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New chronological constraints on the intrakarstic fluvio-glacial fan of the cave Sous-les-Sangles (Bas-Bugey, France)

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Abstract

The age of the Last Glacial Maximum extension of the French north-western Alps is still under discussion. Lateral to the ancient glacial valleys, karstic galleries functioned as glacial sinkholes during the glacial retreat phases and are thus relevant recorders of these glacial phases. In the Bas-Bugey (Ain, France), the cave Sous-les-Sangles hosts a remarkable laminated detrital sequence associated with an ancient position of the Isère glacier in the "Cluse des Hôpitaux". Several U/Th alpha dates undertaken 20 years ago are revised here. Five new U/Th ICP-MS dates on speleothems frame the detrital complex, providing a terminus post quem (TPQ) and a terminus ante quem (TAQ) to this glacial invasion. The TPQ is dated 87.3 ± 3.9 ka (MIS 5.b.c) and the TAQ is dated 11.6 ± 4.3 ka (MIS 1). The laminated detrital sequence is thus better constrained and the glacial invasion could have only been deposited during MIS 4 (locally Würm II, first max) or MIS 2 (Last Glacial Maximum or locally Würm IV) stages. The cave Sous-les-Sangles has a strategic position to constrain maximum glacial extension during the last cold stages of the Quaternary in the French Alps.

Résumé

Nouvelles contraintes chronologiques sur le cône fluvio-glaciaire intrakarstique de la grotte Sous-les-Sangles (Bas-Bugey, France). L'âge de la dernière extension maximale glaciaire des Alpes nord-occidentales françaises est toujours discutée. En position latérale aux anciennes vallées glaciaires, des conduits karstiques ont fonctionné en pertes juxtaglaciaires durant les phases de retrait glaciaire et constituent des enregistreurs pertinents de ces phases glaciaires. Dans le Bas-Bugey (Ain, France), la grotte Sous-les-Sangles abrite une remarquable séquence détritique laminée associée à une position du glacier de l'Isère dans la cluse des Hôpitaux. Des datations entreprises il y a 20 ans (U/Th alpha) sont ici révisées. Cinq nouvelles dates U/Th MC-ICP-MS ont été entreprises sur des spéléothèmes encadrant l'ensemble détritique offrant un terminus post quem et un terminus ante quem à cette invasion glaciaire. Le TPQ est daté à $87,3 \pm 3,9$ ka (MIS 5) et le TAQ est daté à 11.6 ± 4.3 ka (MIS 1). La série détritique laminée est ainsi mieux contrainte et l'invasion glaciaire ne peut se situer que dans les stades MIS 4 (localement Würm ancien) ou MIS 2 (localement Würm récent). La grotte Sous-les-Sangles confirme sa position stratégique pour contraindre l'extension maximale glaciaire au cours des derniers stades froids du Quaternaire.

1. Introduction

The latest maximum glacial extension of the French north-western Alps (Würm) is still under discussion. Does it rather correspond to the ancient Würm (MIS 4) or to the recent Würm (MIS 2)? Lateral to the former glacial valleys, karstic galleries functioned in juxtaposed sinkholes. They are relevant recorders of these phases. South of the Jura, the Bas-Bugey is in a strategic position to record the French Alps glaciers maximum extension and the glacial retreat. The "Cluse des Hôpitaux" is an important valley currently drained by two diverging rivers. During the last glacial maximum, the cluse was invaded by a diffuence of the Isère glacier. The Upper Kimmeridgian limestone karst recorded this invasion. On the surface, the remains of the maximum glacial extension consist of till belts recognised at around

900 to 950 m above sea level (asl) in the Innimond sector and at around 850 to 900 m asl in the Ordonnaz sector (Kerrien *et al.*, 1990). The origin of these the Bas-Bugey glacial overflows has long been attributed to the Rhône (Kerrien *et al.*, 1990) and finally to Isère on the basis of petrographic analysis (Coutterand, 2010). In this sector, where glacial records are remarkable, an important karst develops: the Burbanche karst system (22 km) on the southern edge of the "Cluse des Hôpitaux" (Chirol, 1985; Chirolet Hugon, 2010; Hugon, 2013) (Fig. 1). We chose to analyse an exceptional sedimentary deposit at the Sous-les-Sangles cave (Fig. 2). It has already been the subject of extensive studies (Sbai *et al.*, 1995; Lignier *et al.*, 2002), but the precise chronology of the deposit remains to be established. This is the subject of this note.

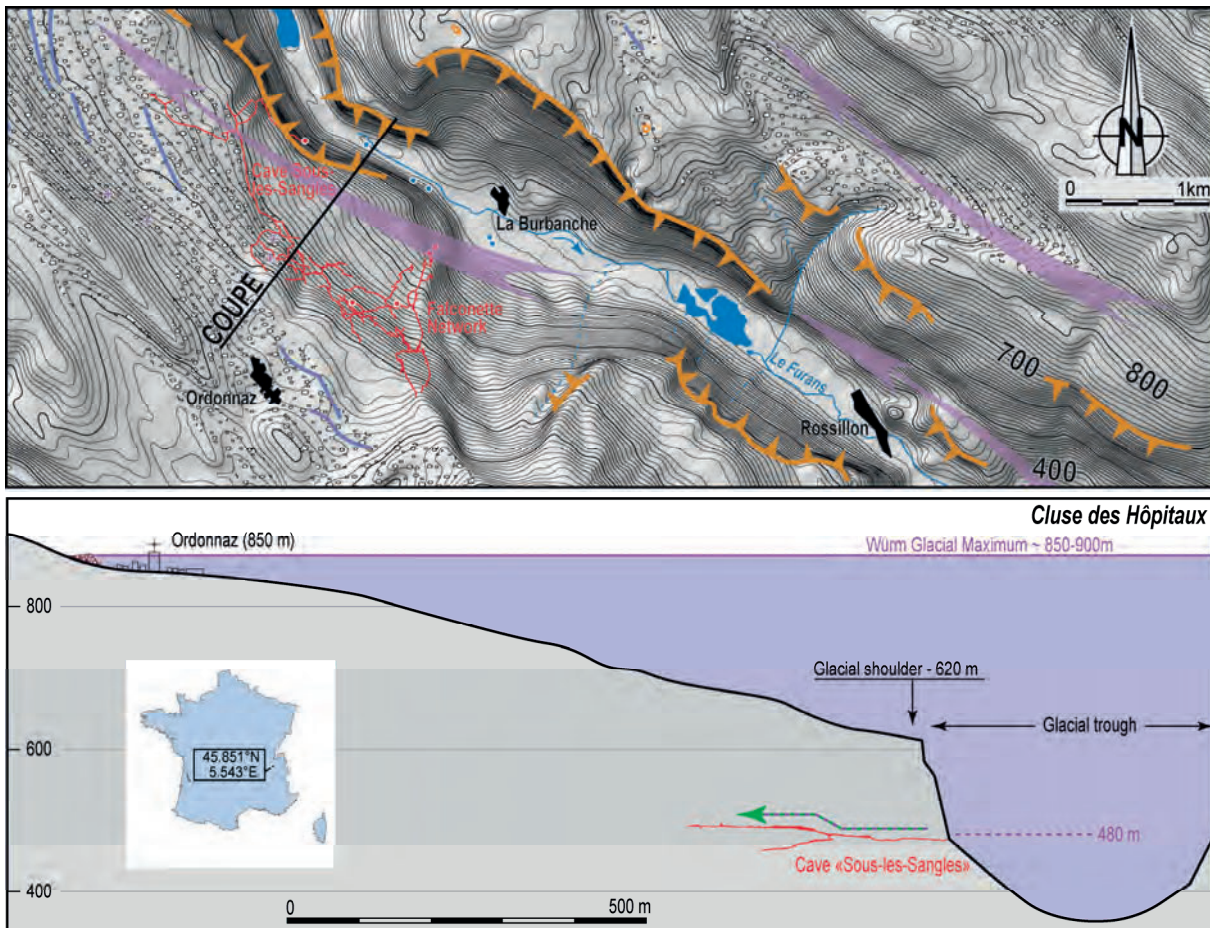


Figure 1: Location of the Sous-les-Sangles cave (plan and section) in the Bas-Bugey. Note the position of the horizontal cave in relation to the WGM (Würm Glacial Maximum) extension.

2. The karstic filling of the Sous-les-Sangles cave

At 475 m asl, the Sous-les-Sangles cave is a horizontal gallery developing in the lower third of the southern slope of the cluse. Underground, three major sedimentary formations have been identified (Fig. 3) (Lignier *et al.*, 2002): (i) at the base, a morainal and fluvio-glacial filling composed of (I₁₋₂) dark, greenish, stratified sands, rich in quartz, mostly unworn (Sbai *et al.*, 1995), covered in discordance by a coarser set (G₂) composed of decimetric blocks with a poorly sorted matrix. On top, a coarser sandy series (I₂₋₃), less stratified and partially channelled, lies in discordance (Lignier *et al.*, 2002); (ii) on this set rests the sequence (G₃), composed of millimetre to multi-centimetre alternation of carbonate silts and clear clays over a thickness of more than 3 m: the Boulevard. A detailed analysis of the laminations made it possible to propose a period of 350 years (Lignier *et al.*, 2002) for the setting. Closer to the entrance of the cavity, a set of clear morainic debris (iii) is identified in the "la Plage" sector (Lignier *et al.* 2002). This material has been largely reworked and washed away by the suffosion operation in the "La Plage" sector. In addition to these three types of deposits, there are also pre- and post-glacial speleothems. The cave was about 350 m below the surface of the glacier during its maximum extension. Under such a

thickness, hydrological circulations are limited to the upper third of the ice mass or within the upper 100 to 150 m (Bini *et al.*, 1998; Irvine-Fynn *et al.*, 2017). Considering these elements, juxta-glacial hydrological penetration is likely to occur when the ice surface is around 550 m, i.e. more than 250 m below the WGM line, i.e. well after the WGM.



Figure 2: The G₃ karstic infill is a 3 m thick sequence composed of millimetre to multi-centimetre alternation of carbonated silts and clear clays.

3. Contemporary filling of deglaciation

We propose the following deglaciation and endokarstic sedimentation scenario:

- **At the WGM (Würm Glacial Maximum)**, the glacial surface is at 850 m asl (Kerrien *et al.*, 1990). Underground, the drain is flooded but does not experience significant hydrological circulation. On the other hand, sedimentary sets at the bottom of galleries are already present (I_{1-2} and G_2 in particular, Lignier *et al.* 2002). These are intra-karstic fluvio-glacial cones dating from a previous glacial phase (Würm possible).

- **During a phase of retreat**, the ice surface stabilises at around 550 m. The sub-glacial flows are then around 480 m and allow hydrological exchanges with the karst in a juxta-glacial sinkholes position. The penetration of large water flow, carrying a fine detrital load and richly carbonated, leads to the sedimentation of the filling (G_3). Such a mechanism presupposes a certain equilibrium, an outlet downstream and a certain duration. These circulations are

conditioned by the cavity altitude and therefore provide information on the glacial surface altitude, which itself give information on the glacier spatial extension.

- The further lowering of the ice surface ended this equilibrium **and the sedimentation stopped**. At the cave entrance, surface circulation can be lost underground with poorly sorted fluvio-glacial material. This coarser material indicates an increased hydrological competence, which can be attributed to a stronger hydraulic gradient. The proximity of the glacier front during the retreat dynamics may explain this temporary hydraulic gradient increase and thus in the importance of the water flows.

- Finally, **the glacier disappears** and the cavity recovers its hydrological functioning, still known today, with partial incision of the sedimentary deposits. Speleothems are set up and seal these sedimentary deposits in their partially dismantled state.

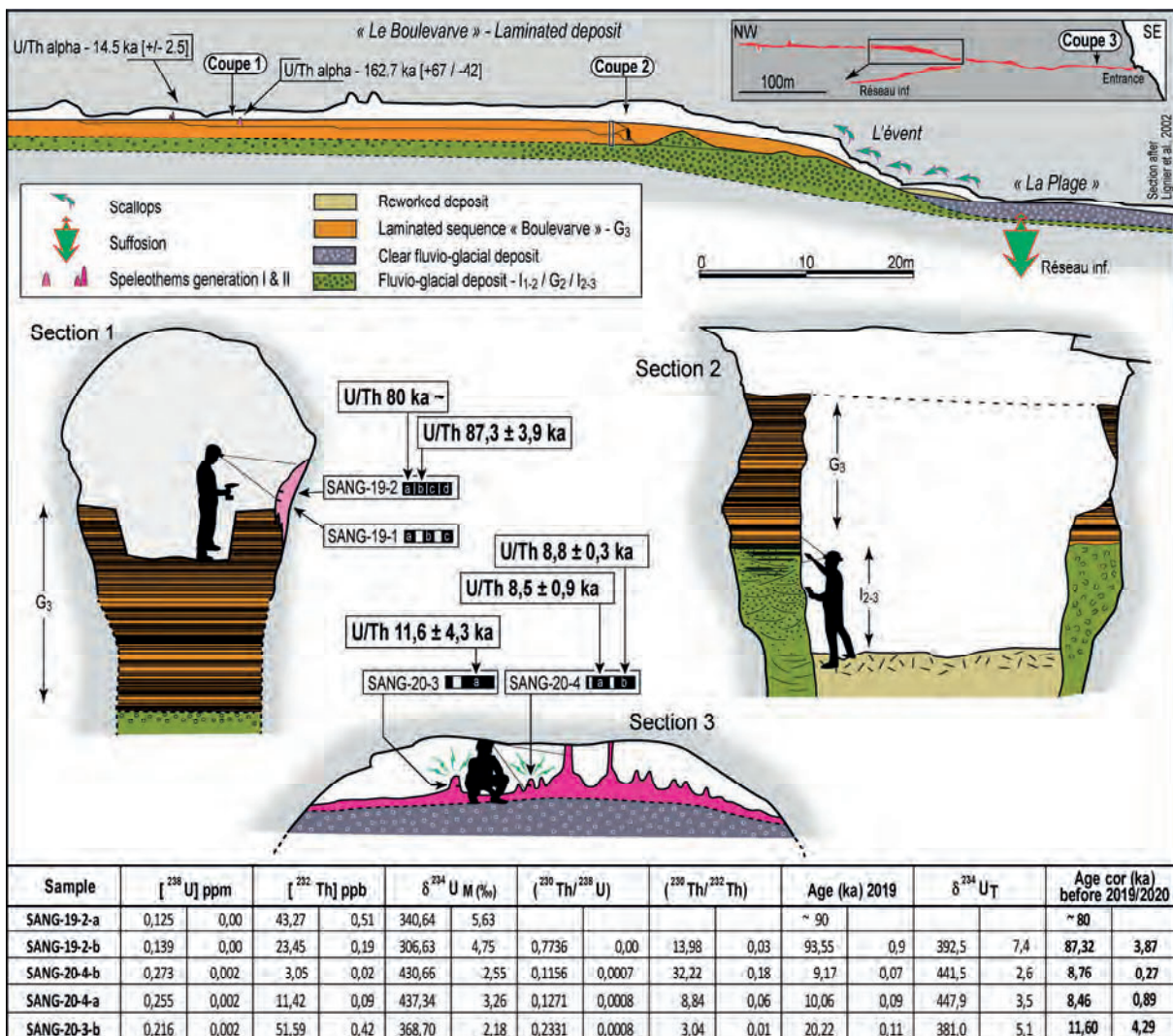


Figure 3: Synthetic section of the cave Sous-les-Sangles with location of the studied sections. Table of the 5 U/Th dates with U and Th contents, activity ratios and ages. Raw ages were corrected ("Age cor" column) assuming a $^{230}Th/^{232}Th$ activity ratio for the detrital phase of $1.5 \pm 50\%$. The data obtained show that the sedimentary ensemble belongs to the MIS 4, 3 or 2 stage.

4. New U/Th dates

For this reconstruction, we propose chronological constraints. U/Th dating (alpha method, Quinif, 1987) had made it possible to propose two dates framing the sequence and gave the following ages: 162.7 ka (+67 / -42) for a flowstone sealed by the G₃ deposit and 14.5 ka (+/- 2.5) for a stalagmite covering the G₃ deposit (Lignier *et al.*, 2002). We have chosen to reuse these dates and supplement them with new analysis. For this purpose, three sections were invested. Section 1 is in line with the flowstone already dated. Analyses were performed at LSCE using a MC-ICP-MS and following the protocol described in Pons-Branchu *et al.*, 2014. Two micro cores (SANG 19-1 and SANG 19-2) were dated, with for sample 2, an age of 87.3 ± 3.9 ka and a second age of approximately 80 ka. Near the entrance (section 3), two stalagmites (SANG 20-3 and SANG 20-4) were likewise cored and delivered the following Holocene ages: 11.6 ± 4.3 ka, 8.5 ± 0.9 ka, 8.8 ± 0.3 ka (Fig. 3). The speleothems SANG 20-3 and SANG 20-4 are shocked (fig. 4), i.e. they are marked by pebble impacts associated with the evacuation of clasts by flood waters. These impacts can only be identified on one side of the stalagmites and are evidence of the clean-up phase (coarse fillings with hydrological and sedimentary circulation) from the interior of the karst towards the valley. It is therefore not possible for glacial material to penetrate after the stalagmites establishment. These dates are terminus post quem and ante quem of the G₃ detrital sequence penetration. Consequently, the last glacial phase responsible for this detritic invasion took place

at MIS stages 4, 3 or 2. Unfortunately, as it stands, it is not possible to distinguish between ancient Würm and recent Würm or even to correctly link this sequence to one of the stages of the glacial retreat. However, it has been possible to better constrain the relationship between the glacial dynamics in the valley and the invasion of sediments. The filling of the Sous-les-Sangles cave is an eloquent case that deserves further study. OSL analyses are planned to directly date the detrital deposits.



Figure 4: Micro-core drilling of the SANG 20-04 speleothem. Note the shocks (white dots in the green circle) showing the evacuation of the pebbles after growth.

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