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A Late Pleistocene Age for the Chironico rockslide (Central Alps, Ticino, Switzerland)

With 6 figures and 2 tables

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Keywords: rockslide-damming, radiocarbon dating, basin fill, Central Alps.

Abstract

The radiocarbon dating of organic remains (wood fragments) enclosed in lacustrine sediments laid down in a rockslide-dammed lake permitted to indirectly constrain the age of the Chironico rockslide (Central Alps, Ticino, Switzerland). Dated samples came from a core drilled for geotechnical purposes and yielded the following ^{14}C ages: 11'340 ± 80, 11'690 ± 85, 11'500 ± 80 (^{14}C yr BP). Calibrated ages indicate that the rockslide took place in the Bølling-Allerød chronozones: 13786–13027, 15101–13428, 13821–13162 (Cal BP).

The occurrence of alluvial sand and gravels over lacustrine sediments suggests that the rockslide dam was stable. The lake had an estimated depth of ~30 m, a length of ~3 km, a surface area of ~1.3 km^2 and a volume of ~39 x 10^6 m^3.

Considering the great uncertainties in estimating Late Pleistocene river discharge and sediment yield we suggest that the lake persisted for ~120–730 yr.

Riassunto

La datazione con il metodo del radiocarbonio di resti di materiale organico (legno), rinvenuti nei sedimenti lacustri depositatisi a seguito dello sbarramento del fiume Ticino da parte di una frana di grandi dimensioni presso Chironico (Alpi Centrali, Ticino, Svizzera), ha consentito di stabilire indirettamente l'età di quest'ultima. I tre campioni analizzati, provenienti da un sondaggio geotecnico, hanno fornito le seguenti età: 11'340 ± 80, 11'690 ± 85, 11'500 ± 80 (^{14}C yr BP). Dopo calibrazione delle età radiocarbonio si ottengono dei valori che situano l'evento nel periodo climatico Bølling-Allerød: 13786–13027, 15101–13428, 13821–13162 (Cal BP).

La presenza di sabbie e ghiaie fluviali al di sopra dei sedimenti lacustri indica che la diga era stabile. Sulla base dello spessore e della distribuzione dei depositi lacustri rinvenuti in diversi sondaggi stimiamo che il lago avesse una profondità di ~30 m, una lunghezza di ~3 km, una superficie di ~1.3 km^2 e un volume di ~39 x 10^6 m^3. Malgrado le molte incognite relative ai valori di portata del fiume Ticino come pure dei carichi solidi in sospensione nel tardo Pleistocene, si può ipotizzare una durata del lago di ~120–730 anni.

1. Introduction

The formation of natural dams is a frequent phenomenon in mountainous areas where steep-walled narrow valleys can be easily blocked by slope failures. For instance, Pirocchi (1992) reported 97 well-documented landslide-damming events oc-

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curred since the last glacial period in the Italian Alps. Recently, the cases of Val Pola (Valtellina, Italy) in 1987 (Huber 1992) and Randa (Valais, Switzerland) in 1991 (Schindler et al. 1993) clearly demonstrated that this kind of event poses a widespread threat to people and property. Hazards associated with natural dams include upstream flooding as the lake rises and, by far more dangerous, downstream catastrophic flooding due to the failure of the dam (Costa & Schuster 1988). A well known and dramatic example is that of Buzza di Biasca in Val Blenio (Ticino) in 1515 (Heim 1932). Two years after the event, the natural dam failed rapidly. The inundation of the valley downstream killed about 600 persons.

Landslide dams are especially subject to erosion and the reconnaissance of ancient events can be difficult considering also the rapid impounding of the lake (e.g. Bromhead et al. 1996). For pre-historic events the sediments trapped in the landslide-dammed basin provide insight into the history and extent of the lake and can deliver suitable material for age determination as for instance was the case of the Flimser Bergsturz in the Alps (Brunner 1963) or the multiples landslide-dammed lakes along the Rio Grande in New Mexico (Reneau & Dethier 1996).

In this paper we present the results obtained by radiocarbon dating on wood fragments found in a core drilled in the Ticino river alluvial plain 2.2 km upriver of the pre-historic valley blocking Chironico rockslide. Radiocarbon age constraints indicate that the lake basin formed in the Late Pleistocene, approximately between 13 and 15 ka cal BP.

2. Geological setting and relative dating

The Chironico rockslide lies within the central part of the Leventina valley in the Ticino river catchment (Central Alps, Switzerland). Geologic units exposed in the area include the crystalline rocks belonging to the Lower Penninic, namely the Leventina-Lucomagno (the deepest unit) and the Simano basement nappes (Fig. 1). These nappes are composed of gneiss cores covered by metasediments (dolomites and calcschists) of variable thickness. These are best preserved in the frontal part of the nappes. The whole area reached amphibolite facies metamorphism during the alpine orogenesis (Frey et al. 1974).

The Leventina nappe consists almost entirely of orthogneiss, the so-called Leventina Granitic Gneiss, a granodioritic intrusive body of variscan age (Casasopra 1939; Köppel et al. 1981). Structurally, Lower Penninic nappes are interpreted as flat lying NW-verging recumbent fold nappes. In the investigated area the foliation dips 25°–30° to the SSW thus generating a dip-slope on the left (eastern) side of the Ticino valley where the rockslide is located (Fig. 1). This argument points to a bedding controlled failure.

The occurrence of boulder debris between Lavorgo and Giornico (~5 km) was first reported and referred to a slide debris by Escher von der Linth (1868) and subsequently by Taramelli (1881). Schardt (1910) wrote the first article dedicated to the rockslide and ten years later appeared the Ph.D. thesis of Nägeli (1920), based on an accurate description of this prominent geological event. Afterwards, little atten-

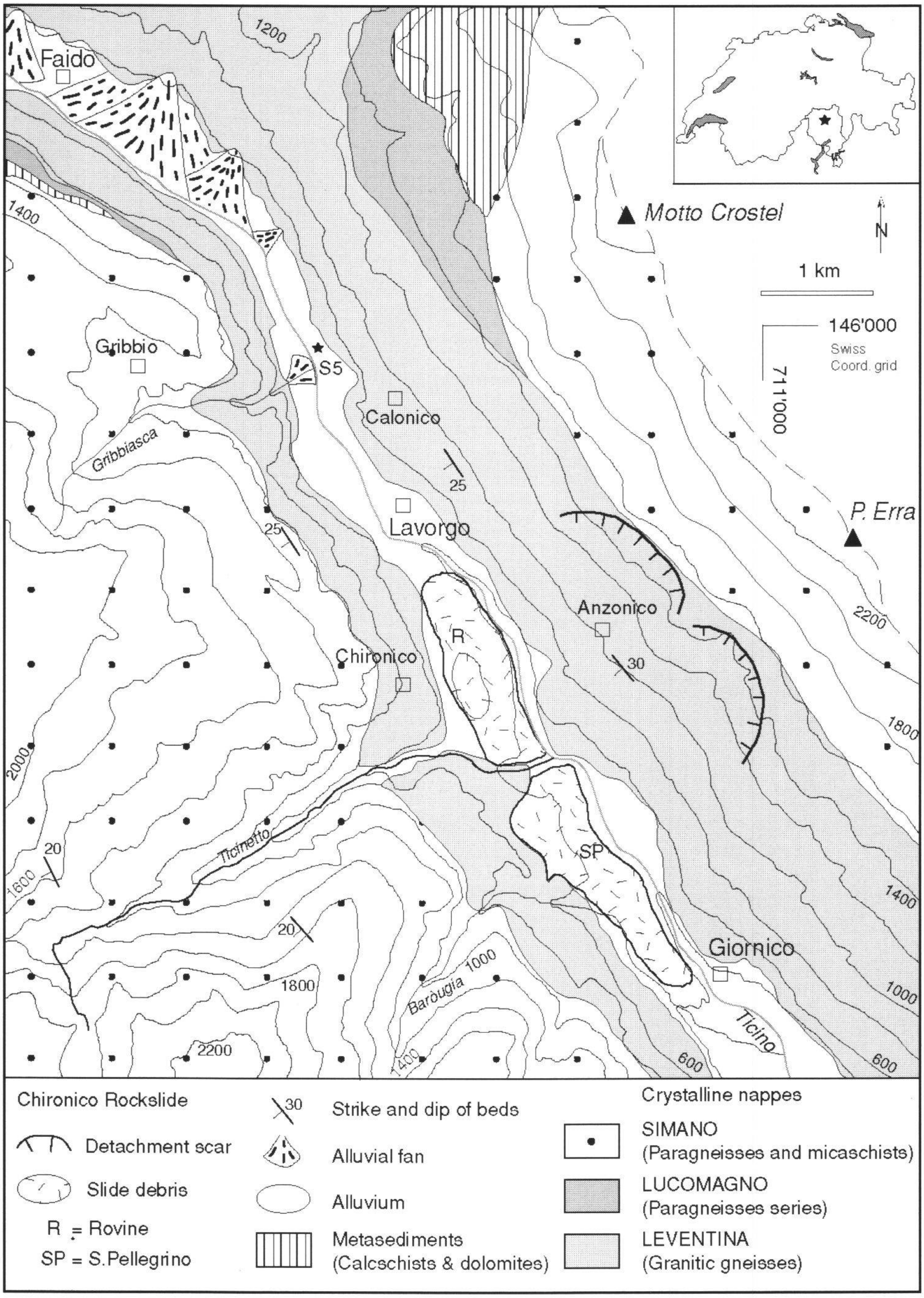

Fig. 1: Tectonic sketch map of central Leventina with location of the Chironico rockslide. Dashed line is the eastern side of the watershed. *S5 shows drilling location. Compiled after Nägeli (1920), Bianconi (1971) and Keller et al. (1980).

tion has been devoted to this huge and complex slope failure, except for the geotechnical problems linked to the construction of the highway (see Dal Vesco 1979).

The Chironico rockslide is known from the literature with different names: «frane di Giornico», Taramelli (1881); «éboulement de Chironico», Schardt (1910), Abele (1974; - n° 3205); «Biaschina-Bergstürze», Nägeli (1920); «Airolo», Pirocchi (1992; - n° 28). We decided to maintain the terminology used by Abele (1974) in order to avoid misleading with the aforementioned and nearby (~10 km) Buzza di Biasca event.

The huge debris mass is subdivided in two parts (the limit corresponding roughly with the Ticinetto creek): Rovine (an eloquent term meaning «ruins») to the north and S. Pellegrino to the south (Nägeli 1920). The first one is characterised by large boulders scattered on the hillside (chaotic block field) whereas S. Pellegrino has a more regular shape and giant blocks are lacking. Nägeli (1920) suggested that at least two rockslides must be taken into account, the older being the S. Pellegrino one. Also Dal Vesco (1979) proposed a double event with the following fascinating scenario: (1) the S. Pellegrino-rockslide damming the valley and creating a lake, (2) the Rovine-rockslide plunging into the lake and generating a giant flood wave (similar to the Vajont case history). Both Authors suggested that the time span between the two events must have been short. Additionally, some interesting data collected during the construction of a tunnel below Chironico in 1907–1910 were reported by Schardt (1910): the slide debris (Rovine-mass) are lying directly on alluvial fan deposits (mainly gravels) of the Ticinetto, without an intermediary layer of fine-grained sediments that could have been laid down in the lake basin.

The present paper deals with the dating of wood remnants deposited to the north of the Rovine-mass, i.e. the youngest event, but considering that the incertitude on absolute age determination is in the order of ± 80 yr. we can reasonably group the two slope failures in a single event referred to as the Chironico rockslide.

Even considering multiple events the volumes are impressive; the Rovine mass attains 300 x 10^6 m^3 and can be placed among the largest rockslides in crystalline rock in the Alps (see the list by Abele 1974). Furthermore, the estimated volume doesn't include the debris mass eroded by the Ticino river that now flows along the rocky left side of the valley.

The slope failures occurred on the eastern side of the Ticino valley at an height of ~1'450 m (ca. 900 m above the valley floor). The detachment scars are not always clearly marked and are placed in the highest part of a fairly convex shape in the valley flank. A detachment surface with an arcuate shape (approx. 1.3 km across) is located between Calonico and Anzonico; another one covers the valley side to the south of Anzonico for approximately 1.3 km (Fig. 1). The whole area is actually densely covered by a forest.

The morphology of this prominent geological event can be correlated with that of a Type II dam according to the classification of Costa & Schuster (1988), even if a short distance downvalley lobe must be taken into account.

The valley-blocking Chironico rockslide generated another temporary lake up-

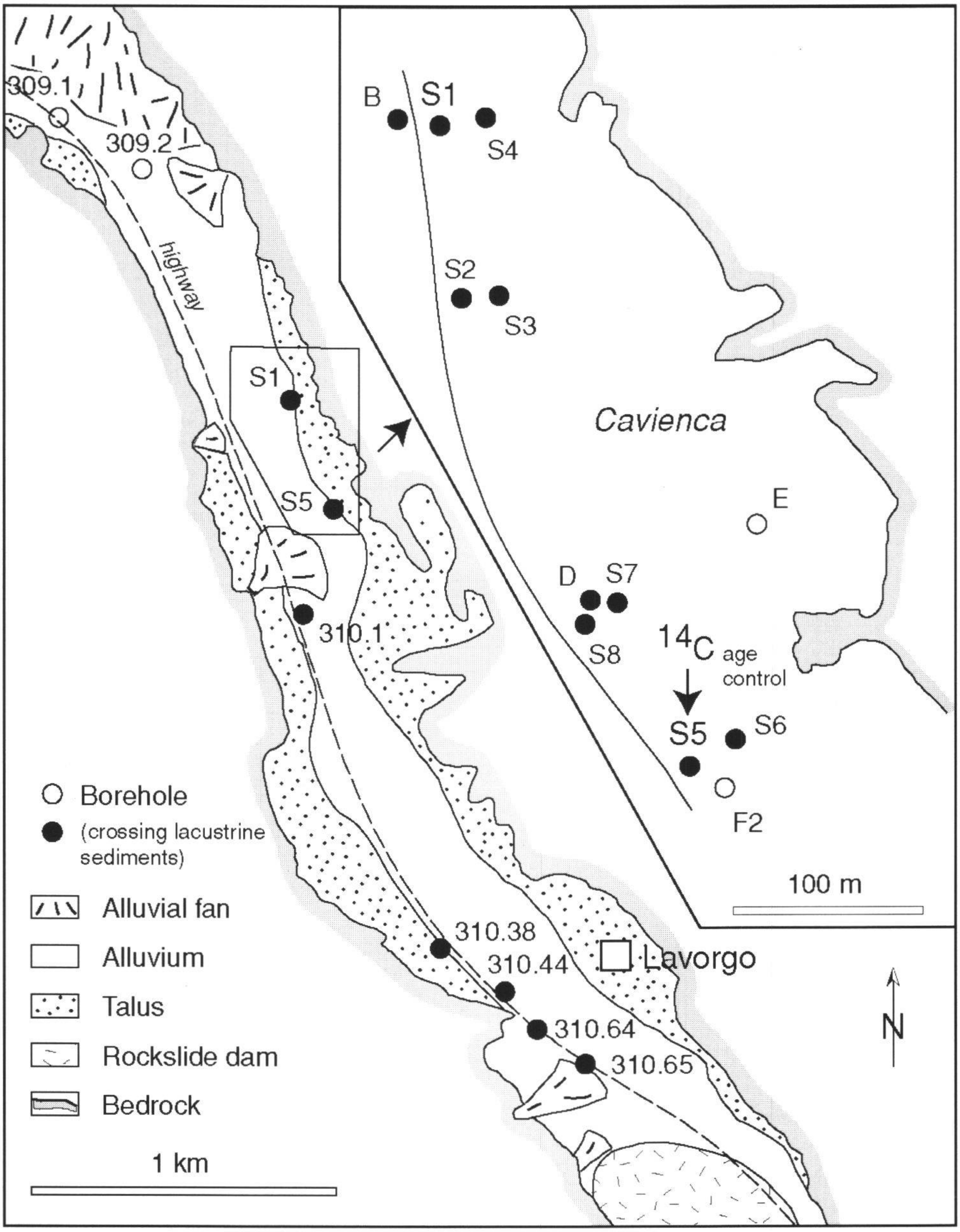

Fig. 2: Map showing the general layout of the drillings carried out in the alluvial plain to the north of Lavorgo. Inset shows a simplified general site map of Cavienca landfill with location of the drillings of 1997 and 2001.

stream of the Ticinetto river. The great impact on the natural drainage pattern is also demonstrated by the diversion of the Baròugia creek (Fig. 1).

Already at the end of the nineteenth century, Taramelli (1881) included the Chironico rockslide in a group of post-glacial rockslides of the southern Alps. Schardt (1910) excluded a glacial origin on the basis of the following arguments:

(1) *Morphology*: the debris mass is aligned parallel to the valley and can't be a recessional moraine of the Ticino glacier.

(2) *Composition*: the accumulated material is represented only by Leventina granitic gneisses which crop out only along the lower slopes of the Ticino valley. The absence of lithologies belonging to the Simano nappe excluded the alternative of considering the debris mass as a terminal moraine of the Ticinetto (see Fig. 1).

Furthermore, the arrangement of the blocks cannot be associated with moraines. Nägeli (1920) reported rare occurrences of glacial material within the debris mass, but interpreted it as glacial deposits laid down on the slope and subsequently removed by the rockslide. Therefore, the Chironico rockslide has been considered as a post-glacial and pre-historic event.

3. Lacustrine deposits and absolute dating

Surface deposits near the rockslide (fine grained deposits in trenches near Lavorgo) indicate that the Chironico rockslide produced a natural dam and temporary lake as clearly recognised by early Authors (Taramelli 1881; Schardt 1910). Nägeli (1920) even reported a small industrial activity related to the extraction of clays close to Lavorgo.

During the last decades several drillings were carried out in the alluvial plain north of Lavorgo mainly for geotechnical purposes (highway construction, landfill design; Fig. 2). Many of them crossed laminated fine-grained deposits up to 30 m thick. The investigated unpublished reports are stocked in the GESPOS-Database (Istituto di Scienze della Terra, SUPSI, Trevano).

Recently, new investigations were performed by Alptransit Gotthard AG in connection with the planned deposit for the excavated material near Chiggiogna, in the Cavienca stone quarry. Five boreholes were drilled in 1997 and lacustrine deposits were crossed in 2 of them. The area was also surveyed by 7 seismic profiles that clearly demonstrated the presence of a layer, underlying the alluvial deposits, characterised by seismic velocities of 1'400 to1'800 m/s and interpreted as lacustrine deposits (Pedrozzi & Associati 1998). A second campaign took place in 2001 with the drilling of eight boreholes (S1-S8; Keller et al. 2002), one of which (S5) yielded organic material suitable for radiocarbon dating.

The borehole Cavienca S5 (LK: 706'920/145'790) is located ~2.2 km upriver of the former dam at an elevation of 643.45 m. A simplified stratigraphic log is presented in Figure 3. Three samples were selected for age determination (Fig. 4). Two came from the same level, the richest in organic material (cm-size pieces of wood and leaves enclosed in a sandy matrix), approx. 35 meters below the present-day valley

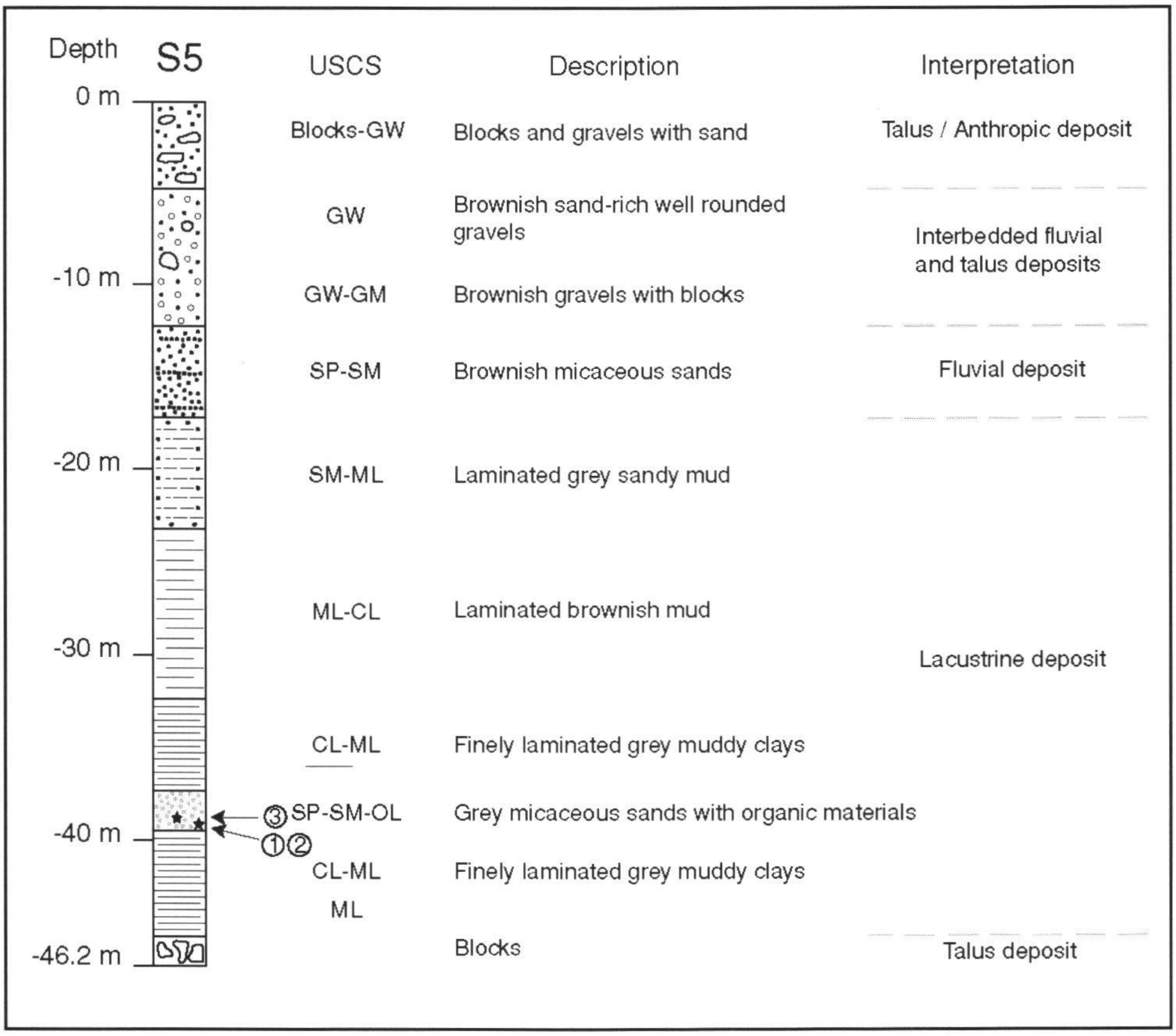

Fig. 3: Simplified stratigraphic log of the Cavienca S5 borehole with emplacement of the dated samples.

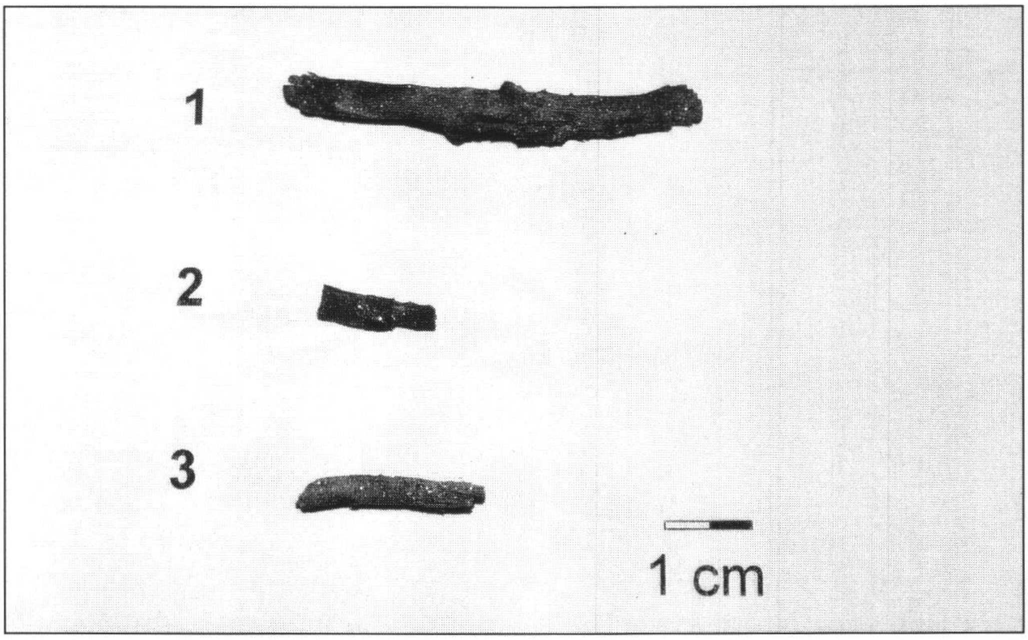

Fig. 4: The three samples used for age determination.

bottom (MCSN1, MCSN2). The third one was taken about 50 cm above the others (MCSN3). All samples were picked up by hand.

Necessary preparation and pre-treatment of the sample material for radiocarbon dating was carried out by the ^{14}C laboratory of the Department of Geography at the University of Zurich (GIUZ). The dating itself was done by AMS (accelerator mass spectrometry) with the tandem accelerator of the Institute of Particle Physics at the Swiss Federal Institute of Technology Zurich (ETH). The results are summarised in Table 1. Values for samples MCSN1 and MCSN3 lie within maximum error bounds. It is as yet unclear why sample MCSN2 is fairly discordant.

Sample no.	Laboratory no.	Material	^{14}C date (yr BP)	$\delta^{13}C$ (‰)
MCSN 1	UZ-4722 / ETH-25354	Wood	11'340 ± 80	-26.7 ± 1.2
MCSN 2	UZ- 4723 / ETH-25355	Wood	11'690 ± 85	-24.7 ± 1.2
MCSN 3	UZ-4724 / ETH-25356	Wood	11'500 ± 80	-21.5 ± 1.2

Tab. 1: Radiocarbon ages from core S5.

Due to substantial variation in ^{14}C production rate and changes in the global carbon cycle there have been shifts in the offset between ^{14}C ages and true calendar ages. Therefore a calibration is necessary to convert conventional ^{14}C ages to calendar dates (the year of reference is always 1950 AD). For calibration, we used the computer program CALIB 4.3 (based on Stuiver & Reimer 1993) and results are presented in Table 2.

Sample no.	^{14}C age (yr BP)	2σ maximum cal age (cal age intercepts) minimum cal age	Calibration data
MCSN 1	11'340 ± 80	Cal BP 13786 (13314, 13258, 13194) 13027	Stuiver et al. 1998
MCSN 2	11'690 ± 85	Cal BP 15101 (13797, 13680, 13544) 13428	Stuiver et al. 1998
MCSN 3	11'500 ± 80	Cal BP 13821 (13455) 13162	Stuiver et al. 1998

Tab. 2: Calibrated ages were obtained using computer program CALIB 4.3 (based on Stuiver & Reimer, 1993; Method A: intercepts with curve).

Calibrated ages indicate that the rockslide took place in the Bølling - Allerød period, according to the GRIP ice core time scale (Johnsen et al. 1992). The dated organic materials are close to the base of lacustrine sediments, therefore our data provide a minimum age for the rockslide event.
According to our data, the Chironico rockslide is older than other big Alpine rockslides that have been recently dated and that resulted to be of Holocene age (Flimser Bergsturz, Poschinger & von Haas 1997; Köfels, Ivy-Ochs et al. 1998). A well-dated slope failure occurring 13'000 yr. ago is the Fulnau landslide in the Swiss Jura Mountains (Becker et al. 2000).

Among triggering factors of dam-forming landslides the most widespread are excessive precipitation and earthquakes (Costa & Schuster 1988). As stated out by Becker et al. (2000), the Late Pleistocene / Early Holocene is believed to be a period of enhanced earthquake activity in Switzerland as also suggested by paleoseismological studies on slump deposits in the subsurface of Lake Lucerne (Schnellmann et al. 2001). It is then tempting to insert the Chironico rockslide in this framework. Furthermore, a major preparatory factor might have been the glacier retreat that occurred after the Last Glacial Maximum (LGM; ~21 ka BP), leaving valley flanks in a relatively unstable state (e.g. Heim 1932).

4. Size and duration of the lake

According to Costa & Schuster (1988) natural dams are usually short-lived, 85% lasted for less than one year. The presence of lacustrine sediments to the north of Lavorgo demonstrates that the dam blocked the Ticino long enough for lake basin to fill with at least 30 m of sediment. The occurrence of alluvial sand and gravel over the now buried lacustrine sediments indicates the progradation of the river over the impounding lake thus suggesting that the rockslide dam was stable. The longevity of this dam was likely due to the volume of the valley-blocking mass and the height of the dam.

Although the lack of data to determine precisely the characteristics of the lake (dimensions and duration), we tried to constrain their general magnitude.
We estimated the dimensions of the rockslide-dammed lake on the basis of core data and the following assumptions: (1) maximum lake elevation is given by the top of the lacustrine deposits in boreholes (i.e. 626 m); (2) the northern limit of the lake likely lies between the northernmost occurrence of lacustrine sediments in boreholes (S1) and the alluvial fan complex to the south of Faido (see Fig. 1 and 2), where the present-day valley-bottom narrows. The maximum width of the lake reached approximately 500 m.

Because drillings are located near the valley flanks and not along the axis of the paleolake, the thickness of 30 m for the lacustrine sediments has to be considered as minimal.

Therefore, we estimate a lake depth of at least 30 m, a length of ~3 km, a surface area of ~1.3 km^2 and a volume of ~39 x 10^6 m^3. The catchment of the former lake in Lavorgo was of 317 km^2.

Determining the duration of the temporary lake is problematic. To calculate how long does it take to create the lake we first considered present-day river discharge. Nowadays, hydrological data are strongly affected by hydroelectric power installations. To limit the anthropogenic influence we considered only mean annual discharge values over a period of many years and the following data were taken into account (see Fig. 6):

I) Long term (1925–1945) mean annual discharge of 19.698 m^3/s in Lavorgo reported by the «Inventario cantonale dei prelievi d'acqua a scopo idroelettrico» (DFE-DT 1997).

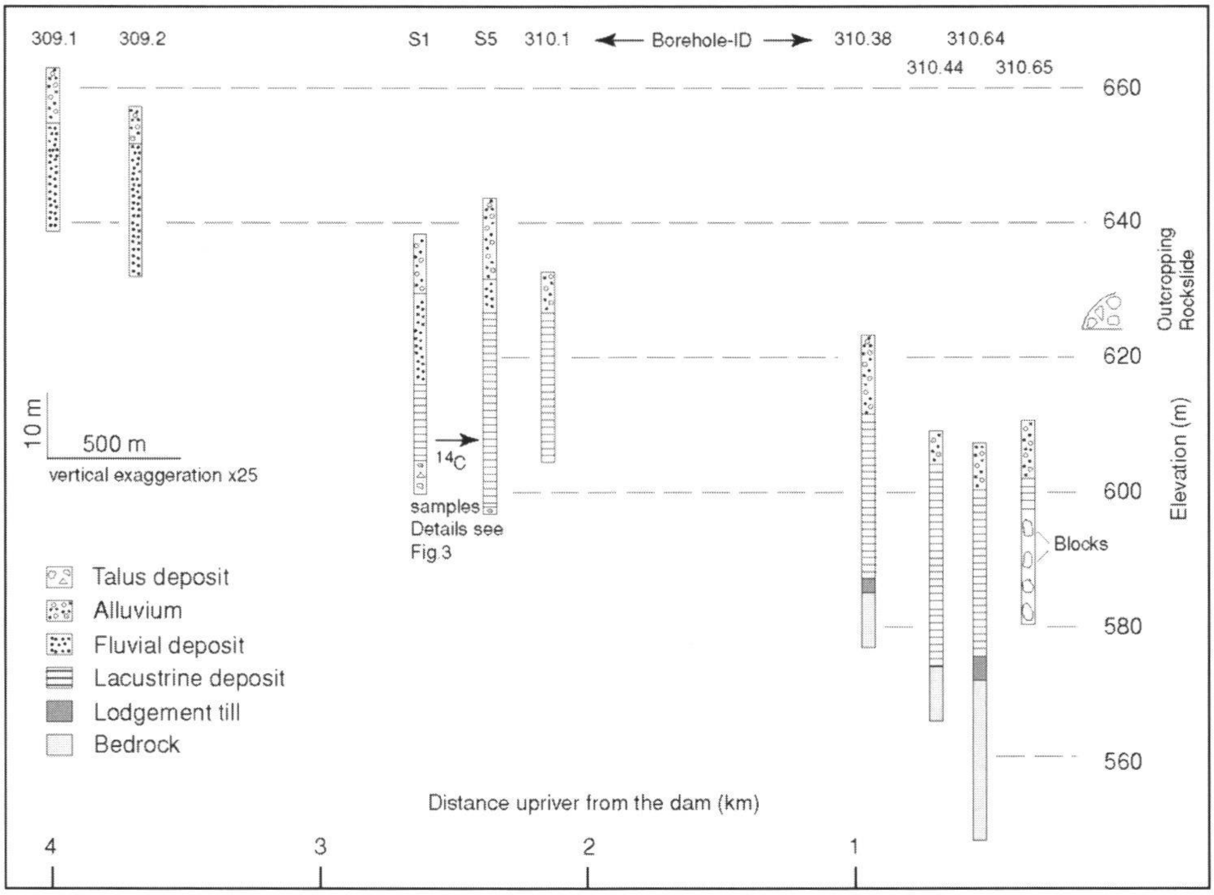

Fig. 5: Schematic logs of selected boreholes in the alluvial plain to the north of Lavorgo.

II) Historic annual discharge at the now abandoned measuring stations of Rodi - Dazio Grande (1909–1928; 13.67 m^3/s) and Piumogna - Dalpe (1916–1928; 1.45 m^3/s), giving 15.12 m^3/s for an area covering approximately 77% of the total watershed (224 + 20.1 km^2, see Fig. 6) (Spreafico & Aschwanden 1991).

Therefore, a reasonable estimate of the mean annual discharge in Lavorgo may be 20 m^3/s. Considering the previously calculated volume of the lake (39 x 10^6 m^3), under present-day conditions the temporary lake could be completely filled with water in ~22 days, assuming that seepage through the dam was negligible.

The estimate of river discharge in the Late Pleistocene times is a big problem and we'll just provide some clues about past climatic conditions. The Bølling - Allerød represented a warm phase in the whole North Atlantic region (Alley & Clark 1999) and it is known as the early pre-Holocene climate optimum. In the Alps, those warmer conditions allowed the onset of vegetation cover in the main alpine valleys (Burga & Perret 1998). Fauquette et al. (1999) reported lower annual mean precipitation than today for the Late Pleistocene in the Vienne region (France). However, in addition to precipitation, catchment runoff was likely also controlled by glacial melting. Global meltwater discharge inferred from sea-level rise clearly shows maximum melting rates centered at 14.5 and 11.5 ka BP (Fairbanks 1989). This might have originated high discharge values during the summer season.

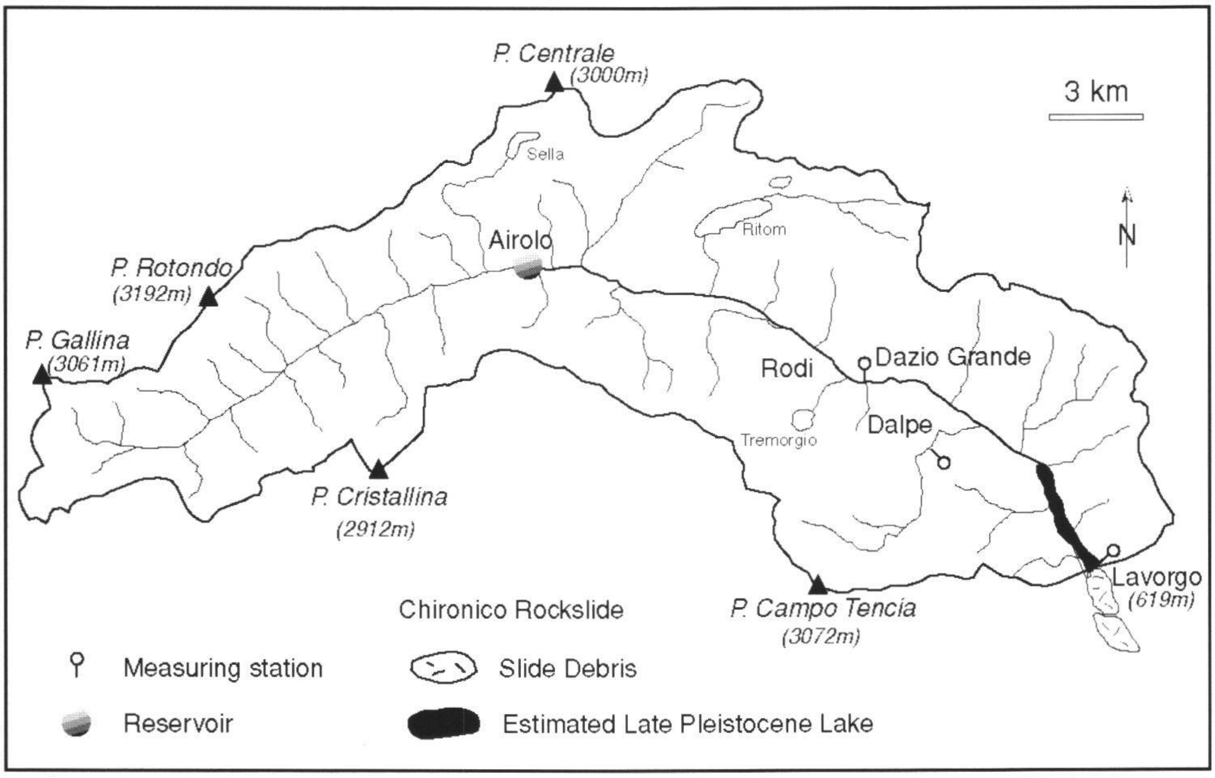

Fig. 6: Hydrographic network of the Ticino catchment in Lavorgo and location of the presumed Late Pleistocene rockslide-dammed lake.

In order to quantify sediment yield we considered the following data:

I) a minimum present-day volume can be deduced from the impoundment of the hydroelectric reservoir in Airolo, upriver of Lavorgo (see Fig. 6; data by AET, Azienda Elettrica Ticinese). The reservoir undergoes a regular «annual cleaning» of 2000 m^3. Additionally, it's completely emptied on a not so regular basis, the last time being in 2000, 14 yr. after the previous one, and the volume of the evacuated material was 45'000 m^3. We then have 73'000 m^3 in 14 yr., i.e. a mean annual volume of 5'214 m^3. The watershed in Airolo is approximately one third (105 km^2) of that in Lavorgo. Therefore, an estimate in Lavorgo can be 15'642 m^3/a. We must also take into account the sediments trapped in the three major lakes (dams; Fig. 6), namely Sella, Ritom and Tremorgio. A reasonable estimate of sediment volume can then be 20'000 m^3/a. Obviously this value is largely underestimated since major parameters, e.g. the sediment trap efficiency of the reservoir, are unknown. Given the volume of material stored in the former lake (~39 x 10^6 m^3) it would then take 1950 yr to completely fill the lake.

II) According to Hinderer (2000), sediment yield in the Alps reached a maximum during deglaciation. For the Ticino catchment (the sediment source area is composed mainly of crystalline rocks), he suggests a post-LGM sediment yield of 1980 t/ km^2 a. Assuming a mean dry bulk density for the lacustrine sediments of 1.9 t/ m^3 (data for unconsolidated sedimentary infill of Alpine valleys, see Hinderer 2000) and the volume of sediments stored in the lake filling (~39 x 10^6 m^3), ~118 yrs would be required to completely fill the lake basin with sediments. Considering modern sediment yield (i.e. 320 t/ km^2 a; Hinderer 2000), we obtain the value of ~730 yr. It is likely that Late-Pleistocene sediment yield lied somewhere in between those bounds.

Applying the same ratio (modern vs. post-LGM) to our minimal data obtained in i) we found a maximal longevity of the lake of ~314 yr for the post-LGM period.

We think that the data about erosional denudation of the Alps proposed by Hinderer (2000) are more reliable than the values of impoundment of a small-scale reservoir and therefore we suggest that the life span of the temporary lake was comprised between ~120 and ~730 yr.

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