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Earthquakes in Switzerland and surrounding regions during 2006

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Key words: earthquakes, focal mechanisms, moment tensors, Switzerland

ABSTRACT

This report of the Swiss Seismological Service summarizes the seismic activity in Switzerland and surrounding regions during 2006. During this period, 572 earthquakes and 91 quarry blasts were detected and located in the region under consideration. Of these earthquakes, two occurred in conjunction with the construction of the new Gotthard railway tunnel and 165 were induced artificially by the stimulation of a proposed geothermal reservoir beneath the city of Basel. With 20 events with $M_L \geq 2.5$, five of which were artificially induced, the seismic activity in the year 2006 was far below the average over the previous 31 years. Nevertheless, six events were felt by the public, most prominently the strongest of the induced Basel events (M_L 3.4), which caused some non-structural building damage. Noteworthy are also the two earthquakes near Cortaillod (M_L 3.2), on the shore of Lake Neuchâtel, and in Val Mora (M_L 3.5), between the Engadin and Val Müstair, as well as the 42 aftershocks of the M_L 4.9 Vallorcine earthquake, between Martigny and Chamonix, of September 2005.

ZUSAMMENFASSUNG

Dieser Bericht des Schweizerischen Erdbebendienstes stellt eine Zusammenfassung der im Vorjahr in der Schweiz und Umgebung aufgetretenen Erdbeben dar. Im Jahr 2006 wurden im erwähnten Gebiet 572 Erdbeben sowie 91 Sprengungen erfasst und lokalisiert. Zwei dieser Erdbeben stehen im Zusammenhang mit dem Bau des neuen Gotthard Eisenbahntunnels und 165 Beben wurden durch Wasserinjektion in 5 km Tiefe bei einem Geothermie Projekt in Basel induziert. Mit 20 Beben der Magnitude $M_L \geq 2.5$, wovon 5 künstlich ausgelöst waren, war die seismische Aktivität im Jahr 2006 weit unter dem Durchschnitt der vorhergehenden 31 Jahre. Trotzdem wurden sechs dieser Beben von der Bevölkerung wahrgenommen, ganz besonders das stärkste der induzierten Basler Ereignisse (M_L 3.4), welches einige nicht-strukturelle Gebäudeschäden verursacht hat. Bemerkenswert sind auch die zwei Beben bei Cortaillod (M_L 3.2), am Ufer des Neuenburger Sees, und in der Val Mora (M_L 3.5), zwischen Engadin und Münstertal, sowie die 42 Nachstösse des M_L 4.9 Bebens bei Vallorcine, zwischen Martigny und Chamonix, vom September 2005.

RESUME

Le présent rapport du Service Sismologique Suisse résume l'activité sismique en Suisse et dans les régions limitrophes au cours de l'année 2006. Durant cette période, 572 tremblements de terre et 91 tirs de carrière ont été détectés et localisés dans la région considérée. Parmi ces tremblements de terre, deux sont conséquents à la construction du nouveau tunnel du Gotthard et 165 ont été induits artificiellement par la stimulation d'un réservoir au dessous de la ville de Bâle dans le cadre d'un projet géothermique. Avec seulement 20 événements de magnitude $M_L \geq 2.5$, et dont 5 ont été induits artificiellement, l'activité sismique de l'année 2006 est inférieure à la moyenne de ces 31 années précédentes. Cependant, six événements ont été ressentis par le public et le plus fort (M_L 3.4) a causé des dommages non-structuraux aux constructions. On retient également deux tremblements de terre, l'un près de Cortaillod (M_L 3.2) sur le bord du lac de Neuchâtel et l'autre dans le Val Mora (M_L 3.5) entre l'Engadine et le Val Müstair. Pendant cette année, il y a eu également 42 répliques du tremblement de terre de Vallorcine, entre Martigny et Chamonix, qui avait atteint une magnitude de 4.9 en septembre 2005.

Introduction

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 first 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)*. Since 1996, annual reports sum-

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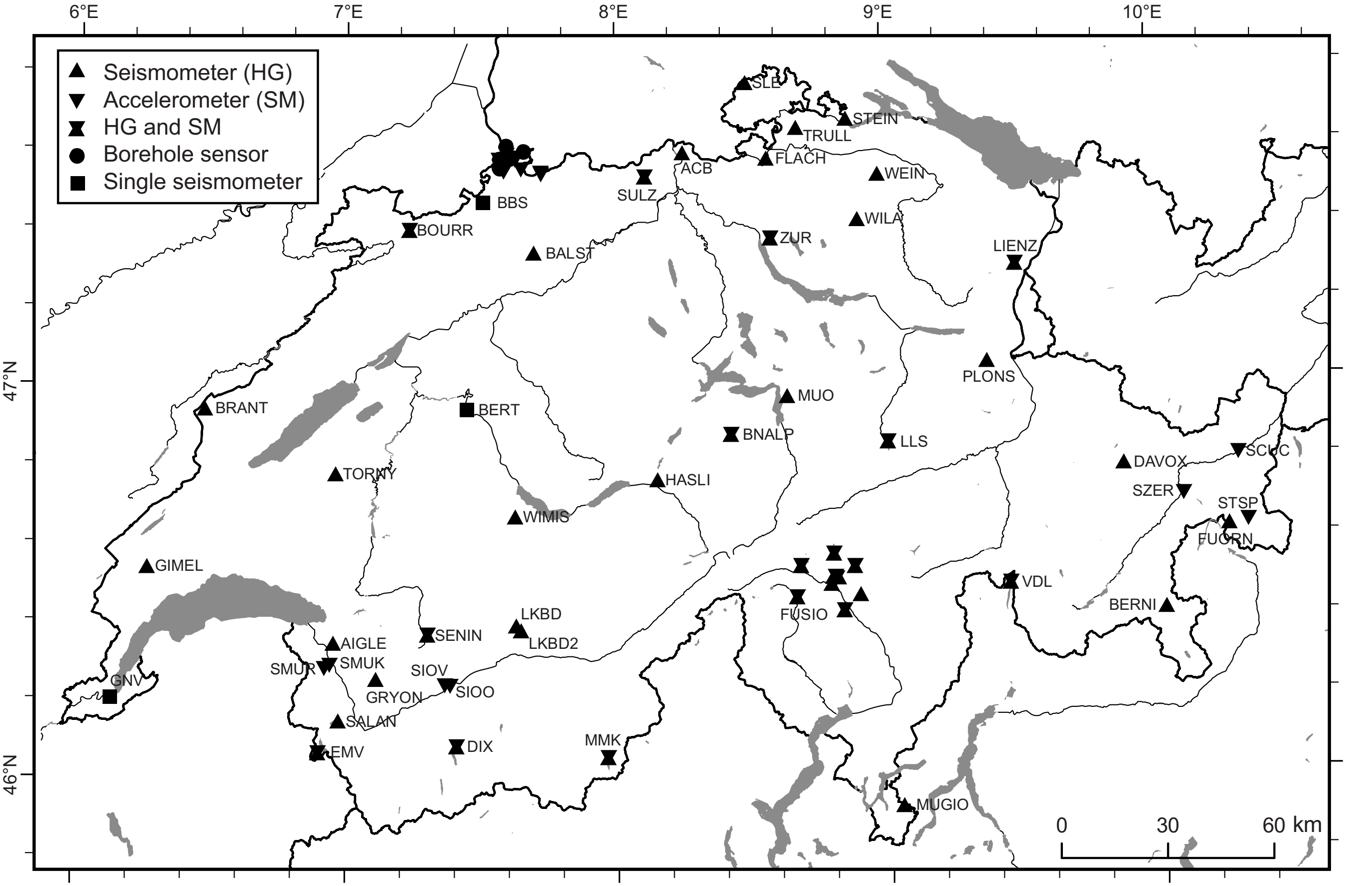

Fig. 1. Seismograph stations in Switzerland operational at the end of 2006. The stations defined as high-gain (HG) are mostly equipped with broad-band or 5 second sensors, whereas the strong-motion stations (SM) are accelerometers.

marizing the seismic activity in Switzerland and surrounding regions have been published in the present form (Baer et al. 1997, 1999, 2001, 2003, 2005; Deichmann et al. 1998, 2000a, 2002, 2004, 2006). In the course of reassessing the seismic hazard in Switzerland, a new uniform earthquake catalog covering both the historical and instrumental periods has been compiled (Fäh et al. 2003). The data in the new Earthquake Catalog of Switzerland (ECOS) are available on line (http://www.seismo.ethz.ch, Swiss Earthquake Catalogs). The new seismic hazard map of Switzerland based on this catalog was officially released in 2004 (Giardini et al. 2004). 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 1990; Pavoni & Roth 1990; Rüttener 1995; Rüttener at al. 1996; Pavoni et al. 1997; Deichmann et al. 2000b; Kastrup et al. 2004).

Seismic stations in operation during 2006

The Swiss Seismological Service operates two separate nationwide seismic networks, a high-gain seismometer network and a low-gain accelerograph network (HG and SM in Figure 1). The former is designed to monitor continuously 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.

Since February 2002, the national high-gain network consists almost entirely of digital data acquisition systems with high dynamic range and with either three-component broadband STS-2 seismometers or Lennartz 5-second sensors ("BB" and "EB" in Table 1). For a detailed description of this data acquisition system, see Baer et al. (2001). Despite the high dynamic range, a magnitude 5 event at a distance of a few km will clip the system. So beginning in 2003, to complement these high-gain signals with strong-motion data that are available in realtime, 12 stations of the broad-band network have been equipped with an additional three-component Kinemetrics EpiSensor accelerometer ("BB, SM" in Table 1).

Initially all the data of the separate strong-motion network were recorded locally and had to be retrieved manually on site or downloaded interactively by telephone. Moreover, these strong-motion instruments have only a limited sensitivity and dynamic range. So in 2006, ten of these strong-motion stations as well as six new sites have been equipped with high-dynamic-range digitizers and with the more sensitive EpiSensor accelerometers ("SM" in Table 1). Moreover, their signals are available in near-realtime, so that they are now also used routinely for determining hypocenter locations.

To monitor with greater precision an ongoing sequence of earthquakes in the immediate vicinity of the southern segment of the new Gotthard railway tunnel that is still under construction, a set of eight stations with short-period seismometers and in part with three-component accelerometers were installed during the late Fall of 2005 in the region between the Lukmanier Pass and the Leventina Valley (Table 2 and Figure 2). In addition, two accelerometers have been installed in the tunnel itself (MFSFA and MFSFB in Table 2). These ten stations are operated under a contract with AlpTransit-Gotthard AG. The signals of seven of these stations are integrated in realtime in the national online network, while the data of one station (LUKA1) is downloaded per telephone, and two stations (CHAT1 and CHAT2) store the data on site.

In the course of 2006 an additional array of seismic sensors was installed in six boreholes at depths between 317 and 2740 m below Basel. This array was designed to monitor the seismicity induced by the injection of large quantities of water at high pressure into a 5 km deep well in the context of a project initiated by Geopower Basel AG, a private/public consortium, to extract geothermal energy. The borehole array is operated by Geothermal Explorers Ltd in Pratteln. The signals of one of these sensors (OTER1 in Table 2 and Figure 2) are transmitted in realtime to the recording center of the Swiss Seismological Service, thus contributing to the event detection. The signals of the other five sensors are retrieved automatically immediately after the detection of an event, so that they are also available for the determination of hypocenter locations. For seismic events of potential or actual concern to the public in Basel it is thereby possible to provide reliable locations and magnitudes within a few minutes after the event.

Data from foreign networks

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 use additional data obtained from the Erdbebendienst des Landesamtes für Geologie, Rohstoffe und Bergbau Baden Württemberg in Freiburg (LED), from the Zentralanstalt für Meteorologie und Geodynamik in Vienna (ZAMG), from the SISMALP array operated by the Laboratoire de Géophysique Interne et Tectonophysique, Observatoire de Grenoble (LGIT), from the Laboratoire de Détection et Géophysique in Bruyères-le-Châtel (LDG), from the RéNaSS array operated by the Ecole et Observatoire des Sciences de la Terre in Strasbourg, from the Istituto Nazionale di Geofisica e Vul-

Table 1. Seismograph stations of the Swiss national network operational at the end of 2006. Instrument type: SP = 1 second, EB = 5 seconds, BB = broad band, SM = accelerometer, 1 = vertical component only, 3 = vertical and horizontal components. Signals of LKBD2 are transmitted via analog telemetry.

National online network recorded in Zürich		
Code	Station name	Type
ACB	Acheberg, AG	EB-3
AIGLE	Aigle, VD	BB-3
BALST	Balsthal, SO	BB-3
BERNI	Bernina, GR	BB-3
BNALP	Bannalpsee, NW	BB-3, SM-3
BOURR	Bourrignon, JU	BB-3, SM-3
BRANT	Les Verrières, NE	BB-3
DAVOX	Davos, GR	BB-3
DIX	Grande Dixence, VS	BB-3, SM-3
EMV	Vieux Emosson, VS	BB-3, SM-3
FLACH	Flach, ZH	EB-3
FUORN	Ofenpass, GR	BB-3
FUSIO	Fusio, TI	BB-3, SM-3
GIMEL	Gimel, VD	BB-3
GRYON	Gryon, VS	EB-3
HASLI	Hasliberg, BE	BB-3
LIENZ	Kamor, SG	BB-3, SM-3
LKBD	Leukerbad, VS	EB-3
LKBD2	Leukerbad, VS	SP-3
LLS	Linth-Limmern, GL	BB-3, SM-3
MMK	Mattmark, VS	BB-3, SM-3
MUGIO	Muggio, TI	BB-3
MUO	Muotathal, SZ	BB-3
OTTER	Otterbach, BS	SM-3
PLONS	Mels, SG	BB-3
SALAN	Lac de Salanfe, VS	EB-3
SAUR	Augst-Römermuseum, AG	SM-3
SBAF	Basel-Friedhofgasse, BS	SM-3
SBAP	Basel-PUK, BS	SM-3
SBAT	Basel-Tropenhaus, BS	SM-3
SBIS	Binningen, BS	SM-3
SCUC	Scuol-Clozza, GR	SM-3
SENIN	Senin, VS	BB-3, SM-3
SIOO	Sion-Ophtalmologie, VS	SM-3
SIOV	Sion-Valere, VS	SM-3
SLE	Schleitheim, SH	BB-3
SKAF	Kaiseraugst-Friedhof, AG	SM-3
SMUK	Muraz-Kläranlage, VS	SM-3
SMUR	Muraz-Reservoir, VS	SM-3
SMZW	Muttenz-Waldhaus, BL	SM-3
SRHB	Riehen-Bäumlihof, BS	SM-3
STEIN	Stein am Rhein, SH	EB-3
STSP	Tschierv, GR	SM-3
SULZ	Cheisacher, AG	BB-3, SM-3
SZER	Zernez, GR	SM-3
TORNY	Torny, FR	BB-3
TRULL	Trullikon, ZH	EB-3
VDL	Valle di Lei, GR	BB-3, SM-3
WEIN	Weingarten, TG	EB-3
WILA	Wil, SG	BB-3
WIMIS	Wimmis, BE	BB-3
ZUR	Zürich-Degenried, ZH	BB-3, SM-3

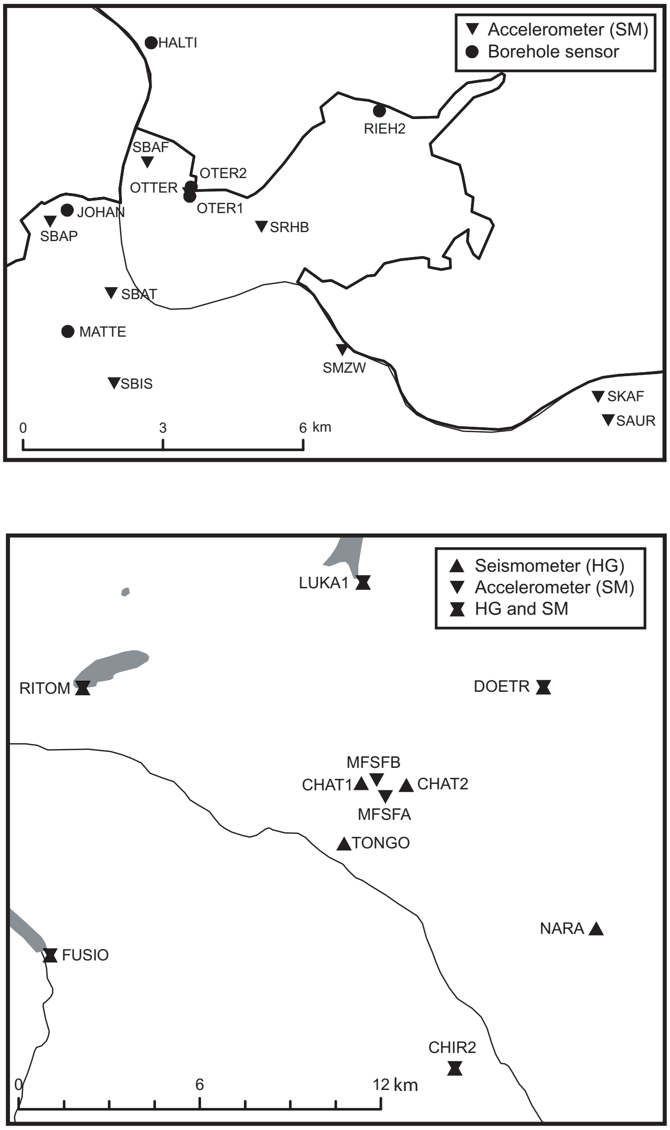

Fig. 2. Top: borehole and surface strong-motion stations in the Basel region with near-realtime automatic data transmission to the SED. Bottom: station array for monitoring seismicity related to the construction of the new Gotthard railway tunnel (AlpTransit-Gotthard, ATG, array); except for CHAT1, CHAT2 and LUKA1, all signals are recorded in near-realtime at the Swiss Seismological Service; station FUSIO is part of the Swiss national network.

canologìa in Rome (INGV), and from the Istituto di Geofisica, Università di Genova.

Table 2. Local seismic networks and single stations operational at the end of 2006. Instrument type: SP = 1 second, SM = accelerometer, 1 = vertical component only, 3 = vertical and horizontal components. The numbers in parentheses next to the borehole stations are the sensor depth with respect to ground surface in meters. Signals of BBS are transmitted via analog telemetry and are recorded by the Landeserdbebendienst Baden-Württemberg; those of BERT and GNV are recorded locally on paper.

AlpTransit-Gotthard Network		
Code	Station name	Type
CHAT1	Predelp, TI	SP-3
CHAT2	Alpe di Cari, TI	SP-3
CHIR2	Chironico, TI	SP-3, SM-3
DOETR	Doetra, TI	SP-3, SM-3
LUKA1	Lucomagno, TI	SP-3, SM-3
MFSFA	Faido (Tunnel), TI	SM-3
MFSFB	Faido (Tunnel), TI	SM-3
NARA	Leontica, TI	SP-3
RITOM	Lago Ritom, TI	SP-3, SM-3
TONGO	Tortengo, TI	SP-3

Basel Borehole Network		
Code	Station name	Type
HALTI	Haltingen (542)	SP-3
JOHAN	Sankt Johann (317)	SP-3
MATTE	Schützenmatte (553)	SP-3
OTER1	Otterbach (500)	SP-3
OTER2	Otterbach (2740)	SP-3
RIEH2	Riehen (1213)	SP-3

Single stations		
Code	Station name	Type
BBS	Basel-Blauen, BL	SP-1
BERT	Bern, BE	SP-3
GNV	Geneva, GE	SP-1

To improve the reliability of automatic locations for events at the periphery or outside of Switzerland we have implemented an automatic system for retrieving near-realtime data from some of the institutions listed above (Baer et al. 2003). Moreover, in the course of a cross-frontier cooperative effort to exchange seismic data in realtime, in 2005 we began to continuously record and archive the signals of two Austrian stations operated by ZAMG (DAVA and WTTA) as well as four stations in northern Italy operated by INGV (MABI, MDI, MONC and DOI). In 2006, two additional stations of INGV (MRGE and SALO) as well as six newly installed stations in Southern Tirol operated by the Zivilschutz der Autonomen Provinz Bozen-Südtirol (ABSI, BOSI, KOSI, MOSI, RISI and ROSI) were added to this set.

Data analysis

Hypocenter location and local magnitude

Since the year 2005, hypocenter locations of most of the local earthquakes have been determined using the software package NonLinLoc (Lomax et al. 2000). The P-wave velocity model used was derived from a 3D tomographic inversion of local earthquake data with constraints from controlled source seismics (Husen et al. 2003), and the S-velocities are calculated from the P-velocity using a V_p/V_s ratio of 1.71. A more detailed documentation of the location procedures can be found in a previous annual report (Deichmann et al. 2006).

Beginning with the transition from the short-period telemetry network to the digital broad-band stations, local magnitudes (M_L) are calculated from the maximum amplitude

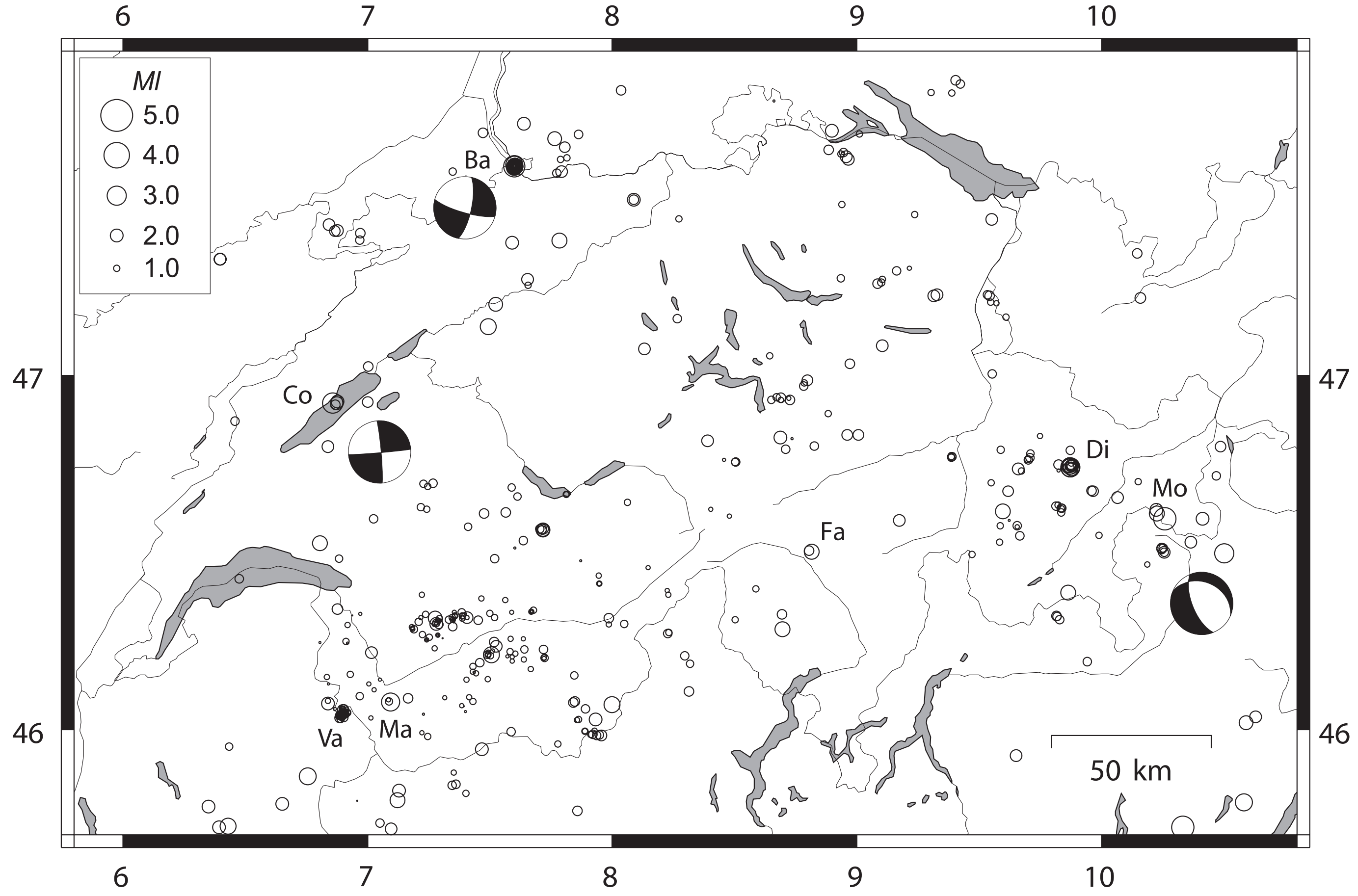

Fig. 3. Epicenters and focal mechanisms of earthquakes recorded by the Swiss Seismological Service during 2006. Epicenters of earthquakes mentioned in the text are Basel (Ba), Cortaillod (Co), Dischmatal (Di), Faido (Fa), Martigny (Ma), Val Mora (Mo), Vallorcine (Va).

of the horizontal components of the digital seismograms filtered to simulate the response of a Wood-Anderson seismograph. 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.

Focal mechanisms, moment tensors and moment magnitude

For the stronger events, the traditional determination of focal mechanisms from the azimuthal distribution of first-motion polarities (faultplane solutions) is complemented by moment tensors based on a full-waveform inversion. Routine moment tensor calculations for local earthquakes at the Swiss Seismological Service began in 1999. The calculations are performed in an interactive procedure based on a method documented in Nabelek and Xia (1995) and in Braunmiller et al. (1995). A short summary of the procedure can also be found in a previous annual report (Deichmann et al. 2000a).

In an effort to automate the procedure, a new automated moment tensor inversion scheme, which estimates the double couple and compensated linear vector dipole (CLVD) components was implemented at the Swiss Seismological Service in 2006. The solution, based on the time domain inversion scheme developed by Dreger (2003), also provides a moment magnitude, M_w, the best fitting double couple, and an optimal depth estimate based on the given location. Synthetic seismograms created using 1-D Green's functions from various simple velocity profiles (Saikia, 1994) are matched with the observed 3-component long period waveforms to minimize the least squares time domain waveform misfit. The range of signal periods used in the inversion are determined from the routinely determined M_L magnitude, and range from 8–20 s for $M_L < 3.8$ to 50–100 s for $M_L > 5.3$. In this fully automated implementation, data from all stations out to 500 km distance which pass quality control criteria are initially individually inverted to rank the stations in terms of waveform quality, and then an iterative search is performed to find the best solution for up to 6 stations. Additional information on the method can be found in Clinton (2006), which describes a similar implementation for the Southern California Seismic Network, USA.

Table 3. Earthquakes with $M_L \geq 2.5$. The focal depths of the earthquakes for which focal mechanisms have been calculated are based on 2-D raytracing or on additional data from foreign networks.

Date & Time UTC	Lat. [°N]	Lon. [°E]	X / Y [km]	Depth [km]	Mag. [M_L]	Q	Location
2006.01.12 05:32:52	45.792	10.583	844/ 76	10	2.7	D	Valli Giudicarie, I
2006.03.18 22:49:32	46.213	7.507	605/118	3	2.6	B	Erdesson, VS
2006.03.29 09:49:45	46.923	6.858	556/197	2	3.2	A	Cortaillod, NE
2006.04.12 22:24:53	46.597	10.259	816/164	2	3.5	A	Val Mora, GR
2006.05.25 08:18:13	47.137	7.493	604/221	6	2.6	B	Brügglen, SO
2006.06.30 00:34:46	45.725	6.430	521/ 64	14	2.5	D	Ugine, F
2006.08.16 15:05:20	46.079	7.094	573/103	6	2.8	B	Martigny, VS
2006.10.17 05:41:34	46.500	10.502	835/154	8	3.1	A	Ortles, I
2006.10.20 00:11:58	45.721	10.332	825/ 67	2	3.6	B	Valli Giudicarie, I
2006.10.24 13:08:11	46.746	9.873	786/180	6	2.6	A	Dischmatal, GR
2006.10.24 20:05:29	46.743	9.873	786/180	6	3.0	A	Dischmatal, GR
2006.10.24 20:11:05	46.746	9.871	786/180	6	2.5	A	Dischmatal, GR
2006.10.31 03:08:07	46.741	9.873	786/179	5	2.8	A	Dischmatal, GR
2006.11.22 15:54:32	45.867	6.755	547/ 80	14	2.7	B	Mont Blanc, F
2006.11.24 21:31:00	46.072	8.000	643/102	9	2.5	A	Saas Almagell, VS
2006.12.08 03:06:18	47.582	7.601	612/270	5	2.6	A	Basel, BS
2006.12.08 15:46:55	47.587	7.599	612/271	5	2.7	A	Basel, BS
2006.12.08 16:48:39	47.582	7.600	612/270	5	3.4	A	Basel, BS
2006.12.08 20:19:39	47.580	7.600	612/270	5	2.5	A	Basel, BS
2006.12.14 22:39:27	47.581	7.602	612/270	4	2.5	A	Basel, BS

Generally a full-waveform inversion is performed for all events with $M_L > 3.5$, but in some cases, with recordings with sufficiently good signal-to-noise ratios at low frequencies, it has been possible to invert for the moment tensor even for events with $M_L < 3$. In 2006, we were able to obtain stable moment tensors for two events using both the interactive and the automated method, and to compare the results to each other and to the faultplane solutions. They are listed with their respective value for the moment magnitude, M_w, in Table 5. The most widely used relation between moment magnitude and seismic moment M_0 is $M_w = (2/3)\ M_0 – 6$, where M_0 is given in N-m (Hanks & Kanamori 1979).

Table 4. Criteria and location uncertainty corresponding to the quality rating (Q) of the hypocentral parameters in Table 3. GAP = largest angle between epicenter and two adjacent stations; DM = minimum epicentral distance; H = horizontal location; Z = focal depth.

Rating	Criteria		Uncertainty	
Q	GAP (degrees)	DM (km)	H (km)	Z (km)
A	≤ 180	$\leq 1.5 \times Z$	≤ 2	≤ 3
B	≤ 200	≤ 25	≤ 5	≤ 10
C	≤ 270	≤ 60	≤ 10	> 10
D	> 270	> 60	> 10	> 10

Seismic activity during 2006

Overview

During 2006, the Swiss Seismological Service detected and located 572 earthquakes in the region shown in Figure 3. As discussed below, of these 572 events, 2 occurred in conjunction with the construction of the new Gotthard railway tunnel and 165 were induced by the stimulation of a proposed geothermal reservoir beneath the city of Basel. Based on such criteria as the time of occurrence, the location, the signal character or on direct information, 91 additional seismic events were identified as quarry blasts and a dozen as landslides.

Magnitude values of the events recorded in 2006 range from M_L 0.1 to 3.6. The events with $M_L > 2.5$ and the criteria used to assign the quality rating for the given locations as well as the corresponding estimated location accuracy are listed in Tables 3 and 4.

Figure 4 shows the epicenters of the 790 earthquakes with $M_L \geq 2.5$, which have been recorded in Switzerland and surrounding regions over the period of 1975–2006. 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 less than 10% of the total number of events detected during that time period in the same area.

At least six of the seismic events that occurred in Switzerland in 2006 where felt by the public. In what follows, we review these six earthquakes.

Significant earthquakes of 2006

Cortaillod

On March 29th, shortly before noon (local time), light shaking with swaying lamps and creaking beams was perceived in several towns along the northern shore of Lake Neuchâtel. This was caused by a magnitude M_L 3.2 earthquake, whose epicenter was located about 3 km south of the town of Cortaillod. This event was followed by three aftershocks with the same epicenter and with magnitudes between 1.5 and 2.0 on April 1st, May 10th and August 1st.

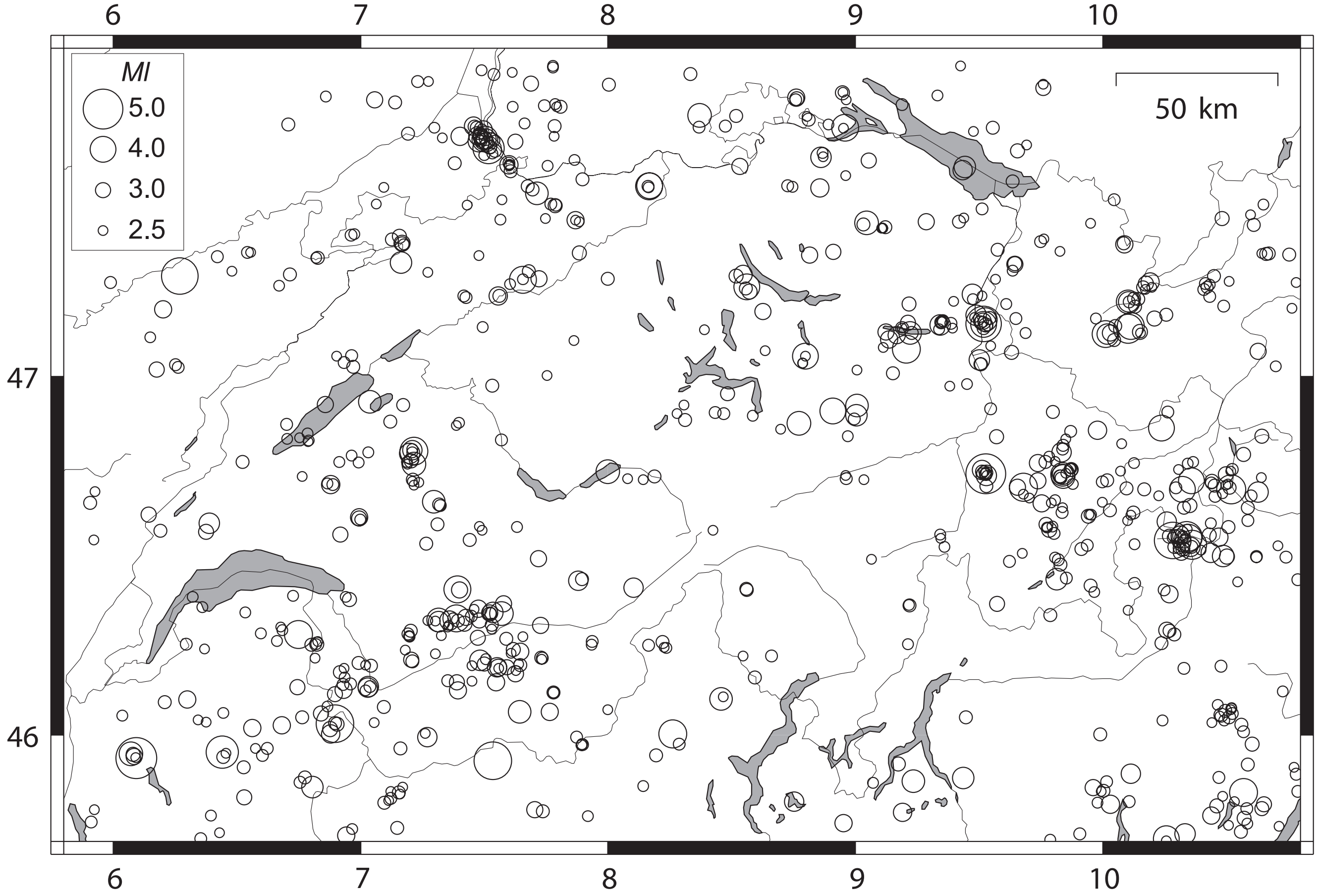

Fig. 4. Epicenters of earthquakes with Magnitudes $M_L \geq 2.5$, during the period 1975–2006.

Although it was recorded by a sufficient number of seismic instruments with good azimuthal coverage, the closest station (TORNY) was too far away (18 km) to constrain the focal depth in a reliable way. The routinely calculated depth based on the 3D velocity model for Switzerland and using all available data gives a focal depth of 6 km; using only data from stations out ot 70 km results in depths of 9–10 km. However, the very pronounced surface waves observed at several stations suggest a much shallower hypocenter. Earthquakes with near-surface sources are known to occur in this region. One of these occurred in 2003 just 2 km north of Neuchâtel at a depth of about 2 km (Deichmann et al. 2004). The focal depth of the Neuchâtel event is well constrained by a strong-motion station situated only 2 km from the epicenter. Comparing the distance at which the wave refracted at the Moho (P_n) begins to arrive before the direct wave (P_g) for these two events shows that their focal depths must be practically identical (Figure 6). For constructing the faultplane solution, we have therefore fixed the focal depth at 2 km (Tables 3 and 5). With the remaining uncertainty (estimated at ± 1 km) and a depth to basement of about 2 km in this area (Sommaruga, 1997), it is not possible to decide whether the source is located in the basement or in the overlying sediments. Again, given the pronounced surface waves observed at several stations, the latter possibility is very likely.

The faultplane solution based on first-motion polarities corresponds to a pure strike-slip mechanism with N-S and E-W striking nodal planes. Although station coverage to the NW is poor, the strike of the two nodal planes is well-constrained by the distribution of the other stations. Given that the mechanism is strike-slip, the result depends only marginally on the correct value of the vertical take-off angles of the rays at the source and is thus insensitive to errors in focal depth. The general nature of the focal mechanism is confirmed also by the two moment tensor solutions based on full-waveform solutions (Figure 5 and Table 5). Both the depth and focal mechanism are nearly identical to those of the well-documented earthquake sequences of Fribourg, located about 28 km to the ESE (Kastrup et al. 2007).

Val Mora

Shortly after midnight between April 12th and 13th, an earthquake with magnitude M_L 3.5 shook the area between the Lower Engadin, Val Müstair and Livigno. Its epicenter was

Table 5. Focal mechanism parameters based on first-motion polarities (lines with M_L) and on the two full-waveform inversion methods discussed in the text (lines with M_w; interactive above and automated below).

Location	Date & Time	Depth	Mag.	Plane 1	Plane 2	P-Axis	T-Axis
	[UTC]	[km]		Strike/Dip/Rake		Az/Dip	
Cortaillod	2006/03/29 09:50	2	M_L 3.2	355/86/-002	085/88/-176	310/04	220/01
		4	M_w 3.1	179/70/ 025	080/67/ 158	309/02	040/32
		5	M_w 3.0	357/80/-016	090/74/-170	313/18	044/04
Val Mora	2006/04/12 22:25	2	M_L 3.5	293/32/-130	158/66/-068	103/62	232/18
		9	M_w 3.4	280/34/-142	157/70/-062	103/56	226/20
		5	M_w 3.3	285/28/-148	166/76/-066	104/53	237/27
Basel	2006/12/08 16:49	5	M_L 3.4	012/73/-013	106/78/-163	330/21	238/03

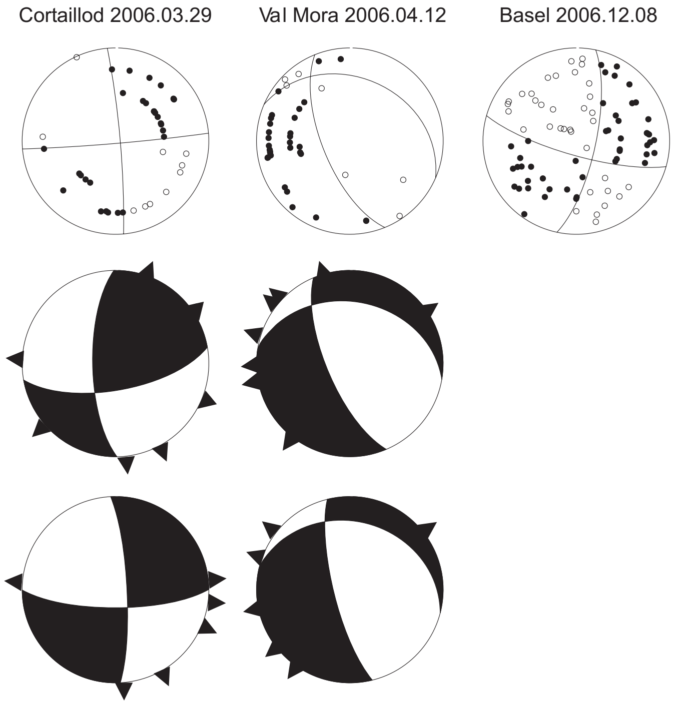

Fig. 5. Faultplane solutions (above) based on first-motion polarities and moment tensors (interactive in the middle and automated below) based on full-waveform inversion. All stereographs are lower hemisphere, equal area projections. In the faultplane solutions, solid circles correspond to compressive first motion (up) and empty circles to dilatational first motion (down); on the moment tensors, triangles show the station locations.

located in the lower part of Val Mora, close to the border to Italy. Due to the remoteness of the source location (6 km from Pass dal Fuorn and 10 km from Livigno) and the time of occurrence, there are only a few reports of it having been felt.

To compute the source location, the records of the national broad-band network was complemented by data from two strong-motion stations at the Punt dal Gall hydroelectric dam (SPGF) and in Zernez (SZEM) as well as from stations in northern Italy (in particular station BRMO, near Bormio 16 km SSE of the epicenter). The hypocenter of this earthquake is certainly shallow. In fact, the arrival-time difference between the S- and P-wave observed at station FUORN is only 0.54 ± 0.02 seconds. Allowing for a reasonable range of V_p and V_s for the upper crust in this region, this places the source at a radial distance of 4.0 ± 0.5 km from FUORN. Considering that FUORN is situated at an altitude of 2300 m, the computed depth of 2 km relative to mean sea level, given in Tables 3 and 5, must be regarded as a maximum value. On the other hand, the steep angles of incidence of the rays at the surface estimated from the polarization of the P-waves observed at stations FUORN (15°) and SPGF (26°) do not allow the depth to be much less than this value. This implies that the epicenter is likely to be closer to FUORN and SPGF than the computed epicentral distances of 2.6 and 5.5 km. These inconsistencies together with large travel-time residuals observed at some stations (e.g. 0.6 s at VDL, located only 70 km from the epicenter) suggest that the 3D velocity model used for the location is not appropriate for this region.

The faultplane solution constructed from the first-motion polarities for this earthquake corresponds to an almost pure normal faulting mechanism. Although the data coverage in the NE quadrant is poor and the mentioned uncertainties of the velocity model might cast doubts on the accuracy of the vertical take-off angles at the source, the good match with the independently computed full-waveform moment tensors indicates that this result is reliable (Figure 5 and Table 5). Common to all three mechanisms is a NE-SW oriented T-axis, which is typical for all focal mechanisms observed in the eastern Alps of Switzerland (e.g. Kastrup et al. 2004). Note, however, that the shallow focal depth does not seem to be resolvable by the full-waveform inversions.

Martigny

Although the magnitude reached only M_L 2.8, this event, which occurred on August 16th at 17:05 local time, was felt by several people at rest in Martigny. It was followed on the same day and on August 19th by two aftershocks of magnitude 0.9 and 1.3. Their epicenters were located near Bovernier, about 3 km SE of Martigny, so that these events are not related in any way to the earthquake sequence of 2001, which occurred 6 km to the NW of the town.

Dischmatal

In October and November a sequence of 12 events with magnitudes between M_L 1.1 and 3.0 was observed in the vicinity of Davos. The strongest event was widely felt by people at rest, who reported rattling windows, swaying lamps and creaking woodwork (intensity III–IV according to EMS98). The epicenters of these events were located in the valley of Dischma, 7 km SSE of the town. With an epicentral distance of only

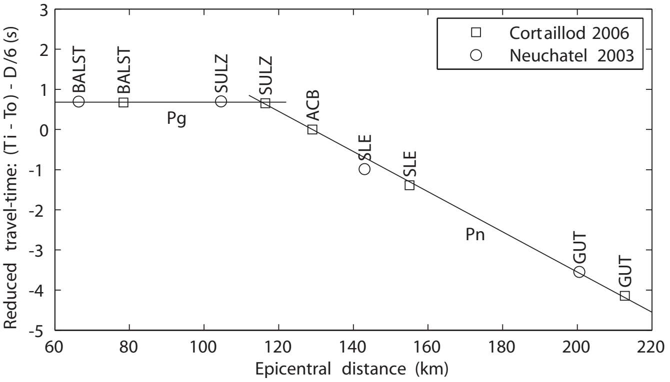

Fig. 6. Arrival times of the Neuchâtel event of 2003 and the Cortaillod event of 2006 observed at stations to the NE of the epicenters. The data for the two events were aligned according to the direct arrivals (Pg). The fact that the arrivals of the wave refracted at the Moho (Pn) match for the two events implies that their focal depths must be nearly identical.

4 km from station DAVOX and good azimuthal coverage by the other stations that recorded these events, the focal depth of 6 km is well constrained. This value matches also the depth of a similar earthquake sequence that occurred in the summer of 2003 in the valley of Sertig, only 3 km to the west (Deichmann et al. 2004). The number of reliable first-motion polarities is not sufficient for a faultplane solution, but the available data is compatible with a normal faulting mechanism similar to that of the Sertig events.

Seismic events and rockbursts in the new Gotthard tunnel

Starting in Spring of 2004, the national seismometer network began detecting a sequence of seismic events near Faido, TI. After a while, it became clear that the events of this sequence are correlated with some rather violent rockbursts in a section of the new Gotthard railroad tunnel, which is still under construction (Deichmann et al. 2006). The strongest event of this sequence recorded so far occurred on March 25th, 2006, at 22:42 local time. Its magnitude was only 2.4 M_L, but, due to its shallow focal depth, it was perceived as a loud bang accompanied by short but intense shaking in the town of Faido and surroundings. A second event with the same source location was detected by the nationwide network on November 6th and had a magnitude of 1.6 M_L. Several additional weaker events have also occurred, but were recorded only by the sensors installed in the immediate vicinity of the epicenter (see Table 2 and Figure 2). A comparison with the records of checkshots set off in the tunnel confirmed that the hypocenters of these earthquakes lie in the immediate vicinity of that part of the tunnel, where many of the rockbursts have occurred and where strong deformations of the tunnel cross-section are observed. More detailed studies of the possible causal relationship between these earthquakes and the observed rockbursts are still underway under a contract with AlpTransit-Gotthard AG.

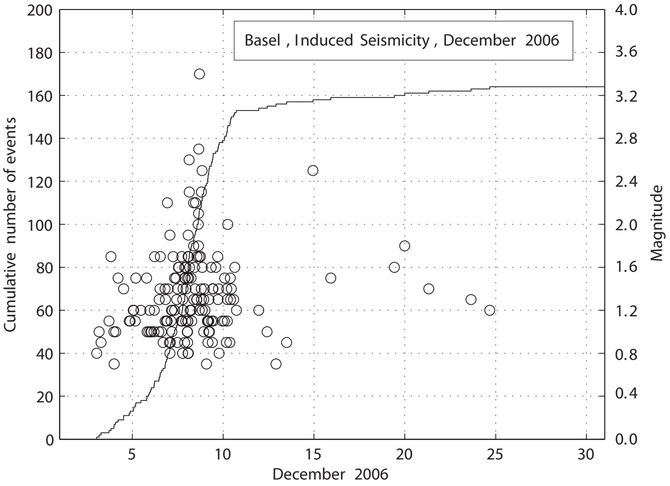

Fig. 7. Cumulative number of events and magnitude of the induced earthquakes in Basel, recorded by the national high-gain network of the Swiss Seismological Service during the month of December 2006.

Induced seismicity in Basel

To stimulate the reservoir for a "hot dry rock" geothermal project, that was initiated by a private/public consortium in the city of Basel, approximately 11500 m^3 of water were injected between December 2nd and 8th, 2006, at high pressures into a 5 km deep well below Kleinhüningen. A six-sensor borehole array, installed by the operators of the project at depths between 317 and 2740 meters around the well to monitor the induced seismicity, recorded more than 10500 seismic events during the injection phase. In the early morning hours of December 8th a magnitude M_L 2.6 event occurred within the reservoir. This exceeded the safety threshold for continued injection, so that the injection was prematurely terminated. In the afternoon and evening of the same day, two additional events of magnitude 2.7 and 3.4 occurred within the same source volume, so that the well was opened and the water allowed to flow back. In the following days about one third of the injected water volume flowed back out of the well, and the seismic activity declined rapidly thereafter (Figure 7).

The vast majority of the induced seismic events were so small that they were detected only by the local borehole array. Consequently, the 164 events, with magnitudes as low as M_L 0.7, that were recorded by the national high-gain network of the Swiss Seismological Service between the beginning of the stimulation and the end of the year, represent only a small fraction of the total number of detected events. An additional event of magnitude 0.7, that was induced by the cementation of the borehole casing, had been recorded already on November 10th. Most of these stronger events were also recorded by the regional networks of France and Germany as well as by up to 30 permanent and temporary strong-motion instruments installed in the epicentral area.

First results of a more detailed analysis that is still under-

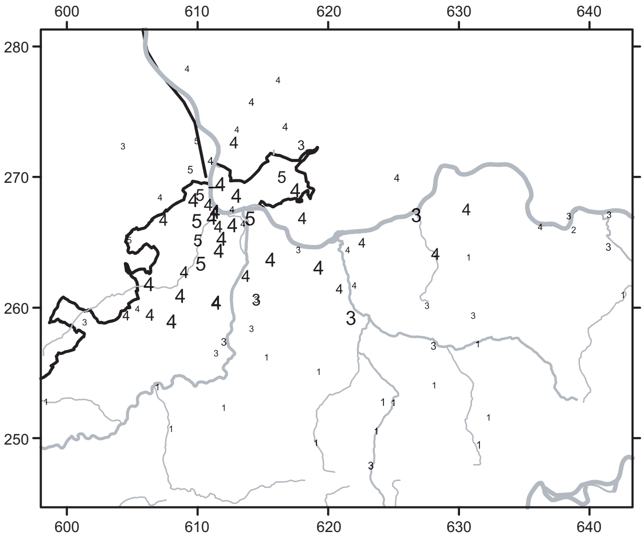

Fig. 8. Macroseismic intensities (EMS98) for the strongest event (M_L 3.4) induced by the geothermal reservoir stimulation in Basel (2007/12/08 17:48 local time). The map is based only on reports communicated to the Swiss Seismological Service, so it is not representative for the true shaking in Germany and France. The number size denotes the quality of the data, ranging from very poor (1–2 reports) to very good (15–60 independent reports). The Swiss cartesian coordinate grid is labeled in km..

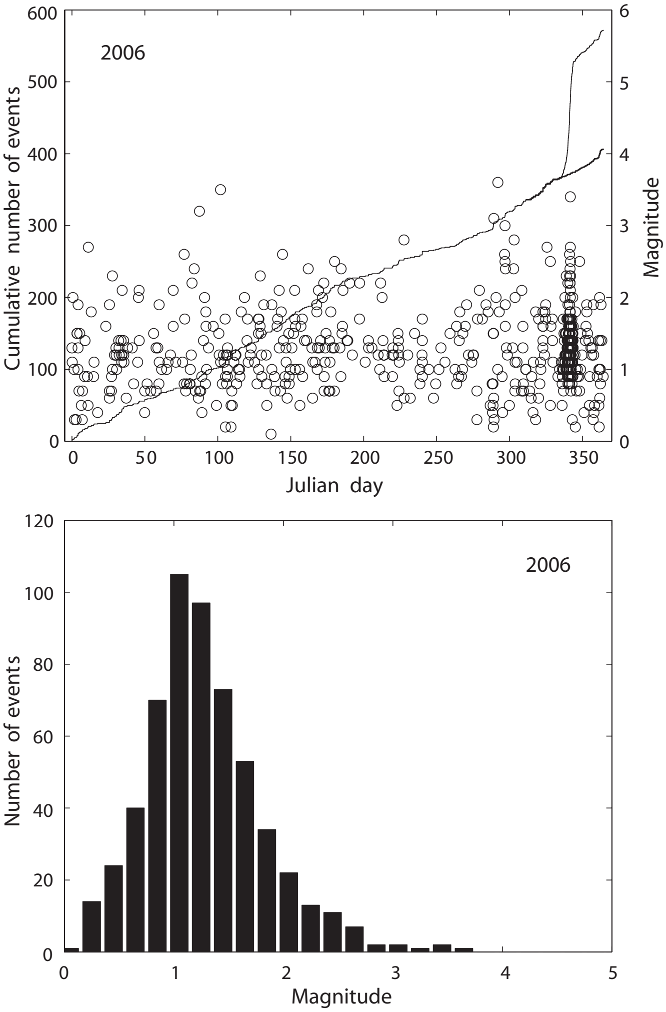

Fig. 9. Earthquake activity during 2006: magnitude of each event and cumulative number of events (above); histogram of magnitudes (below). The lower curve beyond Julian day 313 in the plot of the cumulative number of events represents the evolution in time without the induced seismicity of Basel.

way show that the hypocenters of the located events (about 3500 to date) are restricted to a NNW-SSE oriented lens-shaped cloud, about 1 km in diameter and 200 m wide, with a single offsetting branch to the ESE. The center of this cloud is at a depth of about 4.5 km below ground level. In order to minimize the errors introduced by our imperfect knowledge of the velocity structure, hypocentral locations were calculated using only the P- and S-arrivals at the borehole sensors, which are all situated at radial distances between 2 and 6 km from the source. Compared to relative locations, constrained by a master event that was recorded also by a temporary sensor installed at the beginning of injection in the main borehole near the casing shoe, the absolute epicentral locations given in Table 3 are shifted systematically to the ESE by 600–700 m on average.

Due to the large number of stations in operation at the time, the faultplane solution of the main event is exceptionally well constrained (Figure 5). The focal mechanism is strike-slip with more or less NS and EW striking nodal planes. Moment tensors have also been calculated for this event, and the results are quite similar to the faultplane solution, but the signal-to-noise ratio of the long-period seismograms used for the inversions is so low that this must be regarded as a fortuitously good match rather than as independent evidence. The orientation of the cloud and the focal mechanism match the stress field derived from observations of natural seismicity obeserved in the past in the wider Basel region (Plenefisch & Bonjer 1997, Kastrup et al. 2004).

The main shock was felt distinctly to strongly in the urban area of Basel. People reported a short, high frequency shaking of 1–3 seconds, often accompanied by a loud bang similar to an explosion. The bang contributed significantly to the frightening effect that this event had on many witnesses. Typical macroseismic effects were creaking of woodwork and rattling of doors and windows. Effects more related to low frequency shaking, such as swinging of suspended objects and oscillations in liquid-filled containers, were mentioned less often. From the city as well as from neighbouring communities, very small non-structural damage was reported consistently for hundreds of buildings, such as hair-line cracks to the plaster or damage to the paint at building junctions. Although often difficult to verify, a significant share of the reported instances of damage is presumed to be a direct consequence of this earthquake. Consequently, macroseismic intensity in the different parts of Basel and the neighbouring municipalities ranges from IV to V according the EMS98 scale (Figure 8). The radius of the intensity-IV area is about 10 km, with peaks in a SSW direction (Birsig valley, Therwil, Ettingen) and towards the East in the Rhine valley. Whereas the first peak coincides with the energy radiation pattern expected from the focal mechanism, the Rhine valley anomaly is probably due to site amplifications by poorly compacted alluvial terraces. The most distant well-established felt-reports are from the region of Sisseln/Stein/Eiken, some 30 km east of the epicentre.

Due to the premature abortion of the stimulation process, the size of the stimulated volume is insufficient for a commercially viable exploitation of geothermal energy. As a consequence of how the largest of these induced earthquakes was perceived by the public and of the damage that it presumably caused, the project was put on hold, pending a comprehensive assessment of the seismic risk associated with a continuation.

Landslides

In the Summer of 2006, the east flank of the Eiger near Grindelwald was the site of a recurring sequence of massive rockfalls, to the extent that it became a popular tourist attraction and an enduring topic for the media. Between June and August, a dozen seismic events were recorded by the national high-gain network, which showed a similar pattern of signals at stations HASLI, LKBD and WIMIS. These signals are too emergent to identify clear arrivals and thus their source can not be located in a formal way, but given the combination of stations at which they are visible, they most probably are associated with these rockfalls. The equivalent magnitudes of these events are all well below 2.

Discussion

In 2006, the total number of 20 events with ML ≥ 2.5 was below the 25 events per year observed on average over the previous 31 years in this magnitude category. The activity low of 2006 is even more significant if one considers that five of these events were artificially induced by the geothermal reservoir stimulation in Basel and would presumably not have occurred otherwise.

As in previous years, most of the other earthquakes occurred in the Valais and in Graubünden. It is also worthwhile to note that more than 10% of the naturally occurring earthquakes in 2006 were part of the aftershock activity of the M_L 4.9 earthquake that occurred on September 8th 2005 near Vallorcine, France, about halfway between Martigny and Chamonix (Figure 3). These 42 aftershocks with M_L between 0.5 and 1.7 occurred at a gradually decreasing rate throughout the entire year.

Routinely calculated focal depths for all but 23 events recorded in 2006 were less than 16 km. Of these deeper events 22 are located in the lower crust beneath the Jura Mountains or the Molasse Basin of northern Switzerland with a maximum focal depth of 31 km. One exceptionally large focal depth of 45 km was calculated for a magnitude 1.9 event in the southern Alps, about 20 km E of Lecco. Lower crustal earthquakes are not uncommon in this region. However, according to Waldhauser et al. (1998) the Moho depth below the epicenter is only 41 km, so that, if the calculated focal depth is correct, this would be the first known seismic event in Switzerland and surroundings to have occurred in the upper mantle. On the other hand, the 3-D velocity model is not optimally constrained in this region, and the probability density function of the non-linear location uncertainty extends in the vertical dimension over ± 7 km, so that the calculated focal depth for this event is not sufficiently reliable to support such a conclusion.

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REFERENCES

Baer, M., Deichmann, N., Fäh, D., Kradolfer, U., Mayer-Rosa, D., Rüttener, E., Schler, T., Sellami, S., Smit, P. 1997: Earthquakes in Switzerland and surrounding regions during 1996. Eclogae Geologicae Helvetiae 90/3, 557–567.

Baer, M., Deichmann, N., Ballarin Dolfin, D., Bay, F., Delouis, B., Fäh, D., Giardini, D., Kastrup, U., Kind, F., Kradolfer, U., Künzle, W., Röthlisberger, S., Schler, T., Sellami, S., Smit, P., Spühler, E. 1999: Earthquakes in Switzerland and surrounding regions during 1998. Eclogae Geologicae Helvetiae 92/2, 265–273.

Baer, M., Deichmann, N., Braunmiller, J., Ballarin Dolfin, D., Bay, F., Bernardi, F., Delouis, B., Fäh, D., Gerstenberger, M., Giardini, D., Huber, S., Kastrup, U., Kind, F., Kradolfer, U., Maraini, S., Mattle, B., Schler, T., Salichon, J., Sellami, S., Steimen, S., Wiemer, S. 2001: Earthquakes in Switzerland and surrounding regions during 2000. Eclogae Geologicae Helvetiae 94/2, 253–264.

Baer, M., Deichmann, N., Braunmiller, J., Bernardi, F., Cornou, C., Fäh, D., Giardini, D., Huber, S., Kästli, P., Kind, F., Kradolfer, U., Mai, M., Maraini, S., Oprsal, I., Schler, T., Schorlemmer, D., Sellami, S., Steimen, S., Wiemer, S., Wössner, J., Wyss, A. 2003: Earthquakes in Switzerland and surrounding regions during 2002. Eclogae Geologicae Helvetiae 96/2, 313–324.

Baer, M., Deichmann, N., Braunmiller, J., Husen, S., Fäh, D., Giardini, D., Kästli, P., Kradolfer, U., Wiemer, S. 2005: Earthquakes in Switzerland and surrounding regions during 2004. Eclogae Geologicae Helvetiae 98/3, 407–418, DOI: 10.1007/s00015-005-1168–3.

Braunmiller, J., Nabelek J. L., Leitner, B. & Qamar, A. 1995: The 1993 Klamath Falls, Oregon, earthquake sequence: source mechanisms from regional data. Geophysical Research Letters 22, 105–108.

Clinton, J. F., Hauksson, E. & Solanki, K. 2006, An Evaluation of the SCSN Moment Tensor Solutions: Robustness of the Mw Magnitude Scale, Style of Faulting, and Automation of the Method, Bulletin of the Seismological Society of America 96, 1689–1705.

Deichmann, N. 1990: Seismizität der Nordschweiz, 1987–1989, und Auswertung der Erdbebenserien von Günsberg, Läufelfingen und Zeglingen. Nagra Technischer Bericht, NTB 90–46, Nagra, Baden.

Deichmann, N., Baer, M., Ballarin Dolfin, D., Fäh, D., Flück, P., Kastrup, U., Kradolfer, U., Künzle, W., Mayer-Rosa, D., Röthlisberger, S., Schler, T., Sellami, S., Smit, P., & Giardini, D. 1998: Earthquakes in Switzerland and surrounding regions during 1997. Eclogae Geologicae Helvetiae 91/2, 237–246.

Deichmann, N., Baer, M., Braunmiller, J., Ballarin Dolfin, D., Bay, F., Delouis, B., Fäh, D., Giardini, D., Kastrup, U., Kind, F., Kradolfer, U., Künzle, W., Röthlisberger, S., Schler, T., Salichon, J., Sellami, S., Spühler, E., Wiemer, S. 2000a: Earthquakes in Switzerland and surrounding regions during 1999. Eclogae Geologicae Helvetiae 93/3, 395–406.

Deichmann, N., Ballarin Dolfin, D., Kastrup, U. 2000b: Seismizität der Nord- und Zentralschweiz. Nagra Technischer Bericht, NTB 00-05, Nagra, Wettingen.

Deichmann, N., Baer, M., Braunmiller, J., Ballarin Dolfin, D., Bay, F., Bernardi, F., Delouis, B., Fäh, D., Gerstenberger, M., Giardini, D., Huber, S., Kradolfer, U., Maraini, S., Oprsal, I., Schibler, R., Schler, T., Sellami, S., Steimen, S., Wiemer, S., Wössner, J., Wyss, A. 2002: Earthquakes in Switzerland and surrounding regions during 2001. Eclogae Geologicae Helvetiae 95/2, 249–261.

Deichmann, N., Baer, M., Braunmiller, J., Cornou, C., Fäh, D., Giardini, D., Gisler, M., Huber, S., Husen, S., Kästli, P., Kradolfer, U., Mai, M., Maraini, S., Oprsal, I., Schler, T., Schorlemmer, D., Wiemer, S., Wössner, J., Wyss, A. 2004: Earthquakes in Switzerland and surrounding regions during 2003. Eclogae Geologicae Helvetiae 97/3, 447–458.

Deichmann, N., Baer, M., Braunmiller, J., Husen, S., Fäh, D., Giardini, D., Kästli, P., Kradolfer, U., Wiemer, S. 2006: Earthquakes in Switzerland and surrounding regions during 2005. Eclogae Geologicae Helvetiae 99/3, 443–452, DOI: 10.1007/s00015-006-1201–1.

Dreger, D. S. 2003. TDMT INV: Time Domain Seismic Moment Tensor INVersion. In: W. H. K. Lee, H. Kanamori, P. C. Jennings, and C. Kisslinger (Eds.), International Handbook of Earthquake and Engineering Seismology, Volume B, 1627.

Fäh, D., Giardini, D., Bay, F., Bernardi, F., Braunmiller, J., Deichmann, N., Furrer, M., Gantner, L., Gisler, M., Isenegger, D., Jimenez, M.-J., Kästli, P., Koglin, R., Masciadri, V., Rutz, M., Scheidegger, C., Schibler, R., Schorlemmer, D., Schwarz-Zanetti, G., Steimen, S., Sellami, S., Wiemer, S., Wössner, J. 2003: Earthquake catalog of Switzerland (ECOS) and the related macroseismic database. Eclogae Geologicae Helvetiae 96/2, 219–236.

Giardini, D., Wiemer, S., Fäh, D., Deichmann, N., Sellami, S., Jenni, S. and the Hazard Team of the Swiss Seismological Service 2004: Seismic Hazard Assessment 2004. Swiss Seismological Service, 81 pp.

Hanks, T. C. & Kanamori, H. 1979. A moment magnitude scale, Journal of Geophysical Research 84, B5, 2348–2350.

Husen, S., Kissling, E., Deichmann, N., Wiemer, S., Giardini, D., Baer, M. 2003: Probabilistic earthquake location in complex three-dimensional velocity models: Application to Switzerland. Journal of Geophysical Research, 108, B2 2077–2096.

Kastrup, U., Zoback M.-L., Deichmann, N., Evans, K., Giardini, D., Michael, A.J. 2004: Stress field variations in the Swiss Alps and the northern Alpine foreland derived from inversion of fault plane solutions. Journal of Geophysical Research,109, B1, doi:10.1029/2003JB002550B01402.

Kastrup, U., Deichmann, N., Fröhlich, A., Giardini, D. 2007: Evidence for an active fault below the northwestern Alpine foreland of Switzerland. Geophysical Journal International 169, 1273–1288, DOI: 10.1111/j.1365-264X.2007.03413.x

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.

Lomax, A., Virieux J., Volant P., Thierry-Berge, C. 2000. Probabilistic earthquake location in 3D and layered models. In: C.H. Thurber, and N. Rabinowitz (Eds.): Advances in Seismic Event Location, Kluwer Academic Publishers, Dordrecht/Boston/London, 101–134.

Nabelek, J. & Xia, G. 1995: Moment-tensor analysis using regional data: application to the 25 March, 1993, Scotts Mills, Oregon earthquake. Geophysical Research Letters 22, 13–16.

Pavoni, N. 1977: Erdbeben im Gebiet der Schweiz. Eclogae Geologicae Helvetiae 70/2, 351–370.

Pavoni, N. & Roth, P. 1990: Seismicity and seismotectonics of the Swiss Alps. Results of microearthquake investigations 1983–1988. In F. Roure, P. Heitzmann and R. Polino (Eds.): Deep Structure of the Alps. Mémoire de la Socété géologique de France, 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.

Plenefisch, T. & Bonjer, K.-P. 1997: The stress field in the Rhinegraben area inferred from earthquake focal mechanisms and estimation of frictional parameters. Tectonophysics 275, 71–97.

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.

Saikia, C. K. 1994. Modified frequency-wavenumber algorithm for regional seismograms using Filonís quadrature: Modeling of Lg waves in eastern North America. Geophysical Journal International 118, 142–158.

Sommaruga, A. 1997: Geology of the central Jura and the Molasse basin: new insight into an evaporite-based foreland fold and thrust belt. Mémoire se la Société Neuchâteloise des Sciences Naturelles, Vol. XII, 177 pp.

Waldhauser, F., Kissling, E., Ansorge, J., Mueller, St. 1998: Three-dimensional Interface Modeling with two-dimensional Seismic Data: the Alpine Crust-Mantle boundary. Geophysical Journal International 135, 264–278.

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