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Earthquakes in Switzerland and surrounding regions during 2008

Nicolas Deichmann, John Clinton, Stephan Husen, Florian Haslinger, Donat Fäh,
Domenico Giardini, Philipp Kästli, Urs Kradolfer, Iris Marschall & Stefan Wiemer

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ABSTRACT

This report of the Swiss Seismological Service summarizes the seismic activity in Switzerland and surrounding regions during 2008. During this period, 451 earthquakes and 75 quarry blasts were detected and located in the region under consideration. The three strongest events occurred in the Valais, near Lac des Toules (M_L 3.6), and in Graubünden, near Ilanz (M_L 3.7) and Paspels (M_L 4.0). Although felt by the population, they were not reported to have caused any damage. However, with a total of only 15 events with $M_L \geq 2.5$, the seismic activity in the year 2008 was far below the average over the previous 33 years.

ZUSAMMENFASSUNG

Dieser Bericht des Schweizerischen Erdbebendienstes stellt eine Zusammenfassung der im Vorjahr in der Schweiz und Umgebung aufgetretenen Erdbeben dar. Im Jahr 2008 wurden im erwähnten Gebiet 451 Erdbeben sowie 75 Sprengungen erfasst und lokalisiert. Die drei stärksten Beben haben sich im Wallis, in der Nähe des Lac des Toules (M_L 3.6) sowie in Graubünden bei Ilanz (M_L 3.7) und Paspels (M_L 4.0) ereignet. Mit nur 15 Beben der Magnitude $M_L \geq 2.5$, lag die seismische Aktivität im Jahr 2008 jedoch weit unter dem Durchschnitt der vorhergehenden 33 Jahre.

RÉSUMÉ

Le présent rapport du Service Sismologique Suisse résume l'activité sismique en Suisse et dans les régions limitrophes au cours de l'année 2008. Durant cette période, 451 tremblements de terre et 75 tirs de carrière ont été détectés et localisés dans la région considérée. Les trois évenements les plus forts ont eu lieu en Valais, près du Lac des Toules (M_L 3.6) ainsi que dans les Grisons près d'Illanz (M_L 3.7) et près de Paspels (M_L 4.0). Avec seulement 15 événements de magnitude $M_L \geq 2.5$, l'activité sismique de l'année 2008 est inférieure à la moyenne des 33 années précédentes.

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 summarizing the seismic activity in Switzerland and surrounding regions have been published in the present form (Baer et al. 1997, 1999, 2001, 2003, 2005, 2007; Deichmann et al. 1998, 2000a, 2002, 2004, 2006, 2008). 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; Wiemer et al. 2009). 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; Kastrup et al. 2007).

Data acquisition and analysis

Seismic stations in operation during 2008

The Swiss Seismological Service operates two separate nationwide seismic networks, a high-gain broad-band seismometer

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Swiss Seismological Service, ETH Zürich, Sonneggstrasse 5, CH-8092 Zürich, Switzerland. (http://www.seismo.ethz.ch).

network and a low-gain accelerograph network. 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. Beginning in 2003, efforts are underway to merge these two networks and to record the strong-motion signals continuously and in real-time together with the high-gain signals. First, 12 stations of the high-gain broad-band network have been equipped with an additional accelerometer. Then as of 2006, 10 sites of the existing accelerometer network as well as several new sites have been equipped with modern sensors and digitizers featuring higher dynamic range, broader frequency bandwidth and higher sensitivity (Baer et al. 2007).

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. Moreover, two accelerometers have been installed in the tunnel itself. At the beginning of 2008, an additional broad-band station (PIORA) was put into operation a few km north of this local network to monitor more closely potential seismicity associated with the northward progress of the tunnel construction. These eleven stations are operated under a contract with AlpTransit-Gotthard AG.

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.

A complete list of the available stations in Switzerland and maps with the station locations of the national network as well as of the two local networks in the area of Basel and in the Gotthard region can be found in the annual report for 2006 (Baer et al. 2007). The only changes to the network with respect to 2006 are the removal of two borehole sensors in the Basel area during the course of the summer 2007 (RIEH2 and OTER1 – see Figure 2 of Baer et al. 2007), the installation of an additional strong-motion station (SFRA) in Frenkendorf (BL) at the beginning of December 2007, and, as mentioned above, the integration of station PIORA into the Gotthard network at the beginning of 2008.

To improve the reliability of locations for events at the periphery or outside of Switzerland, we are engaged in an ongoing cross-frontier cooperative effort to exchange seismic data in realtime. Since 2005 we continuously record and archive signals from stations in Austria operated by the Zentralanstalt für Meteorologie und Geodynamik in Vienna (ZAMG) and in Italy operated by the Istituto Nazionale di Geofisica e Vulcanologìa in Rome (INGV), by the Istituto di Geofisica, Università di Genova and by the Zivilschutz der Autonomen Provinz Bozen-Südtirol (Baer et al. 2007). The number of observed stations increases as new high-quality stations come on-line in the border region. In 2008, we have gained real-time access to the stations KIZ, GUT and BFO in southern Germany.

Hypocenter location, magnitude and focal mechanisms

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 Vp/Vs ratio of 1.71.

Local magnitudes (M_L) are calculated from the maximum amplitude of the horizontal components of the digital broadband 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.

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. This procedure, based on a 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.

A more detailed documentation of the data analysis can be found in previous annual reports (Deichmann et al. 2006, Baer et al. 2007).

Seismic activity during 2008

Overview

During 2008, the Swiss Seismological Service detected and located 451 earthquakes in the region shown in Figure 1. Based on such criteria as the time of occurrence, the location, the signal character or on direct communication, 75 additional seismic events were identified as quarry blasts.

Magnitude values of the events recorded in 2008 range from M_L 0 to 4.0. The events with $M_L \geq 2.5$ 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 1 and 2.

Figure 3 shows the epicenters of the 822 earthquakes with $M_L \geq 2.5$, which have been recorded in Switzerland and surrounding regions over the period of 1975–2008. These events represent about 8% of the total number of events detected during that time period in the same area. The chosen magnitude threshold of 2.5 ensures that the data set is complete for the

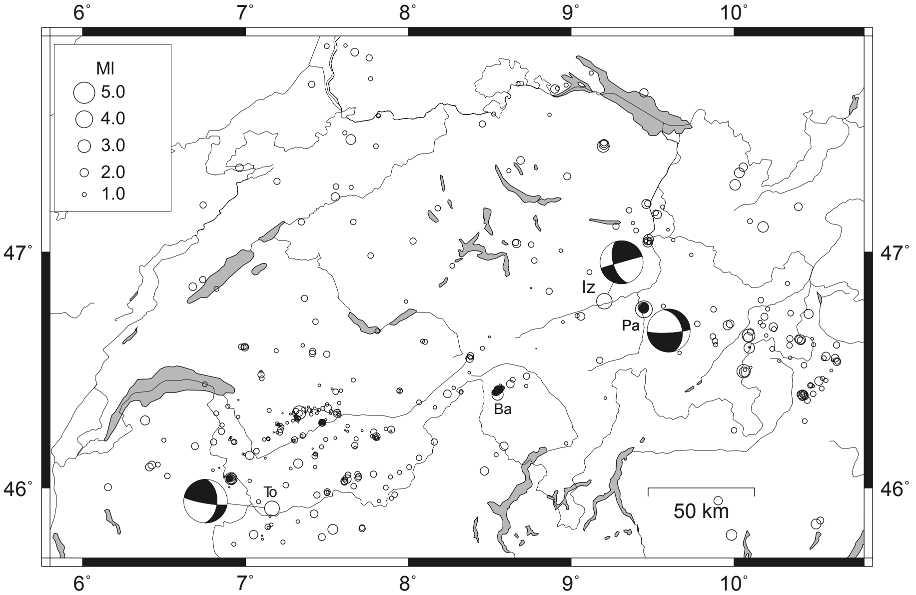

Fig. 1. Epicenters and focal mechanisms of earthquakes recorded by the Swiss Seismological Service during 2008. Epicenters of events mentioned in the text are Val Bavona (Ba), Ilanz (Iz), Lac des Toules (To) and Paspels (Pa).

Table 1. Earthquakes with $M_L > 2.5$.

Date & Time UTC		Lat. [° N]	Lon. [° E]	X / Y [km]	Depth [km]	Mag. [M_L]	Q	Location
2008.01.08	21:41:14	46.596	10.095	803/164	7	2.5	B	Val Trupchun, GR
2008.01.21	16:40:36	46.759	9.447	753/181	8	4.0	A	Paspels, GR
2008.01.21	16:46:44	46.767	9.444	753/181	8	2.6	A	Paspels, GR
2008.02.17	12:41:31	45.920	7.171	579/ 85	7	3.6	B	Lac des Toules, VS
2008.04.17	01:07:37	46.649	10.090	803/170	5	3.1	A	Brail, GR
2008.04.17	21:42:05	46.398	8.548	685/139	7	2.7	B	Val Bavona, TI
2008.06.17	19:48:08	46.321	7.331	592/130	7	3.3	A	Glarey, VS
2008.07.19	23:30:07	47.105	10.178	808/221	3	2.5	C	Arlberg, A
2008.07.24	04:14:08	46.039	6.916	560/ 99	5	2.6	A	Vallorcine, F
2008.08.25	03:10:41	45.799	9.986	798/ 75	3	2.6	B	Endine, I
2008.11.09	07:22:31	46.793	9.204	735/184	8	3.7	A	Ilanz, GR
2008.11.20	13:20:19	46.040	6.912	559/ 99	5	2.9	A	Vallorcine, F
2008.12.13	06:02:24	46.498	10.059	801/153	1	3.3	B	La Stretta, GR
2008.12.16	00:34:33	47.443	9.197	733/256	8	2.9	B	Flawil, SG
2008.12.16	11:22:20	47.281	10.007	794/240	3	2.5	B	Schoppernau, A

given period and that the number of unidentified quarry blasts and of badly mislocated epicenters is negligible.

Significant earthquakes of 2008

Paspels

The strongest earthquake in Switzerland and surroundings during 2008 occurred on January 21st at 17:40 local time. Its magnitude was M_L 4.0 (M_w 3.7) and its epicenter was located near the village of Paspels, 6–7 km N of Thusis (GR). Epicentral intensity reached IV-V and it was clearly felt all over southeastern Switzerland (Figure 4). Three instruments of the strong-motion

Table 2. 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	≤1.5 × Z	≤ 2	≤ 3
B	≤200	≤25	≤ 5	≤10
C	≤270	≤60	≤10	>10
D	>270	>60	>10	>10

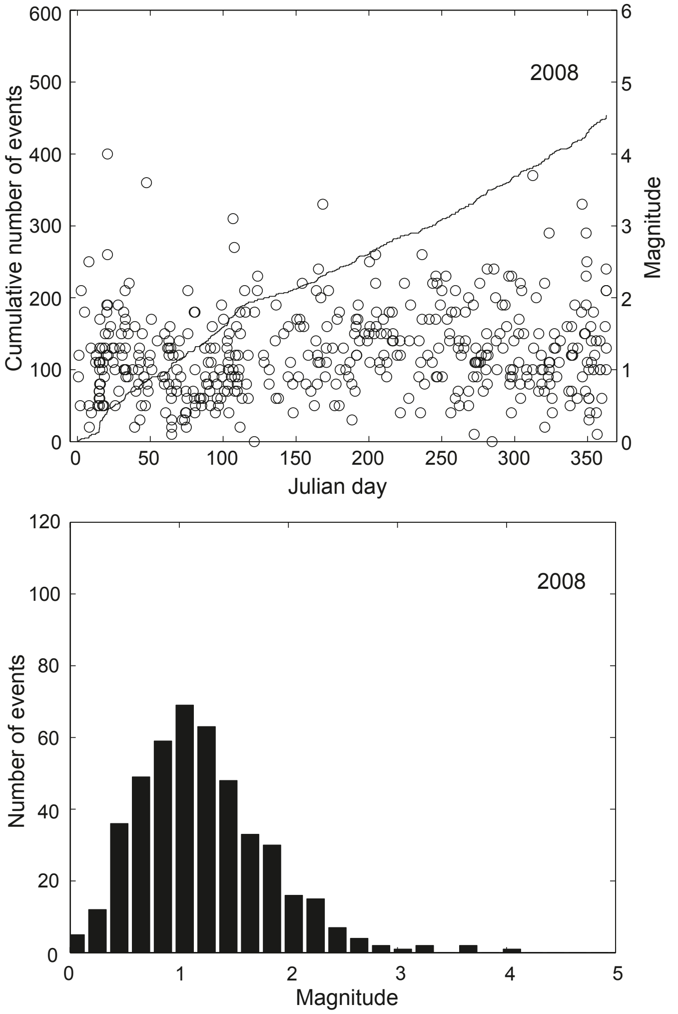

Fig. 2. Earthquake activity during 2008: magnitude of each event and cumulative number of events (above); histogram of magnitudes (below).

network situated at epicentral distances of 9 to 13 km were triggered by the quake and recorded peak horizontal ground accelerations between 0.21 and 0.34 m/s^2.

This earthquake was part of a sequence of 32 events that started in August 2007 and continued throughout the year 2008 (Figure 5). Shortly after the mainshock, a temporary seismograph was installed in the immediate epicentral area. Between January 26th and 30th, this instrument recorded four aftershocks ($0.5 \geq M_L \leq 1.5$) that were detected also by the national network out to epicentral distances of 70–80 km.

With epicentral distances of about 1 km and travel-time differences between the S- and P-arrivals of about 1 s at this temporary station, the focal depths calculated for these four aftershocks vary between 8 and 9 km. This is in good agreement with the value of 7 km obtained for the mainshock from the routine location based on the 3D velocity model. As can be seen from the good agreement between the relative travel times of the reflections at the crust-mantle boundary (Moho) observed at station WILA (Figure 6), the focal depth of the mainshock and the first of the four aftershocks recorded by the temporary station must be practically identical. To calculate the take-off angles of the rays at the source for the fault-plane solution, we fixed the focal depth of the mainshock at 8 km.

The resulting focal mechanism is somewhat unusual, with one near-vertical E–W striking nodal plane and one N–S striking nodal plane dipping rather flatly to the E (Figure 7). The unusual dip of the latter is well-constrained by the downward polarities of Pn refractions at the Moho observed at numerous stations in southeastern Germany. Moreover, the general type of mechanism is also matched by the result of the full-waveform moment tensor inversion, although, as listed in Table 3, the orientation of the P-axes differs by 20 degrees.

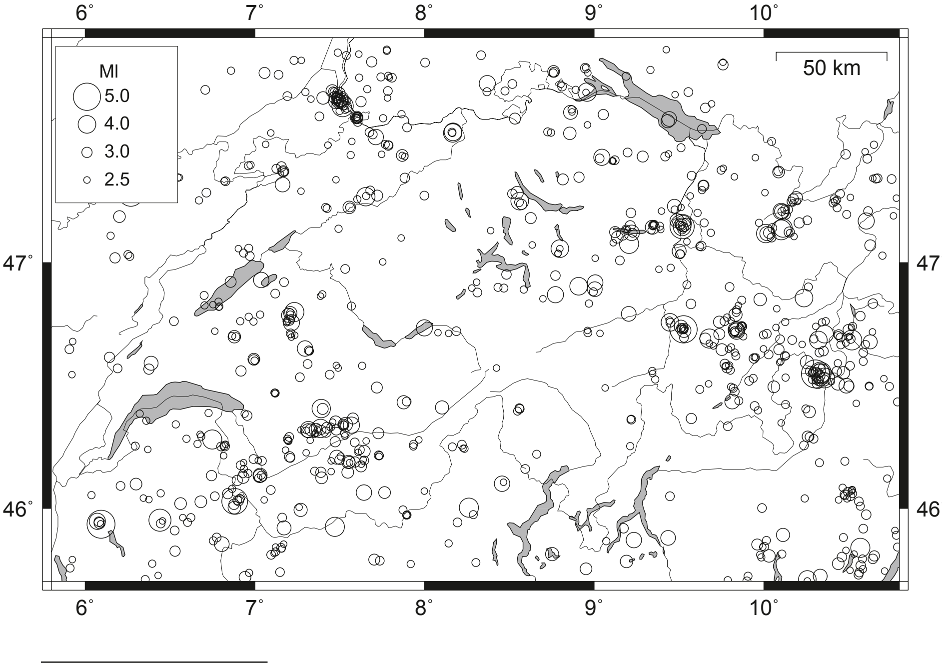

Fig. 3. Epicenters of earthquakes with Magnitudes $M_L \geq 2.5$, during the period 1975–2008.

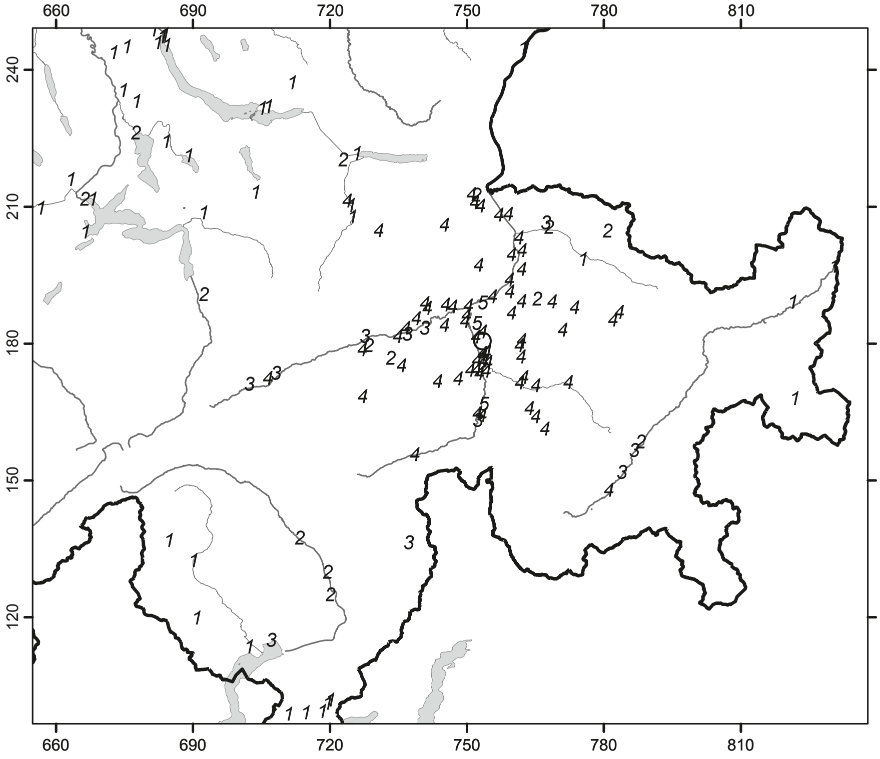

Fig. 4. Macroseismic intensities (EMS98) for the M_L 4.0 event near Paspels (GR). The Swiss cartesian coordinates are labeled in km.

Lac des Toules

On February 17th at 13:41 local time an earthquake with M_L 3.6 occurred in the region between Bourg Saint Pierre and the Col du Grand Saint Bernard. The epicenter was located about 3 km west of Lac des Toules. The calculated focal depth of 7 km is poorly constrained, and the distribution of travel-time residuals and a qualitative assessment of the waveform character at the closer stations suggest that it could be shallower. A shallow focal depth would also be in agreement with the relatively few reports of it having been felt beyond the immediate epicentral area and with the focal depth of 5 km obtained from the full-waveform inversion for the moment tensor (Figure 8). The faultplane solution and the best double couple moment tensor match each other to within 10 degrees (Table 3). The resulting focal mechanism corresponds either to dextral strike-slip motion on a N–S striking and flatly inclined fault or to obliquely upward directed slip on a steeply dipping, WNW–ESE striking fault. The extensional axis is inclined at more than 30 degrees and is oriented in a NNW–SSE direction. For the Penninic domain of the Valais, which is otherwise known for its normal faulting regime with flat-lying T-axes (e.g Kastrup et al. 2004), this focal mechanism is rather unusual.

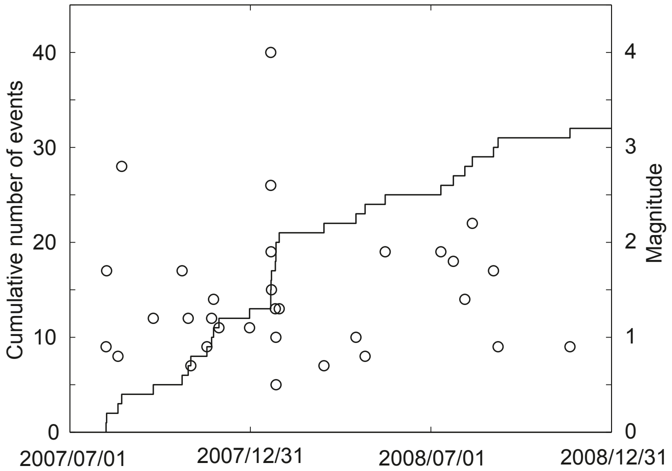

Fig. 5. Cumulative number of events and event magnitudes of the Paspels sequence.

Val Bavona

With a magnitude M_L 2.7, the earthquake that occurred on April 17th at the upper end of Val Bavona, in northern Ticino, was not particularly significant in itself. However it is part of a sequence of 29 events with M_L between 0.6 and 2.7 that occurred in a region which is not known for its seismic activity. About half of the events in this sequence were detected only by the local network installed in the Gotthard region and their signals were integrated into the SED data archive at a later stage. The first event of this sequence was recorded on February 4th and most

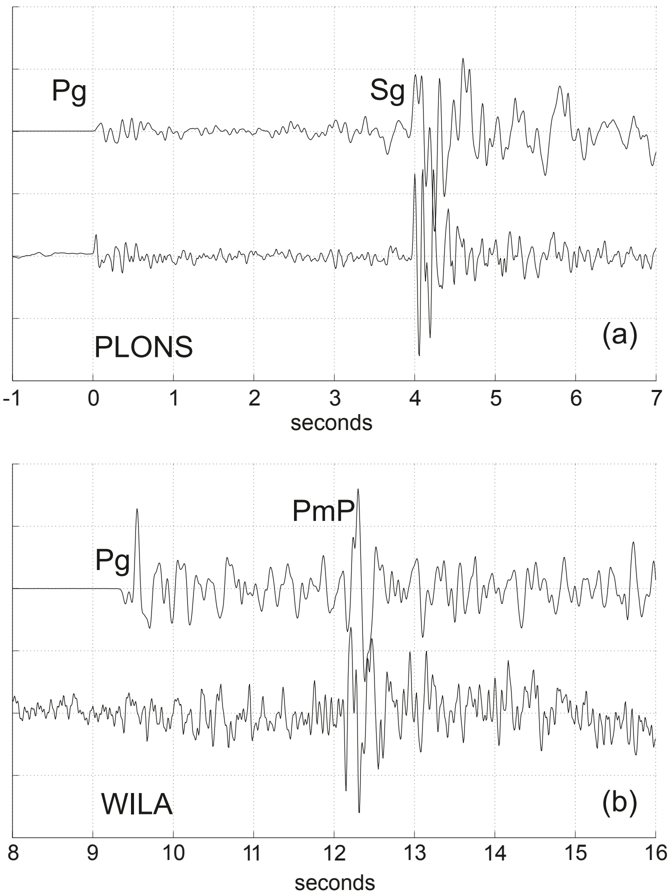

Fig. 6. (a) Seismograms of the M_L 4.0 mainshock (above) and the M_L 1.3 aftershock of 2008/01/26 06:16 (below) recorded at station PLONS (epicentral distance 33 km, azimuth 350 degrees), band-pass filtered 1–10 Hz. (b) Seismograms of the same two events recorded at station WILA (epicentral distance 84 km, azimuth 331 degrees), band-pass filtered 2–10 Hz. Both pairs of traces are aligned with respect to the Pg arrival times at station PLONS. The nearly identical travel times of the Sg phase at PLONS and of the PmP phase at WILA for the two events show that their sources must be located at similar depths.

of the events occurred during the months of February, March and April, but activity persisted through to December.

Ilanz

In the morning of November 9th (08:22 local time) the area around Ilanz (GR) was jolted by an earthquake with M_L 3.7. The epicenter of the earthquake, which was felt throughout northern Graubünden, Glarus and parts of Uri, was located about 2 km N of Ilanz (Figure 9). Since the nearest station (LLS) is located at an epicentral distance of 16 km, the routinely calculated focal depth of 4 km is not well constrained. Lacking observations from stations close to the epicenter, calculated focal depths are constrained mainly by arrivals refracted (Pn) or reflected (PmP) at the Moho. However, the results, particularly for shallow sources, are very sensitive to the crustal velocity model and the assumed Moho topography.

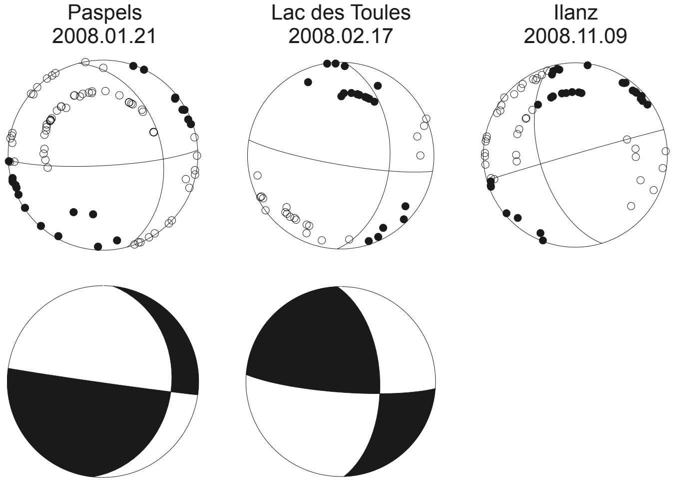

Fig. 7. Faultplane solutions based on first-motion polarities (above) and optimal double-couple moment tensors based on full-waveform inversion (below). All stereographs are lower hemisphere, equal area projections. Solid circles and shaded quadrants correspond to compressive first motion (up); empty circles and white quadrants correspond to dilatational first motion (down).

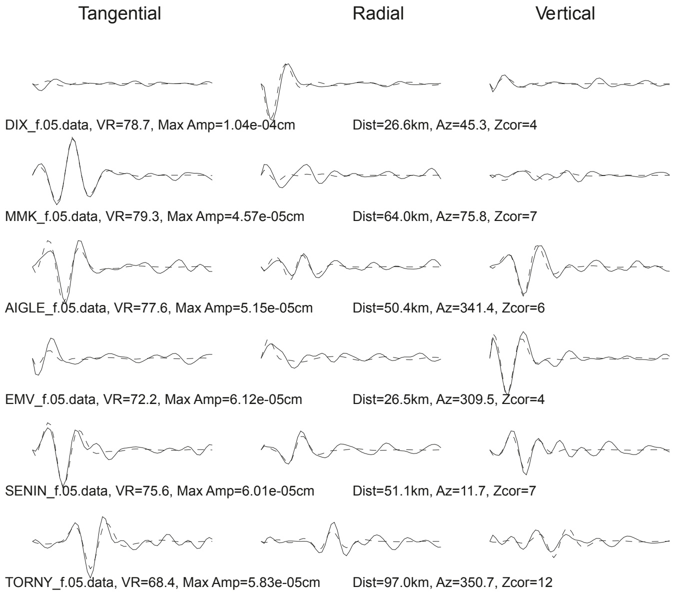

Fig. 8. Recorded signals (continuous lines) and synthetic seismograms (dashed lines) used for the calculation of the moment tensor of the Lac des Toules event shown in Figure 7.

The Paspels earthquake of January 21st, 2008, with its epicenter only 15 km east of Ilanz and with its well-constrained focal depth, offers a unique opportunity to calibrate the velocity model and thus to determine the focal depth of the Ilanz quake relative to that of the Paspels event by means of 2D

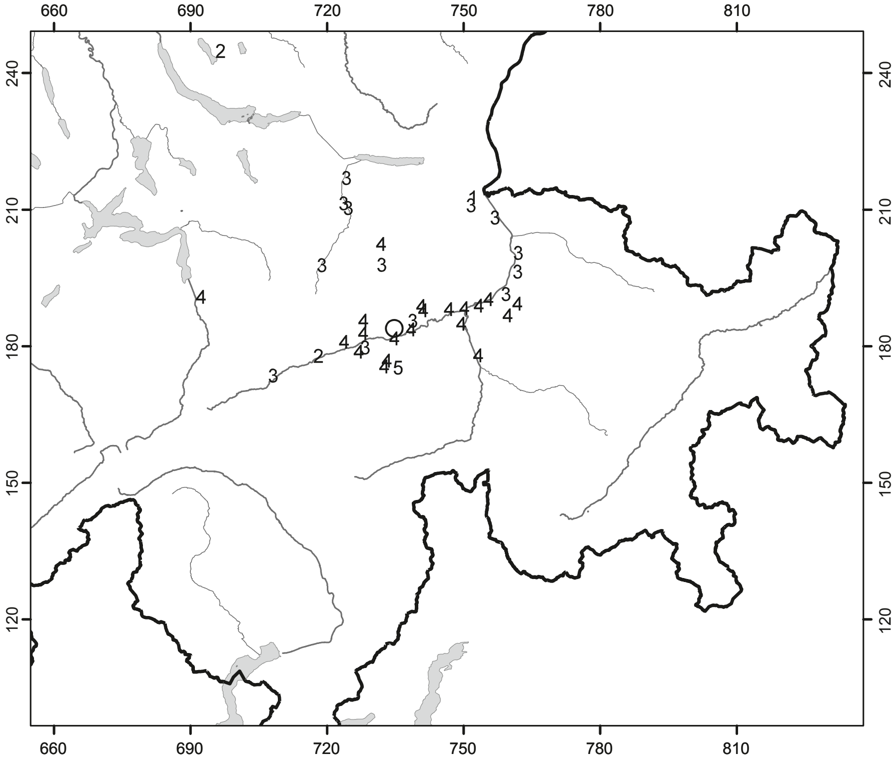

Fig. 9. Macroseismic intensities (EMS98) for the M_L 3.7 event near Ilanz (GR). The Swiss cartesian coordinates are labeled in km.

Table 3. Focal mechanism parameters based on first-motion polarities (lines with M_L) and on an automated full-waveform inversion method (lines with M_w).

Location	Date & Time [UTC]	Depth [km]	Mag.	Plane 1 Strike/Dip/Rake	Plane 2 Strike/Dip/Rake	P-Axis Az/Dip	T-Axis Az/Dip
Paspels	2008/01/21 16:40	8	M_L 4.0	345/38/–015	087/81/–127	322/42	205/27
		11	M_w 3.7	007/29/ 000	098/90/–119	342/38	214/38
Lac des Toules	2008/02/17 12:42	7	M_L 3.6	002/46/ 169	100/82/ 045	223/23	331/36
		5	M_w 3.4	358/56/ 169	094/81/ 034	222/16	322/30
Ilanz	2008/11/09 07:22	8	M_L 3.7	163/58/–001	254/89/–148	123/23	024/21

ray tracing. Ray trace models for both earthquakes were constructed based on the Moho model of Waldhauser et al. (1998) for an azimuth of 320 degrees, equivalent to a NW direction with respect to both Paspels and Ilanz. Figure 10 shows the ray-tracing results for these two earthquakes, assuming a focal depth of 8 km for the Paspels event. Travel times for the Ilanz event were calculated for several focal depths between 4 and 9 km. The best match of the Pn travel times at stations FELD and KIZ, southern Germany, was obtained at the same focal depth for both events. Thus, for determining the focal mechanism of the Ilanz event, the take-off angles were calculated with a source depth fixed at 8 km. Given the large number of azimuthally well-distributed stations that recorded this event, the faultplane solution is well constrained. The result is a strike-slip mechanism with NNW–SSE and ENE–WSW striking nodal planes (Figure 7).

Discussion

In 2008, as in previous years, most of the earthquakes, including the 6 events with $M_L > 3$, occurred in the Valais and in Graubünden. Routinely calculated focal depths for all but 10 events recorded in 2008 are less than 16 km. All the deeper hypocenters, with a maximum depth of 27 km, are below the Molasse Basin and Jura of northern Switzerland and southern Germany. Of the 451 earthquakes recorded in 2008, 29 were part of the Val Bavona sequence and 19 were part of the Paspels sequence. The seismic activity induced by the geothermal project in Basel in 2006 and 2007 (e.g. Deichmann & Ernst 2009; Deichmann & Giardini 2009) continued to decrease over the year 2008, and the events that have been recorded by the local borehole seismometers were too weak to be detected by the national broad-band network. The total number of only

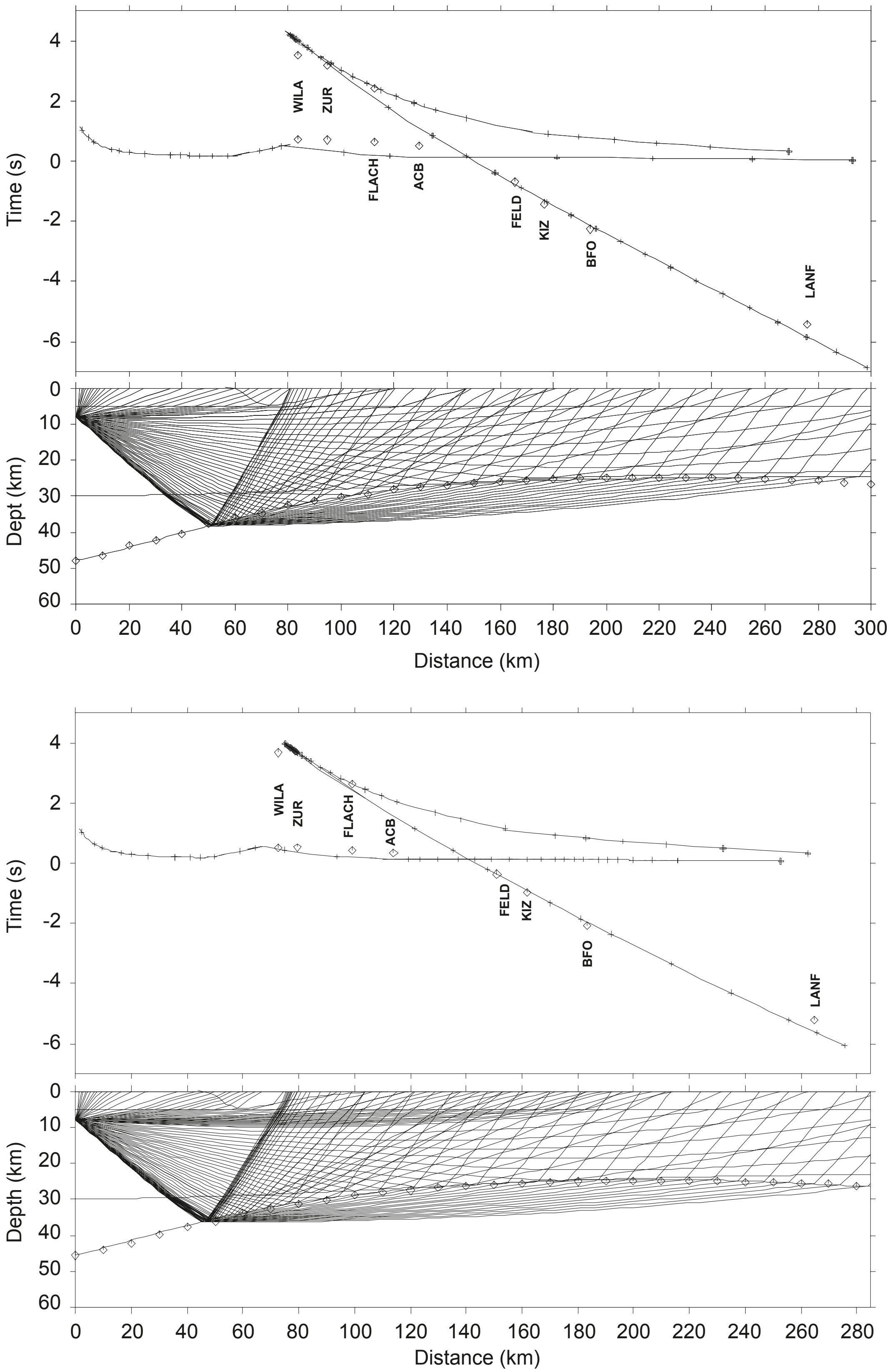

Fig. 10. Comparison of the 2D ray tracing models for the Paspels (above) and the Ilanz earthquakes (below), assuming a focal depth of 8 km for the Ilanz earthquake. The time axes are plotted with a reduction velocity of 6 km/s.

15 events with $M_L \geq 2.5$ was far below the 24 to 25 events per year observed on average over the previous 33 years in this magnitude category. Thus the general trend of lower than average activity, that started in 2005, persisted through the year 2008.

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