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Paleolimnological evidence for increased landslide activity due to forest clearing and land-use since 3600 cal BP in the western Swiss Alps

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Abstract

Schwarzsee is located in the western Swiss Alps, in a region that has been affected by numerous landslides during the Holocene, as evidenced by geological surveys. Lacustrine sediments were cored to a depth of 13 m. The vegetation history of the lake's catchment was reconstructed and investigated to identify possible impacts on slope stability. The pollen analyses record development of forest cover during the middle and late Holocene, and provide strong evidence for regional anthropogenic influence such as forest clearing and agricultural activity. Vegetation change is characterized by continuous landscape denudation that begins at ca. 4300 cal. yrs BP, with five distinct pulses of increased deforestation, at 3650, 2700, 1500, 900, and 450 cal. yrs BP. Each pulse can be attributed to increased human impact, recorded by the appearance or increase of specific anthropogenic indicator plant taxa. These periods of intensified deforestation also appear to be correlated with increased landslide activity in the lake's catchment and increased turbidite frequency in the sediment record. Therefore, this study gives new evidence for a strong influence of vegetation changes on slope stability during the middle and late Holocene in the western Swiss Alps, and may be used as a case study for anthropogenically induced landslide activity.

Introduction

In the last decade, several natural disasters such as landslides, mudflows, storms, and avalanches have affected large regions of the Alps. In the western Swiss Alps, the region surrounding Schwarzsee (Figure 1a) has been particularly affected by large landslides and mudflows. For example, in 1994 a catastrophic landslide destroyed 41 buildings located at the summer resort of Falli Hölli (Figure 1a, landslide n°1; Raetzo & Lateltin, 1996). In addition, some less destructive landslides have occurred more recently, and together with the rare but catastrophic Falli Hölli event have revived concern about slope stability among community groups, local authorities, and researchers. This study is part of a larger project investigating 5 landslides close to Schwarzsee's catchment (Figure 1a) with the objective of defining processes governing the dynamics of large landslides. Early findings suggest that landslides of variable amplitude have occurred over the past 7000 yrs (Raetzo-Brülhart, 1997). Past research in the Alps, which focused on Holocene landslide frequency throughout Switzerland during the Holocene, established correlations between landslide activity and various climate-controlled

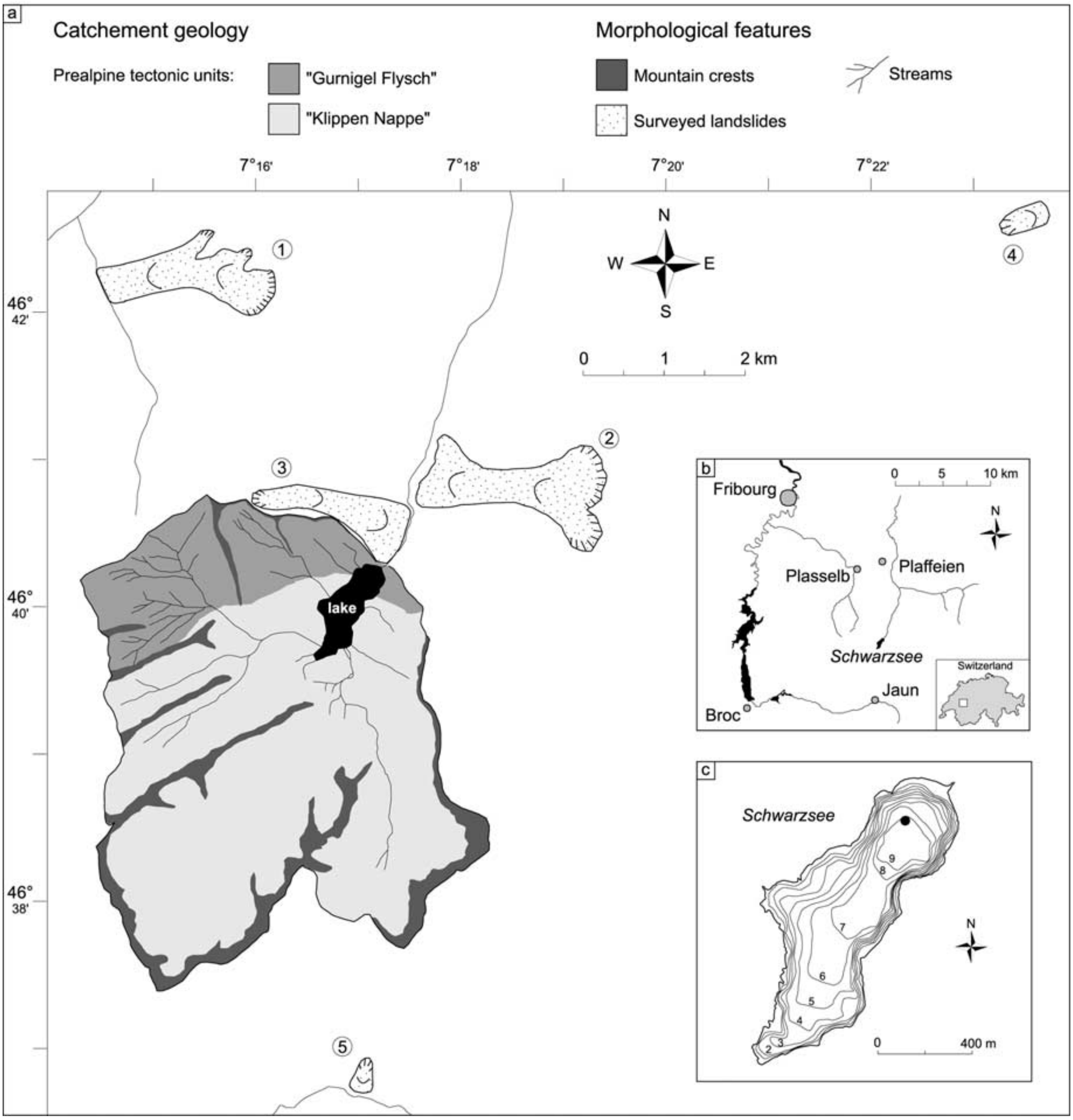

Figure 1. (a) Schwarzsee drainage basin with its hydrographical and geological setting; distribution of five surveyed landslides in the lake's vicinity (1: Falli Hölli, 2: Hohberg, 3: Schlossisboden, 4: Gantrisch, 5: Jaun); (b) location of Schwarzsee in western Switzerland; (c) lake bathymetry (modified from Lister, 1989), and core location.

processes such as glacier advances (Schlüchter, 1990), precipitation (Schöneich, 1991; Raetzo-Brülhart, 1997; Noverraz et al., 1998), and stream torrentiality (Schöneich et al., 1996). However, climate and climate induced factors (e.g., precipitation, temperature, snowmelt) are rarely solely responsible for increased landslide activity and many other factors such as shifts in vegetation, anthropogenic impacts, and earthquakes may also affect slope stability (Sorriso-Valvo, 1997; Thornes, 1997; Dikau & Schrott, 1999).

While recent research efforts have contributed to our understanding of factors responsible for landslide activity, a key question remains: to what extent should parameters such as vegetation cover and anthropogenic impact be considered as significant factors that contribute to increased landslide probability during the Holocene especially compared with broader-scale factors, such as climate? To answer this question, the present study uses the lacustrine sediment record from Schwarzsee to: (i) assess regional vegetation changes through pollen analysis, (ii) generate a chronological framework using the pollen record, (iii) assess anthropogenic impacts on vegetation, and (iv) identify and specify processes that contributed to Holocene landslide activity in the Schwarzsee area.

Geographical and geological setting

Schwarzsee (46° 40′N, 7° 17′E) is a shallow mountain lake, located in the canton of Fribourg, western Switzerland (Figures 1a and 1b; 1046 m a.s.l.). It has gently sloping shores and a regular basin morphometry with a maximum water depth of 9.5 m and an open water area of 0.46 km^2. Its drainage basin covers an area of 19.7 km^2, with several streams that discharge into the lake. Seasonal stream-flow is irregular, with some streams occasionally ceasing flow during dry seasons. The local climate is characterized by a mean annual temperature of 6 °C, with mean summer and winter temperatures of 14 °C and –1.8 °C, respectively; and an annual precipitation of 1620 mm (Lotter et al., 1997). Catchment vegetation is characterized by mixed coniferous/deciduous forests and pastured meadows.

From a geological perspective, Schwarzsee is situated at the intersection of two prealpine tectonic units (Figure 1a). The 'Gurnigel Flysch' consists of sedimentary rocks from a Tertiary sea-basin and contains mostly silicoclastic rocks such as sandstones or shales, and characteristic fossil dynoflagellate cysts which can be used to identify clastic sediment input to the lake originating from this geological unit (van Stuijvenberg, 1979). The 'Gurnigel Flysch' extends to the northern extremity of the lake's catchment, while the 'Klippen Nappe' is present in the central and southern parts of the catchment. The 'Klippen Nappe' contains a wide variety of rock types including carbonate and silicoclastic constituents (limestones, dolomitic or siliceous limestones, shales; Plancherel, 1976).

The composition of the 'Gurnigel Flysch', with up to 50% shales, favours slope instability. Indeed, groundwater can be trapped above impermeable shaley layers and, when water pressure increases, overlying material may begin to slide downhill causing landslides (Lateltin et al., 1997). Current research suggests that Schwarzsee was itself created by a large landslide (Figure 1a, landslide n°3) originating from the 'Gurnigel Flysch' that probably led to damming of the valley.

Methods

A 13 m core was extracted from Schwarzsee in May 1999 at a water depth of 9.2 m, using a modified Livingstone piston corer (Merkt & Streif, 1970) with a diameter of 5 cm and segment lengths of 100 cm, operated from a raft. The core location (46° 40′13″N, 7° 17′05″E, Figure 1c) was chosen in the central basin plain, beyond zones influenced by delta deposition and subaqueous stream deposits, in order to analyse sediments characterized by a low sedimentation rate, not affected by too many disturbing events such as turbidites.

One longitudinal half of the core was sampled for various analyses, whereas the other half was kept intact as reference material. Grain-size analyses were carried out with a Sedigraph 5100 to describe the types of sediments (e.g., debris flow, turbidites, fine particle deposits). Grain-size categories included clay (< 2 µm), silt (2–63 µm), sand (63 µm–2 mm), and gravel (2–60 mm). The semi-quantitative mineral composition of 24 samples of 2 cm^3 (Figure 3) was determined using X-Ray powder diffraction. The samples were chosen to be representative of all kinds of lithologies found in the core (e.g., alluvial sediments, peat, silty-clayey layers, turbidites, debris flow), and were, therefore, not collected at fixed intervals. The samples were first oven-dried and crushed in a mortar to produce a fraction of around 60 µm. All samples were then placed in a Philips PW 1800 diffractometer and analysed at 40 kV and 40 mA with CuKα radiation ranging from 2°–65° 2θ. This method produced semi-quantitative data for the relative abundance of minerals in the sediments. Loss-on-ignition (LOI) analyses were carried out on 258 samples of 1 cm^3, collected at constant 5 cm intervals, to assess total organic matter and carbonate content, using techniques outlined by Heiri et al. (2001). Pollen analyses were carried out on 58 samples of 1 cm^3 collected at 20 cm intervals, excluding depositional events, such as turbidites and debris flows, and prepared according to standard methods (van der Knaap et al., 2000). *Lycopodium* tablets were added to each sample for the determination of pollen concentrations. Average pollen counts were maintained at around 400–

500 pollen grains. The percentages sum (100%) contains arboreal and non-arboreal pollen types, whereas pollen and spores from ferns and aquatics, as well as dinoflagellates, also counted in the pollen slides, are excluded. The pollen analysis and the interpretation in terms of past vegetation, human impact and chronology were carried out by J.F.N. van Leeuwen and W.O. van der Knaap.

One radiocarbon date was obtained from a peat sample extracted at the bottom of the core, between 1240 and 1244 cm depth. Preparation and dating of the sample were performed at the Radiocarbon Laboratory of the Physics Institute, University of Bern, Switzerland. The OxCal program by Bronk Ramsey (1995, based on Stuiver et al., 1993) was used to calibrate the radiocarbon date.

Results

Sedimentological description

At the bottom of the core, a non-laminated sandy alluvial deposit containing plant remains and woody debris is overlain by a clay-rich, dark-brown, 30 cm thick peat layer with abundant plant remains (Figures 2 and 3). The overlying deposits are lacustrine sediments, with the exception of a debris flow deposit, and contain different sediment types:

Homogeneous and finely laminated silt and clay-rich layers occur throughout the core (Figures 2 and 3). They originate from the settling of suspended fine-grained material on the lake bottom. Clays are discharged into the lake by inflowing streams, and dispersed by water circulation and water density.

Numerous turbidites occur throughout the core. They are graded deposits of typically sandy to clayey material, and have a thickness ranging from a few millimeters to ca. 15 cm. The pattern of upward grading controls the mineral distribution. Each turbiditic sequence includes quartz enrichment at the bottom and an increasing amount of non-differentiated clays toward the top of the layer. In the upper 750 cm of the core, turbidites are more common and also thicker on average (Figures 2 and 3). Thirty-six turbidites are recorded down to 750 cm depth, deposited during the past 2000 years, in contrast with 16 such events in the 470 cm below that level (Figures 2 and 3), deposited between 6300 and 2000 cal. yrs BP.

A debris flow deposit extends from 649 to 498 cm depth (Figures 2 and 3), and is characterized by the deposition of non-graded, unlaminated coarse sediments, like cm-scale gravels, in a sandy matrix. Lithologically, the gravels are very similar to the 'Gurnigel Flysch' sandstones, which indicates that the debris flow originated on the northernmost side of the lake, where this formation dominates.

X-ray analysis

Various minerals, such as quartz, calcite, dolomite, gypsum, pyrite (Figure 3), and a large spectrum of phyllosilicates (montmorillonite, kaolinite, illite, muscovite, mixed-layers) are present. Semi-quantitative analyses of samples at selected depths indicate that quartz is the most abundant mineral, resulting from abundant clastic inwash by the catchment's streams. Calcite and dolomite are also common, except in the alluvial sediments at the bottom of the core. Gypsum is present only in samples between 940 and 190 cm depth, and pyrite is present from 1140 to 470 cm depth. Phyllosilicates (not shown in Figure 3) are only present in low relative abundance in all samples.

Loss-on-ignition analysis

Results of LOI measurements are presented in Figure 3. The LOI at 550 °C curve (organic matter) generally ranges between 6 and 10%. The highest values reach ~ 75% in the bottom organic-rich peat layer (1223–1253 cm), while the lowest amounts of organic matter are found in the debris flow deposit. The organic content increases in the upper 200 cm, corresponding to the past 450 years (Figure 3). The LOI at 950 °C curve (carbonate content) is characterized by shifts ranging from 6–14% throughout the lacustrine sediments, including the debris flow deposit, in contrast with the alluvial deposits (~ 1% carbonate) and the peat layer (~ 4% carbonate) at the bottom.

Chronology and vegetation history

The pollen record from Schwarzsee begins at the end of the Older Atlantic pollen zone (*sensu* Firbas, 1949). The basal part of the pollen stratigraphy represents the onset of the regional pollen assemblage zone CHb-7 (*Fagus-Abies-Alnus* pollen assemblage zone, see Ammann et al., 1996) and contains a Holocene vegetation history typical of the region (Figure 2). The vegetation of the past 7000 years is inferred to consist of montane fir-beech forests and spruce forests present in the subalpine belt of Schwarzsee's catchment.

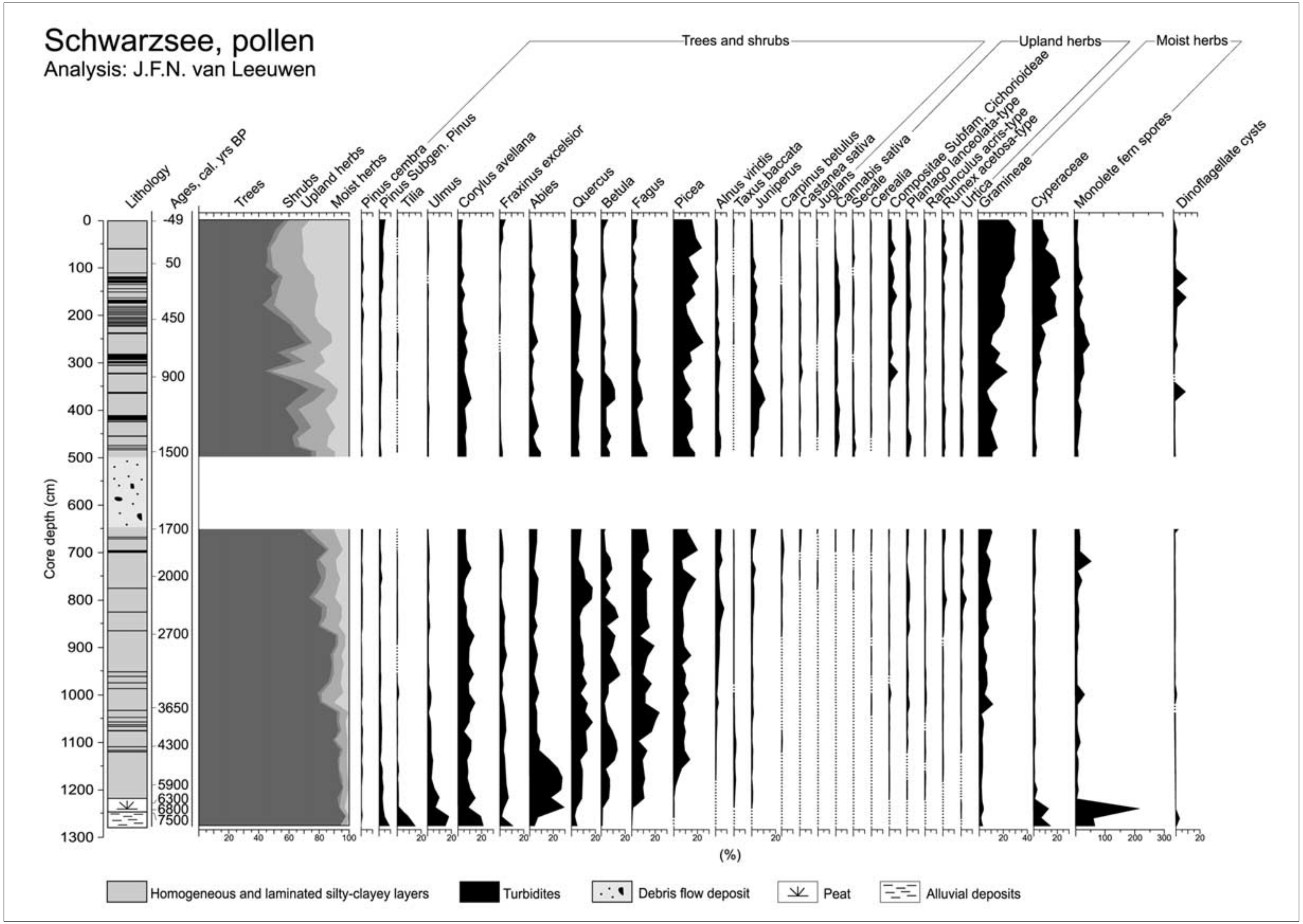

Figure 2. Percentage pollen diagram from the 13 m long Schwarzsee core, illustrating a selection of taxa. The white area delimits the debris flow event.

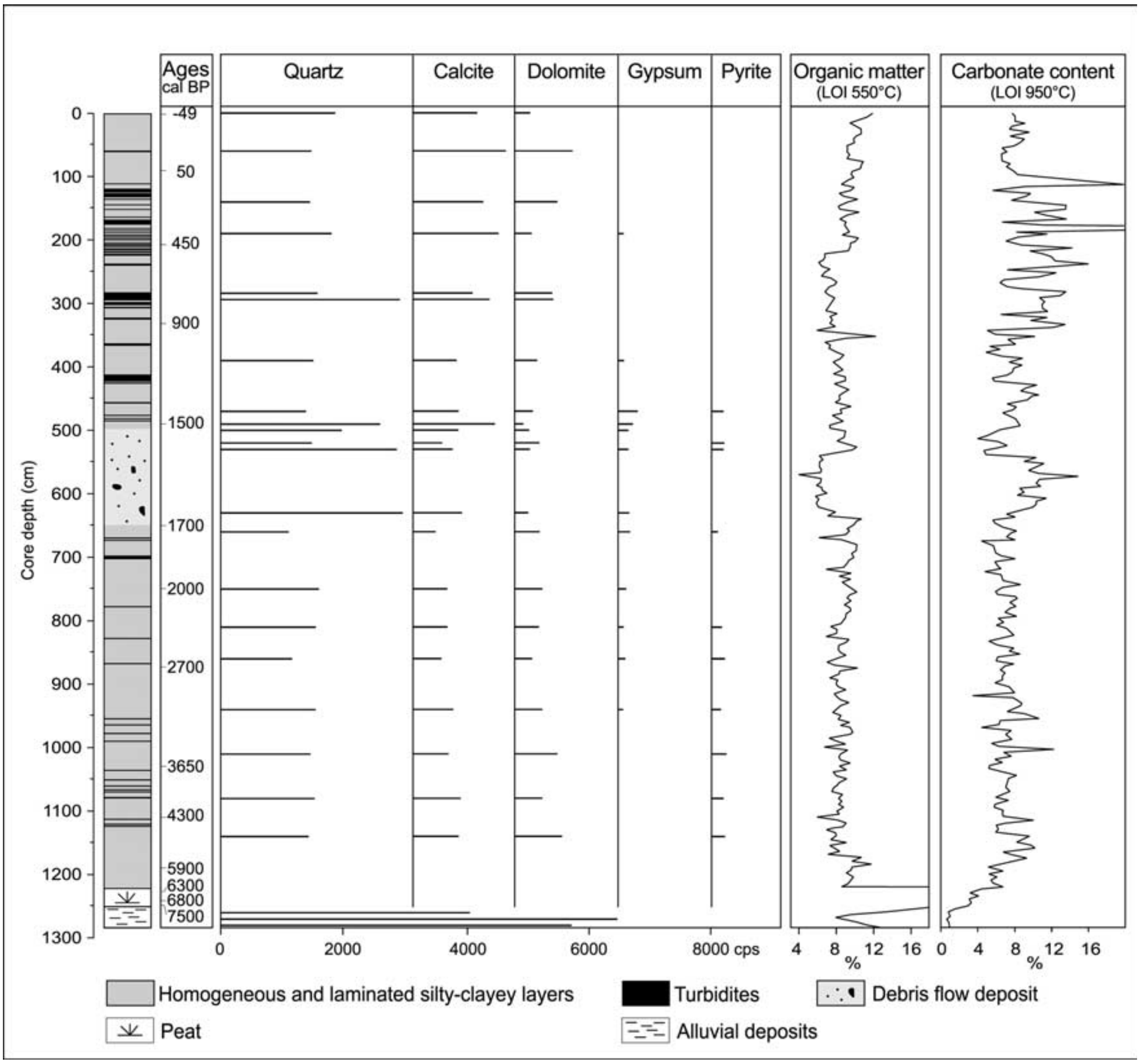

Figure 3. Lithology of the 13 m long Schwarzsee core, with the relative abundance of principal minerals (quartz, calcite, dolomite, gypsum, and pyrite) and the percentages of organic matter (loss-on-ignition at 550 °C) and carbonate (loss-on-ignition at 950 °C).

In order to establish a chronology for the sediment core, the pollen profile from Schwarzsee was compared with well-dated pollen diagrams from the nearby Alps and Swiss Plateau. Dates older than 2000 cal. yrs BP were inferred from regional pollen chronologies, using the following sites: Aegelsee (989 m a.s.l.; Wegmüller & Lotter, 1990), Wachseldorn-Untermoos (980 m a.s.l.; Heeb & Welten, 1972), Gänsemoos (795 m a.s.l.; Welten, 1982), and Lobsigensee (514 m a.s.l., Ammann, 1989). Chronostratigraphic pollen markers (van der Knaap et al., 2000) were used to date the past 2000 years.

An age of ca. 7500 cal. yrs BP was attributed to ca. 1250 cm sediment depth based on a decline in *Tilia*, *Ulmus*, *Pinus*, and *Corylus*, that occurs together with an increase in *Abies*. The rise of *Fagus* and decline in *Ulmus* at ca. 1230 cm is attributed to ca. 6300 yrs BP, whereas the appearance of *Picea* and a further decline in *Ulmus* around 1190 cm are dated to ca. 5900 yrs BP. Due to low concentrations of datable plant remains, only one radiocarbon date could be obtained from the peat layer at the bottom of the core, extracted between 1240 and 1244 cm depth, and revealed an age of 5990 ± 30 conventional ^{14}C yrs BP (B-7595), resulting in a calibrated age ranging from 6890 to 6730 cal. yrs BP. The radiocarbon date thus supports the pollen ages of ca. 7500 cal. yrs BP at ca. 1250 cm depth and ca. 6300 cal. yrs BP at ca. 1230 cm depth.

Human presence is indicated by a decline in *Abies* together with increasing values of *Plantago lanceolata*-type and *Urtica* at 1110 cm, associated with the Egolzwil Neolithic period, ca. 4300 cal. yrs BP. Increased non-arboreal pollen values around 1030 cm, especially herbs associated with human settlement (e.g., Gramineae, Compositae subfam. Cichorioidae, *Plantago lanceolata*-type, *Rumex acetosa*-type, Cerealia), are characteristic of assemblages from the Bronze Age, ca. 3650 cal. yrs BP. Such assemblages are found in many pollen diagrams from the Swiss Plateau and the Alps. At 870 cm, high levels of herb pollen provide evidence for increased human impact. In association with the arrival of *Carpinus*, this suggests an age of ca. 2700 cal. yrs BP and can thus be attributed to the Iron Age.

The arrival of *Castanea* shortly after *Juglans*, at 750 cm, is indicative of the Roman Period commencing around 2000 cal. yrs BP. Further diagnostic features include the end of the *Quercus* maximum in the late Bronze Age, and the increase of *Carpinus*.

Human impact increases substantially at 490 cm and is attributed to the Middle Ages (ca. 1500 cal. yrs BP). Here, a decline in timber trees like *Abies*, *Fagus*, *Picea*, and *Fraxinus excelsior* is accompanied by an increase in herbs, *Cannabis*, and Cerealia pollen. At 330 cm (ca. 900 cal. yrs BP) and at 210 cm (ca. 450 cal. yrs BP) human impact intensified and these trends coincide with an increase in turbidite events (Figure 2). The decline in *Cannabis* at 90 cm represents the end of the 19th century AD (ca. 50 cal. yrs BP).

The curve expressing dinoflagellate abundance (Figure 2) shows several distinct peaks. These unicellular marine organisms (Jan du Chêne et al., 1975) were eroded from the Tertiary rocks of the ‘Gurnigel Flysch’ and washed into the lake. The inwash of dinoflagellates found in the Schwarzsee core arose from the three streams entering the lake at its northwestern side. High numbers of dinoflagellate cysts are present in the alluvial sediments at the bottom of the core, and above all in the upper 400 cm of the core.

Discussion

The changes in vegetation cover since 3650 cal. yrs BP (Figures 2 and 4), principally characterized by a progressive replacement of forested areas with pastures and meadows, are of major importance, since decreasing tree cover has serious consequences for slope stability. Indeed, forest clearing can dramatically accelerate landsliding (Thornes, 1997; Montgomery et al., 2000),

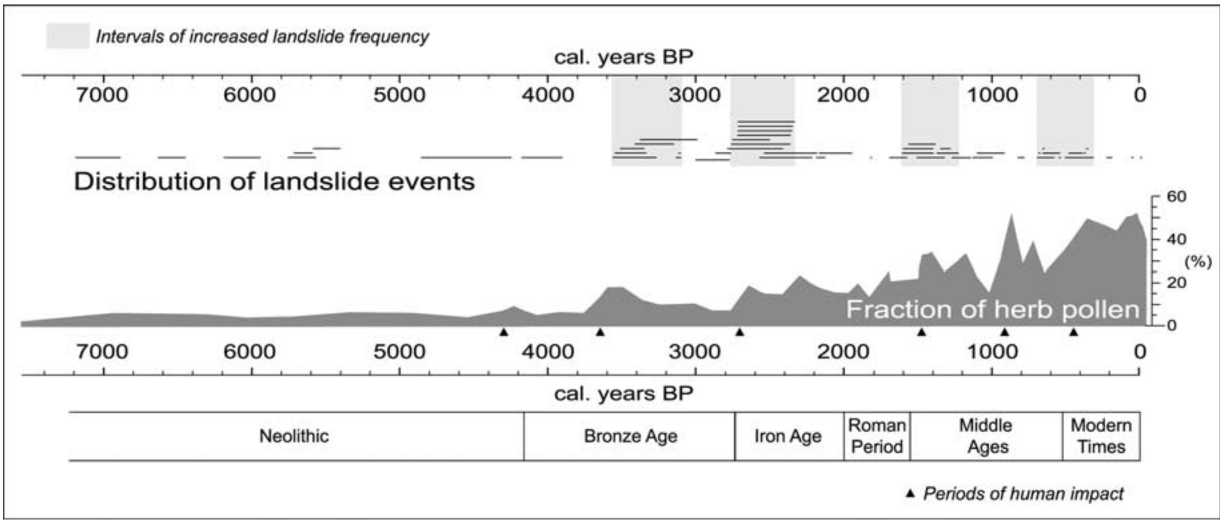

Figure 4. Distribution of landslide events (upper data, modified from Raetzo-Brülhart, 1997) from five different sites (cf. Figure 1) during the middle and late Holocene. Ages are based on radiocarbon and dendrochronological datings of multiple wood samples buried in the landslides. Grey shading emphasizes periods of increased frequency of landslide events. The lower curve expresses the percentage of herb pollen in the 13 m Schwarzsee core. This curve combines the fractions of upland herbs and moist herbs presented in Figure 2. Black triangles placed along the herb pollen curve indicate peaks of human impact, illustrated by the increase of anthropogenic indicator herb taxa at 4300, 3650, 2700, 1500, 900, and 450 cal. yrs BP.

since tree cover reduces water infiltration and contributes to slope stabilization (roots).

The distribution of landslide events during the past 7000 years (Figure 4, Raetzo-Brülhart, 1997) indicates correlations with vegetation changes in the Schwarzsee area. The studied and dated landslides are presented in Figure 1a, all of them located in the vicinity of Schwarzsee, and thus close enough to be fairly correlated to the Schwarzsee core findings, especially with the pollen record. Figure 4 reveals a higher frequency of landslide events since 3600 cal. yrs BP, coinciding with the beginning of noticeable forest opening in the Schwarzsee area, at 3650 cal. yrs BP. The forest clearance is illustrated in Figure 4 by the increase of the herb pollen percentages.

The vegetation history in the Schwarzsee area is linked to land-use development, starting at about 4300 cal. yrs BP, characterized by the replacement of forest surfaces by cereals and herbs associated with human settlements, such as *Plantago lanceolata*-type, *Urtica*, *Rumex acetosa*-type, and *Cannabis*. Distinct successive periods of increased human impact, starting at about 3650, 2700, 1500, 900 and 450 cal. yrs BP, are expressed by increased herb pollen percentages (Figure 4). Also, the enhanced organic content in the upper 200 cm, corresponding to the past ~ 450 years (Figure 3), may be associated with greater human-induced biological productivity in the lake. Indeed, the development of human settlements in the lake's catchment, with increased cattle breeding, agricultural development, and use of fertilizers is likely to have increased lake productivity.

The intervals of increased landsliding, illustrated by grey shading in Figure 4, shortly follow or coincide with periods of enhanced forest clearing. This suggests a relationship between vegetation cover and slope instability. Since vegetation changes at Schwarzsee are related to human influence, this is new evidence of anthropogenic influence on slope stability during the late-Holocene in the western Swiss Alps. At about 900 cal. yrs BP, a large positive shift of herb pollen does not correspond to any significantly high frequency of landslide events, but is synchronous with increased turbidite flow into Schwarzsee. This particular pollen signal might be related to specific land disturbance close to the lake shores.

Ages based on pollen analyses indicate that the turbidite frequency clearly increased between 2000 and 1700 cal. yrs BP (Figures 2 and 3), with 36 turbidite events occuring in the past 2000 yrs interval, in contrast to 16 turbidite events during the previous 4300 yrs interval (from 6300 to 2000 cal. yrs BP). This trend suggests that erosion and runoff in the lake's catchment was promoted by the continuous landscape denudation. Elliot et al. (1995) observed similar phases of increased erosion, recorded in lake sediments in the form of large inwash of inorganic sediments, and could relate them to human-induced deforestation. At Schwarzsee, the increase of erosion and runoff is also recorded by the increased number of reworked fossil dinoflagellates, from ~ 900 cal yrs BP, resulting from the increased erosion of 'Gurnigel Flysch' Tertiary rocks. Therefore, the human-induced vegetation changes that affected the Schwarzsee region had considerable influence on the landscape, firstly by increasing the landsliding potential, and secondly by increasing erosion and runoff.

Conclusion

This study provides strong evidence of a close relationship between human-induced changes in vegetation cover and landslide activity during the middle and late-Holocene in the Schwarzsee area. Indeed, the coincidence of landscape denudation starting at about 4300 cal. yrs BP, and increasing from 3650 cal. yrs BP, together with sedimentological features such as the increase of turbidites, and the enhanced landslide activity from about 3600 cal. yrs BP, provides strong evidence for human-induced environmental changes resulting from changes to vegetation in the landscape initiated and controlled by man. We therefore assert that parameters such as vegetation cover and human impact can be considered major factors contributing to increase landslide activity in the Schwarzsee area during the late-Holocene. Further studies will focus on early to mid-Holocene landslide events, to evaluate the relative importance of vegetation and climatic changes on slope stability before significant human impact, and to further examine the relationship between climatic fluctuations and vegetation changes in the Schwarzsee area.

In conclusion, this study provides evidence for anthropogenic influence contributing to increased slope instability over the past 3600 years. The influence of land-use on slope stability should, therefore, be taken into consideration in the management and prediction of landslides in landslide-prone mountain regions. Territory planning should routinely monitor slope stability, in order to secure the future development of mountain settlements and regional economies. Past landslides contain useful information about velocities, delay of reaction, hydrological context, and land-use. This knowledge may assist land managers to better control and predict the future behaviour of instable slopes.

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References

Ammann, B., 1989. Late-Quaternary palynology at Lobsigensee. Regional vegetation history and local lake development. Dissertationes Botanicae 137: 1–157.

Ammann, B., M. J., Gaillard & A. F. Lotter, 1996. Switzerland. In Berglund, B. E., H. J. B. Birks, M. Ralska-Jasiewiczowa & H. E. Wright (eds), Palaeoecological Events During the Last 15,000 Years – Regional Syntheses of Palaeoecological Studies of Lakes and Mires in Europe. John Wiley and Sons, New York, 647–666.

Bronk Ramsey, C., 1995. Radiocarbon calibration and analysis of stratigraphy: The OxCal program. In Cook, G. T., D. D. Harkness, B. F. Miller & E. M. Scott (eds), Proceedings of the 15th International ^{14}C Conference. Radiocarbon 37: 425–430.

Dikau, R. & L. Schrott, 1999. The temporal stability and activity of landslides in Europe with respect to climatic change (TESLEC): main objectives and results. Geomorphology 30: 1–12.

Elliot M. B., B. Striewski, J. R. Flenley & D. G. Sutton, 1995. Palynological and sedimentological evidence for a radiocarbon chronology of environmental change and polynesian deforestation from Lake Taumatawhana, Northland, New Zealand. Radiocarbon 37: 899–916.

Firbas, F., 1949. Spät- und nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen. Fischer, Jena, 480 pp.

Heeb, K. & M. Welten, 1972. Moore und Vegetationsgeschichte der Schwarzenegg und des Molassevorlandes zwischen dem Aaretal unterhalb Thun und dem obern Emmental. Mitteilungen der Naturforschenden Gesellschaft in Bern 29: 1–54.

Heiri, O., A. F. Lotter & G. Lemcke, (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. J. Paleolim. 25: 101–110.

Jan du Chêne, R., G. Gorin & J. van Stuijvenberg, 1975. Etude géologique et stratigraphique (palynologie et nannoflore calcaire) des Grès des Voirons (Palogène de Haute-Savoie, France). Géologie Alpine 51: 51–78.

Lateltin, O., C. Beer, H. Raetzo & C. Caron, 1997. Instabilités de pente en terrain de flysch et changements climatiques. Rapport final PNR 31, vdf Hochschulverlag AG an der ETH Zürich, 168 pp.

Lister, G.S., 1989. Sedimentation im Schwarzsee, Plaffeien, Fribourg. Schlussbericht, Geologisches Institut, ETH-Zürich, 21 pp.

Lotter, A. F., H. J. B. Birks, W. Hofmann & A. Marchetto, 1997. Modern diatom, cladocera, chironomid, and chrysophyte cyst assemblages as quantitative indicators for the reconstruction of past environmental conditions in the Alps. I. Climate. J. Paleolim. 18: 395–420.

Merkt, J. & H. Streif, 1970. Stechrohr-Bohrgeräte für limnische und marine Lockersedimente. Geol. Jb. 88: 137–148.

Montgomery, D. R., K. M. Schmidt, H. M. Greenberg & W. E. Dietrich, 2000. Forest clearing and regional landsliding. Geology 28: 311–314.

Noverraz, F., C. Bonnard, H. Dupraz & L. Huguenin, 1998. Grands glissements de versants et climat – VERSINCLIM – Comportement passé, présent et futur des grands versants instables subactifs en fonction de l'évolution climatique, et évolution en continu des mouvements en profondeur. Rapport final PNR 31, vdf Hochschulverlag AG an der ETH Zürich, 314 pp.

Plancherel, R., 1976. Essai d'interprétation de la dislocation tranversale Bellegarde-Lac Noir (Préalpes médianes fribourgeoises). Eclogae Geol. Helv. 69: 461–469.

Raetzo-Brülhart, H., 1997. Massenbewegungen im Gurnigelflysch und Einfluss der Klimaänderung. Schlussbericht NFP 31, vdf Hochschulverlag AG an der ETH Zürich, 256 pp.

Raetzo, H. & O. Lateltin, 1996. Rutschung Falli Hölli, ein ausserordentliches Ereignis? Internationales Symposium Interpraevent 1996, Garmisch-Partenkirchen, Tagungspublikation 3: 129–140.

Schlüchter, C., 1990. Instabilities in the area of St. Moritz, Switzerland – Geology, chronology, geotechnology. In: Bonnard, C. (ed.), Landslides. Proceedings of the Fifth International Symposium on Landslides 2, Balkema, Rotterdam, Brookfield, 1375–1380.

Schöneich, P., 1991. Effets des intempéries des 14 et 15 février 1990 aux Ormonts (Alpes vaudoises). Bull. Soc. Vaud. Sci. Nat. 80: 279–297.

Schöneich, P., J. Tercier, J.-P. Hürni, C. Orcel & A. Orcel, 1996. Les crises catastrophiques du glissement des Parchets (Préalpes vaudoises, Suisse): indices d'une augmentation des précipitations extrêmes entre 2'000 et 1'500 ^{14}C BP. Quaternaire 7: 97–109.

Sorriso-Valvo, M., 1997. Landsliding during the Holocene in Calabria, Italy. In: Mathews, J. A., D. Brunsden, B. Frenzel, B. Gläser & M. M. Weiß (eds), Rapid Mass Movement as a Source of Climatic Evidence for Holocene. Paläoklimaforschung – Palaeoclimate Research, 19: 97–108.

Stuiver, M., A. Long & R. S. Kra, 1993. Calibration 1993. Radiocarbon 35: 1–244.

Thornes, J., 1997. Mass failure and climate change in a Mediterranean climate: the case of the Sierra Nevada, south-east Spain. In: Mathews, J. A., D. Brunsden, B. Frenzel, B. Gläser & M.

M. Weiß (eds.), Rapid Mass Movement as a Source of Climatic Evidence for Holocene. Paläoklimaforschung – Palaeoclimate Research, 19: 85–96.

Van der Knaap, W. O., J. F. N. van Leeuwen, A. Fankhauser & B. Ammann, 2000. Palynostratigraphy of the last centuries in Switzerland based on 23 lake and mire deposits: chronostratigraphic pollen markers, regional patterns, and local histories. Rev. Paleobot. Palynol. 108: 85–142.

Van Stuijvenberg, J., 1979. Geology of the Gurnigel area (Prealps, Switzerland). PhD Thesis, Institut de Géologie de l'Université de Fribourg (Suisse), n° 781, 112 pp.

Wegmüller, S. & A. F. Lotter, 1990. Palynostratigraphische Untersuchungen zur spät- und postglazialen Vegetationsgeschichte der nordwestlichen Kalkvoralpen. Botanica Helvetica 100: 37–73.

Welten, M., 1982. Pollenanalytische Untersuchungen zur Vegetationsgeschichte des Schweizerischen Nationalparks. Ergebnisse der wissenschaftlichen Untersuchungen im Schweizerischen Nationalpark 16: 3–43.