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Holocene Paleohydrological Changes Reflected in Lake-Level Fluctuations in Lake Annecy (French Pre-Alps): Climatic Significance and Archeological Implications

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Abstract: Lakes are threatened by contemporary climate change and human activities. Paleohydrological records provide important evidence for developing scenarios for future changes in the availability of freshwater resources. This study presents a synthesis of a sedimentological, archeological, and chronological dataset collected from Lake Annecy (eastern France) to reconstruct a lake-level record documenting the whole Holocene. This dataset shows a pronounced minimum in the lake level during the Holocene thermal maximum (HTM) (ca. 9000–7000 cal BP), preceded by a general lowering trend (early Holocene), and followed by a general rising trend (Neoglacial). On both the millennial and centennial scales, the Lake Annecy record appears to match the regional pattern of Holocene lake-level fluctuations established for West-Central Europe. In agreement with other extra-regional paleoclimatic records, it shows the dominant influence of orbital forcing. The high magnitude of the lake-level lowering (more than 5 m) during the HTM, with a 2–2.5 °C difference between the HTM and the pre-industrial mean summer temperatures, suggests possible drastic lake-level lowering phases in the near future depending on the IPCC scenarios following climate change. This would mean dramatic impacts on human activities and the preservation of exceptional archeological remains in regional lake basins.

Keywords: Holocene; French Pre-Alps; hydrological changes; paleoclimates; prehistoric lake dwellings

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1. Introduction

Hydrological changes and the water cycle appear to be crucial issues in the present context of global warming. While lakes represent 87% of the Earth's liquid surface freshwater and cover only 3% of the global land area, recent studies have shown that the amount of water stored in large lakes (i.e., more than 100 km^2) has significantly decreased over the last three decades due to both climatic and human factors [1].

Sediments accumulated in lake basins provide important archives to establish lake-level records that document past changes in the water balance associated with climate variability [2]. As a contribution to such studies, which can draw lessons from the past for the future, this paper presents a reconstruction of lake-level fluctuations in Lake Annecy (northern Pre-Alps, eastern France) that sheds light on the past 11,700 years.

In recent decades, archeological excavations and paleoenvironmental investigations on the shores and the littoral platform of Lake Annecy have revealed many sediment profiles of interest for the reconstruction of past changes in lake levels. This study provides the first preliminary synthesis of sedimentological, archeological, and chronological data collected around the lake basin to reconstruct the Holocene water-level fluctuations in Lake Annecy. Finally, the Annecy lake-level record presented in this study appears to be the first lake-level record established for a large lake in West-Central Europe, documenting the whole Holocene epoch.

2. Site and Methods

2.1. Lake Annecy

Lake Annecy (45°53′ N, 6°08′ E) is one of the largest natural lakes in France. Its current catchment area (ca. 251 km^2) is located in the northern French Pre-Alps (Figure 1) and is dominated by calcareous limestones and marls ranging from Jurassic to Tertiary. There are neither glaciers nor permanent snow in the catchment area, which has an average altitude of around 900 m a.s.l. and culminates at the summit of La Tournette (2351 m a.s.l.).

The surface area of the lake is 26.5 km^2. The lake consists of two sub-basins, the Grand Lac in the north and the Petit Lac in the south (Figure 2). With the exception of the 82 m deep karst depression known as the "Trou du Boubioz", the maximum water depth of the lake is located in the Grand Lac and reaches ca. 65 m.

Geophysical investigations and deep cores in the northern sub-basin have shown that predominantly silty Holocene sediment layers overlie an older alluvial fan composed of coarser deposits. This fan was constructed by the Fier River during the Late Glacial into a large proglacial lake of ca. 70 km^2 with a water level of ca. 460 m a.s.l. and a catchment area of around 440 km^2 [3,4]. Sedimentological studies on the deep core LDA taken in the Grand Lac (Figure 2) suggest that the Fier River disconnected from Lake Annecy in several successive phases between 11,500 and 8200 cal BP, possibly due to the activity of a major regional fault, as hypothesized by Beck et al. [5]. Other deep cores taken in the Grand Lac (*CLIMASILAC* project; Figure 2) [6] and in the Petit Lac [7,8] have made it possible to establish a Late-Glacial and Holocene pollen stratigraphy [9].

The lake is characterized by a nivo–pluvial regime, with low water levels generally occurring in late summer. The current outflow of the lake consists of two main channels, i.e., the Canal de Vassé and the Thiou River (Figure 1). The Thiou River flows into the Fier River about 3 km downstream (Figure 2). It was regulated to improve flood drainage, as the steep slopes of the catchment area led to rapid and sharp variations in the lake's water level. The historical data for the period of 1863–1965 show a minimum lake level of 446.17 m a.s.l. in 1868 and a maximum of 447.92 m a.s.l. in 1944 [10]. Since 1965, the current average water level has been artificially maintained at ca. 446.97 m a.s.l. As of the XIII century, equipment has been installed in the Thiou River (Figure 1) to use its hydraulic energy for textile and metallurgical activities. In the XIX and XX centuries, the variations in the lake level were regulated by the construction of dams and sluices.

The region's climate is subject to both oceanic and continental influences. The mean annual temperature in Annecy is ca. 10 °C. The mean temperature is −1.5 °C in the coldest month and 19 °C in the warmest month. The mean annual precipitation reaches 1245 mm (in the period of 1976–2010).

Deciduous forests with *Alnus*, *Quercus*, and *Corylus* dominate areas below 700 m a.s.l.; they are heavily affected by human activities. The mountain belt (700–1500 m) is dominated by *Fagus* and *Abies* forests. *Picea abies* and *Pinus uncinata* characterize the subalpine forests (1500–2100 m), which are opened up by extensive grasslands due to grazing activities [9].

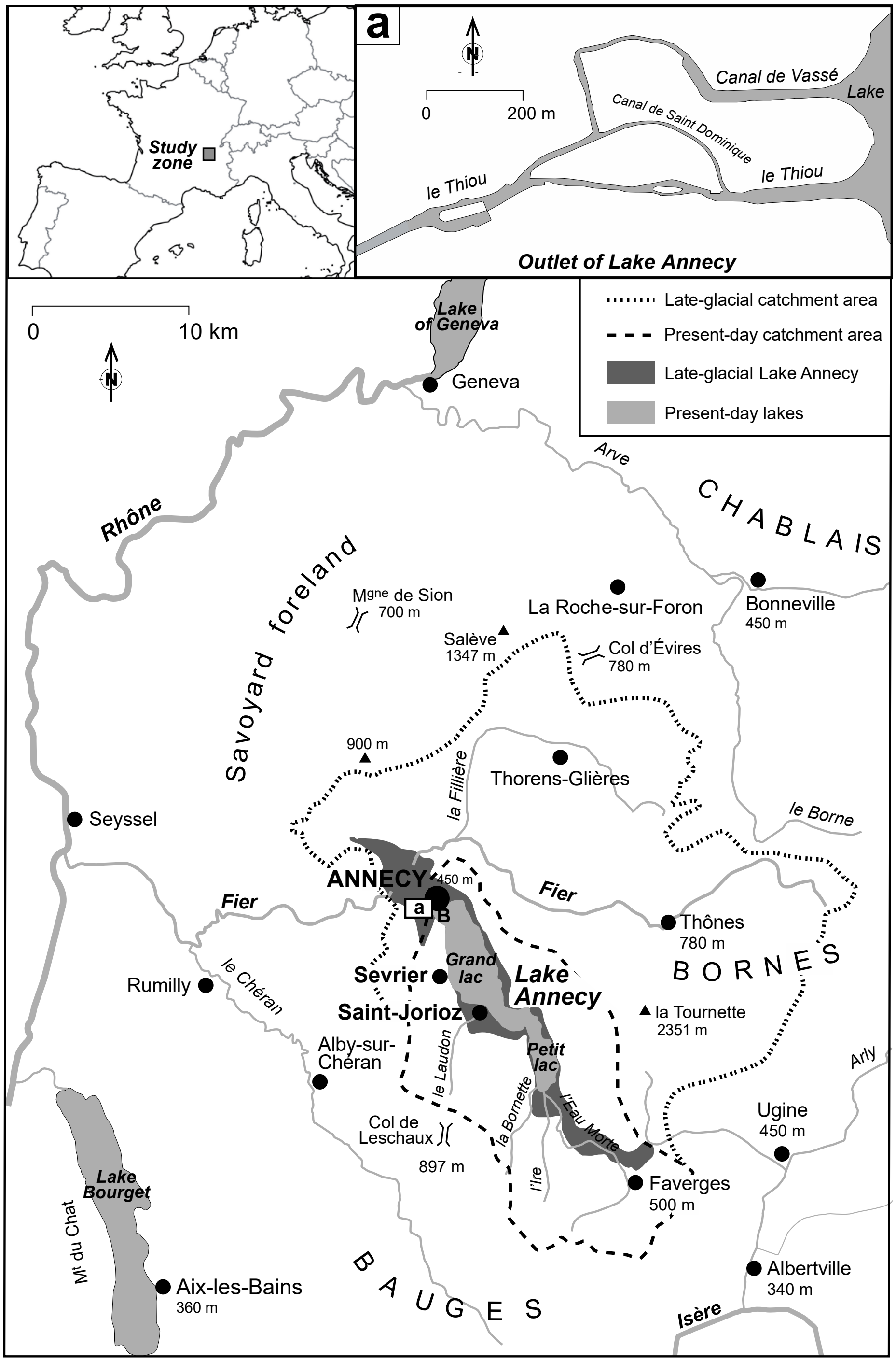

Figure 1. Geographical location of Lake Annecy and its catchment area. a: outlet of Lake Annecy (see insert in the upper part of the figure); B: karstic depression of du Boubioz. Light grey: surface of the Late-Glacial Lake Annecy; dark grey: present-day lakes.

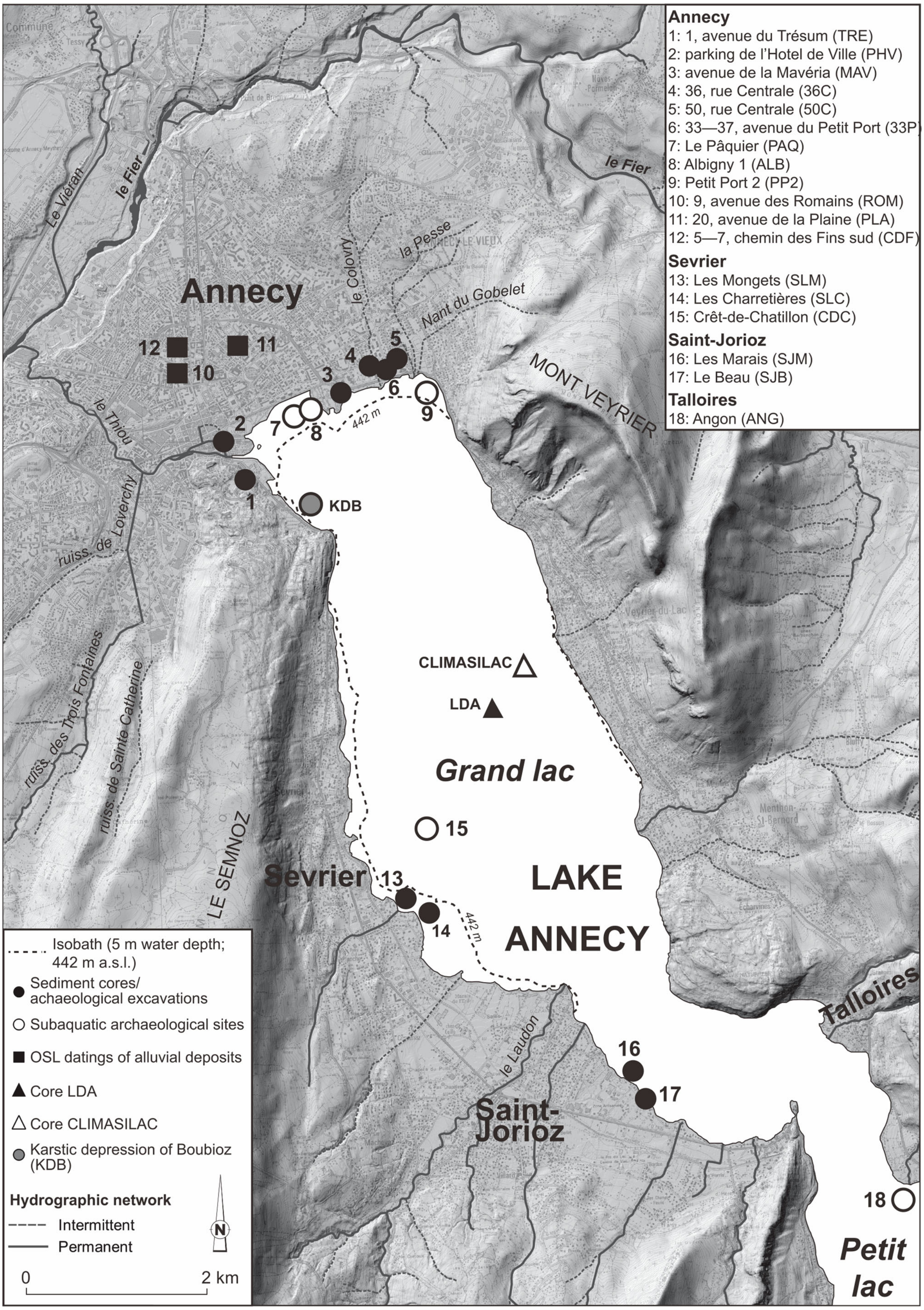

Figure 2. Location of the study sites on the northern and western shores of Lake Annecy. In the lake basin, the dashed line marks the isobath corresponding to 5 m water depth (i.e., 442 m a.s.l.).

2.2. Study Sites

Sediment profiles of interest for the reconstruction of Holocene lake-level fluctuations were evidenced and sampled (i) during archeological excavations on the northern shore of the lake and (ii) using a Russian corer to extract sediment cores from the western littoral platform, where subaquatic archeological investigations have evidenced remains of Neolithic and Bronze Age lake dwellings (Figure 2).

In the northern zone, the study sites are located at Annecy, 1 Avenue du Trésum (TRE), Parking de l'Hôtel de Ville (PHV), Avenue de la Mavéria (MAV), 36 Rue Centrale (36C), 33–37 Avenue du Petit Port (33P), 50 Rue Centrale (50C), 9 Avenue des Romains (ROM), and 20 Avenue de la Plaine (PLA).

On the western lake shore, sediment cores were taken from littoral mires at Saint-Jorioz Le Beau (SJB) and from the littoral platform at the archeological sites of Sevrier Les Charretières (SLC), Sevrier Les Mongets (SLM), and Saint-Jorioz Les Marais (SJM).

The investigations were supported by the CLIMASILAC project [6] and the Paleoenvironment and Archaeology of the Northern Shore of Lake Annecy project [11].

This paper provides a synthesis of previously published paleoenvironmental data originating from the sites listed above [11–15]. Additional data were collected from the archeological sites of Annecy Le Pâquier (PAQ), Albigny 1 (ALB), Petit Port 2 (PP2), Angon (ANG), and Sevrier Crêt de Chatillon (CDC) (Figure 2) [16–24].

2.3. Methods

The shores of the lake basin are characterized by a littoral platform composed of authigenic (bio-induced) carbonate lake marl that accumulates in the shallow littoral water. At a depth of ca. 5 m (i.e., 442 m a.s.l.) (Figure 2), the extremity of the littoral platform is characterized by a steep slope with a rapid increase in the water depth until the depth of 30 m. Past changes in the lake level were reconstructed using a sedimentological method extensively described in former papers [25–27] and based on multiple lines of evidence, as follows:

- Changes in the sediment texture: Coarser deposits correspond to near-shore areas (with shallower water and higher hydrodynamism).
- Changes in the lithology: Organic deposits (detritus gyttja containing terrestrial macrorests from the vegetation of the littoral mires and more or less carbonate silt and peat) often characterize the shallower water or late stages of infillings (shallow residual basins). Carbonate lake marl is found in the deeper water [2,26–29].
- Changes in the assemblages of carbonate concretions: The coarser fraction (>0.2 mm) of the lake marl consists mainly of different morphotypes of carbonate concretions of biochemical origin. Modern analogs show that each morphotype has a specific spatial depth distribution from the shore to the extremity of the littoral platform in association with the hydrodynamics and belts of aquatic vegetation. Oncoliths characterize the nearshore areas with high-energy environments [30].
- Sediment hiatuses: These indicate either erosion or a lack of deposition. They result from a lowering of the sediment limit due to the lowering of the lake level [2,31]. They are marked by unconformities between sediment layers and are identified from core transects perpendicular to the shore, as well as from pollen analyses.

Referring to the littoral modern analogs, the deposition of authigenic carbonate silt corresponds to a mean water depth of ca. 1 m, and that of the detritus gyttja to less than 0.5 m. The accumulation of oncoliths marks the eulittoral zone (i.e., the range between high and low seasonal lake levels), while peat and anmoor generally develop above the mean water level [15].

In addition to lacustrine deposits, the sediment profiles sometimes show the presence of fluvial deposits that have accumulated on the shore or below the water level near the shore. These terrestrial detritic sediment layers give evidence for a lowering of the lake level or increased runoff due to hydroclimatic events or human activities (deforestation).

The chronology is mainly based on radiocarbon dates obtained from terrestrial organic macrofossils. The dates were calibrated (2-sigma range) using Calib 7.10 software [32] and the IntCal13 database [33]. Archeological layers also provided high-resolution tree-ring dates from the wooden posts used by prehistoric humans to build dwellings. These posts are well preserved in the organic anthropogenic layers due to the anaerobic conditions resulting from their embedment in lacustrine sediments below the lake level. In addition, two OSL dates were obtained from alluvial deposits on the northern shore of the lake and interpreted using the minimum age model [34]. The pollen stratigraphy provided additional evidence to check the consistency of the chronology and highlight possible sediment hiatuses. The Holocene history of the regional vegetation is well known, and successive pollen biozones have been defined and radiocarbon-dated [9,14,35].

Each sediment layer identified at a site is defined by a unique ID composed of the acronym of the site (three letters), followed by the number of the core or excavation and, finally, the layer or sediment unit (e.g., layer MAV.7.11 corresponds to layer n° 11 of sediment profile 7 in the Annecy site, Avenue de la Mavéria).

3. Results

Table 1 presents the chronological data provided by the investigated sites. The reconstruction of the changes in the water level of Lake Annecy during the Holocene is based on the synthesis of data collected from sites on both the northern and western shores of the lake and relates (i) to the chronological and altitudinal position of the litho-stratigraphical sediment units identified at the study sites and (ii) to the indications of the sedimentation water depth given by the lithological characteristics of these sediment units. Interestingly, the collected dataset provides a wide altimetric and chronological range from the terrestrial shore to the lacustrine littoral platform. This makes it possible to document periods in lower-lying zones, whereas higher-lying zones may have been affected by sediment hiatuses and/or erosion during a lake-level lowering.

Table 1. Radiocarbon, tree-ring, and OSL dates from sediment sequences used for the reconstruction of Holocene changes in water level of Lake Annecy. Radiocarbon ages are expressed as years cal BP, and tree-ring dates in years BCE/CE. The thick line marks the transition between BCE and CE.

Radiocarbon and Tree–Ring Dates								
SITE	**SITE Acronym .core Number .layer Number**	**Sediment Type**	**Dated Material**	**Elevation (m a.s.l)**	**Radiocarbon Age (BP)**	**Calibrated Age 2σ (cal BP)**	**Calibrated Age 2σ (cal BCE/CE)**	**Laboratory Code**
Sevrier Les Mongets	SLM.6.10	sand	wood	443.78	12,410 ± 90	14,982–14,128	13,033–12,719	AA–22987
Sevrier Les Charretières	SLC.3.25	lakemarl	wood	442.48	12,360 ± 60	14,758–14,107	12,809–12,158	UTC 8988
Sevrier Les Mongets	SLM.5.9	lakemarl	wood	443.84	12,180 ± 110	14,564–13,753	12,615–11,804	AA–22988
Sevrier Les Charretières	SLC.3.9	lakemarl	wood	443.36	11,650 ± 150	13,770–13,173	11,821–11,224	Utc 8989
Saint Jorioz Le Beau	SJB.7.18	clay	organic rests	431.5	11,560 ± 180	13,749–13,076	11,800–11,127	AA–20334
Sevrier Les Charretières	SLC.3.9	lakemarl	wood	443.61	11,060 ± 110	13,097–12,724	11,148–10,775	Utc 8990

Table 1. *Cont.*

Radiocarbon and Tree–Ring Dates								
SITE	**SITE Acronym .core Number .layer Number**	**Sediment Type**	**Dated Material**	**Elevation (m a.s.l)**	**Radiocarbon Age (BP)**	**Calibrated Age 2σ (cal BP)**	**Calibrated Age 2σ (cal BCE/CE)**	**Laboratory Code**
Annecy 36 rue Centrale	36C.3.13	organic layer	organic rests	446.2	10,430 ± 100	12,619–11,988	10,670–10,039	Lyon–14489
Saint Jorioz Le Beau	SJB.7.17	clay	organic rests	433.1	9980 ± 140	12,024–11,178	10,075–9229	AA–20333
Annecy 36 rue Centrale	36C.5.13	organic layer	organic rests	446.2	9870 ± 100	11,750–11,101	9801–9152	Lyon–14490
Sevrier Les Charretières	SLC.2.4	silty sand	wood	444.49	9710 ± 80	11,248–10,778	9299–8829	Utc 8996
Sevrier Les Mongets	SLM.4.10	large oncoliths	wood	444.14	9530 ± 60	11,106–10,607	9157–8658	Utc 8789
Annecy avenue de la Mavéria	MAV.11.16	brun–green sand	wood	443.9	9510 ± 35	11,071–10,678	9122–8729	Ly–17066
Annecy 33–37 avenue du Petit Port	33P.8.9	sand and grey clay with organic macrocrests	hazelnut	444.99–445.39	9365 ± 50	10,718–10,431	8769–8482	Lyon–12224
Annecy 50 rue Centrale	50C.4.11	silt	organic rests	445.3	9395 ± 35	10,712–10,520	8763–8571	Ly–16205
Annecy 33–37 avenue du Petit Port	33P.8.9	sand and grey clay with organic macrocrests	wood	444.99–445.39	9285 ± 35	10,579–10,300	8630–8351	Ly–16921
Sevrier Les Charretières	SLC.2.3	lakemarl	organic rests	444.71	8780 ± 260	10,545–9154	8596–7205	Utc 8995
Annecy 33–37 avenue du Petit Port	33P.8.7	organic layer	wood	445.62	9115 ± 40	10,393–10,203	8444–8254	Lyon–14430
Annecy avenue de la Mavéria	MAV.7.11	organic layer	wood	444.5	9085 ± 40	10,371–10,184	8422–8235	Lyon–14425
Annecy 1 avenue du Trésum	TRE.27.17g	carbonate lakemarl	organic rests	445.22	8960 ± 50	10,228–9917	8279–7968	Poz–40607
Annecy parking Hôtel de ville	PHV.23 éch E	organic layer	wood	443.7	8870 ± 100	10,223–9632	8274–7683	AA–22980

Table 1. *Cont.*

Radiocarbon and Tree–Ring Dates								
SITE	**SITE Acronym .core Number .layer Number**	**Sediment Type**	**Dated Material**	**Elevation (m a.s.l)**	**Radiocarbon Age (BP)**	**Calibrated Age 2σ (cal BP)**	**Calibrated Age 2σ (cal BCE/CE)**	**Laboratory Code**
Sevrier Les Mongets	SLM.4.6	small oncoliths	wood	444.59	8885 ± 85	10,214–9697	8265 –7748	AA–22989
Annecy avenue de la Mavéria	MAV.11.11	organic layer	wood	445.1	8915 ± 40	10,188–9912	8239–7963	Lyon–14426
Annecy avenue de la Mavéria	MAV.7.8	organic layer	wood	445.04	8785 ± 40	10,118–9612	8169–7663	Lyon–14424
Annecy parking Hôtel de ville	PHV.23 éch G	coarse gyttja	organic rests	442.38–442.42	8735 ± 64	10,115–9544	8166–7595	ARC 1139
Annecy avenue de la Mavéria	MAV.6.13	organic layer	wood	445.28	8730 ± 40	9887–9556	7938–7607	Lyon–14427
Sevrier Les Mongets	SLM.6.2	lakemarl	wood	444.56	8470 ± 60	9546–9320	7597–7371	Utc–8756
Saint–Jorioz Les Marais	SJM.1.7	lakemarl	wood	442.54	7480 ± 100	8445–8045	6496–6096	AA–22986
Saint–Jorioz Les Marais	SJM.1.8	sand	wood +charcoal	442.44	7565 ± 40	8428–8321	6479–6372	VERA–1646
Saint–Jorioz Les Marais	SJM.1.8	sand	wood	442.36	7435 ± 35	8341–8184	6392–6235	VERA–1645
Annecy 5–7 chemin des Fins sud	non réf.	sand and pebbles	charcoal	450.7	7360 ± 40	8310–8041	6361–6092	Ly–2407
Saint–Jorioz Les Marais	SJM.1.2	lakemarl and archaeological layer	wood	444.505			3783	felling phase tree–ring date
Annecy Le Pâquier	PAQ	archaeological layer	oak wood	445.24			2870–2843	felling phase tree–ring date
Talloires Angon	ANG	archaeological layer	organic rests	443.5	3910 ± 50	4513 –4158	2564–2209	Gif. 8145
Sevrier Les Mongets	SLM.4.2	archaeological layer	wood	445.26			1803–1766	felling phase tree–ring date

Table 1. *Cont.*

Radiocarbon and Tree–Ring Dates

SITE	SITE Acronym .core Number .layer Number	Sediment Type	Dated Material	Elevation (m a.s.l)	Radiocarbon Age (BP)	Calibrated Age 2σ (cal BP)	Calibrated Age 2σ (cal BCE/CE)	Laboratory Code
Annecy Albigny 1	ALB	archaeological layer	wood	445.34			1624–1619	felling phase tree–ring date
Sevrier Le Crêt de Chatillon	CDC	archaeological layer	wood	443.38	3090 ± 45		1441–1228	ARC. 2193
Annecy Petit–Port 2	PP2	archaeological layer	wood	444.38	2720 ± 45	2923–2751	974–802	ARC. 2191
Annecy, ZAC Galbert	Fs1189	archaeological layer	charcoal	450.5	2645 ± 30	2842–2738	893–789	Ly–11062
Annecy 1 avenue du Trésum	TRE.27.17d	carbonate lakemarl	organic rests	445.42	2520 ± 30	2677–2603	797–542	Poz–40605
Saint Jorioz Le Beau	SJB.B.6	fine sand	wood	445.93	2180 ± 30	2309–2118	360–169	Lyon–16305
Saint Jorioz Le Beau	SJB.B.7	sand and organic macror.	wood	445.86	2150 ± 30	2305–2009	356–60	Lyon–16306
Saint Jorioz Le Beau	SJB.A.3	sand and gravels	organic rests	446.25	1750 ± 30	1726–1566	224–384	Lyon–16304
Annecy parking Hôtel de ville	PHV.23 éch C	silt	horse bone	445	787 ± 47	788–665	1162–1285	ARC 1308
Annecy parking Hôtel de ville	PHV.23 éch B	blue–grey clay	oak wood (plank)	445.04–445.24	774 ± 40	765–663	1185–1287	ARC 1163
Annecy parking Hôtel de ville	PHV.23 éch A	peat	peat	445.67–445.74	420 ± 40	530–320	1420–1630	ARC 1164
Annecy avenue de la Mavéria	MAV.6.7	organic layer	wood	446.6	340 ± 30	480–311	1470–1639	Lyon–14423
Saint Jorioz Le Beau	SJB.A.1	anmoor	wood	446.7	255 ± 30	429–1	1521–1949	Lyon–16303
Annecy 1 avenue du Trésum	TRE.8.16	dark organic clay	human bone	447–447.20	210 ± 30	305–1	1645–1949	Ly–15518

Table 1. *Cont.*

OSL dates						
SITES	**SITE acronym**	**Sediment type**	**Depth (m)**	**Elevation (m a.s.l.)**	**Water content (%)**	**Minimum model age (Ka)**
Annecy 9, avenue des Romains	ROM	sand	1.2	450.1	15 ± 5	8.04 ± 0.78 Ka
Annecy 20, avenue de la plaine	PLA	silty sand with small gravels	1.2	449.8	10 ± 5	6.24 ± 0.82 Ka

Figures 3 and 4 present the sediment profiles of the key sites used for the lake-level reconstruction. Figure 5 shows (i) the curve of the Holocene lake-level fluctuations derived from the available data, and (ii) the altimetric and chronological positions of the key sediment units supporting the reconstruction of the successive lake-level events (Table 2). Twenty-four phases were thus distinguished: even or odd numbers refer to phases of relatively high or low lake levels. Table 2 summarizes major lithological and chronological data documenting each lake-level phase.

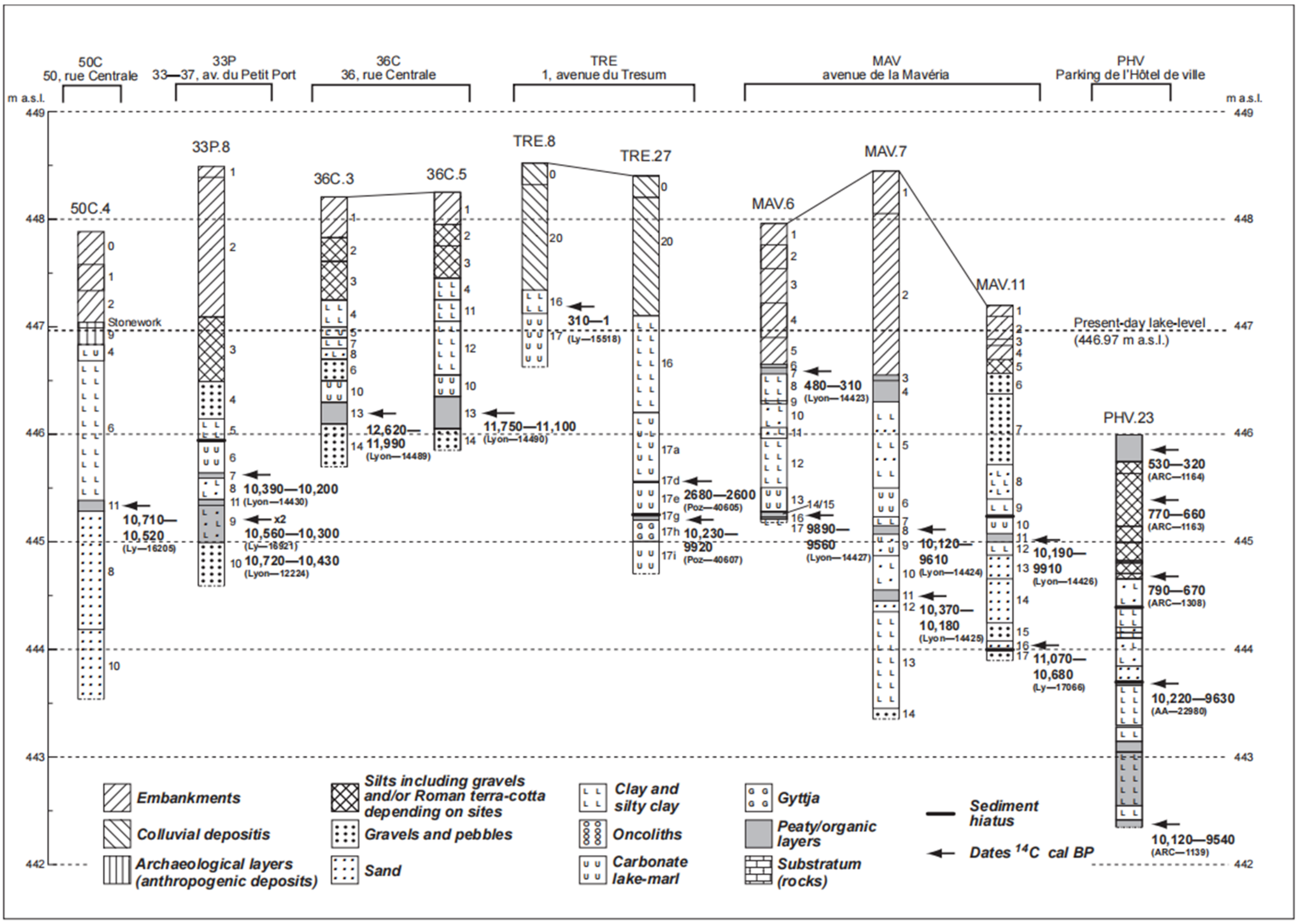

Figure 3. Sediment sequences from the northern shore of Lake Annecy used for reconstructing Holocene lake-level fluctuations [15].

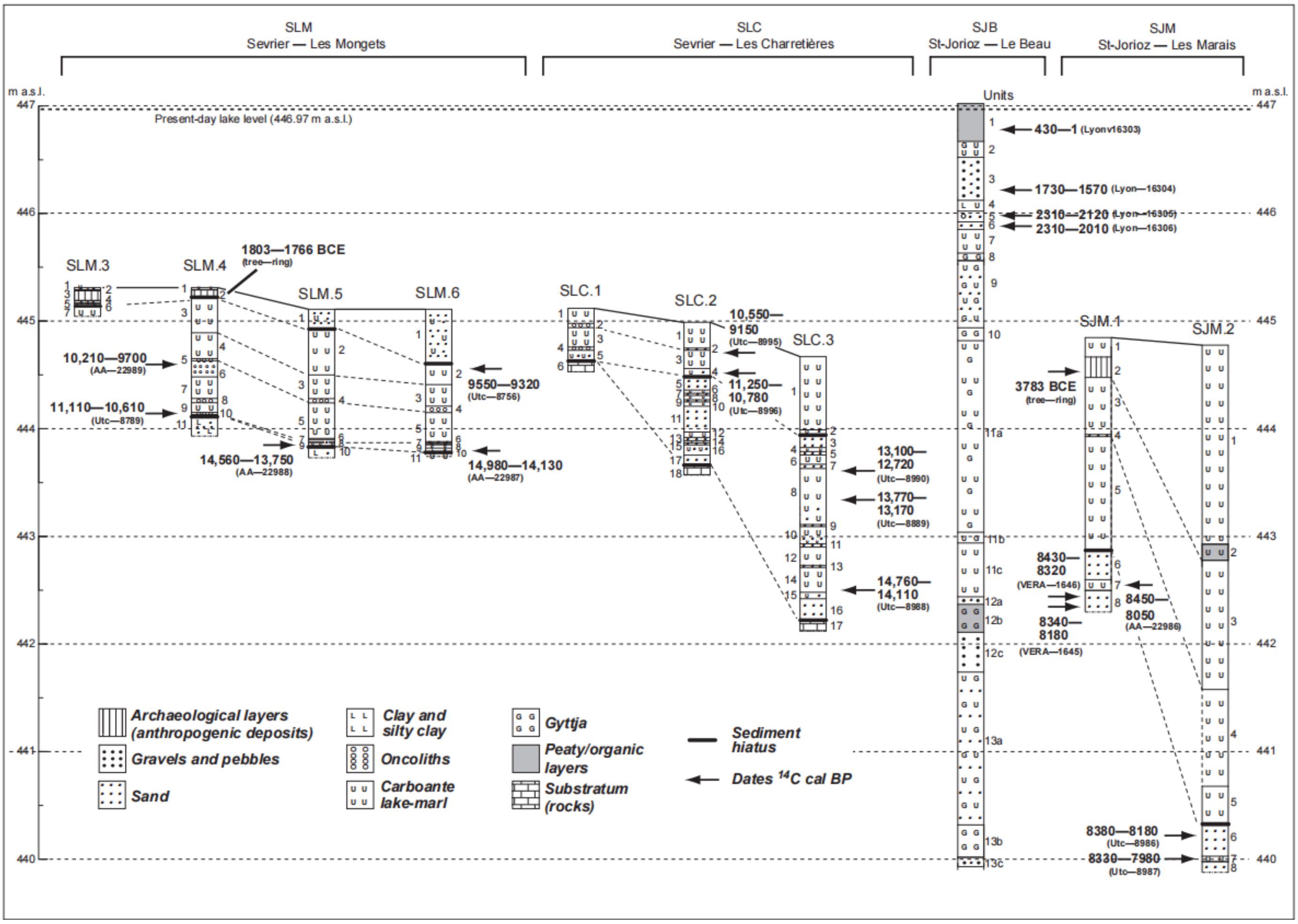

Figure 4. Sediment sequences from the western shore of Lake Annecy used for reconstructing Holocene lake-level fluctuations [12–15].

The peaty layer observed at the site of Annecy-36 Rue Centrale (layers 5–13) suggested a phase marked by a mean lake level of ca. 446.20 m a.s.l. (i.e., ca. 0.8 m below the present-day lake level) during the Preboreal pollen biozone. The sites of Sevrier Les Mongets, Sevrier Les Charretières, and Annecy-Mavéria provided reference sediment profiles to document the period of 11,500–9000 cal BP. The sediment hiatuses and oncolith layers observed in Sevrier, and also the pebble layers in Annecy-Mavéria (layer s11–17), suggested a relatively low lake level at ca. 444/444.5 m a.s.l., i.e., 2.97/2.47 m below the present-day lake level (phase 1).

The sediment profile of Sevrier Les Mongets revealed three successive phases of higher lake levels (phases 2, 4, and 6). The last appears to be the highest and is also evidenced by the deposition of carbonate lake marl in Annecy-Maveria (layers 11–10) and 33–37 Avenue du Petit Port (layers 8–6). The peaty layers observed on the sites of Annecy-Trésum (layers 27–17 g), 33–37 Avenue du Petit Port (layers 8–9), 50 Rue Centrale (layers 4–11), and Avenue de la Mavéria (layers 11–11, 7–11/7–8), which are dated to ca. 10,750–9600 cal BP, suggested a mean lake level at ca. 444.5–445.6 m a.s.l., i.e., 2.47/1.37 m below the present-day lake level.

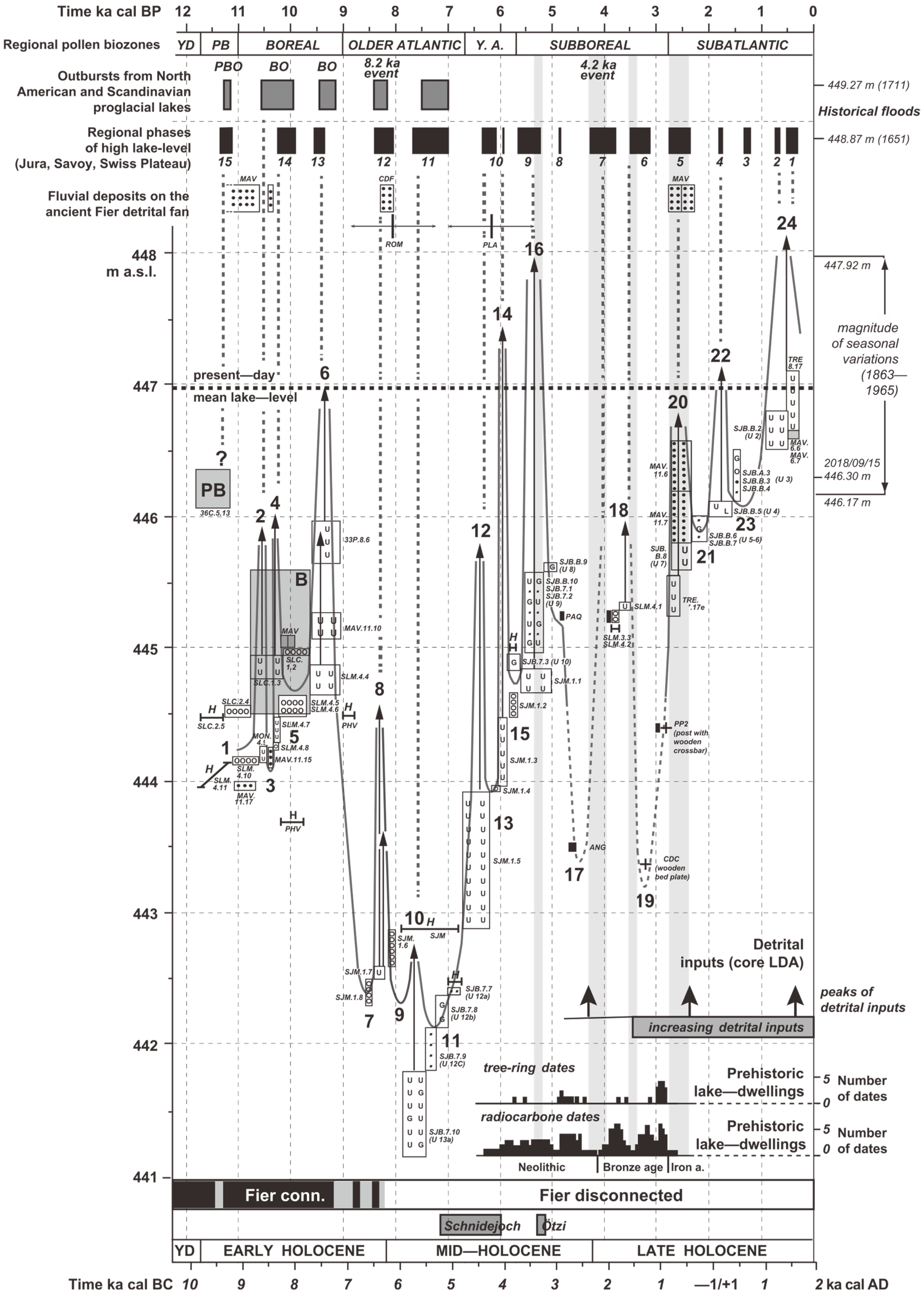

Figure 5. Holocene lake-level fluctuations in Lake Annecy. YD: Younger Dryas; PB: Preboreal; B: Boreal.

PBO: Preboreal oscillation; BO: Boreal oscillation. Grey bands: phases of abandonment of Neolithic and Bronze Age lake dwellings. Grey rectangles: altimetric and chronological positions of peaty sediment units dated to Preboreal (PB) and Boreal (B). In the lower panel, two histograms present the periods of development of Neolithic and Bronze Age lake dwellings (on the shores of Lake Annecy) as reconstructed from (i) tree-ring and (ii) radiocarbon dates (using calibration time-windows at 2 sigma [27]). The data relative to the course of the Fier River and detrital inputs (core LDA) refer to Nomade [36], and those relative to the chronological position of archeological remains of Schnidejoch (Bernese Alps) and Ötzi (Italian Alps) respectively refer to Hafner [37] and Magny and Haas [38].

The period of 9000–7000 cal BP was characterized by a major sediment hiatus at the higher sites of Annecy (Parking de l'Hôtel de Ville, Trésum, and Mavéria). At Parking de l'Hôtel de Ville, the sediment units dated to 10,240–9590 cal BP were overlain by sediments dated to 790–660 cal BP. In Trésum, layers 27–17 h and 27–17 g dated to 10,230–9920 cal BP were overlain by carbonate lake marl (layers 27–17 d) dated to 2680–2600 cal BP. At Sevrier Les Mongets, the sediment deposited during the Boreal pollen biozone was overlain by sediments accumulated during the Subboreal and Subatlantic pollen biozone [12]. Due to the lower elevation, the sediment sequences of the Saint-Jorioz Le Marais and Saint-Jorioz Le Beau sites helped to document this period. They gave evidence of an abrupt lake-level lowering at around 9000 cal BP. Three successive phases of a lake-level minimum could be distinguished (phases 7, 9, and 11). The oncolith layers and sediment hiatus in Saint-Jorioz Les Marais, as well as the deposition of gyttja, sand, and gravels, and the sediment hiatus at Saint-Jorioz Le Beau (unit 12) suggested a lake level of ca. 442.4–442.1 m a.s.l., i.e., ca. 4.6/4.9 m below the present-day lake level.

This period of pronounced lowering of the lake level was interrupted by two phases of higher lake levels:

- The first (phase 8) was well radiocarbon dated to 8300–8200 cal BP at the site of Saint-Jorioz Les Marais;
- The second (phase 10) was recorded in sediment unit 13a at Saint-Jorioz Le Beau, where unit 12 corresponded to lake-level phase 11.

The period of 6700–5200 cal BP marked a trend of lake-level rises through three successive phases, well documented in the sediment sequence from Saint-Jorioz Les Marais and dated to ca. 6500, 6000, and 5300 cal BP. At this site, the low-lake-level phase 15 was dated by a tree-ring date to 3783 BCE (i.e., 5730 cal BP), while the sedimentation rate between two radiocarbon-dated horizons suggested an age of ca. 6050 cal BP for the low-lake-level phase 13 [14]. The sediment sequence of Saint-Jorioz Le Beau supported this reconstruction with sediment units 11c, 11a, and 9 corresponding to lake-level phases 12, 14, and 16, respectively, and sediment unit 10 to lake-level phase 15. The highest lake levels could have reached 448 m a.s.l. (i.e., ca. 1 m above the present-day lake level) during phase 16. Phases 12, 14, and 16 also coincided with an increasing runoff indicated by the deposition of coarse alluvium (OSL dated to 6.24 ± 0.82 ka at the site of Annecy-20 Avenue de la Plaine; Figures 2 and 5) over the old Fier detrital fan to the north of Lake Annecy.

Table 2. Sediment and chronological data documenting Holocene phases of lake-level changes reconstructed at Lake Annecy during the Holocene. PS: Pollen stratigraphy.

Lake–Level Phase	SITE	Unit	Layer	Upper Z (m a.s.l.)	Lower Z (m a.s.l.)	Lithology	Chronological References
Phase 24	Saint-Jorioz Le Beau	2	SJB.B.2	446.78	446.53	carbonate lakemarl + organic remains	PIA fall (≈ XIVth century AD)
	Annecy Parking Hôtel de ville		PHV.23 éch A	446	445.57	silt and peat (resumption of the sedimentation after the Boreal hiatus)	530–320 cal BP before modern embankments
	Annecy av. de la Mavéria	2a	MAV.6.7	446.62	446.56	organic silty clay	480–310 cal BP
	Annecy av. de la Mavéria	2a	MAV.6.6	446.65	446.62	organic sediments	after 480–310 cal BP
	Annecy 1 av. du Trésum	3	TRE.8.17	447.12	446.65	carbonate lakemarl	before 310–1 cal BP
Phase 23	Saint–Jorioz Le Beau	3	SJB.B.4, B.3 et A.3	446.53	446.13	sand, gravels and oncoliths (+silt)	1730–1570 cal BP
Phase 22	Saint–Jorioz Le Beau	4	SJB.B.5	446.13	446.03	clayish carbonate silt	
Phase 21	Saint–Jorioz Le Beau	5	SJB.B.6	446.03	445.93	fin sand + oncoliths	2310–2120 cal BP
	Saint–Jorioz Le Beau	6	SJB.B.7	445.93	445.86	sand with oncolithes and wooden fragments	2310–2010 cal BP
Phase 20	Annecy 1 av. du Trésum	4	TRE.27.17e	445.55	445.25	carbonate lakemarl	2680–2600 cal BP
	Annecy av. de la Mavéria	3	MAV.11.7	446.38	445.72	sand and silt with pebbles and gravels	
	Annecy av. de la Mavéria	3	MAV.11.6	446.57	446.38	silt and clay with pebbles and gravels	
	Saint–Jorioz Le Beau	7	SJB.B.8	445.86	445.64	carbonate lakemarl	Subatlantic (PS)
	Annecy ZAC Galbert			450.5		charcoals in a stone fireplace	2840–2780 cal BP
phase 19	Sevrier Le Crêt de Chatillon		CDC	±443.38		tree–ring dated archaeological layer	1441–1228 cal BC Late Bronze age 1
	Annecy Petit Port 2		PP2	±444.50		tree–ring dated archaeological layer	974–802 cal BC Late Bronze age
phase 18	Sevrier Les Mongets		SLM.4.2	445.29	445.22	archaeological layer + oncoliths	1803–1766 BC Early Bronze age
	Sevrier Les Mongets		SLM.4.1	445.31	445.29	carbonate lakemarl	after 1803–1766 BC
	Sevrier Les Mongets		SLM.3.3	445.28	445.19	archaeological layer + oncoliths	1803–1766 BC Early Bronze age
	Sevrier Les Mongets		SLM.3.2	445.29	445.28	oncoliths	after 1803–1766 BC
	Sevrier Les Mongets		SLM.3.1	445.31	445.29	silty sand + laminae	after 1803–1766 BC
phase 17	Annecy Le Pâquier		PAQ	±445.24		tree–ring dated archaeological layer	2870–2843 BC
	Talloires Angon		ANG	±443.5		archaeological layer	2564–2209 cal BC
	Saint–Jorioz Le Beau	8	SJB.B.9	445.64	445.57	gyttja	Subboreal (PS)

Table 2. *Cont.*

Lake–Level Phase	SITE	Unit	Layer	Upper Z (m a.s.l.)	Lower Z (m a.s.l.)	Lithology	Chronological References
phase 16	Saint–Jorioz Les Marais		SJM.1.1	444.84	444.66	carbonate lakemarl	beginning Subboreal (PS)
	Saint–Jorioz Le Beau	9	SJB.7.2, 7.1, B.10	445.57	444.95	carbonate gyttja with sand laminae	Subboreal (PS)
phase 15	Saint–Jorioz Les Marais		SJM.1.2	444.66	444.47	alternated layers of archaeological remains and carbonate lake marl/oncoliths	3783 BC (+PIA peak), transition Younger Atlantic/Subboreal
	Saint–Jorioz Le Beau	10	SJB.7.3	444.95	444.83	gyttja	PIA peak, transition Younger Atlantic/Subboreal (PS)
phase 14	Saint–Jorioz Les Marais		SJM.1.3	444.47	443.94	carbonate lakemarl	before 3783 BC
	Saint–Jorioz Le Beau	11a	SJB.7.4	444.83	443.05	carbonate lakemarl	late Younger Atlantic (PS)
	Annecy 20 av. de la Plaine		PLA	449.9		sand, silt and clay with rounded gravels	6.24 ± 0.82 ka (Minimum Age Model)
phase 13	Saint–Jorioz Les Marais		SJM.1.4	443.94	443.92	sand and oncoliths	Younger Atlantic (PS; ca. 6050 cal BP from sedimentation rate)
phase 12	Saint–Jorioz Les Marais		SJM.1.5	443.92	442.87	carbonate lakemarl	Younger Atlantic (PS)
	Saint–Jorioz Le Beau	11c	SJB.7.6	442.95	442.45	carbonate lakemarl	Younger Atlantic (PS)
phase 11	Saint–Jorioz Les Marais		toit SJM.1.6	442.87		sediment hiatus	Early Atlantic (PS)
	Saint–Jorioz Le Beau	12c	SJB.7.9	442.12	441.75	gravels and sand	
	Saint–Jorioz Le Beau	12b	SJB.7.8	442.38	442.12	gyttja	
	Saint–Jorioz Le Beau	12a	SJB.7.7	442.45	442.38	gravels and sand	abrupt transition Early/Younger Atlantic (PS)
phase 10	Saint–Jorioz Le Beau	13a	SJB.7.10	441.75	440.33	carbonate gyttja with sand laminae	Early Atlantic (PS)
phase 9	Saint–Jorioz Les Marais		SJM.1.6 moitié sup.	442.87	442.8	sand and oncoliths	Early Atlantic (PS)

Table 2. *Cont.*

Lake–Level Phase	SITE	Unit	Layer	Upper Z (m a.s.l.)	Lower Z (m a.s.l.)	Lithology	Chronological References
phase 8	Saint–Jorioz Les Marais		SJM.1.6 moitié inf.	442.8	442.59	sand	
	Saint–Jorioz Les Marais		SJM.1.7	442.59	442.49	carbonate lakemarl + sand	8450–8050 cal BP
	Saint–Jorioz Les Marais		SJM. 2.6	440.32	440.02	carbonate lakemarl + sand	episode 2 : 8380–8200 cal BP
	Saint–Jorioz Les Marais		SJM.2.7	440.02	439.97	carbonate lakemarl + sand	episode 1 : 8320–8020 cal BP
	Annecy 5–7 ch. des Fins		CDF	450.7		sand with pebbles (Fier channel)	8310–8040 cal BP
	Annecy 9 av. des Romains		ROM	450.14	450.04	sandy/silty lamina between sand and gravels	8.04 ± 0.78 ka (Minimum Age Model)
Phase 7	Saint–Jorioz Les Marais		SJM.1.8	442.49	442.29	sand and oncoliths	upper : 8430–8320 cal BP lower : 8340–8180 cal BP
	Saint–Jorioz Les Marais		SJM.2.8	439.97	439.87	sand and oncoliths	before 8320–8020 cal BP
	Saint–Jorioz Le Beau	13c et 13b	SJB.7.11, 7.12, 7.13	440.33	438.18	change in type of sediments, gyttja with carbonate lakemarl and sand laminae + organic remains	first half of Early Atlantic (PS)
sediment hiatus Boreal/Subboreal or Subatlantic	Annecy av. de la Mavéria	4/3	MAV.11.10	445.24		carbonate lakemarl	*hiatus Boreal/Subatlantic*
	Annecy Parking Hôtel de ville		PHV.23 avant éch C	444.5			*hiatus Boreal/Subatlantic*
	Annecy 1 av. du Trésum	5/4	TRE.27.17g	445.25		organic lamina	*hiatus Boreal/Subatlantic*
	Sevrier Les Mongets		SLM.4.3	444.89		carbonate lakemarl	*hiatus Boreal/Subboreal*
	Sevrier Les Mongets		SLM.5.2	444.93		carbonate lakemarl	*hiatus Boreal/Subatlantic*
	Sevrier Les Mongets		SLM.6.2	444.61		carbonate lakemarl	*hiatus Boreal/Subatlantic*
Phase 6	Annecy av. de la Mavéria	4	MAV.11.10	445.24	445.08	laminated carbonate lakemarl	mid–Boreal (PS)
	Annecy 33–37 av. du Petit Port	4	33P.8.6	445.94	445.64	white carbonate lakemarl	after 10,390–10,200 cal BP
	Sevrier Les Mongets		SLM.4.5	444.89	444.65	carbonate lakemarl	after 10,210–9700 cal BP
	Sevrier Les Mongets		SLM.4.4	444.65	444.63	large oncoliths	end ca. 9550–9320 cal BP

Table 2. *Cont.*

Lake–Level Phase	SITE	Unit	Layer	Upper Z (m a.s.l.)	Lower Z (m a.s.l.)	Lithology	Chronological References
Phase 5	Sevrier Les Mongets		SLM.4.6	444.63	444.48	small oncoliths	10,210–9700 cal BP
	Sevrier Les Mongets		SLM.4.5	444.65	444.63	large oncoliths	Boreal
	Sevrier Les Charretières		SLC.1.2	444.98	444.94	silty sand + oncoliths	after 10,550–9150 cal BP
	Annecy av. de la Mavéria	5	MAV.11.11	445.08	445	organic silt + wood fragments	10190–9910 cal BP
	Annecy av. de la Mavéria	5	MAV.7.11	444.55	444.45	organic macroremains	10,370–10,180 cal BP
	Annecy av. de la Mavéria	5	MAV.7.10	444.87	444.55	sily clay (+sand)	Boreal
	Annecy av. de la Mavéria	5	MAV.7.9	445.07	444.87	carbonate lakemarl (+sand)	Boreal
	Annecy av. de la Mavéria	5	MAV.7.8	445.15	445.07	compact laminated organic layer	10,120–9610 cal BP
	Annecy 1 av. du Trésum	5	TRE.27.17g	445.25	445.2	organic layer	10,230–9920 cal BP
	Annecy Parking Hôtel de ville		PHV.23 éch. E	443.71	443.67	organic clay	10,210–9630 cal BP top = hiatus Boreal
Phase 4	Sevrier Les Mongets		SLM.4.7	444.48	444.28	carbonate lakemarl	Boreal
	Sevrier Les Charretières		toit SLC.1.3	444.94		carbonate lakemarl	before 10,550–9150 cal BP
	Annecy av. de la Mavéria	6a	MAV.11.14	444.66	444.25	layered fine sand with wooden pieces	Boreal
	Annecy av. de la Mavéria	6a	MAV.11.13	444.88	444.66	mid– to coarse sand	Boreal
	Annecy av. de la Mavéria	6a	MAV.11.12	445	444.88	silty clay with organic remains	before 10,190–9910 cal BP
	Annecy 1 av. du Trésum	7	TRE.27.17i	445	444.7	carbonate lakemarl	Boreal
	Annecy 1 av. du Trésum	6	TRE.27.17h	445.2	445	gyttja	before 10,230–9920 cal BP
Phase 3	Annecy av. de la Mavéria	6b	MAV.11.15	444.25	444.08	coarse sand with gravels and small pebbles	after 11,070–10,680 cal BP
	Sevrier Les Mongets		SLM.4.8	444.28	444.24	large oncoliths	Boreal
	Annecy 33–37 av. du Petit Port	5	33P.8.9	445.39	444.99	sandy clay with organic remains	10,580–10,300 cal BP 10,720–10,430 cal BP
Phase 2	Annecy av. de la Mavéria	6c	MAV.11.16	444.08	444	blue–green sand	after 11,070–10,680 cal BP
	Sevrier Les Charretières		SLC.1.3	444.94	444.76	carbonate lakemarl	Boreal
	Sevrier Les Charretières		SLC.2.3	444.73	444.56	carbonate lakemarl	before 10,550–9150 cal BP
	Sevrier Les Mongets		SLM.4.9	444.24	444.15	carbonate lakemarl	after 11,110–10,610 cal BP

Table 2. *Cont.*

Lake–Level Phase	SITE	Unit	Layer	Upper Z (m a.s.l.)	Lower Z (m a.s.l.)	Lithology	Chronological References
Phase 1	Sevrier Les Mongets		SLM.4.11	444.13	443.93	silty sand + laminations	top = hiatus Dryas ancien/Preboreal
	Sevrier Les Mongets		SLM.4.10	444.15	444.13	large oncoliths	11,110–10,610 cal BP
	Sevrier Les Charretières		SLC.2.5	444.49	444.36	sand	top = hiatus Bölling / Preboreal
	Sevrier Les Charretières		SLC.2.4	444.56	444.49	silty sand	11,250–10,780 cal BP
	Annecy av. de la Mavéria	7	MAV.11.17	444	<443.2	sand with gravels and pebbles	before 11,070–10,680 cal BP top = hiatus Preboreal/Boreal
Late—glacial/early Holocene	Annecy 36 rue Centrale	5	36C.3.13	446.3	446.1	clayish silt with thin organic layers	12,620–11,990 cal BP
	Annecy 36 rue Centrale	5	36C.5.13	446.35	446.05	clayish silt with thin organic layers	11,750–11,100 cal BP

The litho-stratigraphical data were scarcer for the period of 5000–2700 cal BP. The altimetric positions of archeological layers at the Annecy-Le Pâquier and Angon sites (Late Neolithic) suggested a marked lake-level lowering during phase 17 (with the lake level at ca. 443.5 a.s.l., i.e., ca. 3.5 m below the present-day lake level). This estimate was close to the one estimated for phase 19 from the altitudinal position (i.e., ca. 443.38 m a.s.l., i.e., ca. 3.6 m below the present-day lake level) of wooden architectural structures (ground floor) observed at the Late Bronze Age site of Sevrier-Crêt de Chatillon. Between phases 17 and 19, the deposition of oncoliths in the archeological layer tree-ring dated to 1803–1766 BCE, i.e., 3753–3716 cal BP (Early Bronze Age), and overlain by a layer of carbonate lake marl contemporaneous with the Subboreal pollen biozone at the site of Sevrier Les Mongets [12,15] gave evidence of a rise in the lake level, which would have reached more than 446 m a.s.l., i.e., ca. 1 m below the present-day lake level (phase 18). Other wooden architectural structures observed at 444.5 m a.s.l. (i.e., ca. 2.5 m below the present-day lake level) at the Late Bronze Age sites of Sevrier-Crêt de Chatillon and Annecy-Petit Port 2 suggest a rise in the lake level beginning before 840 BCE (i.e., 2790 cal BP) during the transition between the Subboreal and Subatlantic pollen biozones.

The reference sites to document the last three millennia were Saint-Jorioz Le Beau, Annecy-Mavéria, and Annecy-Trésum. At Annecy-Trésum, the rise in the lake level in phase 20 corresponded to the end of the major sediment hiatus, with the deposition of carbonate lake marl (layers 27–17e), which was dated to 2680–2600 cal BP. It also corresponded (i) to the deposition of carbonate lake marl at Saint-Jorioz Le Beau (unit 7, before units 5 and 6 dated to 2150 ± 30 and 2180 ± 80 BP) and (ii) to two fluvial pebble layers overlain by silty-clay deposits, including Roman terra-cotta at Annecy-Mavéria (layers 11–5).

At Saint-Jorioz Le Beau, the deposition of carbonate silty-clay (unit 4) between layers of oncoliths and sand dated to 2310–2010 cal BP (units 5 and 6) and 1730–1570 cal BP (unit 3) indicated a rise in the lake level (phase 22), during which the water level may have reached 447 m a.s.l., i.e., close to the present-day lake level.

Finally, the high-lake-level phase 24 was recorded by the carbonate lake marl of unit 2 in the sediment sequence at Saint-Jorioz Le Beau. Unit 2 was overlain by an anmoor layer (unit 1), whose base was dated to 255 ± 30 (430-1 cal BP). Phase 24 was also well documented via several sites at Annecy: Trésum (the carbonate lake marl of unit 3 deposited before 310-1 cal BP), Parking de l'Hôtel de Ville (silts deposited after 790–670 cal BP and overlain by a peat layer dated to 530–320 cal BP), and Mavéria (organic silty-clay of layers 7.3/7.4 and 6.6/6.7 dated to 480–310 cal BP). The carbonate lake marl observed at Trésum indicated that the rise in the lake level during phase 24 may have reached 448 m a.s.l., i.e., ca. 1 m above the present-day lake level.

4. Discussion and Conclusions

4.1. Time Windows Needing Further Investigations

The data collected as part of the *CLIMASILAC* and *Paleoenvironment and Archaeology of the Northern Shore of Lake Annecy* projects made it possible to sketch a first tentative synthesis curve of lake-level fluctuations during the Holocene for Lake Annecy. However, this first composite also gave evidence of still insufficiently documented time windows. First, this applies to the start of the Holocene, especially for the Preboreal pollen biozone (11,750–11,000 cal BP) due to sediment hiatuses that characterize this period in the sediment sequences of Sevrier Les Mongets and Les Charretières. A possible issue could be to extend the core transect initiated at these two sites lakeward (Figure 4) [12]. This could help to provide more detailed data to document the time window encompassed by the Preboreal biozone with a higher resolution.

The period of 5000–2700 cal BP is the second time window needing additional investigations again using a lakeward extension of the core transect initiated on the site of Saint-Jorioz Le Beau to (i) establish a continuous, high-resolution lake-level record for the Subboreal pollen biozone and (ii) potentially provide a more detailed lake-level record for the last three millennia (Figure 4).

4.2. Millennial Lake-Level Fluctuations

Despite the lack of data for the periods mentioned in the above paragraphs, taken as a whole, the lake-level curve presented in Figure 5 reveals two major successive multimillennial trends. The first period, between 11,500 and 9000 cal BP, shows a general trend toward lake-level lowering. After a period of a lake-level minimum until ca. 7000 cal BP, the second trend shows a general tendency toward a rise in the lake level until the present day.

Figure 6 displays a comparison between (1) the Annecy lake-level record (this study), (2) the Cerin lake-level record from the Jura Mountains [39], (3) a tree-line record from the Kauner Valley in the Austrian Alps [40], (4) a glacier record from the Swiss Alps [41], (5) a summer temperature record from West-Central Europe [42], and (6) the orbitally driven changes in seasonal insolation at 40° N [43]. Taken together, the lake-level records of lakes Annecy and Cerin as well as the Austrian and Swiss Alpine paleoclimatic records reflect a dominant influence of the orbital factor, with (i) the lowest lake levels in the French Pre-Alps and the Jurassian Mountains and (ii) the highest elevation of the Austrian timberline and the Swiss glacier tongues during the Holocene climatic optimum [44,45]. It is noteworthy that the rapid lake-level lowering of Lake Annecy and Cerin at ca. 9000 cal BP, i.e., just after the disappearance of the Fennoscandian ice sheet [42], coincided with the rapid afforestation of elevated Alpine zones, as illustrated by the Kauner Valley record. This points to the possible crucial influence of the residual European ice sheet on the climate of Europe during the early Holocene, as discussed by Renssen et al. [42]. This also points to another possible key influence, i.e., that of the maximal development of the vegetation (forests and grasslands) in the lake catchment area during the Holocene climatic optimum and before the first Neolithic human impacts on the vegetation cover. This development could have resulted in a maximum of evapotranspiration and a substantial reduction in the water supply to the lake [46] during phases 7 to 11.

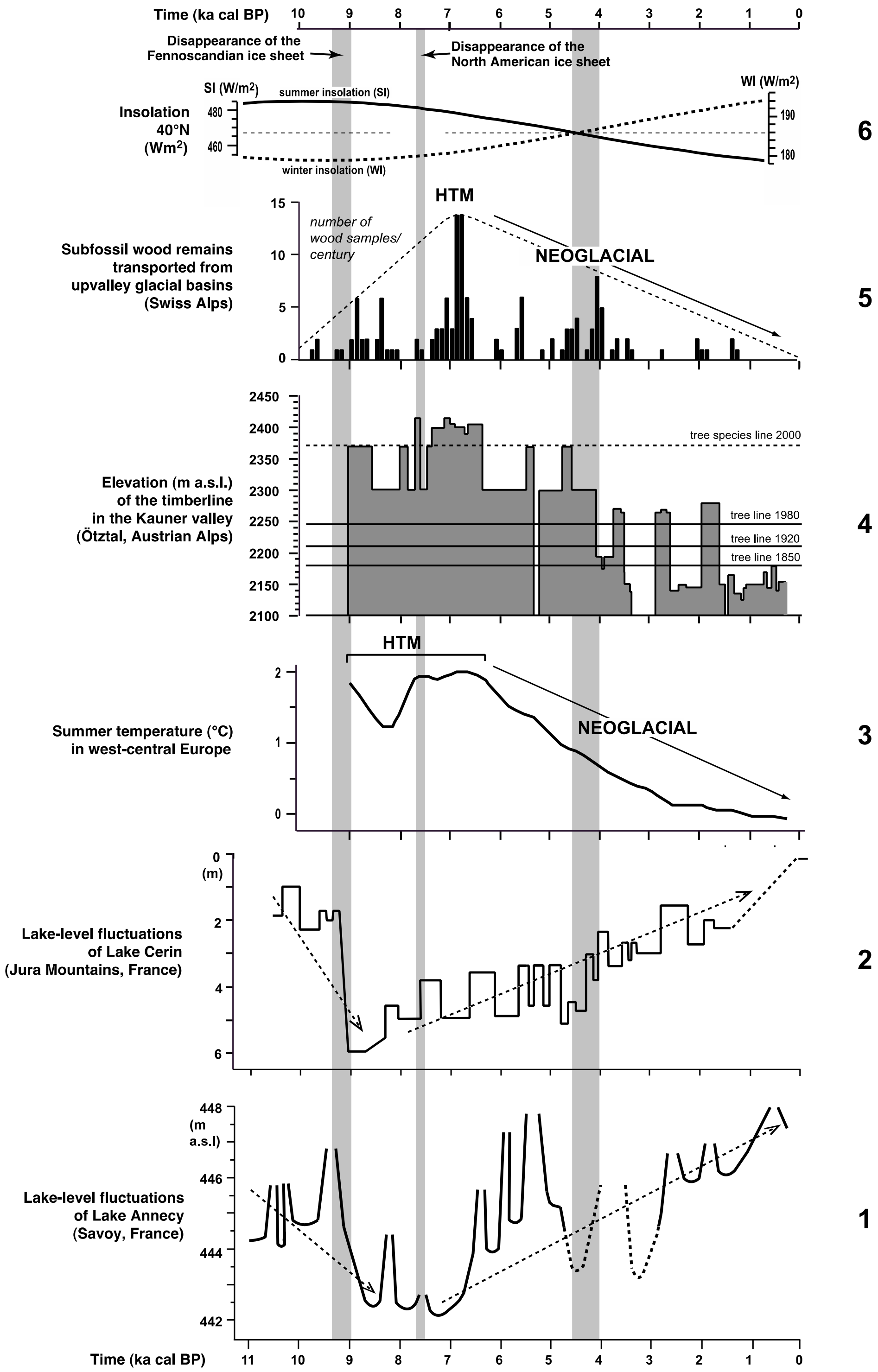

Figure 6. Comparison of (1) the Annecy lake-level record (this study) with (2) the lake-level record from Cerin in the Jura Mountains [39], (3) a mean summer temperature record in West-Central Europe [42], (4) a tree-line record from the Austrian Alps [40], (5) a glacier record from the Swiss Alps [41], and (6) the curves of insolation at 40° N [43]. HTM: Holocene thermal maximum.

In agreement with the paleoclimatic records presented in Figure 6, the Annecy lake-level record (Figure 5) indicates that the Neoglacial climatic trend began at around 7000–6500 cal BP. This is consistent with the preservation of the oldest organic archeological remains discovered to date in the high-elevation areas of the Alps, i.e., (i) a series of Neolithic artifacts found at Schnidejoch in the Bernese Alps at an altitude of 2756 m a.s.l.

and radiocarbon-dated to 7200–4000 cal BP [44] and (ii) others discovered at Gurgler Eisjoch in Süd-Tyrol/Alto Adige (Italy) at 3134 m a.s.l. and radiocarbon-dated to 6500–5700 cal BP [47]. According to Hafner et al. [48], such a preservation suggests that the prehistoric artifacts were continuously covered by ice due to Neoglacial glacier readvance until the recent rapid retreat due to present-day global warming. It can, therefore, be hypothesized that (organic) archeological remains older than those from Schnidejoch, if any, are to be found through investigations at even higher elevations, close to the possible positions of residual permanent snow or glacier tongues during the Holocene thermal maximum. Such investigations are also encouraged by the recent discovery (i) of a mummified marmot dated to ca. 6640–6450 cal BP at an altitude of 4300 m on the slopes of the Lyskamm summit in the Italian Alps [49] and (ii) of a Mesolithic rock crystal extraction site dated to 7850–7350 cal BP at the pass of Fuorcla da Strem (2820 m a.s.l.) in the Swiss Alps [50].

4.3. Multi-Centennial Lake-Level Fluctuations

As illustrated in Figure 5, the Annecy lake-level record also gives evidence of multi-centennial events defined in Section 3 and Table 2. Keeping in mind the uncertainties linked to the radiocarbon dating, Figure 5 suggests that these successive centennial-scale high-lake-level events reconstructed for the Holocene at Lake Annecy appear to be in general agreement with the regional pattern of Holocene changes in the lake levels established for West-Central Europe, i.e., the Jura Mountains, the northern French Pre-Alps, and the Swiss Plateau [25–27]. This suggests possible forcing factors linked (i) to deglacial freshwater outbursts from northern European and North American proglacial lakes during the North Atlantic deglaciation [51,52] and (ii) to a possible solar forcing, as discussed by Magny [25–27].

4.3.1. The Period of 11,700–9000 cal BP

Regarding the early Holocene, Lake Annecy phases 4 and 6 correspond to regional high-lake-level phases 14 and 13. They also coincide with deglacial outbursts [51,52] and with the Boreal oscillations defined at 10.3 and 9.2 ka by Björck et al. [53] and Fleitmann et al. [54]. The sediment hiatuses characterizing the sediment sequences of Sevrier Les Mongets and Les Charretières during the early Holocene appear to be consistent with other regional lake-level records [12], but they prevent us from identifying any high-lake-level phase possibly synchronous with the Preboreal oscillation (PBO) [55]. The large uncertainty range (i.e., 11,750–11,100 cal BP) of the radiocarbon date provided by the peaty layer observed at the site of Annecy-36 Rue Centrale (layers 3.13 and 5.13) does not allow us to establish a reliable correlation between the PBO and this lake-level phase at ca. 446.20 m a.s.l., i.e., ca. 0.80 m below the present-day lake level.

4.3.2. The Period of 9000–7000 cal BP

As concerns the Holocene climatic optimum, phases 8 and 10 correspond to the regional high-lake-level phases 12 and 11 as well as the last deglacial North American events. The bi-partite Lake Annecy phase 8 could be equivalent to that observed for the 8.2 ka event in marine and continental records [51,56]. Locally, Lake Annecy phase 8 is also synchronous with the increasing runoff marked by coarse fluvial deposits on the ancient Fier detrital fan to the northeast of Lake Annecy (the sites of 9 Avenue des Romains and 5–7 Chemin des Fins Sud; Figures 2 and 5).

4.3.3. The Period of 7000–5000 cal BP

Phases 12, 14, and 16 of Lake Annecy mark the end of the Holocene thermal maximum and the start of the Neoglacial [41]. Annecy phases 12 and 14 find equivalents in the two-part regional high-lake-level phase 10 [14,27]. Annecy phase 16 corresponds to regional phase 9. Its high magnitude appears to be consistent with the period of global-scale rapid climate change identified by Mayewski et al. [57] at around 5500 cal BP. It is also synchronous with the Alpine glacier readvance responsible for the burial and preservation of the Ötzi mummy in the Italian Alps dated to 5320–5050 cal BP (Figure 5) [38].

4.3.4. The Period of 5000–2700 cal BP

Due to the scarcity of data, it is not possible to propose a robust and precise reconstruction for the period 5000–2700 cal BP. Lake Annecy phase 18 coincides with the regional phase of high lake level 7. It is synchronous with a major climatic change associated with the 4.2 ka event at the transition between the middle and late Holocene [58] and with a reorganization of seasonal insolation [59] (Figure 6). The sediment sequence of Chindrieux-Châtillon at Lake Le Bourget (French Pre-Alps; Figure 1) provided a high-resolution record of this regional high-lake-level phase 7 composed of two successive rises in the lake level dated to ca. 4200 and 4050–3850 cal BP [60]. This climate change is well-marked in the Alps [61,62], and it coincided with the abandonment of Neolithic lake dwellings (Figure 5). On the shores of Lake Annecy, the Early Bronze Age lake dwellings of Sevrier Les Mongets (1803–1766 BCE, i.e., 3753–3717 cal BP) and Annecy-Albigny 1 (1624–1619 BCE, i.e., 3574–3569 cal BP) were built during the regional phase of low lake levels between the regional phases of high lake levels 7 and 6 (Figure 5). The latest one could correspond to the carbonate lake marl layer overlying the Early Bronze Age archeological layer at the Sevrier Les Mongets site. A magnetic susceptibility record from deep core LDA gives evidence of increases in the detrital input at ca. 4300 and 3500 cal BP [36], synchronous with the regional phases of high lake levels 7 and 6, respectively. This suggests that Annecy phase 18 comprises two distinct high-lake-level phases that preceded and followed the development of the Early Bronze Age lake dwelling of Sevrier Les Mongets, respectively. This would be consistent with the periodization of the development of the prehistoric lake dwellings characterized by the general abandonment of the shores of Lake Annecy at around 4200 and 3400 cal BP (Figure 5). As discussed above, further investigations are needed to better document the time window of 5000–2700 cal BP.

The final Bronze Age between 3150 and 2750 cal BP coincided with a new development of lake dwellings, probably favored by a lake-level lowering (Lake Annecy phase 19), as suggested by the architectural structures observed at the Sevrier-Crêt de Chatillon and Annecy-Petit Port 2 sites (Figures 2 and 5).

4.3.5. The Last 2700 Years

Regarding the last three millennia, Annecy phases 20, 22, and 24 correspond to the regional phases of high lake levels 5, 4, and 2-1, respectively (Figure 5). Annecy phase 20 was synchronous with the general abandonment of lake dwellings. It corresponds to the major, well-documented climate change at the transition between the Bronze and Iron Ages, which coincided with the Subboreal–Subatlantic transition at around 2750/2650 cal BP [63]. This climate change was also marked by a glacier readvance in the Alps [64–66]. The two successive phases of fluvial accumulation observed at Annecy-Mavéria could reflect the two episodes of glacier advance distinguished during this period in the Alps [67]. Finally, phase 24 coincided with the Little Ice Age [64,68] dated to 1260–1860 CE in the Alps [69].

The three successive Annecy phases 20, 22, and 24 clearly indicate an increase in runoff and detrital inputs, as shown by the sediment sequences of the sites studied on the northern lakeshore of the lake (Figure 3). This is supported by the deep core LDA magnetic susceptibility record, which shows a first peak of detrital inputs dated to ca. 4300 cal BP, followed by a multi-millennial trend of increasing detritism from ca. 3500 cal BP to the present day. This general trend was punctuated by two major peaks at ca. 2400 and 400 cal BP (Figure 5). This is also in agreement with the increasing sedimentation rate evidenced by the core LDA from ca. 3000 cal BP [36]. As discussed by Arnaud et al. [70,71] and Magny et al. [60,72], such an increase in detritism recognized in lake basins on a regional scale probably reflects the dual influence of the climate (late Holocene orbital forcing) and human activities (increasing deforestation since the Bronze Age) [35,73,74]. Regarding Lake Annecy, this late Holocene increasing detritism could have reinforced rises in the lake level due to possible perturbations of the lake outlet (i) by detrital inputs from slopes drained by Ruisseau de Loverchy (Figure 2) [4] and (ii) by increasing pressures on the outflow due to the development of the medieval and modern town of Annecy. Since the Neolithic period, and even more since the Bronze Age, the lake water balance may also have benefited from an increase in deforestation leading to a decreasing impact of evapotranspiration. The combination of these different processes (climate, erosion/deforestation, and evapotranspiration) could explain the paradoxical development of late Holocene lake-level maximums, which were higher than those of high-lake-level phases 2 to 6 when the Fier River was connected to Lake Annecy (Figure 5).

4.4. Lake-Level Fluctuations, Climate Changes, and Seismic Events

Seismic reflection investigations developed in the Lake Annecy basin in addition to sedimentological studies of deep cores CLIMASILAC and LDA [3,5] (Figure 2) have evidenced major changes in the sediment flux due to changes in the course of the Fier River, which disconnected from Lake Annecy through several successive steps between 11,500 and 8200 cal BP (Figures 1 and 5). As discussed by Beck et al. [5], this hydrographic change could have been due (i) to changes in the sediment load and channel form or (ii) to a possible influence of neotectonic deformation along the active Vuache fault. The present study appears to support the first hypothesis.

Indeed, the synchronism that appears in the data presented above on both the millennial and centennial scales between the Holocene water-level fluctuations of Lake Annecy and (i) other regional lake-level records as well as (ii) extra-regional paleoclimatic records suggests that the changes in the course of the Fier River (connected to or disconnected from the Lake Annecy basin) did not affect the climatic significance of the Annecy lake-level record during the early–mid-Holocene period. Such a conclusion also seems to be relevant for the late Glacial period, as noted by Magny [12]. Sediment analyses of deep core LDA have shown that the early Holocene avulsions of the Fier River occurred in a context characterized (i) by a rapid decrease in the sedimentation rate from ca. 10,000 to ca. 8600 cal BP and an abrupt drop in detrital inputs at around 9400–9200 cal BP in the deep zone of Lake Annecy [36] and (ii) by a rapid afforestation and stabilization of slopes (reduced runoff, a decrease in erosion, and an increase in evapotranspiration) in the Alpine catchment areas of both Lake Annecy and the Fier River. It is noteworthy that the last connection of the Fier River with Lake Annecy coincided with the 8.2 ka event, which was marked by an increase in the annual precipitation and associated runoff in the catchment area [14,36]. Further investigations on the Holocene stepped fluvial terraces formed by the Fier River in its valley are needed to better understand and date processes and events that determined interactions between (i) Lake Annecy and (ii) the water and sediment fluxes from the Fier River during the Holocene.

4.5. The Present-Day Climate Warming

Finally, the recent period marked by anthropogenic global warming appears to be characterized by a decrease in the water discharge of the Lake Annecy outflow of ca. 24% over the period of 1967–2020 (Figure 7) [10]. In 2018, a long summer drought led to a fall in the lake water table to 446,30 m a.s.l., i.e., ca. 0.70 m below the present-day lake level. Malacological studies have shown a recent warming of the littoral water of Lake Annecy that has been unprecedented for 6700 years [75]. The Holocene Annecy lake-level record gives evidence that the water table underwent strong fluctuations in response to past climatic changes. The data collected from the Alps and West-Central Europe suggest that the difference between the mean summer temperature during the Holocene thermal maximum (around 9000–7000 cal BP) and the pre-industrial period reached ca. 2–2.5 °C (Figure 6) [42,76]. This relatively small range of temperature changes can be compared with the rather larger range of lake-level changes that overpassed 5 m at the same time. Yao et al. [1] pointed out, on a global scale, that the amount of water stored in large lakes has considerably decreased over the last three decades. In the same way, the installations developed at Lake Annecy since the late Middle Ages to regulate the water table and control the outlet discharge may be insufficient in the near future to maintain the lake's water table at a level suitable for human activities. If the current climate warming intensifies, it could have a greater and more permanent impact on the water supply to the lake. Thus, a marked lowering of the lake level during the summer season could seriously affect the tourist activities and facilities at the lake, especially with the emergence of large spaces composed of uncomfortable soft sediment between the water basin and beach or harbor facilities.

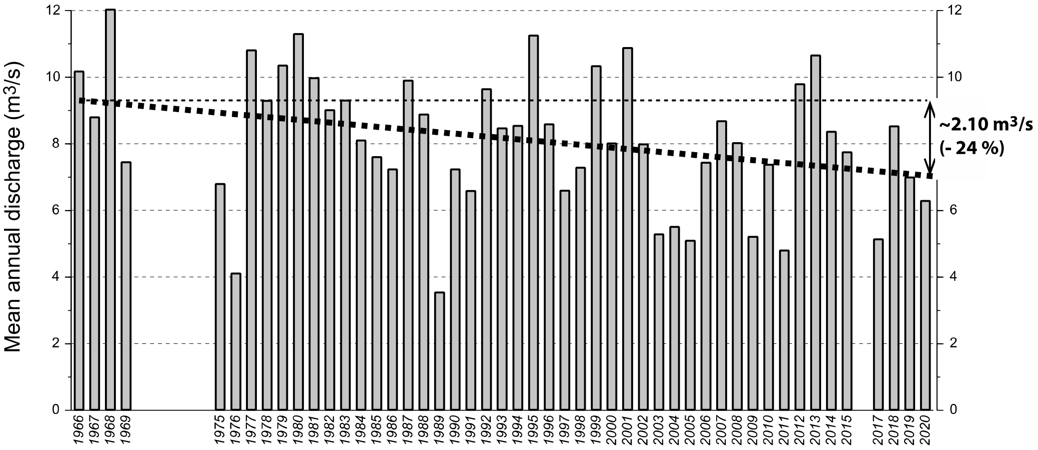

Figure 7. Variations in flow rates observed at the outlet of Lake Annecy for the period of 1967–2020 (without years 1970–1974 and 2016 undocumented; from SILA [10] for the period of 1967–2010, and the data provided by the city council of Annecy for the period of 2011–2020).

Such a prospect, characterized by a significant lowering of the water table in regional lake basins and mires as well as by an unusually rapid retreat of snow and glacier tongues in the Alps, would also directly pose an unprecedented threat to exceptional archeological remains still preserved in wetlands [17,77] and in high-elevation and permafrost areas [48,78–80], not only in Europe but also elsewhere in the world.

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References

1. Yao, F.; Livneh, B.; Rajagopalan, B.; Wang, J.; Crétaux, J.F.; Wada, Y.; Berge-Nguyen, M. Satellites reveal widespread decline in global lake water storage. *Science* **2023**, *380*, 743–749. [CrossRef] [PubMed]
2. Digerfeldt, G. Reconstruction and regional correlation of Holocene lake-level fluctuations in lake Bysjön, South Sweden. *Boreas* **1988**, *17*, 165–182. [CrossRef]
3. Van Rensbergen, P.M.; De Batist, M.; Beck, C.; Manalt, F. High-resolution seismic stratigraphy of Late Quaternary of Lake Annecy (northwestern Alps): Evolution from full glacial to interglacial sedimentary processes. *Sedim. Geol.* **2001**, *117*, 71–96. [CrossRef]
4. Nicoud, G.; Manalt, F. The lacustrine depression at Annecy (France), geological setting and Quaternary evolution. *J. Paleolim.* **2001**, *25*, 137–147. [CrossRef]
5. Beck, C.; Van Rensbergen, P.; De Batist, M.; Berthier, F.; Lallier, S.; Manalt, F. The Late Quaternary sedimentary infill of Lake Annecy (northwestern Alps): An overview from two seismic-reflection surveys. *J. Paleolim.* **2001**, *25*, 149–161. [CrossRef]
6. Oldfield, F.; Berthier, F. The multi-proxy late Pleistocene and Holocene record from the sediments of the Grand Lac d'Annecy, eastern France. *J. Paleolim.* **2001**, *25*, 133–135. [CrossRef]
7. Higgitt, S.R.; Oldfield, F.; Appleby, P.G. The record of land use change and soil erosion in the late Holocene sediments of the Petit Lac d'Annecy, eastern France. *Holocene* **1991**, *1*, 14–28. [CrossRef]
8. Jones, R.T.; Reinhardt, L.J.; Dearing, J.A.; Crook, D.; Chiverrell, R.C.; Welsh, K.E.; Verges, E. Detecting climatic signals in an anthropogenically disturbed catchment: The late-Holocene record from the Petit Lac d'Annecy, French Alps. *Holocene* **2013**, *23*, 1329–1339. [CrossRef]
9. David, F.; Farjanel, G.; Jolly, M.P. Palyno- and chronostratigraphy of a long sequence from Lac Annecy (northern outer Alps, France). *J. Paleolim.* **2001**, *25*, 259–269. [CrossRef]
10. SILA (Syndicat Intercommunal du Lac d'Annecy). *Etude écologique Relative au Rétablissement d'un Marnage sur le lac d'Annecy*; SILA (Syndicat Intercommunal du Lac d'Annecy): Cran-Gevrier, France, 2011; 223p.
11. Vérot, A.; Magny, M.; Morin, E.; Brigand, R.; Richard, H.; Marguet, A.; Gabayet, F.; Hinschberger, F.; Mevel, L. *Paléoenvironnement et Archéologie de la Rive nord du lac d'Annecy à Annecy et Annecy-le-Vieux (Haute-Savoie)*; Rapport de synthèse du PCR 2016–2020; DRAC Auvergne-Rhône-Alpes: Lyon, France, 2021; Volume 2, 440p.
12. Magny, M. Palaeohydrological changes as reflected by lake-level fluctuations in the Swiss Plateau, the Jura Mountains and the northern French Pre-Alps during the Last Glacial-Holocene transition: A regional synthesis. *Glob. Planet. Chang.* **2001**, *30*, 85–101. [CrossRef]
13. Magny, M.; Marguet, A.; Richard, H.; Billaud, Y. Early and late Holocene water-level fluctuations of Lake Annecy, France: Sediment and pollen evidence and climatic implications. *J. Paleolim.* **2001**, *25*, 215–227. [CrossRef]
14. Magny, M.; Bégeot, C.; Guiot, J.; Marguet, A.; Billaud, Y. Reconstruction and palaeoclimatic interpretation of mid-Holocene vegetation and lake-level changes at Saint-Jorioz, Lake Annecy, French Pre-Alps. *Holocene* **2003**, *13*, 265–275. [CrossRef]
15. Magny, M.; Vérot, A.; Morin, E.; Richard, H.; Hinschberger, F.; Marguet, A.; Brigand, R.; Gabayet, F. Variations du niveau du lac d'Annecy (Haute-Savoie, France) au cours de l'Holocène: Implications paléoclimatiques et archéologiques. *Quaternaire* **2022**, *33*, 169–192. [CrossRef]
16. Marguet, A. 2002—Haute-Savoie, lac d'Annecy. Elaboration de la carte archéologique des gisements du lac d'Annecy. In *Bilan Scientifique 2001*; Ministère de la Culture, Ed.; Département des Recherches Archéologiques Subaquatiques et Sous-Marines: Paris, France, 2002; pp. 116–130.
17. Marguet, A. Haute-Savoie, lac d'Annecy. Mise à jour de la carte archéologique des gisements du lac d'Annecy. In *Bilan Scientifique 2002*; Ministère de la Culture, Ed.; Département des Recherches Archéologiques Subaquatiques et Sous-Marines: Paris, France, 2003; pp. 119–125.
18. Billaud, Y.; Marguet, A. Habitats lacustres du Néolithique et de l'Age du Bronze dans les lacs alpins français: Bilan des connaissances et perspectives. In *Wetland Economies and Societies, Proceedings of the International Conference in Zürich, Switzerland, 10–13 March 2004*; Della Casa, P., Trachsel, M., Eds.; Chronos Verlag, Collectio Archaeologica: Zürich, Switzerland, 2005; Volume 3, pp. 169–178.
19. Marguet, A.; Rey, P.-J. Le Néolithique dans les lacs alpins français: Un catalogue actualisé. *Cah. D'archéologie Rom.* **2007**, *108*, 379–406.
20. Rey, P.-J.; Marguet, A. L'occupation du territoire en Savoie et Haute-Savoie au Néolithique. *Bull. D'études Préhistoriques Et Archéologiques Alp.* **2019**, *29–30*, 57–80.
21. Billaud, Y.; Brigand, R.; Raffin, M.; Subtil, M. *Suivi des Stations Palafittiques Savoyardes Inscrites au Patrimoine Mondial de l'Unesco, Campagne 2016: Bilan Documentaire*; Prospection Thématique Subaquatique lac d'Aiguebelette (Savoie) et lac d'Annecy (Haute-Savoie); DRASSM: Marseille, France, 2017.
22. Billaud, Y. Le Crêt de Chatillon–Sévrier, Lac d'Annecy. Monitoring et récentes campagnes de terrain sur un site insulaire du Bronze final. *Palafittes/Pfahlbauten/Palafitte/Koliščа/Pile Dwellings NEWS* **2020**, *1*, 40–45.
23. Brigand, R.; Billaud, Y. Le Néolithique des lacs savoyards: État des lieux et mise en perspective des prospections récentes. In *Statut des Objets, des lieux et des Hommes au Néolithique*; Fromont, N., Marchand, G., Forré, P., Eds.; Actes du 32e colloque InterNéo (Octobre 2017); Presses Chauvinoises: Le Mans, France, 2021; pp. 455–470.
24. Brigand, R. Prospection aérienne et télédétection en archéologie lacustre: Les palafittes néolithiques de la baie d'Annecy. *Bull. De La Société Préhistorique Française* **2021**, *118*, 400–404.

25. Magny, M. Holocene climatic variability as reflected by mid-European lake-level fluctuations, and its probable impact on prehistoric human settlements. *Quat. Intern.* **2004**, *113*, 65–79. [CrossRef]
26. Magny, M. Holocene fluctuations of lake levels in west-central Europe: Methods of reconstruction, regional pattern, palaeoclimatic significance and forcing factors. In *Encyclopedia of Quaternary Geology*; Elias, S., Ed.; Elsevier: Amsterdam, The Netherlands, 2006; pp. 1389–1399.
27. Magny, M. Orbital, ice-sheet and possible solar forcing of Holocene lake-level fluctuations in west-central Europe: A comment on Bleicher. *Holocene* **2013**, *23*, 1202–1212. [CrossRef]
28. Faegri, K.; Iversen, J. *Textbook of Pollen Analysis*; Hafner Publishing Co.: New York, NY, USA, 1964; 237p.
29. Troels-Smith, J. *Characterization of Unconsolidated Sediments*; C.A. Reitzels Forlag Axel Sandal: Copenhague, Denmark, 1955; 99p.
30. Brochier, J.-L. *La baie d'Auvernier, lac de Neuchâtel, Suisse: Evolution paléolimnologique et habitats préhistoriques d'après l'étude des séquences sédimentaires*; Rapport, Musée cantonal d'Archéologie: Neuchâtel, Switzerland, 1986; 83p.
31. Digerfeldt, G. Studies on past lake-level fluctuations. In *Handbook of Holocene Palaeoecology and Palaeohydrology*; Berglund, B.E., Ed.; John Wiley and Sons: New York, NY, USA, 1986; pp. 127–143.
32. Stuiver, M.; Reimer, P.J. Extended 14C database and revised CALIB radiocarbon calibration program. *Radiocarbon* **1993**, *35*, 215–230. [CrossRef]
33. Reimer, P.J.; Bard, E.; Bayliss, A.; Beck, J.W.; Blackwell, P.G.; Ramsey, C.B.; Buck, C.E.; Cheng, H.; Edwards, R.L.; Friedrich, M.; et al. Intcal 13 and Marine 13 Radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* **2013**, *55*, 1869–1887. [CrossRef]
34. Galbraith, R.F.; Roberts, R.G.; Laslett, G.M.; Yoshida, H.; Olley, J.M. Optical dating of single and multiple grains of quartz from Jinmium Rock Shelter, northern Australia: Part I, experimental design and statistical models. *Archaeometry* **1999**, *41*, 339–364. [CrossRef]
35. De Beaulieu, J.-L.; Richard, H.; Ruffaldi, P.; Clerc, J. History of vegetation, climate and human action in the French Alps and the Jura over the last 15000 years. *Dissert. Botan.* **1994**, *234*, 253–276.
36. Nomade, J. Chronologie et sédimentologie du remplissage du lac d'Annecy depuis le Tardiglaciaire: Implications paléoclimatologiques et paléohydrologiques. Ph.D. Thesis, University Joseph Fourier, Grenoble, France, 2005; 357p.
37. Hafner, A. Archaeological discoveries on Schnidejoch and at other ice sites in the European Alps. *Arctic* **2012**, *65*, 189–202. [CrossRef]
38. Magny, M.; Haas, J.N. A widespread climatic change around 5300 cal yr BP at the time of the Alpine Iceman. *J. Quat. Sci.* **2004**, *19*, 423–430. [CrossRef]
39. Magny, M.; Bossuet, G.; Ruffaldi, P.; Leroux, A.; Mouthon, J. Orbital imprint on Holocene palaeohydrological variations in west-central Europe as reflected by lake-level changes at Cerin (Jura Mountains, eastern France). *J. Quat. Sci.* **2011**, *26*, 171–177. [CrossRef]
40. Nicolussi, K.; Kaufmann, M.; Patzelt, G.; Van der Plicht, J.; Thurner, A. Holocene treeline variability in the Kauner Valley, Central Eastern Alps, indicated by dendrochronological analysis of living trees and subfossils logs. *Veg. Hist. Archaeobot.* **2005**, *14*, 221–234. [CrossRef]
41. Joerin, U.E.; Stocker, T.F.; Schlüchter, C. Multicentury glacier fluctuations in the Swiss Alps during the Holocene. *Holocene* **2006**, *16*, 697–704. [CrossRef]
42. Renssen, H.; Seppä, H.; Heiri, O.; Roche, D.; Goosse, H.; Fichefet, T. The spatial and temporal complexity of the Holocene thermal maximum. *Nat. Geosci.* **2009**, *2*, 411–414. [CrossRef]
43. Berger, A.; Loutre, M.F. Insolation values for the climate of the last 10 million of years. *Quat. Sci. Rev.* **1991**, *10*, 297–317. [CrossRef]
44. Ivy-Ochs, S.; Kerschner, H.; Maisch, M.; Christle, M. Latest Pleistocene and Holocene glacier variations in the European Alps. *Quat. Sci. Rev.* **2009**, *28*, 2137–2149. [CrossRef]
45. Johnsen, S.J.; Dahl-Jensen, D.; Gundestrup, N.; Hateffensen, J.P. Oxygen isotope and paleotemperature records from six Greenland ice-core stations: Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP. *J. Quat. Sci.* **2001**, *16*, 299–307. [CrossRef]
46. Zhang, W.; Dawes, R.; Walker, G.R. Response of mean annual evapostranspiration to vegetation changes at catchment scale. *Water Resour. Res.* **2001**, *37*, 701–708. [CrossRef]
47. Steiner, H. Brücken statt Barrieren, Südtiroler Passagen. *Z. Archäologie Dtschl.* **2021**, *21*, 22–27.
48. Hafner, A. (Ed.) *Schnidejoch und Lötschenpass. Archäologische Forschungen in de Berner Alpen*; Band 1 und 2. Archäologischer Dienst des Kantons Bern und Dienststelle für Hochbau; Denkmalpflege und Archäologie des Kantons Wallis: Bern, Switzerland, 2015.
49. Botti, V.; Tutino, S.; Paldin, A.; Samadelli, M.A. Mummified marmot at 4.300 meters: The Efisio Noussan Regional Museum of Natural Sciences takes care of its recovery, conservation, and laboratory investigations. In Proceedings of the 30th Congresso ANMS–Musei Scientifici, Ambiente, Territorio, Nuove Visioni, Obiettivi, Servizi, Relazioni per Comunità Sostenibili, Aosta, Italy, 18–21 October 2022.
50. Cornelissen, M.; Auf der Maur, C.; Reitmaier, T. A glacially preserved Mesolithic rock crystal extraction site in the Swiss Alps. *Norwegian Archaeol. Rev.* **2022**, *55*, 96–102. [CrossRef]
51. Teller, J.T.; Leverington, D.W.; Mann, J.D. Freshwater outbursts to the oceans from glacial Lake Agassiz and their role in climate change during the last deglaciation. *Quat. Sci. Rev.* **2002**, *21*, 879–887. [CrossRef]
52. Magny, M.; Bégeot, C. Hydrological changes in the European midlatitudes associated with freshwater outbursts from Lake Agassiz during the Younger Dryas event and the early Holocene. *Quat. Res.* **2004**, *61*, 181–192. [CrossRef]

53. Björck, S.; Muscheler, R.; Kromer, B.; Andresen, C.S.; Heinemeier, J.; Johnsen, S.; Conley, D.; Koç, N.; Spurk, M.; Veski, S. High-resolution analyses of an early Holocene climate event may imply decreased solar forcing as an important climate trigger. *Geology* **2001**, *29*, 1107–1110. [CrossRef]
54. Fleitmann, D.; Mudelsee, M.; Burns, S.J.; Bradley, R.S. A widespread climate anomaly at around 9200 years before present. *Paleooceanography* **2008**, *23*, PA1102. [CrossRef]
55. Björck, S.; Rundgren, M.; Ingolfsson, O.; Funder, S. The Preboreal oscillation around the Nordic seas: Terrestrial and lacustrine responses. *J. Quat. Sci.* **1997**, *12*, 455–465. [CrossRef]
56. Nesje, A.; Dahl, S.O. The Greenland 8200 cal yr event detected in loss-on-ignition profiles in Norwegian lacustrine sediment sequences. *J. Quat. Sci.* **2001**, *16*, 155–166. [CrossRef]
57. Mayewski, P.A.; Rohling, E.E.; Stager, J.C.; Neider, R.; Steig, E. Holocene climate variability. *Quat. Res.* **2004**, *62*, 243–255. [CrossRef]
58. Walker, M.; Berkelhammer, M.; Björck, S.; Cwynar, L.; Fisher, D.; Long, A.; Lowe, J.; Newnham, R.; Rasmussen, S.; Weiss, H. Formal subdivision of the Holocene series/epoch: A discussion paper by a working group of INTIMATE. *J. Quat. Sci.* **2012**, *27*, 649–659. [CrossRef]
59. Zhao, C.; Yu, Z.; Zhao, Y. Holocene climate trend, variability, and shift documented by lacustrine stable-isotope record in the northeastern United Stated. *Quat. Sci. Rev.* **2010**, *29*, 1831–1843. [CrossRef]
60. Magny, M.; Arnaud, F.; Billaud, Y.; Marguet, A. Lake-level fluctuations at Lake Bourget (eastern France) around 4500-3500 cal. BP and their palaeoclimatic and archaeological implications. *J. Quat. Sci.* **2012**, *26*, 171–177. [CrossRef]
61. Brisset, T.E.; Miramont, C.; Guiter, F.; Anthony, E.J.; Tachikawa, K.; Poulenard, J.; Arnaud, F.; Delhon, C.; Meunier, J.D.; Bard, E.; et al. Non-reversible geosystem destabilisation at 4200 cal. BP: Sedimentological, geochimical and botanical markers of soil erosion recorded in a Mediterranean alpine lake. *Holocene* **2013**, *23*, 1863–1874. [CrossRef]
62. Le Roy, M.; Deline, P.; Carcaillet, J.; Schimmelpfennig, I.; Ermini, M.; ASTER Team. ^{10}Be exposure dating of the timing of Neoglacial glacier advances in the Ecrins-Pelvoux massif, southern French Alps. *Quat. Sci. Rev.* **2017**, *178*, 118–138. [CrossRef]
63. Van Geel, B.; Buurman, J.; Waterbolk, H.T. Archaeological and palaeoecological indications of an abrupt climate change in The Netherlands, and evidence for climatological teleconnections around 2650 BP. *J. Quat. Sci.* **1996**, *11*, 451–460. [CrossRef]
64. Holzhauser, H.; Magny, M.; Zumbühl, H.J. Glacier and lake-level variations in west-central Europe over the last 3500 years. *Holocene* **2005**, *15*, 789–801. [CrossRef]
65. Debret, M.; Chapron, E.; Desmet, M.; Rolland-Revel, M.; Magand, O.; Trentesaux, A.; Bout-Roumazeilles, V.; Nomade, J.; Arnaud, F. North western Alps Holocene paleohydrology recorded by flooding activity in Lake Le Bourget (France) and possible relations with Mont-Blanc glaciers fluctuations. *Quat. Sci. Rev.* **2010**, *29*, 2185–2200. [CrossRef]
66. Simonneau, A.; Chapron, E.; Garcon, M.; Winiarski, T.; Graz, Y.; Chauvel, C.; Debret, M.; Motelica-Heino, M.; Desmet, M.; Di Giovanni, C. Tracking Holocene glacial and high-altitude alpine environments fluctuations from minerogenic and organic markers in proglacial lake sediments (Lake Blanc Huez, Western French Alps). *Quat. Sci. Rev.* **2014**, *89*, 27–43. [CrossRef]
67. Le Roy, M.; Nicolussi, K.; Deline, P.; Astrade, L.; Edouard, J.L.; Miramont, C.; Arnaud, F. Calendar-dated glacier variations in the Western European Alps during the Neoglacial: The Mer de Glace record, Mont Blanc Massif. *Quat. Sci. Rev.* **2015**, *108*, 1–22. [CrossRef]
68. Mann, M.E.; Zhang, Z.; Hughes, M.K.; Bradley, R.S.; Miller, S.K.; Rutherford, S.; Fenbiao, N. Proxy-based reconstructions of hemispheric and global surface temperature variations over the last two millennia. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 13252–13257. [CrossRef] [PubMed]
69. Nicolussi, K.; Le Roy, M.; Schlüchter, C.; Stoffel, M.; Wacker, L. The glacier advance at the onset of the Little Ice Age in the Alps: New evidence from Mont Miné and Morteratsch glaciers. *Holocene* **2022**, *32*, 624–638. [CrossRef]
70. Arnaud, F.; Revillon, S.; Debret, M.; Revel, M.; Chapron, E.; Jacob, J.; Giguet-Covex, C.; Poulenard, J.; Magny, M. Lake Bourget regional erosion patterns reconstruction reveals Holocene NW European Alps soil evolution and paleohydrology. *Quat. Sci. Rev.* **2012**, *51*, 81–92. [CrossRef]
71. Arnaud, F.; Poulenard, J.; Giguet-Covex, C.; Wilhelm, B.; Revillon, S.; Jenny, J.P.; Revel, M.; Enters, D.; Bajard, M.; Fouinat, L.; et al. Erosion under climate and human pressures: An alpine lake sediment perspective. *Quat. Sci. Rev.* **2016**, *152*, 1–18. [CrossRef]
72. Magny, M.; Leroux, A.; Bichet, V.; Gauthier, E.; Richard, H.; Walter-Simonnet, A.V. Climate, vegetation and land use as drivers of Holocene sedimentation: A case study from Lake Saint-Point (Jura Mountains, eastern France). *Holocene* **2012**, *23*, 137–147. [CrossRef]
73. Gauthier, E.; Richard, H. Bronze Age at Lake Bourget (NW Alps, France): Vegetation, human impact and climatic change. *Quat. Intern.* **2009**, *200*, 111–119. [CrossRef]
74. Noël, H.; Garbolino, E.; Brauer, A.; Lallier-Vergès, E.; de Beaulieu, J.-L. Human impact and soil erosion during the last 5000 yrs as recorded in lacustrine sedimentary organic matter at Lac d'Annecy, the French Alps. *J. Paleolim.* **2001**, *25*, 229–244. [CrossRef]
75. Mouthon, J.; Magny, M. Malacological history of Lake Annecy (France): A comparison of Late Holocene (since 4700 BC) and present mollusc assemblages. *Arch. Hydrobiol.* **2004**, *160*, 555–573. [CrossRef]
76. Heiri, O.; Ilyashuk, B.; Millet, L.; Samartin, S.; Lotter, A. Stacking of discontinuous regional palaeoclimatic records: Chironomid-based summer temperatures from the Alpine region. *Holocene* **2015**, *25*, 137–149. [CrossRef]
77. Della Casa, P.; Trachsel, M. Wes'04. Wetland Economies and Societies. In Proceedings of the International Conference, Zürich, Switzerland, 10–13 March 2004; Chronos Verlag, Collectio Archaeologica: Zürich, Switzerland, 2005.

78. Thirault, E. Découvertes et périls pour l'archéologie en altitude dans les Alpes. Dérèglement climatique. Péril sur le patrimoine. *Dossiers d'Archéol.* **2020**, *401*, 22–25.
79. Thirault, E. Mines et glaciers: Nouvelles perspectives de recherche en Préhistoire dans les Alpes françaises. In *Archéologie en Milieu de Montagne Dans la région Auvergne-Rhône-Alpes*; Surmely, F., Ed.; Actes de la Table Ronde du 6 décembre 2019 à Clermont-Ferrand; Presses universitaires Blaise-Pascal (collection Terra Mater, 4): Clermont-Ferrand, France, 2022; pp. 19–53.
80. Reitmaier, T. (Ed.) *Gletscher-archäologie. Kulturerbe in Zeiten des Klimawandels*; Zeitschrift Archäologie in Deutschland: Darmstadt, Germany, 2021.