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## Core-derived historical records of suspended sediment origin in a mesoscale mountainous catchment: the Bléone River French Alps

O. Navratil, O. Evrard, Michel Esteves, Sophie Ayrault, Irene Lefevre, Cédric Legout, Jean-Louis Reyss, Nicolas Gratiot, Julien Nemery, Nicolle Mathys, et al.

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1 SEDIMENTS, SEC 3 • HILLSLOPE AND RIVER BASIN SEDIMENT DYNAMICS •  
2 RESEARCH ARTICLE

3

4 **Core-derived historical records of suspended sediment origin in a mesoscale**  
5 **mountainous catchment: the Bléone River, French Alps**

6

7 **Oldrich Navratil • Olivier Evrard • Michel Esteves • Sophie Ayrault • Irène Lefèvre •**  
8 **Cédric Legout • Jean-Louis Reyss • Nicolas Gratiot • Julien Nemery • Nicole Mathys •**  
9 **Alain Poirel • Philippe Bonté**

10

11 O. Navratil (✉) • M. Esteves • C. Legout • N. Gratiot • J. Nemery

12 LTHE - IRD/Université Grenoble 1/G-INP/CNRS, BP 53, 38041 Grenoble Cedex 9, France

13 e-mail: [navratiloldrich@gmail.com](mailto:navratiloldrich@gmail.com)

14

15 O. Navratil • N. Mathys

16 Irstea, UR ETGR, Erosion torrentielle neige et avalanches, 38402 St-Martin-d'Hères, France

17 e-mail: [navratiloldrich@gmail.com](mailto:navratiloldrich@gmail.com)

18

19 O. Evrard (✉) • S. Ayrault • I. Lefèvre • J.-L. Reyss • P. Bonté

20 Laboratoire des Sciences du Climat et de l'Environnement (LSCE/IPSL) – Unité Mixte de

21 Recherche 8212 (CEA, CNRS, UVSQ), 91198 Gif-sur-Yvette Cedex, France

22 e-mail: [olivier.evrard@lsce.ipsl.fr](mailto:olivier.evrard@lsce.ipsl.fr)

23

24 A. Poirel

25 EDF-DTG, Electricité de France, Grenoble Cedex 9, France

26

27 (✉) **Corresponding authors:**

28 Oldrich Navratil

29 e-mail: [navratiloldrich@gmail.com](mailto:navratiloldrich@gmail.com)

30 and

31 Olivier Evrard

32 e-mail: [olivier.evrard@lsce.ipsl.fr](mailto:olivier.evrard@lsce.ipsl.fr)

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34

35 **Abstract**

36 **Purpose:** Quantifying suspended sediment fluxes and dynamics across mountains and  
37 identifying the origin of sediment in severely eroded areas are of primary importance for an  
38 equilibrate management of water resources. This contribution aims at generalising previous  
39 results of suspended sediment fingerprinting obtained during the 2007-2009 period in a  
40 mesoscale Alpine catchment, the Bléone River (905 km<sup>2</sup>) and to possibly check their validity  
41 throughout the second half of the 20<sup>th</sup> century.

42 **Materials and methods:** Sediment fingerprinting based on elemental geochemistry and  
43 radionuclide measurements was conducted on a sediment core collected in an alluvial  
44 floodplain at the basin outlet. This technique was combined with long hydro-sedimentary  
45 time-series to reconstruct the origin of suspended sediment that deposited at this location  
46 throughout the last 50 years.

47 **Results and discussion:** Hydro-sedimentary interpretation of sedimentation based on  
48 historical hydrological databases corroborates core dating obtained with <sup>137</sup>Cs and <sup>210</sup>Pb<sub>xs</sub>  
49 activity measurements. Black marls and (marly) limestones provided the bulk of sediment  
50 throughout the sequence (40% and 22%, respectively), while they only occupies 10% of the  
51 total catchment area. However, we also showed the occurrence of major floods carrying large  
52 quantities of sediment originating from Quaternary deposits and conglomerates (25% and  
53 16%, respectively). The variability of sediment sources throughout the sequence may reflects  
54 the spatial variability of rainfall within the catchment, depending on air mass origin.  
55 However, the relatively homogeneous sediment composition throughout the sequence  
56 confirms that core-derived information is representative of large-scale flood events.

57 **Conclusions:** In conclusion, these results are consistent with the ones obtained in previous  
58 studies. They also outline the need to take account of the entire grain size range of fine  
59 sediment to provide an overall picture of sediment sources and transfers within highly erosive  
60 catchments. This study finally emphasize the relevance of using archive data to validate  
61 sediment fingerprinting generally conducted during short monitoring programs across larger  
62 time period and large widespread floods.

63

64 **Keywords** Braided river • Erosion • Geochemistry • Radionuclide • Sediment core •  
65 Sediment fingerprinting

66

67

68 **1 Introduction**

69 In mountainous regions, hillslope erosion and mass movements supply large quantities of  
70 fine-grained sediment ( $< 63 \mu\text{m}$ ) to rivers where they generally cause numerous  
71 environmental and economical problems, such as reservoir siltation and operational problems  
72 for hydroelectric power plants (e.g., Valero-Garcés et al. 1999). An excess of sediment supply  
73 can also lead to an increase in water turbidity, eutrophication and degradation of riverine  
74 habitats in lowland areas (e.g. Owens et al. 2005). Furthermore, although suspended sediment  
75 conveys the biogenic elements required by all the living organisms, the finest fraction ( $< 63$   
76  $\mu\text{m}$ ) is also one of the main vectors of contaminant transfer (e.g., PCBs, heavy metals) within  
77 catchments (Owens and Walling 2003; Collins et al. 2005).

78 The Rhône River that flows across Switzerland and France has become the main sediment  
79 supplier to the Mediterranean Sea since damming of the Nile River (Sempéré et al. 2000).  
80 Downstream reaches of this river are confronted with particularly severe contamination and  
81 siltation problems (Antonelli et al. 2008; Sicre et al. 2008). Previous studies hypothesised that  
82 a significant part of sediment probably originated from the badland areas constituted of black  
83 marls and located in the Durance River catchment (e.g. Pont et al. 2002; Di Giovanni et al.  
84 2002). During the 3-year STREAMS (Sediment TRansport and Erosion Across MoutainS)  
85 research project funded by the French Research Agency, a large hydro-sedimentary database  
86 was compiled in the Bléone River catchment (905 km<sup>2</sup>) which is one of the main contributor  
87 of sediment to the Durance River (Mano et al. 2009). The catchment is equipped with 7  
88 hydrometric stations at intermediary scales (i.e., 10–1000 km<sup>2</sup>). Each station is characterised  
89 with high frequency acquisition of discharge and turbidity, and suspended sediment sampling  
90 during floods. This network provided a useful complement to the existing installations of the  
91 Draix Observatory that have been used since 1985 to investigate sediment dynamics in small  
92 ( $< 1 \text{ km}^2$ ) severely eroded headwater catchments (Mathys et al. 2003). Sediment  
93 fingerprinting studies were conducted in this catchment to better understand the dynamics and  
94 to define the origin of the suspended sediment in the catchment. Evrard et al. (2011) and  
95 Navratil et al. (2012) outlined the very large spatial and temporal variability of sediment  
96 sources and exports during this study period. The preliminary results showed that 80% of  
97 suspended sediment was produced by floods generated by widespread low-intensity rainfall  
98 across the catchment. Such result corroborates the conclusions of Duvert et al. (2010, 2011).  
99 Furthermore, the analyses of several 1-2 yrs return period floods and one major flood (10 yrs-  
100 return period flood) that occurred in a subcatchment confirmed the important contribution of  
101 black marls (up to 70%) to sediment transported in rivers, although this substrate only  
102 occupies ca. 10% of the total catchment surface. Sediment exports generated by local

103 convective storms varied significantly at both intra- and inter-flood scales, because of spatial  
104 heterogeneity of rainfall. However, black marls/marly limestones contribution remained  
105 systematically high. In contrast, widespread flood events that generate the bulk of annual  
106 sediment supply at the outlet were characterised by a more stable lithologic composition and  
107 by a larger contribution of limestones/marls, Quaternary deposits and conglomerates (Navratil  
108 et al. 2012).

109 In order to validate those findings over a longer time period and to enlarge the scope of  
110 our fingerprinting study to a larger set of weather and flood conditions, we investigated the  
111 evolution of suspended sediment origin and dynamics over a 50-year period from the severely  
112 eroded Bléone river catchment (905 km<sup>2</sup>). To this end, we collected a sediment core in the  
113 alluvial floodplain at the Bléone catchment outlet. Long-term meteorological and  
114 hydrological datasets were used to interpret the structure of this core and to associate the  
115 sediment deposits with different hydrological periods. Radionuclide and elemental  
116 geochemistry properties were then measured on the core sediment samples. A mixing model  
117 was finally used to trace the origin of suspended sediment transported during a selection of  
118 past large floods.

119

120

## 121 **2 Study area**

122 The Bléone catchment (905 km<sup>2</sup>; lat.: 44°05'34''N, long.: 06°13'53''E), with altitude  
123 ranging between 405 and 2961 m A.S.L. (Above Sea Level), is a mountainous Alpine  
124 catchment located in the Durance River district, in southeastern France (Fig. 1). The  
125 catchment is characterised by a dendritic drainage network dominated by the Bléone River  
126 and several tributaries, among which the Bès River (233 km<sup>2</sup>-subcatchment) is the most  
127 important. Forest is by far the main land use in the catchment (44% of the total catchment  
128 surface; Table 1). The lithology mainly consists of marls, molasses and limestones, with large  
129 areas of exposed Cretaceous and Jurassic black marls, as well as Lias marly limestones (Fig.  
130 2). Geological information was derived from a digitised 1:50,000 spatially-distributed  
131 geological map of the catchment provided by the French Geological Survey (BRGM). Eroded  
132 surfaces (covering 11% of the total Bléone catchment area, see Fig. 2) were delineated in a  
133 GIS using aerial photographs taken during flight campaigns conducted in 2004 by the French  
134 National Geographic Institute (IGN). Eroded surfaces cover a mean surface of 0.45 km<sup>2</sup>  
135 (between 811 m<sup>2</sup> and 1.85 km<sup>2</sup>) and were classified into three groups: debris slope areas (22%  
136 of the eroded areas), sheet and rill erosion areas (48%), and gully erosion areas (30%). Areas

137 covered by black marls are strongly affected by erosion and are characterized by a badland  
138 morphology (Mathys et al. 2005).

139 The climate is transitional and undergoes mountainous and Mediterranean influences. Mean  
140 annual temperature ranges between 12–13°C at 400 m A.S.L., with high temperature  
141 variations between summer and winter (about 18°C). Mean annual rainfall in the catchment  
142 varies between 600–1200 mm at 400 m A.S.L. According to local archives (*Archives*  
143 *Départementales des Alpes de Haute Provence*), the largest historical flood at the basin outlet  
144 is reported to have occurred in July 1854, with a peak discharge estimated at  $\sim 1,100 \text{ m}^3 \text{ s}^{-1}$   
145 (Sogreah, 2005). Over the past decades, the maximum specific peak discharges were  
146 significantly higher in the Bès River subcatchment (165 km<sup>2</sup>) than in other similar catchments  
147 of the Southern French Alps (Fig. 3c):  $3.6 \text{ m}^3 \text{ s}^{-1} \text{ km}^{-2}$  for the Bès River, against less than  $1.4$   
148  $\text{m}^3 \text{ s}^{-1} \text{ km}^{-2}$  in other catchments. This subcatchment has therefore a very specific behaviour.  
149 Furthermore, floods that occurred in this area from 1960 to 2009 were characterised by a  
150 strong seasonality. Most of the floods occurred in autumn (see Fig. 3a). South or South-  
151 Western atmospheric fluxes originating from the Mediterranean Sea and characterised by  
152 humid and warm air flows provide the bulk of annual rainfall in this region. They triggered  
153 most of the largest floods observed since 1960 (see Fig. 3b). The presence of a widespread  
154 depression centered on France is also associated with heavy rainfall in the entire country and  
155 generates large and widespread floods at the basin scale. In contrast, Western weaker  
156 depressions coming from the Atlantic Ocean generally dry up over the first French mountain  
157 ranges (i.e., Massif Central and Pyrénées), so that they only provide low-intensity rainfall  
158 when they reach the Southern Alps. Northern and North-Western fluxes occur when the  
159 Azores High is located at high latitudes; midlatitude cyclones can then arrive from the  
160 Northern Alps and produce the bulk of the snow cover. Eastern fluxes are associated with a  
161 high pressure cell standing over central Europe. Contact between this cold and dry air mass  
162 with the Mediterranean air mass can trigger particularly heavy storms over the Southern Alps  
163 in spring and summer. Finally, when high pressure cells dominate in the region, local  
164 convective storms can also occur due to local air mass instability (Gottardi 2009). These  
165 storms mostly occur between June and September. They are associated with heavy downpours  
166 that may trigger flash floods and debris flows that are otherwise restricted to small headwater  
167 streams.

168

169

170 **3 MaterialS and methodS**

### 171 **3.1 Coring site**

172 A 3-meter long sediment core (5-cm diameter) was collected on 26 November, 2009 with  
173 a Cobra corer in the Bléone River floodplain, upstream of the Malijai dam close to the outlet  
174 (see Fig. 1b; 905 km<sup>2</sup>). Coring was conducted in collaboration with the *Laboratoire de*  
175 *Géophysique Interne et Tectonophysique* (LGIT) and the *Laboratoire des Sciences de*  
176 *l'Environnement* (LSE). The sampling site was selected on a vegetated bar composed of very  
177 fine sediment, adjacent to the river channel, and located about 1 meter above the mean  
178 floodplain level. During floods, water level and flow velocity are controlled so as to ensure  
179 good operating conditions for the dam. In the recent period, we observed that the floodplain  
180 was systematically submerged during the largest floods. There was no evidence of bank  
181 erosion in the vicinity of the coring site. We therefore hypothesize that this site located within  
182 the dam reservoir has underwent a slow sedimentation since the dam building.  
183 Malijai dam was built by the French national electricity producer (EDF) in 1962. During base  
184 flow periods, the dam is closed to divert part of the clear water into a canal. To limit supply of  
185 sediment and associated substances to the downstream Berre lagoon (Accornero et al. 2008),  
186 French authorities fixed a maximal suspended sediment concentration that can be delivered to  
187 the canal, which leads to extra management costs for the company exploiting the power  
188 plants. Consequently, during floods, the dam is opened manually in order to divert water and  
189 sediment into the main channel. Sediment siltation mainly occurs during large floods (>1-2  
190 yrs return period) in the reservoir area where we sampled the sediment core. From 1962  
191 onwards, the dam has accumulated sediment, whereas resuspension of fine sediment and  
192 bedload only occurred in the middle part of the active river channel (see Fig. 1b).

193

### 194 **3.2 Stratigraphic structure of the sediment core**

195 In this study, we used X-ray measurements and visual observations to outline the  
196 stratigraphic structure of the core, i.e. the succession of flood deposits since the Malijai dam  
197 construction (1962).

198 The core was X-rayed at the *Eaux Claires* Hospital of Grenoble, with the aim to associate  
199 specific densities with grey level intensities (de Montety et al. 2003). Longitudinal image  
200 resolution was 2 mm; mean and standard deviation of grey level intensities were then  
201 measured in each section (i.e. horizon) within a 2 by 2 cm window centered on the core axis.  
202 Grey shades are considered to reflect the density of sediment as the grey-scale intensity of an  
203 X-ray image is proportional to beam attenuation of the incident X-ray (Lofi and Weber 1999).

204 The grey intensity variations in that core would therefore undoubtedly reflect the succession  
205 of flood deposits (i.e., varves).

206 Then, the sediment core was cut into two longitudinal parts, photographed, and subsampled  
207 based on two strategies: (1) sections were made following the stratigraphic structures of  
208 varves detected by X-ray analysis and visual observation, on the first half of the core; (2) 2-  
209 cm wide sections were cut on the second half of the core. Sediment samples were ground to a  
210 fine powder and dried at 105°C for 2 hours.

211 Then, we measured the grain-size of a selection of core samples to analyse the inter- and  
212 intra- varve variations of grain-size fraction. Subsamples were analysed with a Malvern®  
213 particle laser sizer after 7-min of stirring and sonication. Grain size distributions and statistics  
214 were computed with Gradistat software (Blott and Pie 2001).

215

### 216 **3.3 Origin of fine sediment**

#### 217 ***3.3.1 Soil and core sediment sampling***

218 Representative soil samples were collected in the Bléone basin to characterize  
219 potential source materials (see Evrard et al. 2011 for details). They were taken mostly on  
220 colluvial toeslopes adjacent to the drainage network to be representative of material eroded  
221 from adjacent hillslopes. Soil samples were dried at 105°C and disaggregated prior to  
222 analysis. As the core sediment samples have a finer grain size than the soil samples (i.e.,  
223 potential sediment sources), we sieved this source material to <63 µm before conducting  
224 radionuclide and geochemical analyses (Navratil et al. 2012).

225 We used the 2-cm core section samples (n = 92 for the core dating and n = 34 for the sediment  
226 fingerprinting) to cover the entire sequence of sediment deposit. The sediment samples were  
227 dried at 40°C, disaggregated and sieved to 63µm.

228

#### 229 ***3.3.2 Measurement of radionuclide and elemental geochemistry***

230 In total, we measured gamma-emitting radionuclide activity in 92 core samples and  
231 the 150 source samples. Sediment was placed in a counting box when there was sufficient  
232 material (≥10 g). Radionuclide activities (<sup>241</sup>Am, <sup>137</sup>Cs, <sup>40</sup>K, <sup>210</sup>Pb, <sup>226</sup>Ra, <sup>228</sup>Ra, <sup>234</sup>Th, <sup>228</sup>Th)  
233 were determined by gamma-spectrometry using the very low-background coaxial N- and P-  
234 types GeHP detectors (Canberra / Ortec / EurisyS) available at the *Laboratoire des Sciences*  
235 *du Climat et de l'Environnement* (Gif-sur-Yvette, France). Efficiencies and background levels  
236 of the detectors were periodically controlled with internal and IAEA (International Atomic  
237 Energy Agency) soil and sediment standards (Evrard et al. 2010; Evrard et al. in press). When

238 there was < 10 g sediment available, filters were placed in tubes and counting was conducted  
239 at the *Laboratoire Souterrain de Modane* (LSM; CNRS-CEA) under the French Alps, using a  
240 very low background, high-efficiency well-type Ge detector (Reyss et al. 1995).

241 For the measurement of elemental geochemistry, dried subsamples (c. 80 mg) of selected 2-  
242 cm core sections (n = 34) were analysed by inductively coupled plasma – mass spectrometry  
243 (ICP-MS; XII CCT Series, Thermo Electron), in solutions containing 0.2 g of solid L<sup>-1</sup>. The  
244 sediment total digestion procedure is described by Le Cloarec et al. (2011). Concentrations  
245 were determined for five major (Al, K, Fe, Mg, Ti) and thirteen trace (Ag, Ba, Cd, Co, Cr, Cu,  
246 Mn, Ni, Pb, Sb, Tl, V, Zn) elements. The accuracy of the elemental concentration  
247 determination was evaluated through the repetitive analysis of the certified reference material  
248 SL-1 (lake sediment, AIEA, Vienna, Austria). The obtained values (n=4), agreed with the  
249 certified concentrations, when available. Certified values are not available for Ag, Al, Ca, Mg  
250 and Tl. The accuracy of the determination of these four elements in SL-1 was cross-checked  
251 with values determined by neutron activation analysis (Ayrault et al. 2010; Evrard et al.  
252 2011). Analytical uncertainties associated with this method did not exceed 20 and 10% for  
253 major and trace element determination, respectively. Analysis of source material is described  
254 in detail in Navratil et al. (2012).

255

### 256 ***3.3.3 Selection of fingerprints and design of a mixing model***

257 Based on the French Geological Survey (BRGM) map of the catchment (see Fig. 2),  
258 we grouped the geological classes represented on the map and corresponding to our sediment  
259 source samples types into 5 classes: (1) marly limestones; (2) limy marls; (3) conglomerates;  
260 (4) Quaternary deposits; (5) black marls (see Evrard et al. 2011). As described by Navratil et  
261 al. (2012), we selected 10 fingerprinting properties that can discriminate between these five  
262 different sediment sources. Among them, 6 properties were sufficient to design the optimum  
263 composite fingerprint. Only one geogenic radionuclide was pointed out (<sup>226</sup>Ra). The other  
264 selected fingerprints were V, Ni, Mn, Sb and Cu. Then, we constructed a Monte Carlo mixing  
265 model as detailed by Navratil et al. (2012) in order to quantify the contribution of each  
266 sediment source to the core sediment samples.

267

### 268 **3.4 Core dating**

269 Dating of the sediment cores relied on the measurement of two radionuclides (i.e.,  
270 <sup>137</sup>Cs and <sup>210</sup>Pb<sub>xs</sub>) that strongly sorb onto fine sediment (Owens et al. 1999). <sup>137</sup>Cs was used as  
271 an event-tracer, whereas <sup>210</sup>Pb<sub>xs</sub> provided the sediment age (Appleby 2000). Both

272 radionuclides are gamma emitters and they can be detected without any previous chemical  
273 treatment of sediment.

274  $^{137}\text{Cs}$  is an artificial radionuclide ( $t_{1/2} = 30$  years) produced by the thermonuclear bomb testing  
275 conducted between the 1950s and the 1980s (with a maximum input in 1963) and, depending  
276 on local weather conditions, after the Chernobyl accident in 1986.  $^{137}\text{Cs}$  is now stored in soils,  
277 and this  $^{137}\text{Cs}$  stock decreases by radioactive decay and by fine sediment transfer to the rivers.  
278 Uncertainty on measurements was ca. 0.5%, and the detection limits reached  $0.3 \text{ Bq kg}^{-1}$ .

279  $^{210}\text{Pb}$  is a natural radionuclide ( $t_{1/2} = 22.3$  years) which is a decay product of  $^{238}\text{U}$  ( $t_{1/2} = 4.5 \times$   
280  $10^9$  years).  $^{238}\text{U}$  decays through a series of short-lived nuclides (e.g.,  $^{226}\text{Ra}$  and  $^{222}\text{Rn}$ ).  $^{222}\text{Rn}$  is  
281 a gas that partly remains *in situ*, forming “supported”  $^{210}\text{Pb}$ , and that partly escapes to the  
282 atmosphere, forming “excess”  $^{210}\text{Pb}$ , which reaches the soil surface by wet and dry fallout. It  
283 then strongly sorbs to soil particles. The activity in “excess”  $^{210}\text{Pb}$  was calculated by  
284 subtracting the supported activity (determined using a  $^{238}\text{U}$  daughter, i.e.  $^{214}\text{Bi}$ ) from the total  
285 activity of  $^{210}\text{Pb}$ . Uncertainty on measurements was thus higher than for  $^{137}\text{Cs}$  (ca. 10%).

286 Sedimentation rates were then calculated based on the Constant Rate Supply (CRS) model  
287 (Appleby and Oldfield 1983).

288

### 289 **3.5 Climatological and hydro-sedimentary databases**

290 Classically, core interpretation involves a count-from-the-top correlation of the  
291 individual flood deposits with flood events that resulted in overbank deposition (e.g. Hobo et  
292 al. 2010). However, evident difficulties prevented to associate each individual varve with  
293 individual flood events: (1) the context of this study (mountainous river with flash floods,  
294 complex sedimentation due to dam functioning) and (2) the lack of long-term water-  
295 level/discharge time-series available at the coring location. We therefore analysed the  
296 correlation between the stratigraphic structure of the core (succession of varve thickness) and  
297 the inter-annual hydro-meteorological variations. Given the lack of discharge data available at  
298 the Bléone River outlet, we compiled data from various sources available at different spatial  
299 scales and temporal resolutions to interpret the flood deposits at the Bléone River outlet:  
300 databases of rainfall time-series, discharge and suspended sediment concentration time-series  
301 and historical floods and mass movements.

302 Ten rain-gauges managed by the *Laboratoire d'étude des Transferts en Hydrologie et*  
303 *Environnement* (R1–R5) and the French *Cemagref* research agency (R6–R10) provided  
304 continuous precipitation records (see Fig. 1; Table 1). Five meteorological stations managed  
305 by the French meteorological office (i.e., *Météo France*) provided rainfall depths and

306 durations, snow depth, temperature as well as information on the occurrence of storm or hail  
307 events (R11–R15). Four of them provided daily rainfall for the 1960-2009 period (R11, R12,  
308 R14, R15; Table 1). These last stations only provided daily records (with the exception of one  
309 station, i.e., R12, providing hourly records). Altogether, these data provided good information  
310 about spatial and temporal variability of rainfall at the Bléone River basin scale.

311 Discharge, suspended sediment concentration (SSC) and yields (SSY) were measured at 1-h  
312 time steps by *EDF* at the Malijai station during the 2001-2003 and 2007–2009 periods (Table  
313 1). Discharges were measured on the Bès River at Pérouré station (165 km<sup>2</sup>; see Fig. 1) during  
314 the 1963–2009 period. SSC have been measured with turbidimeters since October 2007 – see  
315 Navratil et al. (2010) and Navratil et al. (2011) for more information about SSC and SSY  
316 equipments and methods. Discharge, SSC and SSY have also been measured at three other  
317 stations within the catchment (i.e., Duyes River at Mallemoisson, Galabre River at Robine,  
318 Bléone River at Prads) since October 2007 (see Fig. 1; Table 1). Discharge and sediment have  
319 also been monitored since 1985 in the Draix Observatory managed by Irstea in Grenoble. We  
320 took into consideration the data from the monitoring station of the Laval torrent (0.86 km<sup>2</sup>)  
321 available since 1985 and still ongoing (Mathys et al. 2003; see Fig. 1; Table 1).

322 We also used a database of field observations made available by the office in charge of  
323 mountain area restoration in France (i.e., *Restauration des Terrains en Montagne* service  
324 (RTM) of the French National Forest Office; RTM, 2010). Important historical information  
325 has been compiled since 1351 in the Bléone River basin (i.e., the oldest information of  
326 torrential flood available): the occurrence of avalanches, rock falls, debris flows, torrential  
327 floods and landslides. In this study, we extracted from this database the annual frequency of  
328 debris flows/flash floods and landslides observed in the Bléone catchment since 1960 to  
329 document erosion intensity within the Bléone catchment throughout time.

330

## 331 **4 Results and discussion**

### 332 **4.1 <sup>210</sup>Pb<sub>xs</sub> and <sup>137</sup>Cs dating**

333 Gamma spectrometry countings conducted at Gif-sur-Yvette and Modane laboratories  
334 provided very complementary results. We observed a decay of <sup>210</sup>Pb<sub>xs</sub> with depth in the  
335 sediment core when taking all 92 analysed samples into account (Fig. 4) even though  
336 precision obtained on activities was larger on the 45 samples analysed in Modane, because of  
337 the very low level of background at this underground laboratory (see Fig. 4). Sedimentation  
338 rate could be calculated based on <sup>210</sup>Pb<sub>xs</sub> decay of activities and was estimated at 5.4 cm yr<sup>-1</sup>  
339 along the first 150 cm, and at 4 cm yr<sup>-1</sup> if we take the entire depth of the core into account.

340 Activities in  $^{137}\text{Cs}$  provided additional information to date the core. Peak activities were  
341 measured between 278 and 288 cm depths (32–44 Bq kg<sup>-1</sup>). Peak associated with the bomb  
342 fallout (maximum activity in 1963) usually reaches values  $\geq 30\text{--}35$  Bq kg<sup>-1</sup> (e.g., Le Cloarec  
343 et al., 2011; Perga et al., 2010), which remains consistent with our findings. Furthermore,  
344 presence of  $^{241}\text{Am}$  (ca. 1 – 1.5 Bq kg<sup>-1</sup>) could be detected at this depth (265–290 cm),  
345 confirming the bomb origin of  $^{137}\text{Cs}$  fallout. In contrast,  $^{137}\text{Cs}$  activity peak associated with  
346 Chernobyl fallout in 1986 could not be detected. This peak absence can be justified by the  
347 very low cumulative rainfall amount (i.e., 9 mm) observed in the Bléone catchment when the  
348 radioactive cloud flew over the area (i.e., between 30 April – 4 May according to the cloud  
349 dispersion model developed by French Radioprotection and Nuclear Safety Institute (IRSN  
350 2011).

351 Overall datation of the core was therefore obtained by combining the sedimentation rate  
352 derived from  $^{210}\text{Pb}_{\text{xs}}$  decay and the location of the bomb  $^{137}\text{Cs}$  activity peak in depth (see Fig.  
353 4c). We can note that the date of the bottom of the core corresponds to the Malijai dam  
354 building (i.e., 1962). These results only provide an indicative dating of the core, as we  
355 hypothesised a constant rate of sedimentation since 1962. Erosion rate varies between seasons  
356 and years depending on flood magnitude. This point will be explored in detail with the hydro-  
357 sedimentary interpretations.

358

#### 359 **4.2 Stratigraphic structure of the sediment core**

360 In total, 114 varves corresponding to variations of grey shades on the X-ray images  
361 were detected (Fig. 5a, b). These layers were confirmed by visual description of the core after  
362 opening. Mean varve thickness reaches 2 cm, but it fluctuates between 0.2 and 13 cm. The  
363 sediment core is characterised by about 7 cycles having similar stratigraphic structures, i.e. a  
364 succession of several small varves (< 2 cm) followed by one to three larger varves (ranging  
365 from 2–13 cm). The layer located between 91–102 cm could not be analysed because of  
366 technical problems during field sampling. Oblique varves observed between 162–198 cm  
367 depth cannot be attributed to a disturbance of the core during sampling or transport. We will  
368 discuss its possible origin in section 5.

369

#### 370 **4.3 Hydro-sedimentary interpretations**

371 The 1962-2009 discharge time-series available for the Bès River at Pérouré station  
372 (165 km<sup>2</sup>; Fig. 6c) provide information on flood occurrence within the catchment. However,  
373 because of the spatial heterogeneity of rainfall across the catchment, these data do not

374 systematically reflect the flood magnitude at the Bléone River outlet (905 km<sup>2</sup>). At the scale  
375 of the entire catchment, only qualitative information about flood occurrence is available  
376 (Sogreah 2005; RTM 2010; Fig. 7a). Nine major floods that led to infrastructure damages  
377 have been reported by mountainous area restoration office (RTM) at the outlet of the Bléone  
378 River catchment since 1970s (i.e., in July 1973, March 1974, January 1978, October 1979,  
379 1992, 1993, January, September and November 1994). In January 1994, a 10-years return  
380 period flood was observed (Sogreah 2004;  $\sim 400 \text{ m}^3 \text{ s}^{-1}$ ). The peak discharge observed on the  
381 Bès River at Pérouré was about  $41 \text{ m}^3 \text{ s}^{-1}$  (i.e., a two-year return period flood) but the Bès  
382 River subcatchment was not included in the area of maximum rainfall intensity. Two  
383 additional 10-years return period floods were observed in November 1994 and 2000 at the  
384 Bléone River outlet. The corresponding peak discharges observed on the Bès River at Pérouré  
385 indicate that they were associated with a two-year return period at this station.  
386 Furthermore, to obtain additional data at the river basin scale, we analysed the inter-annual  
387 variation of rainfall based on information provided by the different rain-gauges available  
388 within the catchment (see Table 1). A moving average (window size of one year; lag time of 6  
389 months) was applied to monthly rainfall data (see Fig. 6a) and to the maximum daily intensity  
390 of each month (see Fig. 6b). No significant pluri-annual trend could be retrieved for the 1960-  
391 2009 period. We therefore defined “wet” years (i.e., with mean rainfall  $> 900 \text{ mm yr}^{-1}$  and  
392 mean interannual rainfall intensity  $> 25 \text{ mm day}^{-1}$ ; see Fig. 7b) and “dry” years (i.e., with  
393 mean rainfall  $< 900 \text{ mm yr}^{-1}$  and mean interannual rainfall intensity  $< 25 \text{ mm day}^{-1}$ ; see Fig.  
394 7c). A pluri-annual cycle (mean period of ca. 3-5 years) with alternance/succession of “wet”  
395 and “dry” years can thereby be outlined (see Fig. 7 b, c). These periods were found consistent  
396 with the occurrence of large floods (Sogreah 2005; RTM 2010; see Fig. 7a), the hydrometric  
397 stations records (see Table 1) and the database of the hydro-sedimentary activity (RTM 2010;  
398 see Fig. 7a).

399 We can now attempt to correlate the flood deposits with inter-annual hydro-meteorological  
400 patterns by a two-step count-from-the-top method (Hobo et al. 2010). In the first step, the  
401 largest flood deposits were correlated with the occurrence of “wet” years and the largest  
402 floods. In the second step, the smallest intermediate varves were correlated with the “wet” and  
403 “dry” years that occurred between the major events. This correlation method is based on  
404 several assumptions: (1) the largest floods would be responsible for the deposition of the  
405 thickest varves (Hobo et al. 2010); (2) the “wet” years are the most likely periods for the  
406 occurrence of large floods at the Bléone River basin scale (905 km<sup>2</sup>); (3) other small and  
407 large-scale floods can also occur during the same period, but deposits from two or more

408 floods in the same hydrological season may sometimes not be identified separately. Sediment  
409 deposits are indeed likely to be remobilised during the next flood, unless they are fixed by  
410 vegetation during the growing season (Hobo et al. 2010); (4) ‘dry’ years can be associated  
411 with small/moderate overbank floods at the core location and may result in thinner varves.

412 Varve thickness distribution matches well with the variability of the hydro-sedimentary time-  
413 series (see Fig. 7d). The largest varves, i.e., between the horizons 230-260 cm, 150-220 cm,  
414 80-110 cm and 30-50 cm, clearly correspond to the largest floods that occurred during the  
415 “wet” periods, respectively during the periods 1968-1973, 1977-1981, 1992-1994, 1999-2002.  
416 In contrast, the thinnest varves correspond to low magnitude floods that occurred during  
417 “wet” and “dry” periods: 1960-1967, 1974-1976, 1982-1991, 1995-1998, 2003-2009. The  
418 oblique varves observed between 160-200 cm are likely to correspond to the collapse of the  
419 river bank at that location and can be associated with the widespread flood that occurred in  
420 1979 (RTM 2010).

421 The grain-size fraction (<2 mm) is variable (Fig. 8a), with a dominance of silt-clay sized  
422 fraction throughout the core (ca. 80%). The mean D50 is 18.5  $\mu\text{m}$  (range from 0.7 - 84  $\mu\text{m}$ );  
423 the mean D10 is 2.3  $\mu\text{m}$  (range from 0.16-22.7  $\mu\text{m}$ ) and the mean D90 is 160  $\mu\text{m}$  (<1000  
424  $\mu\text{m}$ ). Sand fraction is higher between 120-250 cm (ca. 30%). This core section could  
425 correspond to the large floods documented during the 1970s (1973, 1978, 1979 floods; see  
426 Fig. 3c) thereby confirming our previous interpretation.

427

#### 428 **4.4 Sediment core fingerprinting**

429 Results of the mixing model showed that sediment sources varied during the last 50 years  
430 for the selected core sections (see Fig. 8b). Globally, black marls and (marly) limestones  
431 provided the bulk of sediment throughout the sequence: on mean 40% for black marls (min. =  
432 19% and max = 71%) and on mean 22% for limestones (min = 14%; max = 34%). Major  
433 floods can also generate huge quantities of sediment originating from Quaternary deposits and  
434 conglomerates (respectively, 25% (min = 3%, max = 54%) and 16% (min = 6%, max =  
435 28%)).

436 According to this model, black marls and limestones provided the bulk of sediment during the  
437 1960s (51–88%). Then, during the 1970s, sediment origin was much more equilibrate  
438 between material supplied by a mix of black marls, limestones, Quaternary deposits and  
439 conglomerates. In 1972–1973, a flood was characterized by sediment originating mainly from  
440 Quaternary deposits (84% of sediment), indicating the likely occurrence of mass movements  
441 in the catchment. After this event (between 1974–1978), we calculated again a mixed

442 contribution of four substrate types to the Bléone River sediment with a clear dominance of  
443 Quaternary deposit contribution in 1974. In 1979, a major flood occurred. At this horizon, we  
444 observed a series of vertical varves, indicating the collapse of the river bank at that location.  
445 Major mass movements are likely to have occurred during this period, as indicated by the  
446 dominant contribution of Quaternary deposits and conglomerates to sediment deposited in  
447 between 1970-1981. As reported from the hydrological time-series, rainfall data and past  
448 observations (RTM 2010), this period was very active in terms of sediment transport. Several  
449 other subsequent floods supplied sediment originating from Quaternary deposits and  
450 conglomerates up to 1985. During the other floods that were analysed in detail, black marls  
451 and (marly) limestones provided the bulk of sediment (36–85%), together with a mix of  
452 conglomerates and Quaternary deposits. Deposits corresponding to 1991, 1993 and 2006 were  
453 almost exclusively provided by black marls and marly limestones (74–89%). These variations  
454 of sediment origin can be mainly attributed to the spatial variability of rainfall in the  
455 catchment that triggered torrential floods, but also to the magnitude of the flood and its  
456 capacity to remobilise the fine sediment temporarily stored in the river channel and  
457 floodplain. Furthermore, the relative homogeneity of sediment composition within the core  
458 (coefficient of variation of 31, 22, 61, 30% respectively for black marls, limestones,  
459 Quaternary deposits, conglomerates) confirm that the core-derived information rather reflect  
460 the occurrence of widespread and large-scale floods, with a contribution of all sediment  
461 sources available in the catchment rather than the sediment export triggered by local storm  
462 events.

463 These results are in agreement with the sediment flux time-series recorded at the Laval  
464 Torrent at Draix (drainage area of 0.86 km<sup>2</sup>; Fig. 9). This site was indeed characterised by  
465 massive exports of black marl material (Mathys et al. 2003) in 1992, 1994, 1996 and 2004  
466 and 2006. These floods probably provided the flood deposits observed between 85-105 cm  
467 depth and 28-35 cm depth in the core. For the other sites, only very limited data were  
468 available and they only covered the end of the study period (i.e., 2007-2009) characterised  
469 globally by a low sediment export at the Bléone outlet.

470

#### 471 **4.5 Comparison with flood scale analyses conducted during the 2007-2009 period**

472 These results can be compared to previous findings obtained by sediment  
473 fingerprinting on both riverbed and suspended material collected in the Bléone River  
474 catchment during a more recent period (2007-2009; Fig. 10; Evrard et al. 2011; Navratil et al.  
475 2012).

476 Analysis of the core deposits and the suspended sediment outlined very similar trends at the  
477 catchment outlet (see Fig. 10). Black marl contribution clearly dominates, providing a mean  
478 of 40% for the core deposits and 34% for the suspended sediment. Given this substrate only  
479 occupies 10% of the total catchment area, it underlines the high erodibility of black marls  
480 (e.g., Mathys et al. 2005; Poulenard et al. 2012). Limestones/marly limestones contributions  
481 are also significant (mean of 22% for core deposits and 30% for suspended sediment), but  
482 they remain in the same order of magnitude as the % of catchment surface that they occupy  
483 (ca. 37 %). It confirms the lower erodibility of those substrates compared to black marls.  
484 Analysis of core deposits and suspended sediment also remain consistent regarding  
485 Quaternary deposits (21 % vs. 23%, respectively). This contribution corresponds once again  
486 to the % of occurrence of those substrates within the catchment (ca. 27%). The lowest  
487 contribution corresponds to conglomerate sources (mean of 13% vs. 16%), whereas it  
488 occupies about 25% of the catchment. In contrast, black marls and limestones are under-  
489 represented in riverbed sediment compared to their occurrence within the catchment, whereas  
490 Conglomerates and Quaternary deposits are over-represented in this material.  
491 The grain size of these different sources may explain this variability, even though we could  
492 take those differences into account in our fingerprinting study by conducting appropriate  
493 sieving. Further studies should focus on the variation of grain size of sediments during their  
494 transfer across catchments in order to outline the different erosion/transfer processes that are  
495 involved at different spatial and temporal scales.

496

## 497 **5 Conclusions**

498 We can demonstrate from our core dating study that we could reconstruct the history  
499 of sedimentation since Malijai dam building by analyzing and dating a sediment core  
500 collected at this location, draining a 905-km<sup>2</sup> highly erosive Alpine catchment. Determination  
501 of 1963 bomb fallout peak is confirmed by the detection of <sup>241</sup>Am (emitted by the bombs but  
502 not by Chernobyl accident). We could not detect any peak corresponding to Chernobyl fallout  
503 in 1986 (which is confirmed by the very low rainfall amount observed in this catchment in  
504 April – May 1986), but we could derive a mean sedimentation rate during this period,  
505 providing a way to date the entire sediment core. The hydro-sedimentary interpretation  
506 corroborates this analysis, and we could associate each major varve with very active erosive  
507 periods that produced significant sediment exports since 1962 until 2009 at the Bléone River  
508 outlet.

509 Black marls and (marly) limestones provided the bulk of sediment throughout the sequence  
510 (on mean 40% and 22%, respectively) but we could outline the occurrence of major floods  
511 generating huge quantities of sediment originating from Quaternary deposits and  
512 conglomerates (on mean 25% and 16%, respectively). These results are consistent with the  
513 ones obtained in previous studies where a similar sediment composition was found in  
514 suspended sediment collected during (or after) large and widespread floods that occurred  
515 between 2007 – 2009 in the Bléone River catchment. In contrast, those results slightly  
516 differed with the ones derived from riverbed sediment analysis, outlining the need to take  
517 account of the entire grain size range of sediment material within catchments to provide an  
518 overall picture of sediment sources and transfers within highly erosive catchments.  
519 Overall, this study also underlines the relevance of using archive data – i.e., hydrological  
520 time-series and sediment core – to validate sediment fingerprinting analyses conducted  
521 generally during short monitoring time-period (i.e., several years).

522

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534

535

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650

651

652 **Table and figure captions**

653 **Table 1** Summary of the meteorological and hydro-sedimentary data used in this study (SSC:  
654 suspended sediment concentration; Q: discharge; R: rainfall). “R” and “STA” referred to as  
655 the raingauges and hydrometric stations (Fig. 1)

656  
657 **Fig. 1** Location of the study area in France, and location of the river monitoring stations  
658 (STA1–STA7) and the raingauges (R1–R15) within the Bléone River catchment (Fig. A).  
659 Location of the sediment coring site at the catchment outlet (Fig. B)

660  
661 **Fig. 2** Geology of the Bléone River catchment and location of the river monitoring stations  
662 (from Evrard et al. 2011)

663  
664 **Fig. 3** Distribution of major floods (return period > 1 yr) recorded on the Bès River at Pérouré  
665 station during the 1962-2009 period. Relation with the main hydro-meteorological events  
666 (Fig. A). Seasonality of the major floods since 1962 (Fig. B). Regional variability of the  
667 maximum annual specific discharge in the South-Eastern French Alps (Fig. C)

668  
669 **Fig. 4** Sediment core dating derived from the distribution of  $^{137}\text{Cs}$  (Fig. A) and  $^{210}\text{Pb}_{\text{ex}}$  (Bq  
670  $\text{kg}^{-1}$ , Fig. B) activities with depth. Time-scale based on radionuclide dating (Fig. C)

671  
672 **Fig. 5** Sediment core analysis and varve identification with X-ray intensity level (Fig. A, B).  
673 Time-scale based on radionuclide dating (Fig. C)

674  
675 **Fig. 6** Hydrometeorological data. Fig. A: monthly rainfall (in grey, the monthly data at the  
676 different raingauges). Fig. B: maximum daily rainfall. Fig. C: discharge data of the Bès River  
677 at Pérouré (daily and instantaneous discharge)

678  
679 **Fig. 7** Core interpretation. Flash floods/debris flows and landslides frequency (RTM source;  
680 Fig. A). Mean annual rainfall (moving average; Fig. B) and daily intensity rainfalls (moving  
681 average; Fig. C). The “wet” years (black) and “dry” years (grey) are defined for each variable.  
682 Varves’ thickness (Fig. D). Time-scale based on radionuclide dating (Fig. E)

683  
684 **Fig. 8** Sediment size composition (Fig. A) and sediment composition with geochemistry (Fig.  
685 B). Time-scale based on radionuclide dating (Fig. C)

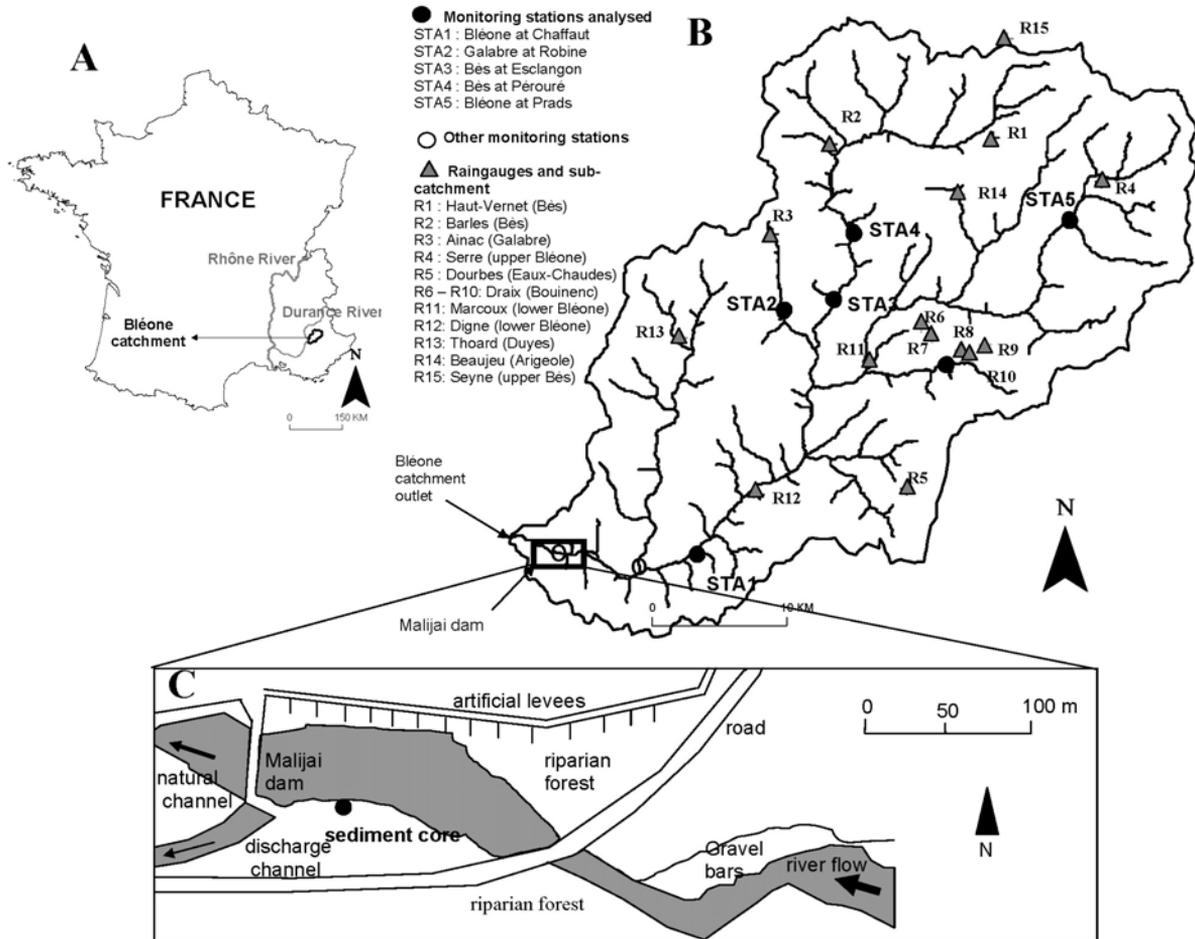
686

687 **Fig. 9** Total sediment yield (suspended sediment and bedload) at the Laval catchment

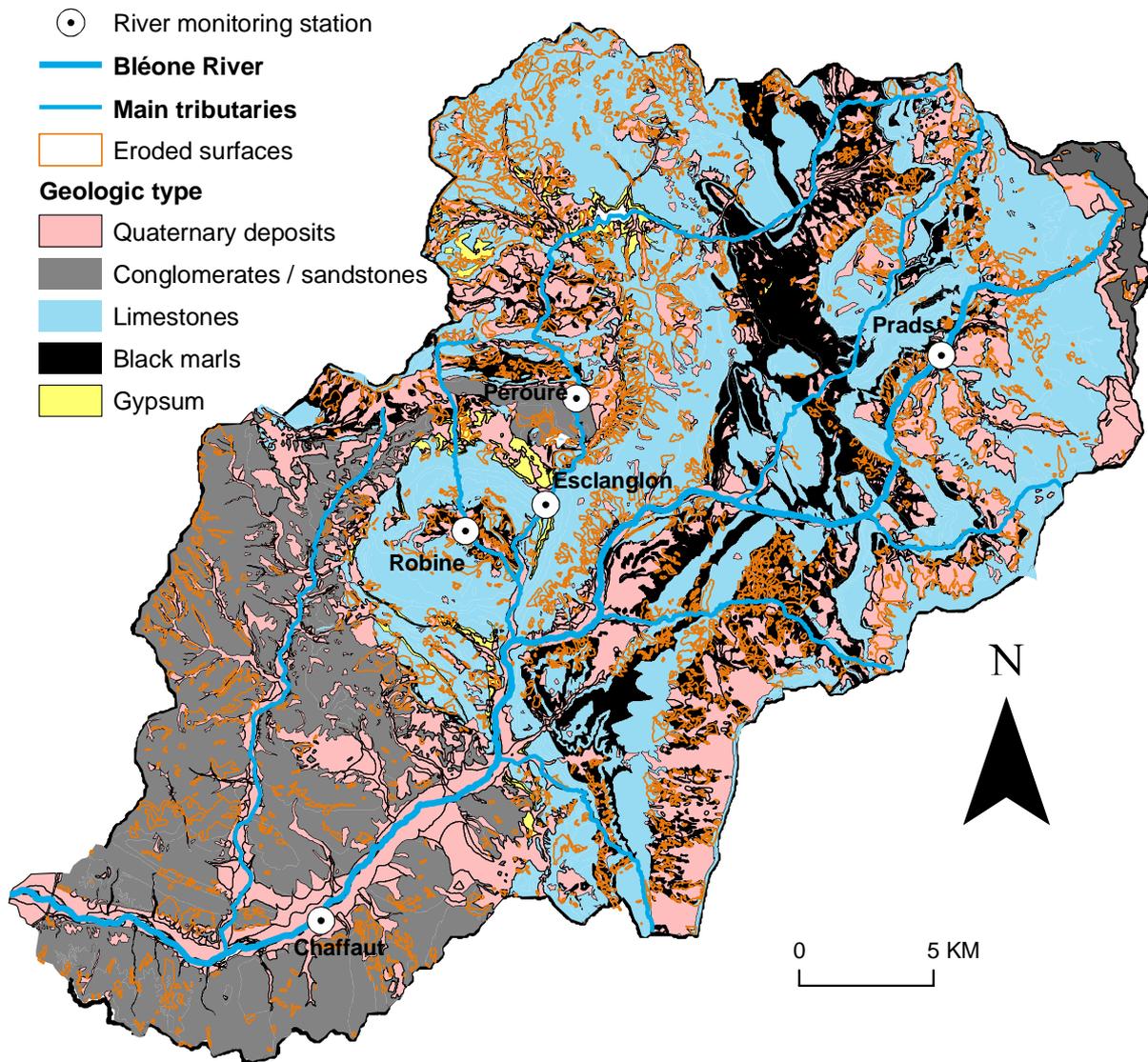
688

689 **Fig. 10** Fine sediment origins at the Bléone River outlet. Proportion of draining catchment  
690 surface occupied by the different lithologic sources (%; black bars), riverbed sediment  
691 composition (%; white bars; Evrard et al. 2011), suspended sediment composition (grey bars;  
692 mean  $\pm$  min./max. range of values obtained for the entire series of samples collected; Navratil  
693 et al. 2012) and core composition (red bars; mean  $\pm$  min./max; this study)

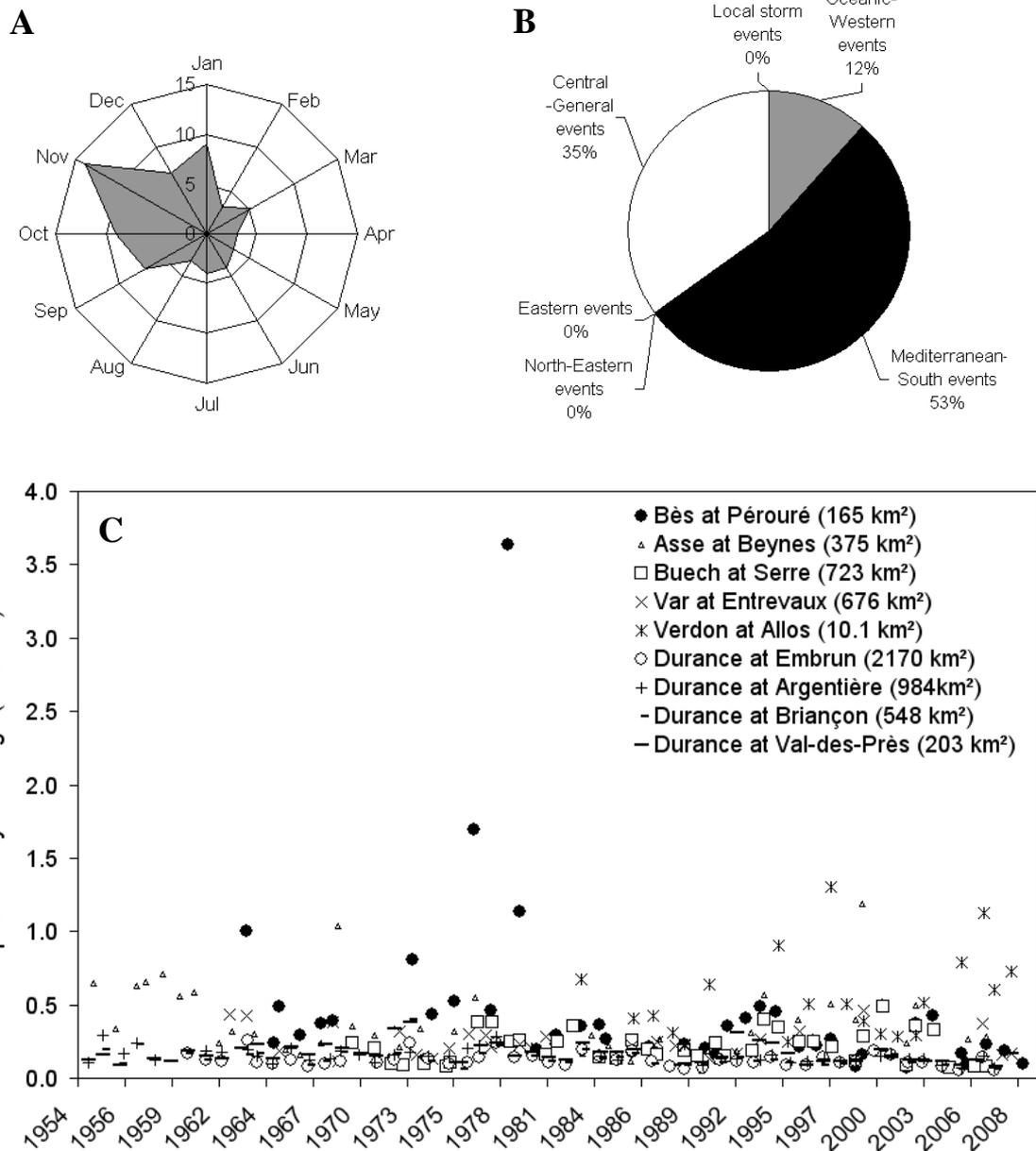
**Fig. 1** Location of the study area in France, and location of the river monitoring stations (STA1–STA7) and the raingauges (R1–R15) within the Bléone River catchment (Fig. A). Location of the sediment coring site at the catchment outlet (Fig. B)



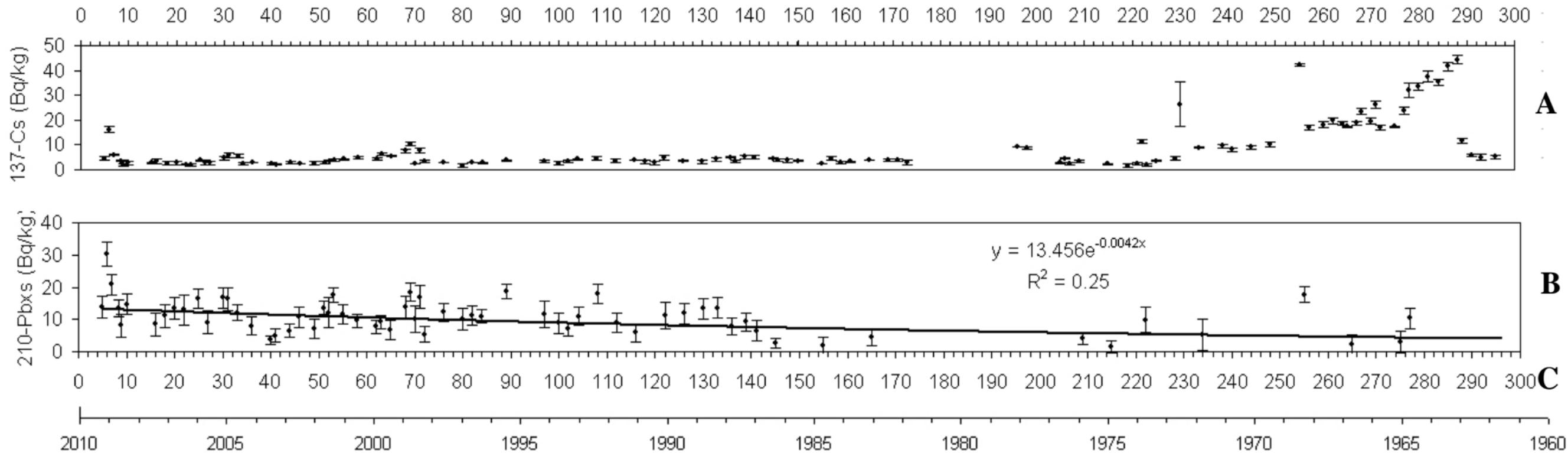
**Fig. 2** Geology of the Bléone River catchment and location of the river monitoring stations (from Evrard et al. 2011)



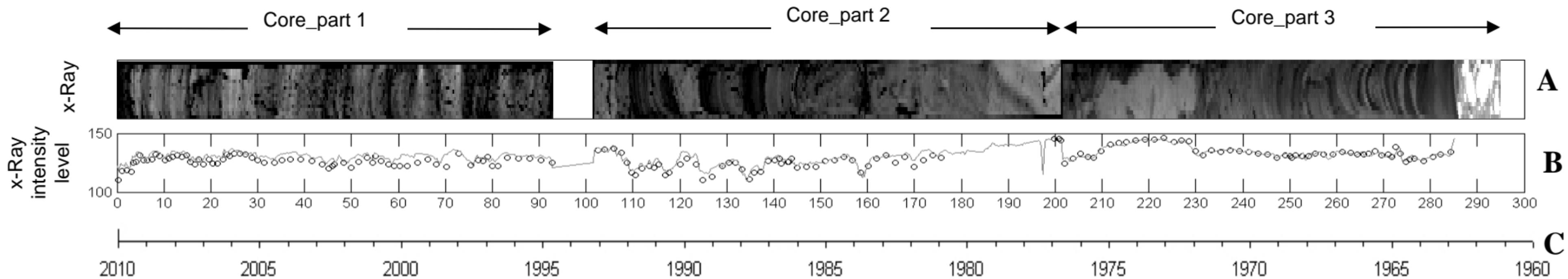
**Fig. 3** Distribution of major floods (return period > 1 yr) recorded on the Bès River at Pérouré station during the 1962-2009 period. Relation with the main hydro-meteorological events (Fig. A). Seasonality of the major floods since 1962 (Fig. B). Regional variability of the maximum annual specific discharge in the South-Eastern French Alps (Fig. C)



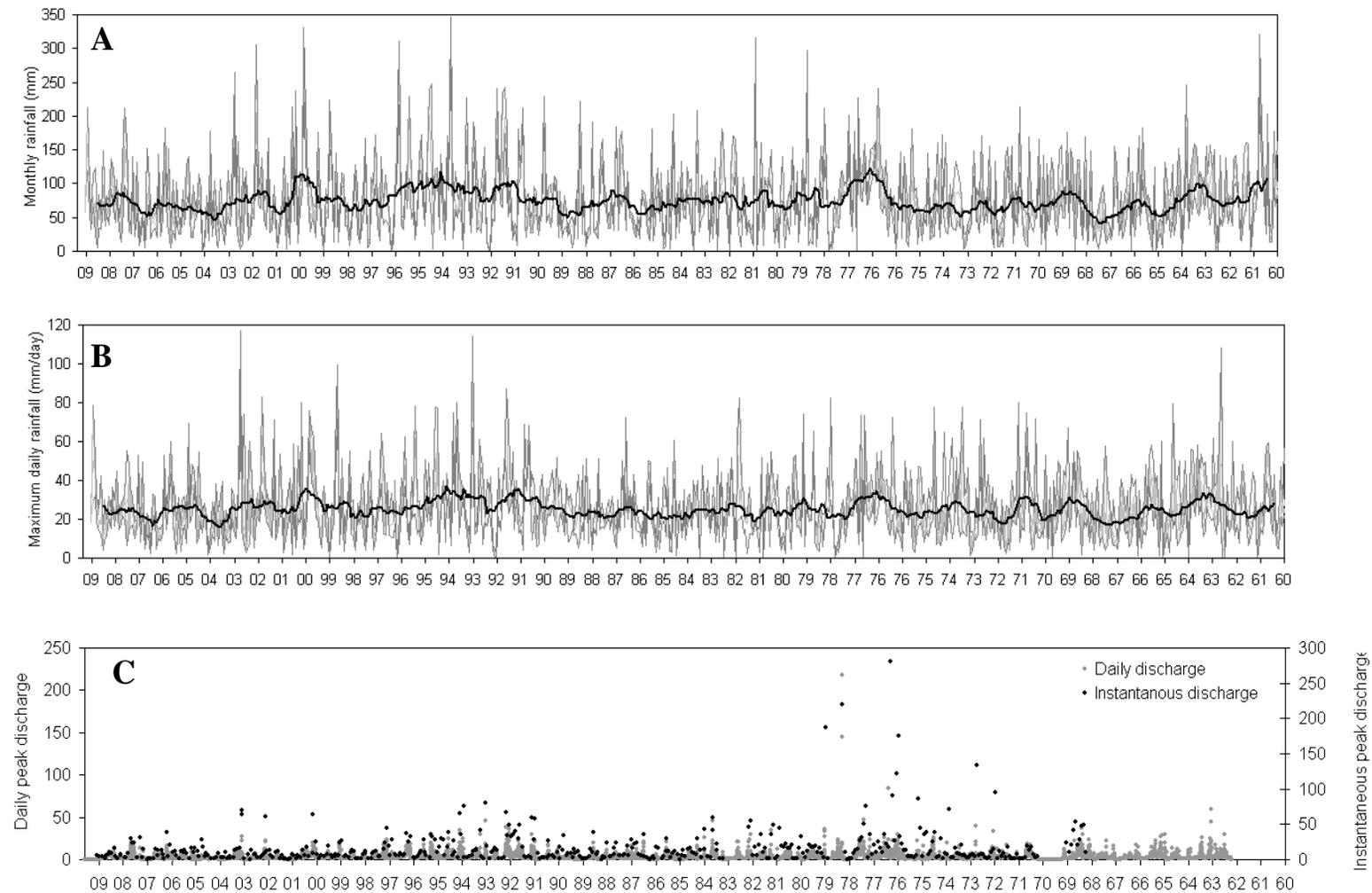
**Fig. 4** Sediment core dating derived from the distribution of  $^{137}\text{Cs}$  (Fig. A) and  $^{210}\text{Pb}_{\text{xs}}$  ( $\text{Bq kg}^{-1}$ , Fig. B) activities with depth. Time-scale based on radionuclide dating (Fig. C)



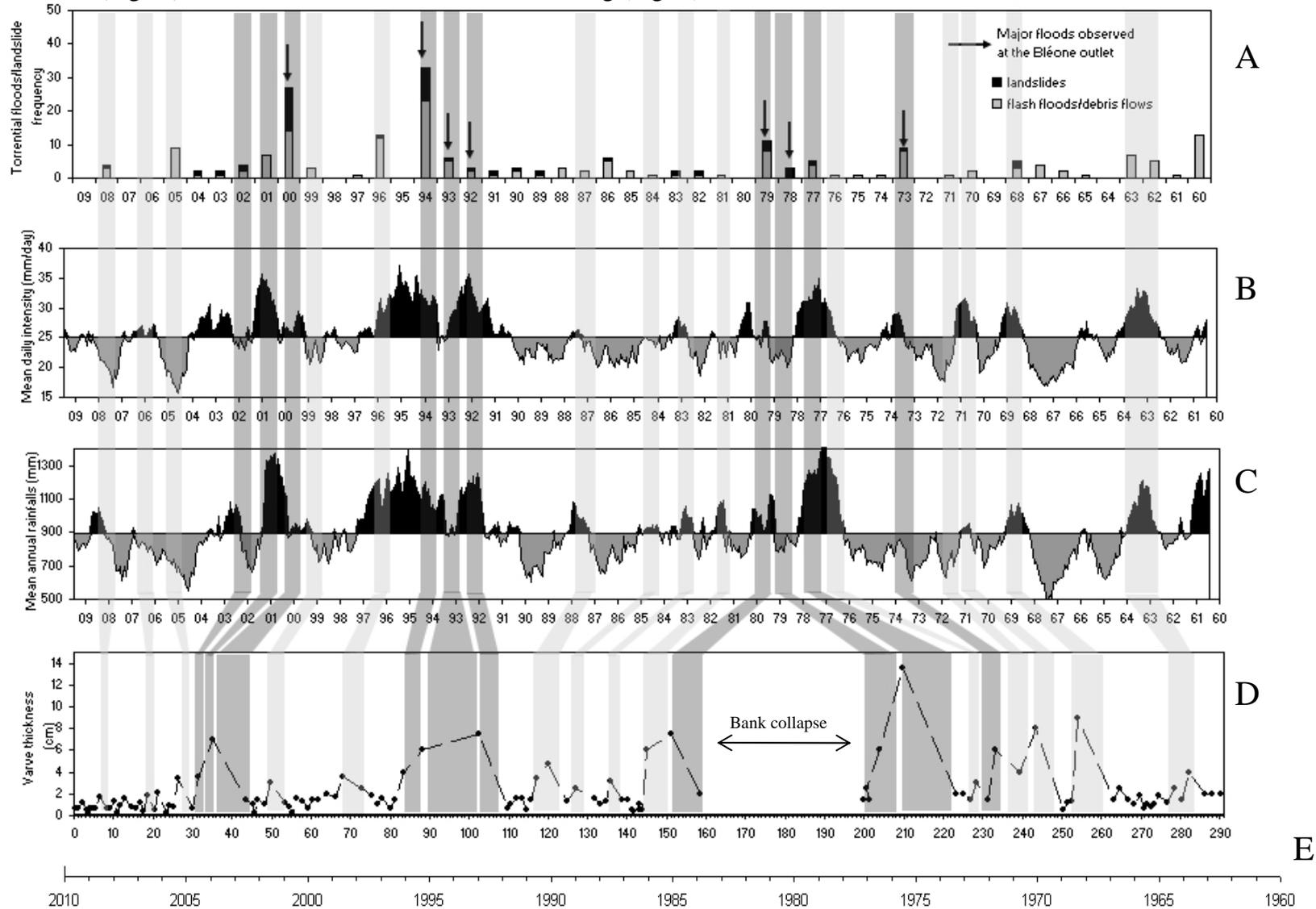
**Fig. 5** Sediment core analysis and varve identification with X-ray intensity level (Fig. A, B). Time-scale based on radionuclide dating (Fig. C)



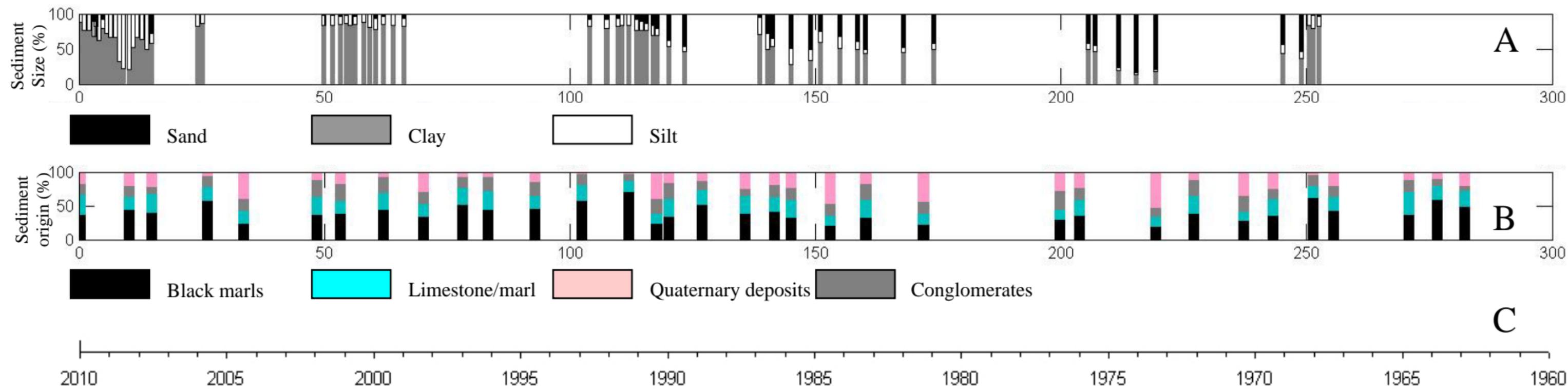
**Fig. 6** Hydrometeorological data. Fig. A: monthly rainfall (in grey, the monthly data at the different raingauges). Fig. B: maximum daily rainfall. Fig. C: discharge data of the Bès River at Pérouré (daily and instantaneous discharge)



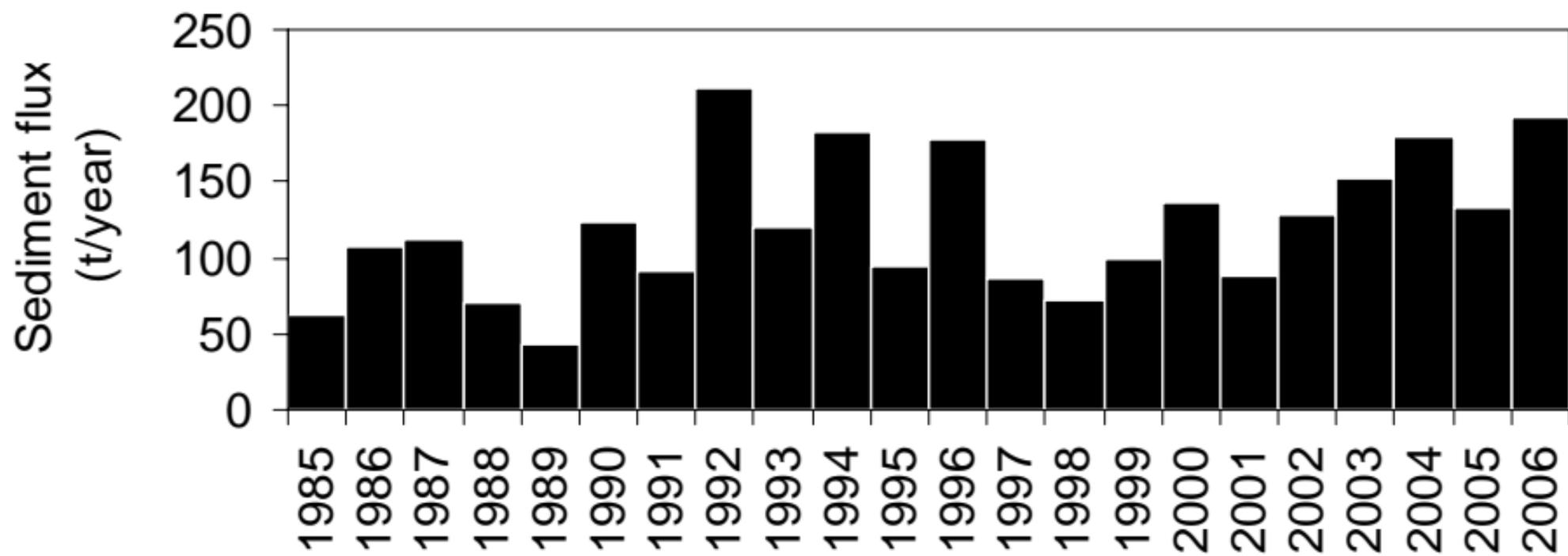
**Fig. 7** Core interpretation. Flash floods/debris flows and landslides frequency (RTM source; Fig. A). Mean annual rainfall (moving average; Fig. B) and daily intensity rainfalls (moving average; Fig. C). The “wet” years (black) and “dry” years (grey) are defined for each variable. Varves’ thickness (Fig. D). Time-scale based on radionuclide dating (Fig. E)



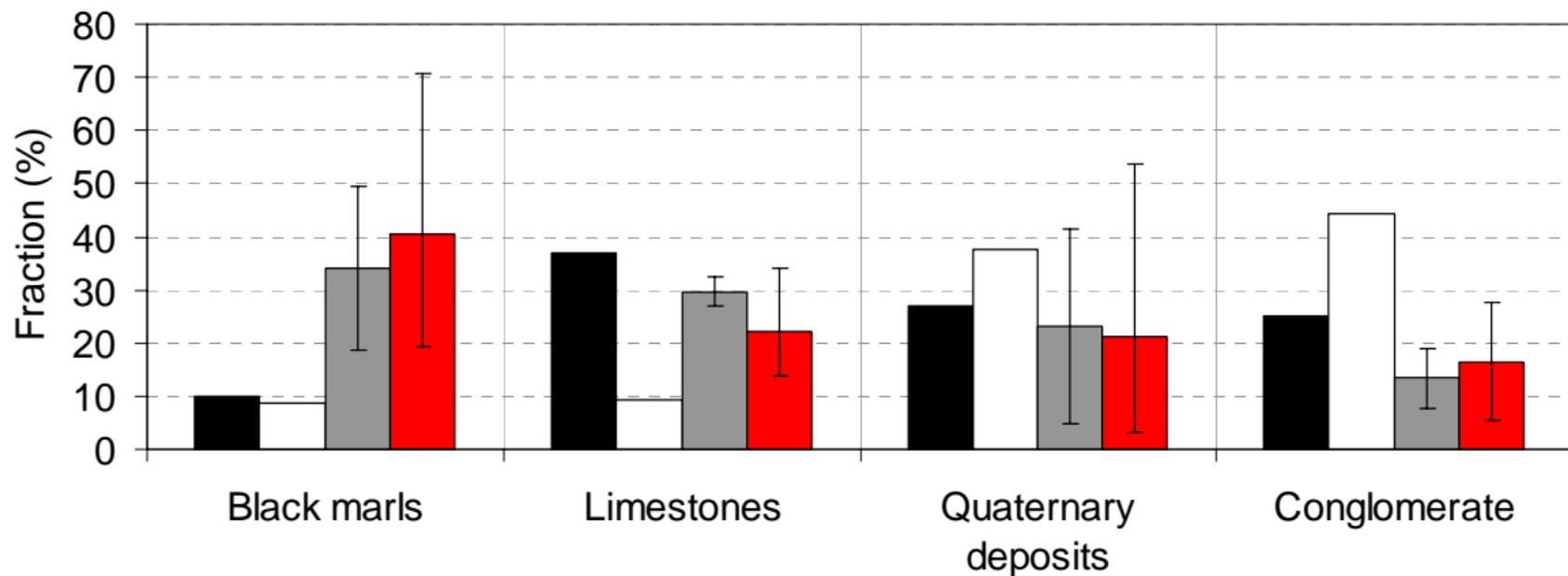
**Fig. 8** Sediment size composition (Fig. A) and sediment composition with geochemistry (Fig. B). Time-scale based on radionuclide dating (Fig. C)



**Fig. 9** Total sediment yield (suspended sediment and bedload) at the Laval catchment



**Fig. 10** Fine sediment origins at the Bléone River outlet. Proportion of draining catchment surface occupied by the different lithologic sources (%; black bars), riverbed sediment composition (%; white bars; Evrard et al. 2011), suspended sediment composition (grey bars; mean  $\pm$  min./max. range of values obtained for the entire series of samples collected; Navratil et al. 2012) and core composition (red bars; mean  $\pm$  min./max; this study)



**Tab. 1** Summary of the meteorological and hydro-sedimentary data used in this study (SSC: suspended sediment concentration; Q: discharge; R: rainfall). “R” and “STA” referred to as the raingauges and hydrometric stations (Figure 1)

<b>Basin name</b>	<b>Station location</b>	<b>Drainage area (km<sup>2</sup>)</b>	<b>Data type</b>	<b>Observation period</b>	<b>Station manager</b>
Laval	Draix	0.86	Q, SSC (variable time step) STA8, R6 to R10 (5. min.)	1984-2010	Cemagref Grenoble/ETNA
Bès	Pérouré	165	Q, SSC (10. min.) ; STA3; STA4	1962- 2010 for Q 2007- 2010 for SSC	SPC Grand Delta, DIREN, EDF-DTG, LTHE
Duyes	Mallemoisson	120	Q, SSC (10. min.) STA 6	2007-2010	LTHE
Galabre	Roubine	22	Q, SSC (10. min.) STA2	2007-2010	LTHE
Bléone	Prads	65	Q, SSC (10. min.) STA5	2007-2010	LTHE
Bléone	Chaffaut	705	SSC (hourly) STA1	2001-2003 ; 2007-2010	EDF-DTG
Bléone	Malijai	870	Q (hourly) ; STA7	2007-2010	EDF-DTG
Arigéole	Beaujeu	---	R (daily); R14	1926-2010	Météo France
Bléone	Digne	---	R (daily); R12	1945-2010	Météo France
Bès	Seyne	---	R(daily); R15	1928-2010	Météo France
Duyes	Thoard	---	R(daily); R13	1999-2010	Météo France
Bléone	Marcoux	---	R(hourly); R11	1938-2010	Météo France
Bès	Haut-Vernet	---	R (5 min.) ; R1	2008-2010	LTHE
Bès	Barles	---	R (5 min.) ; R2	2008-2010	LTHE
Galabre	Ainac	---	R (5 min.) ; R3	2008-2010	LTHE
Bléone	Serre	---	R (5 min.) ; R4	2008-2010	LTHE
Bléone	Les Dourbes	---	R (5 min.); R5	2008-2010	LTHE
Bès	Barles	---	R (5 min.) ; R2	2008-2010	LTHE

**Tab. 2** Concentrations in geochemical elements (mg kg<sup>-1</sup>) and mean radionuclide activities (in Bq kg<sup>-1</sup>, except for K – in %) analysed in the sediment core sections (n=34)

Section n°	Core depth																		
	(cm)	Mg	Al	Ti	Mn	V	Ni	Cu	Ag	Cd	Sb	Ba	TI	Pb	K (%)	Th-234	Ra-226	Ra-228	Th-228
1	5.4	9055	6.6	3647	463	103	50	24	0.16	0.16	0.39	376	0.54	13	1.70	31.1	22.0	32.8	35.0
2	13.4	8463	4.8	3550	582	88	38	20	0.21	0.18	0.36	349	0.38	12	1.59	28.8	22.5	30.6	30.9
3	18.7	10005	6.5	3422	458	102	45	19	0.15	0.14	0.29	273	0.47	13	1.79	26.4	23.0	34.3	32.2
4	27	9348	5.8	4230	680	104	44	20	0.17	0.13	0.34	305	0.43	13	1.55	30.0	23.0	31.6	32.0
5	33.2	6168	5.2	2688	393	81	40	23	0.21	0.14	0.32	446	0.38	12	1.29	24.3	22.0	29.0	27.1
6	45.7	8535	4.0	2917	705	70	39	21	0.19	0.14	0.36	266	0.29	14	1.28	23.9	20.0	28.1	25.9
7	49.7	10306	5.5	3192	568	83	45	20	0.20	3.25	0.42	244	0.37	53	1.27	23.0	20.0	28.4	26.3
8	56.9	8315	4.9	3473	689	88	42	23	0.22	0.14	0.61	359	0.38	13	1.44	30.0	24.0	28.0	30.0
9	65.5	10735	5.1	2929	455	86	43	18	0.15	0.14	0.39	232	0.38	13	1.40	23.9	22.5	28.7	28.6
10	70.8	8211	6.3	4221	580	114	46	26	0.24	0.19	0.54	446	0.53	13	1.63	25.2	26.0	32.4	31.0
11	74.5	8598	4.7	3173	739	82	41	19	0.25	0.14	0.42	259	0.36	13	1.49	19.4	22.5	29.0	28.9
12	84.0	9768	5.8	3210	579	92	44	20	0.27	0.13	0.40	267	0.40	14	1.37	21.0	20.0	28.9	27.8
13	100	9021	5.0	3925	815	94	43	19	0.23	0.14	0.37	292	0.36	13	1.37	21.9	20.0	28.2	28.3
14	109.1	10028	7.8	4842	681	135	44	18	0.45	0.14	0.79	323	0.58	13	1.62	28.5	23.0	35.0	31.1
15	116.4	7221	3.6	1868	489	59	37	18	0.16	0.13	0.39	262	0.26	14	0.88	13.1	19.0	18.6	16.9
16	117.6	7740	3.1	2553	677	59	34	19	0.22	0.15	0.44	254	0.25	12	0.88	13.1	16.0	18.6	16.9
17	123.6	8312	5.1	3795	610	98	41	19	0.29	0.17	0.41	332	0.39	12	2.02	26.3	24.0	33.0	35.7
18	133.0	9406	6.5	3366	433	101	44	19	0.26	0.13	0.36	342	0.47	13	1.63	27.3	21.0	32.4	30.4
19	139.5	8063	4.3	3183	623	80	35	19	0.16	0.17	0.35	315	0.36	12	1.14	22.3	20.0	25.7	22.6
20	142	7579	3.3	2707	628	65	31	17	0.14	0.16	0.29	301	0.28	10	1.13	18.5	18.5	21.1	21.5
21	150.0	7270	3.1	1654	457	48	32	16	0.12	0.11	0.41	256	0.23	12	0.84	16.2	17.0	17.2	17.1
22	157.5	7889	2.8	2349	666	53	34	19	0.17	0.14	0.38	268	0.23	12	0.97	16.7	17.0	21.1	19.5
23	169.5	6995	3.0	1642	471	43	34	17	0.15	0.12	0.44	258	0.22	12	0.87	11.9	17.0	18.7	18.5
24	198.0	9490	4.3	2384	509	78	40	24	0.15	0.13	0.40	268	0.31	15	1.20	21.9	21.0	25.0	24.1
25	207.5	8381	4.2	2676	615	70	33	18	0.23	0.13	0.33	289	0.33	12	1.10	18.4	17.0	18.0	19.2
26	223.0	5620	2.0	914	430	27	26	10	0.04	0.10	0.25	170	0.16	9	0.67	10.4	13.0	11.9	10.8
27	231	7831	3.1	2843	711	66	36	20	0.16	0.17	0.54	246	0.28	15	0.92	13.1	15.0	17.5	16.0
28	241.0	8335	4.1	2282	483	72	39	19	0.15	0.13	0.36	261	0.30	14	1.11	23.8	20.0	24.4	23.9
29	247	9186	4.5	2988	610	72	33	17	0.19	0.14	0.37	286	0.31	11	1.23	23.4	20.5	24.0	24.4
30	255.5	8797	6.1	4093	670	114	47	21	0.21	0.17	0.38	366	0.50	13	1.47	24.5	21.0	27.9	27.3
31	260.0	9712	5.4	2918	523	93	43	19	0.14	0.18	0.36	290	0.39	14	1.59	23.9	23.0	30.6	29.9
32	275.3	10269	6.2	3292	524	98	48	23	0.12	0.18	0.38	382	0.49	15	1.72	27.2	29.0	30.2	31.0
33	280.8	9916	6.2	3818	620	110	42	18	0.21	0.14	0.47	366	0.59	12	1.81	20.1	23.0	31.8	30.5
34	286	12017	6.1	3743	500	105	40	15	0.22	0.13	0.50	307	0.57	12	2.07	30.4	23.0	36.1	36.7