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Climate of the Past Discussions

Interactive comment on "Multidisciplinary distinction of mass-movement and flood-induced deposits in lacustrine environments: implications for Holocene palaeohydrology and natural hazards (Lake Ledro, Southern Alps, Italy)" *by* A. Simonneau et al.

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Subject: Submission of the revised version of manuscript number Clim. Past Discuss.,

8, 3205-3249, 2012, accepted with major revisions in Climate of the Past.

Dear Mrs Nebout, Please find attached the revised version of our manuscript entitled “Multidisciplinary distinction of mass-movement and flood-induced deposits in lacustrine environments: implication for Holocene Palaeohydrology and natural hazards (Lake Ledro, Southern Alps, Italy)”, accepted for publication in the Special Issue “Holocene changes in environment and climate in the central Mediterranean as reflected by lake and marine records” in Climate of the Past. In this revised version of the manuscript we addressed all the remarks from the three reviewers whom we would like to thank for their constructive comments. As suggested, we reorganized the manuscript, clarified the composition of the background sedimentation and deleated our estimations of past precipitations for extreme flash-flood events. As a result, the paper is now slightly shortened and more focused. All other suggestions to improve the text or figures were taken into consideration and the responses to specific remarks are listed in the following point-by-point response.

Yours sincerely, Anaëlle Simonneau and co-authors

Reviewer # RC C2685 : B Wagner

Overall, this is an interesting study, which provides some information on the generation of mass wasting deposits and flooding events in Lake Ledro, Italy. The study is very complex and can be used as a nice example for similar studies in other lakes. However, the manuscript would benefit from some distinct changes. In some parts, the manuscript is too long and needs distinct shortening. On the other hand, important information is missing in this paper and should be added here. For example, the description of the background sedimentation and the age model must be included.

Referring to already published data is not sufficient, as it is substantial for the understanding of processes and the definition of SEs. Therefore some major revisions (and some minor) revisions are needed. One might consider splitting the manuscript into two papers, one with a focus on earthquake history and mass wasting deposits and one

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on the Holocene lake hydrology including catchment vegetation and flooding events. The better solution would be a complete re-structuring of the manuscript, with (i) a detailed description of the background /overall sedimentation including QOP data and a (reduced) chronology and (ii) the focus on event horizons, as promised in the title.

Some more detailed comments are given below:

1- Title and abstract: Generally ok, but both would benefit from shortening. The abstract is now slightly shorter.

2- Title suggestion: Mass-movement and flood-induced deposits in Lake Ledro, Southern Alps, Italy: implications for Holocene palaeohydrology and natural hazards As suggested by Reviewer # RC C2685, the title has been shortened and modified as follow: "Mass-movement and flood-induced deposits in Lake Ledro, Southern Alps, Italy: implications for Holocene palaeohydrology and natural hazards".

Methods: 3- Although the manuscript states that the chronology of the core is presented in another paper of the special issue, it is hard to follow the timing of mass movement events and flood events, if one needs to check the other paper. Therefore I strongly suggest to include at least a table with 14C ages and/or indicate ages in Fig. 3. There is no need here to discuss the ages in detail, if the chronology is reliable, so only the presentation of the data should facilitate reading significantly.

As suggested by Reviewer # RC C2685, we added a new table numbered Table 2, with the 14C ages obtained for cores LL081 and LL082. We also precised it into the text, section 3, line 5, page 3211, as follow: "Age-depth models of lacustrine cores are based on gamma-spectroscopic radionuclide measurements (137Cs, 210Pb) on core LL082 and 19 AMS radiocarbon dates (6 on LL082 and 13 on LL081, Figure 3A) that are reported in Table 2 and discussed in Vannière et al. (this issue)." As a consequence, we also substituted all the former "Table 2" by "Table 3".

Moreover, we also modified the figure 3a and added the ages.

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Results: 4- Chapter 4.1 : p3213, 12: Which event horizons? All of them?

Only the thickest light-coloured events can clearly observe on seismic profiles (corresponding to transparent to chaotic bodies or the hummocky surface) and are picked as seismic-stratigraphic horizons. These events correspond to light-coloured SE 1, 4, 5, 6, 9, 11, 12, 13 and 14 identified in both sedimentary sequences LL082 and LL081. To add precision about this aspect, we changed the sentence in section 4.1, lines 11 to 12, page 3213, as follow: “They represent isochrones and coincide with the thickest sedimentary events (SE) recognized in LL082 and LL081 (SE 1, 4, 5, 6, 9, 11, 12, 13 and 14 , Table 3, Figures 2 and 3a).”

5- Chapter 4.2.: It is hard to follow the chronology without having seen any data (insert Table or add ages in Figure 3).

As previously mentioned, we added both a new table, labelled Table 2, with the 14C ages obtained for cores LL081 and LL082, and the 14C ages on figure 3a.

6- It is also confusing that the cores according to the Methods chapter are 14.6 and 9.9 m long, but in 4. 2 is a statement that the cores "are composed of Holocene sedimentary sequences of 11.7 and 6.9 m. So what forms the lowermost part? Pre-Holocene?

The description in the onset of chapter 4.2 jumps between times and depths; reading would be easier, if you would only refer to depth (with ages in brackets or vice versa). As suggested by Reviewer # RC C2685, we improved the section 4.2, lines 14 to 21, page 3213, precising that the lowermost part of the two sequences is dating from Pre-Holocene and referring the depths in brackets.

We modified the sentences as follow: “Cores LL081 and LL082 are mainly composed of Holocene sedimentary sequences reaching 6.9 m and 11.70 m length, respectively. Before 9000 cal. yrs BP and back to 13300 cal. years BP (i.e. below 620 and 970 cm core depth in core LL081 and LL082, respectively), the background sediment is

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not laminated and is only interrupted by few SE (Figure 3a). After 9000 cal. yrs BP and back to now (i.e. above 620 and 970 cm core depth in cores LL081 and LL082, respectively), the succession becomes finely laminated in the background sediment."

8- As the sedimentological description of the cores apparently needs to be improved in the Vanniere et al. paper (see comments for this paper in CPD), it is necessary to describe here exactly, what is "normal" Holocene sedimentation and what are SE events?

Accordingly, we added a synthetic description of both the background sedimentation and the SE in section 4.2, page 3213

9- How can SE events be separated from short-term climate events (e.g. 8.2 ka cooling event)?

As suggested by Reviewer # RC C2685, line 21, page 3213, we added this sentence: "In both cores, SE interrupt this annual succession. SE are characterized by specific colour, bulk density and grain-size (Figures 3 and 4), clearly contrasting with the background sedimentation."

10- The manuscript would benefit from a little bit more detailed description of the sediment characteristics (probably also a modification of the sub-chapter title is needed).

As suggested by Reviewer # RC C2685, we substituted the title of section 4.2 by "Physical properties of the lacustrine sediment and the sedimentary events".

As mentioned comment 8, we modified the section 4.2 and added a concise description of the background sedimentation. This aspect will be detailled in another publication in preparation (Stefanie B. Wirth, Adrian Gilli, Anaëlle Simonneau, Daniel Ariztegui, Boris Vannière, Lukas Glur, Emmanuel Chapron, Michel Magny & Flavio S. Anselmetti, Seasonality of floods in Northern Italy during the past 2100 years: Interplay of solar forcing, variations in NAO, and ENSO influence), yet available in the Stefanie Wirth's PhD thesis: Stefanie B. Wirth (2012) "The Holocene flood history of the Central Alps

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reconstructed from lacustrine sediments: Frequency, intensity and controlling climate factors", Chapter 4. Dissertation ETH No. 20860, ETH Zurich, Zurich, Switzerland.

11- It is not clear, why the number of dark-coloured SE is based on horizons > 1 cm, those of light-coloured SE > 1.5 cm. This also can affect the number of events in total and averages.

To clarify this point, we included the following sentence, line 3, page 3214: "For analytical reasons, only SE thicker than 1 cm could be sampled, and are considered in the following sections. It means that we are here not discussing minor events (below 1 cm) which are included in the study of Vannière et al. (this issue)."

12- Last sentence: move mean grain size of dark coloured SE to the dark-coulored SE paragraph before.

Accordingly, this sentence is now moved to line 16 , page 3214.

13- Chapter 4.3: p 3215, 3-4 size of gravel is generally defined (2-63 mm), so do you mean gravel or blocks or boths? (see also page 3214, 27)

As suggested by Reviewer # RC C2685, we modified the sentence lines 1 to 4, page 3215 as follow: "They are located in forested areas, do not exceed 70 cm in thickness and form over fissured limestone bearing up to 80% of gravels".

14- p 3215, 16 first part of the sentence should be moved into methods chapter

Accordingly, we shortened the sentence in the section 4.3, line 16, page 3215, deleting the first part of the sentence which has been added in section 3, line 11, page 3212.

Discussion: 15- General: there is no need to refer to the legend of figures in the main text, so modify for example (white circles, Fig. 10) to (Fig. 10).

As suggested by Reviewer # RC C2685, we simplified the text for figures 6 and 10 where we mentioned "white circles", "black squares", etc... (lines 24 and 25, P3215; lines 8, 9, 23 and 27, P3224; lines 10 and 17, P3225; line 1, P3226).

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Accordingly, we modified the figure caption 6 adding the sentence: “White triangles and black squares represent samples taken in light-coloured events or in dark-coloured ones, respectively. Samples taken within the background sedimentation are represented by white diamonds.”

The discussion would benefit from a bit shortening, with a clearer focus on relevant statements and would also need restructuring (see above).

16- p3217, 4 ff I canot remember that the background sedimentation was adequately described, so please add

This comment refers to the organic composition of the light-coloured SE. To clarify this organic characterization, we slightly modified sentence line 4, page 3217, as follow: “Light-coloured SE are mainly composed of gAP similar to the ones observed throughout the background sediment and previously identified as resulting of algal growth in the lake waters. This therefore suggests a common origin between the two sedimentary facies.”.

Indeed, we already precised the organic composition of the background sedimentation at the beginning of section 5.1, lines 14-15, page 3216 , and lines 20-22, page 3215.

17- p3217, 13-17 rewrite and make 2 sentences

As suggested by Reviewer # RC C2685, we divided the sentence as follow: “The constant mean grain-size and the stable values of sorting in these light-coloured SE (Figure 4b) are in addition typical of mass-flow deposits (Mulder and Cochonat, 1996). The latter are therefore interpreted as distal mass-flow deposits. Event 1, only identified in core LL082 (Figure 3a), is composed of tilted finely laminated sediments.”

18- p3218, 3 according to Figure 8 mass wasting deposits 2 and 3 have less than 1.5 cm thicknesses

No, as already indicated in Table 3 (former Table 2), these events are 1.5 cm thick not less.

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19- p3218, 23 ff you state that the number of mass movement deposits increased during the last 5000 kal yr BP, likely due to or promoted by a lake level highstand. However, apparently the number of earthquakes increased (Fig. 8) and this could be the main driving factor.

We agree with this comment, and added at the end of this paragraph (line 2, page 3219) the following sentence: “Otherwise, this could also result from a higher seismicity of the last 5000 years.”

20- p3224 ,7ff The entire paragraph is a general discussion of the QOP data, without discussing the data obtained in this study. So it should be either moved to the methods or to those paragraphs later in the text, when it is relevant in the discussion. The discussion of the Holocene changes is much too long and does not really matches with the title of the paper. Shortening of the discussion and a focus on SE is needed or better re-structuring as described above.

Following the comment of Reviewer # RC C2685, section 5.1.3 (lines 7-24, page 3224) has been shorten (lines 9 to 13 and 22 to 24 are now deleted) since indeed it was already partly mentioned in section 3 (lines 12 to 29, page 3211).

Figures and tables: Figure 1 is somewhat overloaded. The figure could benefit from deleting the photos, not clear, what colours in Fig 1 B indicate, what is Thalweg?, what is grey (5-30% slope?)?

This figure 1B has been clarified: grey areas (slope 5-30%) are now in the figure caption and we specified that thalweg documented by negative curvature index, are focusing eroded soils along steep slopes (grey areas).

Figure 2 : indicate length of all cores in all profiles

This is now done when possible.

Figure 3: 3a: Photos at the left side are too small to allow recognizing any details, enlarge (probably new figure or delete and refer to Fig 3 b and c)

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This figure was not properly edited in the CPD manuscript (missing 3B and 3C sections and associated figure caption). However, following the reviewer comment, this figure is now modified to enlarge the photos at the left side (b) in order to better describe background sedimentation (c.f. reviewer's comment 16).

Figure 6b: red squares (clay reach dark-coloured SE) need to be explained in the legend or in the figure caption.

This has been added in the figure caption as follow: "In this diagram, the red squares represent samples taken in the clay caps which cover the top of two dark-coloured events".

Table 2 hard to follow the number of mass wasting deposits without having seen data. See also comments to the missing ages or age model.

This is now clarified with a new Table 2 (14C ages) and Table 3 (former table 2).

Please also note the supplement to this comment:

P3209 : The sentence has been changed as follow: "The drainage basin of Lake Ledro covers 111 km^2, culminates at 2254m above sea level (m a.s.l.) and is today influenced by a subcontinental climate characterized by mean total annual precipitations of 900 mm, mean annual temperature of 8°C and 20 significant snowfalls in winter above 1500ma.s.l. (Beug, 1964)."

P3218 : The word " historical" has been removed, and the word "that" has been replaced by "which", in the sentence : "Light-coloured SE 4 (Fig. 4b) is dated to 905$\pm$130 cal. yr BP (1045AD$\pm$130) and associated with numerous coeval mass movements along the basin slopes (Fig. 7d, Table 2), which is the typical signature of large earthquakes in lakes (Schnellmann et al., 2002; Lauterbach 10 et al., 2012).

P3226 : The word "were" have been replaced by "was" in the sentence : "In flood SE, a high rAP/LCF ratio is measured (Fig. 10c) suggesting that the material from open landscapes was remobilized. ".

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Reviewer #RC C2713

The manuscript of Simonneau et al., about "Multidisciplinary distinction of massmovement and flood-induced deposits in lacustrine environments: implications for Holocene palaeohydrology and natural hazards (Lake Ledro, Southern Alps, Italy)", provides a reconstruction of frequency of flood layers and mass-movement based on a laminated lacustrine record from Northern Italy. This reconstruction is mostly based on sedimentological and organic matter proxies. The methodological part of this paper about the identification of flood and mass-movement is interesting as well as the part about mass-movement chronicle compared to the Iseo record. But the part other parts of the manuscript are too much speculative (part 5.2 and the beginning of the part 5.3, see major comment 9 and 10) or not related to the scientific question (part 5.3.1, 5.3.2, 5.3.3, 5.3.4, 5.3.5, see major comment 8), there are also some structural problem in the manuscript with not enough sedimentological data (see major comment 2 and 3) and methodological problem about flood chronicle (see major comments 4, 11). When we take into consideration all these major comments (see below) I propose to reject this manuscript for publication in Climate of the Past.

My major comments are focused on 11 points of the manuscript:

1/ What is the effect of alluvial plain on the flood record? Flood event record in the sediment core at a precise location was probably not the same in the past when the alluvial plain was located beyond it present position.

Alluvial plains in Lake Ledro catchment area are resulting from the progradation of the Massangla and the Pur deltas (as given in section 2, lines 7 to 10 page 3210). This general comment of reviewer RC C2713 supposes that flood thicknesses during the Holocene are depending essentially on the delta proximity. This is not supported by Figure 10b and suggests that flood thicknesses (dark-coloured events) are more depending on the intensity of the hyperpycnal current than the proximity of the deltas.

The effets of the alluvial plain (0 to 5% slope area, Figure 1B) are also discussed in

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section 5.2, lines 9-13 page 3221. Generally speaking, the alluvial plain is acting as a sediment trap (storage) and a sediment source (erosion and transport) during flood events. Firstly, it is thus not a specific organic sediment source. Secondly, it is not a significant organic sediment source here, since, as shown in figure 1B, Lake Ledro tributaries are very torrential (very coarse bedload deposits) and only active during flood events. Such fluvial regime reduces storage of fine-grained sediment in the river bed and our study suggests that the main organic sediment sources of Lake Ledro flood deposits are soils located on steep slopes from higher altitude forested or grassland areas (as mentionned in sections 5.2 and 5.3).

2/ In this paper there are not sedimentological description of background sedimentation, why this sedimentation was laminated or not? Do you have smear slide in these units to precisely describe the lamination and the difference between both sedimentation?

To address this comment (and also the first reviewer comment 8), a new paragraph is given section 4.2 and figure 3 has been improved to illustrate these laminated sedimentary facies.

Background sedimentation will in addition be detailled in another publication in preparation: Wirth, Gilli, Simonneau, Ariztegui, Vannière, Glur, Chapron, Magny & Anselmetti, "Seasonality of floods in Northern Italy during the past 2100 years: Interplay of solar forcing, variations in NAO, and ENSO influence", yet available in the Stefanie Wirth's PhD thesis: Stefanie B. Wirth (2012) "The Holocene flood history of the Central Alps reconstructed from lacustrine sediments: Frequency, intensity and controlling climate factors", Chapter 4. Dissertation ETH No. 20860, ETH Zurich, Zurich, Switzerland.

3/ The QOP description have to be moved in the methodological part.

This comment of Reviewer #RC C2713 is unclear because QOP is detailled in section 3, lines 6 to 14, page 3212, and because this study greatly benefits from careful interpretation of QOP data from SE and background sediments. We thus think that it

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is necessary to keep section 4.3 in the results section and to discuss these results in section 5.

4/ Why the authors take into consideration events > 1,5 cm for light coloured SE and 1 cm for dark-coloured SE? Any sedimentological argument for that?

As mentioned section 4.2, line 3, page 3214, we added the following sentence to clarify this point: “For analytical reasons, only SE thicker than 1 cm could be sampled, and are considered in the following sections. It means that we are here not discussing minor events (below 1 cm) which are included in the study of Vannière et al. (this issue).”

The thickness of flood deposit could be influenced by the land used : a flood of 0,5 cm during a period of low land use and a flood of 3 cm during a period of high land use could be related to the same amount of precipitation. Thus if the authors take in consideration only flood > 1 cm this limit is not related to an amount of precipitation and the flood chronicle cannot directly compared to other climatic proxies. We fully agree with the general comment concerning a possible link between land-use and flood thickness (section 5.3.4, lines 1 to 4, page 3227). In section 5, we use organic results to track potential human impacts on vegetation cover. Land-use is in addition discussed based on pollen data on core LL081 by Joannin et al. (this issue).

We agree and for this reason, Vanniere et al (this issue) takes into consideration all the flood deposits using an automatic method in order to discuss the respective contribution of climate and human impacts. Our paper taking into consideration only major events is thus complementary to Vannière et al. paper (see above general comment 11, first reviewer).

5/ What is the resolution of the seismic data? The authors correlate 5 cm thick SE to seismic reflector, thus do you have a sufficient high resolution to make this type of correlation?

As shown in figure 3, some SE are producing abrupt changes in bulk density. This

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physical parameter is strongly controlling the acoustic impedance (the product of density and sound velocity) and thus the generation of acoustic reflections. In such a context it is thus possible to correlate a relatively thin SE (below 10 cm thick) with a continuous reflection that can be mapped accross the deep central basin, based on 3.5 kHz seismic data. In Lake Ledro, this is in particular the case for several light-coloured flood deposits.

Moreover, P3217L17 : If the SE 1 was too thin (12cm) to be correlated to seismic reflector, I thinks that all light coloured events cannot be identified in seismic data because they ranging between (1,5 and 13cm) P3214L18, thus how did you define your correlation between sediment and seismic? For example how an event of 5 cm thick (event 5) can be identified in seismic? Light-coloured mass-wasting deposits are not specially characterized by abrupt changes in bulk density on sediment cores. They are thus difficult to identify on seismic profiles. However, as explained in section 4.1, lines 4 to 14, page 3213, light-coloured SE are always matching a seismic reflection laterally associated with larger coeval chaotic lenses reflecting mass-wasting processes along the shores of Lake Ledro. For example, event 5 (4.4 cm thick, new table 3) is clearly stratigraphically linked with a large chaotic body identified along Lake Ledro shore near its outlet (figures 2C and 2E). In total, up to three coeval chaotic bodies can be stratigraphically linked with event 5, strongly suggesting that this event has been triggered by a regional earthquake (new table 3).

These interpretations are further supported by figure 7 and new table 3 illustrating the very contrasted geometries and sources areas of large to very large flood (event J) and earthquake-triggered slide deposits (SE 4 and 11).

6/ Please clearly indicate in the manuscript the SE indexation between number (light) and letter (Dark).

To clarify this point, we added section 4.2, lines 4 and 17 page 3214, that dark-coloured SE and light-coloured SE are labelled by letters or by numbers, respectively, as follow:

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(line 4, page 3214) “Dark-coloured SE (labelled by letters) are graded beds...” and (line 17 page 3214) “Light-coloured SE (labelled by numbers) thicker than 1.5 cm...”.

7/ It is not clear in seismic profile, if mass-movement are triggered from the Eastern part of the lake or not, i.e. the eastern part of the Lake have probably a sediment accumulation lower than the rest of the lake because furthest from the main source of sediment, thus this part was probably less unstable. Clarify this question.

The eastern source area for earthquake-triggered slides is clearly shown in figure 7D and 7E mapping the extention of mass-wasting deposits 4 and 11. This figure also shows limited instabilities near the deltas (along the western and the southern slopes). This is suggesting that the location of slides is mainly controlled by the angles of the subaquatic slopes and also eventually by the accumulation of clastic sediments close to the lake outlet during large flood events in such a small lake. However, the stability of Lake Ledro sediments along the slopes can only be addressed by additional sediment cores and is thus beyong the scope of this paper.

8/ The main part of the discussion (section 5.3) is for me not related to the scientific question about Holocene palaeohydrology and natural hazards.

We don’t understand this comment because section 5.3 addresses the “climatic significance of flash-flood deposits in Lake Ledro” which is one of the goals of this paper.

This part discuss about environmental changes on the watershed and not about the chronicle of flood or mass-movement events as suggest by the Title. The chronology of SE is discussed in the former section 5.1. To fully answer the reviewer comment, we modified section 5.3 and deleated lines 13 to 26, page 3222, dealing with the tentative quantification of precipitation regimes associated with flood deposits.

If environmental changes are need to understand flood chronicle (with a discussion about variation of thickness or petrographic content of deposits) Ok, but it was not presented like this in the paper. Moreover flood frequency is studied in detail in another

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paper in the same issue that consider all events (Vannière et al. submitted), I'm not sure that this part of the manuscript bring more information than the other manuscript on this topic. In the present paper, we determine the sediment source of catastrophic SE (flood and earthquake-triggered slides) and discuss their reccurence during the Holocene. This paper is thus complementary to Vannière et al. Paper only documenting the frequency of the flood events.

Finally if this paper the flood > 1 cm were studied thus the flood chronicle was biased see above main comment number 4. The flood chronicle is the main objective of Vannière et al paper. Our paper allows to identify dominating sedimentary processes in Lake Ledro and to focus on catastrophic SE in order to address natural hazards in this key area submitted both to storms and strong earthquakes. For this reason, we focussed our study on the thickest SE.

9/ Part 5.2: This part is very very confusing with a lot of non-scientific approximation: a/ As you demonstrate by your correlation in figure 3 the thickness of flood event was not constant over the deeper part of the basin, moreover the author's argue also that hyperpycnite at a given location is linked to many parameters (P3219L18-19). Thus it is not correct to calculate a mean thickness of a flood event over a part of the lake basin or at least to associate this value to an uncertainty probably bigger than the calculated value.

We estimated that only 7% of the flood event volume was underestimated by this approach. This is now clearly mentionned in section 5.2, at the end of second paragraph, by the following sentence: "Such an approach is only slightly underestimating (by 7%) the accurate volume of event J which could be precisely mapped on seismic sections (Figure 7B)."

b/ P3320L27 author's make another big assumption, with a relation between the amount of rAP in a flood deposit and the amount of material from the watershed. This relation was not demonstrated in the paper.

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As shown in figure 6, and lines 8 to 9, page 3216, statistics performed on quantitative organic petrography results show that dark-coloured events (that are flood deposits) are “essentially composed of rAP”. In these events, the autochtonous algal production (represented by the gAP particles in quantitative organic petrography) only represents 12% (line 9, page 3216). We therefore consider that 88% of the event is composed of allochtonous components. To clarify this point, we corrected the lines 20-21, page 3221 as follow: “It is on average composed of 90 % of allochtonous components which correspond to 53460 m3 of accumulated terrestrial material.”

We also modified the figure 3 to clarify the organic composition of the different facies observed in Lake Ledro lacustrine sequences.

c/ in figure 9 the author’s try to estimate the proportion of sheet vs gully erosion, but in this case we cannot considerate the same density: the density of soil was very low in the first mm and strongly increase with the depth, thus if the watershed was submitted to sheet or gully erosion the density vary strongly probably more than a factor 2 (i.e.: more deeper was the erosion more dense was the soil), thus add an uncertainty to this estimation.

We fully understand this comment, however, as precised lines 20-21, page 3220, the density measurements performed on each soil layers of each profiles sampled “vary from 1.04 to 1.7 g.cm-3”, indicating that soil density is essentially linked with its nature more than its thickness.

d/ The erosive zone was defined by author’s as controlled by two process (slope >30_ and gullying) ok but what is the type of soil eroded litter, leptosol, cambiosol, these differents soils have of course an implication on the model (density of these types of soil was not the same). thus as no uncertainty are integrated in this model in relation to the previous cited assumption the eroded area calculated cannot be rigorous. If the author’s test the sensitivity of this model their probably find a huge uncertainty.

According to Cerda (1999), it is more the parent material than the soil type, which

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controls the soil erodability. Over the catchment area of Lake Ledro, the parent material is homogenous and made of carbonated rocks (lines 3 and 4, page 3210). We thus suggest (and this has been largely documented in the litterature) that the slope and the geomorphology stay the two main parameters drinving the erosion processes.

In addition, the soils present over the erosive zone of the catchment area of Lake Ledro are Leptosol (in altitude), Cambisol or Colluvic Regosol (on slopes) (as given lines 7-11, page 3211). The density measurements performed in these soils layers are very similar (from 1.2 and 1.4 g.cm-3). We therefore consider that the soil density was almost the same for the soils affected by erosive processes and do not affect our calculations.

Moreover the result of the present model are compared to a study by Raclot and Albergel (2006) that describe eroded material in relation to runoff in Tunisia, I'm not sure that these authors are in agreement to compare runoff in Tunisia (with a very specific climate and vegetation) to this high elevated area in Italia. We fully agree with this remark. However, this publication is the only one considering the quantification of erosion rate, in terms of the thickness of soil eroded by runoff process, at catchment scale.

10/ Part 5.3. : Based on this very hypothetic estimation of eroded material the author's estimate in this part an amount of precipitation! The model for estimation of precipitation has to be further developed in this part before to be used. Erosional susceptibility (Es) estimated by De Ploey vary by factor 10 for grassy surface (0.05-0.005s2/m2) and also by a factor 10 for forested surface (0.5-0.05 s2/m2) thus for a homogenous surface the calculated precipitation vary by a factor 10. If the surface is not homogenous Es vary by a factor 100. Thus with the uncertainty of estimated eroded volume (see above comment) and the uncertainty of Es the calculated amount of precipitation are not credible.

We understand the reviewer comment and accordingly, we decided to deleate this part of the manuscript dealing with the estimations of precipitation using De Ploey model.

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As a result, section 5.3 is now shortened and more focused, as suggested by the reviewer.

In spite of that authors calculate an amount of precipitation by event of more than 1,6 meters (more than two times the volume received today in one year) and deduce from this result that snowmelt erosion was a main process! But the authors have not considered that their model is completely false: : : To make this type of model the authors have to calibrate its model at least with instrumental data on a long time period. This part has to be completely removed.

This section is now deleted.

11/ P3222L11-13 : the relation between the thickness of flood-deposit, the river discharge and the rain intensity was not directly related, its depend on eroded material on the watershed, on human activity: : : this relation is site-dependent and the authors have not demonstrate the relation in this study.

Mulder et al., 2003 demonstrated a positive relationship between suspended particle concentration and river discharge enables a scaling of the flood event by the detrital layer thickness. We fully agree that this relationship is site-dependent (human activities), however, Mulder et al. 2003 demonstrated that this relationship follows a power law function making the lacustrine sedimentary record very sensitive to variations in the river discharge of extreme floods.

Minor comments:

Abstract is too long and could be reduced by half.

Accordingly, the abstract is now slightly shortened.

Method : specify the localisation where the different analysis was done.

For punctual analysis, such as the organic ones, the localisations of the lacustrine sediment samples are given figure 3. This figure was not properly edited in the CPD

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manuscript (missing 3B and 3C sections and associated figure caption). The location of each samples is now clearly indicated in modified Figure 3.

P3209L11: Flash-flood is a type of flood, is it really flash-flood in this watershed?

Yes, since the rivers are intermitent and torrential and only active during flash-flood events (as shown in figure 1B).

P3209L20 : Beug, 1964 : Do you have a more recent reference for today climatology/meteorology in this area?

Unfortunatly, no more recent reference is available for this area.

P3211L2 : specify the grain size analysis resolution

As suggested by the reviewer, we specified that grain-sized analyses are punctual and only performed on few SE samples. The following sentence is now added line 1, page 3211: "Punctual laser diffraction grain-size measurements were performed using a Malvern Mastersizer 2000 on several sedimentary event (SE) samples."

P3211L5 : Which type of soil horizon were sampled, do you sample also the litter? P3211L6 ; How do you sample the river bed , it's better to carry sediment during flash flood events with a sediment trap, because how are you sure that this sediment was 1/ transport during flash flood and 2/ end its transport in the lake?

As given in the following sentence, all soil layers were sampled and fluvial samples were taken directly at the river bed when the tributaries were dry. The sentence (line 6, page 3211) is now changed: "In July 2011, 11 complete pedological profiles and 6 (dry) river beds were sampled within the watershed (coloured circles in Figure 1B)."

P3212L12 : indicate which part of the deposit was sample for QOP analysis

This is now clearly shown in figure 3.

P3212L21 : what is the mean velocity taken to convert twt in meter? Any argument for

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that do you measure P-waves?

The Mean velocity used is equal to 1450 m/s. This value is based on P-waves measurements performed with a GEOTEK multi-sensor core logger on Lake Ledro sediments.

P3213L12 : Sedimentary Events

Accordingly, we substituted “SE (i.e. Sedimentary Events)” for “sedimentary events”.

P3214L8 : I do not see an inverse grading for events presented in figure 4

We do not understand this comment since inverse grading is shown for dark-coloured events I and D, presented figure 4. This is beside discussed into the text lines 7 to 10, page 3214.

P3214L14-19 : Do you have any reason to compare dark events thicker than 1 cm to light event thicker than 1.5 cm? why not have kept the same limit?

To clarify this point, we included the following sentence, line 3, page 3214: “For analytical reasons, only SE thicker than 1 cm could be sampled, and are considered in the following sections. It means that we are here not discussing minor events (below 1 cm) which are included in the study of Vannière et al. (this issue).”

Give also the mean grain size and density of this both group of deposit.

Following first reviewer comment 12, this is now clarified.

P3215L29 : make also a regression line for light events.

As suggested by the reviewer, the regression line has been added on figure 6. Accordingly, the text (line 29, page 3215) has been modified as follow: “Regression lines are calculated for background sediment and SE samples...”.

P3218L28 : If the lake level have an effect on slope-instability, please add the curve of lake level on Figure 8. As suggested by the reviewer, the lake level curve has been added on figure 8.

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P3219L7-9 : If you observed successively inversely and normally graded event please show the data in figure 4, because from the current version of this Figure we do not clearly see that.

The data are already represented by event D (figure 4)

P3219L13-16 : If this event (J) is remarkable add the picture and grain size data of this event in figure 4.

Available density data from event J are now included in figure 4 (no grain-size data are available).

P3222L1 : lithic, rendzic and leptosol (62% of the catchment area) are not well develop soil

We fully agree wth this remark, but Cambisol (21% of the catchment area) are well developped, and also affected by erosive processes. We thus suggest that the pedogenesis in Ledro catchment area is not significantly affected by the occurence of flash-flood events.

Figure 3: Photos at the left side are too small. Where are (b) and (c) in the figure?

This figure was not properly edited in the CPD manuscript (missing 3B and 3C sections and associated figure caption). Figure 3 is now clarified accordingly.

Figure 4 : It would be much better to display all the grain size data in a contour plot. Plotted in such a way it allows the reader to see the evolution of grain size variability in all size fractions. Please indicate in the caption and in the figure which event was dark and light. D is it a light event? It is darker that event G but it is under light title. Where is the base of the event 4.

This figure was not correctly edited by CPD (missing titles and borders to clearly distinguish light and dark-coloured events). As suggested by the reviewer, tops and bases have been specified for each event presented in figure 4.

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Figure 5 : plot soil and river bed with different marker on the part A. Reduce the size of the marker or make a small zoom on the origin of the figure.

As suggested by the reviewer, soil and river bed samples have now specific markers and a small zoom has been added on the origin of the figure.

Figure 6 : What is red square? Plot also a regression line for light coloured events

This precision has been added in the figure caption as follow: “In this diagram, the red squares represent samples taken in the clay caps which cover the top of two dark-coloured events”. Moreover, the regression line for light-coloured event has been added.

Figure 7 : Please indicate an error for the age of seismic event

As suggested by the reviewer, age errors have been added for each event.

Figure 8 : add the lake level curve.

As suggested, the lake Ledro level curve has been added in figure 8.

Reviewer #RC C2738 : JL Schneider

Comments on the manuscript entitled “Multidisciplinary distinction of mass-movement and flood-induced deposits in lacustrine environments: implications for Holocene palaeohydrology and natural hazards (Lake Ledro, Southern Alps, Italy)” The purpose of the manuscript entitled Multidisciplinary distinction of mass-movement and floodinduced deposits in lacustrine environments: implications for Holocene palaeohydrology and natural hazards (Lake Ledro, Southern Alps, Italy) submitted by A. SIMONNEAU and Colleagues at Climate of the Past Discussions deals with the problem of the sedimentary record of tectonic and climatic events in lacustrine sediments. The manuscript is very well written and organized. It provides original data to discuss the sedimentary signatures of earthquake and flash flood events as well as climatic variations and human activities impacts on the sediment infill of an Alpine lake, Lake Ledro. The study

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is based on the use of various methods (geophysics, core analysis, organic matter characterization. From my knowledge, it is the first time that precise data on the organic matter content of the lacustrine sediments is used to reconstruct the evolution of the soils, vegetal cover and land use in the catchment of a lake. Moreover, the multidisciplinary approach adopted for this study allows to make the distinction between the effect of instantaneous events (earthquakes and flash-floods) and more long-term background sedimentation in the sedimentary column recovered in the deep basin of the lake. Precise arguments are developed to attest the effects of earthquake in mass wasting processes along the lake's slopes and to characterize the flood-related deposits. Attempts of quantification of the soil erosion processes in the catchment are appreciable. Data are very well presented and arguments are incisively presented. An excellent age control is used to reinforce the interpretations. Description and interpretations are well distinguished, and the final discussion part of the manuscript is well supported by the data. Finally, this work allows the authors to reconstruct a precise story of the evolution of the catchment characteristics in terms of climate and vegetal evolution and, also, about the human activity in the area. I am strongly convinced that this work will be a reference paper for further studies in lake sedimentology, paleoclimatology and event stratigraphy. However, some imperfections remain within the manuscript. They correspond to minor typographic and grammatical errors. Moreover, for figure 3, parts (b) and (c) are missing in the submitted manuscript.

All the identified imperfections are directly indicated within an electronic version of the manuscript that is sent with this comments letters and that can be transmitted to the main author. In conclusion, this is a very interesting and convincing manuscript that deserves to be published with very minor corrections in Climate of the Past Discussions.

P3207 – line 9 : We substituted "occurring" for "present".

P3207 – line 13 : "dense, what is dense ?" This is now deleted from the abstract.

P3207 – line 18 : We deleted the "s" at the end of "event".

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P3207 – line 23 : We substituted “estimating” for “to estimate”.

P3208 – line 8 : We substituted “results” for “data”.

P3208 – line 12 : We substituted “actual” for “present-day”.

P3209 – line 23 : We substituted “create” for “develop”.

P3209 – line 26 : We substituted “blocked” for “dammed”.

P3209 – line 27 : We substituted “in the east” for “along its eastern side”.

P3210 – line 6 : We deleted the “s” at the end of “forest” and “landscape”.

P3211 – line 4 : 7 stars are reported on figure 3. Radiocarbon ages (stars) are now shown in figure 3.

P3212 – lines 1, 2 and 3: We deleted the “s” at the end of “suggest”. We deleted the word “which” and inserted “of which” in the sentence..

P3213 – line 21: We deleted the “s” at the end of “represent”. We deleted the word “cumulative” and inserted “a cumulative length of” in the sentence.

P3214 – line 15: We deleted the expression “on average” and inserted “in average” at the end of the sentence.

P3215 – line 26: We substituted “inferior” by “lower than” in the sentence.

P3217 – lines 25, 26: We substituted “contemporary to” by “consistent with”, and added “, the epicenter of which being” after “2004 AD”, and the sentence is now: “This event 1 is dated to 2005 AD$\pm$3 and consistent with the Salo earthquake in 2004AD, the epicenter of which being located at only 35 km SW from Lake Ledro (Fig. 1a, Tables 1 and 2).”

P3217 – line 27: We added “event” after “trigger” in the sentence.

P3218 – line 8: We substituted “is” by “are”.

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P3218 – line 12: We substituted “impacted” by “affected”.

P3218 – line 28: We moved “by higher lake levels” before “based” in the sentence.

P3221 – line 11: We substituted “stocked” by “stored”.

P3221 – line 23: We added “,” after “similarly”.

P3226 – line 18: We substituted “in particular” by “particularly”.

Please also note the supplement to this comment:
http://www.clim-past-discuss.net/8/C3365/2013/cpd-8-C3365-2013-supplement.pdf

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Interactive comment on Clim. Past Discuss., 8, 3205, 2012.

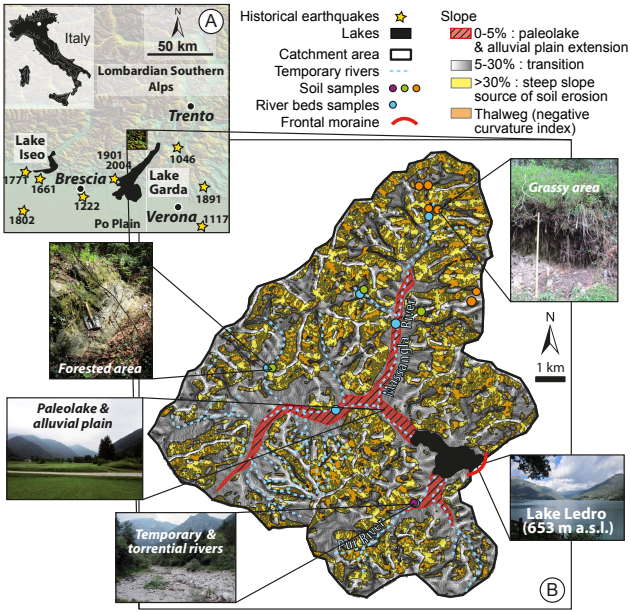

Fig. 1. Figure 1

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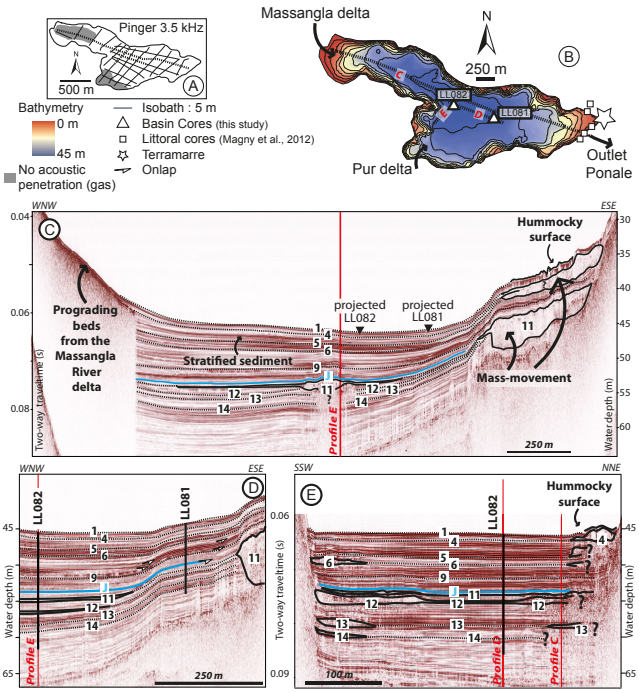

Fig. 2. Figure 2

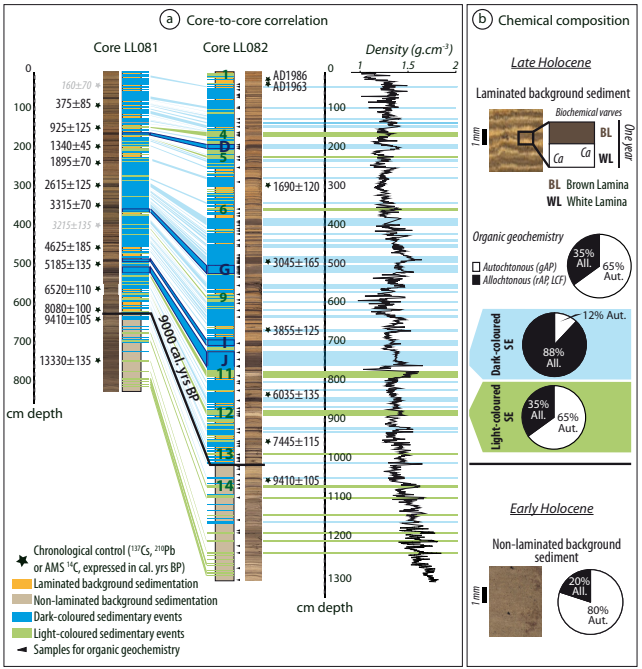

Fig. 3. Figure 3

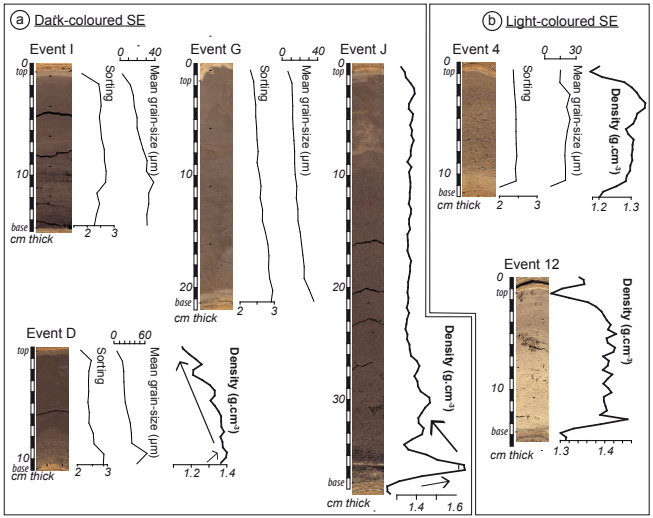

Fig. 4. Figure 4

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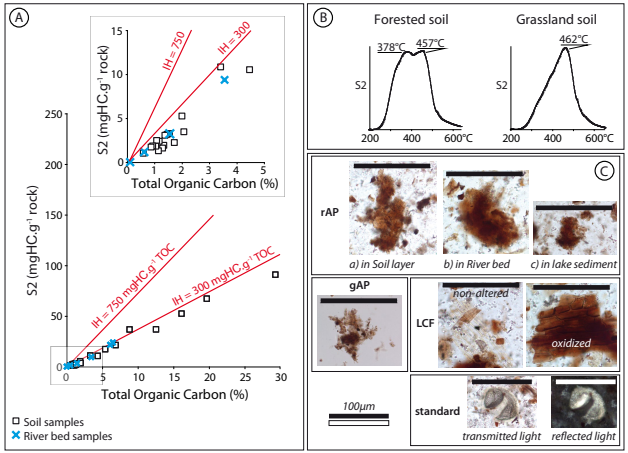

Fig. 5. Figure 5

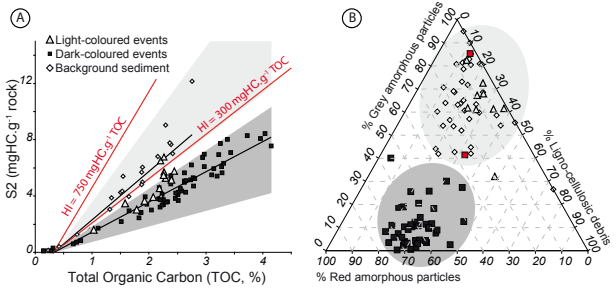

Fig. 6. Figure 6

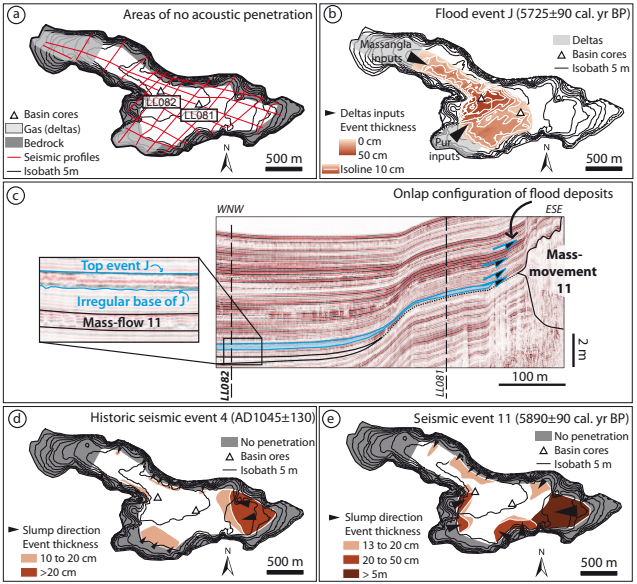

Fig. 7. Figure 7

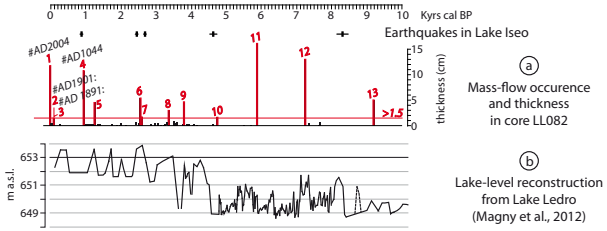

Fig. 8. Figure 8

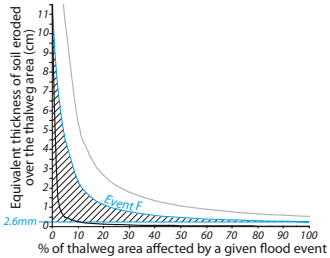

Fig. 9. Figure 9

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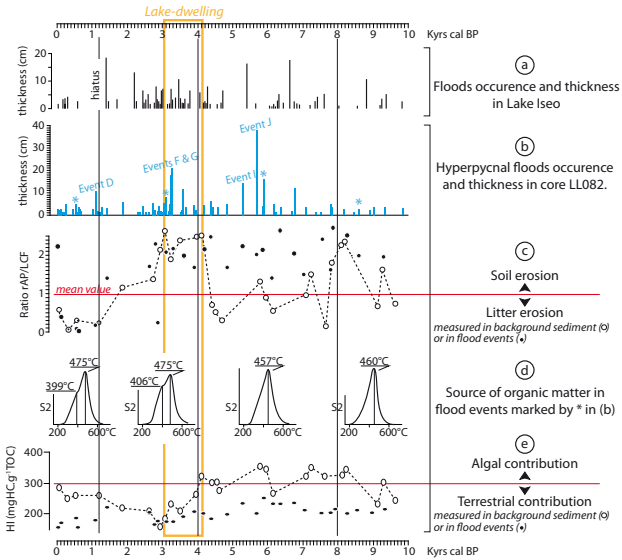

Fig. 10. Figure 10

Table 1

Year	Location	Distance from Lake Ledro	Equivalent magnitude M_s	Epicentral intensity at epicentre I_0
AD2004	Salo	~35 km SSW		VIII
AD1901	Salo	~35 km SSW	5.7	VIII
AD1891	Illasi valley	~55 km SE	5.9	VIII-IX
AD1117	Verona	~53 km SSE	6.8	IX
AD1046	Adige valley	~25 km E	6	IX

Fig. 11. Table 1

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Table 2

Method	Material	Laboratory	MC depths (cm)	Radiocarbon ages	Calibrated ages (cal. yrs BP)
Core LL082					
AMS ^{14}C	Leaf remains	ETH-39232	303	1765±35	1690±120
		ETH-40410	493.5	2890±50	3045±165
		ETH-10411	666	3575±35	3855±125
	Leaf remains and needles	ETH-39233	840	5200±35	6035±135
	Needles	ETH-39234	960.5	6530±40	7445±115
		ETH-39235	1065.5	8405±40	9410±105
Core LL081					
AMS ^{14}C	Wood Peat Charcoal	*POZ-27888*	*16.5*	*255±30*	*160±70*
		POZ-30216	82	290±30	375±85
		POZ-30218	142	1020±30	925±125
		POZ-30219	194	1445±30	1340±45
		POZ-30220	239	1945±30	1895±70
		POZ-30221	299	2520±35	2615±125
		POZ-27890	351	3095±30	3315±70
		POZ-30222	*402.5*	*3030±35*	*3215±135*
		POZ-27891	461.5	4080±35	4625±185
		POZ-30223	499	4550±35	5185±135
		POZ-27892	562.5	5720±40	6520±110
		POZ-30224	616	7270±50	8080±100
		POZ-27894	641.5	8385±35	9410±105
		POZ-27895	759.3	11480±60	13330±135

Fig. 12. Table 2

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Table 3

Events	Thickness in core LL082 (cm)	Estimated ages inferred from Vannière et al. (this issue)	Regional earthquakes	Numbers of associated mass wasting deposits	Likelihood of earthquake triggering
SE 1	11.8	AD2005±3	Salo (AD2004)	2	Very high
SE 2	1.5	AD1871±39	Salo (AD1901)	?	High
SE 3	1.5	AD1863±42	Illasi valley (AD1891)	?	High
SE 4	10.8	AD1044±127	Verona (AD1117) or Adige valley (AD1046)	9	Very high
SE 5	4.4	1256±115 cal. yr BP		3	High
SE 6	5.3	2545±104 cal. yr BP	Iseo event (2525±110 cal BP)	5	Very high
SE 7	1.6	2595±102 cal. yr BP		?	High
SE 8	2.9	3348±79 cal. yr BP		?	Moderate
SE 9	4.6	3815±84 cal. yr BP		2	High
SE 10	1.5	4742±156 cal. yr BP	Iseo event (4488±110 cal BP)	?	High
SE 11	16.1	5889±92 cal. yr BP		10	High
SE 12	13	7190±127 cal. yr BP		10	High
SE 13	5	9183±84 cal. yr BP		2	High
SE 14	4.6	11493±339 cal. yr BP		2	High

Fig. 13. Table 3

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