Zeitschrift: Eclogae Geologicae Helvetiae
Herausgeber: Schweizerische Geologische Gesellschaft
Band: 91 (1998)
Heft: 2

Artikel: Earthquakes in Switzerland and surrounding regions during 1997
Autor: Deichmann, Nicolas / Baer, Manfred / Ballarin Dolfin, Dominique
DOI: https://doi.org/10.5169/seals-168420

0012-9402/98/020237-10 $1.50 + 0.20/0
Birkhäuser Verlag, Basel, 1998

Eclogae geol. Helv. 91 (1998) 237–246

Earthquakes in Switzerland and surrounding regions during 1997

NICOLAS DEICHMANN, MANFRED BAER, DOMINIQUE BALLARIN DOLFIN, DONAT FÄH, PAUL FLÜCK, ULRIKE KASTRUP, URS KRADOLFER, WALTER KÜNZLE, DIETER MAYER-ROSA, STEPHAN RÖTHLISBERGER, THOMAS SCHLER, SOUAD SELLAMI, PATRICK SMIT & DOMENICO GIARDINI[1]

Key Words: Earthquakes, landslides, focal mechanisms, Switzerland

ABSTRACT

This report of the Swiss Seismological Service summarizes the seismic activity in Switzerland and surrounding regions during the previous year. During 1997, 239 earthquakes were detected and located in the region under consideration. In addition, 54 seismic events were identified as quarry blasts and 5 as rock avalanches. In terms of numbers of earthquakes, the seismic activity in 1997 was close to the average over the last 23 years. However, with not a single event having a magnitude $M_L > 4$ and only one with $M_L > 3.5$, the strength of the earthquakes was relatively low. The strongest event, with M_L 3.8, occurred on November 22nd on the north shore of the Walensee and attained an epicentral intensity of V (MSK). Its source was shallow and located in the immediate vicinity of the quarry of Quinten. As in the past, most of the earthquakes occurred in the Valais as well as in Graubünden and were restricted to the upper 15 km of the crust. In agreement with previous observations, the 5 hypocenters with depths greater than 20 km were all located below the Jura Mountains and Molasse Basin of northern Switzerland.

ZUSAMMENFASSUNG

Dieser Bericht des Schweizerischen Erdbebendienstes stellt eine Zusammenfassung der im Vorjahr in der Schweiz und Umgebung aufgetretenen Erdbeben dar. Im Jahr 1997 wurden im erwähnten Gebiet 239 Erdbeben erfasst und lokalisiert. Zusätzlich wurden 54 Sprengungen und 5 Felsstürze aufgezeichnet. Die Anzahl der im Jahr 1997 beobachteten Erdbeben entspricht etwa dem Mittel über die letzten 23 Jahre. Es wurde aber kein Beben mit der Magnitude $M_L > 4$ und nur ein einziges mit $M_L > 3.5$ verzeichnet, so dass in Bezug auf die Stärke der Ereignisse die Aktivität relativ gering war. Das stärkste Beben mit M_L 3.8 ereignete sich am 22. November am Nordufer des Walensees und erreichte eine Epizentralintensität von V (MSK). Das Hypozentrum war oberflächennah und lag in unmittelbarer Nähe des Steinbruchs von Quinten. Wie schon in der Vergangenheit waren die meisten Beben im Wallis und in Graubünden zu verzeichnen und ihre Herdtiefen waren auf die obersten 15 km der Erdkruste beschränkt. In Einklang mit früheren Beobachtungen ereigneten sich die 5 Erdbeben mit Herdtiefen grösser als 20 km alle unter dem Jura und dem Nordschweizer Molassebecken.

RESUME

Avec le présent rapport, le service sismologique suisse résume l'activité sismique de l'année écoulée, en Suisse et dans les régions limitrophes. En 1997, 239 tremblements de terre ont été détectés et localisés dans la région considérée. En plus, 54 événements ont été identifiés comme des tirs de carrière et 5 comme des éboulements. Considérant le nombre d'événements, l'activité sismique de 1997 est proche de la moyenne sur les 23 dernières années. Mais l'activité était faible en tenant compte qu'aucun événement ne dépasse la magnitude M_L 4 et un seul excède M_L 3.5. L'événement le plus fort avec M_L 3.8 a eu lieu le 22 Novembre sur la rive nord du Walensee et atteint l'intensité épicentrale de V (MSK). Son hypocentre était peu profond et proche de la carrière de Quinten. L'activité la plus importante a eu lieu en Valais et aux Grisons et se limitait aux 15 premiers kilomètres de la croûte. Les 5 hypocentres avec des profondeurs focales superieures à 20 km sont situés sous les monts du Jura et le bassin molassique du Nord de la Suisse, corroborant de précédentes observations.

Introduction

The present contribution of the Swiss Seismological Service is the second article in a new series of annual reports summarizing the seismic activity in Switzerland and surrounding regions during the previous year (Baer et al. 1997).

Past earthquake activity in and around Switzerland has been documented in an uninterrupted series of annual reports from 1879 until 1963 *(Jahresberichte des Schweizerischen Erdbebendienstes)*. Three additional annual reports have been published for the years 1972–1974. These reports together with historical records of earthquakes dating back to the 13th century have been summarized by Pavoni (1977) and provided the basis for the current seismic hazard map of Switzerland (Sägesser & Mayer-Rosa 1978). With the advent of routine data processing by computer, the wealth of data acquired by

[1] Swiss Seismological Service, Institute of Geophysics, ETH Hönggerberg, CH-8093 Zürich, Contribution No. 1031, Institute of Geophysics, ETH-Zürich

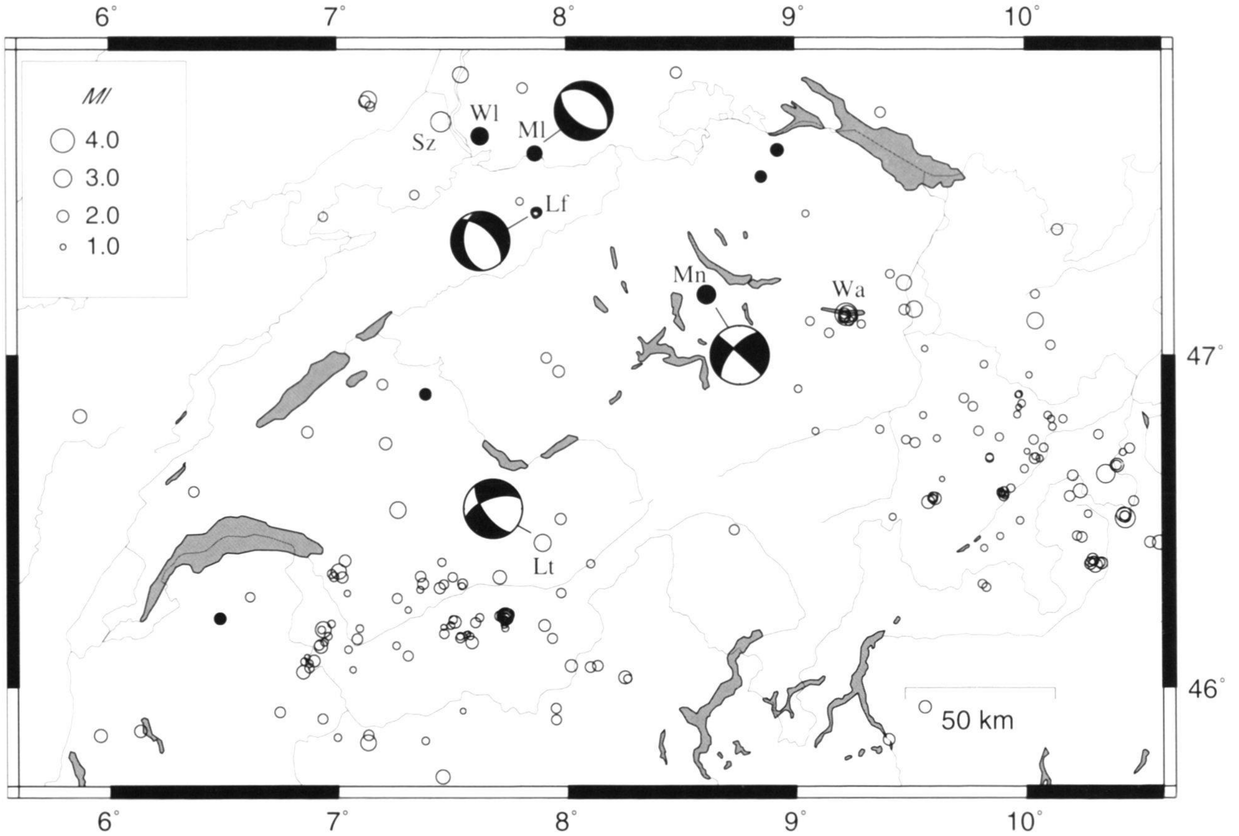

Fig. 1. Epicenters and focal mechanisms of earthquakes recorded by the Swiss Seismological Service during 1997. The black symbols correspond to events with focal depths >15 km. Epicenters of earthquakes mentioned in the text are labeled: Lf = Läufelfingen, Lt = Lötschental, Ml = Möhlin, Mn = Menzingen, Sz = Sierentz, Wa = Walensee, Wl = Weil.

the nationwide seismograph network has been regularly documented in bulletins with detailed lists of all recorded events *(Monthly Bulletin of the Swiss Seismological Service)*. In addition, numerous studies covering different aspects of the recent seismicity of Switzerland have been published in the scientific literature (for an overview and additional references see, e.g. Deichmann & Baer 1990; Pavoni & Roth 1990; Deichmann, 1992b; Rüttener 1995; Rüttener at al. 1996; Pavoni et al. 1997).

Seismic stations in operation during 1997

The Swiss Seismological Service operates two separate nationwide seismic networks, a high-gain seismometer network (Baer 1990) and a low-gain accelerograph network (Smit, 1998a). The former is designed to continuously monitor the ongoing earthquake activity down to magnitudes well below the human perception threshold, whereas the latter is principally aimed at engineering concerns and thus only records so-called strong motions. The observations presented here are based mainly on the high-sensitivity monitoring network. The data that has been collected by the strong-motion network is documented in a separate report (Smit 1998b).

The number and configuration of the high-gain stations in operation during 1997 was essentially the same as during the previous year. A complete list and map of the stations, together with details on the various recording systems, can be found in Baer et al. (1997). The only changes concern stations EIT (Eiteberg) and ACB (Acheberg) of the local network in northern Switzerland. Station EIT, which also functioned as telemetry relay between ACB and the central recording site, broke down in October and needed major repairs. Since EIT is a relatively noisy site and has repeatedly been subject to vandalism in the past, it was closed as a seismic station and the telemetry relay has been moved to a more convenient location nearby. For detailed studies of selected earthquakes and for constraining the location and the focal mechanisms of earthquakes situated on the periphery or outside the Swiss station networks, we also use data obtained from the Landeserdbebendienst in Freiburg, Germany, from the SISMALP array operated by the Laboratoire de Géophysique Interne et Tectonophysique, Ob-

Tab. 1. Earthquakes with $M_L \geq 2.5$. Notes: (1) locations based on additional foreign data or 2-D ray-tracing; (2) location fixed (see text).

Location	Date & Time [UT]	Lat. [°N]	Lon. [°E]	X / Y [km]	Depth [km]	Mag. [M_L]
Gams, SG	1997.01.01 19:56:43	47.214	9.475	754/231	1	2.6
Rhinegraben, F	1997.01.15 05:35:11	47.753	7.139	577/289	10	2.9
Sierentz, F	1997.02.01 14:01:58	47.688	7.456	601/282	10	3.4
Turtmanntal, VS	1997.02.19 18:41:56	46.217	7.731	622/118	2	2.7
Rhinegraben, D	1997.02.20 15:39:35	47.826	7.543	608/297	10	2.7
Bormio, I	1997.04.12 23:00:00	46.513	10.435	830/156	10	3.4
Bormio, I	1997.04.14 13:13:13	46.523	10.429	829/157	10	2.5
Turtmanntal, VS	1997.04.26 08:24:13	46.213	7.732	623/118	2	2.5
Turtmanntal, VS	1997.04.27 17:01:14	46.218	7.730	622/118	1	2.8
Ofenpass, GR	1997.05.13 02:58:42	46.645	10.351	823/170	10	3.1
G. S. Bernard, I	1997.07.14 02:57:57	45.833	7.129	576/ 76	10	2.7
Leysin, VD	1997.07.23 18:15:58	46.352	7.002	566/133	5	2.6
Gstaadt, BE(1)	1997.08.01 20:58:36	46.544	7.269	586/154	10	2.8
Buchs, SG	1997.08.08 10:54:46	47.135	9.519	758/222	1	2.8
Möhlin, AG(1)	1997.09.02 00:30:53	47.606	7.861	632/272	23	2.6
Menzingen, ZG(1)	1997.10.23 12:07:01	47.181	8.624	689/226	30	3.2
Weil, D(1)	1997.11.17 17:09:23	47.639	7.626	614/277	17	3.1
Walensee, SG(2)	1997.11.18 12:23:47	47.134	9.189	733/222	1	2.9
Walensee, SG(2)	1997.11.22 04:56:11	47.134	9.189	733/222	1	3.8
Dents du Midi, VS	1997.11.27 04:03:48	46.177	6.933	561/114	4	2.7
Lötschental, VS(1)	1997.11.28 08:30:21	46.437	7.898	635/143	12	2.9
Arlberg, A	1997.12.28 22:52:27	47.101	10.046	798/220	10	2.8

servatoire de Grenoble, France, from the Laboratoire de Détection et Géophysique in Bruyères-le-Châtel, France, and from the Istituto di Geofisica, Università di Genova, Italy.

Data analysis

Preliminary hypocenter locations are determined on the basis of an automatic arrival time picker (Baer & Kradolfer 1987), but final arrival times and locations are subsequently reviewed by a seismologist. Locations are calculated with a modified version of the widely used HYPO-71 algorithm originally developed by Lee & Lahr (1972). The seismic velocity models consist of three horizontal crustal layers with constant velocities overlying a mantle half-space. The models account for differences between the near-surface geology in the Alps and foreland as well as, in a simplified way, for the large depth variation of the crust-mantle boundary. In addition, calculated travel times are corrected for differences in station elevation.

Routinely determined focal depths are reliable only if the epicenters are located inside the station network and if at least one station lies within an epicentral distance that is less than twice the focal depth. In the case of selected events, in particular those for which we constructed focal mechanisms, focal depths were checked by 2-D ray-trace modelling of the travel-time differences between the direct ray (Pg) and the reflection from the Moho (PMP) or between the Pg and the ray refracted in the upper mantle (Pn) (e.g. Deichmann, 1987; Deichmann & Rybach 1989). The crustal velocities used for the ray-trace models were obtained from tomographic and seismic refraction studies (e.g. Maurer & Ansorge, 1992; Maurer & Kradolfer 1996; Pfister 1990; Yan & Mechie 1989; Ye et al. 1995) and the Moho topography was based on the results of Waldhauser (1996), thus accounting more realistically for the known crustal heterogeneity. The same ray-tracing technique was also employed to help in correctly identifying the first arrivals and to estimate the take-off angles of the rays at the source, which are used for constructing the focal mechanisms (e.g. Eva et al. 1998).

Magnitudes are determined from the maximum amplitudes of the vertical components of ground velocity. In order to obtain the local magnitude (M_L), these amplitude values and the corresponding period are converted to what they would be if the signals had been recorded by a standard Wood-Anderson seismograph, and the attenuation with epicentral distance is accounted for by an empirically determined relation (Kradolfer & Mayer-Rosa 1988). The final magnitude corresponds to the median value of all individual station magnitudes. In the case of events with $M_L > 3$, for which most signals are clipped, the final magnitude is based only on the stations with low-gain channels.

Seismic activity during 1997

Overview

During 1997, the Swiss Seismological Service detected and located 239 earthquakes in the region shown in Figure 1. Based on such criteria as the time of occurrence, the location, the signal character or direct information, 54 additional seismic events were identified as quarry blasts. As discussed in more detail below, the network also recorded 5 landslides or rock avalanches.

Routinely calculated focal depths range between 0 and 31 km, but only 7 hypocenters are located at depths greater than 15 km. One of these deeper events ($M_L = 2.0$) is located 16 km below the Chablais, south of Lake Geneva, but its loca-

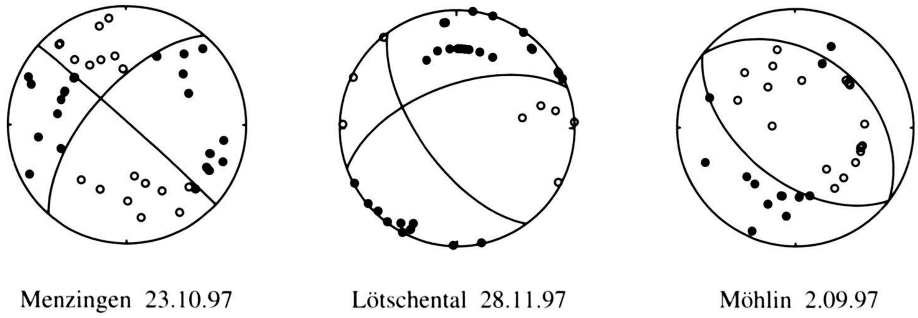

Fig. 2. Fault-plane solutions (lower hemisphere, equal area projection) of selected earthquakes. Solid circles, compressive first motion (up) and empty circles, dilatational first motion (down).

Tab. 2. Focal mechanism parameters.

Location	Mag. $[M_L]$	Date & Time [UT]	Depth [km]	P-Axis Az.	P-Axis Dip	T-Axis Az.	T-Axis Dip
Menzingen	3.2	1997.10.23 12:07	30	179	19	84	16
Lötschental	2.9	1997.11.28 08:30	12	105	41	198	3
Möhlin	2.6	1997.09.02 00:30	23	38	82	218	8
Läufelfingen	1.8	1997.02.21 05:04	8	170	69	63	7

Tab. 3. Earthquakes near Quinten (Walensee) recorded by the national seismograph network in 1997.

Date & Time [UT]	Mag. $[M_L]$
1997.04.10 07:24	1.7
1997.11.18 03:57	1.8
1997.11.18 12:24	2.9
1997.11.22 04:56	3.8
1997.11.22 05:32	1.8
1997.11.22 06:09	1.5
1997.11.22 06:26	1.6
1997.11.22 23:04	1.8
1997.11.23 20:27	1.8
1997.12.29 11:40	1.4

tion is poorly constrained. Another deeper one is the M_L 3.1 event of Nov. 17th, located north of Basel at a depth of 17 km. The other 5 deep events are all located at depths greater than 20 km in the lower crust beneath the Jura Mountains and Molasse Basin of northern Switzerland.

Magnitude values of the events recorded in 1997 range between M_L 0.5 and 3.8. The events with $M_L \geq 2.5$ are listed in Table 1. Where available, the epicentral coordinates and focal depths given in Table 1 are based on the results that include additional data from foreign networks and on 2-D ray-tracing. The fault-plane solutions are shown in Figures 2 and 6, and the corresponding parameters are listed in Table 2. In what follows, we present the highlights of the seismic activity observed during 1997 as well as a brief discussion of the recorded landslides and rock avalanches.

Significant earthquakes of 1997

Walensee

With a magnitude M_L of 3.8, the earthquake which occurred on November 22 at 05:56 local time beneath the north shore of the Walensee, was the strongest event in Switzerland during 1997. It was clearly felt by the residents of Quinten, but the observed intensities decrease rapidly with distance (Fig. 3), which suggests that the source was shallow. This event is actually part of a swarm that has been active intermittently for some time and of which the national network recorded 10 events in 1997 (Tab. 3). Judging from the similarity of the observed signals (Fig. 4), the hypocenters of all these events must be tightly clustered and the focal mechanisms must be similar. Moreover, also the M_L 2.5 event of October 11, 1996 (Baer et al. 1997, Tab. 2) is part of this cluster. Whether additional events recorded in previous years also belong to the same cluster remains to be investigated. A temporary three-component digital seismograph was installed a few hundred meters east of Quinten one day after the mainshock. During the week in which this temporary station was in operation, it recorded the aftershock of Nov. 23, which was detected by the national network, as well as numerous weaker events.

Due to the fact that the true seismic velocities associated with the complex 6 km thick sedimentary structure in the Walensee region deviate strongly from the simple regional velocity model adopted in the routine location procedure, it is difficult to obtain a stable and reliable location. Even the temporary station at Quinten did not improve the location accuracy significantly. However, the travel time differences between the P- and S-waves of all the aftershocks observed at this station are less than 0.5 s, so that the radial distance to the source must be less than about 3 km. The three-dimensional particle motion of the P-waves at the temporary station suggest that the source was situated NW of Quinten. However, due to the steep topography all along the E-W trending northern shore of the Walensee, it is very likely that the rays arriving at the temporary station are deviated by a lateral velocity gradient. Consequently, based on the particle motion alone, the source could be located anywhere inside a NW-SW sector from Quinten.

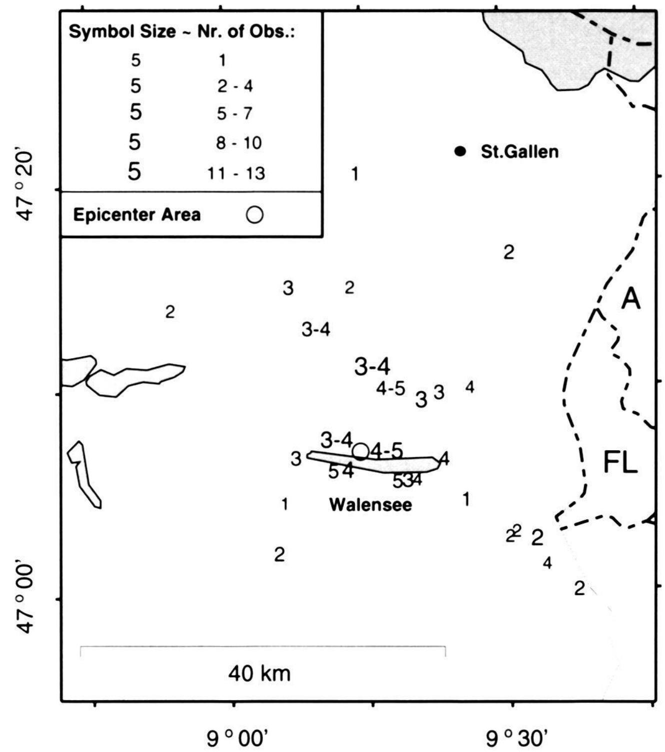

Fig. 3. Macroseismic observations of the M_L 3.8 Walensee event of Nov. 22. 1997.

Fig. 4. Seismograms of the 1997 Walensee events recorded at station WIL (vertical component), as listed in Table 3 (from top to bottom).

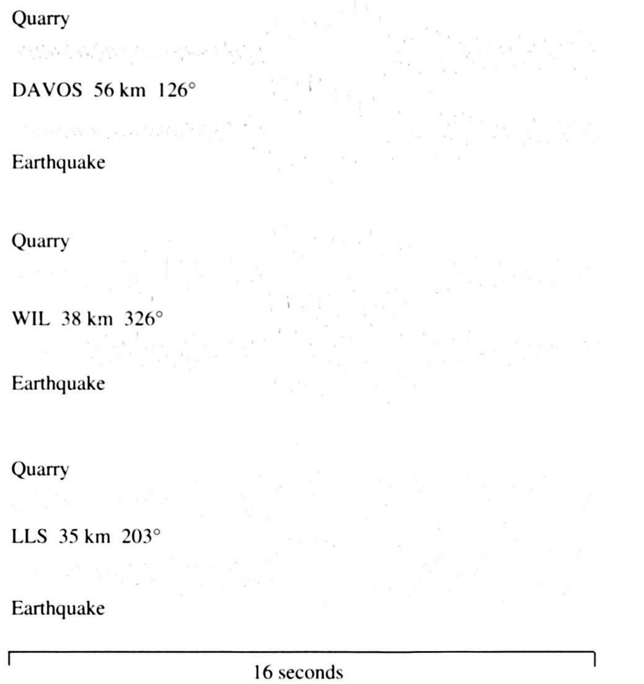

Fig. 5. Pairs of seismograms of the explosion of 1997.02.24 in the quarry of Quinten (upper trace) and the M_L 1.8 earthquake of 1997.11.18 recorded at stations DAVOS, WIL and LLS (with epicentral distance and azimuth from the quarry to each station). The large amplitude phases in the middle of each trace correspond to the shear and surface waves. The signals of the explosion and the earthquake are plotted with the same time difference for all three stations.

The strongest constraint on the locations, however, is given by a comparison of the earthquake records with the signals recorded from several explosions in a quarry situated just 2.5 km W of Quinten. Despite the fact that neither the focal mechanisms nor the depths of the earthquakes and the explosions are the same, there is a striking similarity among the corresponding signals (Fig. 5). This similarity together with the fact that the S-wave arrival-time differences seem to be almost the same for all azimuths suggests that the epicenter of the earthquakes must be in the immediate vicinity of the quarry. In an attempt to relocate the earthquakes relative to the quarry, the large timing uncertainties of the weak and emergent arrivals of the explosion signals could be reduced by performing a cross-correlation in the time domain between the signals of one of the explosions and the first foreshock. Then, with the relative arrival times obtained from the cross-correlation the relocation was performed using a linearized master event location procedure (Console and DiGiovambattista 1987) and a realistic velocity structure that accounts for the sedimentary layers overlying the crystalline basement. Even allowing for the remaining timing uncertainties due to ambiguities in the correlation, the earthquake hypocenters seem be located 1–2 km below and within about 0.5 km horizontally from the quarry.

Because of the shallow hypocenter and the complex geologic structure in the source region, the polarity of the P-ar-

Tab. 4. The 1997 earthquake sequence of Läufelfingen. M = master event for relative location; R = relocated events.

Date & Time [UT]	Mag. [M_L]	
1997.02.21 00:50	1.7	M
1997.02.21 02:29	1.1	R
1997.02.21 02:55	1.2	R
1997.02.21 03:28	1.3	R
1997.02.21 05:04	1.8	R
1997.02.21 05:48	1.4	R
1997.02.21 07:02	1.1	R
1997.02.21 08:17	1.3	
1997.02.21 09:05	1.2	R
1997.02.21 09:38	1.2	
1997.02.21 10:58	1.2	
1997.02.21 11:56	1.4	
1997.02.21 13:36	1.1	R
1997.02.21 18:43	1.6	

rivals beyond an epicentral distance of about 100 km can not be determined with sufficient confidence to construct a reliable fault-plane solution. Further efforts to correctly model the take-off angles at the source might at least constrain the focal mechanism type. This would then allow one to address the question of whether the location of the Walensee earthquakes so close to the quarry of Quinten is merely fortuitous or whether the events actually may have been triggered by the mining activity.

Menzingen

With a focal depth of 30 km, the M_L 3.2 earthquake of Menzingen (ZG), which occurred at 14:07 local time on October 23, belongs to a previously known group of lower-crustal events in the area between the lakes of Zürich and Zug. The well-constrained fault-plane solution corresponds to a strike-slip mechanism with a N-S trending P-axis (Fig. 2), in agreement with the other known focal mechanisms in this region (Deichmann 1992b).

Lötschental

The hypocenter of the M_L 2.9 earthquake that occurred on November 28 at 09:30 local time, about 3 km east of Fafleralp in the Lötschental, was located at a depth of about 12 km below the southern margin of the Aar Massif. Unfortunately, the first arrivals at the more distant stations to the southwest are unclear and inconsistent, so that the fault-plane solution is not well constrained. Thus the range of focal mechanisms compatible with the available first-motion polarities alone ranges from almost pure strike-slip to a normal fault with a transcurrent component. However, the chosen solution (Fig. 2 and Tab. 2), which exhibits a strong normal-faulting component with a NNE-SSW trending T-axis, is also in agreement, at least in a qualitative way, with the relative P- and S-wave amplitudes of the observed seismograms. An M_L 3.5 earthquake occurred at almost the same location in 1986, but the focal mechanism of this earlier event still remains to be evaluated.

Möhlin

On September 2 at 02:30 local time, a magnitude M_L 2.6 earthquake occurred just north of the Rhine near the town of Möhlin. Despite its low magnitude and a relatively large focal depth (23 km), it is, together with the events of Sierentz and Weil (Tab. 1), one of three earthquakes that were felt in the Basel area during 1997. The focal mechanism of this event is well constrained and corresponds to a pure normal fault (Fig. 2).

Läufelfingen Cluster

The seismic activity below the Jura Mountains southeast of Basel is known to occur in a swarm-like fashion: a significant fraction of the earthquakes tend to occur tightly clustered in space and time. The signals of the individual events in such earthquake clusters usually show a high degree of similarity, which is an indication of a common focal mechanism, and the hypocenters tend to lie on a plane which coincides with one of the nodal planes of the fault-plane solution (Deichmann 1990). The 14 events, ranging in magnitude between 1.1 and 1.8, which occurred on February 21 at a depth of 7–8 km below Läufelfingen, (Tab. 4) are a typical example of this behaviour.

Because of the low magnitude of these events, the number of usable signals is insufficient for the construction of a unique fault-plane solution based on first-motion polarities alone. However, the relative amplitudes of the P- and S-waves in the observed seismograms show large variations, depending on how close the corresponding take-off angles of the rays at the source are to a nodal plane. Thus, of all the possible fault-plane solutions, the one shown in Figure 6 is the only one which is consistent, at least in a qualitative way, with the character of the observed signals. Based on the results of a high-precision master-event location technique using waveform cross-correlations (Deichmann and Garcia-Fernandez 1992), the individual hypocenters of this cluster lie on a NNW-SSE striking plane that is almost coincident with the NW-SE striking nodal plane of the focal mechanism (Fig. 6).

The routinely calculated location of this earthquake cluster practically coincides with the location of a larger swarm that occurred in April 1987 (Deichmann and Garcia-Fernandez 1992). Indeed, applying the above mentioned relative location technique to the master events of the two clusters shows that the 1997 cluster was located about 250 m below and 300 m north of the 1987 cluster. However, it is interesting to note that, whereas in 1997 slip occurred on a normal fault striking roughly NW-SE with a dip of about 60°, the main part of the 1987 cluster occurred as left-lateral slip on an almost vertical and more or less N-S striking fault.

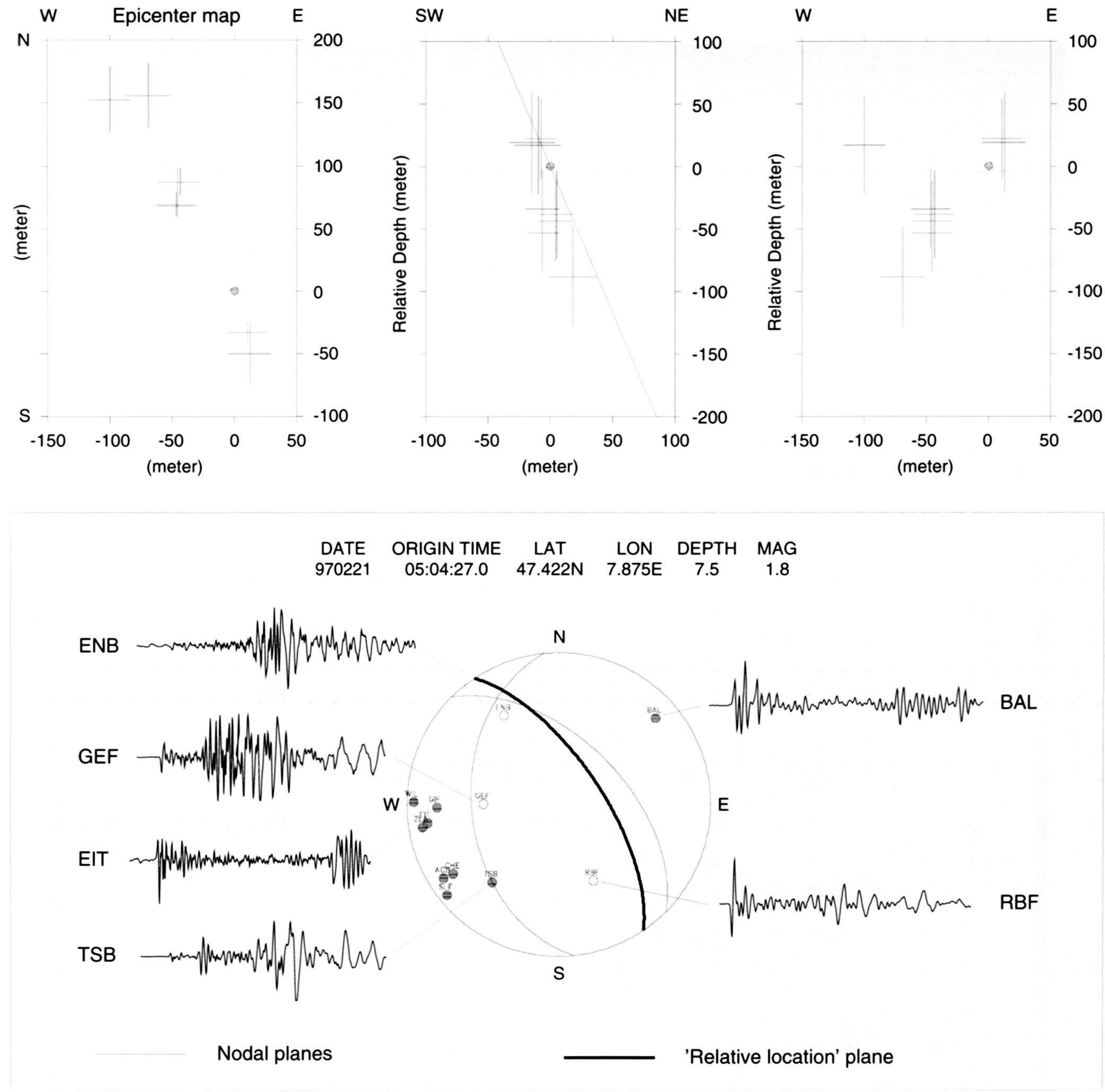

Fig. 6. The Läufelfingen swarm of February 21, 1997. Bottom: fault-plane solution of the best recorded event with selected seismograms illustrating the dependence of the signal character on the proximity to the nodal planes. Top: locations of the individual events (crosses) relative to the master event (black dot). Left: epicenter map; middle: SW-NE cross-section with trace of the inferred fault plane (bold curve in the fault-plane solution shown below); right: W-E cross-section. The size of each cross corresponds to one standard deviation of the location.

Landslides and rock avalanches

Montblanc

At 14:55 local time on January 18th, a rock mass of roughly 1.5 Mio m^3 broke off from the Brenva face of the Montblanc and fell onto the underlying Brenva Glacier. There it entrained large quantities of snow, thus triggering a massive avalanche of snow and ice mixed with rock fragments, that swept across the lower parts of a ski run of Courmayeur, killing two skiers (Keusen 1997). The seismic signals associated with this event were recorded by almost the entire seismograph network of Switzerland. The amplitudes of the signals correspond to an M_L 2.2 earthquake and the total signal duration is about 3 minutes. On the records observed at the stations located at Emos-

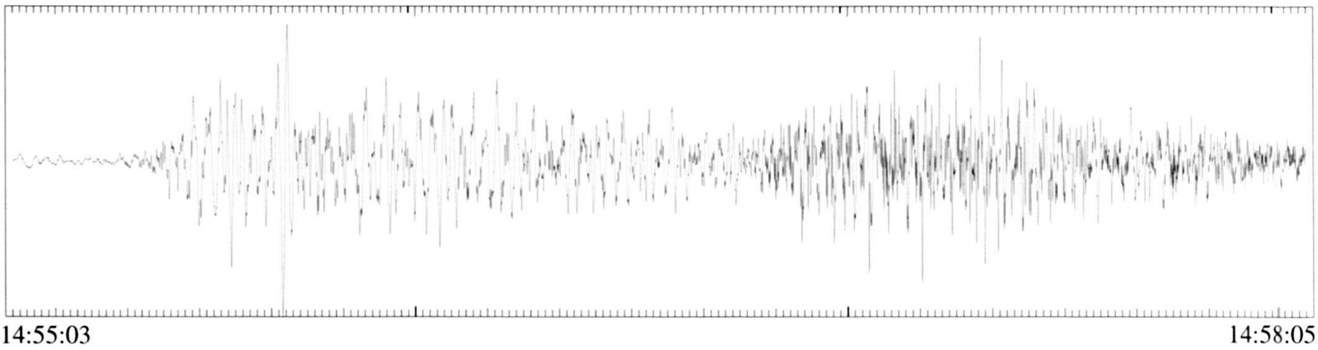

Fig. 7. Vertical component of ground velocity caused by the rock and ice avalanche off the E face of Montblanc, recorded at station Vieux Emosson (EMV) on January 18, 1997.

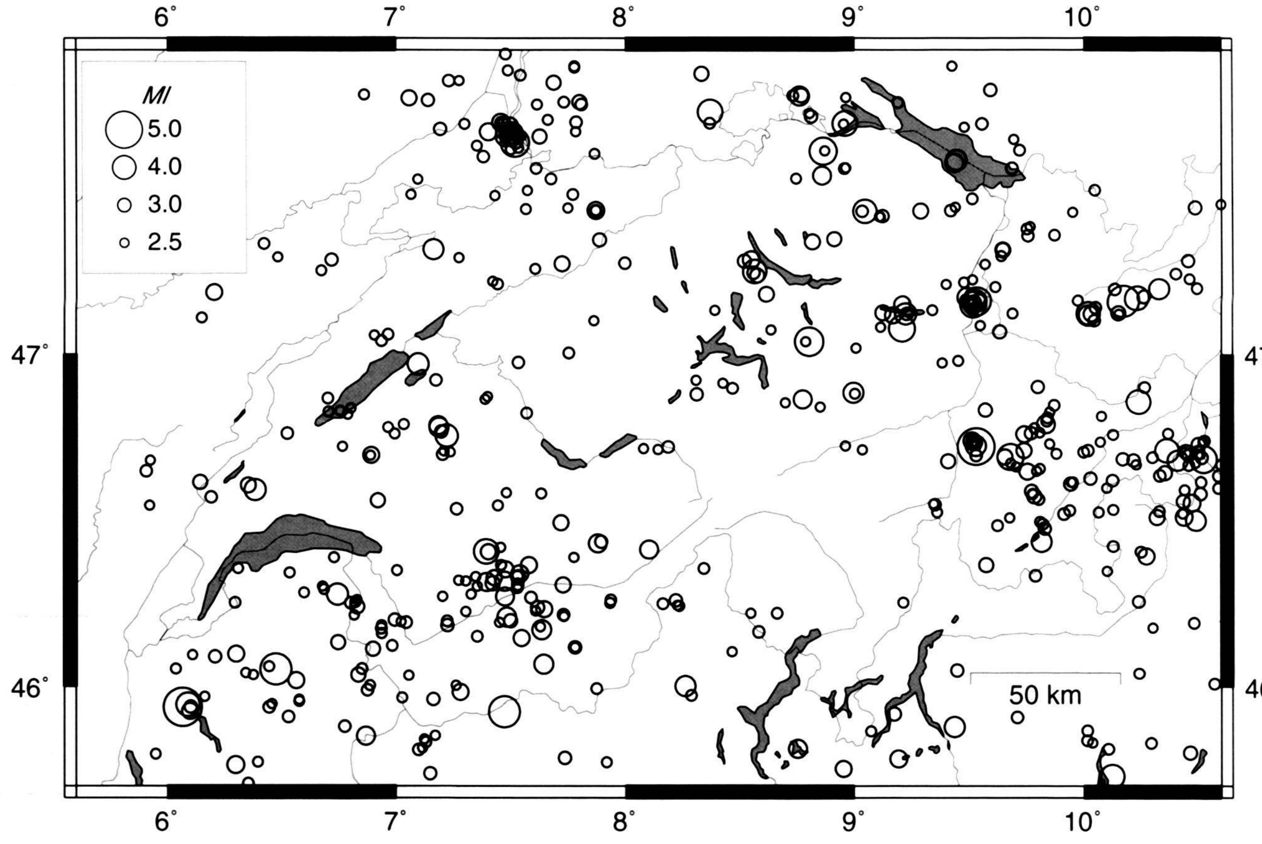

Fig. 8. Epicenters of earthquakes with Magnitudes $M_L \geq 2.5$, during the period 1975–1997.

son, VS, at a distance of about 25 km (Fig. 7), one can clearly identify a first low-frequency phase, followed 1.5 minutes later by a second phase with higher frequencies. These two distinct phases in the signals are presumably associated with the avalanche first hitting the relatively flat part of the Brenva Glacier at the foot of the mountain and then later continuing down the steeper lower part of the glacier towards the valley floor.

Aiguille du Petit Dru

In the middle of the night at 01:23 local time of Sept. 18th, another rock avalanche in the Montblanc massif broke loose from the west face of the Aguille du Petit Dru. Again the seismic signals associated with this event were recorded by the entire Swiss seismograph network and correspond to an M_L 2.4 earthquake. Ten days later, on Sept. 28th, 17:52 local time, a second smaller rock avalanche occurred in the same location and generated signals corresponding to an M_L 1.6 event.

Zuetribistock

Already in 1996, several massive landslides broke loose from the southeast face of the Zuetribistock, south of Linthal, GL, and buried part of the Sandalp under tens of meters of debris. The largest of these events produced seismic signals equivalent to a magnitude M_L 2.8 (Baer et al. 1997). In 1997, the mountain continued to discharge rock avalanches of various sizes. The seismic signals of two of these rock avalanches (1997.09.24 16:49 and 1997.09.27 10:00 local time) were recorded by the seismographs installed near the Linth-Limmern dam 3 km away. However, at all other stations, the signals were two weak to emerge significantly above the background noise, indicating that these events were much smaller than those of the previous year.

Discussion

Figure 8 shows the epicenters of the 551 earthquakes with $M_L \geq 2.5$, which have been recorded in Switzerland and surrounding regions over the period of 1975–1997. The chosen magnitude threshold of 2.5 ensures that the data set is complete for the given period and that the number of unidentified quarry blasts and of badly mislocated epicenters is negligible. These events represent about 10 % of the total number of events detected during that time period in the same area. Averaged over the last 23 years, the earthquakes shown in Figure 8 are equivalent to 24 events with $M_L \geq 2.5$ per year. Thus, with 22 earthquakes having an $M_L \geq 2.5$, the seismic activity in 1997 was close to normal in terms of number of events. However, without a single event with $M_L > 4$ and only one having an $M_L > 3.5$, the seismicity was below average in terms of magnitudes.

In agreement with longterm observations, most of the earthquakes occurred in the Valais and in Graubünden. Particularly noteworthy is the concentration of earthquakes, including two $M_L > 3$ events, in the area between the Ofenpass, GR, and the upper part of the Valtellina, Italy, which was unusually quiet during 1996 (Baer et al. 1997). Unfortunately, due to the unavailability of data from stations south of the border, the epicentral locations are poorly constrained and the focal mechanisms in that region are unknown.

Both the lower-crustal seismicity below the northern Alpine foreland as well as the lack of seismicity deeper than about 15 km below the Alpine mountain chain confirm the focal depth distribution documented in previous studies (Deichmann & Baer 1990; Deichmann 1992a). The Lötschental earthquake provides, at present, the only known focal mechanism in the Aar Massif. Thus, it is not yet possible to draw any general conclusions about the style of deformation in that region. However, the three focal mechanisms in northern Switzerland presented in this report, are typical of the ENE-WSW oriented extension common to all earthquakes observed below the northern Alpine foreland (Pavoni 1987; Deichmann 1990; Deichmann 1992b; Baer et al. 1997).

Acknowledgements

Monitoring the seismicity in a small country is not possible without international cooperation. We thank all individuals who kindly responded to our requests for information and data: W. Brüstle, S. Mellert and S. Stange of the Landeserdbebendienst in Freiburg, M. Cattaneo and E. Eva of the University of Genova, J. Fréchet and F. Thouvenot of the Observatoire de Grenoble, and B. Massinon and F. Schindele of the Laboratoire de Détection et Géophysique in Bruyères-le-Châtel. We are also very grateful to our colleagues in the electronics lab, C. Bärlocher, M. Grieder and P. Zweifel, for their relentless efforts in ensuring the continuous reliability of the data acquisition systems and to A. Blanchard for the compilation of the macroseismic data. M. Funk, VAW-ETHZ, provided the information regarding the rock avalanches in the Mont Blanc area. We also acknowledge financial support from the Nationale Genossenschaft für die Lagerung radioaktiver Abfälle, Nagra, for the operation of the stations in northern and central Switzerland, as well as from the Verband Schweizerischer Elektrizitätswerke, VSE, for the instrumentation of the dam sites.

REFERENCES

BAER, M. 1990: The seismic station network of the Swiss Seismological Service. In: I. Workshop on: MEDNET, the Broad-Band Seismic Network for the Mediterranean (Ed. by E. BOSCHI, D. GIARDINI and A. MORELLI). Istituto Nazionale Geofisica, Roma, 345–350.

BAER, M. & KRADOLFER, U. 1987: An automatic phase picker for local and teleseismic events. Bull. Seis. Soc. Am. 77, 1437–1445.

BAER, M., DEICHMANN, N., FAH, D., KRADOLFER, U., MAYER-ROSA, D., RUTTENER, E., SCHLER, T., SELLAMI S., & SMIT, P. 1997: Earthquakes in Switzerland and surrounding regions during 1996. Eclogae geol. Helv. 90/3, 557–567.

CONSOLE, R. & DI GIOVAMBATTISTA, R. 1987: Local earthquake relative location by digital records. Phys. Earth. Planet. Inter. 47, 43–49.

DEICHMANN, N. 1987: Focal depths of earthquakes in northern Switzerland. Annales Geophysicae 5B, 395–402.

– 1990: Seismizität der Nordschweiz 1987–1989, und Auswertungen der Erdbebenserien von Günsberg, Läufelfingen und Zeglingen. NTB 90–46, NAGRA, Baden.

– 1992a: Structural and rheological implications of lower-crustal earthquakes below northern Switzerland. Phys. Earth Planet. Inter. 69, 270–280.

– 1992b: Recent seismicity of the northern Alpine foreland of Switzerland. Eclogae geol. Helv. 85/3, 701–705.

DEICHMANN, N. & BAER, M. 1990: Earthquake focal depths below the Alps and northern Alpine foreland of Switzerland. In: The European Geotraverse: Integrative Studies. (Ed. by R. FREEMAN, P. GIESE and ST. MUELLER). European Science Foundation, Strasbourg, France, 277–288.

DEICHMANN, N. & GARCIA-FERNANDEZ 1992: Rupture geometry from high-precision relative hypocenter locations of microearthquake clusters. Geophys. J. Int. 110, 501–517.

DEICHMANN, N. & RYBACH, L. 1989: Earthquakes and temperatures in the lower crust below the northern Alpine foreland of Switzerland. In: Properties and Processes of the Lower Crust. (Ed. by R. F. MEREU, ST. MUELLER & D. FOUNTAIN). Am. Geophys. Union, Geophysical Monograph 51, IUGG Vol. 6, 197–213.

EVA, E., PASTORE, S. & DEICHMANN, N. 1998: Evidence for ongoing extensional deformation in the western Swiss Alps and thrust-faulting in the southwestern Alpine foreland. Journal of Geodynamics 26/1, 27–43.

KEUSEN, H.R. 1997: Courmayeur/Brenva, éboulement du 18 janvier 1997, rapport géologique. Geotest S.A., Zollikofen, 18 pp.

KRADOLFER, U. & MAYER-ROSA, D. 1988: Attenuation of seismic waves in Switzerland. In: Recent seismological investigations in Europe. Proceedings of the XIX General Assembly of the ESC. Moscow, October 1–6, 1984, 481–488.

LEE, W. H. K. & LAHR, J. C. 1972: HYPO-71 a computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes. U.S. Geol. Surv., Open-File Rep.

MAURER, H. & ANSORGE, J. 1992: Crustal structure beneath the northern margin of the Swiss Alps. Tectonophysics 207, 165–181.

MAURER, H. & KRADOLFER, U. 1996: Hypocentral parameters and velocity estimation in the western Swiss Alps by simultaneous inversion of P- and S-wave data. Bull. Seis. Soc. Am. 86, 32–41.

PAVONI, N. 1977: Erdbeben im Gebiet der Schweiz. Eclogae geol. Helv. 70/2, 351–370.

– 1987: Zur Seismotektonik der Nordschweiz. Eclogae geol. Helv. 80/2, 461–472.

PAVONI, N. & ROTH, P. 1990: Seismicity and seismotectonics of the Swiss Alps. Results of microearthquake investigations 1983–1988. In: Deep Structure of the Alps. (Ed. by F. ROURE, P. HEITZMANN & R. POLINO). Mém. Soc. geol. France, N. S., 156, 129–134.

PAVONI, N., MAURER, H., ROTH, P., DEICHMANN, N. 1997: Seismicity and seismotectonics of the Swiss Alps. In: Deep structure of the Swiss Alps, results of NRP 20, Birkhäuser, Basel, 241–250.

PFISTER, M. 1990: Gemeinsame Auswertung von Erdbeben-, Refraktions- und Reflexionsdaten in der Nordschweiz. Diploma thesis, Institute of Geophysics, ETH-Zürich.

RÜTTENER, E. 1995: Earthquake hazard estimation for Switzerland. Matér. Géol. Suisse, Geophys. Nr. 29, Schweizerische Geophysikalische Kommission, ETH-Zürich, 106 pp.

RÜTTENER, E., EOGOZCUE, J., MAYER-ROSA, D. & MUELLER, S. 1996: Bayesian estimation of seismic hazard for two sites in Switzerland. Natural Hazards 14, 165–178.

SÄGESSER & MAYER-ROSA 1978: Erdbebengefährdung in der Schweiz. Schweizerische Bauzeitung 78/7, 3–18.

SMIT, P. 1998a: The Swiss National Strong Motion Network – Achievements and prospects. Proc. 11th Conference Earthquake Engineering, 6.–11. September 1998, Paris.

– 1998b: Swiss National Strong Motion Network: Strong motion bulletin, October 1996 – May 1998. Publ. Series of the Swiss Seismological Service, Nr. 111, ETH-Zürich.

WALDHAUSER, F. 1996: A parametrized three-dimensional Alpine crustal model and its application to teleseismic wavefront scattering. Ph.D. Thesis Nr. 11940, ETH-Zürich, 137 pp.

YAN, Q. Z. & MECHIE, J. 1989: A fine structural section through the crust and lower lithosphere along the axial region of the Alps. Geophys. J. Int. 98, 465–488.

YE, S., ANSORGE, J., KISSLING, E. & MUELLER, S. 1995: Crustal structure beneath the eastern Swiss Alps derived from seismic refraction data. Tectonophysics 242, 199–221.

Manuscript received June 4, 1998