Supplementary information of "Late Cenozoic evolution of the Ariège River valley (Pyrenees) constrained by cosmogenic ²⁶Al/¹⁰Be and ¹⁰Be/²¹Ne dating of cave sediments" by A Sartégou, P.-H. Blard, R. Braucher, D.L. Bourlès, et al.

Lithological and structural contexts of the central-eastern Pyrenees

Knowledge of the sources of analyzed minerals, river profiles and potential sediment storage sites is crucial in studies based on the measurement of cosmogenic nuclide concentrations.

Quartz-crystalline zones within the Axial Zone are orthogneiss massifs (Aston, Hospitalet, and Trois Seigneurs) that are occasionally intruded by granite plutons or granitoids (e.g., Vacherat et al., 2016); the remainder of the Axial Zone comprises undifferentiated Palaeozoic terrains. The North Pyrenean Zone of the Ariège area consists of Palaeozoic basement that lies upon stratigraphic or tectonic contacts with Jurassic and Cretaceous basins, which were heated during a rifting episode; the sediments exhibit hightemperature metamorphic and ductile structural fabrics. The Tarascon basin is a syncline characterized by a Palaeozoic basement underlying a highly folded Mesozoic sedimentary cover. Mesozoic terrains (dolomites, limestones, and marls) are enclosed between three Palaeozoic North Pyrenean massifs (Saint-Barthélémy, Trois Seigneurs, and Arize) composed of metamorphic rocks, Palaeozoic schistose series, and intrusive granites. The basin is separated from the Axial Zone by the North Pyrenean Fault. In the southern part of the basin, narrower valleys are excavated into the compact Aptian limestones, with the synclines of Quié de Lujat and Cap de la Lesse on the right and left banks, respectively. In the northern part of the basin, the relief consists of a series of anticlines at lower altitudes (by 400 m elevation), including the Sédour and Calamès massifs on the left bank of the Ariège. Faults in the study area do not exhibit Neogene activity (Lacan and Ortuño, 2012).

Quaternary history of the Ariège catchment

The Quaternary geomorphic evolution of the basin can be reconstructed from glacial landforms (trough valleys, moraines, and erratic blocks) and alluvial terraces (e.g., Delmas et al., 2012). Precipitation accumulated above the palaeo-equilibrium line of several massifs (1,600–1,700 m a.s.l.) and generated ice flows that passed through valleys upstream of the Tarascon basin, joined the Ariège axis, and formed a 60–80-km-long glacial tongue that reached the Foix basin (Delmas, 2009).

Four deglaciation stages are observed in the Ariège river valley. The Garrabet stage, the first deglaciation stage after the last glacial maximum, was characterized by the upstream withdrawal of ice lobes over a horizontal distance of approximately 7 km; upstream ice thicknesses in the Ariège valley remained significant. The Bompas-Arignac deglaciation stage (20.1–19 ka) was characterized by a general decrease of ice volume (Delmas et al., 2011), which confined ice tongues at the bottom of trough valleys. At that time, the Ariège glacier did not exceed 850 m a.s.l. During the Bernière deglaciation stage (20.1–19 ka), the presence of an ice tongue in the Tarascon basin indicates that the Ariège glacier was continually fed upstream by one of its last tributaries, the Aston glacier. Nevertheless, 1 km upstream of the Bompas-Arignac front, the ice volume of the glacial tongue had decreased to a maximum thickness of a few tens of meters. The Petches deglaciation stage (15.2 ± 3.3 to 13.9 ± 2.1 ka) is mainly characterized by the withdrawal of the Ariège glacier, which was then restricted to its high valley (Delmas, 2009).



Figure S1: Extent of the Pleistocene paleoenglacements of the Ariège River valley during the MIS 4 stage (modified after Delmas et al., 2012). During the Quaternary, the Ariège massifs were repeatedly completely covered by the Ariège and Vicdessos glaciers.

Sample (lab ID)	Mass of dissolved quartz (g)	⁹ Be spike weight (μg)	¹⁰ Be/ ⁹ Be	1 σ (%)	²⁷ Al spike weight (µL)	²⁷ Al (at in sol)	²⁶ A1/ ²⁷ A1	1σ (%)
BE1	14.055	0.101	5.90E-14	19	-	1.2653E+20	4.69E-15	38
BE2	12.830	0.094	2.70E-14	29	-	1.8158E+20	2.07E-15	45
BE3	16.514	0.101	3.67E-14	17	-	1.1334E+20	1.71E-15	48
CALA-14-01	8.892	0.104	4.37E-14	9	-	3.68E+19	1.76E-15	58
CALA-14-01b	11.276	0.099	4.02E-14	16	-	6.52E+19	3.42E-15	41
CALA-14-02	10.096	0.101	3.18E-14	6	-	6.6E+19	1.17E-14	24
CALA-14-03	8.796	0.095	3.83E-14	13	-	8.27E+19	4.21E-15	38
CALA-14-04	12.927	0.102	2.01E-14	16	-	1.2E+20	3.63E-15	45
CALA-14-05	9.586	0.102	3.20E-14	8	-	8.4E+19	9.00E-15	28
CALA-14-06	13.834	0.102	4.85E-14	10	-	1.2E+20	6.49E-15	33
LO1	18.082	0.101	2.22E-14	29	-	4.7806E+20	1.44E-15	50

Table S1 : Additional data table. More informations are available on request

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Sample (lab ID)	Mass of dissolved quartz (g)	⁹ Be spike weight (μg)	¹⁰ Be/ ⁹ Be	1 σ (%)	²⁷ Al spike weight (µL)	²⁷ Al (at in sol)	²⁶ A1/ ²⁷ A1	1σ (%)
LO2	18.660	0.077	4.06E-14	12	-	1.02E+20	5.24E-16	100
LO3	24.518	0.099	4.97E-14	6	-	8.92E+19	8.36E-15	32
LO4	21.926	0.101	5.38E-14	5	-	7.36E+19	1.67E-14	17
LO4b	23.964	0.102	6.35E-14	5	0.251	5.95E+19	2.61E-14	13
LO4c	19.992	0.101	0.00E+00	0	-	1.02E+20	6.53E-15	28
LO5	13.266	0.101	2.00E-14	11	-	1.21E+20	1.54E-15	58
LO6	25.064	0.101	5.24E-14	11	-	1.66E+20	1.65E-15	60
LO7	19.121	0.101	2.75E-14	9	-	8.99E+19	2.94E-15	38
LO8	10.061	0.101	5.42E-14	11	-	9.55E+19	1.67E-15	58
LS1	24.613	0.100	2.15E-14	10	_	1.00E+20	9.37E-15	24
LUJ1	13.140	0.102	7.44E-15	12	-	5.7E+19	2.23E-15	58

Sample (lab ID)	Mass of dissolved quartz (g)	⁹ Be spike weight (μg)	¹⁰ Be/ ⁹ Be	1 σ (%)	²⁷ Al spike weight (µL)	²⁷ Al (at in sol)	²⁶ A1/ ²⁷ A1	1 σ (%)
LUJ2	8.817	0.100	5.48E-14	15	-	1.12E+20	2.43E-15	50
LUJ3	9.553	0.098	1.44E-14	10	-	6.56E+19	6.35E-16	100
LUJ3b	5.366	0.100	5.16E-15	16	-	5.61E+19	0.00E+00	+Infini
MOU1	8.774	0.104	2.66E-14	13	-	3.82E+19	6.07E-16	100
MOU1b	9.744	0.100	1.74E-14	19	-	7.25E+19	5.53E-16	100
NI-13-05	11.812	0.102	3.31E-14	6	-	4.1E+19	7.09E-15	33
NI-13-08	17.487	0.102	2.46E-14	13	-	1.5E+20	1.74E-15	76
NI-13-10	5.226	0.102	2.04E-14	10	-	5.3E+19	2.49E-15	58
NI-13-12	10.991	0.101	6.21E-15	12	0.6275	2.0E+19	8.35E-15	50
NI-13-13	6.539	0.097	8.82E-15	11	_	5.3E+19	1.10E-14	28
NI-13-15	13.352	0.125	1.49E-14	17	-	1.3E+20	2.94E-15	50

Sample (lab ID)	Mass of dissolved quartz (g)	⁹ Be spike weight (μg)	¹⁰ Be/ ⁹ Be	1 σ (%)	²⁷ Al spike weight (μL)	²⁷ Al (at in sol)	²⁶ A1/ ²⁷ A1	1σ (%)
NI-13-17	16.861	0.098	0.00E+00	0	-	4.0E+20	9.48E-16	100
NI-13-20	7.996	0.102	1.31E-14	12	-	7.3E+19	1.06E-14	27
NI-13-23	11.387	0.102	1.75E-14	9	-	8.8E+19	6.36E-15	36
NI2	13.340	0.101	1.59E-14	18	-	1.7890E+20	1.03E-15	58
SED-13-02	15.965	0.102	2.51E-14	18	-	1.6E+20	3.00E-15	50
SO1	12.383	0.101	1.29E-14	41	-	2.3855E+20	4.02E-16	100

ABOU101 sampling site: Niaux Cave



Figure S2: Niaux Cave map drawing by the Spéléo-Club Haut-Sabarthez (F. Rouzaud, P. Sorriaux, L. Walh and M. Ségondy) and the Service Régional Archéologique, with the locations of the sampling sites



ABOU103 sampling site: Bouicheta Cave

Figure S3: Bouicheta Cave map drawing by the Spéléo-Club Haut-Sabarthez (R & E Guinot)





Figure S4: Moutons Cave map drawing by the Spéléo-Club Haut-Sabarthez (M. Claustres), with the sampling site (red star)



ASAR 110 sampling site: Lombrives Cave

Figure S5: Lombrives Cave map drawing by the Spéléo-Club Haut-Sabarthez (L. Wahl), with the locations of the sampling sites

ASAR111 sampling site: Lombrives Tunnel Cave

Fills are numerous, mostly of glacial origin. The ASAR111 outcrop is in the center of the gallery. The exact location is delivered on the overall topography of Lombrives cave (see ASAR110 site above).



Figure S6: Photography by P. Sorriaux of the ASAR111_001 sampling site.

ASAR116 sampling site: Spoulga de Souloumbrié

To access this cave, it is necessary to climb by the thalweg and to follow the wall by a path used by the shepherds. The first porches are quite impressive.

The first leads to a beautiful gallery with lapiaz and pots that shrinks quickly. Sands are present but the angular clasts suggest an internal origin. Clay plating is also visible on some walls.

The second porch is a tunnel filled with scree. It allows access to the spoulga (= means cave in the local dialect).

The third porch gives access to the widest gallery of the cave. The epiphreatic circulation clues (pots, lapiaz, etc.) are abundant but deposits are absent from the walls. The gallery is then obstructed by scree at the upper corridor. This is where the only veneer in the gallery, composed of gravel and quartz pebbles, including one of smoked quartz, remained. It should be noted that the totality of the material present, scanty, was taken to constitute the sample ASAR116_001.



Figure S7: Map of the Souloumbrié Cave (SCHS document, by Vialard, Bernard & Chaput), on the territory of the Cazenave town.

ASAR117 sampling site: Bédeilhac Cave

The galleries of this cave are very wide and have been frequented by the Magdalenians.

The Achille gallery does not contain alluvial deposits, but crystalline free pebbles and blocks of the same nature are present on the ground.

The Vidal Gallery, with Magdalenian remains (archeological examination in progress), contains many fillings clad on the walls and fault planes. It is most often gravelly sands such as those taken at the front door, constituting sample ASAR117_001.



Figure S8: Topography of the Bédeilhac cave (SCHS, C. Rauzy). Samples are designated by stars and red comments. The blue dots indicate various remarkable places. 1: old stalagmitic floors. 2: concreted gallery and large free pebbles. 3: residual alluvium hung on the wall. 4: residual alluvial fillings. 5: perched floors.
6: beveled floors. 7: plated sandy deposits. The Mandement Gallery has been dug by hand and is filled with clays. 8: survey showing the glacial sands. 9: imposing deposit of pebbles.

ASAR118/ABOU118 sampling site: Enchantées Cave



Figure S9: Topography of the Enchantées Cave (SCHS, M. Claustres, Q. Maza, J.-F. Leduc, M. Buttard, P. Sorriaux) The red star is the sampling location.

This cave is located on the southern slope of the massif and has a development of about 300 m. The galleries are horizontal and show signs of vault corrosion. Alluvial deposits like sandstone veneered on the walls and vaults are relatively abundant.



Figure S10: At left: Entrance porch and two erratic granitic blocks. At right: sampling point marked by the red star (photo A. Bourdet).

ASAR122 sampling site: Esplourgues de Calamès Cave



Figure S11: Map of the Esplourgues de Calamès cave, after Gallego (1982). The sampling points of two ESR samples are represented by the red star. The measurement holes are still in place.



Figure S12: Coarse alluvial fillings into the porch I of Esplourgues de Calamès



Figure S13: A) Porch of the Esplourgues de Calamès I, at 700 m height. B) Junction between the Esplourgues de Calamès I and II, at 705 m. C) Porch of the Esplourgues de Calamès II at 705 m. D) Porch Esplourgues Calamès III at 710 m (photo A. Bourdet).

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