous), "Schrattenkalk" (Barremian-Aptian, urgonian facies, Lower Cretaceous) and "Quintnerkalk" (Upper Malm). The largest cave systems such as Hölloch and Silberen cave systems develop in Schrattenkalk. Spectacular Karrenfields develop in this region (Bögli, 1970) in both Schrattenkalk and Quintnerkalk (Silbern-Twärenen-Bödmeren; Charetalp).

Helvetic nappes continue further east in the vicinity of Lake Walensee forming massifs of Glärnisch, Säntis and Churfirsten, enclosing some significant caves, mainly in "Schrattenkalk".

In the western part of Switzerland Prealps units (penninic nappes) are located on top or in front of the Helvetic nappes and formed mountains reaching an elevation of 2400 m a.s.l. The main karstified formation, enclosing large cave systems in the Prealps (Combe du Bryon cave system, Morteys cave system) is the Tithonian limestone (Malm).

The Rätikon region, located east of the Rhine River, includes a karst region mostly developed on the Austrian flank, but including a narrow band of Jurassic limestone in Switzerland (Sulzfluh nappe, Penninic). It encloses large fossil caves at an elevation of nearly 2300 m. a.s.l. (Apollohöhle, Seehöhle, Weidmann *et al.*, 1996; Wildberger, 1996).

A narrow penninic band of Permo-Carboniferous Marble in southern Switzerland (northern Ticino) encloses a remarkable flow-through cave at an elevation of 2200 m a.s.l. (Acqua del Pavone).

Evaporites (mainly Triassic gypsum) are present as many small patches in the Swiss Alps. Crête de Vaas, in central Rhône valley (Valais) is 1 km long, and the longest known cave in gypsum in the Alps (Wildberger and Preiswerk, 1997).

A few caves have developed in travertines, one being large enough to be used as a show cave (Höllgrotten, ZG).

Pseudo-karst is described in Valais with one cave in quartzite (Triassic age). Further karst features are known in sandstone of the Alps (Hohgant sandstone, Eocene), of the Swiss Plateau (Molasse, Oligocene to Pliocene), and in some quaternary moraines or alluvial deposits. Open cracks including caves are known in many other rocks than limestone (e.g. gneiss), mainly related to tectonic faults parallel to steep valley flanks in the Alps.

Caves

Nearly 9,000 caves are known in Switzerland (state 2013, Näff 2013) making a total length of about 1,300 km or explored and mapped cave passage. Most of them are rather small (10 to 100 m). Only about 30 are larger than 5 kilometers, 12 larger than 10 km, and the four largest cave systems add up to a length of 460 km.

Some 160 caves are deeper than 150 m, 20 more than 500 m and only 2 more than 1000 m.

Two regions enclose some of the largest limestone caves in Europe: Siebenhengste (Siebenhengste cave system with ~160 km and Bärenschacht with 70 km) and Bödmeren-Silberen (Hölloch cave system with 200 km and Silberen System with 39 km). These systems are also among the deepest with depths ranging between 880 and 1340 m. Table 1 summarizes the characteristics of the main caves in Switzerland.

What is probably the highest cave in Europe has been found in Jungfraujoch at an elevation of 3482 m a.s.l. (Häuselmann 2004b). The cave is 108 m long and developed in a thin limestone bed (~20m) interlayered within the Jungfrau Granite (age probably Permo-Carboniferous).

The number of caves registered in central Swiss cave data-base reflects somehow the caving activity of the Swiss Speleological Society (SSS/SGH): 900 caves in 1958, 1350 in 1964, 1800 in 1975, 7500 in 1996 and 9000 in 2013.

Lists or inventories of caves were first published in the sixties and seventies. In 1976 a more systematic series of cave inventories started with: n° I "Canton of Neuchâtel" by Gigon (1976) with 282 described caves; n° II "Canton of Jura" by Gigon and Wenger (1986) with 258 described caves; n° III "Region Basel - Laufen" by Bitterli (1996); n° IV "Western Vaud Jura" by Audétat and Heiss (2002) with 864 described caves, n° V "northern Vaud Jura" by Deriaz et al. (2007) with 150 described caves. Other volumes are being prepared.

Cave/cave system	Number on figure 1	Length (km)	Depth (m)	Community/Canton
Hölloch	1	200421	± 939	Muotathal / Schwytz
Sieben Hengste Hohgant –Höhle	2	157000	± 1340	Eriz+Beatenberg+Habkern / Bern
Bärenschacht	3	73640	–979	Beatenberg / Bern
Silberensystem	4	38375	± 888	Muotathal / Schwyz
Bettenhöhle-Boniloch	5	28531	± 804	Kerns / Obwalden
Schrattenhöhle	6	19645	± 573	Kerns / Obwalden
Réseau des Grottes aux Fées	7	19132	± 227	Vallorbe /Vaud
K2 Hohgant	8	13996	± 741	Habkern / Bern
Gütschtobelhöhle	9	13096	± 629	Muotathal / Schwyz
Neuenburgerhöhle	10	12086	± 217	Flühli / Luzern
Beatushöhle	11	12015	+ 353	Beatenberg / Bern
A2 Loubenegg	12	10958	– 687	Beatenberg / Bern
Grotte de Milandre	13	10520	± 135	Boncourt / Jura
Réseau du Poteux	14	9000	± 250	Saillon / Valais
Réseau des Morteys	15	8600	± 556	Charmey / Fribourg
Windloch, Klöntal	16	8000	± 349	Glarus / Glarus
Muttseehöhle	17	7880	–1070	Linthal / Glarus
Haglätschhöhle	18	7717	± 240	Habkern / Bern
Nidlenloch	19	7561	– 407	Oberdorf / Solothurn
Selun Höhlensystem	20	6407	± 507	Alt St, Johann / Sankt Gallen
Lachenstockhöhle	21	6223	± 247	Innerthal / Schwyz
Grottes de l'Orbe	22	6000	± 116	Vallorbe / Vaud
Warzensystem	23	5425	± 419	Flühli / Luzern
Dreckiges Paradies	24	5175	± 274	Muotathal / Schwyz
Gouffre de Longirod	25	5100	– 519	Longirod / Vaud
Chli Mälchtalhöhle	26	5070	± 355	Muotathal / Schwyz

Table 1. Longest caves in Switzerland (more than 5 km in length, State 2013). As published by NÄFF (2013).
Tabla 1. *Las cuevas más largas de Suiza (más de 5 km de longitud, Datos Estatales de 2013). Publicado por NÄFF (2013)*

Organized cave exploration

This started in about 1930 with the creation of the "Club des boueux" (club of the muddies), which initiated the foundation of the Swiss Speleological Society (SSS/SGH) in 1939, which has now about 1000 members since the 1980s.

In 2000 SSS/SGH founded the Swiss Institute for speleology and karst-studies (SISKA) located in La Chaux-de-Fonds. Its tasks cover scientific research, consulting and the practical management of the karst environment in Switzerland, such as karst protection schemes, cleaning actions and the heightening public and authority awareness to karst and caves. With this institute cavers acquired an official status among authorities, academics, schools and public.

Before the existence of SSS/SGH a few cave-related documents were produced by naturalists and archaeologists, mainly in the XIXth Century (Hugi, Browne, Desor, De Saussure, etc.). The poorly detailed description of the Môtiers cave near Neuchâtel written by Jean Jacques Rousseau in 1763 is one of the oldest written reports of a cave visit in Switzerland (Pittard 1985). The first known cave map of a Swiss cave is the one of Mondmilchloch am Pilatus sketched by Kappeler (1767) (Fischer, 1993).

Show caves

Nine show caves are being operated in Switzerland namely: Grotte aux fees, Lac souterrain de Saint Léonard (Valais); Grotte de Vallorbe (Vaud); Moulins souterrains du Col-des-Roches (Neuchâtel); Grotte de Reclère (Jura); Beatushöhle (Bern); Höllgrotte (Zug); Hölloch (Schwyz); Kristallhöhle Kobelwald (Sankt Gallen). The first show cave (Höllgrotte) was open in 1887 and the latest (Col-des-Roches) in 1988.

Monographies including historical aspects as well as cave descriptions and cave genesis of several show caves have been published since 2000 (e.g. Häuselmann 2004a).

Cave climate

Cave climate has been investigated by cavers (e.g. Trüssel 1997, Lütscher and Jeannin 2004), notably the ice caves of the Jura Mountains (Brulhard 1998, Lütscher 2002, Lütscher 2005). The effect of cave climate on cave fauna was summarized by Blant (2002).

Cave protection

In September 2001 the Entlebuch district in Canton Luzern became the first UNESCO Biosphere Reserve in Switzerland. The spectacular karst landscape of Schrattenfluh, including many alpine caves is part of it (Hapka 2002). Caves in Switzerland do belong to the state (i.e cantons) and are generally protected to a certain degree. Special protection schemes are designed for selected objects defined as geotopes. Dozens of polluted caves have been cleaned up every year since 2003 within the framework of the non-military national service.

Cave biology

The first biospeological publication in Switzerland came out in 1861, but research really expanded between 1920 and 1966. During this period of time 180 studies brought together original data forming the base of the fauna inventory of Swiss caves. Up to 1966 about 1300 hundred caves had been explored in Switzerland and 341 had been biospeologically investigated (Strinati, 1966a, b), especially in the Jura Mountains and Ticino. Biospeological data from the Prealps and from the calcareous Alps were mainly collected afterwards.

The significant and exhaustive publication entitled "Faune cavernicole de Suisse" (Cave Fauna of Switzerland) by Pierre Strinati in 1966 a,b represents a synthetic outlook of biospeological knowledge in Switzerland at that time.

An updated outlook was given by Bernasconi 2010.

3. Short description of selected cave systems

The Hölloch cave system

With more than 200 km the Hölloch cave is the largest in Switzerland and in western Europe. The Hölloch is almost connected to Silberensystem, which is nearly 40 km long. Hölloch and nearby caves have been explored by the "Arbeitsgemeischaft Höllochforschung, AGH". Exploration of Hölloch started in the 1880s and was one of the three longest known caves in the world until the 1970s.

The cave develops within a series of about 4 thrusts and superimposed tectonic digitations mainly formed of Schrattenkalk-limestone (Lower Cretaceous, Urgonian facies), leading to a total thickness of about 1000 m of limestone. Impervious layers are locally interbedding along tectonic overthrusts perching in some parts of the cave.

The Hölloch cave entrance is an overflow spring of the Schliechenden Brünnen spring karst hydrogeological system, with a catchment area of about 32 km^2. The Hölloch cave develops in the downstream part of the system, mainly within the epiphreatic zone. The catchment area lies between 638 and 2349 m a.s.l. in an alpine context with 2600 mm of annual precipitation, much snow, but no glacier. The lower part of the catchment is covered with forest and the highest part with pastures and nacked limestone pavements.

The lowest cave passages belong to the phreatic zone and sumps were dived down to a depth of 88 meters. The cave reaches the phreatic zone at many different locations and only a few of them have been dived so far. At low water, the level of all these sumps is nearly the same with a very low gradient towards the spring (~0.5 %, Bögli 1980).

A large part of the cave is flooded during high water events. Between 1999 and 2005, four major rain events induced exceptional flooding of the cave, far above the highest level observed during the previous 50 years (Wildberger et al. 2001, Bättig and Wildberger 2007). In the far end of the cave, 5.2 km from the spring, water raised 320 m above the low water level. Hölloch cave is therefore an interesting cave for the hydrogeological observation of the epiphreatic zone and was used to develop some hydraulic modelling of flow in karst conduits (Jeannin 2001).

The upper part of the cave is no longer flooded, but was mostly generated within the epiphreatic zone as well, as demonstrated by the typical elliptical cross-sections of the passages found all over the cave. Younger shafts, crossing the old epiphreatic conduits are mostly found in the upper part of the cave system.

Information can be found direcly on the web-site of the AGH: http://www.hoelloch.org/index.php/en/ . Further information can be found in Bögli (1977), Bögli (1980), Wildberger and Preiswerk (1997), Wildberger *et al.* (2001), Jeannin and Wildberger 2003, AGH 2007, Häuselmann (2013).

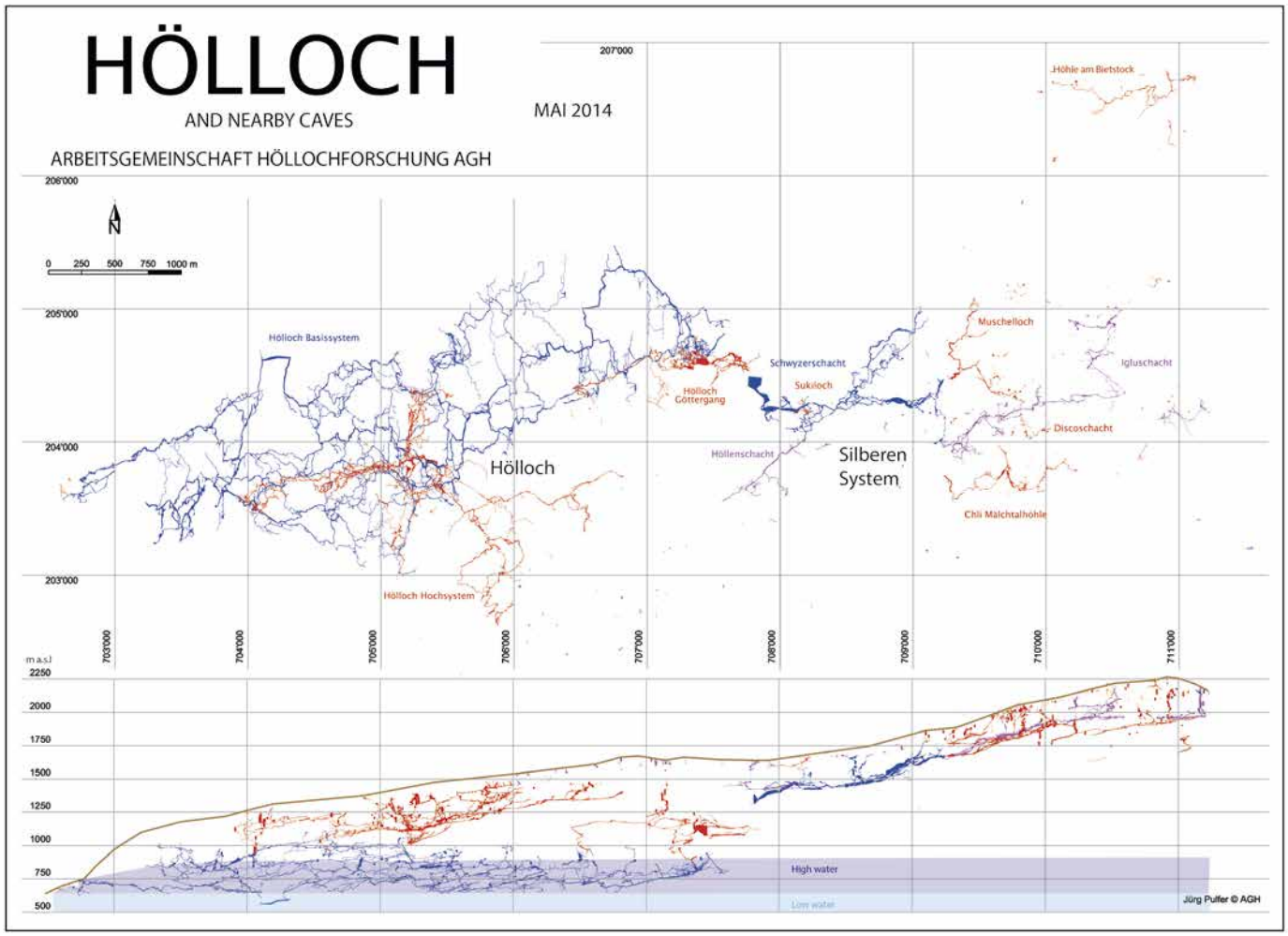

Figure 2. Plan view and vertical projection of Hölloch and nearby caves, including a sketch of the highest water levels observed during storm events.
Figura 2. *Vista en planta y proyección vertical de Hölloch, cerca de las cuevas, incluyendo un esquema de los niveles de agua más altos observados durante eventos de tormenta*.

The Siebenhengste cave system

With more than 160 km of connected passages the Siebenhengste cave system (Réseau Siebenhengste-Hohgant) appears to be the second largest in western Europe. With 1340 m of elevation difference between its highest and lowest points the cave is also the deepest in Switzerland. Bärenschacht, with more than 70 km represents the downstream part of the system, but could not be connected so far. A series of other large caves (K2-Hohgant, Beatushöhle, A2-Loubenegg, Haglätsch, etc.) are being explored in this region totalling a length of more than 320 km (Fig. 3). The team of cavers known as "Höhlenforschung Region Hohgant, HRH" forms the coordination of the explorations in this region.

The main part of the Siebenhengste cave system develops within a monocline Schrattenkalk-limestone (Lower Cretaceous, Urgonian facies) dipping 25° towards southeast. The limestone is partially covered by Eocene sandstone.

The Siebenhengste cave has 35 entrances. Some of them, the most direct ones, are typically followed by 150 to 200 m of shaft-series crossing the limestone down to its bottom. Shafts are separated and/or followed by high (5 to 20 m) and narrow (0.4 to 1.5 m) meanders following the limestone strata down-dip. Many other entrances connect to the main system through a complex series of narrow meanders (canyons) cross-cutting fossile phreatic passages and heading to shafts of variable depths. Near to the bottom of the limestone, this alpine type of caves

cuts or joins fossil phreatic (elliptic) passages, which developed in the past at different depths along the strike of the limestone strata. Many of the passages are rather small (less than 1 m in diameter) but the largest reach 7 to 10 metres of diameter. This complex labyrinth of fossile passages is drained below by a series of parallel underground streams, flowing downdip.

Studies of cave morphology and genesis (Bitterli 1988, Jeannin et al. 2000, Häuselmann et al. 2002, Häuselmann *et al.* 2003a, Häuselmann *et al.* 2006) evidenced that the oldest phreatic cave passage, very close to the top of the mountain (~1900 m a.s.l.) are 4.5 millions years old. At that time water was flowing from southwest to northeast. This was the case for several upper cave levels located above 1500 m a.s.l. Lower cave levels, located below 1440 m, clearly show that the direction of flow changed by 180°, from northeast towards southwest. This must be related to a change in the position of the main valley during the Quaternary and was date to 0.8 Ma (Häuselmann et al 2006). This flow direction was maintained until today, as water flows towards the main spring (Bätterich cave) of the system, which is located within Lake Thun.

The hydrogeological system of Bätterich spring has a catchment area estimated to 32 km^2 (Häuselmann *et al*. 2003b), which expands in the northeast at least 10 km beyond Siebenhengste cave system until the Schrattenfluh massive, where marvelous limestone pavements includes some significant caves such as Neuenburgerhöhle and Warzensystem... The catchment area lies between 558 and 2,190 m a.s.l. in an alpine context with 2000 mm of annual precipitation, much snow, but no glacier. The lower part of the catchment is covered with forest and moors (on sandstones) and the highest part with pastures and nacked limestone pavements.

Bärenschacht develops directly upstream of Bätterich spring over a distance of 4 km as the crow flies. The cave has only a single entrance followed by 900 metres of shafts and meanders before reaching the main cave network. The deepest part of the cave is similar to Hölloch with a labyrinth of elliptic (phreatic and epiphreatic) cave passages lopping up and down within and above the epiphreatic zone of the Bätterich hydrogeological system. Flooding during high water events is in the order of 50 to 120 metres in Bärenschacht.

More information about this cave system can be found in the following references: Bitterli 1988, Wildberger and Preiswerk (1997), Hof (1997), Funken (1994), Häuselmann and Jeannin (2003), Jeannin and Häuselmann (2005), Häuselmann (2013).

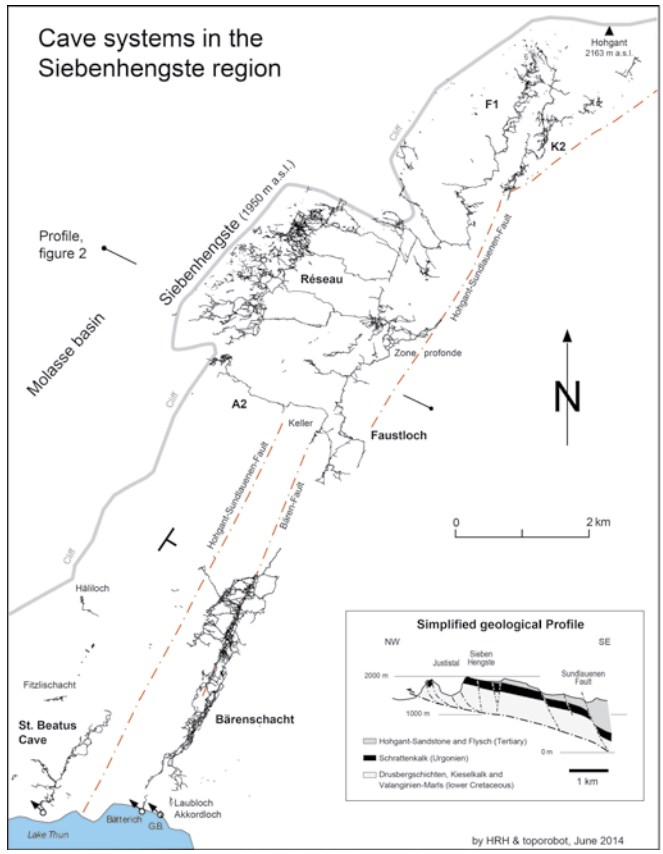

Figure 3. Plan view and geological sketch of caves in the Siebenhengste region.
Figura 3*. Vista en planta y esquema geológico de las cuevas en la región de Siebenhengste.*

The Réseau des Grottes aux Fées de Vallorbe

With more than 20 km of explored passage (Summer 2014), this cave system is the largest in the Swiss Jura Mountains. The large and well visible entrance section has been known since "ever" and was possibly already used by humans in prehistoric times if we consider human occupation in nearby caves (Gigon 1976, Audétat *et al.,* 2002). However, no artefact has so far been found in the Grottes aux Fées. The cave was first mentioned in a written document in 1795, and a series of maps has been edited describing this 200 metre-long cave with large passages. In 2,000 a fissure with a strong air draft was enlarged and the continuation of the cave has been explored since 2004 by the "Groupe d'exploration aux Fées, GEF". Information on this cave come mainly from Audétat and Heiss 2002, Dutruit *et al.* 2007 and from the GEF website:
(http://www.speleo-lausanne.ch/06_Activites/Explorations/Vd-Jura/Vallorbe-fees/_Fees-vallorbe.htm).

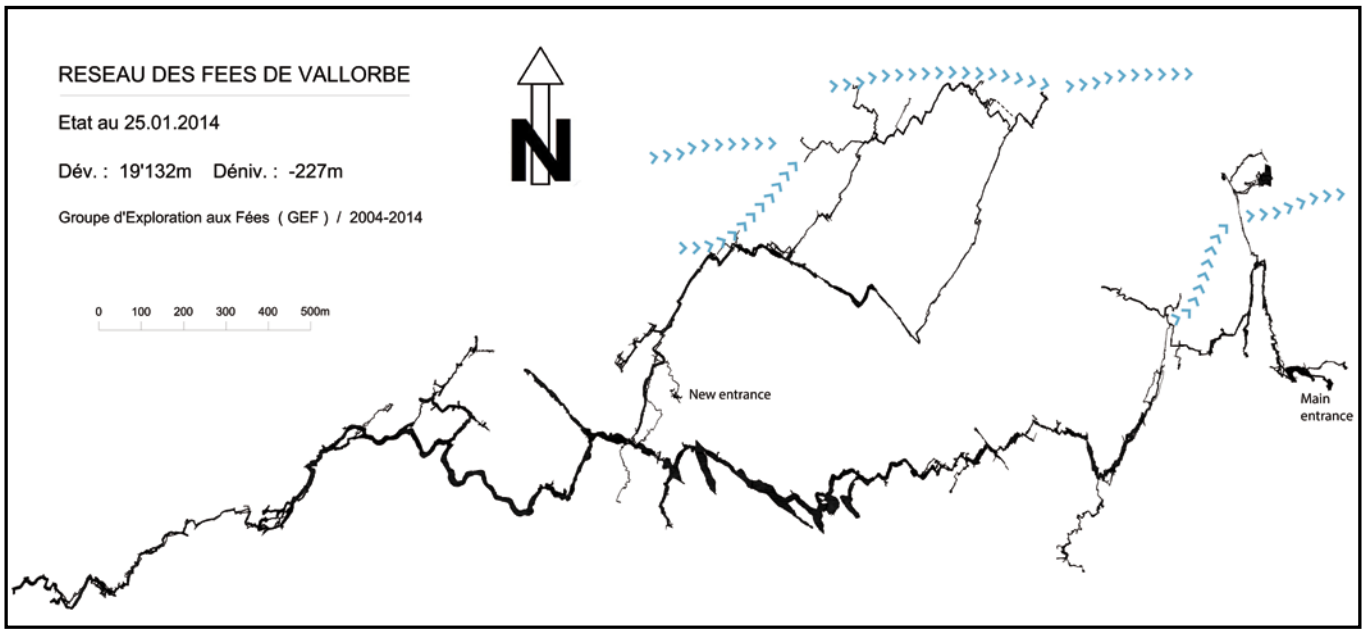

Figure 4. Plan view of the Réseau des Fées de Vallorbes, GEF, (2014).
Figura 4. *Vista en planta de Réseau des Fées de Vallorbes, GEF, (2014).*

The cave develops in slightly dipping (a few degrees towards the north) Malm (Jurassic) limestone. The cave entrance is a sub-fossil horizontal passage located 50 metres above the Gerlettes perennial spring. During extreme flood events the cave entrance becomes active and many passages in the cave are flooded. Discharge rates of the Gerlette system range between 200 and 5,000 L/s, and the assessed catchment area is 27 km^2.

The cave includes various types of passages, most of them developed first as phreatic or epiphreatic passages, which were later entrenched by vadose canyons. Some parts of the cave include large elliptical conduits (15 to 20 m in diameter). The main passage is located in the southern part of the cave system, heading west from the cave entrance through a cave distance of more the than five kilometres. Its elevation increases from east to west by about 100 m over a distance, as the crow flies, of more than 3 km. This part is mainly fossile and remains dry besides some parts in the east. The active passages are located along the northern part of the cave. Flow is towards the east, towards the Gerlettes spring.

In 2008 a new entrance, through a shaft series of 155 m, was found in the central part of the cave (Baume des Follatons) providing an easier access to the remote parts of the cave. This entrance, as the whole cave is subject to flooding, and both entrances were gated for security reasons.

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