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The earthquake in Unterwalden on September 18, 1601: A historico-critical macroseismic evaluation

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Key words: Earthquake, macroseismic, slumps, Central Switzerland, 17th century, historico-critical investigation, rockfall, Renward Cysat

ABSTRACT

The present study is part of the new Earthquake Catalogue of Switzerland (ECOS). It combines historical information clearly categorized according to its quality, with the aim of assessing the intensity and magnitude of the 1601 earthquake in Unterwalden. On the basis of eyewitness testimonies, subsidized by copies of lost sources, the epicenter can be located in Unterwalden, with an epicentral intensity of VIII and a moment magnitude of 6.2. Consequently, the 1601 earthquake is the strongest known event in central Switzerland of the post millenium and among the seven strongest events in Switzerland during the last millennium.

ZUSAMMENFASSUNG

Die vorliegende Untersuchung ist Teil der historisch-kritischen Revision des "Earthquake Catalog of Switzerland" (ECOS). Das Epizentrum des Erdbebens vom 18. September 1601 konnte auf der Basis von zeitgenössischen Augenzeugenberichten, ergänzt durch Kopien verlorener Quellen, in Unterwalden lokalisiert werden. Es wurde eine Epizentralintensität von VIII und eine Momenten-Magnitude von 6.2 bestimmt. Damit ist dieses Erdbeben nicht nur das stärkste historisch nachweisbare Ereignis der Innerschweiz im letzten Jahrtausend, sondern gehört zu den sieben stärksten der Schweiz in diesem Zeitraum.

Introduction

During the years 2000–2002 the Swiss Seismological Service at the Institut of Geophysics, ETHZ, performed a historico-critical and macroseismic revision of the Earthquake Catalogue of Switzerland (ECOS). Today the historico-critical qualification of sources is generally accepted in seismology as "conditio sine qua non", since a check of the previously used earthquake compilations for the Early and High Middle Ages resulted in a very large number of errors (Alexandre 1990: 6). Consequently, macroseismic analysis of documents should be based mainly on reports written by eyewitnesses. These documents have to be checked considering the observer, the date, place and description of the event as well as the lapse of time between the event and its recording (Vogt 1979; Alexandre 1984, 1990:7; Stucchi et al. 1998: 1, 12). Copies of lost documents may be included in the discussion as uncertain pieces of information. The data provided by the historico-critical review was transformed into the European Macroseismic Scale EMS 98 (Grünthal 1998).

In the course of the revision of the catalogue, the earthquake in Unterwalden on September 18, 1601 was of special interest due to its size and reported effects. However, information on it can be supplemented only because the majority of compilers already knew the most important testimony of an eyewitness. This already allowed for a reliable assessment of the macroseimic intensity at an early stage of research.

It was the Lucerne scientist and city clerk Renward Cysat (1545–1614) who, as an eyewitness, produced at the end of December 1601 a long report on this earthquake that is unique in its details. Cysat's report was published by Schneller in 1846, by Schmid in 1969 and by Papastamatiou in English in 1983. The numerous and mainly correct assessments of the event depend mostly on this report. The earthquake was discussed for example in the compilations of Volger (1857), Montandon (1942/43), and Ortelli (1997/98), and the information can be found in the French earthquake database Sisfrance, as well as in Bertrand (1756), Scheuchzer (1706) and other compilations. The assessment of the epicentral intensity varies for different compilers between VIII and IX. Thus the event has long been recognized as belonging to the strongest earthquakes of the last millennium in Switzerland. The main goal of this investigation was to increase the number of Swiss eyewitness reports.

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Date and Time: September 18, 1601, around 1:45 a.m.

The simultaneous use of two calendar systems in Switzerland between 1584 and 1812 (Grotefend 1991: 24–27) created misunderstandings as far as dating of the 1601 event is concerned. In the protestant cantons of Switzerland it was dated in the old Julian style (night of September 7 – 8) and in the catholic cantons in the contem porary Gregorian style (night of September 17 – 18). Other errors occurred, as for example in the copy of an unknown source from Stans in which the date is given by mistake as September 15 (StASZ, PA 13, Slg. Kyd, Bd. 2: 330). The wrong year 1600 can often be traced back to a misprint in the book of Spon (1682: 140–142) about the history of Geneva. Supplementary court records from Lucerne (StALZ: AKT 17 890) confirm the date 1601. They refer to the behavior of people returning after the earthquake from a festival in Sarnen (Durrer 1920: 59).

The statements about the exact time of the quake are inconsistent. A number of the awakened eyewitnesses erroneously thought that it was before midnight and dated the event to September 17 in Gregorian style. However, the majority of the accounts refer to one and two o'clock in the morning of September 18. The main eyewitness, Renward Cysat from Lucerne, put down the hour as "a short time before two o'clock", as does Clussrath (Schneegans 1855: 193) from Strasbourg with "a quarter of an hour before two o'clock". They are both confirmed by observers from St. Gallen (StBSG. Cod. Sang. 1162), Stammheim (StAZH: E III 0117:3), Lausanne (ACVD: DG 288: 217) and other locations. An observer in Como seems to fix the hour in the Italian style further: "... alle 6: ore di notte ..." (Paravicini 1884: 105). Only the Bieler Rathsprotokoll differs in its indication of one o'clock: "Als die Glocken ein Uhr schlugen" (Blösch 1875: 59–60). But to fix the event more precisely than "around one quarter before two o'clock" would overtax the technical possibilities of the 17th century.

More difficult is the measurement of the duration of the event because of the insufficient methods of the observers. In earlier centuries short periods of time were assessed by well-known prayers. So the earthquake was felt in Strasbourg for the duration of a Paternoster or a Credo (Schneegans 1855: 193). The anonymous author in the book of Blaurer wrote about an incredible duration of two hours (StBSG.Cod. Sang. 1162). According to Cysat the duration of the main shock can be assessed at several minutes because he describes the waking by the earthquake and the following discussion about the phenomenon. And he is the only observer who described a weak aftershock a quarter of an hour later. The rockfall from the mount Bürgenstock into Lake Lucerne followed immediately after the main shock. A later supplement in Cysat's report defined the duration of the aftershock sequence in Unterwalden as September 1601 to November 1604.

A confusion of seismological and meteorological phenomena, e.g. with a storm, can be excluded because Cysat described the night in Arth as still and clear; the noise, wind and dust started after the earthquake. Bartholomäus Anhorn at Maienfeld (Sprecher 1992: 290) and Clussrath in Strasbourg (Schneegans 1855: 193) described the same meteorological situation although during the 10th to the 20th of September wind from the north was blowing most of the time (Pfister 1984), which is also confirmed by the court records of Lucerne (StALU: AKT 17 890) for the afternoon of the event.

Location

Renward Cysat located Unterwalden as the most severely hit region. Here several houses and churches collapsed and most of the stoves were destroyed. Further damage is described in primary sources, especially around Lake Lucerne, in Zurich (Gerber 1602: 32), Schaffhausen (Burgauer 1651: 430), St. Gallen (StBSG: Cod. Sang. 1162) and Maienfeld (Sprecher 1992: 290). Archaeological surveys in Zug, Oberwil on the Lake of Zug, and Flüeli Ranft reveal damage which can be interpreted with a certain reliability to have been caused by the 1601 earthquake (Zug Archaeological Service, ZUGAD). At Somvix as well as in Chur (Ardüser 1877: 168), Basel (Gross, 1624: 228), Biel (Blösch 1875: 59–60), Geneva (Spon 1682: 140–42) and Lausanne (ACVD: DG 288:217) the shock was felt strongly although damages are not reported.

In so far as the ECOS-Project is concerned, it was not possible to investigate reports on observations outside Switzerland. But Cysat describes the area in which the earthquake was felt as Switzerland, Germany, the Netherlands, Burgundy and Italy, without indications about his sources. Clussrath in Strasbourg (Schneegans 1855: 193) was in possession of unknown information from Basel and Frankfurt. The database SisFrance marked the boundary of this area with Cologne, Munich, Reggio and Lyon. An interesting report in the Italian compilation by Baratta (1901) about a destructive earthquake in Issime in the valley of Gressoney (40 kilometers south of Zermatt) with the date "September 1600" (sic!) could not be investigated further.

Damage distribution

The main shock of September 18 produced several rockfalls in central Switzerland. Of these, however, only those on the mount Hahnen near Engelberg and the mount Bürgenstock are described. Bartholomäus Keckermann (1607, 1611) reports rockfalls on both sides of the Bürgenstock. The latter caused a high wave in Lake Lucerne, adding to the previous wave caused by the earthquake so as to damage the shores and trigger subaquatic landslides. Ongoing limnogeological investigations recognized such phenomena in the Vitznau basin (Schnellmann et al. 2002).

The wave in Lake Lucerne caused the river Reuss in Lucerne to flow back six times during the first hour after the earthquake, with the result that each time the riverbed was empty for several minutes and the mills were stopped (Cysat 1969: 886; Meyer von Schauensee, ZHBLU). This horrifying phenomenon was immediately interpreted as an obvious sign of the anger of God. Until 1604 quite a number of weaker

Tab. 1. Some of the most important Swiss intensity site points

name	latitude	longitude	I min.[6]	I max.	Iw	historical quality[7]
UNTERWALDEN	46.90	8.40	7	8	**8**	**B**
FLUEELI RANFT	46.87	8.27	6	7	**7**	**C**
BECKENRIED	46.94	8.48	7	8	**7**	**A**
ZURICH	47.37	8.54	6	7	**7**	**A**
LUCERNE	47.05	8.29	7	8	**7**	**A**
OBERWIL B. ZUG	47.13	8.51	6	7	**7**	**C**
SCHAFFHAUSEN	47.72	8.63	6	7	**7**	**A**
STANS	46.96	8.36	6	7	**7**	**A**
ZUG	47.17	8.52	6	7	**7**	**C**
OBERRICKENBACH	46.88	8.44	7	8	**7**	**B**
BASEL	47.56	7.59	6	7	**6**	**B**
BRUNNEN	47.00	8.60	6	7	**6**	**B**
ENGELBERG	46.82	8.45	5	7	**6**	**B**
SOLOTHURN	47.21	7.53	6	7	**6**	**C**
ST. GALLEN	47.42	9.37	6	7	**6**	**A**
MAIENFELD	47.02	9.53	6	7	**6**	**A**
DINHARD	47.56	8.76	5	6	**5**	**A**
CANTON GLARUS	46.98	9.06	4	6	**5**	**C**
RUEMLANG	47.45	8.53	5	6	**5**	**A**
STEIN AM RHEIN	47.67	8.86	5	6	**5**	**A**
SUMVITG	46.77	8.88	5	6	**5**	**A**
UNTERSTAMMHEIM	47.65	8.79	5	6	**5**	**A**
KILCHBERG ZH	47.32	8.55	4	6	**5**	**A**
APPENZELL	47.32	9.41	5	6	**5**	**C**
GENEVA	46.21	6.14	4	5	**5**	**B**
ARTH	47.07	8.54	5	6	**5**	**A**
CHUR	46.85	9.53	5	6	**5**	**B**
FRAUENFELD	47.56	8.90	5	6	**5**	**B**
BIEL/BIENNE	47.14	7.25	5	6	**5**	**B**
COMO	45.81	9.08	5	6	**5**	**B**
LAUSANNE	46.52	6.63	4	6	**5**	**A**

[6] Intensity: minimum (min), maximum (max) and most probable (w)
[7] A: primary source, eyewitness; B: secondary source, incomplete sources, C: uncertain source, copy of an unknown source, archaeological reports.

shocks and few damaging events followed, but further historical material is lacking.

The damage noted in the documents was used to assign site intensities in the European Macroseismic Scale, 1998: III (weak), IV (widely observed), V (strong), VI (slightly damaging), VII (damaging), VIII (heavily damaging), IX (destructive) (Grünthal 1998). For every site we determined a minimum (Imin), a maximum (Imax) and a most probable intensity (Iw). It was possible to assess 38 sitepoints in Switzerland.

Unterwalden: Intensity VII-VIII

Renward Cysat's report on the damages in Unterwalden in the translation by Papastamatiou (1983: 1250): "Although the catastrophe struck my canton severely, our neighbours in Unterwalden suffered far worse. Not only was the shaking of the ground far more intense, but it was also felt more acutely in the churches, houses and other buildings, some masonry was reduced to rubble and in the wooden houses all the stoves were thought to have been destroyed (there was said to be no undamaged oven throughout the whole canton). Apart from this, the effects from the earthquake were said to have been felt for a long time afterwards, especially during the night. Some natives of rural districts said that it continued into December. Beggenried [Beckenried] is a village on the shore of Lake Lucerne further up than Buochs in the canton of Unterwalden, it forms part of the parish of Buochs. In each of these villages the effects of the earthquake had been particu-

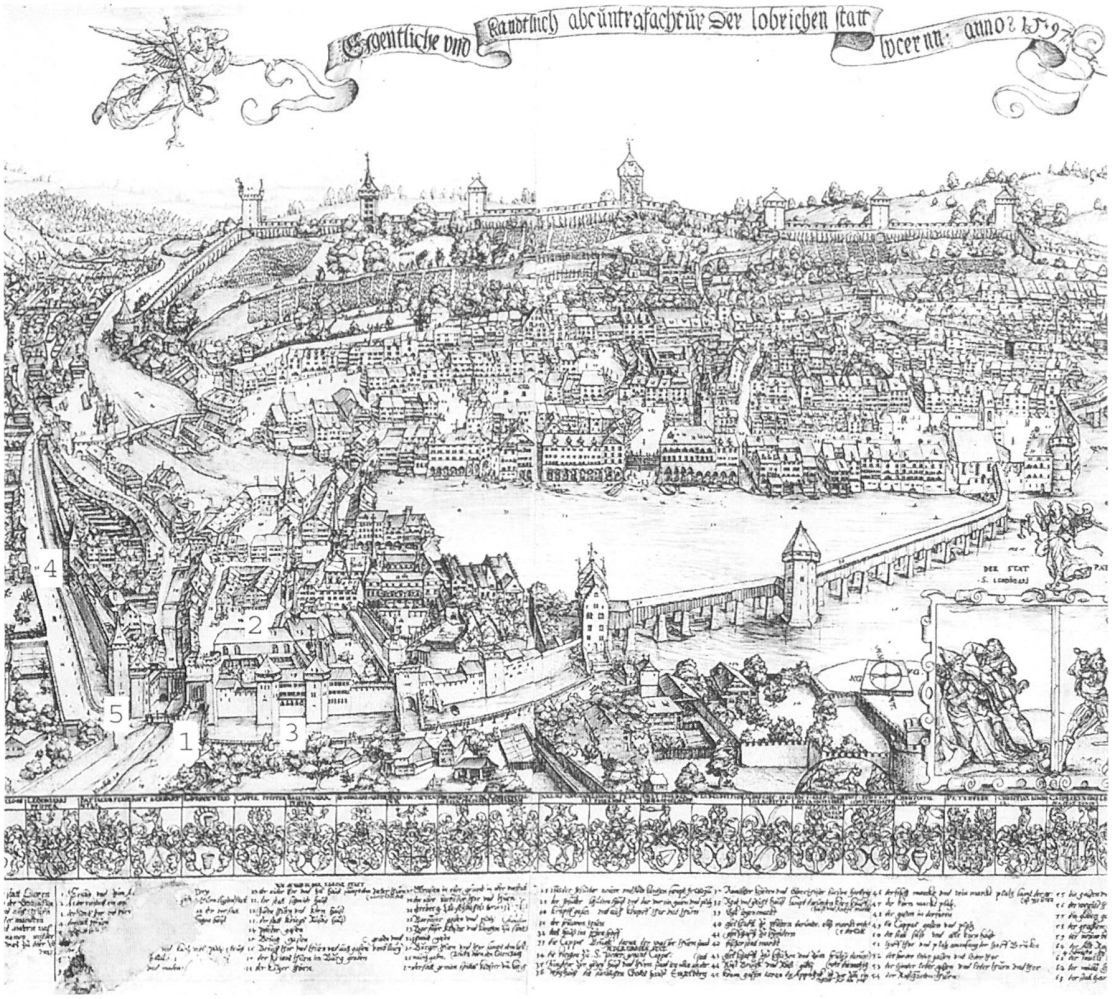

Fig. 1. Detail of the view of Lucerne by Martinus Martini, 1597 (revised by Renward Cysat):
1: Obertor, town gate
2: Barfüsser Monastery
3–5: Towers

larly intense. The churches in Beggenried had been rebuilt two years previously and now they would again have to be reconstructed; ... ."[1] (annotations see page 448)

Felix Donat Kyd (1793–1869) a historian and compiler from Brunnen, copied out of a lost collection of manuscripts by Bünti in Stans (StASZ, PA 13, Slg. Kyd, Bd. 2: 330) and reported similar phenomena of rockfalls and a horrifying noise in the mountains, a destroyed chapel in Oberrickenbach and a chapel in Stans that was carried away by a landslide: "Erdbeben Anno 1601. In der Nacht zwischen 1 und 2 Uhr nach des hl. Kreuzistag im Herbstmonat [September 15, error in the original] erhob sich der entsetzliche, und zuomahlen sehr schädliche Erdbeben; thate sonderlich Schaden an Oefen, Kaminen und Gemäurgebäuden. Zuo Stans hinter dem Capuciner-Kloster hat er eine wohlgezierte Kapelle in dem Stentbach genannt, mit einem Erdbruch völlig niedergerissen und von dem Grund über einen Rein hinunter geschleifet, dass keine Zeugenschaft mehr darvon geblieben. Desgleichen ist die Kapelle zu Oberrickenbach auch im Erdbidmen verfallen. (...) Es verursachte dieses Erdbidem ein so grausam und erschröckliches Getöse in den Gebirgen, und Holzwäldern mit Rüfinen und Steintrölen, das sich jedermann mit grossem Schrecken gleichsam eines gänzlichen Untergangs versehen. Dieser Erdbeben wurde noch öfter malen gespürt bis nach Maria Lichtmess tag (2.2.)."

The Engelberg monastery does not meet the expectations of providing more descriptions, probably because of its economic difficulties at the time in question. A short notice records gallows that had to be repaired because of the earthquake (Heer 1975: 200), and in the church history of Caspar Lang printed in 1692 there is a report without indication of

[1] Annotations see page 448

source about "1000 feet of rocks" which fell down from the Hahnen east of Engelberg. Finally, in the chapel of Flüeli Ranft an altar seems to have been repaired following quake damage (Durrer 1920: 944).

The strangest sources are the court records of Lucerne (StALU: AKT 17 890) on the behavior of three drunken men in Stansstad. After the earthquake one of them made jokes about a crack in the wall of a chapel that were felt to be blasphemous and caused him to be brought to justice. But apart from this crack in the chapel, we find only few indications about minor incidents during the earthquake, such as a candle falling in a pub and two stones falling down from the roof of the same building.

The most severe damage caused by the earthquake and related rockfalls hit the Canton of Unterwalden followed by the region around Lake Lucerne. The site intensities are assessed as between VII and VIII (Table 1).

Lucerne: Intensity VII

According to Cysat, chimneys and tiles fell and walls cracked in the whole of Lucerne. However, most seriously affected was the so-called little town, a part of Lucerne built on stakes in marshland. We have indicated the known destroyed buildings on the map of Lucerne designed by Martinus Martini in 1597 (Fig. 1). "The two masonry towers of the monastery (2) which stood further behind, alongside the encircling city wall, had been severely shaken; as a result they had shifted more than half a foot away from the wall. Then we came to the next tower at the gateway to the town which was called the Oberthor (1). Here the roofing along with the dome and the sidereal clock (built onto a section of masonry which jutted out over the street) all this had been knocked over and had fallen in the direction of the town onto the roof of the tower. The roof had been broken under the impact. The seven people who lived in the tower had been in great peril. The clock had been thrown right into the town. The whole tower suffered very serious damage and multiple cracks were showing everywhere. As a result, it was no longer safe to remain in the vicinity. It was decided that the whole building would have to be demolished and rebuilt. The next tower was called the Kätzerthurm (5); this tower had also been subject to shaking and many small crevices and cracks were visible. The third domed tower along by the ditch (moat) had been damaged on the roof and the walls – may it soon be repaired." (Papastamatiou, 1983: 1249)[2]

Lake Lucerne and Zug: Iw VI-VII

Apart from the church of Beckenried, already mentioned, various other cases of damage have been reported around Lake Lucerne. In the Kyd collection in the Cantonal Archives of Schwyz there is a copy of a bill for repairs to the roof and in the choir of a chapel at Ingenbohl dating from 1601 (StASZ: PA 13, Slg. Kyd, 2). The reason for the repair is not mentioned – it was probably too obvious at the time: "Anno domini 1601

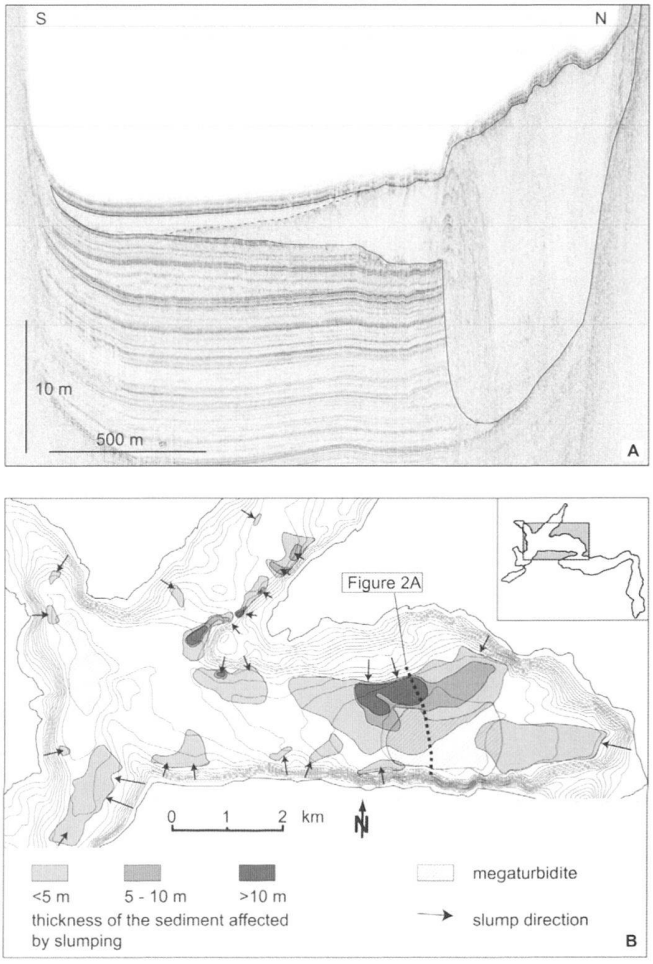

Fig. 2. A: Seismic profile across the Vitznau basin
B: Map of Chrüztrichter and Vitznau basins

jar han ich heiny ianser und katzer iob der zit der kabälen uf ingbol vogt den halben deil an der kabalen schaden halb gägen der strass lassen decken und den teil am kor ...". At the end of the 18th century the archives of Altdorf burnt down and it seems that they actually do not hold original information about the event of 1601. The archeological service of the Canton of Zug (ZUGAD) has noticed cracks in the wall of the castle in Zug and a crack under the chapel of Oberwil that might have been caused by the event of 1601.

The Protestant theologian and philosopher Bartholomäus Keckermann from Danzig traveled around Switzerland in September and October of the year 1601 and published his report in 1607. It contains the only notice about a rockfall on the southern side of the Bürgenstock: "On the other side of this same mountain, where the people of Unterwalden live, some part of the mountain was thrown down which killed seven of the inhabitants of that region"[3].

Along the shores of Lake Zug and Lake Lucerne cracks in the ground were observed and in the area of Vitznau as well as

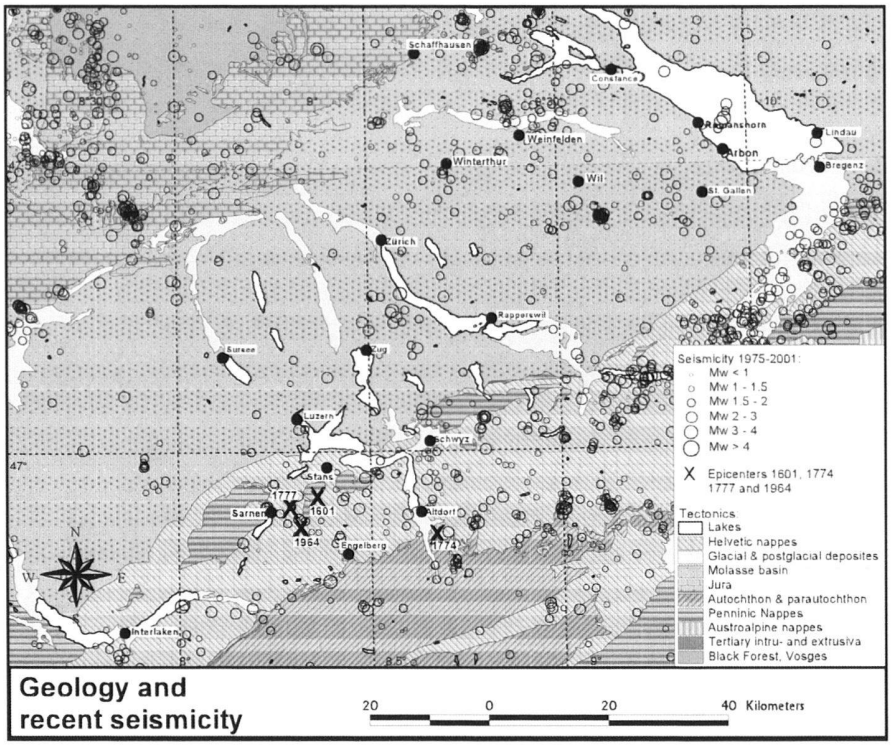

Fig. 3. Geology and recent seismicity

around Buochs and Beckenried parts of the shore collapsed and disappeared in the lake (Cysat 1969: 883–887). People who lived along the shore of Lake Lucerne described mountains of waters that arose in the center of the basins (Cysat 1969: 887). In the area between Buochs and Beckenried the water was washed behind the shore over a distance of 1000 paces (Cysat 1969: 886). In Lucerne, as mentioned before, the river Reuss flowed back six times during the first hour after the earthquake. For the Canton of Uri, Cysat notes waves in Urnersee lasting an incredible eight-day period.

The strong effects of the earthquake on Lake Lucerne and its shores as described in the historic documents left marks in the sediments of the lake. Siegenthaler et al. (1987) related two huge slump deposits in the subsurface of the Vitznau and Gersau subbasins of Lake Lucerne to the 1601 A.D. earthquake. Figure 2A shows a high-resolution seismic profile across the subsurface of Vitznau basin which images one of these deposits. In a recent study, the subsurface of the Vitznau, Chrüztrichter and Küssnacht basins was mapped out in detail in order to assess the traces of the 1601 earthquake in the sediments and to identify similar prehistoric events deeper in the lake sediments (Schnellmann et al. 2002). Figure 2B shows distribution and thickness of slump deposits related to the 1601 A.D. earthquake. All these deposits occur within a single seismic stratigraphic horizon and are interpreted as the result of contemporaneous slumping triggered by the seismic shaking.

Numerical modelling reveals that slumps of this size can induce of up to 3 meters high water waves (Schnellmann et al. 2002). In 1601 A.D., numerous slumps coincided with the rockfall from Bürgenstock and the induced waves added up to produce the water movements described in historic documents.

The seismic profile across the Vitznau basin (Lake Lucerne) images a slump deposit related to the 1601 earthquake (for location of the profile see figure 2B), indicated in gray shadings. The sediment affected by slumping is outlined in black. Whereas the undisturbed basin fill is acoustically laminated, slump deposits are characterized by a chaotic to transparent seismic facies that lacks continuous reflectors. At the foot of the northern slope, the deep-reaching chaotic seismic facies indicates deformation of the basin sediment by the impact of the slump masses. In the central part of basin, the slumped material lies on top of undisturbed basin sediments. In the deepest, southern part of the basin, the slump deposits are directly overlain by a megaturbidite, which is imaged by a transparent seismic facies. The Map of Chrüztrichter and Vitznau basins (Lake Lucerne), Fig. 2B, shows the distribution and thickness of slump deposits related to the 1601 earthquake (indicated in gray shadings). Hachured areas mark the extent of megaturbidites directly overlying the slump bodies. Correlation between individual slump deposits was achieved using seismic-stratigraphic methods. Bathymetric contour interval is 10 m (in figure caption).

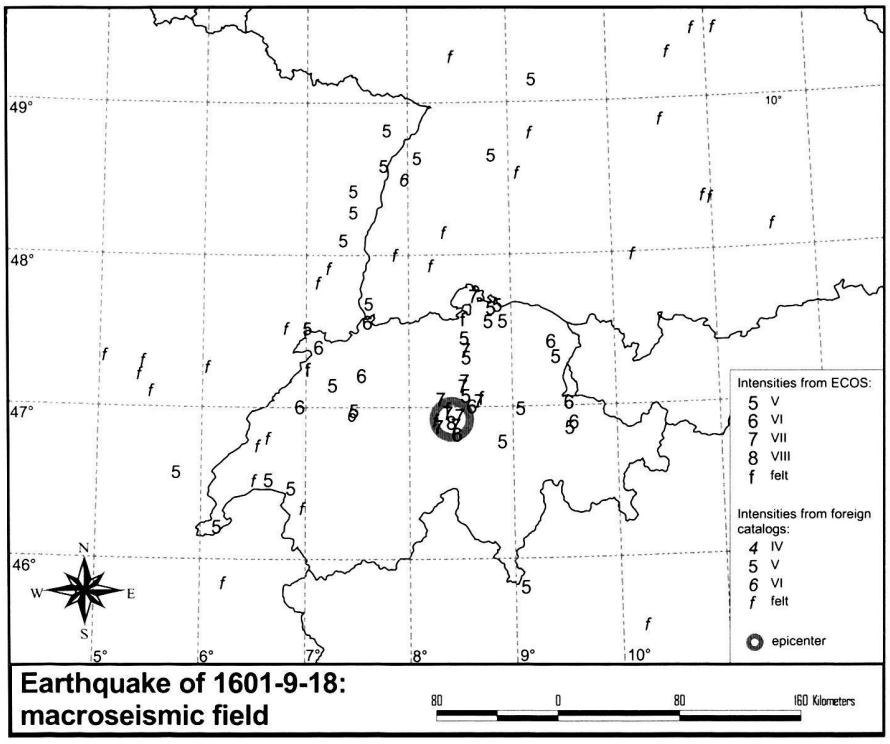

Fig. 4. Sitemap: Event 31, September 18, 1601, 1:45 a.m.

North and East Switzerland: Intensity V-VII

Eyewitnesses in Zurich, Maienfeld, St. Gallen and Schaffhausen attest weaker damages. A poem by pastor Gerber in Bülach records that the Grossmünster in Zurich suffered several cracks without collapsing (Gerber 1602). The cracks were repaired immediately after the event. "Nor shall I omit how the silent vault of the noble church in the city of Zurich cracked severely – but the Lord prevented the ruin. Meanwhile the magistrate Fries orders the ready workers to speed up the renovation: and already the church is more resplendent on every side".[4] Descriptions of the event in Zurich in copies of earlier documents give different accounts, but we presume that at least some minor damage occurred. Pastors in Rümlang (StAZH: E III 099.1) and Dinhard (StAZH: E III 027.2) have made notes about the quake without mentioning any damage.

The pastor Bartholomäus Anhorn in Maienfeld reports a roaring in the air, destroyed chimneys and chickens falling from their perches (Sprecher 1992). In St. Gallen an anonymous author has left a notice about some destroyed chimneys (StBSG: Cod. Sang. 1162). Johann Burgauer at Schaffhausen made the same observation. He even reported 26 destroyed chimneys in his town (Burgauer 1651: 430). In the village of Stammheim near Schaffhausen a pastor confirms the earthquake observation, but without noticing any destruction (StAZH: E III 0117.3).

Northwest Switzerland: Intensity V

Johannes Gross published a history of Basel in 1624 and described vibrations in the city hall. Only Volger (1857) mentioned damage in the city hall, which can not be confirmed. This earthquake was also felt in Biel (1875: 59–60), Lausanne (ACVD: DG 288:217) and Geneva (Spon 1682: 140–142).

Seismotectonic setting

Even with due allowance for the remaining location uncertainty, the epicenter of the 1601 earthquake is certainly situated in the Helvetic domain south of the northern Alpine front (Fig. 3). A comparison with the seismicity recorded instrumentally since 1975 (Fig. 4) shows that it apparently does not coincide with an area of enhanced seismicity. In fact, over the last 20–30 years the earthquake activity in the Helvetic domain has been significantly greater in the northern Wallis in the west and in the Rhine Valley of St. Gallen in the east. However, the historical record shows that the recent seismic activity in central Switzerland has been exceptionally low and that the last 30 years can not be considered as representative. Both the regions of Altdorf (Uri) and of Sarnen (Nidwalden) have been repeatedly the scene of damaging earthquakes in the past. The most recent of these was the event of 1964/03/14 near Sarnen, with an estimated moment magnitude of 5.7. This event was part of a sequence of more than 1000 events, which occurred over a

period of a few months. The occurrence of earthquakes clustered in time and space seems in fact to be a characteristic feature of the seismicity in central Switzerland: a similar sequence occurred in 1777 and with lesser intensity also in 1917.

Reliably located hypocenters of recent events show that focal depths are restricted to the upper 15 km of the crust in the Helvetic domain of central Switzerland, whereas they reach depths of around 30 km below the Molasse basin north of the Alpine front (e.g. Deichmann et al. 2000a, 2000b). From fault-plane solutions of several recent earthquakes there is evidence that in central Switzerland focal mechanisms of different types coexist within a small volume: examples of this are the mechanisms of the events of Kerns (reverse) and Sachseln (normal) of 1985. The hypocenters of these two events are only 5 km apart and both at a depth of 1–2 km within the sedimentary cover (Deichmann et al. 2000b). The coexistence within such a small volume of two in principle mutually exclusive mechanisms is indicative of a stress field which is either strongly heterogeneous or which features a small magnitude difference between maximum and minimum principal stress. The latter would imply that earthquakes in central Switzerland can be triggered at relatively low levels of shear stress and that consequently the effective stress on some faults (i.e. the rock strength) is at least locally comparatively low (Deichmann et al. 2000b).

Magnitude assessment of and discussion

The quality of the macroseismic conclusion depends on the quantity of detailed eyewitness accounts. The growing literacy in Switzerland in the 16th century and a partly successful conservation of documents in the archives and libraries permitted a reliable reconstruction of the 1601 event, although the macroseismic field shows an inhomogeneous distribution of the reported intensities. Only explicitly described damages are evaluated and represent a minimum value. The higher density of sources to the north of the epicenter allows assigning intensities between VI and VII up to Schaffhausen. A lack of information exists mainly in Unterwalden and in the south of the Lake Lucerne. The data available from the west and the south of Lake Lucerne should be supplemented by investigations on a broader scale in town and parish archives of that region. To date no research has been done in the majority of these smaller archives.

Earthquake parameters of this event in the revised macroseismic Earthquake Catalogue of Switzerland (ECOS) have been determined by a modified Bakun & Wentworth (1997) grid search approach based directly on the individual intensity data points (Fäh et al. 2003). The estimated epicentral location is 46.92N/8.36E with an uncertainty of less than 20 km, which corresponds roughly to the area between Sarnen, Engelberg, Altdorf and Lucerne. The resulting macroseismic magnitude, Mm, which has been calibrated to correspond to moment magnitude, Mw, is 6.2, with an uncertainty of less than 0.5 units. The re-evaluation of the historical records as well as the systematic and consistent reassessment of the macroseismic intensities presented in this article have contributed significantly to a more reliable estimate of both the epicentral location and the magnitude of this earthquake.

At first sight, the damage caused by the 1601 earthquake in central Switzerland and the consequent economic loss appear to be small. However, the risk associated with the possible recurrence of this event should not be underestimated. In fact, over the last 400 years, the population density in the potential epicentral area and the vulnerability of the corresponding infrastructure have increased enormously. Thus, based on earlier intensity assessments of the 1601 earthquake, present-day loss estimates for a similar event due to structural damage alone range from 760 to 8'950 million Swiss Francs (Schaad 1988).

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ANNOTATIONS

[1] "Diser jammer jst zwar vff vnserm theil gross, aber by vnsern nachpuren von Vnterwalden noch vil grösser vnd schwärer gsin nit allein sovil das erschütten dess erdrichs belangt, sondern ouch der kilchen, hüsern vnd gebüwen, dann es jn selbigen vil hefftiger sich erzeigt, ja ouch ettlich gemurete gebüw gar nider geworffen, vnd jn den überigen höltzinen vffs wenigst die öffen allso zergent, dz man (der gmeinen sag nach) vermeint, kein offen jm gantzen land meer gantz oder vnbeschediget bliben sye; über das man ouch den erdbidem noch lang vnd vil zyts meer darnach gespürt. (...) Vff dem land hatt es glychwol den kilchen ettlichen schaden gethan; ouch die glogkenthürn erschüttet, das die glogken angeschlagen, aber am meisten jm land Vnderwalden. (...). Es hatt ouch diser erdbidem vff dem land an keinem ort schädlicher vnd vngestümer erzeigt dann jn disem land Vnderwalden wie jch dann das landtvolck selbs hab erzellen hören vnd den ougenschyn allenthalben jm land, so jch durchreiset, selbs gesehen an gebüwen glych kleinen vnd grossen vnd sonderlich an kilchen vnd glogkenthürnen, die es so hefftig erschüttet, das die glogken klein vnd gross sich selbs gelüttet vnd angeschlagen vnd allso die türn vnd kilchen geschädiget, dz man ettlichen theil müessen abschlyssen vnd wider nüw machen, ettlichs aber sonsten mitt grossem kosten wider erbessern. (...) Beggenriet jst ein dorff an dem Lucerner seew jn Vnderwaldner gepiet glych oberhalb Buochs, der pfarr gedach(t)s gepiets gelegen. An diesen beiden orten hatt es ouch bsonder streng gehuset vnd gewüettet. Zuo Beggenriet hatt es die kilchen, die erst by 2 jaren nüw widerumb erbuwen worden allso geschediget, dz man sich verwegen, sy widerumb geschlissen vnd nüw erbuwen werden müessen." (Cysat, 1969: 886)

[2] "Die zwen gemurten thürn dess closters, so hinden an der statt ringkmuor gegen dem Graben stand, hatt es ouch zerschüttlet vnd den einen meer dann vmb ein halben schuoch (about 15 cm) von der mur dannen gestossen. Darnach jst es kommen an den nächsten thurn der statt porten, dz Oberthor (1) genannt; da hatt es das tach mitt helmknopf vnd sternen ab dem gemureten ergkel, so vsswendig gegen der strass obsich am thurn stat, überworffen vnd ynhar gegen der statt werts vff dess thurns tach gefellt vnd das tach gar zerbrochen, allso das die menschen, so jm thurn behuset, by 7 personen, jn höchster gfar jres lebens gewesen; den sternen hatt es vil schritten wytt jn die statt hinyn gworffen vnd den gantzen thurn dermaassen zerschüttet vnd überschüyige spällt zu allen orten geworffen, allso das man nitt meer sicher da blyben mögen, jme ouch anderst nitt ze helffen dann das man jnne uff den grund abschlyssen vnd wider vffbuwen müessen. Den nächsten thurn oberhalb daby der Kätzerthurn (5) genannt, hatt es ouch erschüttlet, allso dz er vil doch

kleine riss vnd spällt geworffen. Aber den dritten gehelmten thurn, so am nächsten daby jm Graben statt, den hatt es ouch beschediget sowol am tach alls ouch an den muren, wöllichs doch bald verbesert worden." (Cysat, 1969: 885-886)

[3] Keckermann, B. (1607, 1611: 157): "...ex alteravero parte istius montani tractus, qua Underwaldii habitant, itidem montis aliqua pars deiecta, ex accolis septem dicebatur oppressisse." Keckermann (1571/73-1608) has had a determining influence on the development of the relationship between theology and the natural sciences.

[4] (16) Non ego augusti tacitos relinquam / Fornices templi Tigurina in urbe / Haud fatiscentes leviter, sed arcet / Iova ruinam. Interim aedilis jubet expeditos / Frisius fabros, opus ut nouandum / Vrgeant: templum meliore forma hinc / Inde renidet. (Gerber, 1602: 4)

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Jehan Vullyamoz: DG 288, p. 217.

StALU: Luzern, Staatsarchiv
AKT 17 890. Court records.

StASZ: Schwyz, Staatsarchiv
PA 13, Slg. Kyd, Bd. 2. Kyd, Felix Donat; manuscript.

StAZH: Zurich, Staatsarchiv
E III 0117.3: Stammheim, Taufen, Ehen, 1581–1606, 1525–1797.
E III 099.1: Rümlang, Taufen 1563–1606.
E III 027.2: Dinhard, Pfarrbuch, 1600–1740.

StBSG: St. Gallen, Stiftsbibliothek
Cod. Sang. 1162. Blaurer, Ambrosius (1565): Deutsche Predigten 1565. Contains an anonymous manuscript note about the 1601 earthquake.

ZBZ: Zurich, Zentralbibliothek, Handschriftenabteilung
Msc. S 156, Nr. 4 [p.32ff]. Gerber Gabriel (1602): Terrae motus anni MDCI September VIII. A print bound to the manuscript tracts of the Simmleriana. Not catalogued.

ZHBLU: Luzern, Zentral- und Hochschulbibliothek
No shelf mark. Franz Leonz Meyer von Schauensee (1656–1737). Miscellaneous codex in the Familienarchiv Amrhyn.

ZUGAD: Zug, Archäologischer Dienst
Castle of Zug and chapel St.Niklaus at Oberwil. Unpublished archaeological reports and photographs by Toni Hofmann, Archäologischer Dienst des Kantons Zug, copy at the Institut of Geophysics, ETHZ.

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