Historical seismicity in Central Switzerland

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Key words: Historical seismicity, Macroseismicity, Central Switzerland, Alps

ABSTRACT

An overview of seismic activity in Central Switzerland is presented. As earthquake activity has been very low for the time period of modern instrumental observation, we focus on the largest known earthquakes in the historical past (September 18, 1601, September 10, 1774, January 23, 1775, and the swarms of 1777 and 1964). The epicenters of these events indicate a concentration of activity around Altdorf (1774, 1775) and Sarnen (1601, 1777, 1964), whereas recent instrumentally observed microearthquakes are distributed more evenly over the whole area. Moreover, earthquake activity was extraordinarily low since the beginning of modern instrumental observations. The irregular episodes of strong earthquakes, both in space and time, characterize the seismicity of Central Switzerland. The results of the study make it evident that earthquake activity is not necessarily stationary. As earthquake recurrence intervals are important factors in seismic hazard assessment, well-documented information on historical earthquakes are particularly important.

ZUSAMMENFASSUNG

Dieser Beitrag gibt einen Überblick über die seismische Aktivität der Zentral-Schweiz. Da die Erdbebentätigkeit für die instrumentelle Periode bislang sehr gering war, werden die stärksten bekannten Erdbeben in der Geschichte der Region behandelt (18. September 1601, 10. September 1774, 23. Januar 1775 sowie die Erdbebenserien von 1777 und 1964). Die Epizentren dieser Ereignisse zeigen eine Konzentration der Tätigkeit um Altdorf (1774, 1775) und Sarnen (1601, 1777, 1964), während die instrumentell gemessenen Mikro-Erdbeben der neueren Vergangenheit gleichmässiger über das ganze Gebiet verteilt sind. Weiterhin war die Erdbebentätigkeit ausserordentlich niedrig seit den Anfängen der instrumentellen Messungen. Die sowohl zeitlich als auch örtlich unregelmässigen Episoden seismischer Aktivität charakterisieren die Seismizität der Zentral-Schweiz. Kenntnisse der Wiederkehrperioden von Erdbeben über einen längeren Zeitraum sind zentral für die Gefährdungsanalyse. Daraus wird deutlich, wie wichtig gut dokumentierte Informationen über historische Erdbeben sind.

1 Introduction

Central Switzerland (46.75 and 47.20 north, 8.0 and 8.8 east) is an active seismic area, with a number of strong earthquakes in the past (see Fig. 1). Since the beginning of modern instrumental observations however, earthquake activity in this region was extraordinarily low. As earthquake recurrence intervals are important factors in seismic hazard assessment and for an evaluation of the seismotectonic significance of present seismicity, well-documented information on past earthquakes is very important. In this paper we will discuss all known damaging earthquakes in the history of Central Switzerland. The results presented in this paper are part of a major revision of the Earthquake Catalog of Switzerland (Swiss Seismological Service 2002, Fäh et al. 2003). ECOS is the new unified earthquake catalogue for Switzerland and neighboring regions, covering all seismogenic areas which produce significant seismic hazard for Switzerland. ECOS is characterized by homogeneous assessment of earthquake parameters, by a common magnitude M_W (Moment Magnitude) for all the events and by the assessment of errors or bounds for all source parameters. A major aim of the project was to improve the quality of historical data underlying macroseismic and seismological parameters. This involves the research and interpretation of historical documents using historical methods (Gisler 2003). A substantial investigation of so-called primary sources, i.e. historical documents that were produced coeval to an event has been undertaken. As a consequence, the investigation and interpretation of historical documents let to a comprehensive and homogeneous database. The consequent approach resulted in numerous improvements regarding intensity and reliability of the events. This has already been shown in earlier contribution to Eclogae, or will be presented in the near future (Gisler et al. 2003, 2004a; Schwarz-Zanetti et al. 2003, 2004).

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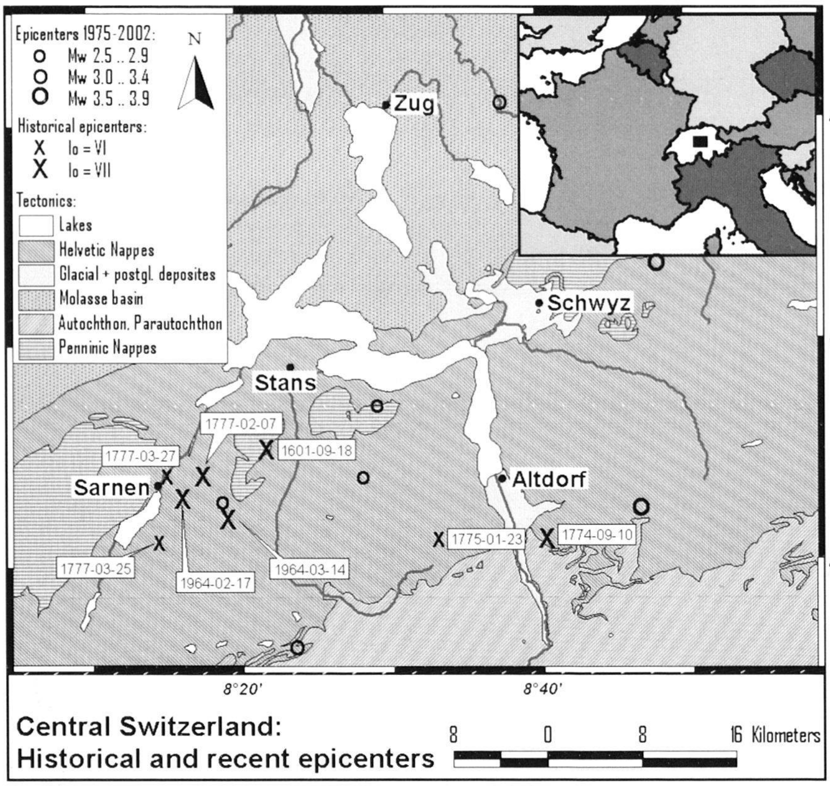

Fig. 1. Map of events with intensities Io ≥VI (EMS 98) and Mw≥2.7

The historical seismicity of Central Switzerland was the topic of several (scientific) publications. Volger (1857) has investigated the events of Central Switzerland, among others, in his earthquake chronicle of Switzerland. All entries in this catalog are of narrative type, copying older, unproved historical information. Schaller-Donauer (1937) discussed earthquakes among other natural phenomena in Canton Uri. Montandon (1942/1943) provided a catalog of large earthquakes in Switzerland, including those in Central Switzerland. This catalog is based on the Mercalli-Cancani-Sieberg Scale (MCS Scale) and intensity estimation is generally too high compared to what we presently know about historical earthquakes in Switzerland.

Previous versions of the Swiss earthquake catalog (Swiss Seismological Service 1999) have been used in the studies of Pavoni (1977) Sägesser & Mayer-Rosa (1978), Rüttener (1995), and Deichmann et al. (2000), the latest providing information about the locations of active deformation and the state of stress in the earth's crust of Central Switzerland. A comparison of these former catalogs with the newly established ECOS exposes major differences. The consequent historico-critical approach of ECOS resulted in numerous improvements regarding intensity and reliability of the events. Several events had to be downgraded in terms of their intensity, or they were revealed as fake events. The most prominent examples in this regard are the events of 1375 (month and day are unknown), February 29, 1616 and February 22, 1780. Intensities of the events of 1375 and 1616 had to be downgraded substantially (from VIII to V) because no evidence was to be found for heavy damage. The supposed earthquake of 1780 was a fake entry. The event was *predicted* in a publication of 1783 (Ziehen 1786), but never occurred. Nevertheless, the French seismologist Perrey ([1847]) listed the quake in his earthquake compilation. Other catalogs (e.g. Volger 1857) copied this compilation without checking its reliability. From there it entered into modern catalogs. Other events as the April 7, 1765 and the October 9, 1770 event had to be downgraded fairly. They consequently disappeared from the list of damaging events. Such substantial amendments have a key influence in the seismic hazard assessment (Gisler et al. 2004b).

In what follows, an overview of the seismicity in Central Switzerland will be presented by focussing on the earthquakes of September 18, 1601, September 10, 1774, January 23, 1775, the earthquake swarm of 1777, and the earthquake swarm of 1964 with its two major shocks on February 17 and March 14, 1964 (Table 1). These events are known as having been the largest in the history of this region, as they caused major damage. For the time period before 1600, no damaging earthquakes are yet known from this area. We emphasize however, that historical data can always be corrected when new evidence is found, as for example when new archival material comes to light. Furthermore, paleoseismological investigations (Monecke et al. 2004; Schnellmann et al. 2002) will additionally shed light on the long-term seismicity for this region.

Tab. 1. Major known earthquakes in Central Switzerland ($I_0 \geq VI$)
M_W=Moment magnitude
I_{MAX}=Maximum intensity
I_0=Epicentral intensity

year	latitude	longitude	Mw	Imax	Io	place name
1601-09-18	46.92	8.36	6.2	8	7	UNTERWALDEN
1774-09-10	46.85	8.67	5.9	8	7	ALTDORF/UR
1775-01-23	46.85	8.55	4.7	6	6	URI-ROTSTOCK, ALTDORF/UR
1777-02-07	46.9	8.29	5.1	7	7	KERNS/OW
1777-03-25	46.85	8.24	4.2	6	6	SACHSELN/OW
1777-03-27	46.9	8.25	4.2	6	6	SARNEN/OW
1964-02-17	46.88	8.27	5.0	7	7	FLÜELI/OW
1964-03-14	46.87	8.32	5.7	7	7	KERNS/OW

Time span	Completeness
563–799	n
800–899	u
900–999	n
1000–1099	n
1100–1199	n
1200–1299	n
1300–1399	n
1400–1499	n
1500–1599	n
1600–1679	VIII
1680–1730	VII
1730–1750	VII
1751–1800	VI
1801–1850	VI
1851–1878	VI
1878–1963	V
1964–1974	IV

Tab. 2. Completeness of observed intensities for Central Switzerland for defined time periods. Although small intensities appear in the early centuries, completeness can be assumed for the largest intensity grades only
n: no coeval sources found
u: completeness unknown

2 Methodology

Historical sources: typology and criticism

When updating the Swiss earthquake catalog ECOS, the objective was to fill information gaps regarding the effects of earthquakes in Switzerland and neighbouring regions and also to identify previously unknown events (Fäh et al. 2003). This was achieved by studying historical documents, preferably those produced close to the event. Information on data in historical documents has been taken from earthquake compilations, i.e. chronological collections of earthquake data, and investigations in regional and local repositories. As the investigated time period is not homogenously covered by documents, a high variability in time and space occurs. Coeval sources for Central Switzerland are to be found after 1600 only. Central Switzerland was a rural region. Except for a tradition of writing skills existing in monasteries (Engelberg for example), the production of written records was marginal in the region for a long time. Moreover, a fire in the cantonal archive in Altdorf in the year 1799 resulted in the destruction of a large number of archival materials. Part of the sources is consequently irrevocably lost. This might be one reason for the lack of information for the time period before 1600. Table 2 gives an overview on the completeness of observed intensities for Central Switzerland for defined time periods. Although small intensities appear in the early centuries, completeness can be assumed for the largest intensity grades only.

It is well known that narrative sources that serve as basic data for historical seismology shift in the course of time as to their form and function. Quantity and quality of the sources used are thus inhomogeneous. For early modern times (ca. 1600–1800), a variety of private records exist, e.g. leaflets, letters, diaries, memoirs, autobiographies and sermons, produced in monasteries or by individuals. Official records, as for example protocols of councils, complement them. In addition, the production of pamphlets and newspapers increased during these centuries. Newspapers are important for obtaining a general overview of an event. For modern times (ca. 1800 up to the present) newspapers were the most frequent documents to be analyzed.

The Swiss earthquake commission, established in 1878, produced yearly bulletins of earthquakes occurring in the respective period. This information was of importance for our investigations. However, due to material lacking for the time period 1964–74, summary reports were available only for the investigation of the two events in 1964. Since 1964, the Swiss Seismological Service has collected macroseismic data by distributing earthquake questionnaires in the respective regions. Questions are about damage to buildings and objects, but also about subjective perceptions. Regarding the event of March 14, 1964, questionnaires have been included in the analyses of the event.

All historical documents have been analysed by taking into consideration historical and philological methods (Gisler 2003). It will become evident, when discussing the events, that some of them rely upon a small corpus of documents, whereas others are based on a good number of historical sources. The increased information allowed for cross checking of events and for the definition of quality of this information. Many mistakes could be corrected, such as misprints, which appeared in chronicles and have been transferred over the years. The use of coeval documents allows a more reliable understanding of earthquake damage as a basis to map macroseismic fields.

Intensity and magnitude assessment

Intensities for each event were assessed using the data made available by historical sources according to the criteria established by the European Macroseismic Scale (EMS 98) (Grünthal 1998). This scale provides a series of idealized descriptions of the effects of an earthquake, starting with the very weakest (intensity I: the shaking is imperceptible) up to the very strongest (intensity XII: everything is totally destroyed).

Grünthal (1998) divides the structures of buildings into five classes (class A: most vulnerable; class E: least vulnerable). For this study, vulnerability of buildings was generally attributed to class B, while for the more massive buildings an average vulnerability of class C was supposed. The percentage of damaged buildings was estimated empirically, taking into consideration the figures available for the inhabitants at each place. For assessing grades of damage, distinctions were made between buildings reported with cracks in walls, fall of large pieces of plaster or partial collapse of chimneys (moderate damage of grade 2) and those with large and extensive cracks in walls, chimneys fractures, detached roof tiles or failure of individual non-structural elements (substantial to heavy damage of grade 3).

Problems occurred when the historical texts reported on isolated buildings only. It usually concerned the main public buildings, which were of large interest. If this was the case, we assumed with some restraint that this was only *pars pro toto* for larger damage, though not reported in the documents, and assigned intensity respectively. Another difficulty was due to cumulative descriptions, i.e. when identical damage was reported for different places (e.g.: "In Sarnen, Kerns and Alpnach the church suffered great damage"). We tried to overcome this problem by comparing different descriptions, if possible.

At several places the information comes from one source only. This was not a difficulty with respect to intensity assessment; however, the assertion has to be regarded with some restraint. As not all intensity degrees can be decided upon with much confidence, we assigned a minimum (Imin) and maximum intensity (Imax) for each site point and set a most probable intensity degree (I_W). A key problem of the assignment of intensity site points is the poor or uncertain information in historical data. We therefore set the quality of each intensity site point by using a range of scale between very poor and very good (very poor, poor, middle, good, very good). For all earthquakes discussed below, epicenter intensity (I_0), maximum intensity (I_{MAX}, largest site intensity of an event), and the respective uncertainties are provided. We followed Gasperini et al. (1999) and defined epicentral Intensity, I_0, to be equal to the observed maximum intensity if at least two data points with that intensity value are given; otherwise, I_0 is set to the second highest observed value (lower bound represented by I_{MAX} minus one degree). Definition of uncertainty parameters is discussed in Fäh et al. (2003) and in an internal report that can be downloaded from the webpage of the Swiss Seismological Service (http://histserver.ethz.ch/).

Maps with available intensity site points (I_W) and tables with coordinates for the respective site points complete the information. Intensity values in figures and tables are all given in EMS 98. Time data is given in UTC.

For all earthquakes with a sufficient number and distribution of intensity points in the ECOS catalog, source parameters (epicenter, hypocentral depth class, epicentral intensity, maximum intensity, macroseismic magnitude) and uncertainties have been derived, using a regression scheme that accounts for regionalized intensity attenuation and hypocentral depth (Fäh et al., 2003). Moment magnitude M_W has been adopted as the size estimator for all events in ECOS, because M_W is directly related to source physics, unlike other magnitude scales based on seismogram amplitude measurements (like the body wave, surface wave, and local magnitude scales). Earthquake parameters for all historical events were then determined directly from the intensity data points by applying the Bakun & Wentworth (1997) grid search, using the derived magnitude calibration function for Switzerland. Associated uncertainties in determining source parameters are controlled here by the number and azimuth distributions of available intensity site points, the degree to which intensity site points are available at near distances, and the internal consistency of such points. The details of the procedure are described in Fäh et al. (2003).

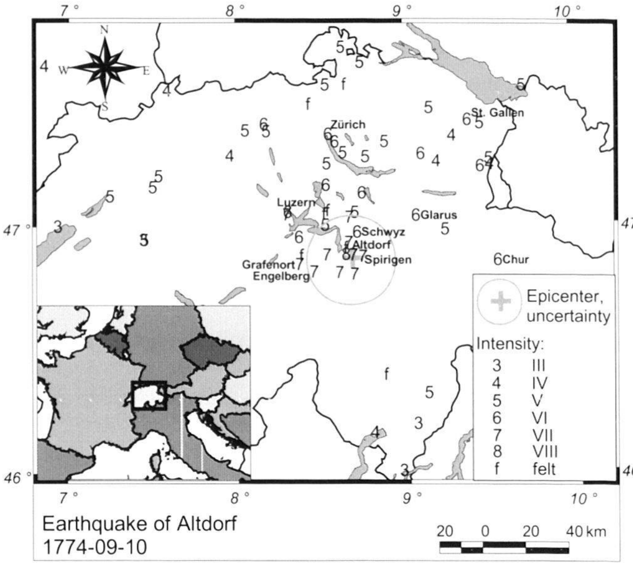

Fig. 2. Macroseismic map of the September 10, 1774 event in the region of Altdorf/UR; the size of the circle gives the uncertainty bound for the location

3 The Earthquake of September 18, 1601 in the Region of Unterwalden

This event has been discussed by Schwarz-Zanetti et al. (2003). In the epicenter area a maximum observed intensity (I_{MAX}) at one site (Nidwalden) is assigned with VIII (EMS 98). The epicentral region is Unterwalden (46.92/8.36) with an epicenter intensity (I_0) of VII and a moment magnitude (M_W) of 6.2. The earthquake has long been recognized as belonging to the strongest earthquakes of the last millennium in Switzerland. This was due to a sole analysis of so-called earthquake compilations, which – from a historical point of view – cannot be estimated as reliable anymore due to their uncritical use of historical data. It was thus the aim of the project to analyze historical documents coeval with the event, in order to provide an increasing amount of reliable data. A systematic and consistent reassessment of these data allowed reducing I_0 from VIII–IX of former catalogs to VII. With a magnitude of 6.2 (uncertainty ≤0.5) the earthquake remains the largest event known for Central Switzerland.

year	month	day	hour	minute	name	latitude	longitude	Mw	Io	
1774	9	10	3	0	Altdorf/UR	46.85	8.67	2.4	3	Foreshock
1774	9	10	5	30	Altdorf UR	46.88	8.65	3.5	4.5	Foreshock
1774	9	10	10		Altdorf/UR	46.88	8.65	3.9	5	Foreshock
1774	**9**	**10**	**15**	**30**	**Altdorf/UR**	**46.85**	**8.67**	**5.9**	**7**	**Main shock**
1774	9	10	17	0	Altdorf/UR	46.85	8.67	3.2	4	Aftershock
1774	9	10	19	0	Altdorf/UR	46.85	8.67	3.2	4	Aftershock
1774	9	10	22		Altdorf UR	46.88	8.65	3.1	4	Aftershock
1774	9	11	8	15	Altdorf UR	46.88	8.65	2.3	3	Aftershock
1774	9	11	13		Altdorf UR	46.88	8.65	3.1	4	Aftershock
1774	9	14	22	15	Seedorf UR	46.88	8.62	3.1	4	Aftershock
1774	9	16	4		Engelberg/OW	46.82	8.45	3.2	4	Aftershock
1774	9	18	–	–	Riemenstalden/SZ	46.95	8.55	3.1	4	Aftershock

Tab. 3. Felt fore-, main and aftershocks of the September 10, 1774 event

4 The Earthquake of September 10, 1774 in the Region of Altdorf/UR

The earthquake of September 10, 1774 at 15.30 p.m. (UTC) caused severe damage in the region of Altdorf. Moreover, two people died as a result of falling objects. The main shock was felt widely in Switzerland as well as in southern Germany. Smaller foreshocks announced the main event. Felt aftershocks started on the same day and continued until September 18.

The epicentral region is Altdorf (46.85/8.67) with an estimated epicentral location uncertainty of ≤20km. The maximum observed intensity (I_{MAX}) is assigned with VIII at Altdorf. As only one data point with an intensity value of VIII is given, epicenter intensity (I_0) is set to the second highest observed value VII (uncertainty ≤1). Epicenter intensity is thus downgraded one degree compared to former catalogs. Moment magnitude (M_W) is 5.9 with an uncertainty of ≤0.5 (Fig. 2).

Historical sources

Information on the event is based upon several reliable historical sources. For the most heavily affected region, the protocols of councils of Stans and Schwyz do exist, as well as observation records by the residents of the monastery of Engelberg. A monthly newspaper (*Monatliche Nachrichten*), printed in Zurich, collected earthquake descriptions from large parts of Switzerland. Moreover, numerous entries in journals, chronicles, letters and observation books allow a profound presentation of the event also for regions with greater distance to the epicenter region.

Distribution of effects

According to a record by an anonymous observer (Anonymous 1774), foreshocks started early in the morning of September 10, at 3, 5.30 and 10 a.m. (UTC). They were gentle and did not cause any damage. They were felt at **Altdorf** and surroundings, but not farther than **Lucerne**.

The main shock occurred around 15.30 p.m. (UTC) (Fig. 2; Table 3). Damage (Intensity VIII and VII EMS 98) was suffered at 11 places, slight damage (Intensity VI EMS 98) at 14 places, and not only in the epicenter region.

A contemporary report gives an overview on the event: «Aus Uri in der Schweiz hört man die allerfurchtbarsten Berichte von entsetzlichen Erderschütterungen, welche vom 10ten bis zum 18ten passati alle Tage mit den heftigsten Stössen verspührt wurde; worunter die gräulichste Bewegung den 10ten passati abends um 4 Uhr war. Die steinernen Gebäude litten dabei ungemeinen Schaden. Auch im flachen Altdorf sind zweÿ Gebäude völlig eingestürzt; mehrere andern aber zerspalten und gesprengt. Zu Sisiken und Flüelen nächst an der See ist ein ganz Stück Land von der See verschluckt worden. So ist nicht auszusprechen, wie erschrecklich des 10ten passati das Brüllen und Toben in den Gebürgen war.» (Handschriftenabteilung Zentralbibliothek Zürich S 633).

Other sources (Anonymous 1774; Staatsarchiv Luzern AKT 12 /224; Staatsarchiv Nidwalden WRP Vol. 33; Staatsarchiv Schwyz cod 100, RP 1774–1776; Staatsarchiv Schwyz PA 13, Slg. Kyd) agree upon serious damage in **Altdorf/UR** and surroundings, the inhabitants being horrified. Most stone buildings suffered heavy damage (damage grade 3, EMS 98), two of them being totally destroyed. Walls inside and outside houses suffered large fissures, and it has been recorded that two third of all chimneys collapsed. In the church towers, the bells started to ring, windows and doors swung open or shut. Regarding official buildings, many churches suffered heavy damage. The churches of St. Martin, Heiligkreuz and one of the female monasteries are known to have been affected by major damage, as church towers and vaults collapsed. The city hall (Rathaus), school and hospital suffered damaged walls and windows. Furthermore, we know of several private buildings being greatly affected when hundreds of tiles fell from the roofs. It was only the wooden houses that were not heavily damaged.

After the first shock, people left their houses, due to fear. Some of them were not able to reenter because the buildings needed to be repaired. Thus the people remained in cabins and barns for several days. On the fields, penitential sermons and processions were held, so as to banish more misfortune (Anonymous 1774, Lusser 1862).

Several other villages in the surrounding area and also fur-

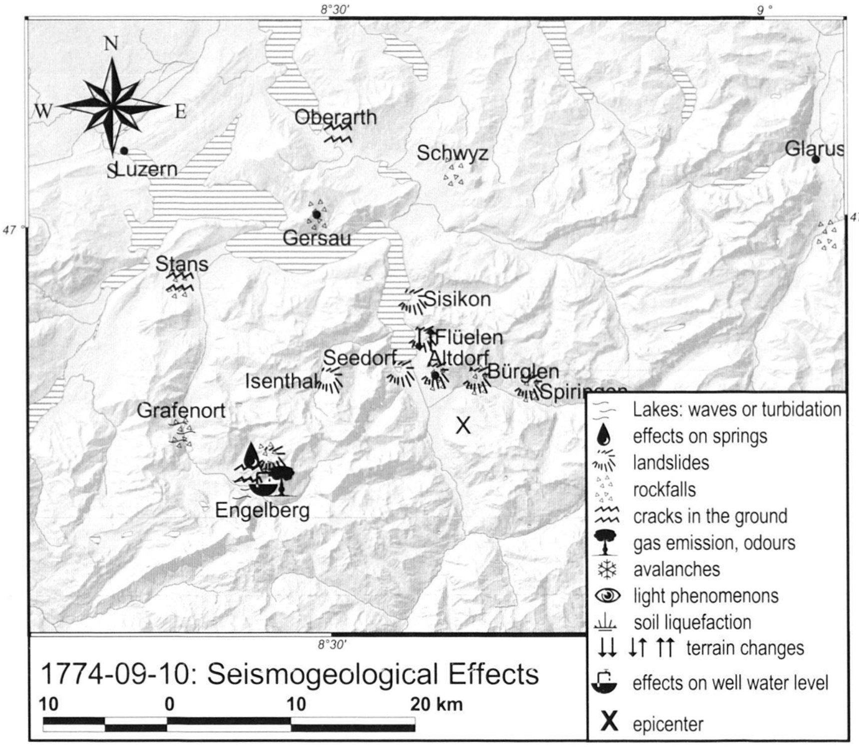

Fig. 3. Seismogeological effects of the September 10, 1774 event

ther away were damaged to a greater or lesser extent. In **Spiringen/UR**, the main church collapsed totally, the Heiligkreuz chapel partially. The collapsing vaults of the church hit a woman, so that she died the very same night (Anonymous 1774).

In **Engelberg/OW**, the inhabitants agreed on the fact that they did not remember an event of that size. Several chimneys of private houses collapsed totally or partially. Several parts of the monastery, such as the church, the library, the abbey and the chapel suffered large fissures in the inside walls. Inside the church, the high altar was destroyed. Panicking, people left their houses. Tiles falling from the roof of the monastery struck a member when escaping from the building, so that he died (Archiv des Benediktinerklosters Engelberg Cod. 344; Actuum Capitularium; Heer 1975). In the community **Grafenort/OW** several buildings were damaged both on inside and outside. Furthermore it is said that one third of the chimneys collapsed (Anonymous 1774).

Damage is also reported for **Lucerne, Schwyz** and **Glarus**, where churches and private houses were hit (Anonymous 1774, Staatsarchiv Luzern AKT 12/224, Landesbibliothek Glarus N 184).

Reports on damage or noticeable observations exist also for regions far from the epicenter. Damage is reported for several villages in eastern Switzerland (Bräker 1998) as well as the towns of **St. Gallen** and **Chur** (Handschriftenabteilung Vadiana St. Gallen S 109). In the northern and western part of Switzerland, the earthquake was widely felt but no damage is reported (Haller 1923; Handschriftenabteilung Universitätsbibliothek Basel L III 23). In the south, slight shocks were perceived (see Fig. 2).

The event is associated with several seismogeological effects. Records describe observations in the region of Lake Lucerne, mainly referring to (minor) rock falls (Fig. 3). In **Flüelen** and **Sisikon**, parts of the lakeshore broke off and sank into the lake (Anonymous 1774, Handschriftenabteilung Zentralbibliothek Zürich S 633). Near **Altdorf**, a rock fall in Lake Lucerne caused high waves. Stone or rock falls are also reported for the areas near **Bürglen, Engelberg, Gersau, Grafenort, Schwyz, Spiringen** and **Stans** (Anonymous 1774; Schwyzer Zeitung 1911-11-22; Staatsarchiv Schwyz PA 13, Slg. Kyd). In the region between **Seedorf** and **Isenthal,** landslides were produced by the main shock (Anonymous 1774, Staatsarchiv Luzern AKT 12/224).

Aftershocks

Aftershocks that were felt started the same day at 17 p.m. (UTC) and lasted until September 18. They were observed almost every day, none of them known to have caused damage (Table 3).

Intensity assessment

Table 4 provides the minimum, maximum and most probable intensity at all sites with Iw≥V for the main shock of September 10, 1774.

Tab. 4. Macroseismic parameters of the September 10, 1774 event, for all sites with Iw≥V.
EMS I_{MIN}: Minimum intensity according to European Macroseismic Scale 1998
EMS I_{MAX}: Maximum intensity according to European Macroseismic Scale 1998
EMS I_W: Most probable intensity according to European Macroseismic Scale 1998

name	latitude	longitude	EMS_Imin	EMS_Imax	EMS_Iw	site quality
ALTDORF UR	46.89	8.64	8	8	8	good
SILENEN	46.8	8.69	6	8	7	very poor
ERSTFELD	46.81	8.6	6	8	7	very poor
BUERGLEN UR	46.88	8.69	6	7	7	poor
SPIRINGEN	46.88	8.74	7	8	7	medium
ISENTHAL	46.88	8.53	6	8	7	very poor
SISIKON	46.93	8.66	6	8	7	very poor
SCHWYZ	47.04	8.67	7	7	7	good
ENGELBERG	46.82	8.45	7	8	7	good
GRAFENORT	46.85	8.37	7	8	7	medium
LUZERN	47.05	8.29	6	7	7	very poor
ULM	48.36	10	5	6	6	medium
WATTWIL	47.29	9.09	5	6	6	very poor
SAX	47.23	9.44	5	6	6	very poor
ST. GALLEN	47.42	9.37	5	6	6	medium
CHUR	46.85	9.53	6	7	6	very poor
STANS	46.96	8.36	6	7	6	poor
ZUG	47.17	8.52	6	7	6	very poor
LUZERN	47.06	8.3	6	6	6	good
WILDEGG	47.41	8.16	5	7	6	very poor
ZUERICH	47.37	8.54	6	7	6	medium
GLARUS	47.04	9.05	5	6	6	very poor
EINSIEDELN	47.13	8.74	5	7	6	very poor
ZOLLIKON	47.34	8.58	5	7	6	very poor
RIED (MUOTATHAL)	46.98	8.71	6	7	6	very poor
LENGGENWIL	47.47	9.14	4	6	5	poor
SENNWALD	47.26	9.49	5	6	5	very poor
HAUSEN AM ALBIS	47.25	8.53	5	6	5	very poor
HERRLIBERG	47.3	8.63	4	6	5	very poor
GRUENINGEN	47.28	8.76	5	6	5	very poor
BAERETSWIL	47.34	8.88	5	6	5	very poor
BASADINGEN	47.66	8.74	4	5	5	very poor
SCHAFFHAUSEN	47.72	8.63	4	5	5	very poor
SELMA	46.32	9.11	5	6	5	very poor
SOLOTHURN	47.21	7.53	5	6	5	very poor
BERN	46.95	7.45	4	5	5	very poor
NIDAU	47.12	7.24	5	6	5	very poor
MATT	46.98	9.22	4	6	5	very poor
AARAU	47.39	8.05	4	5	5	very poor
LENZBURG	47.39	8.17	4	5	5	very poor
LINDAU/D	47.56	9.7	5	6	5	very poor
FREIBURG	48	7.87	–	–	5	medium
OETTINGEN	48.95	10.61	–	–	5	poor
GERSAU	47.01	8.52	5	6	5	very poor
EGLISAU	47.57	8.53	4	5	5	very poor
ICHERTSWIL	47.16	7.5	4	5	5	very poor
SPEICHER	47.41	9.44	4	6	5	very poor
KANTON SCHWYZ	47.06	8.69	4	6	5	very poor

5 The Event of January 23, 1775 in Canton Uri

The event of January 23, 1775 has to be taken into consideration as a damaging earthquake despite its scarce documentation. It has been preceded by a smaller shock on January 20, 1775 at 3 a.m. (UTC), felt in Altdorf, Arth, Sarnen, Stans and Gersau (Monatliche Nachrichten Jan./Feb. 1775). Both events can be considered as aftershocks of the 1774 event.

The event of January 23 was assigned with intensity VI in terms of maximum observed (I_{MAX}) and epicenter intensity (I_0) (uncertainty ≤1). Due to access to contemporary sources (mainly newspapers) it had to be downgraded by one degree compared to former catalogs. The epicenter region, determined with the modified Bakun-Wentworth approach, is Uri-Rotstock, Altdorf/UR (46.85/8.55) (uncertainty ≤50km) with

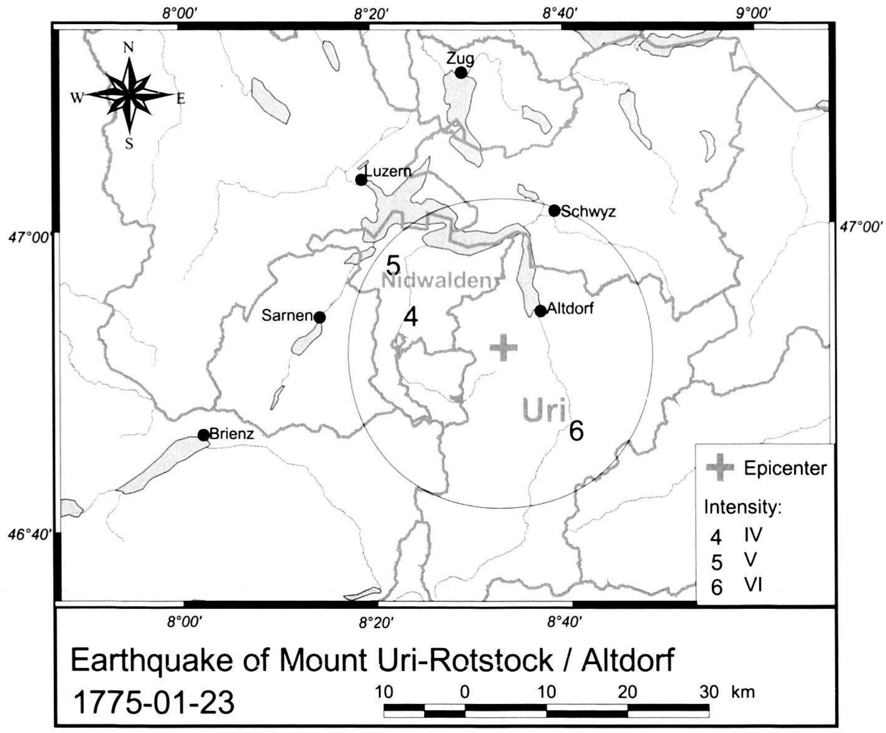

Fig. 4. Macroseismic map of the January 23, 1775 event in Canton Uri

M_W=4.7 (uncertainty ≤1). The location error is much larger than that of the 1774 event. For this reason, the epicenter location could be much closer to the 1774 event than proposed (Fig. 4).

Distribution of effects

The event on January 23, 1775 was perceived in **Canton Uri** at 3.25 a.m. (UTC) as heavy, being much stronger than the one of January 20, but not as severe as the one of September 10, 1774. As a consequence, large pieces of stone in the walls fell, and already existing fissures in walls (after the earthquake of 1774) were enlarged (Staatsarchiv Nidwalden Odermatt; Monatliche Nachrichten Jan./Feb. 1775). Unfortunately, details regarding the respective places are lacking. It has been added that the event was also felt in **Canton Nidwalden**. This information could be verified by an official protocol of the council of Stans/NW. This record mentions the earthquake and closes with the remark that as a consequence of it, dancing was forbidden for several weeks (Staatsarchiv Nidwalden A 1002). This indicates the severity of this event.

Intensity assessment

Although information on the event is difficult to interpret regarding localities, we generated a macroseismic field by assigning site intensities for two cantons and one community (Fig. 4, Table 5). I_0 was downgraded one intensity to I_0=VI compared to former catalogs.

6 The Earthquake Swarm of 1777 in the Region of Sarnen

This series of events started with the main damaging shock on February 7, 1777, at 1 a.m. (UTC), with an epicenter in Kerns/OW (46.9/8.29) (uncertainty ≤20km) with I_0=VII (uncertainty ≤0.5) and M_W=5.1 (uncertainty ≤0.5) (Fig. 5). Such earthquake swarms are different from the well-known foreshock/aftershock sequences in that they show no regularity regarding increase and decrease in intensity. Subsequent earthquakes causing damage occurred on March 25 and 27, 1777. Further felt events without damage occurred over the entire year; the last felt event was observed on December 20, 1777

name	latitude	longitude	EMS_Imin	EMS_Imax	EMS_Iw	site quality
KANTON URI	46.76	8.68	6	7	6	very poor
STANS	46.96	8.36	4	5	5	very poor
KANTON NIDWALDEN	46.9	8.4	4	5	4	very poor

Tab. 5. Macroseismic parameters of the January 23, 1775 event

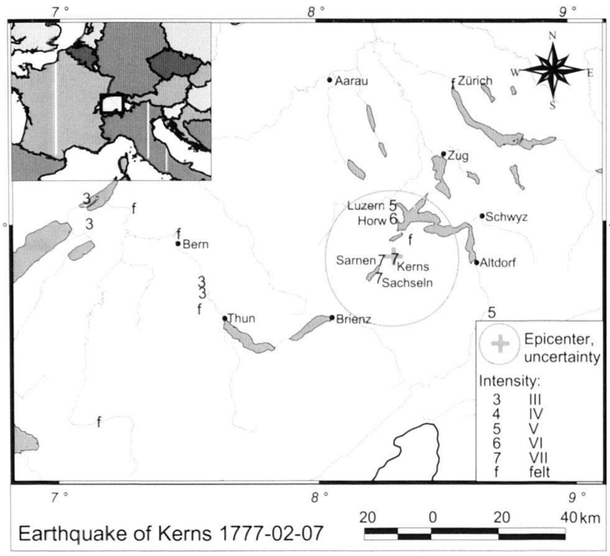

Fig. 5. Macroseismic map of the February 7, 1777 event in the region of Kerns/OW

(the reported events are given in Table 6). Compared to former catalogs several shocks of this sequence were downgraded by one degree.

Historical sources

Several reliable documents exist for these events. For the epicenter area the *Monatliche Nachrichten* (March 1777) provided ample information on the effects of the earthquakes. Furthermore a contemporary compilation on natural catastrophes for the region of Lucerne (Staatsarchiv Luzern AKT 12/224), and the protocol of council for Sarnen is available (Staatsarchiv Obwalden T 2 RP. 28). A look at the macroseismic map (Fig. 5) of the main shock of February 7, 1777, shows that the distribution of intensity is very inhomogeneous. While in the western part of Switzerland the main shock was felt, no such evidence is given for the eastern part. This, we suppose, is due to a lack of available sources. For Bern and parts of the French-speaking area we have some eyewitness records that report the perceived shocks in detail (Burgerbibliothek Bern Mscr. Oek. Ges. Quarto 16; OG Msc. Fol. 21). On the other hand, the situation regarding sources for northern and eastern Switzerland, including Zurich, is poor. Nevertheless we assume that the earthquake was slightly perceived in these regions as well.

Different indications of the duration of the earthquake illustrate that such reports do not always agree on certain statements. While the compilation of Lucerne (Staatsarchiv Luzern AKT 12/224) speaks of trembling that lasted almost a minute, the newspaper *Monatliche Nachrichten* (April 1777) says that the shock's duration lasted not more than two seconds. Probably the truth lies somewhere in between.

Tab. 6. Earthquake sequence of 1777: all earthquakes with Mw ≥ 2.7 are itemized

year	month	day	hour	minute	name	latitude	longitude	Mw	Io
1777	2	7	1		Kerns/OW	46.9	8.29	5.1	7
1777	3	23	15		Sarnen/OW	46.88	8.25	2.7	3.5
1777	3	25			Sachseln OW	46.85	8.24	4.2	6
1777	3	27	23	45	Sarnen/OW	46.9	8.25	4.2	6
1777	4	3	14		Sarnen/OW	46.88	8.25	3.9	5
1777	4	8	16	30	Sarnen/OW	46.88	8.25	3.5	4.5
1777	6	8	9	45	Sarnen/OW	46.88	8.25	3.9	5
1777	7	2			Sarnen/OW	46.9	8.23	2.7	3.5
1777	8	5	18		Sarnen/OW	46.88	8.25	4.3	5.5
1777	9	19	19		Sarnen/OW	46.88	8.25	3.9	5
1777	12	20			Sarnen/OW	46.88	8.25	3.5	4.5

Event of February 7, 1777 – Distribution of effects

The compilation of Lucerne (Staatsarchiv Luzern AKT 12/224) gives a good overview of the event: «Zu Obwalden wurde dieses Erdbeben seit dem 7.[ten] Hornung [february] bis d. 11.[ten] D[to] zu verschiedenen Mahlen sehr heftig verspührt, so das in dem Fleken Sarnen in einigen Häuseren Öfen einstürzten. Es wurden auch zu Obwalden einige Processionen angestelt und gehalten. [...] In den hochen Bergen wurde dies Erdbeben am heftigsten verspürt.»

So the whole of Canton Obwalden perceived the earthquake. In **Sarnen**, some stoves broke. As a consequence, the people held a procession. The earthquake was also observed in the mountains, although no close description is given. The *Monatliche Nachrichten* (March 1777) gives more details on the event. The shock was perceived as rather violent, alarming and scaring practically all the inhabitants, rousing the sleeping people. Damage occurred not only in Sarnen, but also in **Sachseln** and **Kerns**, where stoves were broken and chimneys collapsed partially. In **Altdorf,** people were frightened, whereas no damage occurred.

Intensity assessment

According to the reports, we assigned intensity I_W=VII at Kerns, Sarnen and Sachseln and I_W=VI at Horw (Table 7). Epicenter intensity (I_0) is VII at Kerns/OW. Figure 5 shows a rapid attenuation in the western part of the epicenter. Due to a lack of information, we have no clear picture of the effects of the event in the east.

Events of the swarm

An anonymous observer speaks of 60 felt shocks in the region of Sarnen between February and December 1777, none of them causing major damage (Monatliche Nachrichten March 1777). A clergyman gives more detail, describing how much people hoped the earthquakes might come to an end (Monatliche Nachrichten April, June 1777). In the region of Sarnen, shocks were daily observed until

Tab. 7. Macroseismic parameters of the February 2, 1777 event

name	LAT	LON	EMS_Imin	EMS_Imax	EMS_Iw	site quality
SARNEN	46.9	8.25	6	7	7	good
SACHSELN	46.85	8.24	6	7	7	poor
KERNS	46.91	8.3	6	7	7	poor
HORW	47.01	8.3	6	7	6	very poor
LUZERN	47.05	8.29	4	5	5	poor
KANTON URI	46.76	8.68	4	5	5	very poor
LA NEUVEVILLE	47.07	7.1	3	4	3	very poor
INS	47	7.11	3	4	3	very poor
KIRCHDORF BE	46.82	7.54	3	4	3	very poor
GERZENSEE	46.85	7.54	3	4	3	very poor
BASEL	47.56	7.59	1	3	1	poor

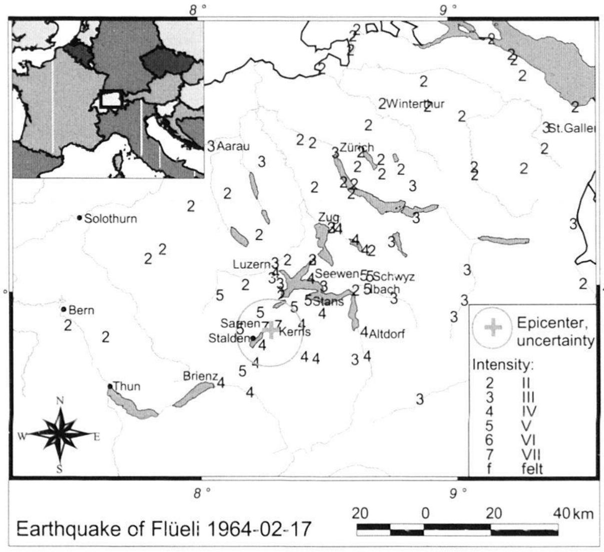

Fig. 6. Macroseismic map of the February 17, 1964 event in Flüeli/OW

Fig. 7. Sarnen: The top of a chimney destroyed part of the roof (Vaterland, February 18, 1964)

February 18. In the following, the events of March 25 and March 27 caused minor damage in the epicenter area (I_0=VI). They were described as being almost as strong as the ones on February 7; see Table 6 for all known shocks with $M_W \geq 2.7$.

7 The Earthquake Swarm during 1964

The sequence of events in 1964 started with a strong event on February 17, causing damage in the area of Sarnen-Alpnach-Kerns. The series lasted more than one month with a second strong event on March 14. The seismicity in this area can be characterized by this type of swarm-like activity, as in 1917 another sequence occurred, even though a non damaging one (Deichmann et al. 2000).

The event of February 17, 1964 in Flüeli/OW

This earthquake was observed in the whole of Central Switzerland, with rapid attenuation outside the epicenter region. The main shock occurred at 12.20 p.m. (UTC) with I_{MAX} and I_0=VII (uncertainty ≤1 resp. ≤0.5); Epicenter area is Flüeli/OW (46.88/8.27) (uncertainty ≤10km) with M_W=5 (uncertainty ≤0.2) (Fig. 6).

Historical sources

The main sources for the event are newspapers, essentially the regional ones, but also newspapers from more distant regions for reports on the respective area. However, such reports are often not primary but rather communications via agencies so that duplicate records appear quite often.

Distribution of effects

The event was recorded as having started with a bang that reminded of an explosion, followed by several aftershocks that were felt all over Central Switzerland. In **Sarnen**, the inhabitants thought of an explosion first, and ran into the streets. They were thus able to observe how chimneys and tops of

name	latitude	longitude	EMS_Imin	EMS_Imax	EMS_Iw	site quality
KERNS	46.91	8.3	6	7	7	very poor
SARNEN	46.9	8.25	6	7	7	medium
LUNGERN	46.79	8.16	–	–	5	very poor
BUOCHS	46.97	8.42	–	–	5	very poor
SCHWYZ	47.04	8.67	5	6	5	very poor
IBACH	47	8.65	5	6	5	very poor
SEEWEN SZ	47.04	8.64	5	6	5	very poor
ALPNACH DORF	46.94	8.23	5	6	5	poor
STALDEN (SARNEN)	46.9	8.15	5	6	5	very poor
ENTLEBUCH	46.99	8.07	4	5	5	poor
STANS	46.96	8.36	4	5	5	very poor

Tab. 8. Macroseismic parameters of the February 17, 1964 event; all site intensities with Iw ≥ 5 are itemized

year	month	day	hour	minute	name	latitude	longitude	Mw	Io
1964	**2**	**17**	**12**	**20**	**FLÜELI OW**	**46.88**	**8.27**	**5**	**7**
1964	2	17	16	9	SARNEN	46.9	8.3	3.1	4
1964	2	18	6	8	SARNEN	46.92	8.28	3.1	4
1964	2	18	16	29	SARNEN	46.88	8.28	2.7	3.5
1964	2	18	16	58	SARNEN	46.85	8.3	2.7	3.5
1964	2	18	21	53	SARNEN	46.85	8.23	3.1	4
1964	2	21	5	8	SARNEN	46.85	8.27	3.1	4
1964	2	25	18	17	SARNEN	46.88	8.37	3.1	4
1964	3	11	19	19	Sachseln/NW, Sarnen/OW	46.87	8.3	4.3	5.5
1964	3	13	15	42	SARNEN	46.87	8.35	3.1	4
1964	**3**	**14**	**2**	**39**	**ALPNACH/OW**	**46.87**	**8.32**	**5.7**	**7**
1964	3	14	4	46	Sarnen/OW	46.9	8.25	3.9	5
1964	3	14	14	9	SARNEN	46.9	8.33	2.7	3.5
1964	3	15	2	35	SARNEN	46.9	8.25	2.7	3.5
1964	3	15	5	22	ALPNACHER SEE	46.97	8.32	3.4 -	
1964	3	16	13	30	SARNEN	46.9	8.25	3.1	4
1964	3	16	13	45	SARNEN	46.9	8.25	2.7	3.5
1964	3	17	1	19	SARNEN	46.9	8.25	2.7	3.5
1964	3	18	2	38	SARNEN	46.88	8.43	2.7	3.5
1964	3	26	4	40	FLÜELI OW	46.87	8.33	2.7	3.5

Tab. 9. Sequence of the February / March 1964 earthquake, all events with Mw ≥ 2.7 are itemized

chimneys were shifted or toppled over (Fig. 7), and cracks in walls were generated. Numerous windowpanes broke and the electricity supply was cut off. Within half an hour, twenty or more strongly felt aftershocks occurred, followed by slightly felt events during the following hours. In the Capuchin monastery fairly large pieces of plaster fell from soffits. The chapel of the women's monastery was heavily affected, too. In the church of **Stalden**, a statue of a saint toppled over.

Heavy damage was also reported from **Kerns**, where chimneys collapsed and large plaster pieces fell from the church's outside wall. In **Lucerne**, the electricity supply was interrupted, which hindered public transportation. In **Canton Uri** objects were shifted.

In other villages in Central Switzerland, no damage occurred. In **Stans**, the bell of the council rang. **Schwyz, Ibach** and **Seewen** are only known to have observed the earthquake, without further information (Vaterland 1964-3-16).

Intensity assessment

Though we are now dealing with data which were produced in recent time, it has still to be kept in mind that reports are based on information that comes from individuals with a subjective focus on the event. We thus set a range of intensity values (Imin, Imax) here as well, and assigned the most probable intensity (Iw) (Table 8).

Aftershocks

Aftershocks started right after the main shock and several of them were felt during the following week. After a period of relative quiescence, seismic activity picked up again in mid March (Table 9).

The event of March 14, 1964 in Kerns/OW

The event occurred at 2.39 a.m. (UTC); with I_{MAX} and I_0=VII (uncertainty ≤1 resp. 0.5) and M_W=5.7 (uncertainty ≤0.2) at Kerns/OW (46.87/8.32) (uncertainty ≤10km), being stronger than the one in February 1964. It was announced by a foreshock at 1.06 a.m. (UTC). The event was observed all over Switzerland, in the north up to Alsace, in the west up to the French Jura, in the east up to Prättigau (Grisons) and in the south to Lugano. Newspapers and questionnaires from the respective regions provide reliable information on the event (Fig. 8 and 9).

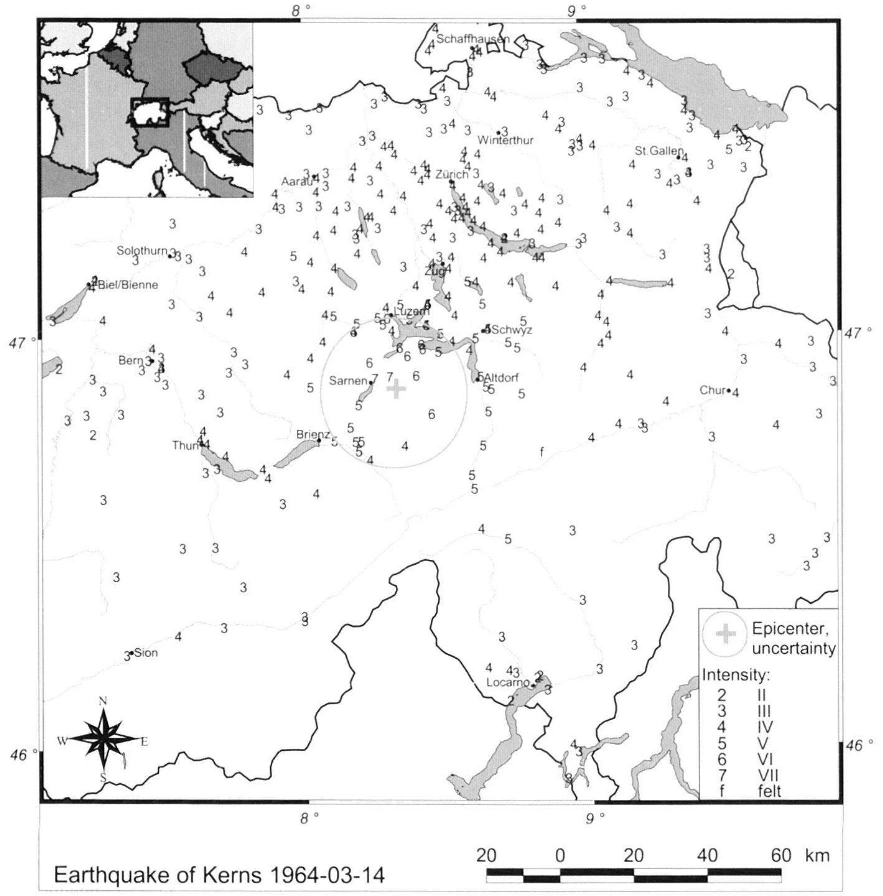

Fig. 8. Macroseismic map of the March 14, 1964 event in Kerns/OW

Distribution of effects

Sarnen, Kerns and Alpnach were affected equally by damage to chimneys and cracks in walls. Generally the older buildings of simple stone suffered heavily. Several churches were damaged, mainly those that were already affected by the earthquake in February. At **Sarnen**, tiles and part of chimneys fell from the roofs, shop windows broke; pieces of plaster fell both inside and outside of buildings, etc. (Fig. 10). Many people, mostly tourists or students, left the village immediately after the event. In **Kerns**, people had to leave an old hotel, due to its heavy damage. Damage was also reported for the main church and the cemetery, where tombstones toppled over (Fig. 11). In the area between Sarnen and Kerns heavy rocks fell into the wood and splintered trees and bushes (Fig. 12). **Alpnach**, which was not affected during the February earthquake, was this time heavily affected by broken chimneys, fissures in outer walls, busted water pipes etc. (Vaterland 1964-3-16; Neue Zürcher Zeitung 1964-3-16; Tages Anzeiger 1964-3-16).

Damage was also reported for **Engelberg, Wolfenschiessen, Stans** and **Lucerne**, mainly to chimneys (Luzerner Neueste Nachrichten 1964-3-16). In the south of Sarnen, in **Sachseln, Wilen** and **Schwendi**, few effects were observed.

In the communities in Canton Uri, the event was widely observed but no damage was reported. The earthquake was felt in large parts of Switzerland as well as in bordering regions (Luzerner Neueste Nachrichten 1964-3-16).

Intensity assessment

Several hundred intensity site points determine the event. Table 10 gives macroseismic parameters for all site points that reached intensities 5 and higher.

Aftershocks

Aftershocks started right after the main shock and are documented to have lasted until May of the same year, none of them causing damage (table 9).

9 Conclusions

Studies of historical earthquakes in Central Switzerland give evidence of a seismically active region in the past, with a recurrence that is rather irregular. The instrumentally observed microearthquakes of the recent past are distributed more evenly

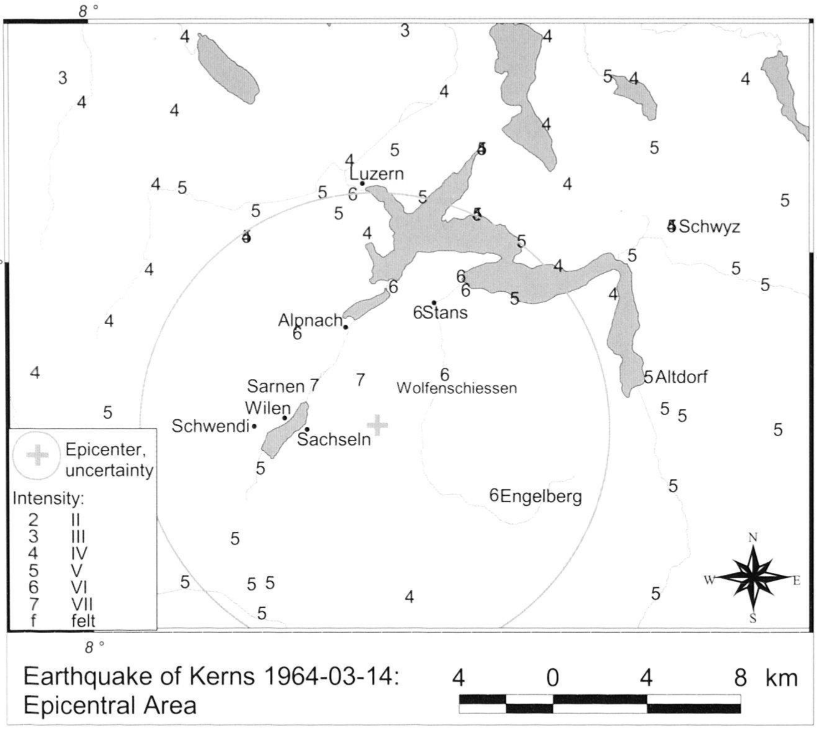

Fig. 9. Macroseismic map of the epicentral region of the March 14, 1964 event

Fig. 10. Sarnen: A church, built in 1646, suffered heavy damage (Luzerner Tagblatt, March 16, 1964)

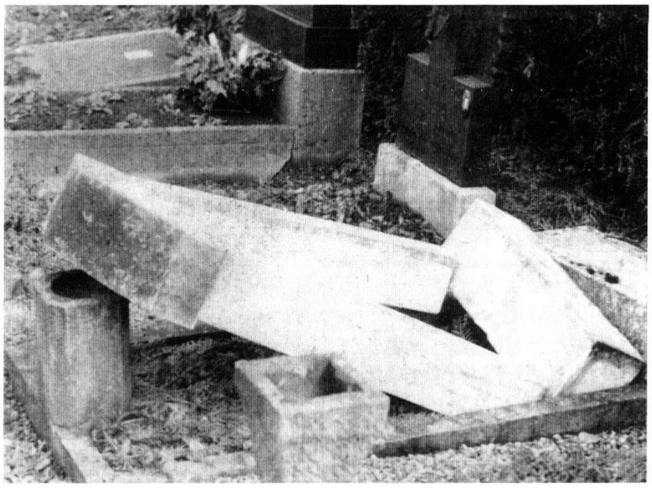

Fig. 11. Kerns: Cemetery with toppeled and/or damaged tombstones (Luzerner Neueste Nachrichten, March 16, 1964)

over the whole area (Deichmann et al. 2000). Characteristic of Central Switzerland is a temporal concentration of stronger events within few months or years, alternating with silent periods of some decades.

We do not know of large earthquakes before 1600, mostly due to a lack of historical data. In the 17th century, one major earthquake (September 18, 1601) is known. In the 18th century an accumulation of strong earthquakes took place between

Fig. 12. Area between Sarnen and Kerns: heavy rock falls smashed trees and bushes (Luzerner Neueste Nachrichten, March 16, 1964)

1774 and 1777 (September 10, 1774; January 23, 1775; February 7, 1777; March 23 and 25 1777). In the 19th century, no major earthquake is known. In the 20th century, two damaging earthquakes occurred on February 17 and March 14, 1964 (Table 1). The macroseismic epicenters of these earthquakes give evidence of a concentration of activity around Altdorf (1774, 1775) and Sarnen (1601, 1777, 1964).

The earthquake series of 1777 and 1964 in the Sarnen area may be associated with a left lateral strike-slip fault system along the valley of Obwalden (Schindler 1980; Schindler et al. 1996). Such a fault mechanism would be in agreement with the actual stress field of the area derived from instrumental data (Kastrup 2002; Kastrup et al. 2004). The valley and associated fault system are oriented at 30 to 40 degrees with respect to the strike of the Alps (see figure 1 of the tectonic situation in the Sarnen-Brünig area in Schindler 1980, p. 2). This fault system was reactivated several times in the geological past. Observed gas exhalation at the lake of Lungern can be partly associated with this system. The resulting displacement causes a large difference in the geological structures between eastern and western flank of the valley. To the south of the Lungern Lake, the fault system splits up in many small faults that appear slightly rotated with respect to the valley axes. The main faults are best documented for the area between Lake Lungern and Lake Sarnen with a fault on both valley borders (Schindler 1980). One of these faults emerges west of the Kaiserstuhl and continues in SW-NE direction to Aaried. The second fault was identified west of Alpnach with a WNW-ESE orientation. The surface expression of the faults disappears to the south of Lake Sarnen, but might continue towards the north to the Sarnen region (Beer 1997). In addition to these two well-known larger faults, some smaller faults were identified. By assuming that the faults might be connected in NS direction, the total length of the fault system is between 15 and 20km. With this hypothesis the fault system has the potential for an earthquake with magnitude larger than 6.

The locations of the faults that caused the 1601 and 1774 earthquakes are unknown due to the large uncertainties (radius of 20km) regarding the epicenter locations.

Events can be grouped in two depth classes, according to the characteristics of the macroseismic field and the instrumental information: shallow events are characterized by high attenuation of intensity with distance in the near epicentral area while deep events show a lower attenuation. From the analysis of the macroseismic fields, the events of 1601 and 1774 have been classified as deep events (approx. between 7–20km). This might be the reason that no surface expression of the faults has been found so far. In contrast to that, the macroseismic fields of the 1964 events suggest a shallow source (<7km).

Comparing with recent seismicity we can state that in the time period between 1975 and 2002, no more than six events exceeded Magnitude $M_W=2.5$ (Swiss Seismological Service 2002). The strongest ones occurred on August 28, 1994 in Schächental (46.87/8.78) with $M_W=3.7$ and on November 16, 1995 in Oberiberg (47.06/8.8) with $M_W=3.8$. Thus, since the beginning of modern instrumental observations, earthquake activity in Central Switzerland was extraordinarily low. At least four of these six events, and probably also the others, occurred in the sedimentary cover. In contrast to the situation in northern Switzerland, but in agreement with what is generally observed in the Swiss Alps, the seismicity in Central Switzerland is restricted to the upper 15–20 km of the earth's crust (Deichmann et al. 2000).

Repeated occurrence of earthquakes concentrated both in space and time was common in the past. Most damaging earthquakes took place between 1774 and 1777 around Altdorf and Sarnen. The latter was also the site of two earthquake sequences in 1917 and 1964, which lasted for several months and caused significant damage. One should expect at least temporary increases in seismic activity in the future, particularly in the area of Sarnen. The irregular episodes of strong earthquakes, as well as the occurrence of strike slip and thrust source mechanisms, characterize the seismicity of Central Switzerland, and indicate the differences to other seismically active regions such as the Valais or Basel areas. The results of the study of past earthquakes make it evident that earthquake activity is not necessarily stationary in space and time and that studying paleoseismicity and historical sources is of main importance.

Acknowledgements

The revision of the events discussed above was part of the upgrading of the Earthquake Catalog of Switzerland (ECOS), a project of the Swiss Seismological Service. We thank several colleagues at the Swiss Seismological Service for contributing to these researches. We also would like to thank all libraries and archives mentioned in the reference list, for their support. This paper was supported by the Swiss National Science Foundation, Project Nr. 205121-100510.

Tab. 10. Macroseismic parameters of the March 14, 1964 event; all site intensities with Iw≥5 are given

name	latitude	longitude	EMS_Imin	EMS_Imax	EMS_Iw	site quality
KERNS	46.91	8.3	7	7	7	medium
SARNEN	46.9	8.25	7	7	7	medium
STANS	46.96	8.37			6	very poor
LUZERN	47.05	8.29	6	7	6	poor
ALPNACH DORF	46.94	8.23	6	7	6	very poor
ENGELBERG	46.82	8.45	6	6	6	very poor
BUOCHS	46.97	8.42	–	–	6	very poor
ENNETBUERGEN	46.98	8.42	–	–	6	very poor
WOLFENSCHIESSEN	46.91	8.4	–	–	6	very poor
STANSSTAD	46.98	8.34	–	–	6	very poor
ALTDORF UR	46.88	8.64	–	–	5	very poor
MALTERS	47.04	8.18	–	–	5	very poor
HEIDEN	47.44	9.53	–	–	5	very poor
ILLGAU	46.99	8.73	–	–	5	very poor
AMBRI	46.51	8.71	–	–	5	very poor
ERSTFELD	46.82	8.65	–	–	5	very poor
BUERGLEN UR	46.88	8.66	–	–	5	very poor
FLUEELEN	46.91	8.63	–	–	5	very poor
BRUNNEN	47	8.61	–	–	5	very poor
MUOTATHAL	46.97	8.76	–	–	5	very poor
MERLISCHACHEN	47.08	8.44	–	–	5	very poor
SATTEL	47.08	8.64	–	–	5	very poor
SCHWYZ	47.02	8.65	–	–	5	very poor
EIGENTHAL	47.02	8.17	–	–	5	very poor
KRIENS	47.03	8.28	–	–	5	very poor
KRIENS	47.03	8.28	–	–	5	very poor
BRIENZWILER	46.75	8.1	–	–	5	very poor
BECKENRIED	46.97	8.48	–	–	5	very poor
UNTERSCHAECHEN	46.86	8.77	–	–	5	very poor
GURTNELLEN	46.74	8.63	–	–	5	very poor
GOESCHENEN	46.67	8.59	–	–	5	very poor
ANDERMATT	46.63	8.6	–	–	5	very poor
UNTERAEGERI	47.14	8.58	–	–	5	very poor
WEGGIS	47.03	8.43	–	–	5	very poor
VITZNAU	47.01	8.48	–	–	5	very poor
REUTI (HASLIBERG)	46.75	8.18	–	–	5	very poor
LUNGERN	46.79	8.16	–	–	5	very poor
GISWIL	46.84	8.19	–	–	5	very poor
MEGGEN	47.05	8.37	–	–	5	very poor
EBIKON	47.08	8.34	–	–	5	very poor
LITTAU	47.05	8.26	–	–	5	very poor
HASLIBERG/WASSERWENDI	46.75	8.2	4	5	5	very poor
LONS-LE-SAUNIER	46.68	5.55	–	–	5	good
SOERENBERG	46.88	8.02	–	–	5	very poor
WERTHENSTEIN	47.06	8.1	–	–	5	very poor
ALTISHOFEN	47.2	7.96	–	–	5	very poor
OBERIBERG	47.04	8.78	–	–	5	very poor
MEIRINGEN	46.73	8.19	–	–	5	very poor

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