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Earthquakes in Switzerland and surrounding regions during 1998

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Key Words: Earthquakes, landslides, focal mechanisms, Switzerland

This article is dedicated to our colleague Dr. Dieter Mayer-Rosa, who, in 1998, retired after 26 years of activity as head of the Swiss Seismological Service.

ABSTRACT

This report of the Swiss Seismological Service summarizes the seismic activity in Switzerland and surrounding regions during 1998. During this period, 226 earthquakes were detected and located in the region under consideration. In addition, 54 quarry blasts and 3 rock avalanches were identified. With only 18 events with $M_L \geq 2.5$ and with only a single event reaching $M_L = 3.6$, the seismic activity in 1998 was below the average over the last 24 years. 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. Noteworthy are the two earthquake swarms near Walenstadt, SG, and Grimentz, VS, that together account for three of the five events with $M_L > 3$ and for about 20% of the total seismic activity observed in 1998.

ZUSAMMENFASSUNG

Dieser Bericht des Schweizerischen Erdbebendienstes stellt eine Zusammenfassung der im Vorjahr in der Schweiz und Umgebung aufgetretenen Erdbeben dar. Im Jahr 1998 wurden im erwähnten Gebiet 226 Erdbeben erfasst und lokalisiert. Zusätzlich wurden 54 Sprengungen und 3 Felsstürze aufgezeichnet. Mit lediglich 18 Beben mit Magnituden $M_L \geq 2.5$ und keinem Beben mit $M_L >$ 3.6, war die seismische Aktivität im Jahr 1998 gering. 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. Beachtenswert sind die zwei Erdbebenserien von Walenstadt, SG und Grimentz, VS, die zusammen für drei der fünf Ereignisse mit $M_L > 3$ sowie für rund 20% aller im Jahr 1998 registrierten Beben aufkommen.

RESUME

Le présent rapport du Service Sismologique Suisse résume l'activité sismique de l'année écoulée, en Suisse et dans les régions limitrophes. En 1998, 226 tremblements de terre ont été détectés et localisés dans la région considérée. De plus, 54 événements ont été identifiés comme des tirs de carrière et 3 comme des éboulements. Avec seulement 18 événements de magnitude $M_L \geq$ 2.5 et sans un seul événements de $M_L > 3.6$, l'activité sismique de 1998 se situe en dessous de la moyenne sur les 24 dernières années. Comme par le passé, la plupart des tremblements de terre de sont produits dans le Valais ainsi que dans les Grisons, dans les 15 premiers kilomètres de la croûte. Deux essaims notables ont eu lieu près de Walenstadt, SG, et Grimentz, VS. Trois des cinq événements de $M_L > 3$ et environ 20% du nombre total des seismes observés en 1998 correspondents à ces deux essaims.

Introduction

The present contribution of the Swiss Seismological Service is the third article in the new series of annual reports summarizing the seismic activity in Switzerland and surrounding regions (Baer et al. 1997, Deichmann et al. 1998).

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 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 et al., 1996; Pavoni et al., 1997).

Seismic stations in operation during 1998

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

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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 until May 1998 by the strongmotion network is documented separately (Smit, 1998b) and an additional report for the following time period is in preparation.

The configuration of the national high-gain network is undergoing a fundamental change since 1997. The analog data transmission technology of the mid-seventies, when the national telemetry network was first set up, poses severe restrictions on the dynamic range and frequency bandwidth of the recorded seismic data. With the advent of modern digital technology and broadband sensors, these restrictions can now be overcome. As a consequence, the Swiss Seismological Service has begun to modernize its entire network, which entails replacing most of the existing short-period sensors by three-component STS-2 broad-band instruments. The signals, which are digitized at the remote recording sites, are transmitted over a nationwide INTRANET to the processing center in Zürich, where a Nanometrics NAQS32 data acquisition system has been installed. This system is designed to store ten days of seismic data and state of health information in a circular buffer. Each 24 bit digitizer is synchronized with GPS time and samples the seismic signals at 120 Hz, thus making use of the full frequency range of the STS-2 sensors up to 50 Hz. The two hour solid state data buffer of the digitizers together with the retransmit functionality of the NAQS32 system ensures high completeness of the data.

In the course of these changes, a few of the old sites will have to be abandoned in favour of more suitable locations. This modernization is expected to be completed by the middle of the year 2000. During Autumn of 1998, five of the new stations have been put into operation: AIGLE, BNALP, BOURR, VDL and ZUR. The first three are new sites, whereas VDL is operating in parallel to the old short-period instrument and at station ZUR the existing STS-1 broad-band sensor has been supplemented by an STS-2 sensor, whose signals are now available on-line. Station BNALP replaces the two analog magnetic tape recorders installed as temporary stations ZFLI and ZEHW in central Switzerland in the context of monitoring the local seismic activity in the neighborhood of the proposed site for low-level nuclear waste disposal. A complete list of the seismic stations in operation at the end of 1998 and an updated station map are given in Table 1 and Figure 1.

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, Observatoire de Grenoble, France, from the Laboratoire de Dé-

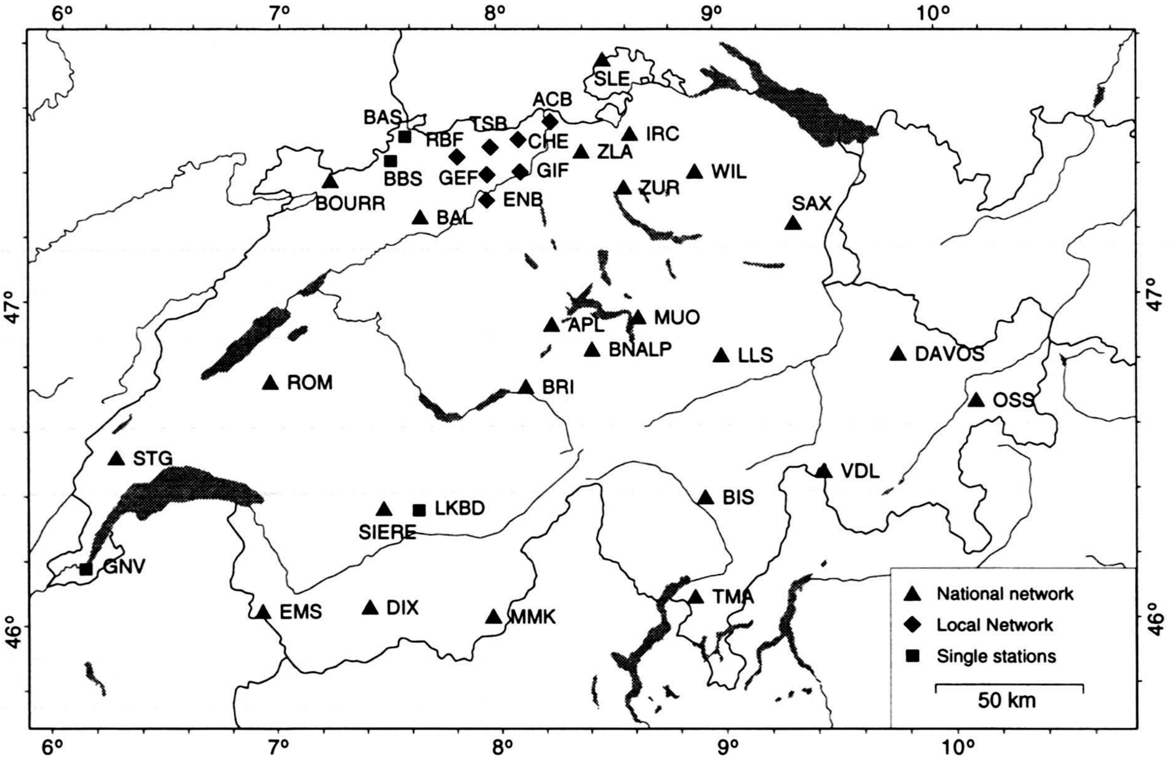

Fig. 1. Seismograph stations operational at the end of 1998.

Tab. 1: Seismograph stations operational at the end of 1998. Instrument types: SP = short period, BB = broad band, 1 = vertical component only, 3 = vertical and horizontal components, 4 = additional low-gain vertical component channel, 6 = all three components recorded at high and low gain.

National telemetry network recorded in Zürich			
Code	Station name	Type	Remarks
AIGLE	Aigle	BB-3	
APL	Alpnach	SP-4	
BAL	Balsthal	SP-4	
BNALP	Bannalpsee	BB-3	
BIS	Biasca	SP-3	
BOURR	Bourrignon	BB-3	
BRI	Brienz	SP-4	
DAVOS	Davos	SP-4	
DIX	Grande Dixence	SP-1	dam site
EMS	Emosson	SP-1	dam site
IRC	Irchel	SP-1	
LLS	Linth-Limmern	SP-3	dam site
MMK	Mattmark	SP-3	dam site
MUO	Muotathal	SP-1	
OSS	Ova Spin	SP-1	dam site
ROM	Romont	SP-4	
SAX	Säntis	SP-3	
SIERE	Sierre	SP-4	
SLE	Schleitheim	SP-3	
STG	Saint Georges	SP-3	
TMA	Monte Tamaro	SP-3	
VDL	Valle di Lei	SP-1, BB-3	dam site
WIL	Wil	SP-4	
ZLA	Zürich-Lägern	SP-1	
ZUR	Zürich-Degenried	BB-3	
Local telemetry network recorded at station CHE			
Code	Station name	Type	Remarks
ACB	Acheberg	SP-3	
CHE	Cheisacher	SP-6	
ENB	Engelberg	SP-1	
GEF	Geissflue	SP-1	
GIF	Gisliflue	SP-1	
RBF	Rickenbacherflue	SP-1	
TSB	Tiersteinberg	SP-1	
Single stations			
Code	Station name	Type	Remarks
BAS	Basel	SP-3	digital
BBS	Basel-Blauen	SP-1	recorded by LED
GNV	Geneva	SP-1	paper records
LKBD	Leukerbad	SP-3	digital
ZUR	Zürich-Degenried	VBB-3	digital VBB

tection 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 either with a modified version of the widely used HYPO-71 algorithm originally developed by Lee & Lahr (1972). In addition, a grid search algorithm has been developed, which can use any earth model for which the travel times of seismic waves can be computed. Whereas HYPO-71 is usable for local events only, the grid search algorithm also allows the location of teleseismic events. 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 are 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 is based on the results of Waldhauser (1996) and Waldhauser et al. (1998), thus accounting realistically for the crustal heterogeneity. The same ray-tracing technique is 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 analog signals are clipped, the final magnitude is based only on the stations with low-gain channels.

Seismic activity during 1998

Overview

During 1998, the Swiss Seismological Service detected and located 226 earthquakes in the region shown in Figure 2. 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 several landslides or rock avalanches.

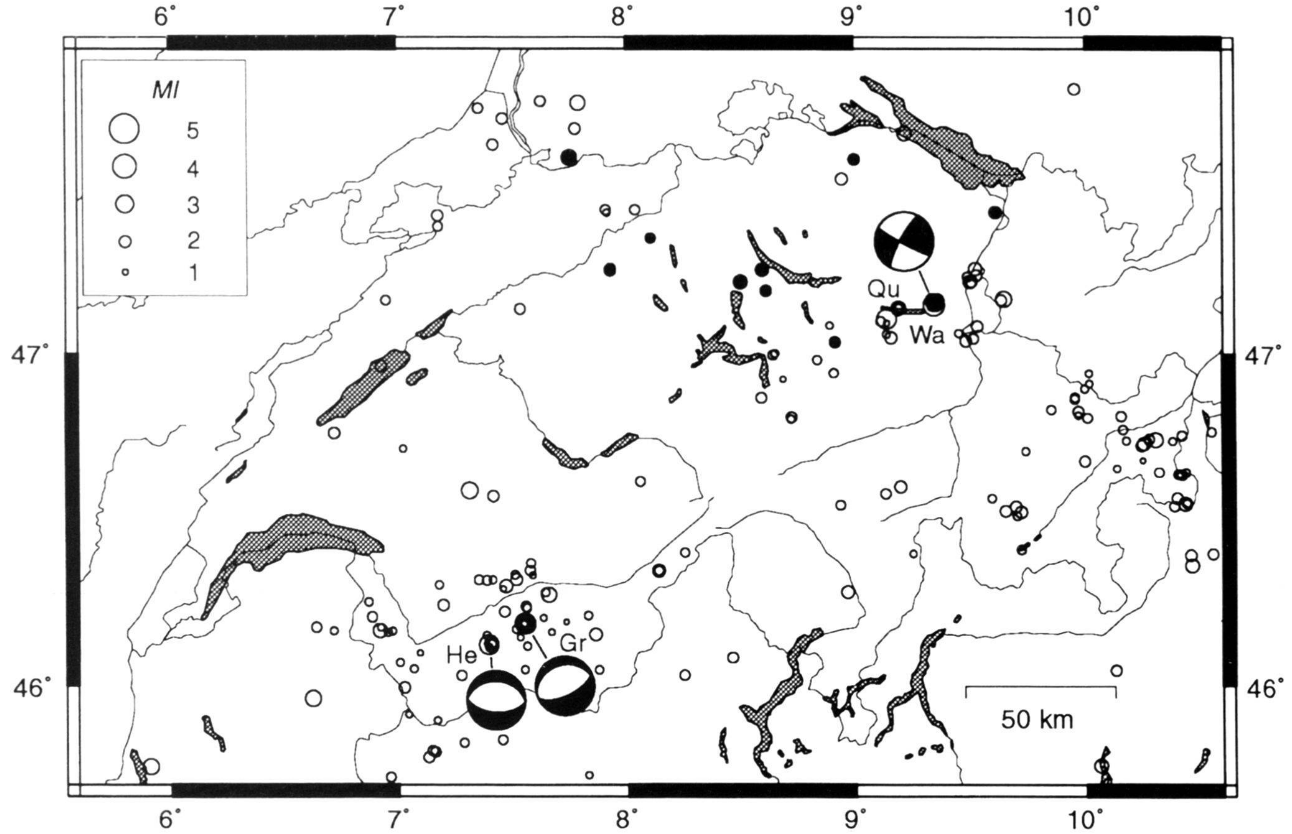

Fig. 2. Epicenters and focal mechanisms of earthquakes recorded by the Swiss Seismological Service during 1998. The black symbols correspond to events with focal depths ≥ 20 km. The focal depths of all other events are < 15 km. Epicenters of earthquakes mentioned in the text are labeled: He = Val d'Hérémence, Gr = Grimentz, Qu = Quinten, Wa = Walenstadt.

Location	Date & Time [UT]	Lat. [°N]	Lon. [°E]	X / Y [km]	Depth [km]	Mag. [M_L]
Haute Savoie, F	1998.03.03 13:52:36	45.755	5.911	481/ 68	10	2.7
Vorarlberg, A	1998.03.20 03:11:42	47.161	9.648	767/226	4	2.7
Kerenzerberg, GL	1998.03.23 13:07:19	47.102	9.137	729/218	5	3.3
Jaunpass, FR	1998.03.30 20:48:60	46.590	7.311	590/160	12	2.8
Walenstadt, SG	1998.04.21 02:30:56	47.143	9.344	744/223	10	3.6
Dinkelberg, D	1998.04.25 04:17:21	47.741	7.794	627/288	10	2.5
S'Charl, GR	1998.04.29 03:40:18	46.742	10.306	819/181	10	2.5
Val d'Hérémence, VS	1998.05.07 17:16:43	46.126	7.393	596/108	6	3.3
Walenstadt, SG	1998.05.14 00:25:20	47.150	9.347	745/224	10	2.6
Oberems, VS	1998.05.15 17:33:35	46.277	7.657	617/125	3	2.5
Walenstadt, SG	1998.07.26 12:46:39	47.152	9.351	745/224	10	2.5
Walenstadt, SG	1998.08.21 04:19:56	47.154	9.354	745/224	10	2.7
Walenstadt, SG	1998.09.02 12:51:33	47.150	9.347	745/224	10	2.9
Grimentz, VS	1998.12.07 13:46:26	46.189	7.556	609/115	4	3.3
Col de Balme, F	1998.12.09 08:56:02	45.963	6.622	537/ 90	5	2.7
Grimentz, VS	1998.12.09 13:49:47	46.187	7.559	609/115	4	2.5
Grimentz, VS	1998.12.09 22:08:14	46.191	7.552	609/115	4	3.4
Rheinfelden, D	1998.12.17 19:36:24	47.580	7.755	624/270	25	2.6

Tab. 2: Earthquakes with $M_L \geq 2.5$. The focal depths of the earthquakes of Walenstadt, Val d'Hérémence and Grimentz are based on 2-D rey-tracing. The depth of the Rheinfelden event is well constrained by stations close to the epicenter. All other focal depths are poorly contrained.

Routinely calculated focal depths range between 0 and 31 km, but only 11 hypocenters are located at depths greater than 14 km. One of these deeper events (1998.04.26 12.43, M_L = 1.8) is located 20 km below the Klöntal at the northern edge of the Helveticum, but its location is poorly constrained. The other 10 deep events are all located at depths of at least 20 km in the lower crust beneath the Jura Mountains and Molasse Basin of northern Switzerland. The hypocentral locations of the earthquakes observed in 1998 thus confirm once again the focal depth distribution documented in previous studies (Deichmann & Baer, 1990; Deichmann, 1992a).

Magnitude values of the events recorded in 1998 range be-

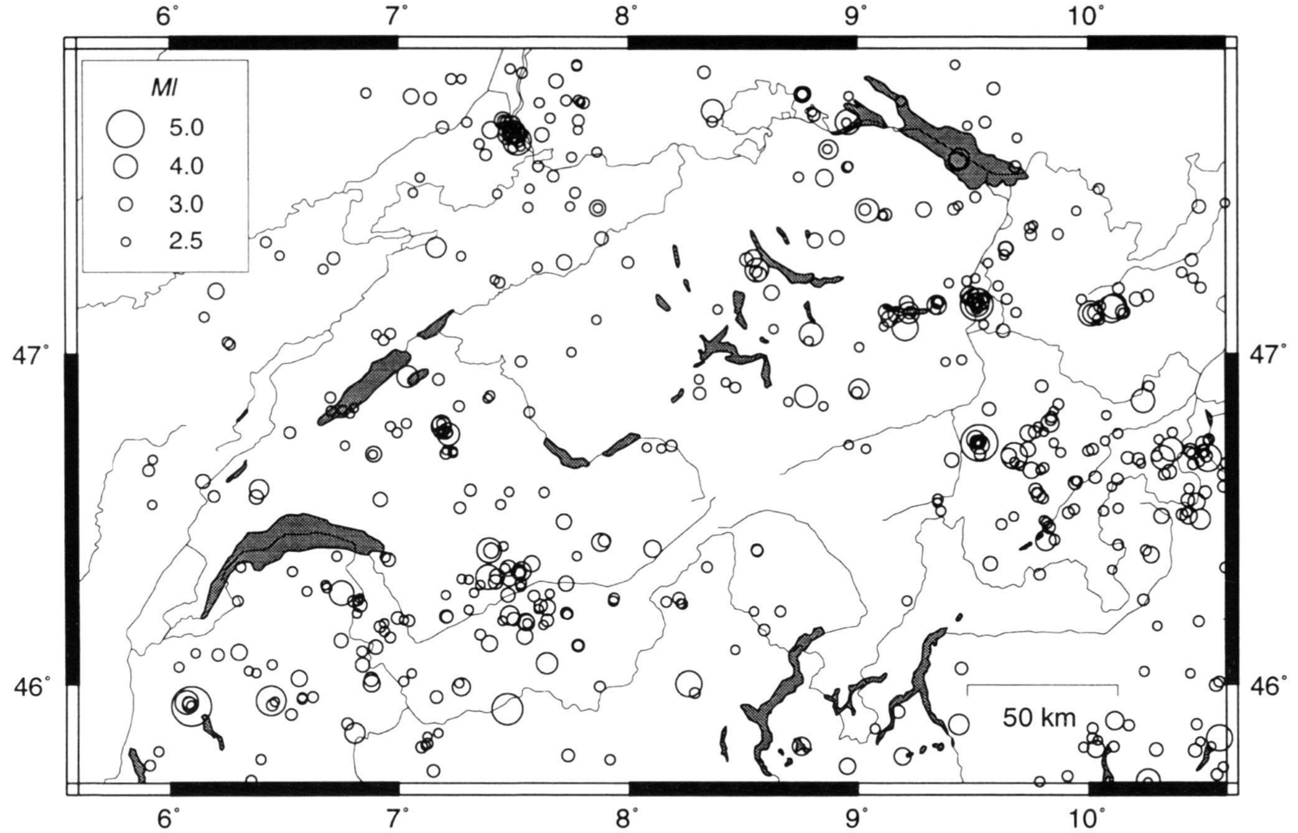

Fig. 3. Epicenters of earthquakes with Magnitudes $M_L \geq 2.5$, during the period 1975–1998.

Location	Mag. $[M_L]$	Date & Time [UT]	Depth [km]	P-Axis Az.	P-Axis Dip	T-Axis Az.	T-Axis Dip
Walenstadt	3.6	1998.04.21 02:30	10	164	4	73	13
Val d'Hérémence	3.3	1998.05.07 17:16	6	2	80	182	10
Grimentz	3.4	1998.12.09 22:08	4	323	72	159	17

Tab. 3: Focal mechanism parameters.

tween $M_L = 0.8$ and 3.6. The events with $M_L \geq 2.5$ are listed in Table 2. Where available, the epicentral coordinates and focal depths given in Table 2 are based on the results that include additional data from foreign networks and on 2-D ray-tracing. The locations of all earthquakes with $M_L \geq 2.5$ recorded in Switzerland and surroundings since 1975 are shown on the epicenter map in Figure 3. The fault-plane solutions with first-motion directions are shown in Figure 4 and the corresponding parameters are listed in Table 3. In what follows, we present the highlights of the seismic activity observed during 1998 as well as a brief discussion of the recorded landslides.

Significant earthquakes of 1998

Walensee

Already in 1997, the Walensee region was the site of enhanced seismic activity with a series of events that included an M_L = 3.8 earthquake. As illustrated in Figure 5, these earthquakes

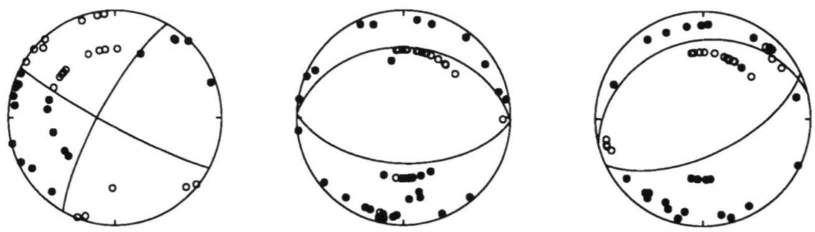

Fig. 4. Fault-plane solutions (lower hemisphere, equal area projection) of selected earthquakes. Solid circles, compressive first motion (up) and empty circles, dilatational first motion (down).

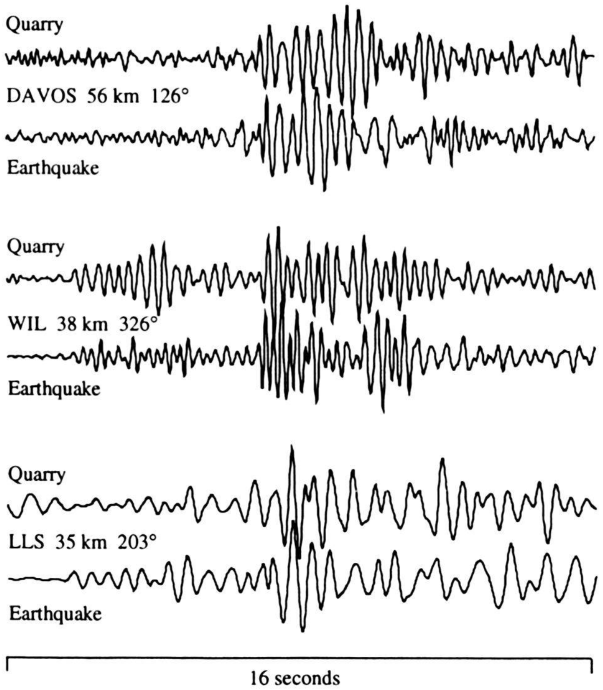

Fig. 5. Pairs of seismograms of the explosion of 1997.02.24 in the quarry of Quinten (upper trace) and the M_L 1.8 earthquake of 1997.11.18 recorded at stations DAVOS, WIL and LLS (with epicentral distance and azimuth from the quarry to each station). The signals of DAVOS and WIL are horizontal component records, whereas LLS is a vertical component record. 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 close match shows that the earthquake source must be located in the immediate vicinity of the quarry. (Reproduced from Deichmann et al. 1998)

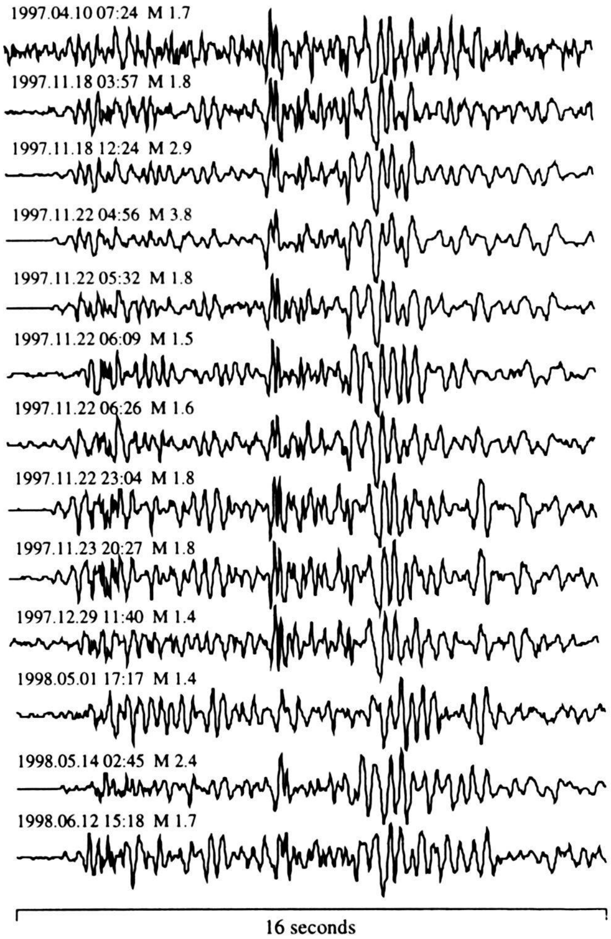

Fig. 6. Seismograms of the 1997 and 1998 Walensee events recorded at station WIL (vertical component).

must have been located at a shallow depth below the quarry of Quinten (Deichmann et al. 1998). Of all the earthquakes that occurred in the area of the Walensee in 1998, three produced signals that are sufficiently similar to those observed in 1997 (Fig. 6) to conclude that the same source continues to remain active.

However, in 1998, the two strongest events occurred in the Kerenzerberg area, at the SW end of the lake (1998.03.23 14:07, local time, with M_L = 3.3) and near Walenstadt, at the NE end (1998.04.21 04:30, local time, with M_L = 3.6). While the Kerenzerberg event was followed three months later by two possible aftershocks, the Walenstadt earthquake was part of a series of 25 events lasting from the end of March to the end of December. The irregular distribution in time of both the number of events and their magnitudes shown in Figure 7 is typical of swarm-like behaviour as opposed to a classical mainshock-aftershock sequence. Moreover, judging from the routinely computed locations as well as from the high degree of signal similarity between the individual events, the Walenstadt series must form a tight cluster of nearly colocated hypocenters. With the closest station at an epicentral distance

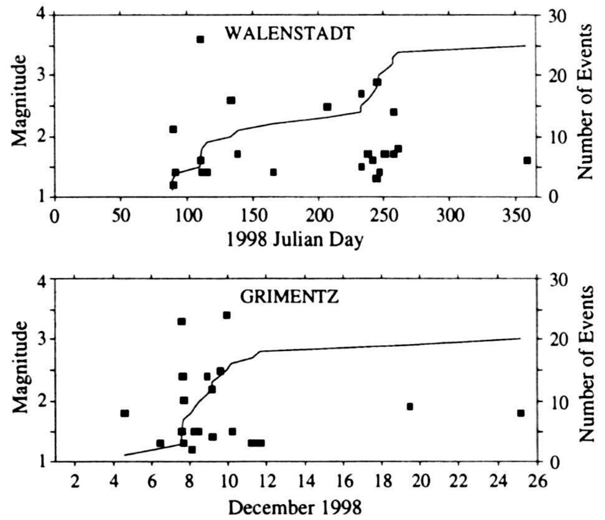

Fig. 7. Magnitude (black squares) and cumulative number of events (continuous line) as a function of time for the Walenstadt and Grimentz earthquake swarms

of 12 km and clear PmP and Pn arrivals at several stations, the focal depth of 10 km is sufficiently well constrained to conclude that these earthquakes occurred in the basement rather than in the thick sedimentary cover in this region. The fault-plane solution corresponds to a nearly pure strike-slip mechanism with a NNW-SSE striking P-axis (Fig. 4).

Val d'Hérémence

The epicenter of the Val d'Hérémence earthquake, which occurred on May 7 at 19:17 local time, was located 5 km N of the Grande Dixence Dam. With a magnitude $M_L = 3.4$ and a focal depth of only 5–6 km, it triggered both the accelerometers in the dam and the free-field accelerometers in Sion. It was followed by five aftershocks with magnitudes decreasing from $M_L = 2.2$ to $M_L = 0.9$. The first three aftershocks occurred within a day after the mainshock, while the last two occurred five and twelve days later. The focal mechanism corresponds to a pure normal fault with a N-S trending T-Axis (Fig. 4).

Grimentz

In December, a similar swarm-like activity to the one observed north of Walenstadt occurred also near the village of Grimentz, at the southern end of Val d'Anniviers. With a total of 20 events and maximum magnitudes reaching 3.3 and 3.4, the activity in the Grimentz series is comparable to that of the Walenstadt swarm (Fig. 7). However, practically the whole Grimentz sequence took, place within a single week, while the one near Walenstadt continued for more than half a year. Again, both the routinely computed locations and the similarity of the observed signals are evidence for a tightly clustered hypocentral distribution. The focal depth obtained from 2-D raytracing is 4 km. Such a relatively shallow focal depth is also suggested by the fact that the two main events were clearly felt by the population (epicentral intensity = IV), despite their moderate magnitudes. The focal mechanism of the strongest event and probably also of the most of the other events in this earthquake sequence corresponds to an almost pure normal fault with a NNW-SSE oriented T-axis (Fig. 4).

Landslides

Zuetribistock

Several massive Landslides broke loose from the southeast face of Zuetribistock, south of Linthal, GL, in 1996 and buried part of Sandalp under tens of meters of debris. In the following year, the mountain continued to discharge rock avalanches of various sizes. This activity continued in 1998 with several landslides and numerous smaller rock avalanches. As in the past, some of these events produced seismic signals comparable to small earthquakes: the landslides of March 31st at 09:43 and 11:58 local time were equivalent to earthquakes of magnitude M_L 1.7 and 1.8, whereas the event of May 10th at 06:43 attained M_L 1.5. Additional rock avalanches on May 10th (one at 06:39 and three between 13:46 and 13:49 local time) were recorded mainly by the seismographs installed at the Linth-Limmern dam 3 km away. Thus all of these events were significantly smaller than the main landslide from Zuetribistock in 1996, which was equivalent to a magnitude M_L 2.8 earthquake (Baer et al. 1997).

Discussion

Figure 3 shows the epicenters of the earthquakes with $M_L \geq 2.5$, which have been recorded in Switzerland and surrounding regions over the period of 1975–1998. 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 abut 10% of the total number of events detected during that time period in the same area. Averaged over the last 24 years, the earthquakes shown in Figure 3 are equivalent to 24 events with $M_L \geq 2.5$ and at least one event with $M_L \geq 4$ per year. The strongest events in this time span are the two magnitude 5 events of 1990 near Vaz, Graubünden, and of 1996 near Annecy, France. Thus, with only 18 earthquakes having an $M_L \geq 2.5$ and without a single event with $M_L \geq 3.6$, the seismic activity in 1998 was below average both in terms of number of events and in terms of magnitude.

In agreement with longterm observations, most of the earthquakes occurred in the Valais and in Graubünden. In addition, however, the year 1998 saw a remarkable concentration of activity in the area of the Walensee and in the Rhine Valley bordering on Liechtenstein. It is also noteworthy that 20% of the seismic events recorded in 1998 occurred in the two swarm-like earthquake clusters of Walenstadt and Grimentz.

The orientation of the P- and T-axes of the strike-slip focal mechanism of the Walenstadt series is in general agreement with other known focal mechanisms in this area (Roth et al. 1992) and the normal faulting mechanisms of the Val d'Hérémence and Grimentz earthquakes are typical for the extensional deformation observed in the Penninic domain of the western Swiss Alps (Maurer et al. 1997; Eva et al. 1998).

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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, B. Rinderknecht, D. Winiger 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. 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.

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Appendix

Figure 8 is Figure 6 of the 1997 report (Deichmann et al. 1998). It shows the results of the analysis of the Läufelfingen swarm of February 21, 1997. It is included again here because of the poor reproduction quality of the original figure.

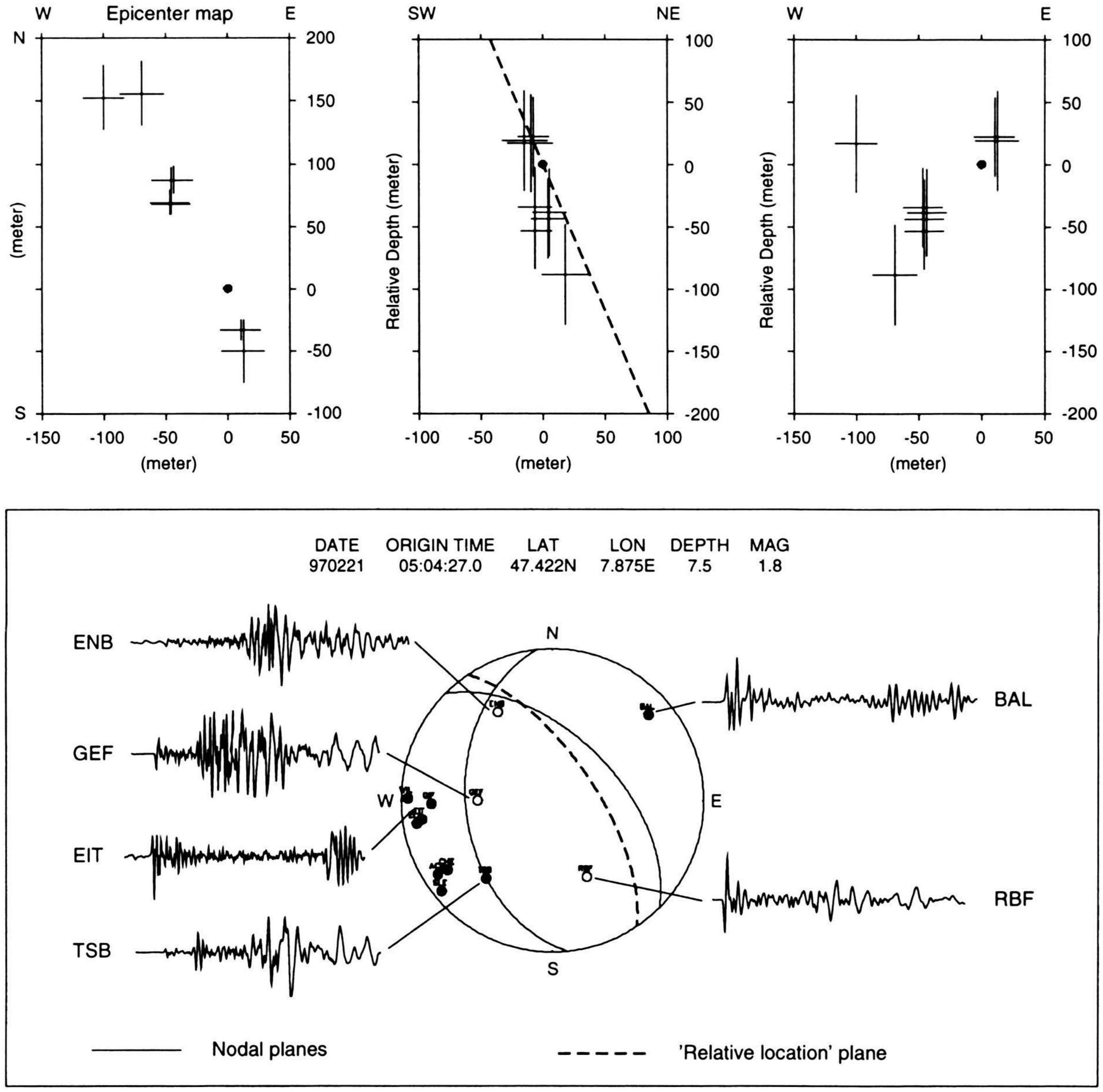

Fig. 8. The Läufelfingen swarm of February 21, 1997: Bottom: fault-plane solution of the best recorded event wih selected seismograms illustrating the dependence of the signal character on the proximity to the nodal planes. Top: locations of the individual events (crosses) relative to the master event (black dot). Left: epicenter map; middle: SW-NE cross-section with trace of the inferred fault plane (dashed curve in the fault-plane solution shown below); right: W-E cross-section. The size of each cross corresponds on one standard deviation of the location.
A detailed discussion of the results can be found in Deichmann et al. (1998).