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## Cross-formational flow, diffiufence and transfluence observed in St. Beatus Cave and Sieben Hengste (Switzerland)

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### Abstract:

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Observations in St. Beatus Cave and neighbouring caves revealed complex water flowpaths that can be used for explaining the behaviour of tracing experiments. The observations prove that even in vadose conditions, cross-formational flow, diffiufences and transfluences are a quite common feature. Therefore, also the vadose karst has a very complex organisation.

**Keywords:** flow paths, karst hydrogeology, vadose zone, tracing experiments.

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### INTRODUCTION

Tracing experiments in karst often evidence "strange" flowpaths. Many of these results have had hitherto only theoretical explanations and no directly observable analogon. Observations in caves provide nice examples explaining this type of "strange" behaviour, which we believe is far more common than one might assume. We will mainly concentrate on the vadose parts of a karstic aquifer. As a general rule, water flowpaths in the vadose part are considered as being vertical to subvertical, until they reach either the phreatic parts or an aquiclude rock, on which they then flow down dip and/or towards the spring. The first impression of St. Beatus Cave matches exactly this rule (Fig. 1). However, detailed observations show that there are many differences to it, which shall be explained here.

The St. Beatus Cave is located in central Switzerland, north of Lake Thun and south of the Sieben Hengste mountain (Fig. 2). The cave is spring of a catchment area that extends to the north. There is no connection to the catchment or the caves of the neighbouring Sieben Hengste area (Häuselmann and Otz 1997), that constitutes one of the biggest cave complexes of the

Alps, with a total of 280 km of surveyed passages.

The stratigraphy is presented in Fig. 1. Over the siliceous limestone (lower Cretaceous), that is medium karstifiable, lie the 30 to 50 m thick Drusberg marls, which in almost all cases constitute an aquiclude and therefore the base for the subterranean flowpaths. The lower Cretaceous Schrattekalk (160-320 m) then follows, a very well karstified pure limestone, in which almost all caves develop. On top of the Schrattekalk lies the Eocene Hohgant series, a complex mixture of sandstones, sandy limestones and shales, that is usually only permeable along fractures.

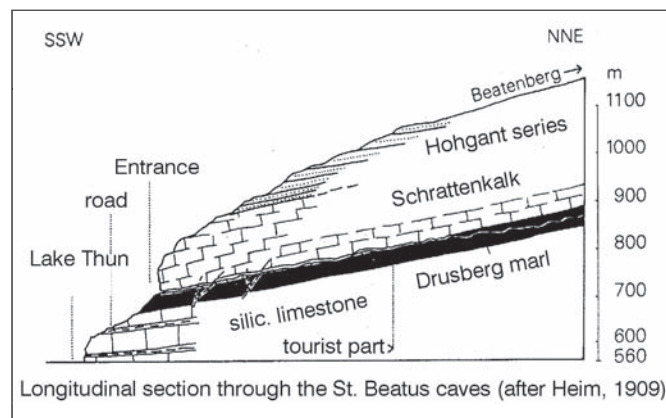


Fig. 1. Longitudinal section through the St Beatus caves (after Heim, 1909).

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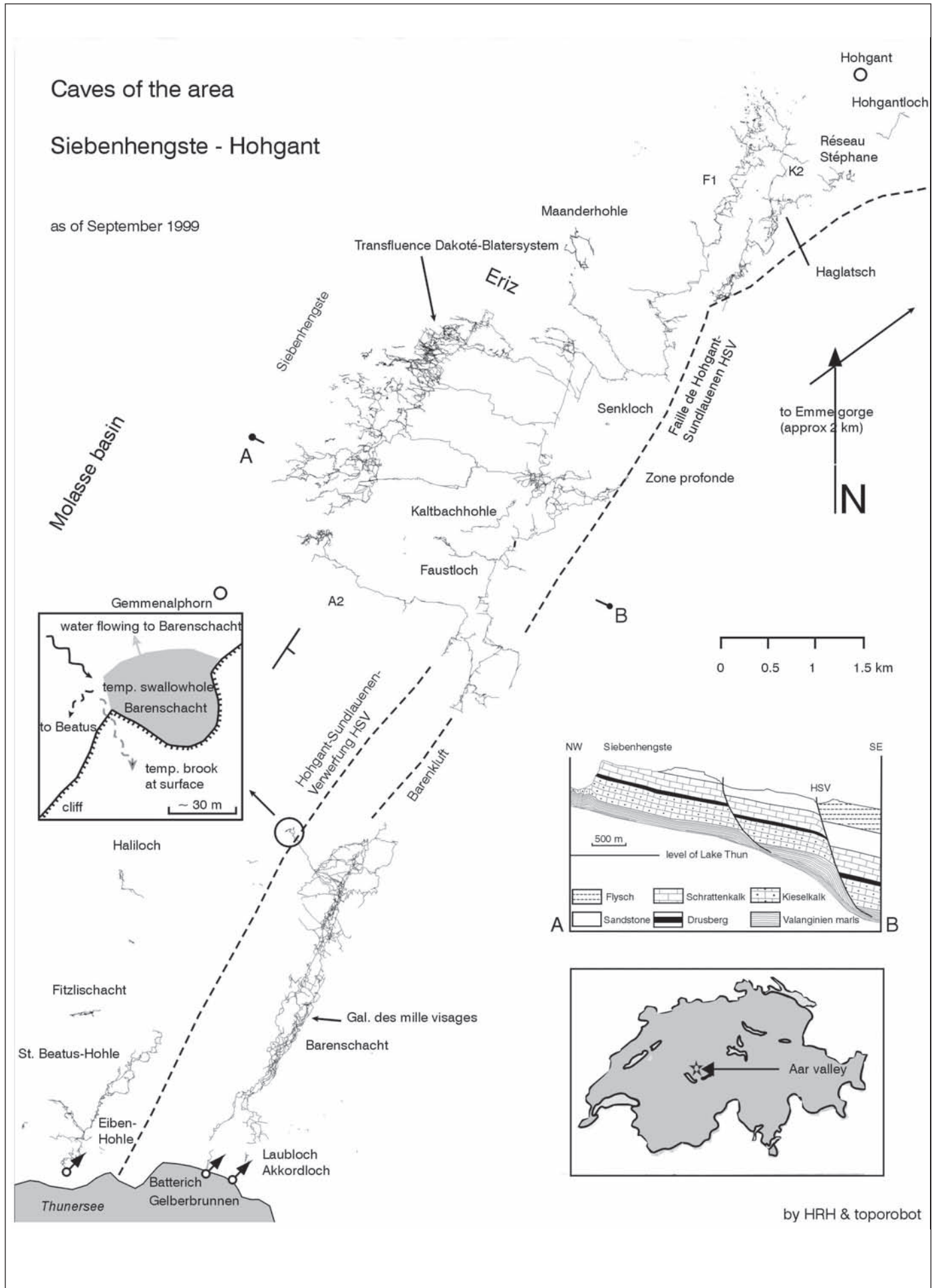


Fig. 2. Overview over the cave region of Sieben Hengste with some localities.

## CROSS-FORMATIONAL FLOW

Cross-formational flow as such has been described many times, but often it is related to confined settings or to vadose downcutting into another layer (e.g. Calaforra and Pulido-Bosch, 2000). Here, the situation is a little bit different.

The boundary between Drusberg and Schrattekalk is not a sharp one. Especially in St. Beatus Cave, we observed three beds of limestone within the uppermost Drusberg layers. This interbedding is due to the changes in sea level and consequent sediment deposition. At least one of those limestone layers disappears towards the entrance of the caves (Figs. 3 and 4).

The observation of those different interlayers has been possible because there are several cave passages in them, that alternate between the limestone parts. Why do passages exist there? One possible explanation would be that the sedimentation of Schrattekalk and Drusberg interfingers as shown in Fig. 3, and that the different water courses then are trapped between Drusberg layers. Whereas this might be a possibility for the initial capturing of the waters, observations

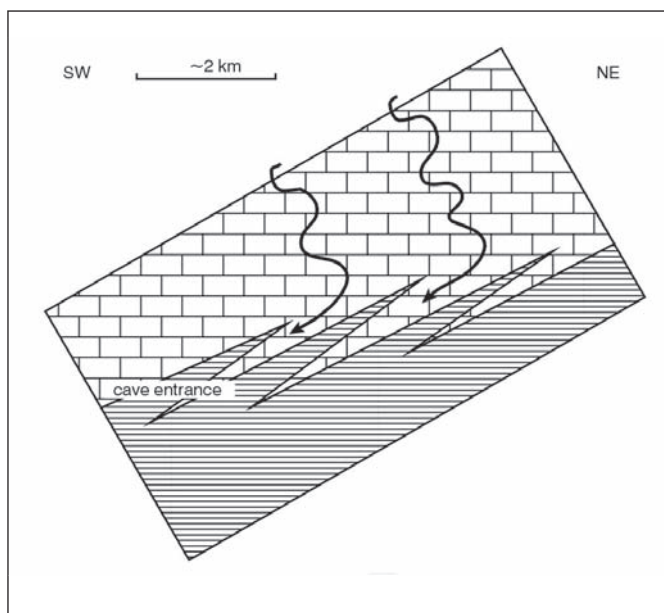


Fig. 3. Possible explanation for the primary origin of the different water courses.

show repeated jumping between the layers, which cannot be explained any more by simple trapping (Fig. 4). The structure of the rocks (fractures etc) has to play a role.

It is well known that relatively thin aquicludes can be cut by the erosional forces of a vadose stream, allowing the water to flow into the strata below, as is the case in the Faustloch meander in Sieben Hengste (for location see fig. 2). The morphology of the galleries of St. Beatus Cave, however, show that the jumping (both up and down the strata) already occurred in phreatic state (Fig. 6 as additional illustration). There are even some small parts of St. Beatus Cave that developed entirely within the marly parts of the "aquiclude". The same thing is observed in nearby Bärenschacht (Sieben Hengste system), where most of the "Galerie des mille visages", about 200 m long, developed straight across the Drusberg marls on the SE side of a thrust fault. Some tens of meters farther down, a phreatic gallery again crosses an upthrust Drusberg block without any sign of following the limestone that lies some meters higher.

Those examples show that cave genesis is well possible within, below and across "aquicludes" under phreatic conditions. Later vadose flows in those conduits may follow those flowpaths or create new ones, leading to some strange results often displayed by tracing experiments.

## THE DIFFLUENCES

Anyone knows the famous children's game about the water from the home well, that flows into the small brook, that reaches the river, which in turn joins the stream that flows into the sea. Adult persons call it "dendritic system" and claim that it is ubiquitous on Earth. Hydrogeologists, however, have a more differentiated picture of reality, since they know that under phreatic conditions, water flows according to its head, and that a karst region might have several springs connected to one injection point (see the example of Totes Gebirge in Austria by Maurin and Zötl 1964). So far, so good. Now, we

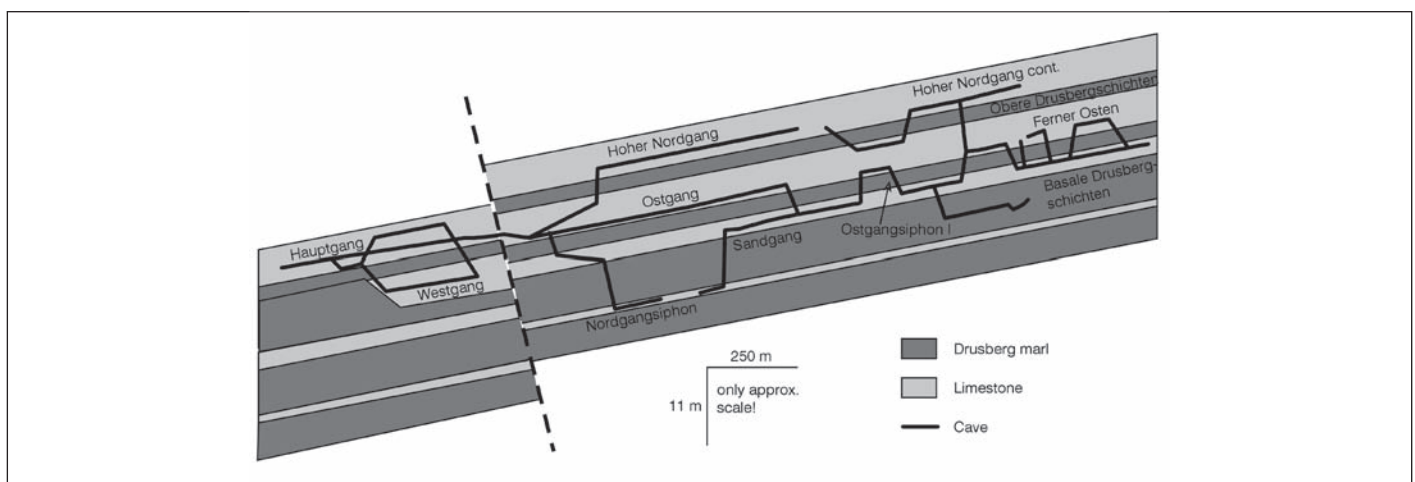


Fig. 4: Schematic profile through St Beatus Cave and the location of the galleries.

know that resembling flowpaths also are proved by tracing experiments in regions where the phreatic realm should be located much lower than the geologic barriers (e.g. in some parts of the Swiss Jura). If we can exclude the above mentioned possibility of conduit development in aquiclude formations, another answer to this behaviour must be found.

One possible answer lies in the fact that vadose diffluences (rivers parting and taking two different ways) also exist and that they are much more numerous than one might think - especially in areas with low hydraulic gradients such as Mammoth Cave. In the St. Beatus Cave, we found at least six proven diffluences (Fig. 5). The first one can be seen just behind the entrance to the cave. There, the water course divides from a lake dammed by sinter and breakdown, and joins again only at the surface. The second is the brook coming from the sewage station from Beatenberg. It is met as a whole in the far end of Erosionsgang and later divides, reappearing in Bachgrotte and Spaghettigrotte. The third, small one is the seepage in Erosionsgänge that divides on sinter floor. The fourth one is found in Alibaba, where a waterfall partly splashes into Alibaba and partly into the main gallery of Westgang. The fifth one is in Hauptgang, where a lake, dammed by sinter, is emptied through both sides, inflow coming from the ceiling of the cave. The sixth one at the entrance of Der Vermisste, where the water divides on Sinter

floor. There is even a seventh one in the Tourist part, that divides only under flood conditions.

Other vadose diffluences are found in Kaltbachhöhle, Senkloch, K2, Bärenschacht, and the Cave System of Sieben Hengste, all caves being in Sieben Hengste region (Fig. 2). This enumeration is by far not complete. All cited examples are **not** dependent on local geology, but inherent to karstological features. Of course, vadose diffluences also occur in other caves, as the example by Weidmann et al (1994) shows for the Mutteehöhle in Central-Eastern Switzerland.

As a conclusion, it seems that vadose diffluences are not as rare as assumed, but seem to be quite a common feature for underground rivers. In all of the examples cited above, the water finally reappears at the same spring. But, of course, this is by no means obligatory, and depending on the voids encountered, flowpaths divided in vadose conditions might join quite different springs.

An extreme case of division is encountered near the entrance of Bärenschacht (Fig. 2). The small river disappearing just before reaching Bärenschacht entrance flows into Beatus cave (Häuselmann and Otz 1997). If there is high flood, it rushes down past Bärenschacht and flows down on the surface. Every water falling to the left side of this brook, within some 100 m<sup>2</sup>, will join Bärenschacht and therefore Bätterich spring.

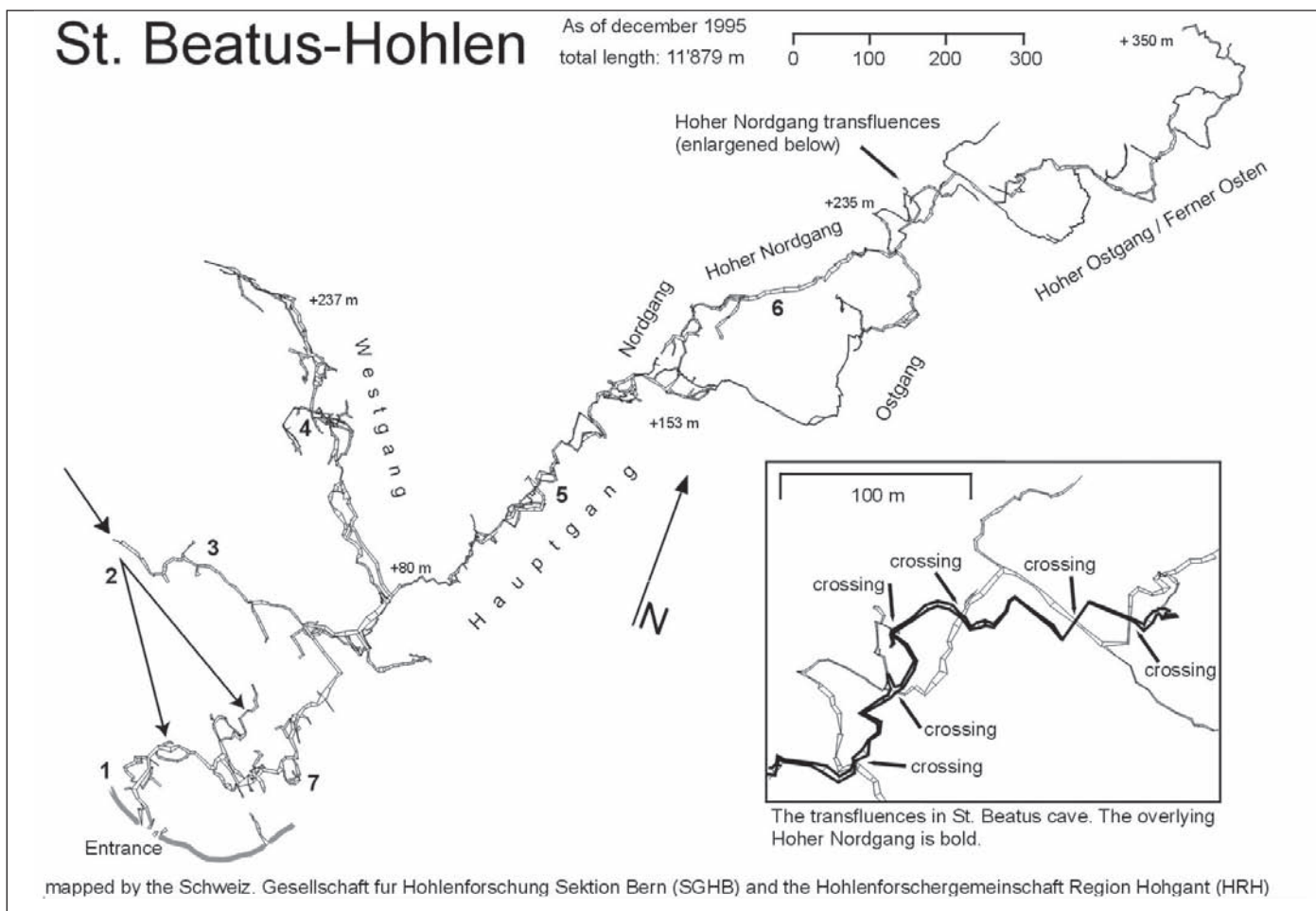


Fig. 5. The diffluences in St. Beatus Cave. The numbers refer to the text.

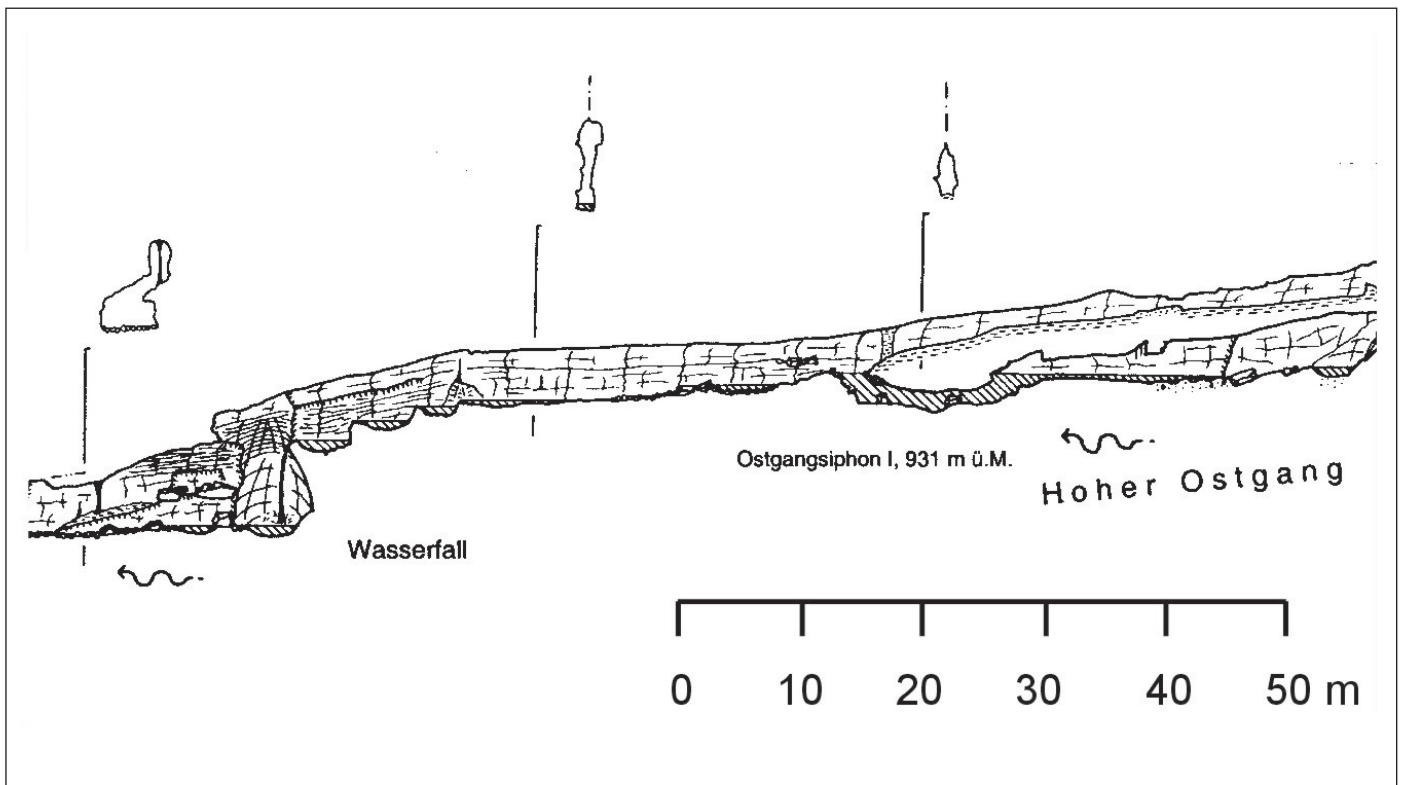


Fig. 6: Longitudinal section through the Ostgang, St. Beatus Cave. At the location "Wasserfall", the passage cuts across a marly layer, following a fracture. Between "Wasserfall" and "Ostgangsiphon", the passage then follows the upper boundary of the layer (symbolised by the horizontal line in the middle of the drawing). The passage then doubles - a small passage stays above the layer, the main passage goes back below, thus forming a sump. The "Hoher Ostgang" is formed below.

### TRANSFLUENCES

It is known that, if karst rocks are overlain by impermeable caprocks, there are surface streams that often flow in another direction than the karstic flowpaths below. It is less known that the same thing may happen even if there's no caprock present - although examples have already been described (e.g. Mammoth Cave, Palmer 2000). The Emme river flows through a gorge between Hohgant and Schrattenfluh that is cut into the Schrattenkalk (Fig. 2). In the same Schrattenkalk, the waters coming from the Schrattenfluh flow in direction of Lake Thun, so almost the opposite way. There is, at least in normal conditions, no indication of waterloss in the Emme gorge nor indication of present or former caves. We assume that in geologic time, this Emme crossing might disappear and the river may eventually dry up in profit of the subterranean system. However, for historic times and for tracing experiments, today's state is important and is being measured.

Transfluences are also observed in St. Beatus Cave. The Hohe Nordgang and the Ostgang were created at the same time and under phreatic conditions. They are divided by the uppermost Drusberg intercalation (see Fig. 4). Today, flow in both galleries is essentially vadose. The Hoher Nordgang river crosses the Ostgang several times without loss of water, until they eventually join to form the stream of the main gallery. Here, the division is due to geologic structure.

Another transfluence is known in Sieben Hengste, where a small brook from the Dakoté entrance of the

Cave System (Fig. 2) flows in southeast direction, whereas a rivulet in Blatersystem, some 150 m below, flows in southwestern direction.

### CONCLUSION

All the observations presented here are observable analoga to the behaviour of tracing experiments. Especially in St. Beatus Cave, we observed all three cases of flow, therefore the cave represents a sort of a "hydrogeological model" that is observable *in situ*.

Cross-formational flow, diffluences and transfluences can explain most "strange" results of dye tracings in karst regions. One problem, however, still exists for those dye-tracings where *in situ*-observations or for example the structure of the bedrock are not known: It will often be quite impossible to tell which of those three types is dominant and responsible for the results observed by dye tracing experiments.

### ACKNOWLEDGEMENTS

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