UNIL | Université de Lausanne

Institute of Earth Sciences

Were Holocene large slumps in Lake Geneva off the city of Lausanne caused by fault activity?

Jehanne Correia Demand (1), François Marillier(1), Katrina Kremer(2,3), and Stéphanie Girardclos (2,3)

jehanne.correia-demand@unil.ch
francois.marillier@unil.ch

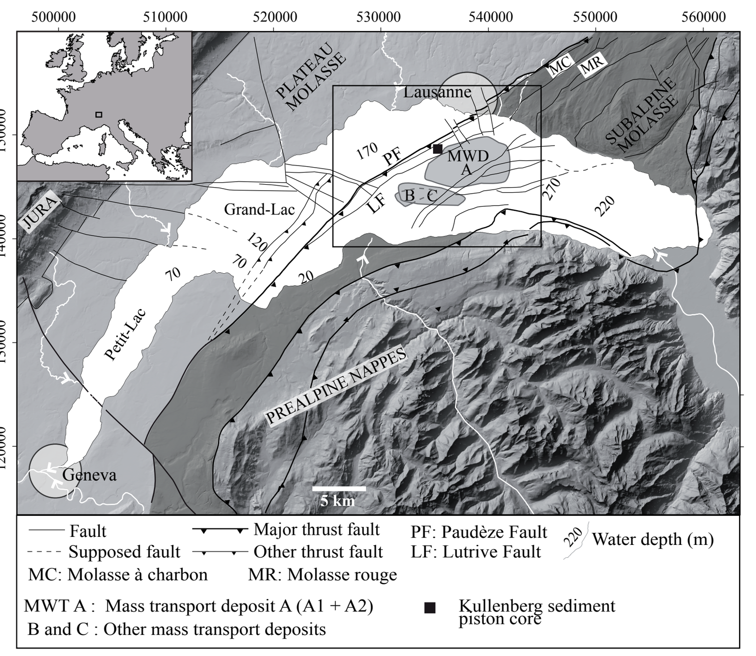

Fig. 1 Location map and tectonic setting (modified after Dupuy et al. in press).

Summary

We present evidence for lacustrine landslides of Holocene sediments in Lake Geneva based on seismic reflection and other data. A large one occurred along the northern slope of the lake off the city of Lausanne (Fig. 1). The landslide was associated with several **mass transport deposits** (MTDs), the main one with a volume of 0.13 km^3.

The slide was most likely triggered by an earthquake because it was synchronous with other MTDs coming from the southern slope of the lake. Numerical simulations have shown that the main MTD could have generated a tsunami with local wave heights of up to 6 m on the lake northern shore (Kremer et al. 2014). 14C dating gives an age interval of 1865-1608 BC.

Close to the main MTD depot centres, two intriguing features consisting of layered, tilted and vertically offset Holocene sediments are associated with positive lake-bottom topographic features. At least one of them is interpreted as a consequence of active tectonics in the underlying Molasse basement. There, displacements along large thrust faults and along smaller strike-slip faults that offset the former are interpreted to have built the anomalous features. Additional observations suggest that these movements were associated with an earthquake located along the Molasse faults.

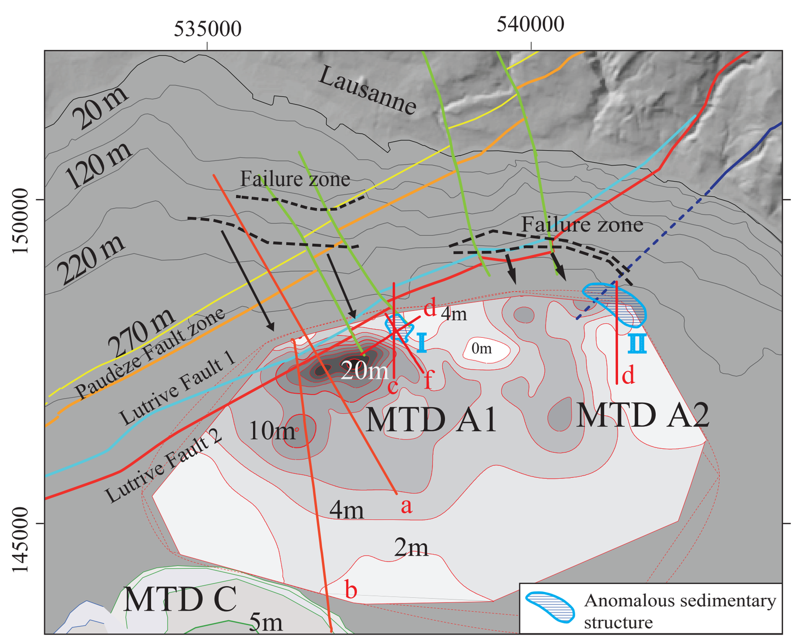

Fig. 3 Detailed thickness map of MTDs A1 and A2. Landslide failure zones and slide directions are indicated by dashed lines and black arrows respectively. I and II = anomalous sedimentary structures. Seismic profiles: a = IM2 (Fig. 2), b = Pinger profile (Fig. 4), c = GLw4 and GLp4 (Fig. 6), d = YD1 and GLp9 (Fig. 7), e = GLw16 and GLp16 (Fig. 8), f= GLp13 (Fig. 9)

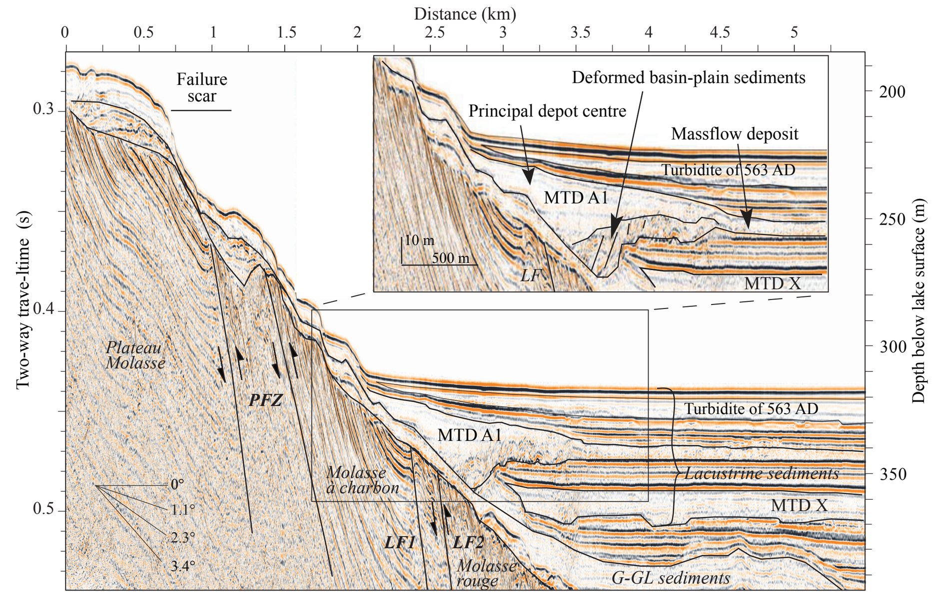

Fig. 2 Seismic profile IM2 (air gun) showing details of MTD A1. For location see Fig. 3. MTD X is an older unidentified event.
PZF = Paudèze Fault zone, ***LF1*** and ***LF2*** = Lutrive Faults 1 and 2.
G-GL = Glacial and Glacio-lacustrine sediments

Mass transport deposits

On seismic profiles (Fig. 2), the slides are characterized by 1) a principal depot centre (up to 20 m thick) associated with sediments deformation and erosion of the underlying units, 2) a much larger zone of massflow/turbidite deposits that may or may not have eroded underlying sediments, and 3) scars that indicate the zone of initial failure. The slide off the city of Lausanne is associated with two main depot centres, MTD A1 and MTD A2 (Fig. 3).

MTD A1 was dated (1865 to 1608 BC) using the 14C technique applied to plant remains within a Kullenberg sediment core (Fig. 4). Above it, an earlier thick turbidite is observed across the entire Lake Geneva. It was responsible for a large tsunami in 563 AD (Kremer et al. 2012).

Fig. 3 shows the lateral extent and thickness of the slide deposits. We established that MTDs A1 and A2 were triggered simultaneously based on the continuity of seismic reflections that link the two MTDs. Also shown on Fig. 3 is MTD C that occurred further south. The pinger data (Fig. 4) show that MTDs A1 and C were also simultaneous.

The failure scars associated with MTDs A1 and A2 appear as two separated entities (Fig. 3). However, multi-beam bathymetric data (not shown in this poster) along the northern slope of Lake Geneva off the city of Lausanne indicate that an essentially continuous failure scar zone, at least 7 km long, associated with the two slides.

The fact that MTDs A1, A2 and C were simultaneous suggests that they were all triggered by the same event, most probably an earthquake.

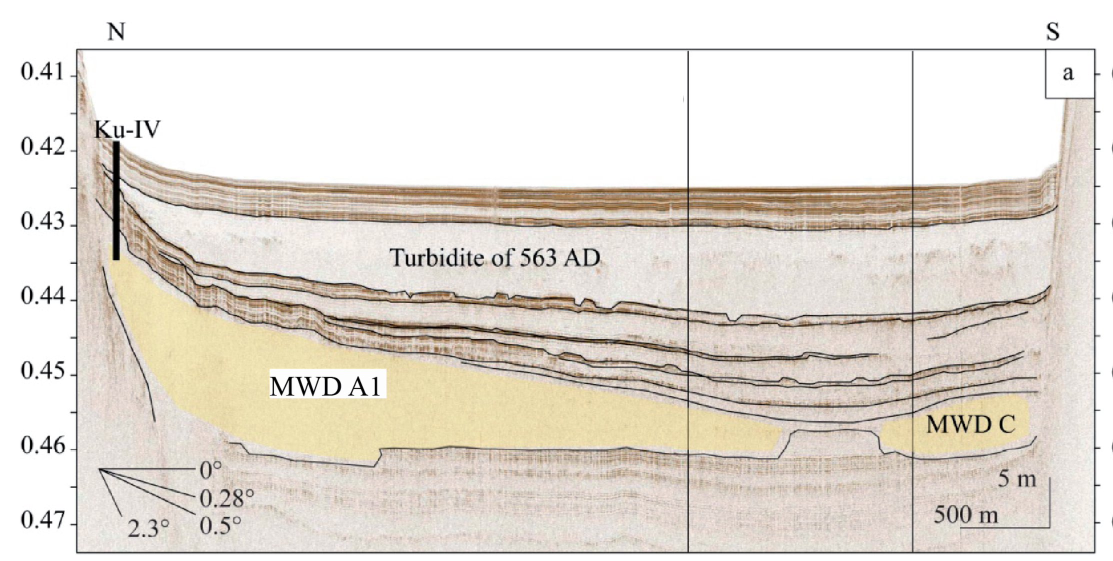

Fig. 4 Pinger profile showing the relative position of synchroneous MTDs A1 and C. For location see Fig. 3. The location of the Kullenberg core Ku-IV is indicated in Fig. 1.

The Seismic data

They consist of multichannel reflection profiles (24 channels) with either air-gun (Sodera MiniGI) or water-gun (Sodera S15) sources and of single-channel pinger source profiles. The dominant frequency of these sources is 330 Hz for the air gun, 670 Hz for the water gun and 3.5 kHz for the pinger providing a theoretical vertical resolution of 1.1 m, 0.6 m and 0.3 m, respectively, for a velocity 1500 m/s.

Processing of the multi-channel data included gain ranging, bandpass filtering (75-500 Hz for the air gun, 200-1700 Hz for the water gun), deconvolution, DMO and migration. Processing of the pinger data consisted of bandpass filtering (2300-6500 Hz), gain ranging and migration.

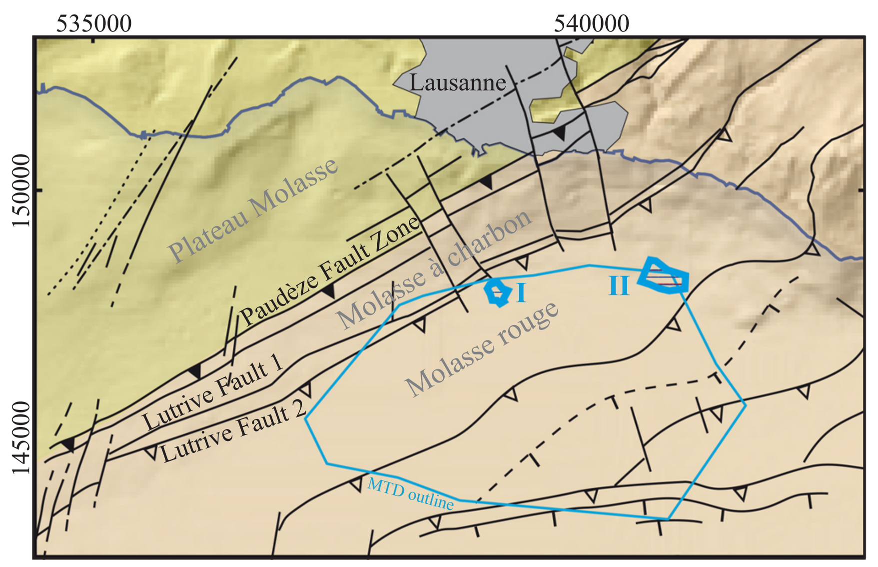

Fig. 5 Detailed map showing the location of faults affecting the Molasse under Quaternary cover (modified after Dupuy et al., in press). Superimposed are the anomalous structures I and II observed in the Holocene sediments as well as the outline of the principal MTD.

Anomalous sedimentary structures

Two anomalous sedimentary structures (I and II) are observed north-east of MWD's A1 and A2 (Figs. 3, 5, 6, 7 and 8). Several corresponding seismic horizons within and outside of the anomalous structures are offset to the south and the southwest. Horizons on both sides of the offset can be continuously followed on intersecting seismic profiles that link both sides of the offset. Some horizons are titled towards the slope.

We interpret the anomalous structures (I and II) as shallow - and therefore recent - expressions of fault activity within the deeper Molasse layers. Relative mouvements along the strike-slip fault that offset the Lutrive 2 Fault near structure I (Fig. 5) may have been associated with an horizontal compression component that resulted in the observed features.

These observations together with the presence of a more or less continuous landslide failure-scar along the northern slope of the lake off Lausanne and the occurrence of a large MTD (0.13 km^3 in volume) suggest that an earthquake along these faults or in the near vicinity triggered the observed synchronous landslides.

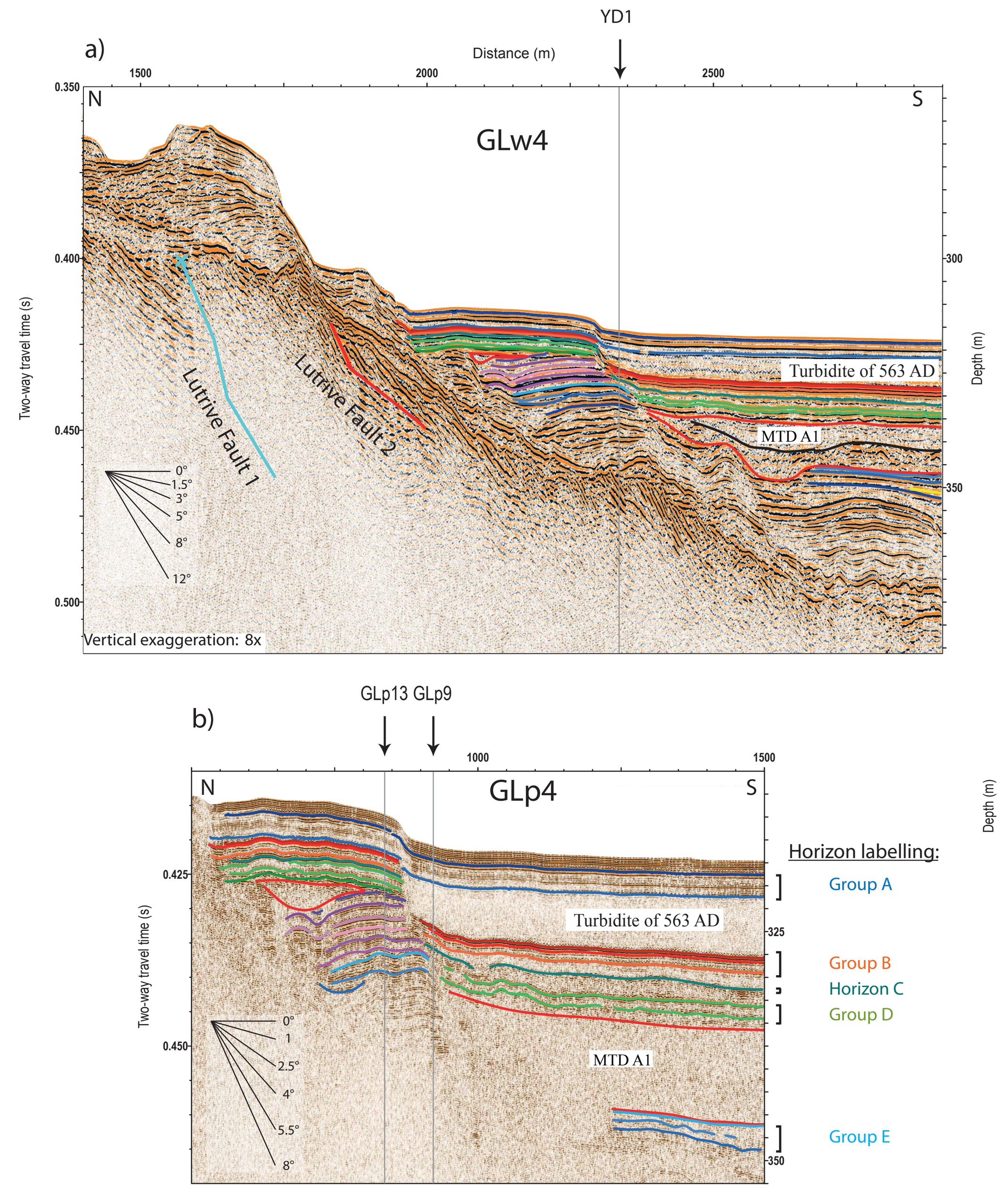

Fig. 6 a) Water gun profile GLw4 and b) pinger profile GLp4 across anomalous structure I. The two profiles are co-linear. For location see Fig. 3

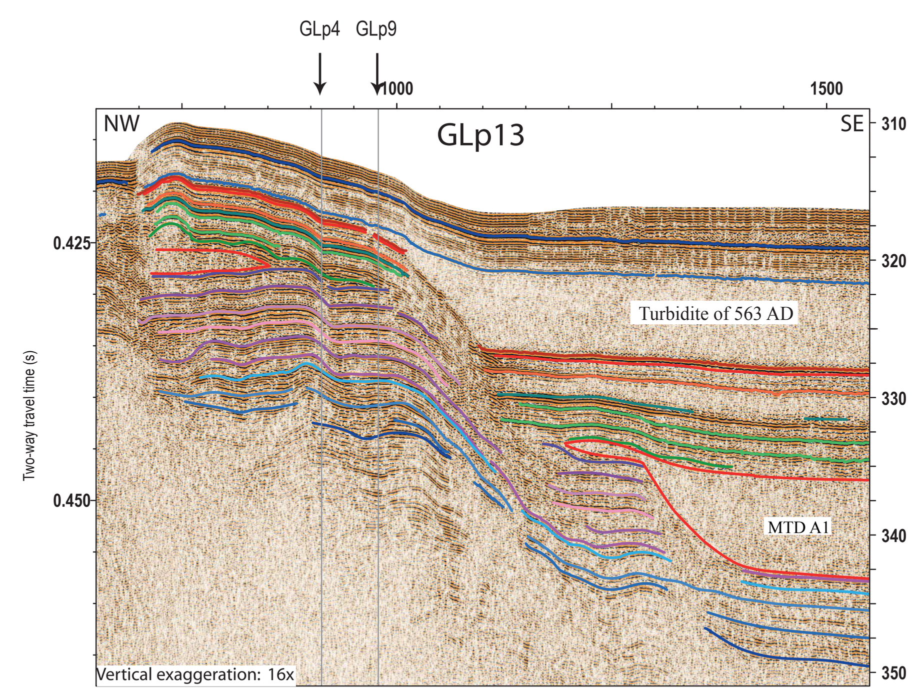

Fig. 9 Pinger profile GLp13 across anomalous structure I. For location see Fig. 3

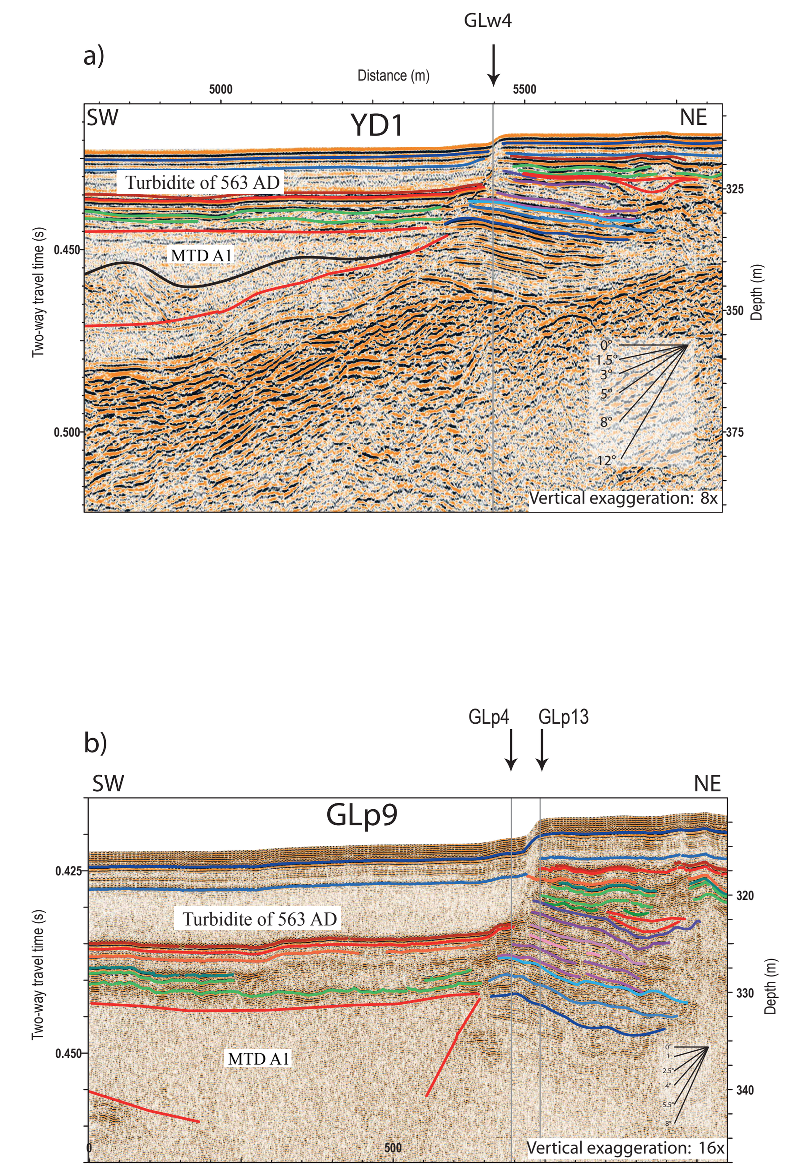

Fig. 7 a) Water gun profile YD1 and b) pinger profile GLp9 across anomalous structure I. The two profiles are co-linear. For location see Fig. 3

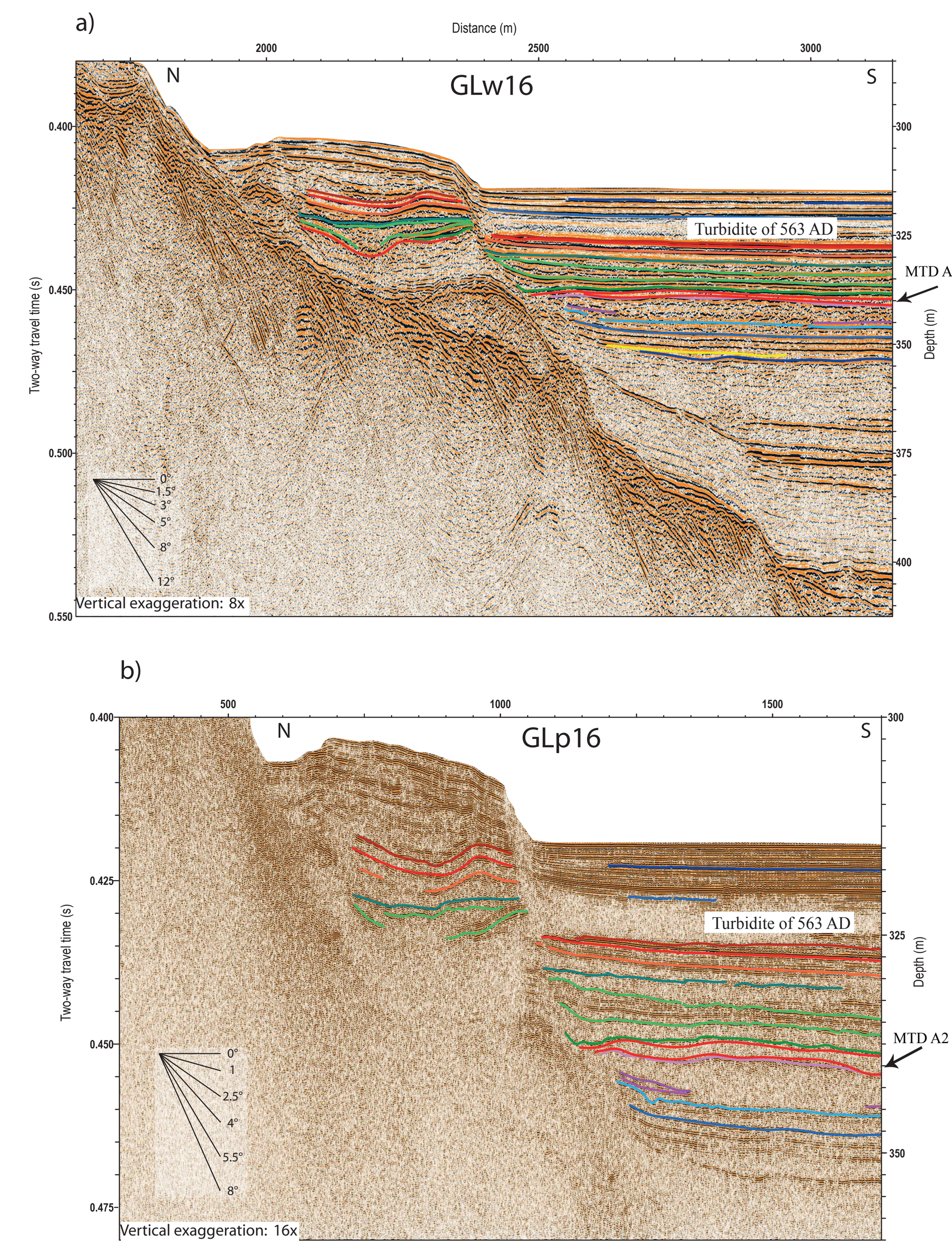

Fig. 8 a) Water gun profile GLw16 and b) GLp16 across anomalous structure II. The two profiles are co-linear. For location see Fig. 3

Seismic horizons

Starting from water bottom downwards we are able identify 5 groups of lacustrine horizons (A to E).

Group A :

These horizons are later than the 563 AD turbidite

Group B :

These horizons lie just below the 563 AD turbidite. There are characterized by strong continuous reflections that apparently drape the older formations. We were able to follow them on the entire zone on the flank of anomalous structures I and II. In these area they are offset by 7 to 15 m.

Groups C and D:

Horizons from groups C and D are in places interrupted by chaotic sediments (Fig. 7b, GLp9). In the deeper part of the lake they are deposited above deposits of MTD A while in the anomalous structure I horizons of group C-D overlay horizons of group E with an angular unconformity (Fig. 6b, GLp4, 7a, YD1, 7b, GLp9 and 9, GLp13)

Group E :

The upper part of the group is only observed above the topographic highs associated with the anomalous structures I and II. Elsewhere, they are totally eroded during deposition of MTD A (Fig. 9, GLp13). The oldest deposits of this group are present throughout the area. In anomalous structure I, group E deposits are tilted with an angle of the order of 1° towards the N-E (Fig. 7a, YD1 and 7b, GLp9). Moreover, horizons of this group are offset by 12 m for the most superficial ones (Fig. 9, GLp13) and by up to 20 m for the deepest ones (Fig. 7b, GLp9).

References

Dupuy, D., Marillier, F., Plancherel, R. and Weidmann, M., in press. *Analyse sturcturale de la région lémanique basée sur la sismique réflexion dans le Léman (Grand Lac et Haut Lac) et la géologie des rives nord et sud.* Matériaux pour la carte géologique de la Suisse, swisstopo.

Kremer, K., Simpson, G. and Girardclos, S., 2012. *Giant Lake Geneva tsunami in AD 563*. Nature Geoscience, 5 (11), 756-757 and 5(12), 840.

Kremer et al., 2014. *Lake dwellers occupation gap in Lake Geneva (France–Switzerland) possibly explained by an earthquake–mass movement –tsunami event during Early Bronze Age.* Earth and Planetary Science Letters, 385, 28–39.

Acknowledgements

The data were collected using the boat "La Licorne" of the Institute Forel, University of Geneva. The acquisition of seismic data was carried out over several years and we acknowledge the help of too numerous persons to be named here. The interpretation of the seismic data was done with the Kingdom® software.

(1) Institute of Earth Sciences, University of Lausanne, Switzerland

(2) Section of Earth and Environmental Sciences, University of Geneva, Switzerland

(4) Environmental Sciences Institute, University of Geneva, Switzerland