Architecture and evolution of a post-glacial deltaic system: seismic stratigraphy of the Mentue Delta (Lake of Neuchâtel – Swizerland)

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Abstract

The stratigraphy, the internal architecture and the evolution of the last-postglacial deltaic sequence occurring in the Pleistocene-Holocene succession of the Lake Neuchatel has been analysed by using seismic profiles, which allowed the recognition of distinct seismostratigraphic units. The deltaic sequence contains a channel complex formed during the first phase of the deglaciation (U3a, b). Specifically, three channels have been identified, whose seismic facies suggest that their formation was associated with massive meltwater inflow from the ice sheet. The activity of deep-rooted fault present in the study zone could have strongly influence the evolution and the spatial arrangement of the deltaic sequence.

Key words: seismostratigraphic, last-postglacial, deltaic sequence, fault.

Résumé

La stratigraphie, l'architecture interne et l'évolution de la dernière séquence deltaïque postglaciaire dans la succession Pléistocène-Holocène du lac de Neuchâtel ont été analysées en utilisant des profils sismiques qui ont permis de reconnaître des unités sismostratigraphiques distinctes. La séquence deltaïque comprend un complexe de chenaux formé lors de la première phase de la déglaciation (U3a, b). Trois chenaux ont été identifiés de manière précise. Leurs faciès sismiques suggèrent que leur formation est associée à un flux massif d'eau de fonte de glacier. L'activité des failles profondes présentes dans la zone d'étude pourrait avoir fortement influencé l'évolution et la disposition spatiale de la séquence deltaïque.

Mots clés : sismostratigraphique, postglaciaire, séquence deltaïque, faille.

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Introduction

Infilling of postglacial lake valleys has been the subject of several studies highlighting sedimentological processes and the paleoenvironmental setting of lakes (Daxer et al, 2018). Understanding the mechanisms of melting of large ice-sheets and the subglacial processes of sediment transport and sedimentation allows improving knowledges of the last deglaciation period.

Estimating the sedimentary rates of large water fluxes caused by rapid melting processes is important to predict such processes in the future, especially in condition of accelerate warming, such experienced at the termination of the Last Glacial Maximum. In the Switzerland Plateau, these processes, which characterise most of abandoned underfilled glacial valleys, occurred at the end of the LGM glacial cover, which, according to other sites in the Switzerland Plateau (Moscariello, 1998), occupied the region at least until 19'000-year BP.

The post glacial lacustrine sequence in the study area has revealed an interesting sequence which shows a clear evolution of the depositional environment from proximal pro-glacial chaotic processes of mass destruction to the establishment of the Holocene postglacial lacustrine sequence (Ndiaye et al., 2014).

In this paper, we propose a detailed description and evolutionary model of the post-glacial deltaic sequences of the La Mentue delta, in order to investigate in detail, the seismic stratigraphy of the post-glacial deltaic depositional sequences, which took place during the last-postglacial event.

Geographical and Geological setting

Lake Neuchâtel, located at the foothills of the Jura Mountains, in Western Switzerland, is one of the numerous perialpine lakes on the Switzerland Plateau occupied during the Quaternary glaciation of the Last Glacial Maximum (LGM) by the large northern branch of the Rhone glaciers (Vernet & Horn, 1971; Vernet et al., 1974; Moscariello et al., 1998). The latter merge in this region with the glacial systems originating from the Jura Mountains (Finckh et al., 1984; Houbolt & Jonker, 1968; Van Rensbergen, 1996; Van Rensbergen et al., 1998; Van Rensbergen et al., 1999; Beck et al., 2001; Schwalb, 1992; Schwalb et al., 1994; Beres & Gorin, 2002; Beres et al., 2003; Gorin et al., 2003; Clerc, 2006; Fiore, 2007; Ndiaye, 2006; Ndiaye et al., 2014). Lake Neuchatel overlies a SW-NE trending paleovalley, which was eroded during Quaternary glaciations by a branch of the Rhône Glacier extending northeastwards over the Swiss Plateau (Fig. 1). This paleovalley, incised in siliciclastic molasses and accessorily in Mesozoic carbonates, was infilled by late Quaternary sediments.

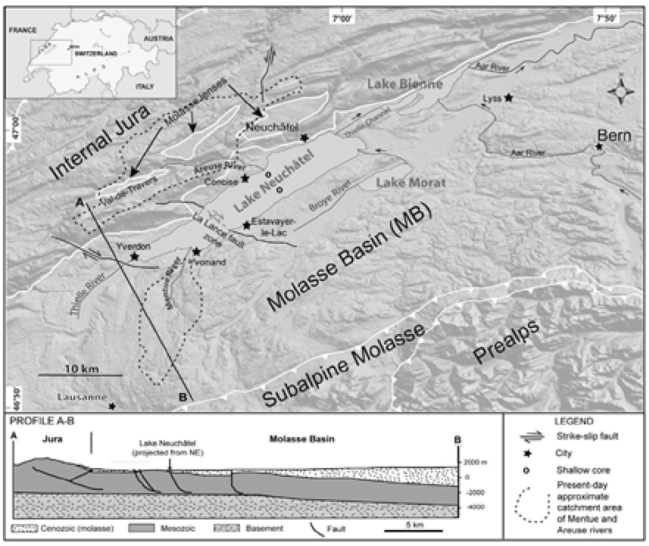

Fig. 1. Lake Neuchâtel location map with main city locations, hydrology and hillshaded relief in the background (Swisstopo data) modified after Ndiaye et al. (2014). Main thrust faults, strike-slip faults and tectonic contacts are indicated.

Present-day catchment areas of Mentue and Areuse rivers after Zwahlen (1981) and Blant et al. (2011), respectively. Geological profile A-B across the Jura and Swiss Molasse Basin modified after Sommaruga (1997).

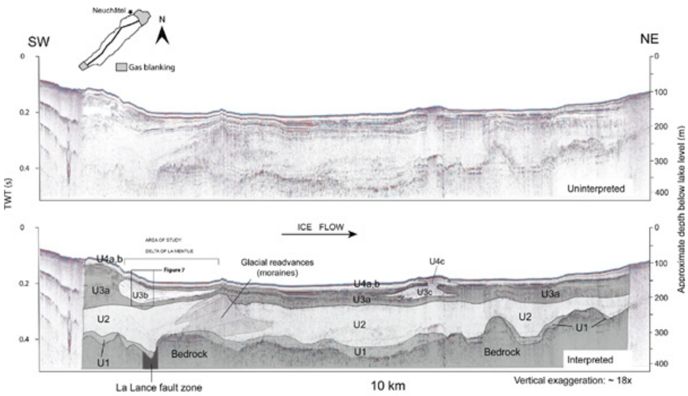

Fig. 2. Non-interpreted and interpreted longitudinal seismic profile of Lake Neuchâtel showing late Quaternary infilling with seismic stratigraphic (sub)units U1, U2, U3a,b,c and U4a,b,c. Depth scale is calculated using velocities of 1500 m/s for the water column and 1800 m/s for sediments (Ndiaye et al. 2014).

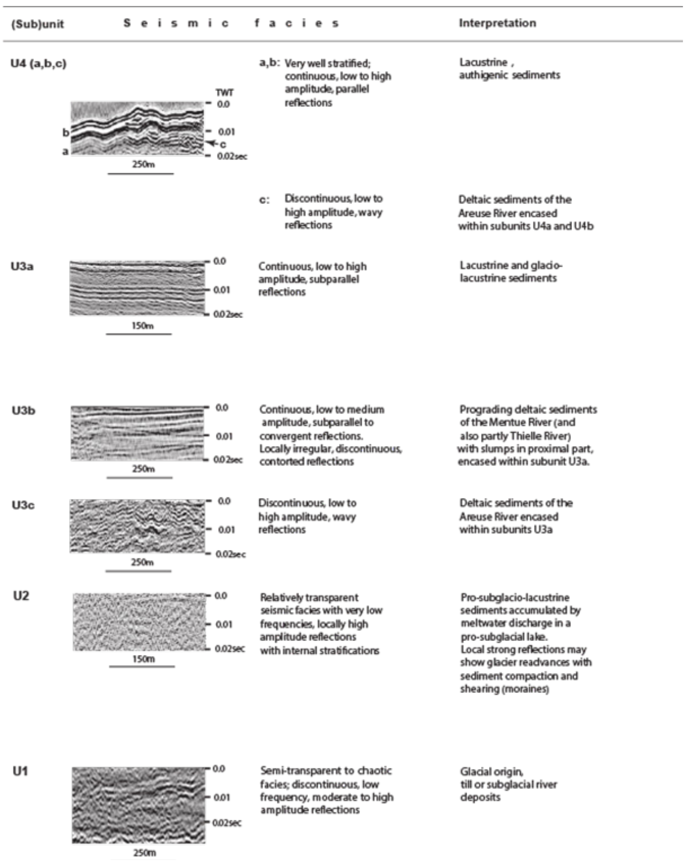

Fig. 3. Seismic facies and units in Lake Neuchâtel with their interpretation (Modified after Ndiaye et al (2014))

The seismic facies of the lake-infill have been broadly described in Ndiaye et al. (2014). It consists of four seismic stratigraphic units (Units U1 to U4) (Figs. 2 and 3). Units U1 and U2 are directly related to the Rhône Glacier and Jura Ice Cap activity. Unit U1 corresponds to chaotic subglacial deposits interpreted as tills (and locally eskers). It is associated with the LGM (Würm Glacial Maximum, WGM) and probably to the beginning of deglaciation of the Rhône Glacier and Jura Ice Cap. Subunit U3a marks the beginning of a glacio-lacustrine, and later, lacustrine environment. It extends over the whole lake and contains two more localized subunits (U3b and U3c) displaying prograding and downlapping reflections, as well as signatures of mass transport deposits. These two subunits are interpreted as deltaic sequences from the La Mentue (Subunit U3b) and Areuse (Subunit U3c) tributary rivers. The base of these sequences marks the synchronous onset of a major melting phase, respectively in the Rhône Glacier and in the Jura Ice Cap. Correlation with previously obtained core data indicates that the lower part of Unit U3 most certainly dates back to the Oldest Dryas and that the U3 depositional processes lasted at least until the end of the Younger Dryas and possibly until the Boreal biozone. This is in contrast with the Mentue River deltaic seismofacies (Subunit U3b), which ends close to the base of Subunit U4a. Unit U4 is interpreted as lacustrine sequence with continuous and subparallel seismic reflectors extending across the whole area. Correlation with earlier sediment cores from Lake Neuchâtel and similar deposits in Lake Annecy allows dating the onset of lacustrine sedimentation between the end of the Younger Dryas and the Boreal biozones.

Data and Methods

A seismic survey was realised in 2004 in the Lake of Neuchâtel over the La Mentue delta located to the SW border of the lake (Fig. 4). 75 km of seismic lines were acquired in total by using 5-inch^3 and 1-inch^3 airguns and 24 channels hydrophone cable. In addition, existing seismic lines acquired by the University of Geneva were used, resulting in a grid of high-resolution seismic profiles which imaged up to 200 m thickness of sedimentary sequence underlain by the Tertiary basement. The depth scale in meter is calculated using velocities of 1500 m/s for the water column and 1800 m/s for sediments.

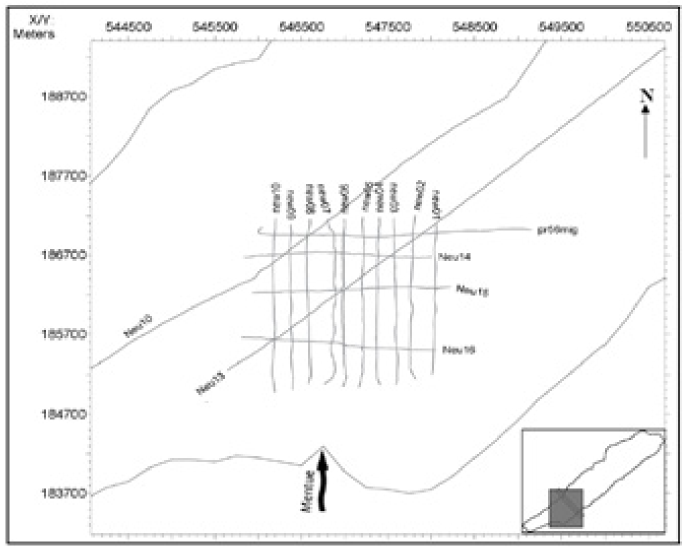

Fig. 4. 2D seismic lines location in the Delta of La Mentue area

Results and discuss

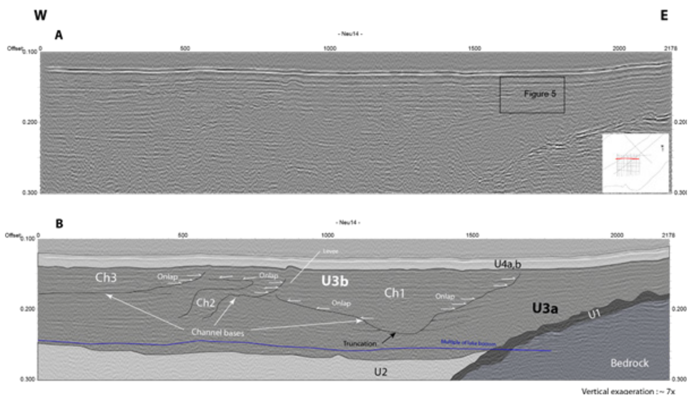

Fig. 5. Detail of seismic unit U3a and U3b channel systems.

The seismostratigraphic Unit 3 considered in this study represents one of shallowest recognised in the area of study (Ndiaye et al., 2014). This unit has been subdivided into two subunits: U3a, and U3b (Figs 5 and 6).

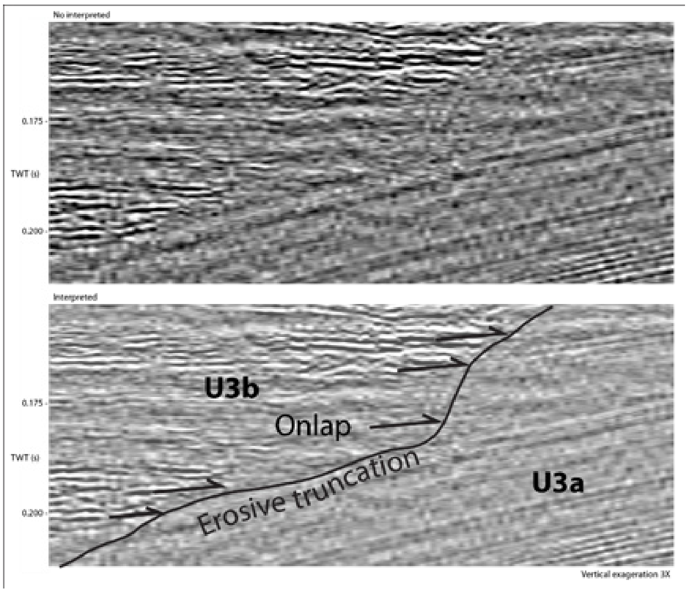

Fig. 6. Details of the subunits U3a and U3b showing the erosion of the subunit U3a linked to the deltaic subunit U3b (see Fig. 3 for location)

Subunit U3a

The reflectors of the U3a subunit are continuous, low to high amplitude and subparallel (Figs 5 and 6). At the top, this subunit is bounded by an erosional truncation on which the U3b subunit is onlapping. It is partially cored by Shwalb et al (1994) and consists of rhythmic laminations of authigenic silty calcite and detrital clayey silt in upper part, transitioning to glacial rythmites. Subunit U3a was interpreted as lacustrine and glacio-lacustrine sediments (Ndiaye et al, 2014). Comparatively to others perialpine lakes, it corresponds to:

- units 3 and 4 in Lake Annecy (Van Rensbergen, 1996; Chapron, 1999);
- units D3 (Moscariello et al 1998), units U8 and U12 (Fiore et al, 2011) in Lake Geneva;
- units 3, 6, 7 and 8 (Clerc, 2006), units U3 and U4 (Ndiaye, 2006) and unit 3 (Gorin et al, 2003) in Lake Neuchâtel;

Subunit U3b

Reflectors of subunit U3b are continuous with low to medium amplitude and subparallel to convergent. They are also locally irregular, discontinuous and contorted. The subunit U3b is not cored. It displays prograding and onlap reflectors and signatures of mass transport deposits (Figs 5 and 6). The subunit U3b is interpreted as prograding deltaic sediments encased within subunit U3a (Ndiaye et al, 2014).

Within this unit, three channel systems have been recognised (Ch1, Ch2 and Ch3; Fig. 7) based on the interpretation of a convex base. Based on their distribution and reconstructed paleo-direction, these channels vary in width between 15 and 20 m with a maximum length between 4 and 5 km, and an inclination which varying between 1° and 2° (Fig. 8).

Subunit U3b is interpreted as deltaic sequences from the La Mentue Delta (Ndiaye et al., 2014) which testifies of the important meltwater inflow from the Rhône Glacier and Jura Ice Cap. It consists of a complex channel-levee network creating very high erosion in the seismic glacio-lacustrine environment subunit U3a. During this period, global warming modified the hydrographic state by stepping up their debit. Very important quantities of sediments are transported in the La Mentue Delta area, by a complex channels network (Chapron, 1999; Deptuck et al., 2003; Ndiaye et al., 2014). This could be influenced by the activity of the "La Lance Fault zone" during this period.

Some highly sinuous forms could reflect changes in slopes. Aggradational channels with levees show classic 'gull-wing' geometry (Wynn et al., 2007) and have lower sinuosity than the truly sinuous forms present within the amalgamated channel units (Figs 7 and 8).

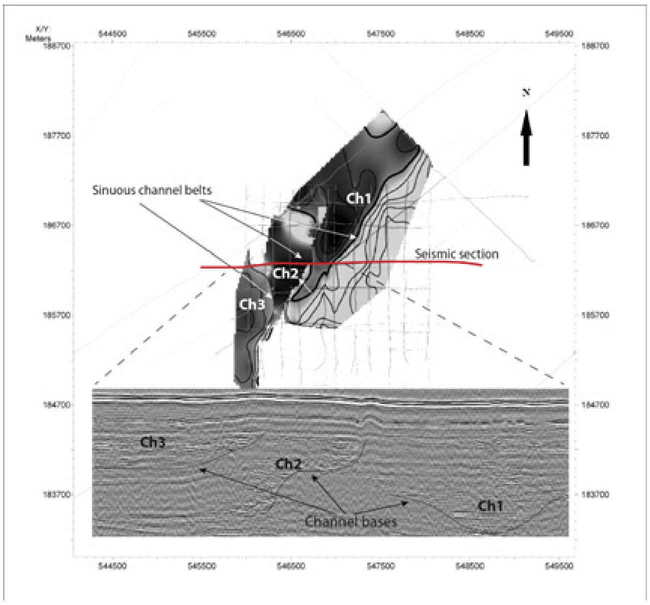

Fig. 7. Map of channel base with corresponding seismic section, illustrating seismic geometries of the sinuous channel complex in the seismic unit U3b.

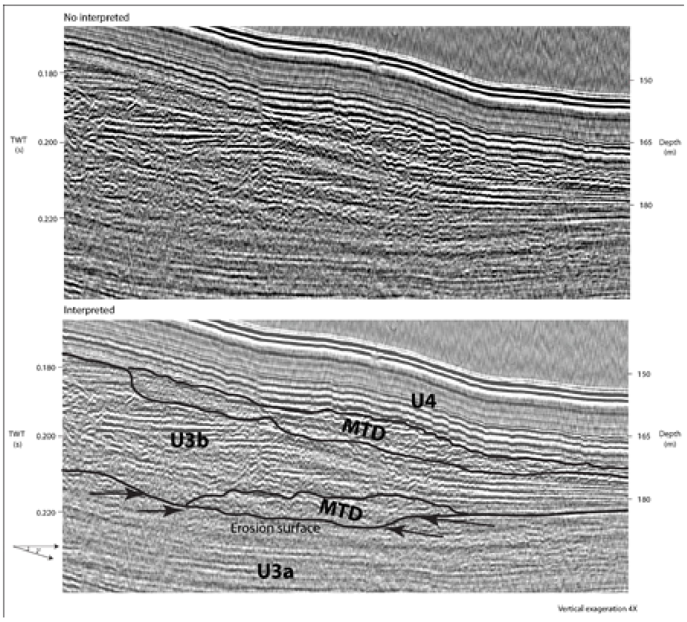

Fig. 8. Details of deltaic subunit U3b (see Fig. 2 for location). Seismic profile in the distal part of the Mentue Delta (Subunit 3b), subparallel to sediment progradation. Downlapping and pinching-out deposits indicate higher energy sedimentation than in under- and overlying subparallel U3a deposits. Note the horizontal, high-amplitude reflectors in the seismic unit U3b (MTD: Mass Transport Deposits).

The delta progradation on the base of slope is documented by the vertical succession of facies (Van Rensbergen et al., 1999). It is mainly characterized by prograding sigmoidal clinoforms that bound closely spaced, horizontal, high-amplitude reflectors (Fig. 8). The progradation of the delta system is marked by progradational sigmoidal clinoforms that developed during different episodes of delta sedimentation.

Conclusion

The buried sediments of the La Mentue delta, specifically belonging to the seismic unit U3b are interpreted as originated from a delta in a postglacial lake. The seismic unit U3b appear as a complex channel system, with levee and erosional structures. The formation of this deltaic sequence during the postglacial period due to massive meltwater inflow from the two ice masses of the Rhône and the Jura. This deltaic system varies in width between 4 and 5 km and maximum length between 15 and 20 km. The average of the inclination varies between 1° and 2°. An activity in the "La Lance fault zone" could be the origin of these sedimentary features in the seismic unit U3b. The base of the unit U3b marks the synchronous onset of a major melting phase in respectively the Rhône Glacier and Jura Ice Cap.

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