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► To cite this version:

C. Bicalho, C. Batiot-Guilhe, J.D. Taupin, N. Patris, S. van Exter, et al.. A conceptual model for groundwater circulation using isotopes and geochemical tracers coupled with hydrodynamics: A case study of the Lez karst system, France. *Chemical Geology*, 2017, 10.1016/j.chemgeo.2017.08.014 . hal-01883170

HAL Id: hal-01883170

<https://hal.science/hal-01883170v1>

Submitted on 7 Mar 2022

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1 **A conceptual model for groundwater circulation using isotopes and geochemical**
2 **tracers coupled with hydrodynamics: a case study of the Lez karst system,**
3 **France**

4
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6
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10
11 **Abstract**

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13
14 Geochemical and isotopic tracers ($\delta^{18}\text{O}$, $\delta^2\text{H}$, $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{13}\text{C}_{\text{TDC}}$) were used to constrain origins and
15 chemical evolution of groundwater in a Mediterranean karst system. The Lez spring is the main perennial
16 outlet of this karst system and supplies the metropolitan area of Montpellier (southern France) with drinking
17 water. Groundwater samples were collected at the Lez spring and surrounding springs and wells under
18 different hydrodynamic conditions during two hydrological years, from June 2008 until May 2010. The
19 results show that multiple hydrological compartments interact through an important network of fractures and
20 faults. They notably reveal connections between the main Jurassic limestone aquifer and the overlying
21 Cretaceous (Valanginian) compartment, and between the surface and deep levels of the karst system.
22 Isotopic tracers provided information about atmospheric recharge origins, lithological signatures and
23 chemical evolution of waters. Long residence-time groundwaters, issued from deep layers have a Triassic
24 hydrochemical fingerprinting, being enriched in $\delta^{13}\text{C}_{\text{TDC}}$ and characterized by high concentrations in Cl^- as
25 well as high Sr/Ca , Mg/Ca and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. Evidences suggest that these waters mix with waters from the
26 lower layers of the main Jurassic aquifer constitute an intermediate storage compartment prone to rise
27 through piston-flow mechanism. A two-end member hydrograph separation based on EC-TDS was used to
28 determine the proportion of the deep compartment's contribution to the Lez spring outflow. On average over
29 the study period, the main aquifer compartment and the deep aquifer compartment are estimated to
30 contribute 92.6% and 7.4 % of groundwater flow at the Lez spring, respectively.
31

32 **Key words:** hydrogeology, karst, hydrochemistry, natural tracing, isotopes, hydrograph separation
33

34

1 - Introduction

Investigations on karst systems aim at establishing water origins (Bouchaou, Michelot, Qurtobi, Zine, Gaye, Aggarwal, Marah, Zerouali, Taleb and Vengosh, 2009; Desmarais and Rojstaczer, 2002; Wong, Mahler, Musgrove and Banner, 2012), evaluating quantitatively and qualitatively water resources and understanding karsts vulnerability to contamination (Charlier, Bertrand and Mudry, 2012; Massei, Mahler, Bakalowicz, Fournier and Dupont, 2007; Mendizabal and Stuyfzand, 2010). Geochemical and isotopic properties of groundwaters in karst systems reveal water-rock interactions and water mixing processes, occurring along flowpaths in the aquifer (Barbieri, Boschetti, Petitta and Tallini, 2005; Celle-Jeanton, Travi and Blavoux, 2001; Frondini, 2008; Millot, Petelet-Giraud, Guerrot and Négrel, 2010) and give information about transit time and origin of groundwater flow. The monitoring of physicochemical and chemical parameters provides insightful information about the reactivity and vulnerability of the aquifer to pollution and transfer processes. Temporal variations observed in groundwater chemistry are usually related to the physical characteristics and carbonate permeability of the aquifer, and help to identify hydrodynamic behaviour (Geyer, Birk, Liedl and Sauter, 2008; Kilroy and Coxon, 2005; Wittenberg, Kutiel, Greenbaum and Inbar, 2007). Coupling hydrodynamics and hydrochemistry by using mixing equations allows assessing solute transport for conservative compounds (Aquilina, Ladouche and Dörfliger, 2006; Batiot, 2002; Beven, 2001; Drever, 1982; Emblanch, Zuppi, Mudry, Blavoux and Batiot, 2003; Garry, 2007; Hartmann, Weiler, Wagener, Lange, Kralik, Humer, Mizyed, Rimmer, Barberá, Andreo, Butscher and Huggenberger, 2013; Katz, Catches, Bullen and Michel, 1998; Ladouche, Probst, Viville, Idir, Baqué, Loubet, Probst and Bariac, 2001; Long and Putnam, 2004; Petelet-Giraud and Négrel, 2007; Ribolzi, Moussa, Gaudu, Vallès and Voltz, 1997; Wang, Guo, Su and Ma, 2006). This approach is often used to assess the multiple end-members participation in water flow by using natural tracers. Mixing models based on mass conservation describe water contributions using isotopic or chemical tracers from rainwater, pre-event water and flow hydrograph.

The Lez Spring, one of the major karst springs in France, supplies water to the metropolitan area of Montpellier, France, since the 19th century. Former studies have shown this karst system to be a complex and heterogeneous system in terms of structure and functioning (Fleury, Ladouche, Conroux, Jourde and Dörfliger, 2009; Joseph, Rodier, Soulte, Sinigre, Baylet and Deltour, 1988; Karam, 1989; Marjolet and Salado, 1976; Thierry and Bérard, 1983). Since 2008, the Lez Spring has been continuously monitored. Recent observations showed that the Lez spring flow can be described with different water types resulting

65 from a mixing of various end-members: recently infiltrated waters; main aquifer compartment (mainly
66 Jurassic limestone), and a deep aquifer compartment (Caetano Bicalho, Batiot-Guilhe, Seidel, Van Exter and
67 Jourde, 2012). According to hydrological conditions, each compartment contributes in various proportions to
68 the Lez spring flow. In particular, (Caetano Bicalho, Batiot-Guilhe, Seidel, Van Exter and Jourde, 2012)
69 showed that waters with high TDS (Total Dissolved Solids) flow as a response to extreme hydrological
70 conditions in relationship with intense rainfall over the watershed. This phenomenon has often been observed
71 and reported by several works undertaken on karst terrains (Blavoux, Gilli and Rousset, 2004; Desmarais and
72 Rojstaczer, 2002; Emblanch, Blavoux, Puig and Couren, 1998; Grobe and Machel, 2002; López-Chicano,
73 Bouamama, Vallejos and Pulido-Bosch, 2001; Rosenthal, Zilberbrand and Livshitz, 2007). The deep
74 karstification observed in some Mediterranean karst systems (e.g. the Lez and the Vaucluse karst systems) is
75 generally put forth to explain the existence of long residence-time and relatively high TDS concentration
76 waters flowing at the springs, especially after intense rainfalls. This specificity adds more complexity to karst
77 systems situated in this context whereas other karst systems, that did not undergo a deep karstification
78 process, are commonly crossed by waters in a rapid flow, i.e. with low residence times.

79 The present paper aims to i) understand the behaviour of the whole karst system together with the
80 functioning of the various springs by using supplementary tracers, such as stable isotopes of water ($\delta^{18}\text{O}$
81 and $\delta^2\text{H}$), strontium isotopes ($^{87}\text{Sr}/^{86}\text{Sr}$) and Total Dissolved Inorganic Carbon isotopic composition
82 ($\delta^{13}\text{C}_{\text{TDIC}}$), ii) assess both the origin and dynamics of groundwater within the different compartments of the
83 system, iii) deepen the comprehension of groundwaters chemical evolution over the hydrological cycle, and
84 iv) accomplish a preliminary hydrograph separation in order to estimate the proportions of deep water
85 outflowing at the Lez spring.

86

87 **2 - Study Area**

88 **2.1 - Geology**

89 The Lez Spring (43.718°N, 3.844°E), located 15 km north of Montpellier and 28 km from the
90 Mediterranean Sea, is the main perennial outlet of the Lez karst system, with maximum groundwater
91 discharge around 15 m³/s, and a mean annual discharge of 2.0 m³/s (1963-2008, (Jourde, Batiot-Guilhe,
92 Bailly-Comte, Bicalho, Blanc, Borrell, Bouvier, Boyer, Brunet, Cousteau, Dieulin, Gayard, Guinot,
93 Hernandez, Kong, Siou, Johannet, Leonardi, Mazzilli, Marchand, Patris, Pistre, Seidel, Taupin and Van-

94 Exter, 2011)). The Lez karst system also discharges at intermittent springs (Lirou, Restinclières, Fleurettes,
95 and Gour Noir springs) (Fig. 1). Restinclières, Fleurettes and Gour Noir used to be perennial springs before
96 1962, when pumping within the Lez spring started to supply Montpellier and its metropolitan region with
97 drinking water. The hydrogeological basin of the Lez spring is located between the Hérault and Vidourle
98 river valleys and covers about 380 km² (Thierry and Bérard, 1983), while the recharge catchment through the
99 Jurassic limestone outcrops located by the western and north-eastern limits of the basin is only about 188
100 km² (Leonardi, Jourde, Dausse, N.Dörfliger, Brunet and Maréchal, 2013). Indeed, most of the
101 hydrogeological basin is confined by low-permeability aquitards (Marjolet and Salado, 1976). Local
102 recharge also occurs through fractures and sinkholes within the basin, especially through the major fault of
103 *Corconne-Les Matelles* (Fig. 1) located in the northern part of the basin (Dubois, 1964).

104 The lithology of the Lez karst system corresponds to massive limestone of the Upper Jurassic
105 (Kimmeridgian) and Early Cretaceous (Beriasian) with a 650 to 1100 m thickness (Fig. 2). The marls and
106 marly-limestones of the Middle Jurassic (Callovian-Oxfordian) constitute the lower boundary of the
107 aquifer. The marls and marly-limestones of the Early Cretaceous (Lower Valanginian) constitute the upper
108 boundary of the aquifer, causing low permeability and a partly confined system. The major tectonic events
109 that influenced the Lez aquifer were the Hercynian/Variscan orogeny, the Pyrenees formation, and the
110 opening of the Lion Gulf (Bousquet, 1997).

111 A perched aquifer located within the Upper Valanginian layer (Fig. 2,) overlies the Lez aquifer (Pane-
112 Escribe, 1995). The communication of this perched aquifer with the Jurassic layer is very limited due to the
113 low permeability of the marls that compose it. However, point-source infiltration occurs from the
114 Valanginian aquifer towards the Lez aquifer (Boinet, 2002). Indeed, groundwater outflowing from springs
115 that drain the Valanginian aquifer (Lauret, Dolgue, and Lavabre springs) locally recharge the Lez karst
116 system along the *Corconne-Les Matelles* fault (Boinet, 2002).

117 The Lez karst system was described by Avias (1992) as a Vaucluse-type system deeply developed
118 below the present-day spring level. This results from an intense karstification (i.e. conduit enlargement
119 caused by low-acidified water weathering over limestones) that reached several hundred meters during the
120 Messinian Salinity Crisis- from 5.96 to 5.33 Ma (Celle-Jeanton, Travi and Blavoux, 2001; Cita and Ryan,
121 1978; Clauzon, 1982; Joseph, Rodier, Soulte, Sinègre, Baylet and Deltour, 1988; Ryan, 1976). The
122 karstification network is mainly oriented along NS and EW directions in zones where tectonic deformation is

123 weak and NE-SW near major tectonic changes (Leonardi, Jourde, Dausse, N.Dörfliger, Brunet and Maréchal,
124 2013). The Lez system is highly karstified, but the presence of impermeable Pliocene marine and continental
125 sediments preserved it from seawater contamination (Bakalowicz, 2005; Fleury, 2005; Fleury, Bakalowicz
126 and de Marsily, 2007).

127 **2.2 - Rainfall**

128 The precipitation data used in this study come from three Météo France meteorological stations,
129 (Valflaunès, Saint-Martin-de-Londres, and Prades) all at a distance lower than 12km from the Lez spring
130 (Fig. 1). The hydrological year begins in September, after 2 to 3 months of relative dryness. The wet season
131 (high stage) lasts from September to May and the dry season (low stage) from June to August. Over the last
132 40 years, the average annual rainfall calculated at the Valflaunes station was 942 mm with a minimum of 474
133 mm (year 1985) and a maximum value of 1,620 mm (year 1972). During the study period, the annual
134 rainfalls were 849 mm for 2007-2008, 1,266 mm for 2008-2009 and 666 mm for 2009-2010. For the 1970-
135 2010 period, the intra-annual rainfall distribution was: 37% in autumn, 27% in winter, 22% in spring, and
136 13% in summer.

137

138 **3 - Materials and Methods**

139

140 **3.1 - Continuous monitoring and sampling**

141

142 Samples were collected at the Lez spring for chemical and isotopic analysis twice a month, with daily
143 sampling during high discharge events from June 2008 to May 2010. At Lirou, Restinclières, and Fleurettes
144 springs, sampling was carried out during the wet season only, from September to May. An automatic sampler
145 with 24 bottles (11 acid-cleaned polyethylene bottles) was used for water sampling at the Lez spring during
146 high flows.

147 Additional samples were collected during low stage period from: 1) adjacent systems that are
148 potentially connected to the Lez karst system, including Fontbonne and Sauve springs (Fig. 1), Valanginian
149 springs and wells, including Boinet, Olivier, and Lavabre wells but also Lauret, Lavabre, and Dolgue
150 springs, and 3) wells within the Lez spring hydrogeological basin (referred to as Lez KS wells): Fontanes,
151 Laudou, Bois des Rozières, and Gour Noir (Fig. 1).

152 Temperature (T), pH, and Electrical Conductivity (EC $T_{ref}=25^{\circ}C$) were measured in the field using a
153 pH meter and conductivity meter (WTW 330 i) on each sample. Continuous data were obtained from
154 automatic measurement. Temperature, turbidity, EC, and Groundwater Level (GW level) were measured at
155 an hourly time step at the Lez Spring with an automatic data logger (CTD diver, SDEC) and hereafter
156 referred to as Lez Well. Temperature, EC, and groundwater level measurements were performed at an hourly
157 time step at the Lez Spring spillway and Lirou Spring (CTD diver, SDEC).

158 Rain waters were regularly sampled (monthly to bi-monthly) for water isotopes analysis from an
159 underground tank connected to raingauges at Viols-le-Fort and Sauteyrargues stations (Fig. 1) between May
160 2009 and May 2010. To complete the lack of rainwater isotopic data at the beginning of the study period, the
161 monthly average rainfall isotopic composition at the Montpellier raingauge, located 9 km downstream the
162 Lez spring and sampled daily over the whole study period, was used as a reference for the input signal. The
163 interpretation took into account the limitations related to the observed differences in the rainfall isotopic
164 composition between Montpellier and the karst system recharge area.

165 49 samples were collected for $\delta^{13}C_{TDIC}$ measurement on dissolved carbonate at the following springs:
166 32 at the Lez spring, 8 at the Lirou spring, 6 at the Restinclières spring and 3 at Fleurettes spring. Water
167 samples were collected in glass bottles and quickly sealed on the field with gas tight rubber/teflon plugs.
168 Three $\delta^{13}C_{CO_2}$ measurements from soil covers were carried out in April 2010 over the Lez spring catchment
169 in order to characterize the main vegetal and pedogenic covers: (1) vineyards developed on Quaternary
170 deposits (2) scrublands over Jurassic limestones and (3) olive grove developed on Tertiary deposits.

171

172 **3.2- Analytical methods**

173

174 Total alkalinity was measured at HydroSciences Montpellier (HSM) laboratory, by acid titration with
175 HCl 0,01N. Major ions (Cl^{-} , NO_3^{-} , SO_4^{2-} , Ca^{2+} , Mg^{2+} , Na^{+} , and K^{+}) were analysed by ionic chromatography
176 (DIONEX ICS 1000) on filtered samples (0.22 μ m) with an analytical accuracy of 5%, after an acidification
177 with 1‰ suprapur HNO_3 for cations. Trace elements (Li, B, Al, V, Cr, Mn, Co, Ni, Cu, Zn, As, Rb, Sr, Mo,
178 Cd, Ba, Pb, and U) were analysed using Q-ICPMS X series II Thermo Fisher at the AETE (Analyse des
179 Eléments en Trace dans l'Environnement) technical platform of University of Montpellier on filtered and
180 acidified samples (0.22 μ m, 1‰ suprapur HNO_3), with a greater than 8% accuracy. Samples with ion balance

181 error greater than 5% were excluded from the dataset. Samples for Total Organic Carbon (TOC) were
182 collected in dark glass bottles previously combusted for 6 h at 550°C, acidified with 1‰ H₃PO₄ and analyzed
183 with catalytically aided platinum 680 °C combustion technique (Shimadzu VCSH).

184 Isotopic compositions of water carbonate $\delta^{13}\text{C}_{\text{TDIC}}$ and soil $\delta^{13}\text{C}_{\text{CO}_2}$ samples were analysed at *Université*
185 *d'Avignon et des Pays de Vaucluse* (UAPV) Hydrogeology Laboratory on a Finnigan Mat Delta S mass
186 spectrometer after acid digestion of the dry precipitate of carbonate. Isotopic carbonate values are reported
187 relative to the V-PDB scale, with an overall uncertainty of $\pm 0.05\text{‰}$.

188 Water stable isotopes ($\delta^{18}\text{O}$ and $\delta^2\text{H}$) were analysed at the LAMA mass spectrometry laboratory of
189 HSM on an Isoprime mass spectrometer. $\delta^{18}\text{O}$ was measured with the classical CO₂ equilibration method,
190 with an overall uncertainty of $\pm 0.1\text{‰}$. δD was measured in continuous-flow mode with a Eurovector Pyr-OH
191 analyser converting H₂O to H₂ on Cr at 1070°C, with an overall uncertainty of $\pm 0.8\text{‰}$. All isotopic water
192 values are reported in this paper relative to the V-SMOW scale.

193 Strontium isotopic composition was measured on 16 samples collected across the whole system.
194 $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were measured at the Rennes University using the Faraday cups of a five-collector Finnigan
195 MAT 262 mass spectrometer. Sr²⁺ was separated using a cation exchange column (Dowex AG50X8) with
196 HCl₂N as eluent. All measured $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were normalized to $^{86}\text{Sr}/^{88}\text{Sr}=0.1194$. Initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios
197 were calculated using $^{87}\text{Rb}/^{86}\text{Sr}$ ratios as determined by the isotope dilution method (Petelet, Luck, Ben
198 Othman, Negrel and Aquilina, 1998). High-precision ^{84}Sr and ^{87}Rb spikes gave maximum errors of 2%.

199

200 **4 - Results and Discussion**

201

202 The Lez spring flow is composed of different water types resulting from a mixing of various hydrologic
203 end-members. These water types were described by Caetano Bicalho et al. (2012) using a specific
204 terminology that is applied in the present text and graphs: 1) “High waters” discharge during high water
205 stages and are associated with high groundwater levels and EC oscillations; 2) “Low waters” discharge
206 during low stage periods and are associated with low groundwater levels and high, stable EC; 3) “Dropping
207 waters” discharge during the transition between the high and low stages and are associated with a decrease in
208 groundwater level and an increase in EC. Extreme values of high or low EC were respectively referred to as

209 4)“Piston-flow waters” (EC>780 $\mu\text{S}/\text{cm}$) and 5)“Dilution waters” (EC< 600 $\mu\text{S}/\text{cm}$) (Caetano Bicalho,
210 Batiot-Guilhe, Seidel, Van Exter and Jourde, 2012).

211 **4.1 - Hydrochemistry and water isotopes**

212
213 The complete dataset collected from the karst springs is presented in Table 1 and Table 2. Table 3
214 presents the average values and range of variations for the dataset.

215 EC indicates generally higher TDS in groundwater at the Lez spring than at other springs: the mean EC
216 measured during both the fall and spring seasons was 711 $\mu\text{S}\cdot\text{cm}^{-1}$ at Lez spring, 661 $\mu\text{S}\cdot\text{cm}^{-1}$ at
217 Restinclières spring, 655 $\mu\text{S}\cdot\text{cm}^{-1}$ at Fleurettes spring and 581 $\mu\text{S}\cdot\text{cm}^{-1}$ at Lirou spring. During the same
218 period, Restinclières and Fleurettes springs generally presented higher values of temperature than the Lez
219 spring (average temperatures of 17.0, 16.0 and 15.7°C, respectively) (Table 2). Restinclières and Fleurettes
220 springs had a very similar geochemistry mostly associated with the presence of limestones (Chamayou and
221 Auroux, 1992). Lirou waters had the lowest TDS (516 $\text{mg}\cdot\text{l}^{-1}$ in average) and temperature (mean value of
222 14.3°C), which indicates a large participation of recent infiltration waters, suggesting rapid groundwater
223 circulation. Hydrochemical facies of Lez (Table 1) and Lirou springs (Table 2) indicate different
224 groundwater flowpaths for these springs, despite their geographical proximity. The Lirou spring drains a
225 karst catchment characterized with fast infiltration and rapid groundwater transfers; it has a carbonated
226 facies, i.e., concentrations are high in bicarbonates and low in Cl^- , SO_4^{2-} , Mg^{2+} and trace elements. Peaks of
227 TOC concentration confirm rapid infiltration and a potential high vulnerability to superficial contamination.

228 The water isotopic input signal was calculated from three raingauges located at Sauteyrargues, Viols le
229 Fort and Montpellier (Table 4). In the $\delta^2\text{H}$ vs. $\delta^{18}\text{O}$ diagram (Fig. 3), rainwater showed a wide range of
230 composition, mostly distributed between the Global Meteoric World Line (GMWL) and the Mediterranean
231 Meteoric World Line (MMWL). Likewise, most groundwater samples lied about these lines, indicating that
232 they originated as meteoric recharge (Grobe and Machel, 2002; McIntosh and Walter, 2006).

233 The local meteoric water line was calculated from 22 rainwater samples collected during a hydrological
234 year at the Lez basin raingauges (Sauteyrargues and Viols-le-Fort) by using linear least squares, and was
235 $\delta\text{D}= 7.3* \delta^{18}\text{O} +7.8\text{‰}$. The relatively low slope (7.3) and y-intercept (+7.8‰) observed, suggest that partial
236 evaporation of raindrops may have a measurable influence on the isotopic input signature over the area
237 (Ladouche, Luc and Dörfliger, 2009). In order to consider only the air masses origins and condensation
238 processes that control the isotopic composition of meteoric water, and excluding fractionation linked with

239 evaporation of water during the raindrops fall to the ground, nine evaporated rainwater samples (identified
240 with low deuterium excess $d < +8\text{‰}$, with $d = \delta^2\text{H} - 8 \times \delta^{18}\text{O}$) were removed from the previous dataset. This
241 allowed the determination of a Local Meteoric Line (LML) of non-evaporated rainwaters: $\delta\text{D} =$
242 $7.5 \times \delta^{18}\text{O} + 12.5\text{‰}$. The y-intercept of this LML is $+12.5\text{‰}$, indicating that rainwaters in the Lez basin
243 typically resulted from vapour transports temporally alternated from Mediterranean ($d > 12\text{‰}$) and Atlantic
244 origins ($d = 10\text{‰}$) (Celle-Jeanton, Travi and Blavoux, 2001; Ladouche, Luc and Dörfliger, 2009).

245 The temporal variability of EC and $\delta^{18}\text{O}$ (Fig. 4) shows how ^{18}O isotopes varied during rainfall events
246 on the monitored springs with respect to the rainfall water entry (infiltration) signal. The $\delta^{18}\text{O}$ weighted
247 average of rainwater in the study period was about -6.2‰ , while for the Lez waters the average was -5.7‰ .
248 In general, the groundwater samples showed a much reduced variability in $\delta^{18}\text{O}$ when compared to rainwater
249 inputs (Fig. 4). The monthly rainwater means calculated for Montpellier station presented a relatively large
250 $\delta^{18}\text{O}$ amplitude (-9.0‰ to $+0.6\text{‰}$ over the period); on the other hand, seasonal isotopic variations were
251 strongly reduced at the springs, especially at the Lez and Restinclières springs, which showed a significant
252 attenuation of the signal variability, typically about 1.5‰ in amplitude.

253 Despite the dampening of the signal and a low variability, $\delta^{18}\text{O}$ varied as much as $+1\text{‰}$ during the first
254 high flows of autumn 2008 (zoomed $\delta^{18}\text{O}$ scale on Fig. 4). This variation is low but is still important enough
255 to suggest that rapid infiltration waters participated to the Lez spring discharge, considering the isotopically
256 enriched rainwaters during the same period ($\delta^{18}\text{O} = -3.78\text{‰}$ for the corresponding 4-day long event at
257 Montpellier station). Restinclières and Fleurette springs also presented dampening of the $\delta^{18}\text{O}$ signal which
258 denotes a residence-time at least equal to the period of the input function, i.e. one year. This indicates the
259 existence of an important storage component and an efficient mixing of infiltrated waters with stored waters,
260 which suggests an important autogenic recharge through diffuse percolation of precipitation waters deposited
261 directly onto the karst landscape. Consequently, the seasonal behaviours and recharges are difficult to
262 identify solely from the springs characteristics (Barbieri, Boschetti, Petitta and Tallini, 2005; Long and
263 Putnam, 2004; Négrel and Petelet-Giraud, 2005).

264 Unlike the other springs of the system, the Lirou spring showed a remarkable $\delta^{18}\text{O}$ variability,
265 especially during the storms of October 2008 (Fig. 4) characterized by a relatively large rainfall amount (121
266 mm registered during the first day of a storm that lasted 3 days). This important rainfall input has triggered a
267 large infiltration and an immediate hydrologic response of the Lirou spring, where a marked groundwater EC

268 decrease was observed. This behaviour illustrates the great reactivity of Lirou spring compared to the other
269 springs, indicating that it is effectively under a comparatively stronger influence of recent rainfalls, and
270 presents short residence times through a shallow groundwater flow-path within the limestone bedrock.

271

272 **4.2 - Carbon isotopes**

273 The use of $\delta^{13}\text{C}_{\text{TDIC}}$ as a natural tracer in karst systems can help differentiating water originated from
274 the unsaturated zone from water sourced from the saturated zone (Emblanch, Zuppi, Mudry, Blavoux and
275 Batiot, 2003). In the unsaturated zone, the system behaves like an open system with regard to biogenic CO_2
276 from the soil (Clark and Fritz, 1997; Desmarais and Rojstaczer, 2002; Emblanch, Zuppi, Mudry, Blavoux
277 and Batiot, 2003; Gillon, Barbecot, Gibert, Corcho Alvarado, Marlin and Massault, 2009; Gonfiantini and
278 Zuppi, 2003; Yoshimura, Nakao, Noto, Inokura, Urata, Chen and Lin, 2001). Soil CO_2 was thus investigated
279 under three different environments across the basin in April 2010. The mean results obtained for three
280 different vegetal and pedogenic covers tested over the Lez system were as follow: (1) vineyards developed
281 on Quaternary deposits: $\delta^{13}\text{C}_{\text{CO}_2} = -22.28\text{‰}$; (2) scrublands over Jurassic limestones: $\delta^{13}\text{C}_{\text{CO}_2} = -21.69\text{‰}$; and
282 (3) olive grove developed on Tertiary deposits: $\delta^{13}\text{C}_{\text{CO}_2} = -20.42 \text{‰}$. At each site, values presented little
283 variability compared to the differences observed between different covers. Former studies over the
284 Mediterranean karst basin of Vaucluse showed low seasonal variations on $\delta^{13}\text{C}_{\text{CO}_2}$ in soil covers (Batiot,
285 2002) (Emblanch, Zuppi, Mudry, Blavoux and Batiot, 2003). Thus, the input $\delta^{13}\text{C}_{\text{CO}_2}$ signal can be
286 considered constant. The mean $\delta^{13}\text{C}_{\text{CO}_2}$ value of -21.06‰ was used as the local biogenic soil CO_2 value.

287 The Lez spring displayed remarkable variations in $\delta^{13}\text{C}_{\text{TDIC}}$ values in the range -10.06‰ to -14.73‰
288 (Table 1). The most $\delta^{13}\text{C}_{\text{TDIC}}$ -enriched waters, associated with high EC, corresponded to the fall periods of
289 October 2008 and October 2009 (Fig. 5). A slow and progressive $\delta^{13}\text{C}_{\text{TDIC}}$ enrichment was observed during
290 the dry season, extending from the 2008-2009 winter until the first recharge event in 2009 (autumn). Higher
291 $\delta^{13}\text{C}_{\text{TDIC}}$ values indicate a comparatively larger contribution of groundwater marked with water-rock
292 interaction ($\delta^{13}\text{C}_{\text{rockcarbonate}}=0\text{‰}$ to -2‰) occurring in closed condition within the saturated zone. The most
293 negative values were observed during the middle of the wet season, where $\delta^{13}\text{C}_{\text{TDIC}}$ as well as E.C. presented
294 a sudden decrease (Fig. 5). These low $\delta^{13}\text{C}_{\text{TDIC}}$ values measured in groundwaters at the Lez spring suggests
295 flushing of infiltration waters.

296 The variability of $\delta^{13}\text{C}_{\text{TDIC}}$ at the Lez spring supports the hypothesis that different compartments of the
297 system contribute to the flow, with an enhanced participation of groundwater associated with higher water-
298 rock interaction signature during the dry season, but also during the first flood events of the wet season. The
299 contribution of freshly infiltrated waters to the Lez spring flow was observed to be more important during the
300 entire humid season, especially after recharge events.

301

302 **4.3 - Reactions controlling water chemistry**

303 Isotopic ratios of C and Sr were coupled with water chemistry to characterize the chemical evolution of
304 waters, comparing the behaviour of the various springs to one another and the chemical variations during
305 dissimilar hydrological situations. The $\delta^{13}\text{C}_{\text{TDIC}}$ ratios in groundwater are affected by carbonate dissolution
306 that is linked to the degree of openness to soil CO_2 . The CO_2 gas/water isotopic exchange is a very quick
307 process. Consequently, if the chemical equilibrium within the aquifer is attained under open conditions
308 regarding the gaseous phase, the soil $\delta^{13}\text{C}_{\text{CO}_2}$ determines the $\delta^{13}\text{C}$ of groundwater (Appelo and Postma, 2005).
309 If the system is closed to soil CO_2 , TDIC can be derived up to about equal proportions from the dissolution
310 of CO_2 (g) and from the CaCO_3 weathering (Appelo and Postma, 2005).

311 Covariance of $\delta^{13}\text{C}_{\text{TDIC}}$ with Mg/Ca and with Sr/Ca (expressed as molar ratios in Fig. 6) indicates an
312 evolution trend for the Lez system: the $\delta^{13}\text{C}_{\text{TDIC}}$ became more enriched as Mg/Ca and Sr/Ca increased (Fig.
313 6). $\delta^{13}\text{C}_{\text{TDIC}}$ was comparatively more enriched in the Lez system samples (except Lirou spring) than in the
314 Valanginian ones, with the exception of Lauret and Boinet wells which were closer to typical Lez waters.
315 Lirou generally showed $\delta^{13}\text{C}_{\text{TDIC}}$ values more depleted than other samples across the Lez system, which
316 together with the high variability of $\delta^{18}\text{O}$, confirms the shorter water residence time, with a flowpath taking
317 place in the shallow aquifer where the influence of soil CO_2 is comparatively more important than limestone
318 dissolution. The coupling between $\delta^{13}\text{C}_{\text{TDIC}}$ and elemental ratios (Fig. 6) reflects different processes or
319 origins for the groundwater outflowing at the Lez system springs on one hand and Valanginian springs on the
320 other hand. The concomitant increases of $\delta^{13}\text{C}_{\text{TDIC}}$, Mg/Ca and Sr/Ca observed at the Lez spring (particularly
321 well demonstrated during “Piston-Flow waters”) suggest that groundwater possibly evolve via carbonate
322 minerals dissolution under closed system conditions, i.e. with limited influence from surface waters. This
323 reflects the relative isolation of the reservoir feeding Lez spring waters from shallow groundwater, and

324 indicates longer residence times. On the other hand, the relatively higher Mg/Ca and higher Sr/Ca ratios
325 observed in Valanginian waters are most likely due to the lithology of the drained compartments: the
326 Cretaceous marls and marly-limestones are richer in Mg²⁺ than the Jurassic limestones, causing
327 comparatively higher Mg/Ca and Sr/Ca ratios without coincident $\delta^{13}\text{C}_{\text{TDC}}$ enrichment (Harrington, Herczeg
328 and Le Gal La Salle, 2008; Moral, Cruz-Sanjulián and Olías, 2008; Stuart, Maurice, Heaton, Sapiano,
329 Micallef Sultana, Gooddy and Chilton, 2010).

330 Among the various spring waters draining the Lez aquifer, the water described at the beginning of
331 section 3 as “Piston-flow Water” (characterized by EC>780 $\mu\text{S}/\text{cm}$) at the Lez spring has the highest Sr²⁺
332 concentration. Strontium concentrations are highly correlated with [SO₄²⁻], [B] and [Li] (R²= 0.70, 0.80 and
333 0.76, respectively). It also shows a good correlation with [Cl⁻], but only when peaks of [Cl⁻] concentrations
334 are observed, which indicates a common origin for both elements in this specific case. Several possible
335 parameters can have a control on Sr²⁺ concentrations in waters, e.g. initial (atmospheric) inputs, mineralogy
336 along flowpaths, mineral dissolution characteristics or residence time. Moreover, Sr²⁺ concentration could be
337 influenced by multiple reactions, e.g. re-crystallization, incongruent dissolution or celestite precipitation
338 (Bernasconi, 1999; Tellam, 1995). Two possible mechanisms can be proposed to describe the chemical
339 reactions controlling Sr²⁺ concentration in Lez spring groundwater with high TDS. (i) The dissolution of
340 dolomite promoting calcite precipitation led by evaporite salts dissolution, which enriches the fluids in both
341 Sr²⁺ and Mg²⁺ with respect to Ca²⁺. Indeed, during the calcite recrystallization, Sr/Ca increases in
342 groundwater because the calcite lattice favours Ca²⁺ and Mg²⁺ over Sr²⁺ during the precipitation (Jacobson,
343 Blum and Walter, 2002; McIntosh and Walter, 2006; Négrel and Petelet-Giraud, 2005; Nisi, Buccianti,
344 Vaselli, Perini, Tassi, Minissale and Montegrossi, 2008; Stuart, Maurice, Heaton, Sapiano, Micallef Sultana,
345 Gooddy and Chilton, 2010). In this case, high Sr/Ca ratios indicate that waters have been extensively altered
346 by the incongruent dissolution of carbonate minerals and the dissolution of evaporites (Jacobson and
347 Wasserburg, 2005; McIntosh and Walter, 2006; Samborska and Halas, 2010). (ii) The evaporite dissolution
348 may enrich fluids in Sr²⁺ because they contain more Sr²⁺ than calcite and dolomite (Grobe and Machel, 2002;
349 Jacobson and Wasserburg, 2005; McIntosh and Walter, 2006; Petelet, Luck, Ben Othman, Négrel and
350 Aquilina, 1998; Wu, Xu, Yang, Yin and Tao, 2009). As Sr²⁺ concentrations increase, Mg/Ca ratios also
351 increase, suggesting progressive water-rock interactions (McIntosh and Walter, 2006).

352 Sr isotopes were used to test these hypotheses, focusing on the highly mineralised waters of the Lez
353 spring. The combined use of major elements, mineral saturation state, elemental ratios and $^{87}\text{Sr}/^{86}\text{Sr}$ help
354 identifying the reactions that control the evolution of the waters chemistry, such as incongruent dissolution
355 of dolomites and calcite precipitation (Jacobson and Wasserburg, 2005; Katz, Catches, Bullen and Michel,
356 1998; Kloppmann, Négrel, Casanova, Klinge, Schelkes and Guerrot, 2001; Nisi, Bucciatti, Vaselli, Perini,
357 Tassi, Minissale and Montegrossi, 2008; Oetting, Banner and Sharp, 1996; Wang, Guo, Su and Ma, 2006).

358 The upper panel of Figure 7 represents $^{87}\text{Sr}/^{86}\text{Sr}$ as a function of $1/[\text{Sr}]$. The water samples from the
359 Valanginian aquifer are clustered around a straight line pointing at an isotopic signature of $^{87}\text{Sr}/^{86}\text{Sr}$ between
360 0.7073 and 0.7075 for high $[\text{Sr}]$ values, representative of Cretaceous and Jurassic formations. A few samples,
361 notably the Lez water sample identified as “Piston-flow” (Caetano Bicalho, Batiot-Guilhe, Seidel, Van Exter
362 and Jourde, 2012), and to a lower extent the Lirou and Lez Low Waters (Fig. 7), presented a relatively
363 enriched $^{87}\text{Sr}/^{86}\text{Sr}$ ratio with high to median Sr concentrations. This behaviour indicates either possible extra
364 sources of Strontium with different Sr isotope ratios along the flowpath, or chemical reactions involving Sr
365 addition or removal (Grobe and Machel, 2002).

366 Meteoric waters generally have high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios but low Sr concentrations, while carbonate rocks
367 usually present low $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (Négrel and Petelet-Giraud, 2005; Oetting, Banner and Sharp, 1996).
368 However, according to the groundwaters’ chemical properties and on the basis of Sr concentrations, the
369 meteoric water influence can be ruled out. Sr^{2+} sources are therefore mostly related to the dissolution of Sr-
370 rich minerals and/or the chemical evolution of waters, leading Sr^{2+} concentration to high values.

371 The Lez water samples corresponding to "Piston Flow" and to “Low Waters” also presented the highest
372 Cl^- concentrations together with the highest $^{87}\text{Sr}/^{86}\text{Sr}$ ratios observed in the Lez system. The most radiogenic
373 $^{87}\text{Sr}/^{86}\text{Sr}$ was observed at the Sauve spring, at the northern limit of the Lez catchment (Fig. 1), which is
374 connected to an adjacent granitic system. This isotopic ratio in this case is probably associated to a granitic
375 bedrock fingerprinting, this lithology being present on the upstream part of the Sauve catchment, unlike in
376 the Lez basin. The lithology that could explain a common origin for high Cl^- and radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ at the
377 Lez spring corresponds to the Triassic bedrock: the $^{87}\text{Sr}/^{86}\text{Sr}$ evolution curve peaked during Triassic (with a
378 ratio $^{87}\text{Sr}/^{86}\text{Sr} \sim 0.708$) and then continuously decreased from Late Triassic to Late Cretaceous rocks
379 (Koepnick, Denison, Burke, Hetherington and Dahl, 1990). Oetting *et al.* (1996) also found higher $^{87}\text{Sr}/^{86}\text{Sr}$
380 ratios in waters from carbonate and evaporite aquifers, indicating a source of Sr^{2+} from underlying units.

381 These elements confirm the hypothesis presented by Caetano Bicalho et al. (2012) of a piston flow
 382 mechanism involving a deep water compartment, especially active at the onset of the humid season.

383

384

385 **4.4 - Hydrograph separation at the Lez spring**

386 Mass balance calculations were accomplished in an initial attempt to quantify mixing proportions at the
 387 Lez spring using a simple mixing model. The resolution of the end-member mixing, taking into account
 388 multiple hydrological reservoirs and water types is beyond the scope of the present paper. The intention of
 389 this mass balance calculation is to estimate the proportion of deep waters participating to the Lez outflow
 390 during the whole study period. Calculations were thus performed (Eq. 1 to 5) assuming a simple mixture of
 391 two end-members (deep and main aquifer compartments) that could be unambiguously identified by one
 392 parameter: EC. The choice of EC as tracer is justified by both the good representativeness of this parameter
 393 and the high frequency of the available data (continuous EC monitoring at the hourly time-step at the Lez
 394 spring).

395 The two end-members considered are defined as follows. (1) The main aquifer compartment, roughly
 396 corresponding to a water bearing the mean characteristics of the high stage season ("High Waters" and
 397 "Dilution waters" as defined by Caetano Bicalho et al. (2012)), with $EC = 650\mu S/cm$, corresponding to the
 398 baseline value of EC at the Lez spring during the wet season (Fig. 4). (2) The deep waters compartment,
 399 characterized by an EC value of $1,840\mu S/cm$ corresponding to that of the Bajocian underlying aquifer which
 400 was measured (16-day average, corrected for temperature) in the 1200 m deep Antigone borehole
 401 (productive levels between 843 and 953 m) in the city of Montpellier (Chamayou and Auroux, 1992).

402

403 The contributions are calculated following Eq. 1 to 4:

404

$$Q_{spring} EC_{spring} = Q_{deep} EC_{deep} + Q_{main.aquifer} EC_{main.aquifer} \quad (1)$$

405

$$x_{deep} + x_{main.aquifer} = 1 \quad (2)$$

406

$$EC_{spring} = EC_{Main.aquifer} \times (1 - x_{deep}) + EC_{deep} \times x_{deep} \quad (3)$$

407

$$x_{deep} = \frac{EC_{spring} - EC_{main.aquifer}}{EC_{deep} - EC_{main.aquifer}} \quad (4)$$

408

409 Where:
410 Q_{spring} , $Q_{\text{main.aquifer}}$, Q_{deep} : water discharge at the spring, main compartment discharge, and deep
411 compartment discharge at the spring;
412 EC_{spring} , $EC_{\text{main.aquifer}}$, EC_{deep} : electrical conductivity measured at the spring; main compartment and
413 deep compartment electrical conductivities as defined above;
414 X_{main} , X_{deep} : end members contributions to the water discharge at the spring.

415
416 Figure 8 presents the two end-member separation achieved by the application of the equations 1 to 4,
417 using the water discharge at the Lez spring and the EC measured, on a daily time-step, from the beginning of
418 January 2008 until the end of May 2010. The mean contribution to the outflow at the Lez Spring is estimated
419 to be 92.6% for the main aquifer compartment and 7.4% for the deep aquifer compartment. Winters are
420 characterised by a lower participation of the deep compartment to the Lez outflow, about 5.3% compared to
421 10% during summer and about 6.2 % during autumn and spring. During the low stage, the average
422 contribution of the deep compartment is remarkably stable. During the high stage this contribution is more
423 variable and can reach peak values of 21.8%, immediately followed by a steep decrease. On average though,
424 high-stage deep compartment contributions are proportionally lower (Fig. 8).

425 This hydrograph separation illustrates the temporal distribution of both end-members under a wide
426 range of hydrological conditions, denoting their strong variability. The limitation of this calculation relies on
427 the definition of the so-called deep compartment. The middle Jurassic layer taken as a reference point may
428 result from a mixing between water circulating in Inf. Jurassic layers and a deeper flux which seems to rise
429 through faults from deeper Triassic levels, carrying Cl-rich waters with higher TDS. This may constitute an
430 intermediate storage compartment prone to react quickly through a piston-flow mechanism to a steep
431 recharge.

432
433 **4.5 - Conceptual model: Groundwater circulation within the Lez karst**
434 **system**
435

436 The results obtained in this work improve the argumentation presented by Caetano Bicalho *et al.* (2012)
437 who suggested that the Lez spring water contains a small proportion of groundwater issued from deep layers.
438 Apparently, a shallow buffering zone (Fig. 9) allows the storage of rising waters from deep origin. The water
439 from this zone mainly participates to the outflow at Lez spring during high recharge events.

440 Water stable isotopes indicated that the Lez system springs (Lez, Lirou, Restinclières and Fleurettes)
441 have a common recharge origin. The Lirou spring is the most sensitive to shallow infiltration waters among
442 the springs. Groundwater flowpaths of Lirou spring are basically located on Jurassic limestones and outflow
443 in the contact zone with the Valanginian layer. Thus it can be proposed that Lirou groundwaters do not flow
444 bellow the Valanginian overlying unit in accord with the results obtained from chemical tracers (lower
445 Mg/Ca and Sr/Ca ratios), water stable isotopes (high variability), $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (lower values) and depleted
446 $\delta^{13}\text{C}_{\text{T DIC}}$.

447 The hydrochemical characteristics of Restinclières and Fleurettes springs are very similar in terms of
448 EC, elemental ratios and $\delta^{13}\text{C}_{\text{T DIC}}$, and can be mostly related to interaction with limestones and marly-
449 limestones from Upper Jurassic and Early Cretaceous, indicating groundwater circulation bellow the
450 Valanginian covering of the aquifer.

451 Lez, Restinclières and Fleurettes springs have rather similar properties during Lez spring high-flow
452 periods, i.e., when all springs discharge simultaneously. The low-flow Lez waters tend to get progressively
453 enriched in $\delta^{13}\text{C}_{\text{T DIC}}$. Indeed, at the beginning of high-flow periods, groundwater at the Lez spring are distinct
454 from all the other springs, presenting higher chemical evolution, marked by longer water-rock interaction
455 and possibly the presence of an evaporitic signature in a low percentage, i.e. a depleted $^{87}\text{Sr}/^{86}\text{Sr}$ Triassic
456 signature. Finally, Lez spring waters corresponding to the “Piston Flow” waters (Caetano Bicalho, Batiot-
457 Guilhe, Seidel, Van Exter and Jourde, 2012) have a specific hydrochemical fingerprint (high $\delta^{13}\text{C}_{\text{T DIC}}$, Mg/Ca
458 and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios), which clearly differentiate them from Restinclières and Fleurettes spring waters.

459 The results obtained from the hydrograph separation allowed to estimate the temperature of the deep
460 end-member. Using a mean deep-water contribution of 7.4% ($\pm 1\%$); and considering the temperature of the
461 high TDS waters at the Lez spring (17.4°C) and the annual air temperature average for the study area
462 (16.1°C, at Montpellier Collège F.Rabelais meteorological station) (Hérault, 2009), by application of Eq. (4)
463 and replacing EC with T, we obtain a temperature of the deep waters equivalent to 33.7°C ($\pm 2.1^\circ\text{C}$).
464 Considering the average geothermic gradient of 1.8°C/100m for our study zone (Lucazeau, 1979), we obtain

465 a characteristic depth of about 978 (± 115) meters. This estimate is consistent with the hypothesis presented
466 earlier of a storage compartment located within the mid-Jurassic calcareous formation, and acting as a buffer
467 zone between the deep compartment and the main aquifer.

468

469 **5 - Conclusion**

470

471 In the present study, elemental geochemical tracers coupled with isotopic ratios ($\delta^{18}\text{O}$, $\delta^2\text{H}$, $^{87}\text{Sr}/^{86}\text{Sr}$
472 and $\delta^{13}\text{C}_{\text{TDIC}}$) were used to understand groundwater origins and hydrochemical evolution in the Lez Karst
473 system (southern France). Groundwater samples were collected from the Lez spring and surrounding springs
474 and wells under various hydrological conditions during two years (from June 2008 until May 2010).

475 Water stable isotopes evidenced that the Lirou intermittent spring flow is more responsive to freshly
476 infiltrated waters than the other springs of the system, denoting as a consequence shorter groundwater
477 residence times. For the other springs, on the contrary, important signal attenuation is observed, indicating
478 the existence of a mixing of infiltrated waters with longer residence time groundwater stored in the aquifer.

479 The similar fingerprinting of water stable isotopes measured at the various springs (Lez, Lirou,
480 Restinclières and Fleurettes) indicates that their recharge has the same origin. However, the relative disparity
481 of their water chemistry indicates that recharge waters flow along distinct flowpaths. The hydrochemical
482 characteristics of Restinclières and Fleurettes springs are very similar to one another and can be mostly
483 attributed to interaction with limestones and marly-limestones from Upper Jurassic and Early Cretaceous,
484 indicating groundwater circulation below the Valanginian overlying unit. At the Lez spring, the high-TDS
485 groundwaters ("Piston-Flow waters" with $\text{EC} > 780 \mu\text{S}\cdot\text{cm}^{-1}$) issued from deep layers have probably been
486 extensively modified by evaporite dissolution, calcite precipitation and incongruent dissolution of dolomite.
487 This phenomenon was evidenced by: (i) high Mg/Ca and Sr/Ca ratios concomitant with an increase of
488 $\delta^{13}\text{C}_{\text{TDIC}}$, possibly via calcite dissolution and incongruent dissolution of carbonate minerals under closed
489 system conditions driven by evaporitic minerals dissolution; (ii) high Cl^- concentration positively correlated
490 with $[\text{Sr}^{2+}]$ and presumably of evaporitic origin; (iii) high $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the Cl-rich waters at the Lez
491 spring, suggesting a Triassic signature, and (iv) high Sr/Ca ratio, which can be explained by calcite
492 recrystallization involving a continuous addition of Sr^{2+} induced by Ca^{2+} depletion in water solution.

493 A simple 2-end member hydrograph separation was used to determine the relative proportions of the
494 deep water compartment and the main aquifer to the Lez spring over the study period, using EC as tracer.

495 The deep compartment end-member was characterized by an EC value of 1,840 $\mu\text{S}/\text{cm}$, corresponding to that
496 of the Bajocian underlying aquifer, measured in a 1200 m deep borehole in the city of Montpellier. The mean
497 contribution to the Lez outflow was estimated to be 92.6% for the main aquifer compartment and 7.4% for
498 the deep compartment. This analysis showed that the deep waters end-member as defined may result from a
499 mixing between water circulating in Inf. Jurassic layer and a deep flux which seems to rise through faults
500 from deeper Triassic levels, constituting an intermediate compartment prone to react through piston-flow
501 mechanism to a strong recharge.

502 This approach combining hydrodynamics, hydrochemistry and isotope tracers on a continuous 2-year
503 record appears to be a very efficient tool for characterizing groundwater flow on karst systems, and is
504 potentially applicable to other complex karst systems with deep karstification. This work was efficient on
505 shedding some light on the Lez system behaviour which is an intrinsically complex Vauclusian karst system.
506 Differently from ordinary karst systems, long residence-times and deep water rising seem to be associated
507 with this aquifer; such information being invaluable to the exploitation management of the Lez spring. The
508 core of such a complexity is related to a multiplicity of compartments and lithologies that confer different
509 chemical properties to the groundwaters.

510 Finally, the use of isotopes allowed refining the interpretation of the hydrochemical dataset, furnishing
511 details about the chemical evolution of waters. This combination of methods seems to be efficient for
512 characterizing groundwater flow on karst systems and is potentially applicable to other complex systems
513 with deep karstification.

514

515 **6 - Acknowledgments**

516

517 This work was performed within the framework of the MEDYCYSS observation site, part of the
518 KARST observatory network (www.sokarst.org) initiative from the INSU/CNRS, which aims to strengthen
519 knowledge-sharing and promote cross-disciplinary research on karst systems. It was financed by a PhD
520 scholarship from *CNPq*, National Council of Technological and Scientific Development, of the Science and
521 Technology Ministry of Brazil. Analyses and samplings were financed by HydroSciences Montpellier, IFR
522 ILEE, Montpellier town Council and OSU OREME. Special thanks to the technical staff of AETE analytical
523 platform and the Hydrogeology Laboratory of Avignon, for the analytical work support.

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734 **Fig. Captions**

- 735 Fig. 1 – Hydrogeological map of the Lez karst system indicating sampled springs, wells, raingauges and
736 cross-section locations (Caetano Bicalho, Batiot-Guilhe, Seidel, Van Exter and Jourde, 2012).
737 Fig. 2 – NW-SE Interpretative cross-section over the study area (Caetano Bicalho, Batiot-Guilhe, Seidel,
738 Van Exter and Jourde, 2012).
739 Fig. 3 – Top: $\delta^2\text{H}$ (Deuterium) vs. $\delta^{18}\text{O}$ (‰) for the Lez system spring waters (Lez, Lirou, Fleurettes and
740 Restinclières) and rainwater samples from the 3 raingauges (Saint Gély du Fesc, Viols le Fort and
741 Sauteyrargues). Bottom: zoom showing spring water data in detail.
742 Fig. 4 – Rainfall (Montpellier, Viols le Fort and Sauteyrargues stations); E.C., $\delta^{18}\text{O}$ (‰); zoomed $\delta^{18}\text{O}$ (‰)
743 and deuterium-excess for the Lez system springs (Lez, Lirou, Fleurettes and Restinclières).
744 Fig. 5 – Rainfall, E.C., water discharge and $\delta^{13}\text{C}_{\text{TDIC}}$ at the Lez spring (Sept.2008-March 2010).
745 Fig. 6 – Mg/Ca and Sr/Ca vs. $\delta^{13}\text{C}_{\text{TDIC}}$ for Lez karst system springs and wells, and for springs and wells
746 belonging to the surrounding karst systems.
747 Fig. 7– $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs $1/[\text{Sr}]$ and $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs $[\text{Cl}^-]$ for the Lez karst system springs and wells, and for
748 springs and wells belonging to the surrounding karst systems. $^{87}\text{Sr}/^{86}\text{Sr}$ ratio typical ranges are indicated for
749 Triassic, Jurassic and Late Cretaceous (Koepnick, Denison, Burke, Hetherington and Dahl, 1990) and granite
750 and fresh waters (Kloppmann, Négrel, Casanova, Klinge, Schelkes and Guerrot, 2001).
751 Fig. 8 – Two end-member hydrograph separation from 2008 to 2010, using EC as tracer. The end-members
752 are “Main aquifer compartment” with EC= 650 $\mu\text{S}/\text{cm}$, and “Deep aquifer compartment”, with EC=
753 1,840 $\mu\text{S}/\text{cm}$.
754 Fig. 9 – Conceptual model for groundwater circulation through the Lez karst system.

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756 **Table Captions**

757

- 758 **Table 1**– T, EC , pH, major and trace element concentrations and isotopic ratios for the Lez spring.
759 **Table 2** – T, EC , pH, major and trace element concentrations and isotopic ratios for Lirou, Restinclières, and Fleurettes
760 springs and other sampling points.
761 **Table 3** – Average values and range of variations for T, EC, pH, major and trace element concentrations and isotopic
762 ratios for the springs: Lez, Lirou, Restinclières and Fleurettes.
763 **Table 4** – Water stable isotope range for the sampled springs and raingauges and water stable isotope weighted average
764 for rainwater.

765

Table 1 – T, EC, pH, major and trace element concentrations and isotopic ratios for the Lez spring.

Sampling date	Lez spring	T°C	CE	pH	HCO ₃ ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	toc	Li ⁺	Br ⁻	B ³⁺	Sr ²⁺	Ba ²⁺	δ ² H	δ ¹⁸ O	δ ¹³ C	⁸⁷ Sr/ ⁸⁶ Sr
		(°C)	(µS.cm)		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(‰ V-SMOW)	(‰ V-SMOW)	
13/06/08	1		773		379.2	50.5	5.6	32.4	143.2	7.7	25.1	1.1	1.2	3.4			18.8	442.4	13.1	-30.4	-5.1	
15/06/08	2		763		375.5	48.3	6.5	30.9	140.1	7.4	24.2	1.1	3.9	3.2			17.7	419.9	12.6	-30.0	-5.7	
07/07/08	3	16.1	747	7.16	372.0	49.2	4.6	29.7	127.4	8.3	26.2	1.3	1.0							-31.7	-5.7	
21/07/08	4	16.4	746	7.05	354.3	50.7	4.7	28.1	132.8	8.2	28.4	1.4	1.1	4.0			426.5	16.9		-32.4	-5.6	
05/08/08	5	16.7	763	7.15	368.1	56.0	5.5	29.1	125.7	9.7	33.6	1.7	1.2	4.2			388.9	17.7		-32.7	-5.7	
26/08/08	6	16.9	756	7.19	361.3	56.3	4.8	27.8	123.9	10.1	34.2	1.7	0.4	4.1			373.9	18.5		-31.1	-5.2	
10/09/08	7	17.2	761	7.14	365.1	56.9	5.0	26.7	128.3	10.1	36.2	1.9	0.6	4.1			369.1	19.0		-34.3	-6.0	-12.7
22/09/08	8	17.2	753	6.97	365.7	53.2	6.1	26.3	121.1	9.0	30.6	1.2	0.4	3.9			358.9	18.7		-34.4	-5.9	-12.4
07/10/08	9	17.3	762	7.05	368.8	55.8	6.7	26.1	120.2	9.3	32.0	1.3	0.3	4.2		6.2	356.4	18.9		-34.0	-5.9	
13/10/08	10	17.3	763	7.14	365.1	63.3	6.6	26.7	116.5	9.2	33.3	1.3	0.6	4.1		5.9	352.6	18.3		-34.3	-5.9	
21/10/08 N°1	11	16.6	704	7.26	339.0	43.0	4.8	22.9	120.5	6.9	24.2	1.2	2.2	3.2	109.1	13.7	320.5	15.5		-31.5	-5.6	
21/10/08 N°2	12	16.7	643	7.24	283.0	37.3	5.5	20.9	105.9	5.9	21.3	1.0	3.6	3.1	107.2	12.8	326.4	13.9		-31.1	-5.6	
21/10/08 N°3	13	17	748	7.14	358.7	50.0	4.3	23.7	114.8	8.0	29.4	1.3	5.3	3.8	117.6	14.7	346.3	17.3		-34.1	-5.8	
21/10/08 N°4	14	17	748	7.11	339.2	49.8	3.5	23.8	115.3	8.1	29.4	1.2	4.4	3.8	121.4	14.5	347.3	17.5		-27.1	-3.2	
22/10/08 N°1	15	16.6	682	7.10	344.0	36.7	6.2	22.2	111.7	6.2	20.9	1.2	2.9	0.2	112.5	<LD	62.1	6.7		-31.6	-5.5	
22/10/08 N°2	16	16.7	681	6.89	348.9	35.7	6.8	21.1	113.4	6.4	20.6	1.2	2.7	3.0	109.2	17.3	324.5	16.3		-31.4	-5.6	-13.3
23/10/08 N°1	17	16.9	855	6.94	336.7	80.0	5.3	37.3	112.2	11.0	49.7	2.2	2.2	6.5	136.9	19.1	543.6	22.1		-31.9	-5.5	-12.2
23/10/08 N°2	18	16.9	859	7.08	339.2	80.1	5.0	37.2	112.9	11.0	50.2	2.2	2.0	6.3	134.2	18.7	540.9	22.4		-31.1	-5.5	-12.0
24/10/2008 N°1	19	16.7	739	7.01	352.6	46.2	5.7	28.9	113.4	8.9	26.7	1.4	1.7	4.6	117.6	16.6	537.6	19.8		-31.1	-5.6	-13.1
24/10/2008 N°2	20	16.5	707	6.93	348.9	36.6	6.1	26.5	115.8	8.1	20.3	1.2	1.6	4.1	112.3	15.1	519.2	18.7		-31.1	-5.5	
22/10/08	21		753		351.4	51.4	3.7	24.3	115.4	8.3	30.5	1.3	2.7	4.0		13.9	327.9	17.7		-33.5	-5.7	
23/10/08	22		847		336.7	78.4	5.3	36.1	110.6	10.9	48.6	2.1	1.3	6.2		18.6	541.1	21.7		-30.6	-5.2	
23/10/08	23		842		339.2	78.4	5.4	36.5	111.1	10.8	48.8	2.2	3.0	6.2	103.6	18.5	541.9	21.2		-31.5	-5.5	
24/10/08	24		741		348.9	47.9	5.8	29.4	114.6	9.0	28.0	1.5	1.6	4.5		17.4	487.7	20.4		-30.9	-5.5	
24/10/08	25		706		341.6	38.5	5.1	27.0	113.7	8.1	21.3	1.5	1.6	4.2		16.6	513.0	19.8		-31.2	-5.2	
24/10/08	26		692		339.2	36.2	6.4	26.3	114.9	7.9	19.4	2.6	2.4	3.9	109.7	17.7	467.6	19.3		-31.5	-5.4	
26/10/08	27	15.9	645	7.02	334.3	26.4	4.7	20.5	113.0	6.3	14.4	0.9	1.8		105.9					-30.6	-5.2	
27/10/08	28	17	656	7.46	341.6	27.2	5.5	21.5	112.8	6.5	15.1	0.9	2.1	2.9	106.1	12.1	430.3	16.6		-29.4	-5.2	
29/10/08	29	15.9	683	7.04	356.2	30.4	6.3	22.8	115.7	6.7	16.9	1.2	1.7	3.3	112.7	15.6	466.5	17.9		-29.5	-5.4	
31/10/08	30	15.9	705	7.00	356.2	34.5	6.8	23.5	118.0	6.6	19.1	1.4	1.6	3.5	113.9	17.1	480.2	17.8		-29.9	-5.4	
03/11/08	31	15.9	699	7.09	339.2	37.3	6.3	24.3	116.9	6.0	20.8	1.5	1.7	3.6	109.6	17.8	462.1	16.7		-28.8	-5.3	
05/11/08	32	15.7	650	7.13	341.6	24.3	6.8	21.1	117.3	5.0	13.3	1.0	2.8	2.8	101.0	14.8	394.4	15.7		-28.4	-5.1	-12.1
07/11/08	33	15.4	644	6.95	351.4	21.3	7.2	20.5	119.9	4.9	11.4	0.9	3.0	2.6	103.0	13.8	394.2	15.1		-27.2	-5.2	-14.7
12/11/08	34	15.5	705	7.07	373.3	35.6	7.0	23.6	122.0	5.8	19.0	1.1	5.6	3.5	107.8	15.1	431.8	15.4		-29.8	-5.3	
14/11/08	35	15.5	722	7.18	393.6	42.6	7.5	26.6	132.6	6.9	23.6	1.3	4.0	3.7	110.1	13.1	464.4	15.9		-29.7	-5.4	

Sampling date	Lez spring	T°C	CE	pH	HCO ₃ ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	toc	Li ⁺	Br ⁻	B ³⁺	Sr ²⁺	Ba ²⁺	δ ² H	δ ¹⁸ O	δ ¹³ C	⁸⁷ Sr/ ⁸⁶ Sr
		(°C)	(μS.cm)		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(‰ V-SMOW)	
18/11/08	36	15.5	721	7.10	362.5	40.0	6.6	26.0	129.0	7.2	22.7	1.2	4.6	3.7	106.9	14.0	460.3	15.3	-28.8	-5.3		
21/11/08	37	15.5	721	7.15	346.0	42.2	6.8	27.3	124.9	6.8	22.7	1.2	1.7	3.9	<LD	13.1	486.8	15.5	-29.8	-5.4		
05/12/08	38	15.8	741	7.35	355.1	45.0	5.0	27.3	127.5	8.0	26.2	1.3	1.2	3.9	115.8	19.4	482.1	16.4	-30.6	-5.6	-14.3	
16/12/08	39	15.1	661	7.23	372.2	28.2	6.3	27.9	124.9	7.2	15.8	1.1	1.1	3.4		19.9	528.0	15.8	-32.1	-5.4		
09/01/09	40	14.9	721	7.20	368.6	41.5	6.9	27.0	130.1	7.2	23.5	1.2	1.0	3.6	110.6	17.3	472.4	14.7	-35.1	-5.7		
28/01/09	41	14.8	689	7.28	361.2	28.9	5.4	27.5	124.6	6.8	16.4	0.9	1.4	3.3	73.1	16.6	502.3	15.3	-35.3	-5.7		
02/02/09	42	14.5	673	7.35	355.1	27.8	5.4	24.6	118.6	5.7	16.1	0.9	1.9	2.9	103.2	15.3	428.9	13.6	-37.6	-6.0		
09/02/09	43	14	599	7.39	361.2	34.2	5.2	23.8	123.3	6.1	19.5	1.0	1.3	3.1	99.6	14.8	420.4	13.5	-39.6	-6.3		
12/03/09	44	15.3	707	7.39	349.0	33.3	4.0	25.1	115.1	8.7	22.5	1.2	0.9	3.8	103.6	15.5	480.4	15.2	-37.7	-6.0		
27/03/09	45	15.5	723	7.11	271.5	43.2	4.1	31.5	130.6	8.6	26.8	1.1	2.2	4.9	112.1	11.5	510.5	15.8	-37.3	-6.0	-13.8	
09/04/09	46	15.4	661	7.24	347.8	32.3	4.6	29.1	113.6	3.8	17.6		1.5	4.3	133.1	10.3	530.7	15.8	-37.4	-5.9		
22/04/09	47	15	710	7.52	355.1	37.1	4.9	27.3	117.3	6.6	22.0	1.0	2.0	4.6	126.0	6.2	517.8	15.0	-38.7	-6.0	-13.9	
06/05/09	48	15.2	706	7.53	355.1	34.2	3.8	26.2	122.7	6.8	21.0	0.8	1.6	4.1		22.5	516.7	15.5	-38.1	-6.0		
13/05/09	49	15.4	708	7.22	355.2	36.6	3.1	25.0	118.0	7.5	25.0	0.8	1.2	3.9		18.5	509.9	16.3	-37.5	-6.1		
25/05/09	50	16	721	7.18	361.2	40.6	3.6	25.5	121.1	7.7	26.1	1.2	1.5	4.1		18.2	499.9	15.4	-37.6	-5.9		
27/05/09	51	15.8	723	7.17	361.2	40.8	3.6	25.4	123.8	7.7	25.0	1.1	0.9	4.1		18.6	489.7	17.9	-37.8	-5.9	-14.0	
03/06/09	52	16	727	7.18	361.4	41.2	3.6	24.3	119.8	7.8	25.1	1.1	0.8	3.9		17.6	446.3	16.4	-37.2	-5.9	-13.9	
04/06/09	53	16	728	7.29	383.8	41.5	3.7	24.2	119.7	7.7	25.3	1.1	0.6	4.0		17.7	454.2	16.4	-37.3	-6.1	-10.1	
09/06/09	54	15.9	725	6.99	366.1	43.7	3.5	24.3	121.4	7.8	26.3	1.6	0.6	3.9		17.6	439.5	16.3	-37.1	-5.9	-13.6	
11/06/09	55	16.1	732	7.15	363.7	45.4	3.7	25.1	121.5	8.0	28.7	1.6	1.5	4.2		18.4	439.4	16.8	-36.8	-5.9	-13.7	
23/06/09	56	16.2	729	7.10	356.8	16.3	5.5	21.9	124.5	9.9	8.9	0.6	0.9	3.7		20.2	414.9	17.3	-36.0	-5.8	-13.9	
16/07/09	57	16.7	761	7.08	378.3	50.0	3.8	23.0	127.2	8.5	31.3	1.7	2.0	4.5	118.0	21.6	382.9	18.0	-35.4	-5.7	-13.2	0.70786
03/08/09	58	17	771		374.6	53.2	4.0	26.0	123.7	9.9	35.0	1.8	0.4	4.3		22.3	396.9	18.9	-35.2	-6.3	-13.4	
25/08/09	59	17.2	787	7.29	369.8	58.0	3.9	25.8	128.4	10.4	37.3	1.9	0.8	3.7		25.4	416.3	20.5	-35.3	-6.1	-13.2	
02/09/09	60	17.2	771	7.34	373.4	57.3	4.2	25.7	123.0	9.0	34.8	1.7	2.2	4.3	170.0	21.3	385.6	19.5	-35.3	-6.1	-13.1	
17/09/09	61	17.2	765	7.04	400.3	52.2	4.1	23.0	127.5	9.9	32.9	1.7	0.5	4.0	<LD	20.5	363.9	19.0			-13.1	
07/10/09	62	17.3	776	6.98	278.2	57.0	3.5	23.7	118.6	9.1	33.7	1.4	1.4	4.1		21.4	403.0	19.3	-35.1	-6.1		
22/10/09	63	17.2	749	7.00	361.2	52.7	3.5	23.1	115.5	8.9	31.2	1.4	0.4	4.2	88.9	20.5	367.3	19.5	-35.7	-6.3	-13.6	
24/10/09	64	15	811	7.15	341.7	74.5	4.9	32.5	111.4	10.8	44.5	2.1	<LD	5.4		25.8	514.0	21.8	-34.9	-6.1		
25/10/09	65	15	844	7.13	342.9	84.7	4.7	36.0	109.8	11.5	49.7	2.3		5.9	118.0	25.5	555.7	22.4	-34.5	-6.1		
26/10/09	66	17	898	6.98	342.9	98.6	4.2	40.4	110.4	12.9	58.9	2.5	1.6	5.0	118.0	25.2	649.1	21.1	-34.7	-6.2	-12.1	0.70792
29/10/09	67	16.5	705	6.97	349.0	40.3	4.1	29.0	111.9	10.1	23.5	1.4		4.2		24.9	585.0	19.5	-35.5	-6.2	-13.2	
05/11/09	68	16.2	698	6.97	346.6	37.4	5.6	24.6	113.4	8.5	22.0	1.6	0.8	7.3		26.6	625.9	23.9	-34.6	-5.9	-13.6	
01/12/09	69	16.8	636	6.90	360.0	56.1	5.5	25.3	116.5	8.4	33.4	1.5							-34.5	-6.0	-13.6	
16/12/09	70	17	639	7.18	363.7	41.8	3.9	18.9	112.7	9.3	33.2	1.6	0.6						-34.9	-6.0	-13.5	
07/01/10	71	15.8	702	7.17	336.8	41.4	8.6	26.4	107.9	7.8	24.3	1.8	1.3	3.7	50.0	22.0	637.6	17.5	-35.1	-5.8	-13.7	
25/01/10	72	15	712	7.24	350.3	42.1	8.3	26.7	123.7	6.0	24.4	1.6	1.3	3.3		18.4	548.8	14.4	-36.1	-6.2	-14.3	

Sampling date	Lez spring	T°C	CE	pH	HCO ₃ ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	toc	Li ⁺	Br ⁻	B ³⁺	Sr ²⁺	Ba ²⁺	δ ² H	δ ¹⁸ O	δ ¹³ C	⁸⁷ Sr/ ⁸⁶ Sr
		(°C)	(μS.cm)		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(‰ V-SMOW)	
11/03/10	73	14.7	629	7.10	339.2	34.0	5.1	28.0	126.1	6.2	20.1	1.2	1.6	3.8		21.3	536.1	14.5	-37.2	-6.4	-14.0	
22/03/10	74	14.9	699	7.09	358.7	36.5	4.5	27.8	122.4	6.5	21.5	1.2	1.1	3.8		20.9	473.7	14.3	-36.7	-6.2		
07/04/10	75	14.9	631	7.20	370.9	33.5	4.6	27.4	126.7	6.9	20.2	1.1	1.4	3.6		20.0	518.6	14.0	-36.3	-6.2		
20/04/10	76	15.3	706	7.03	355.1	40.1	4.0	27.6	125.1	7.3	23.9	1.4	0.9	4.0		18.9	511.8	14.4	-35.8	-6.2		
03/05/10	77	15.4	717	7.01	353.8	39.4	4.9	29.6	127.8	6.7	24.8	1.5	1.3	4.1		25.3	491.7	15.6	-36.2	-5.9		
27/05/10	78	15.5	692	7.23	356.4	35.5	3.5	27.0	121.2	6.5	19.6	1.1	0.9	3.9		20.8	501.6	14.8			-14.0	

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Table 2 – T, EC , pH, major and trace element concentrations and isotopic ratios for Lirou, Restinclières, and Fleurettes springs and other sampling points.

Sampling date	Spring	T°C	CE	pH	HCO ₃ ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	toc	Li ⁺	Br ⁻	B ³⁺	Sr ²⁺	Ba ²⁺	δ ² H	δ ¹⁸ O	δ ¹³ C	⁸⁷ Sr/ ⁸⁶ Sr
		(°C)	(μS.cm)		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(‰ V-SMOW)	
02/06/08	Lirou	14.3	630	7.07	371.1	12.4	1.4	10.1	129.2	1.2	4.8	0.1	1.2	0.3		10.7	74.6	6.1	-28.7	-4.8		
05/06/08	Lirou	14.1	646	7.65	401.5	13.8	1.4	8.7	132.7	0.9	4.8	<LD	1.7	0.3		8.8	64.7	6.6	-30.4	-5.3		
24/06/08	Lirou			7.10	376.9	11.7	2.8	8.4	127.4	1.7	4.8	0.1	1.5						-30.8	-5.3		
21/10/2008 N°1	Lirou	14.8	613	7.07	375.8	11.1	2.7	10.7	111.7	10.3	5.7	0.5	3.2	1.1			138.9	8.8	-34.1	-5.8		
21/10/2008 N°2	Lirou	14.9	624	7.14	370.9	11.4	2.2	12.1	110.7	12.6	6.4	0.6	2.0	1.2	97.0		157.2	9.2	-34.6	-5.9		
23/10/08 N°1	Lirou	14.5	517	7.04	300.1	7.7	2.0	6.0	107.4	0.7	4.3	0.4	2.7	0.2	92.2		64.3	6.2	-23.3	-4.3		
23/10/08 N°2	Lirou	14.4	522	7.00	314.8	8.0	2.4	6.0	107.7	0.7	4.3	0.4	3.9	0.2	88.9		69.1	6.2	-23.3	-4.3	-14.9	
22/10/08	Lirou	14.6	544	7.09	327.0	10.2	4.2	7.2	109.3	1.3	5.0	0.5	4.1	0.4	103.8		79.5	6.1	-26.1	-4.7	-15.0	
24/10/08	Lirou	14.4	543	7.20	339.2	8.4	2.2	6.2	112.8	0.8	4.6	0.4	2.2	0.3	88.1	9.2	66.5	6.8	-24.5	-4.2		
27/10/08	Lirou	14.4	561	7.11	344.0	8.5	2.8	6.4	116.5	0.8	4.5	0.4	6.4	0.3	95.3		68.1	6.9	-24.3	-4.5		
29/10/08	Lirou	14.3	565	7.08	351.4	8.6	3.0	6.4	117.8	0.9	4.5	0.3	3.0	0.3	<LD		71.7	6.6	-24.9	-4.6		
03/11/08	Lirou	14.3	552	7.30	339.2	9.0	1.8	6.5	116.1	0.7	4.5	0.3	1.5	0.2	96.7		69.6	6.4	-25.1	-4.4		
05/11/08	Lirou	14.3	590	7.15	363.6	10.7	1.7	7.5	124.7	0.9	5.0	0.2	2.8	0.2	94.0		73.8	6.2	-26.1	-4.7		
07/11/08	Lirou	14.1	618	7.04	378.2	11.4	1.5	7.5	131.0	0.8	5.3	0.2	12.0	3.1	99.5	17.1	364.2	17.1	-28.2	-4.9	-13.5	0.70786
12/11/08	Lirou	14.2	622	7.11	388.0	10.9	1.6	7.7	131.3	1.3	5.2	0.2	8.5	0.3	<LD		65.9	7.4	-29.5	-5.1		
14/11/08	Lirou	14	631	7.18	388.1	11.7	2.0	9.0	131.8	1.7	5.3	0.2	2.5		101.4				-29.7	-5.0		
18/11/08	Lirou	14.2	619	7.12	369.8	11.4	1.8	8.2	136.6	2.4	5.4	0.2	1.5		96.9				-29.3	-5.2		
21/11/08	Lirou	14.2	631	7.14	375.3	11.1	2.1	8.7	132.1	2.4	5.3	0.1	0.9						-29.8	-5.1	-16.2	
09/01/09	Lirou	14.1	617	7.15	392.4	10.8	2.2	9.3	135.2	3.2	5.4	0.3	0.5	0.4	99.7	7.0	65.8	7.0	-35.5	-5.9	-15.8	
16/01/09	Lirou		590	7.20	387.5	10.4	1.9	8.3	133.1	3.6	5.3	0.2	0.4	0.3	104.9	6.9	61.6	6.8	-35.3	-5.8		
28/01/09	Lirou	14	593	7.30	367.3	8.9	1.8	7.6	126.0	1.5	5.2	0.2	1.3	0.2	88.6	6.6	64.2	6.5	-34.7	-6.2		
02/02/09	Lirou	13.3	522	7.83	324.6	7.5	1.1	7.0	106.4	0.9	4.5	0.2	2.1	0.2	80.3	7.2	60.1	6.0	-40.3	-6.9		
09/02/09	Lirou	14	599	7.39	374.4	8.9	1.1	6.0	128.7	1.8	5.1	<LD	1.8	0.3	88.6	5.9	50.6	6.6	-38.1	-6.5		
09/04/09	Lirou	15	556	6.99	349.0	9.3	3.5	8.1	111.6	<LD	4.7	<LD	1.6	0.5	100.4	0.4	83.7	7.1			-15.8	
13/05/09	Lirou	14.3	593	7.11	373.4	8.7	1.3	8.2	121.7	3.8	5.1	<LD	1.0	0.4		9.7	79.1	7.1			-15.9	

Sampling date	Spring	T°C	CE	pH	HCO ₃ ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	toc	Li ⁺	Br ⁻	B ³⁺	Sr ²⁺	Ba ²⁺	δ ² H	δ ¹⁸ O	δ ¹³ C	⁸⁷ Sr/ ⁸⁶ Sr
		(°C)	(μS.cm)		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(‰ V-SMOW)	
05/03/10	Lirou	15	517	7.29	358.7	9.0	0.9	8.0	113.0	2.9	5.0	0.4	0.8	0.5		10.2	81.0	7.1	-37.4	-6.6		
07/04/10	Lirou	14.1	544	7.10	374.5	9.8	1.3	8.6	131.2	2.6	5.2	0.3	1.1	0.4		9.1	74.2	6.5	-37.9	-6.6		
03/05/10	Lirou	14.4	627	6.95	388.0	9.0	1.8	12.7	135.0	5.5	5.5	0.3	1.3	0.8		12.4	118.0	6.9	-35.5	-5.6		
27/05/10	Lirou	14.5	600	7.15	375.9	9.2	1.7	8.3	127.1	2.7	5.0	0.3	0.5	0.4		10.0	82.7	6.9			-15.9	
12/11/08	Restinclières	17.6	669	6.61	395.3	13.3	7.3	16.7	130.1	5.2	6.0	0.3	5.2	2.4		15.3	406.4	25.6	-29.8	-5.2	-14.6	
14/11/08	Restinclières	17.1	674	7.05	375.8	14.9	7.8	19.1	131.6	5.8	6.8	0.4	4.8	2.5	101.5	15.8	398.8	26.6	-31.4	-5.1		0.70756
18/11/08	Restinclières	17.2	669	7.06	382.6	16.6	8.4	21.6	139.7	6.6	7.9	0.5	5.9	2.5	109.9	16.1	400.0	27.7	-31.1	-5.2		
21/11/08	Restinclières	16.7	655	7.17	360.6	17.9	8.6	22.4	129.5	6.8	8.8	0.6	1.3	2.4	110.4	15.3	348.6	21.1	-30.3	-5.3		
05/12/08	Restinclières	16.6	634	7.17	362.5	16.5	6.9	19.9	121.8	6.5	8.3	0.5	2.3	2.2	114.4	14.0	306.4	19.0	-30.0	-5.2	-13.8	
16/12/08	Restinclières	17.6	719	7.20	430.2	27.7	9.4	27.7	133.9	8.5	14.7	1.0	1.2	3.2	<LD	21.4	429.2	24.7	-32.2	-5.1		
09/01/09	Restinclières	17.1	670	6.92	416.2	14.3	8.1	19.7	137.1	6.5	7.1	0.4	1.1	2.5	<LD	17.0	415.7	26.3	-33.2	-5.6		
16/01/09	Restinclières	16.5	673	7.09	393.0	15.4	8.1	21.8	139.5	6.6	7.6	0.4	0.9	2.4	<LD	16.1	386.8	25.2	-34.0	-5.9		
28/01/09	Restinclières	15.9	611	7.29	336.8	16.3	6.8	21.3	128.5	7.0	8.4	0.4		2.2	<LD	14.1	313.7	19.3	-33.5	-5.9		
02/02/09	Restinclières	16.8	675	7.07	397.9	12.5	6.8	17.7	132.3	5.4	6.5	0.3	1.7	2.1	<LD	13.4	357.2	23.1	-35.9	-6.1	-15.0	
09/02/09	Restinclières	16.2	673	7.22	397.9	12.4	5.1	18.3	132.7	4.9	6.5	0.2	1.7	2.0	106.2	13.1	355.0	26.4	-35.8	-6.1		
26/02/09	Restinclières	16.5	669	7.11	391.8	13.1	6.1	19.9	136.0	5.6	6.7	0.3	1.2	2.2	103.8	13.9	352.7	24.2	-38.2	-6.5		
12/03/09	Restinclières	16.5	649	7.38	361.2	15.8	8.5	22.9	125.3	6.6	8.3	0.4	1.2	2.4	<LD	14.8	317.3	23.1				
27/03/09	Restinclières	17	706	7.38	373.4	21.9	7.0	25.2	138.2	9.3	12.4	1.0	1.8	2.7	116.0	18.3	389.5	24.6	-35.8	-6.1		
09/04/09	Restinclières	17.5	706	7.07	373.4	29.0	5.8	25.9	133.2	5.5	9.2	1.1	1.6	4.7	116.1	13.8	517.8	27.5	-35.5	-6.2		
22/04/09	Restinclières	17.1	620	7.01	367.3	15.0	5.8	22.7	116.0	3.9	7.4	<LD	1.6	3.3	<LD	6.3	400.2	22.9	-36.1	-6.1		
06/05/09	Restinclières	16.7	658	7.42	373.4	14.0	5.8	22.5	122.7	5.9	7.2	0.3	2.1	3.2	360.5	2.4	413.6	25.1	-36.9	-6.2	-13.8	
13/05/09	Restinclières	16.5	614	7.54	355.1	14.9	4.3	19.8	118.0	6.2	7.4	0.2	2.0	2.5		18.9	343.4	20.2	-36.4	-6.2		
25/05/09	Restinclières	17.2	637	7.12	361.2	13.8	5.7	20.8	120.1	7.4	8.2	0.1	1.2	2.8		17.9	367.0	22.5	-36.5	-6.1		
27/05/09	Restinclières	17.5	702	7.14	379.5	26.8	5.3	24.5	123.2	8.6	15.7	0.8	0.9	3.8		18.7	471.4	25.3	-36.0	-5.8		
03/06/09	Restinclières	17.5	697	7.12	379.5	26.9	5.2	24.4	123.1	8.4	15.7	0.8	0.9	3.7		18.4	469.3	25.5	-36.2	-6.1		
09/06/09	Restinclières	18	704	7.16	378.2	27.8	5.3	25.5	124.5	9.0	16.2	0.8	0.9	3.9		18.2	479.4	27.5	-36.1	-6.2		
23/06/09	Restinclières	18.3	693	6.92	391.1	21.9	5.9	25.5	127.2	9.1	12.6	0.6	0.8	3.8		19.4	493.9	31.7	-36.3	-6.1	-13.7	
25/01/10	Restinclières	18.6	706	7.06	375.7	16.5	5.6	22.1	125.8	10.0	9.0	0.6	0.8	3.2		18.4	433.8	33.5	-35.0	-5.8	-13.3	
08/02/10	Restinclières	16.4	628	7.26	345.4	16.5	8.2	20.7	124.0	6.1	8.2	0.7	1.1	1.6		13.3	328.5	17.0	-35.8	-6.2		
22/02/10	Restinclières	16.9	681	6.91	390.5	13.3	7.3	19.8	142.4	5.6	7.4	0.5	1.4	1.9		14.9	454.7	21.4				
11/03/10	Restinclières	16.6	656	6.96	386.7								2.1	2.3		16.4	422.3	24.5	-38.0	-6.2		
22/03/10	Restinclières	16.4	594	6.98	367.3	15.2	5.7	23.3	131.3	5.9	7.8	0.6	1.1	2.7		18.8	374.2	23.8	-37.9	-6.2		
07/04/10	Restinclières	16.2	616		352.6	14.9	5.3	21.1	125.8	6.5	8.1	0.6	0.8	2.3		18.2	308.3	19.0	-37.2	-6.0		
20/04/10	Restinclières	16.2	580	7.18	361.1	15.4	5.7	23.7	127.5	6.5	8.2	0.6	1.1	2.5		18.4	360.3	21.0	-36.0	-5.9		
03/05/10	Restinclières	17	665	7.02	360.0	21.1	8.4	27.6	129.2	7.7	11.3	1.0	1.5	3.1		23.9	420.5	24.3	-35.6	-6.0		
20/05/10	Restinclières	17.1	683	6.91	374.5	22.9	6.3	27.8	131.8	8.2	13.2	0.8	1.4	3.7		22.5	464.6	23.8	-35.7	-5.8		
27/05/10	Restinclières	16.6	624	7.00	357.6	15.3	5.1	24.3	134.2	6.9	8.4	0.6	1.4	2.7		19.0	355.5	21.2				

Sampling date	Spring	T°C	CE	pH	HCO ₃ ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	toc	Li ⁺	Br ⁻	B ³⁺	Sr ²⁺	Ba ²⁺	δ ² H	δ ¹⁸ O	δ ¹³ C	⁸⁷ Sr/ ⁸⁶ Sr
		(°C)	(μS.cm)		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)	(‰ V-SMOW)	
05/11/08	Fleurettes	15.5	649	6.98	385.5	11.5	3.4	21.0	132.2	2.3	5.1	0.2	3.3	1.5	89.0	12.7	231.6	10.2	-28.8	-5.0		
07/11/08	Fleurettes	14	677	6.98	405.0	12.4	5.1	20.1	138.1	3.3	5.7	0.3	2.3	1.9	102.4	13.5	302.4	15.7	-30.0	-5.1	-15.2	
09/11/08	Fleurettes	16.3	672	7.04	380.6	13.3	6.9	19.2	134.7	4.4	6.0	0.3	1.9	2.2	103.0	15.2	374.5	24.8	-31.7	-5.2		
12/11/08	Fleurettes	16.6	668	7.08	390.4	13.6	6.1	20.3	132.8	5.0	6.1	0.4	5.1	2.4	104.6	15.8	399.9	32.2	-32.0	-5.3		
14/11/08	Fleurettes	16.6	669	7.00	388.1	14.9	6.1	22.6	143.9	5.8	7.0	0.5	5.6	2.4	102.7	16.0	390.1	33.4	-31.9	-5.2		
18/11/08	Fleurettes	16.4	680	8.55	389.9	14.6	5.7	21.7	140.8	5.9	7.1	0.5	1.5	2.4	109.4	15.8	390.8	33.5	-31.6	-5.3	-14.5	
09/01/09	Fleurettes	16.4	662	7.06	356.4	14.6	6.0	22.5	140.5	5.9	7.2	0.4	1.1	2.4		16.0	397.9	31.4	-34.2	-6.0		
02/02/09	Fleurettes	15	568	7.22	336.8	7.8	2.5	16.8	114.4	1.7	4.9	0.4	2.1	1.1	84.3	12.0	185.1	9.9	-44.0	-7.4		
22/04/09	Fleurettes	16.1	668	7.17	385.7	13.2	4.7	23.3	129.0	5.4	6.7	0.4	1.8	3.0	102.2	1.6	418.9	31.1	-39.3	-6.5	-14.2	
09/02/09	Fleurettes	16	651	7.17	379.5	13.4	4.7	20.8	131.1	5.8	7.1	0.4	1.8	2.3	358.0	14.6	350.0	25.6	-37.0	-6.2		
08/02/10	Fleurettes	16.4	678	6.97	386.9	13.0	7.2	22.9	136.8	3.2	6.3	0.4	1.5	2.3		17.2	419.0	20.6	-36.1	-6.2		
22/02/10	Fleurettes	15.7	646	6.91	378.3								1.7	1.9		15.9	357.3	20.7	-38.4	-6.4		
11/03/10	Fleurettes	15.5	608	6.92	380.6	13.9	5.1	25.0	140.2	5.4	7.2	0.6	1.5	2.5		18.4	351.1	28.0	-37.7	-6.2		
07/04/10	Fleurettes	16.3	628	7.09	402.6	14.8	5.5	24.8	143.7	6.5	7.5	0.5	2.1	2.7		18.9	445.6	32.6	-37.1	-6.0		
03/05/10	Fleurettes	16.8	678	7.00	388.0	14.3	4.8	28.6	141.5	6.9	7.9	0.5	2.2	3.2		20.3	459.0	32.9	-35.7	-5.9		
20/05/10	Fleurettes	16	673	6.99	401.5	12.7	4.9	23.6	150.6	6.1	7.0	0.5	1.7	2.7		17.8	407.8	29.4				
16/07/09	Sauve spring	14.2	518	7.33	286.8	9.0	2.7	36.6	82.9	16.6	6.9	1.7	1.6	2.1	<LD	17.9	244.6	28.8	-34.8	-5.8	-13.9	0.70854
16/07/09	Fontbonne spring	18	629	7.43	366.6	11.3	5.4	16.6	129.4	5.0	5.2	0.2	1.0	1.9	<LD	13.0	277.2	9.1	-35.8	-5.7	-13.2	0.70764
21/07/09	Olivier well	18.6	677	7.84	341.8	17.2	25.9	28.7	107.2	20.3	8.8	1.3	1.3	9.3	154.9	56.5	1998.0	24.0	-35.9	-6.0	-10.9	0.70737
21/07/09	Boinet well	15.7	859	7.08	488.2	25.4	19.2	33.9	149.7	19.5	9.3	0.4	1.8	7.9	192.4	54.0	3266.0	16.0	-32.6	-6.3	-14.3	0.70733
21/07/09	Foux de Lauret	13.8	583	7.51	379.1	5.7	1.0	10.5	119.4	4.0	4.0	0.4	1.3	0.9	83.3	10.8	456.7	7.5	-38.5	-6.0	-15.0	0.70745
21/07/09	Dolgue spring	13.2	708	7.32	426.5	13.9	1.0	26.8	140.4	8.2	5.8	0.2	1.7	3.5	177.0	21.7	862.6	13.5	-35.6	-6.0	-16.0	0.70744
21/07/09	Lavabre spring	14	637	7.38	403.3	8.0		14.3	129.2	6.0	5.0	0.1	1.2	2.2	151.9	18.6	821.0	9.3	-36.8	-5.9	-16.4	0.70742
21/07/09	Lavabre well	18.5	640	7.16	424.0	10.8		19.0	126.1	6.5	6.0	0.7	1.0	2.5	140.0	15.6	666.5	9.4	-35.9	-6.0	-16.3	
31/08/09	Fontanes well	15.3	649	7.01	401.5	10.4	6.7	21.2	133.2	5.4	5.5	0.5	0.6	3.9	160.0	19.6	410.2	10.7	-34.1	-5.8	-13.5	0.70760
31/08/09	Laudou well	14.9	661	6.99	422.3	11.6		11.2	132.2	0.7	4.8	0.9	5.0	1.3	240.0	11.9	327.1	13.0	-36.2	-6.2	-15.8	0.70756
31/08/09	Bois Roziers well	15.8	605	7.07	375.9	10.4	3.5	16.0	128.2	3.1	6.5	0.6	1.0	1.6	150.0	13.8	329.4	9.2	-35.6	-6.0	-14.3	0.70761
02/09/09	Gour Noir well	17.4	664	7.23	407.6	13.0	3.4	14.8	137.5	3.4	7.5	0.8	1.8	2.2	<LD	16.2	296.8	15.3	-35.7	-5.9	-14.7	0.70764

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772**Table 3** – Average values and range of variations for T, EC, pH, major and trace element concentrations and isotopic ratios for the springs: Lez, Lirou, Restinclières and Fleurettes.

Spring	Average and range	T°C	CE	pH	HCO ₃ ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	toc	Li ⁺	Br ⁻	B ³⁺	Sr ²⁺	Ba ²⁺	δ ² H	δ ¹⁸ O	δ ¹³ C
		(°C)	(µS.cm)		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(‰ V-SMOW)
Lez (78 samples)	Average	16.1	725	7.14	353.6	45.3	5.1	26.6	120.1	8.0	26.8	1.4	1.7	4.0	111.0	17.7	454.8	17.1	-33.6	-5.7	-13.3
	Minimum	14.0	599	6.89	271.5	16.3	3.1	18.9	105.9	3.8	8.9	0.6	0.3	0.2	50.0	5.9	62.1	6.7	-39.6	-6.4	-14.7
	Maximum	17.3	898	7.53	400.3	98.6	8.6	40.4	140.1	12.9	58.9	2.6	5.6	7.3	170.0	26.6	649.1	23.9	-27.1	-3.2	-10.1
Lirou (29 samples)	Average	14.3	585	7.17	363.5	10.0	2.0	8.1	122.6	2.5	5.0	0.3	2.6	0.5	95.1	8.7	90.0	7.2	-30.7	-5.3	-15.4
	Minimum	13.3	517	6.95	300.1	7.5	0.9	6.0	106.4	0.7	4.3	0.1	0.4	0.2	80.3	0.4	50.6	6.0	-40.3	-6.9	-16.2
	Maximum	15.0	646	7.83	401.5	13.8	4.2	12.7	136.6	12.6	6.4	0.6	12.0	3.1	104.9	17.1	364.2	17.1	-23.3	-4.2	-13.5
Restinclières (33 samples)	Average	17.0	661	7.1	375.9	17.8	6.6	22.4	129.3	6.8	9.3	0.6	1.7	2.8	137.6	16.2	395.6	24.1	-34.9	-5.9	-14.0
	Minimum	15.9	580	6.6	336.8	12.4	4.3	16.7	116.0	3.9	6.0	0.1	0.8	1.6	101.5	2.4	306.4	17.0	-38.2	-6.5	-15.0
	Maximum	18.6	719	7.5	430.2	29.0	9.4	27.8	142.4	10.0	16.2	1.1	5.9	4.7	360.5	23.9	517.8	33.5	-29.8	-5.1	-13.3
Fleurettes (16 samples)	Average	16.0	655	7.1	383.5	13.2	5.3	22.2	136.7	4.9	6.6	0.4	2.3	2.3	128.4	15.1	367.6	25.8	-35.0	-5.9	-14.7
	Minimum	14.0	568	6.9	336.8	7.8	2.5	16.8	114.4	1.7	4.9	0.2	1.1	1.1	84.3	1.6	185.1	9.9	-44.0	-7.4	-15.2
	Maximum	16.8	680	8.6	405.0	14.9	7.2	28.6	150.6	6.9	7.9	0.6	5.6	3.2	358.0	20.3	459.0	33.5	-28.8	-5.0	-14.2

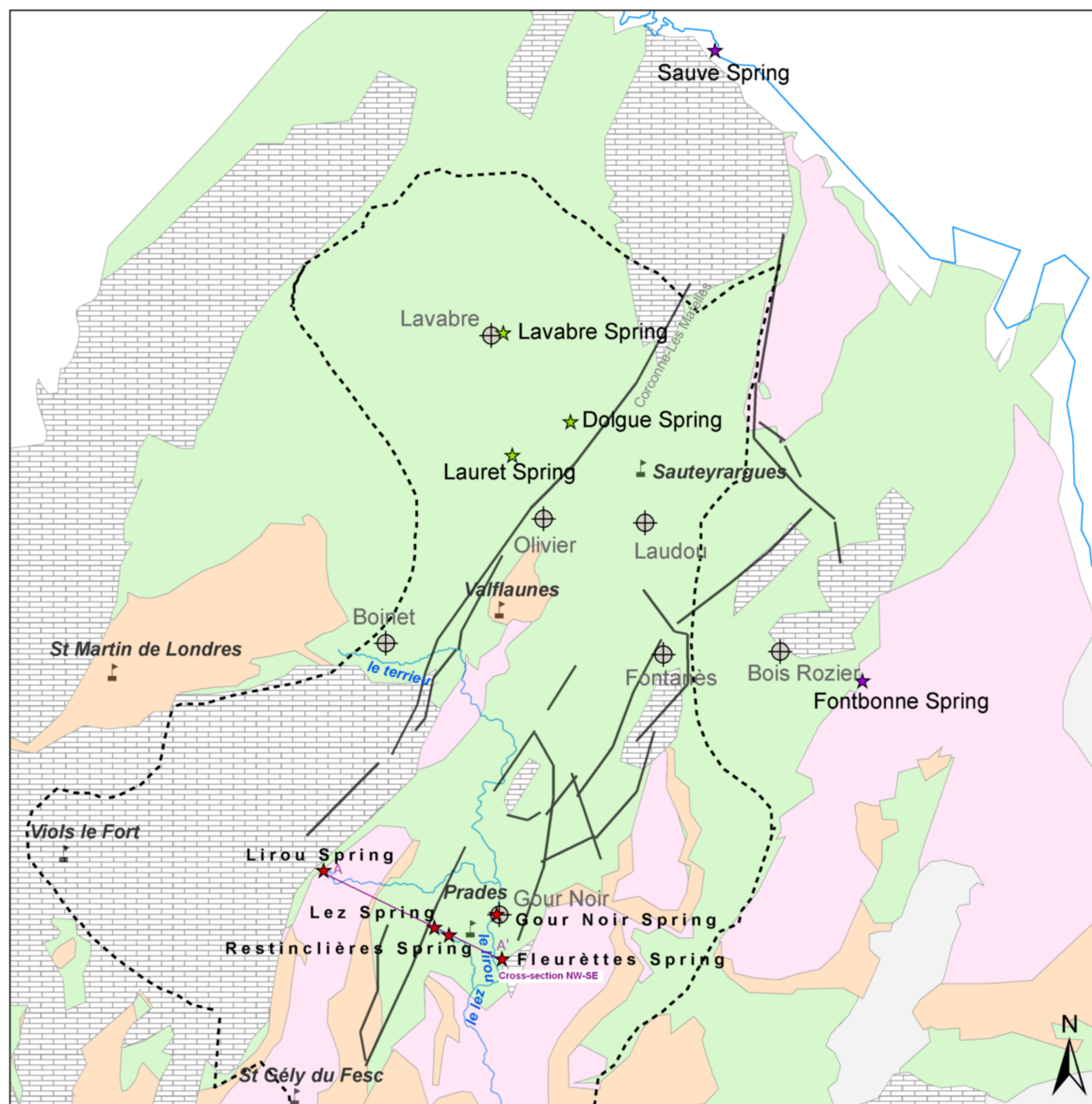
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Table 4 – Water stable isotope range for the sampled springs and raingauges and water stable isotope weighted average for rainwater.

Springs / raingauges	$\delta^{18}\text{O}$ range (‰ VSMOW)	$\delta^2\text{H}$ range (‰ VSMOW)	$\delta^{18}\text{O}$ (‰ VSMOW) Rainwater weighted average	$\delta^2\text{H}$ (‰ VSMOW) Rainwater weighted average
Lez spring	-6.38 to -4.94	-39.6 to -30.1		
Lirou spring	-6.92 to -4.21	-40.3 to -23.3		
Restinclières spring	-6.47 to -5.13	-38.2 to -29.8		
Fleurettes spring	-7.35 to -5.00	-44.0 to -28.8		
Viols le Fort raingauge (06/09 to 05/10)	-12.27 to -2.88	-53.6 to -14.2	-4.93	-28.3
Sauteyrargues raingauge (10/09 to 05/10)	-10.59 to -3.44	-63.4 to -14.5	-7.55	-46.7
Montpellier raingauge (monthly means, 06/08 to 05/10)	-9.05 to +0.67	-58.8 to +5.6	-6.76	-41.4

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Lez karst system Springs

- ★ Fleurèttes
- ★ Gour Noir
- ★ Lez Spring
- ★ Lirou
- ★ Restinclières

Valanginian Springs

- ★ Dolgue
- ★ Lauret
- ★ Lavabre

Connexe Systems Springs

- ★ Fontbonne
- ★ Sauve Spring

Geology

- Miocene: Limestones
- Oligocene: Clay and conglomerates
- Eocene: Limestones
- Cretaceous: marls and marly limestones
- Jurassic: Limestones

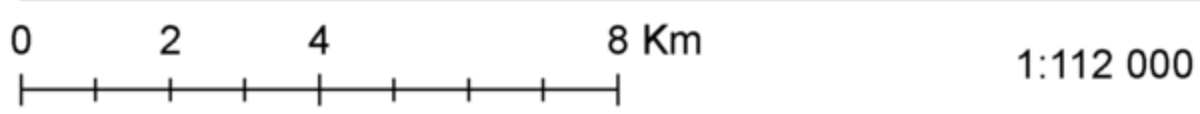
- Cross-Section NW-SE
- Main river and tributaries
- Faults
- - - - Delimitation of the zone in hydraulic connexion with the Lez spring (pumping tests) Thierry and Bérard (1983)

Sampled wells

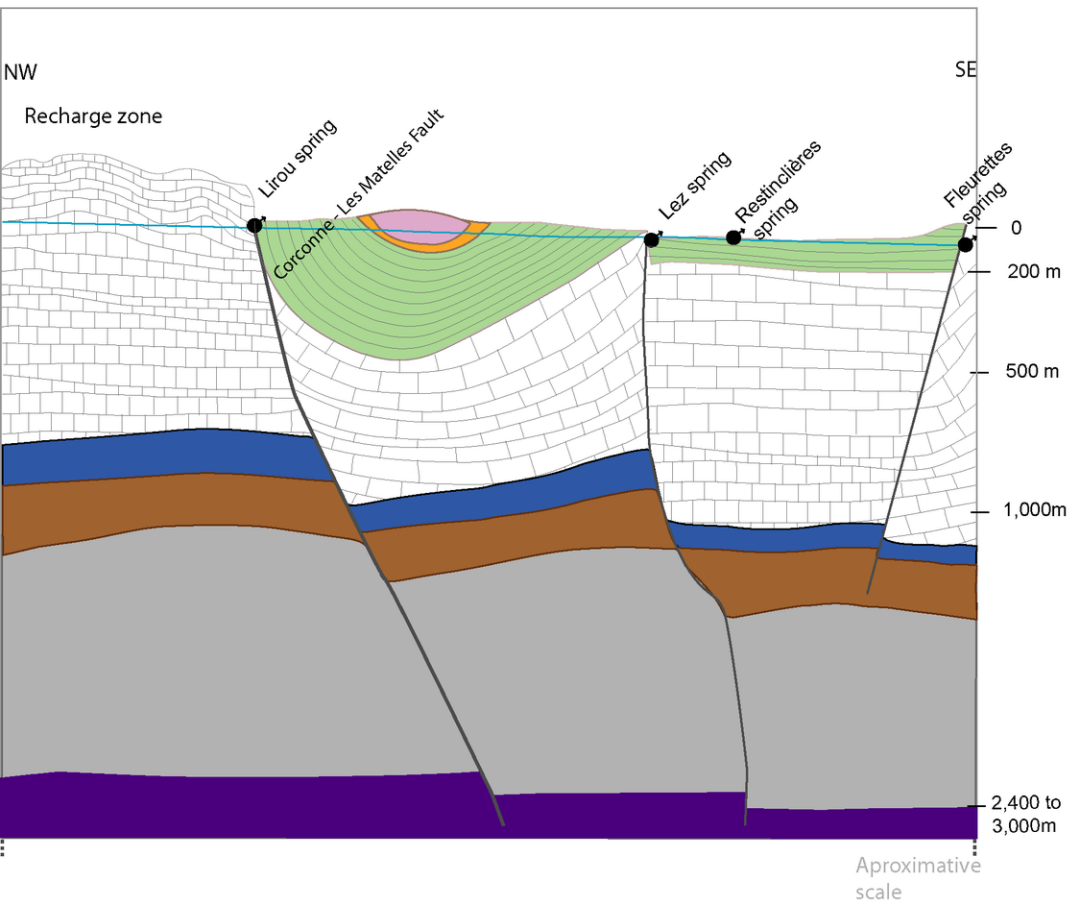
- Boinet
- Bois Rozier
- Fontanès
- Gour Noir
- Laudou
- Lavabre
- Olivier

Rainfall stations









- ▮ Prades
- ▮ St Martin de Londres
- ▮ Valflaunes

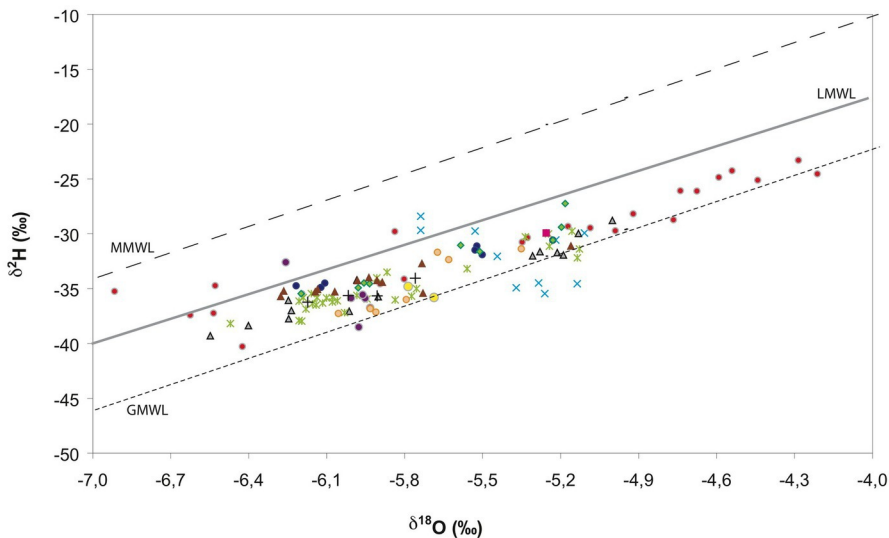
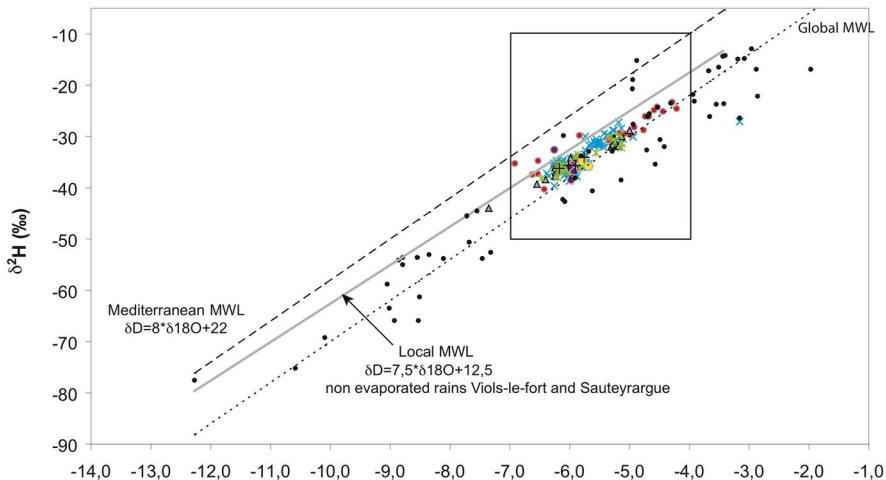


France



Stratigraphy

-  Clay and conglomerates: Oligocene
-  Marls and limestones: Eocene
-  Marls and marly-limestones: aquifer covering Valanginian
-  Limestones: Main aquifer Berriasian (Cretaceous) to Kimmeridgian (Jurassic)
-  Marls and marly-limestones: Oxfordian and Callovian
-  Limestones and dolomites: Bathonian and Bajocian
-  Marls, marly-limestones, limestones and Dolomites: Aalenian to Hettangian
-  Sandstones, clays and evaporites: Triassic



GROUNDWATERS

Lez spring

- Piston Flow waters
- × High waters
- ▲ Low waters
- ◆ Dilution waters
- Dropping waters

Lez system

- ▲ Fleurettes spring
- Lirou spring
- × Restinclières spring
- + Veolia wells

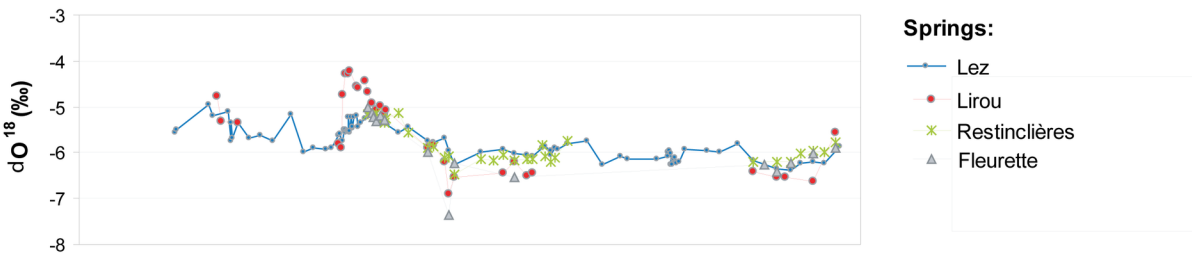
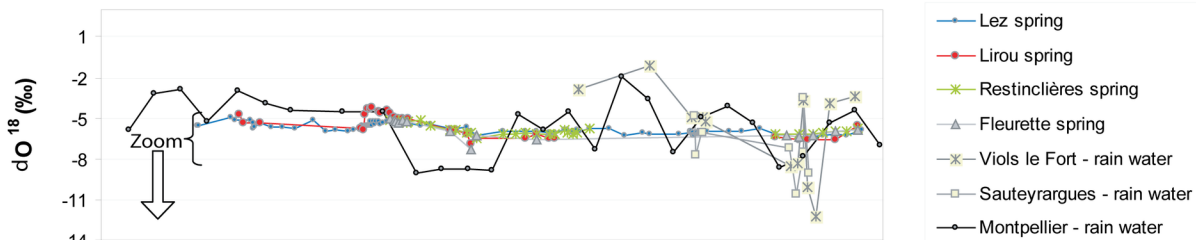
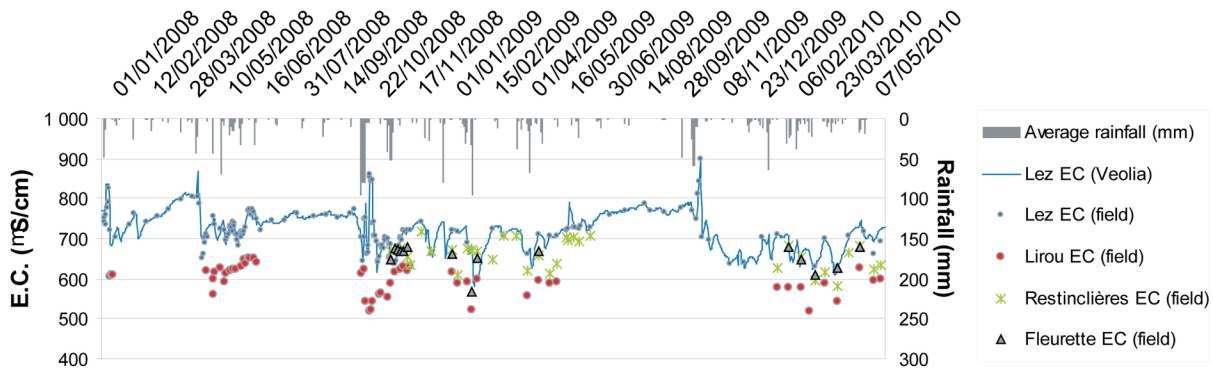
Other connexe systems

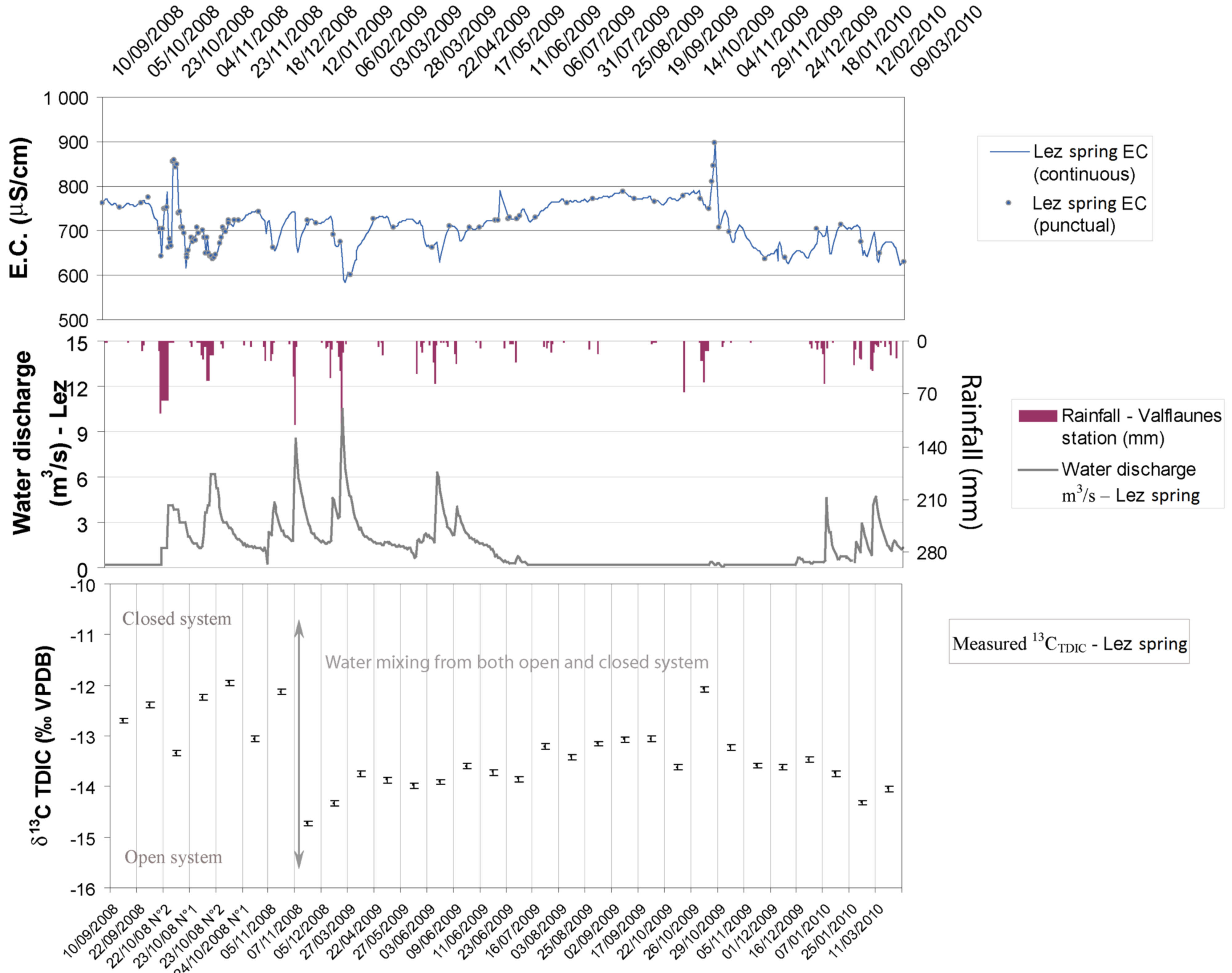
- Surrounding systems
- Valanginian springs and wells

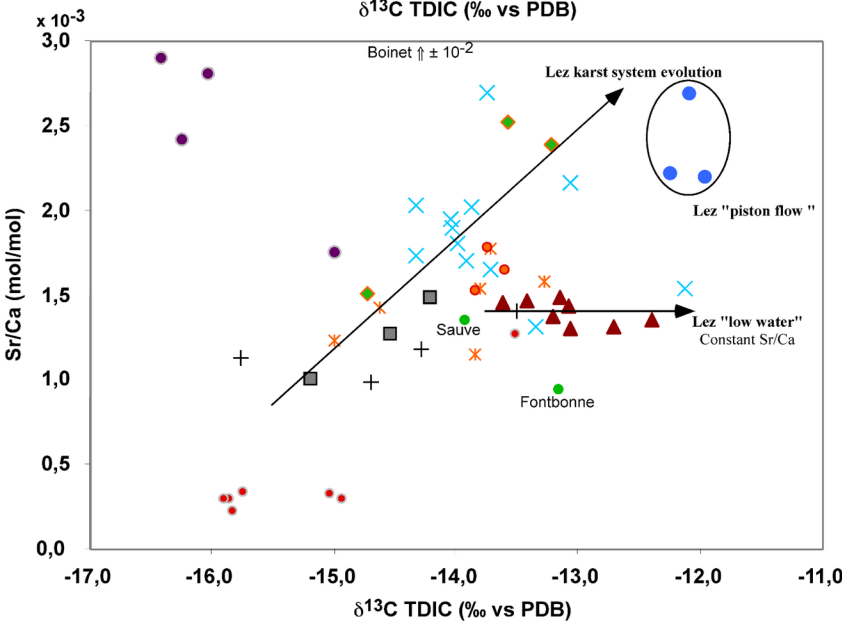
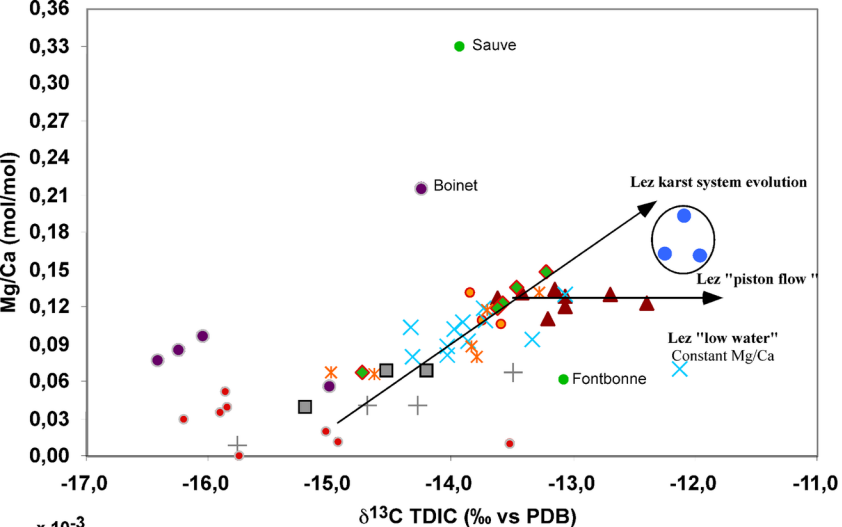
RAINWATERS

(upper panel only)

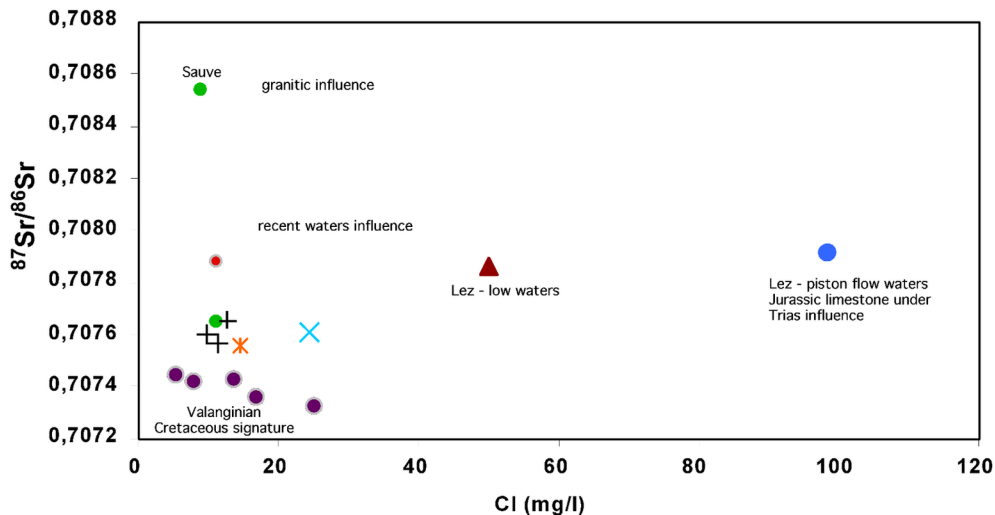
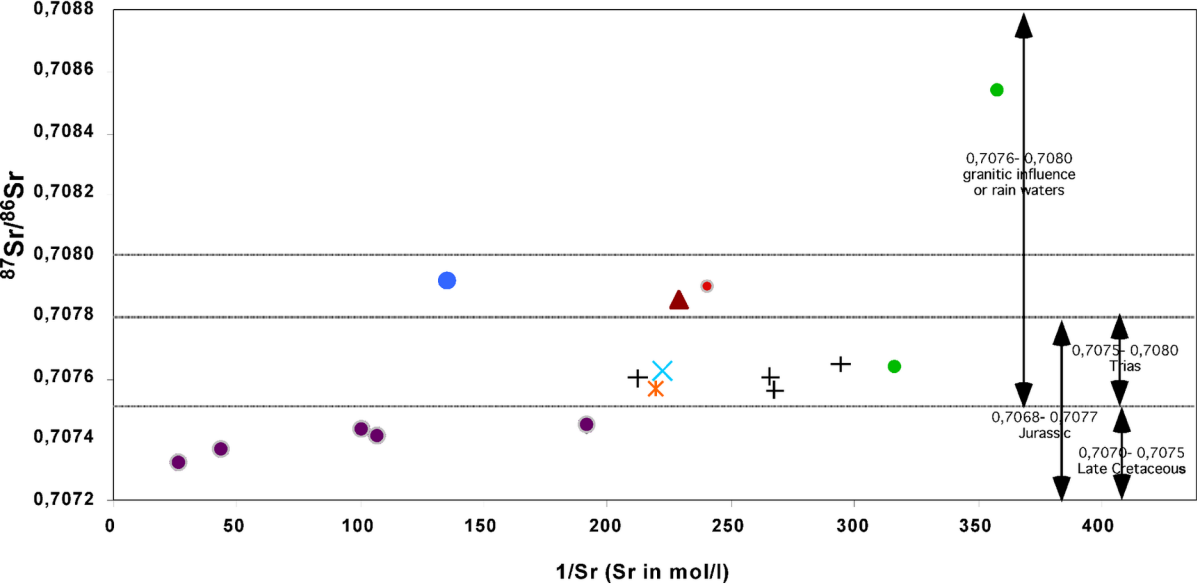
- Viols-le-Fort, Sauteyrgues, Montpellier



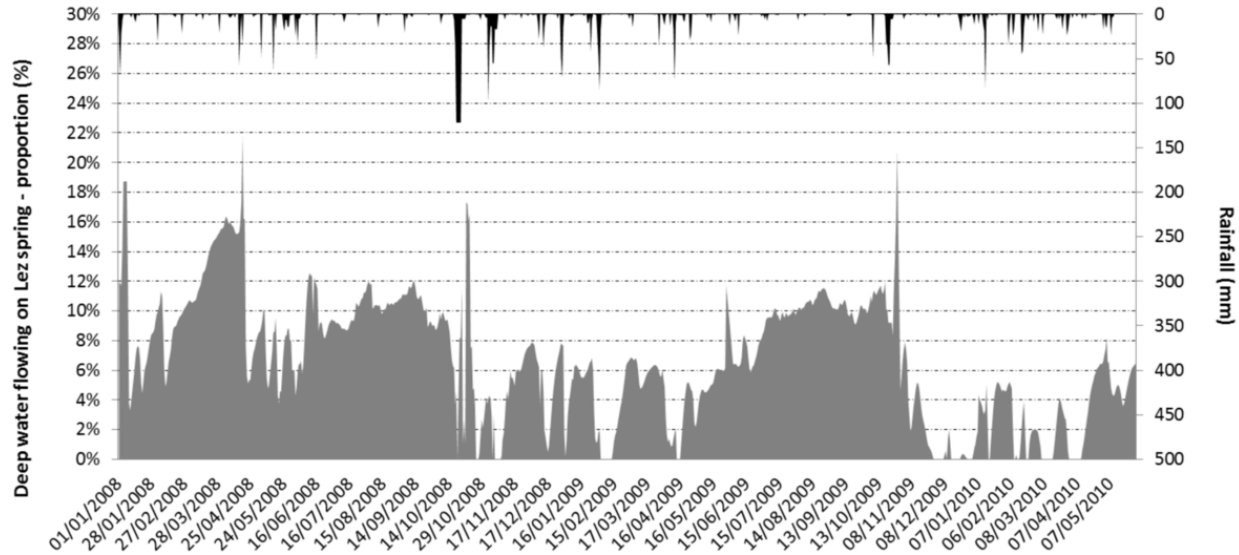




- ▲ Lez - low waters
- ◆ Lez - dilution waters
- Lirou spring
- × Lez - high waters
- + Lez KS wells
- Valanginian
- Lez - piston flow waters
- × Restinclère spring
- Others systems
- Lez - dropping waters
- Fleurette spring



- ▲ Lez - low waters
- × Lez - high waters
- Lez - piston flow waters
- +
 Lez KS wells
- ✱ Restinclière spring
- Lirou spring
- Valanginian
- Others systems



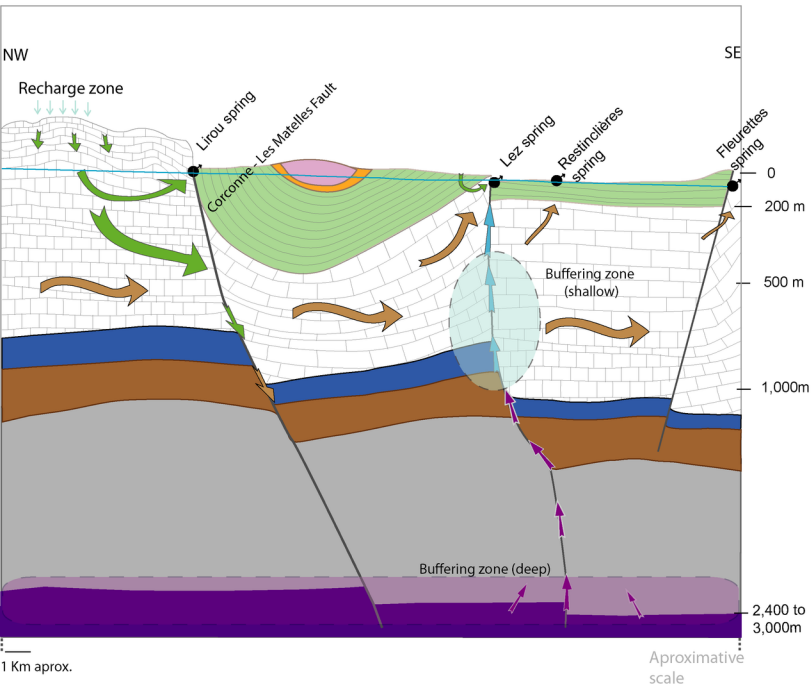
■ Deep aquifer - proportion (%)

■ Rainfall mm (St Martin raingauge)

- Tracer: EC

- End-members:

- Deep aquifer: EC: 1,840.00 μ S
- Main aquifer: EC: 650.00 μ S

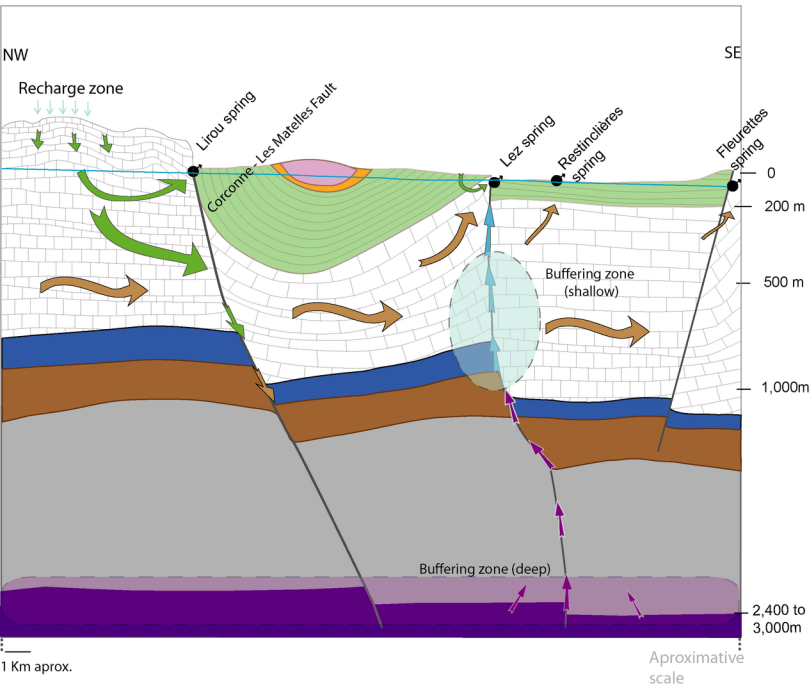


Groundwaters (Predominant mineralization)

- Infiltration (diffuse and punctual)
- Main aquifer
- Deep rising (shallow buffering zone)
- Deep rising (deep buffering zone)

Stratigraphy

- Clay and conglomerates: Oligocene
- Marls and limestones: Eocene
- Marls and marly-limestones: aquifer covering Valanginian
- Limestones: Main aquifer Kimmeridgian (Jurassic) to Berriasian (Cretaceous)
- Marls and marly-limestones: Callovian and Oxfordian
- Limestones and dolomites: Bajocian and Bathonian
- Marls, marly-limestones, limestones and Dolomites: Hettangian to Aalenian
- Sandstones, clays and evaporites: Triassic



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