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River response to climate variability and land-use in the Bernese Alps during the last 2400 years.

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Introduction and regional setting

Gently sloping surfaces for settlement are scarce in high mountains ranges and they are commonly related to distal parts of alluvial fans where floods hazards can be expected. To understanding the influence of external factors, such as climatic variability and land uses, on the alluvial fan accretion and flooding processes, sedimentology and pollen analysis from local site provide valuable data. Fluvial sedimentation is intermittent in time and space and sediments may be removed by subsequent reworking phases (Lewin and Macklin, 2003). Despite the discontinuities of these records, fluvial sediments provide accurate data about terrestrial environmental change such as hydrological regime, sediment supply and land use. The Alps, bordering mountains between the humid mid-latitudes with Atlantic influence and the Mediterranean subtropical zone, are especially sensitive to events of extreme precipitation and disastrous floods and to changes in the circulation of the atmosphere at global scale (Wanner et al., 2004; Pfister, 2004). Natural paleofloods result from excessive rainfall intensity and frequency, snowmelt, glaciermelt, precipitation combined with frozen soils etc. However, land-use can modify substantially mountain ecosystems and dynamics of river systems.

Our research focuses on a multi-proxy approach to gain a greater understanding of the fluvial and geoecological dynamic of the Lütschine fan delta (601 - 564 m asl) during the last 2400 years. We chose the Lütschine fan delta as case study for several reasons: first, its strategic location at the valley mouth of an alpine river system at the northern slope of the Swiss Alps; furthermore, the spatial coexistence of wetland, alluvial and fluvial environments on the low gradient alluvial fan connected with a lake generating a high resolution fluvial record; moreover, the Lütschine catchment shows a specific spatial lithological settings of crystalline and carbonated sedimentary rocks; and, finally, the existence of exceptional exposures accessible during the construction of the "Theme Park of Mysteries" near the town of Interlaken.

Since the retreat of the Aare glacier system during the Late Glacial period the Lütschine drains the northern fringe of the Jungfrau massif (4158 m asl) to the Aare river and build up the fan delta, which separates Lake Thun from Lake Brienz. 17,4% of the 379 km^2 large Lütschine catchment is still covered by alpine-type glaciers (e.g. Lower Grindelwald glacier) and smaller hanging glaciers (e.g. Eiger glacier).

The Late Holocene depositional history of the Lütschine fan delta was reconstructed from morphological mapping, sedimentology, geochemistry, palynology, historical maps, building inventories and ^{14}C-dating techniques. The study aims to integrate theses data with other case studies of fluvial and glacial environments of the Swiss Alps and Central Europe.

Results

The sedimentology of the fan delta deposits, studied in five well-exposed profiles and in 9 drillings, detected several sedimentation cycles of riverbed sediments, organic rich silt layers and peat horizons from 4420±40 yr BP to present. The 90 m-wide exposed key section IN-2 (Fig.1) records a detailed sequence of organic rich paludal sediments deposited from 2200±70 to 1980±30 yr BP, four peat horizons providing dates of 1980±30, 1810±20, 1650±20 and 1160±20 yr BP, separated by fluvial and paludal sediments, and alluvial and colluvial deposits in the top.

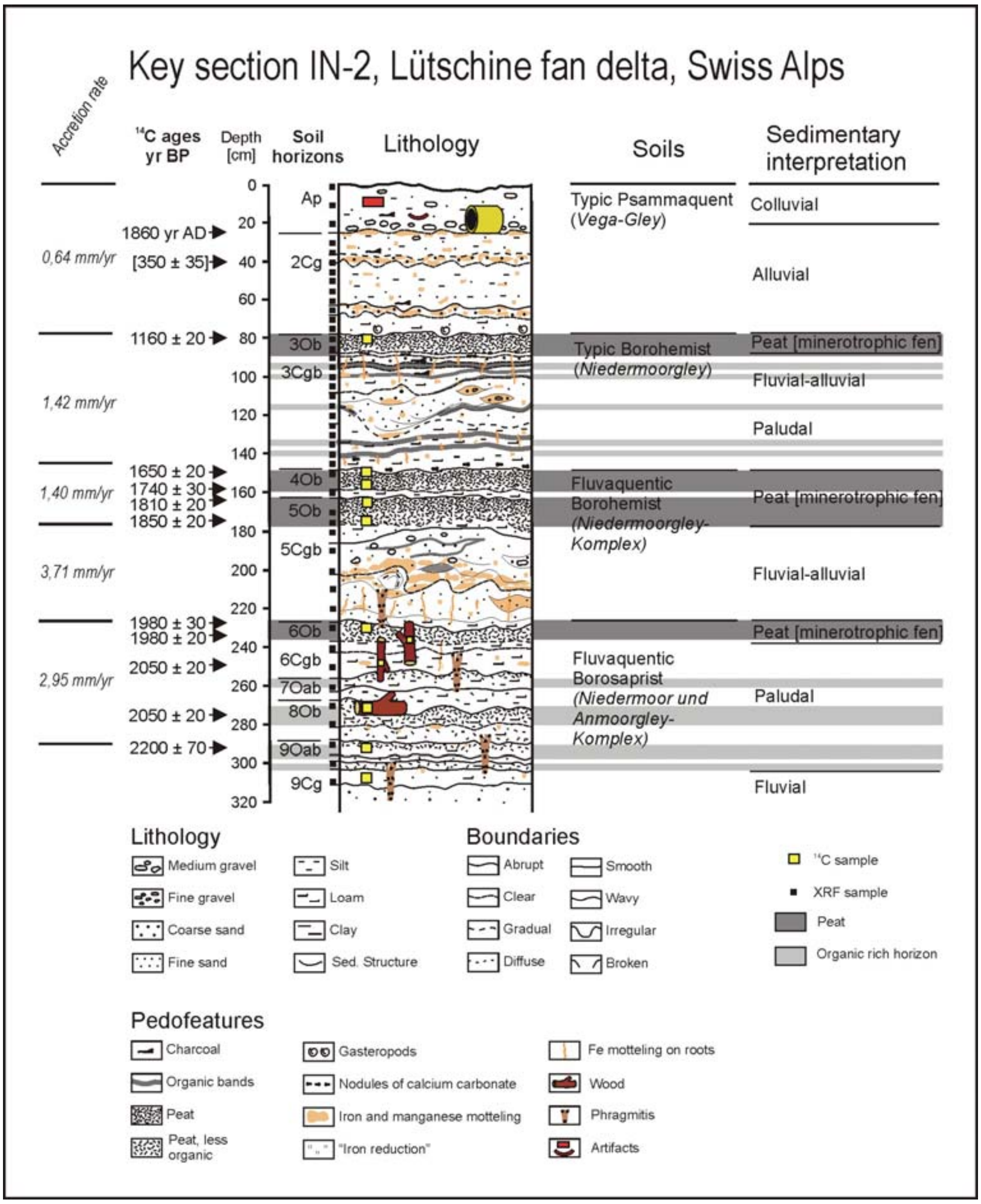

Figure 1: Lithology and chronology of key section IN-2, Lütschine fan delta, Swiss Alps.

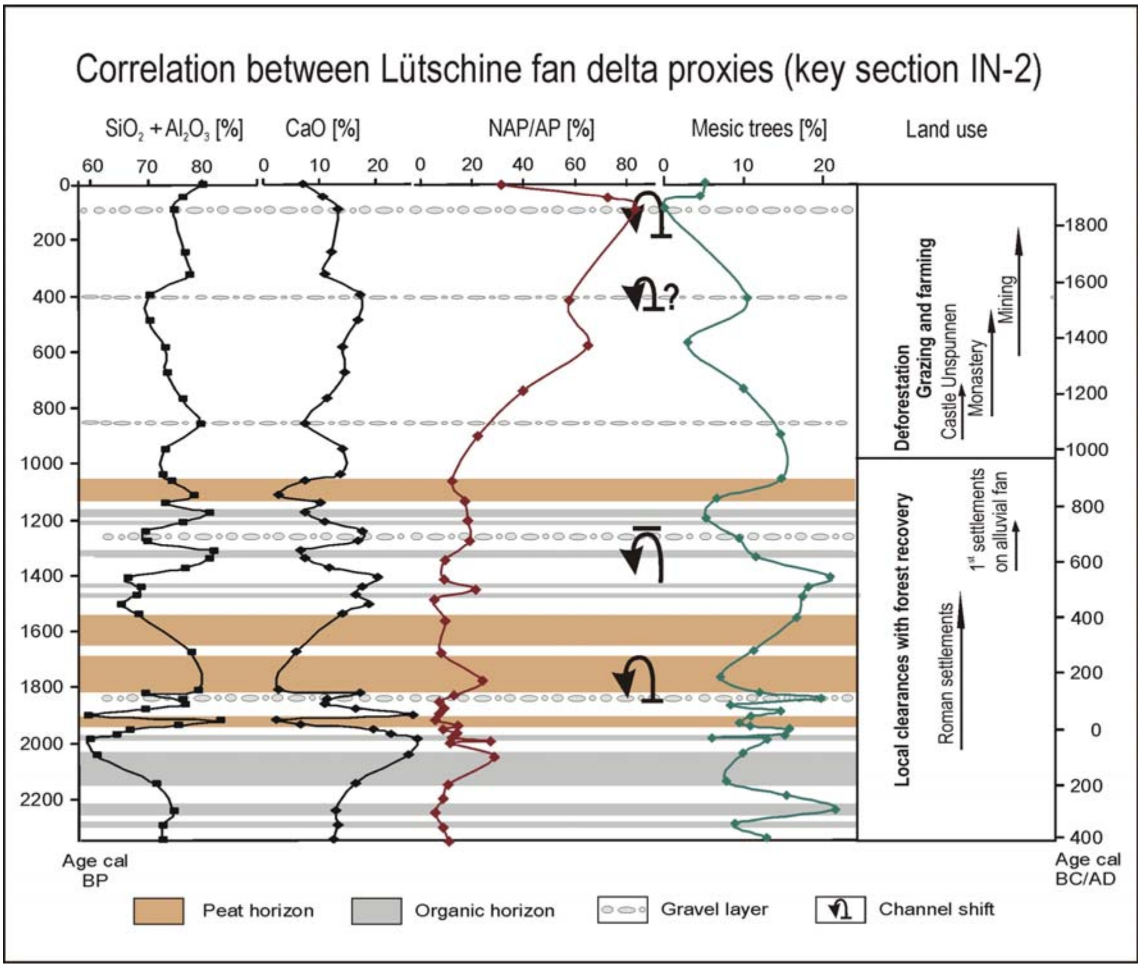

Figure 2: Correlation between geochemistry and pollen proxies of the Lütschine fan delta.

The inverse relationship between SiO_2, Al_2O_3 and CaO contents, determined by X-ray fluorescence, stresses a lithological control of the geochemistry of the profile IN-2 samples (Fig. 2). Variations result predominately from the deposition of siliciclastic sediments and carbonate rich fine sediments and pedogenic processes in the peat horizons.

The general stratigraphical framework of profile IN-2 and the lateral extension of the specific units can also be traced from the key sections IN-4, IN-10a, IN-10b and IN-10c and to a less degree also from cores IN-7 and IN-8. However, for an accurate geomorphic interpretation of the sedimentation units of the key section, spatial control of the fan delta channels are necessary. The identification of palaeochannels, their migration, abandonment and control by man requires a complex multi-proxy approach. The location of palaeochannels was reconstructed from 43 historical maps, published from 1496 to 1900, historical building inventories, geomorphological fieldwork, and survey of aerial photographs from 1928 to 1998. According to our findings, the western channels of the fan delta shifted westwards during Roman times and early Middle Ages, whereas the two closer channels at the east of key section IN-2 were abandoned between 1578 and 1797 and between 1796 and 1811.

The pollen diagram of key profile IN-2 records the vegetation dynamic over the last 2200±70 yr BP and can be subdivided in two mayor zones. The lower zone shows a dense tree vegetation cover composed predominantly by a conifer forest (*Picea*, *Abies*, *Pinus*), mesic trees (*Fagus*, deciduous *Quercus*) and riverside trees (*Alnus*). From the beginning of the sequence, human activity is documented by wood clearances for local agriculture activity (Cerealia, *Linum*, Cannabaceae) and grazing (*Plantago, Asphodelus*). However, the vegetal ecosystem is still sustainable as shown by the arboreal pollen recovery. The upper pollen zone extends from 1160±20 yr BP until present days and records a continuous regional deforestation as consequence of the human impact since the 12th c. related to the economic prosperity of the Monastery of Interlaken. The human impact and partly anthropogenic river diversion (Vischer, 1989) changed the depositional conditions and brought to an end the wetland environments.

Furthermore, the building inventories of six municipals were examined regarding house building on the flood plain of the Lütschine fan delta. The 31-year moving average of number of constructed houses per year was plotted versus time for the period from 1425 to 1880 AD. Periods of limited house building occurred around 1550, from 1700 to 1730 and between 1815 and 1835 AD.

Discussion

The Late Holocene depositional and vegetation history of the Lütschine fan delta records important environmental changes. Despite of the anthropogenic influence the independent variables CaO and mesic pollen percentages show a similar pattern from 2400 to 1000 yr cal BP (Fig. 2) and could be interpreted as natural response to climate forcing.

Peat horizons correspond to the climate optimums indicated by the negative radiocarbon anomalies. Other climate optimums are represented by the maximum values of mesic trees and by organic rich horizons. By contrast, the continuous anthropogenic impact after the 11th century masks the climate signal during the second Millennium. However, gravel and coarse sand layers, deposited during palaeofloods, proximately about 100, 700, 1100 y 1550 yr AD, correlate with positive radiocarbon anomalies.

Regarding the mechanism of the sediment supply we suggest that during mild-humid phases fine-grained, calcium rich material came from lower areas with carbonate rock predominance (Helveticum), whereas during cold-dry phases coarse-grained silica-rich material proceed from glacial and periglacial environments of the higher areas dominated by crystalline rocks (granite and gneis of the Aare massif).

For the period from 1425 to 1880 AD the building inventory of the Lütschine flood plain and the radiocarbon anomalies shows similar tendencies. Periods of enhanced house building coincides with periods of increased solar activity and vice versa. The long-term increase of construction could be ascribed to socio-economic and demographic factors, whereas the multi-decadal changes provide evidences for the influence of climate forcing on the settlement on the fan delta. The increase of flood magnitude and frequency could have played an important role. Furthermore, we can correlate two gravel layers and minimums of construction to periods of flooding (from 1550 to 1580 and from 1827 to 1875) recorded in the Alpine Rhine, Reuss and Rhone river systems by documentary data (Pfister, 1999).

In short, mayor sedimentation processes of the Lütschine river system occurred during the cooler Holocene climate events (Holzhauser et al., 2005) such as the Early Subatlantic Ice Advance (Göschen I period), Early Medieval Ice Advance (Göschen II period) and the Little Ice Age. In contrast, fluvial dynamics during the Roman and Medieval Climate Optimum were less significant and peat formation occurred.

Concluding remarks

From our findings we draw the following concluding remarks:

1) The 90 m wide exposed section and drills in the Lütschine fan delta show several cycles of riverbed sediments, organic-rich silty layers and peat horizons from 4420+/-40 yr BP to present.

2) The natural fluvial archives of the Lütschine fan record palaeoclimatic variability from 2400 to 1000 yr cal BP

3) For the last millennium the anthropogenic impact changed the depositional conditions and brought to an end the wetland environments. In addition, this impact occults the climate signal of the pollen and geochemistry proxies.

4) The return interval of recorded flood events of the last 2400 years varies between 300 and 600 years.

5) Human occupation of the Lütschine floodplain was influenced by climate variability.

6) The calibration of the natural proxies with documentary and instrumental data should be improved increasing the number of case studies of alpine catchments to check our fluvial response model.

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