NORSAR Scientific Report No. 2-2011

Semiannual Technical Summary

1 January - 30 June 2011

Frode Ringdal (ed.)

Kjeller, August 2011

6.3 The 21 July 2011 earthquake in Hedmark, Southern Norway

6.3.1 Introduction

On 21 July 2011, at 02:59 local time an earthquake with a local magnitude of about 3.8 awaked many people in Hedmark, Southern Norway. A very preliminary automatic location of the event clearly located the earthquake within the NORSAR array (NOA), between the communities of Elverum and Rena, about 40 - 50 km north of the 07 April 2004 Flisa earthquake (see Fig. 6.3.1 and Schweitzer (2005)). With the 42 seismic sites of the NORSAR array at epicentral distances between about 10 and 60 km from the event and several additional seismic stations in the region, it was possible to perform a high quality determination of the hypocenter.

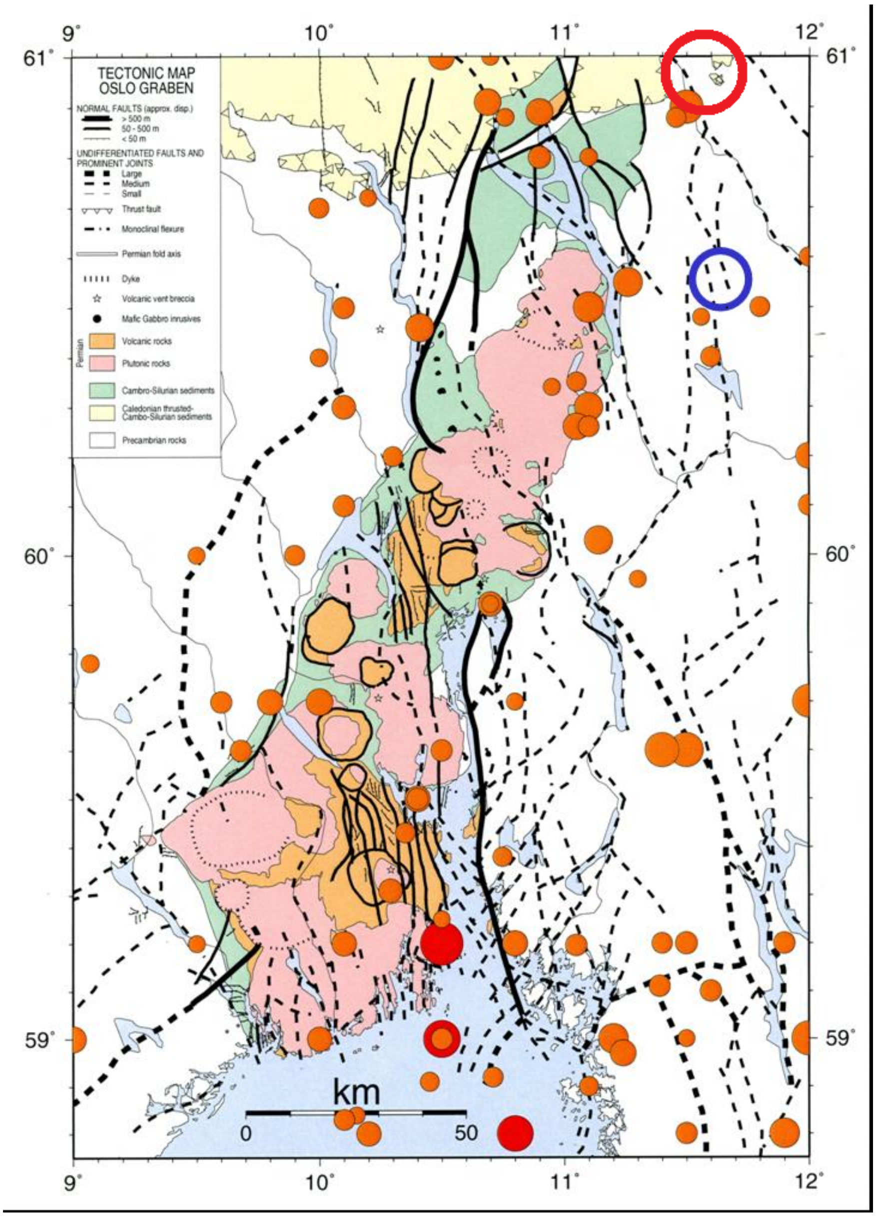

Fig. 6.3.1. Map (modified from Hicks, (1996)) of historical seismicity in south-east Norway around the Oslo Graben and the source regions of the 21 July 2011 Elverum-Rena (red circle) and of the 07 April 2004 Flisa earthquakes (blue circle, Schweitzer 2005).

6.3.2 Data analysis

Although the earthquake had been recorded with very impulsive first onsets by the different sensors at local distances, reading the exact onset times of the different seismic phases at the NOA stations became difficult; due to the large amplitudes, an acausal ringing effect of the antialias FIR filter in the digitizers is visible at all seismic traces and disturbs the onset time reading. The top trace in Fig. 6.3.2 shows the start of the raw earthquake recording, sampled with a rate of 40 Hz, at the closest NOA site NC403; the FIR filter effect is obvious. Bandpass filtering of the record between 0.01 and 15 Hz does not and cannot fully remove the filter effect (second trace from top). Since we know the FIR filter response of the SHI digitizers installed at NOA, we can use this to correct the observations. The third trace shows the original seismogram now deconvolved with the known instrument response (Pirli & Schweitzer, 2007). There is still some high frequency ringing visible, which totally disappears after filtering the seismogram with the mentioned Butterworth bandpass filter (Fig. 6.3.2, bottom trace). On such processed seismogram records, the onset time of the first P phase could be picked with an uncertainty of +/- 1 or 2 samples (0.025 - 0.05 s).

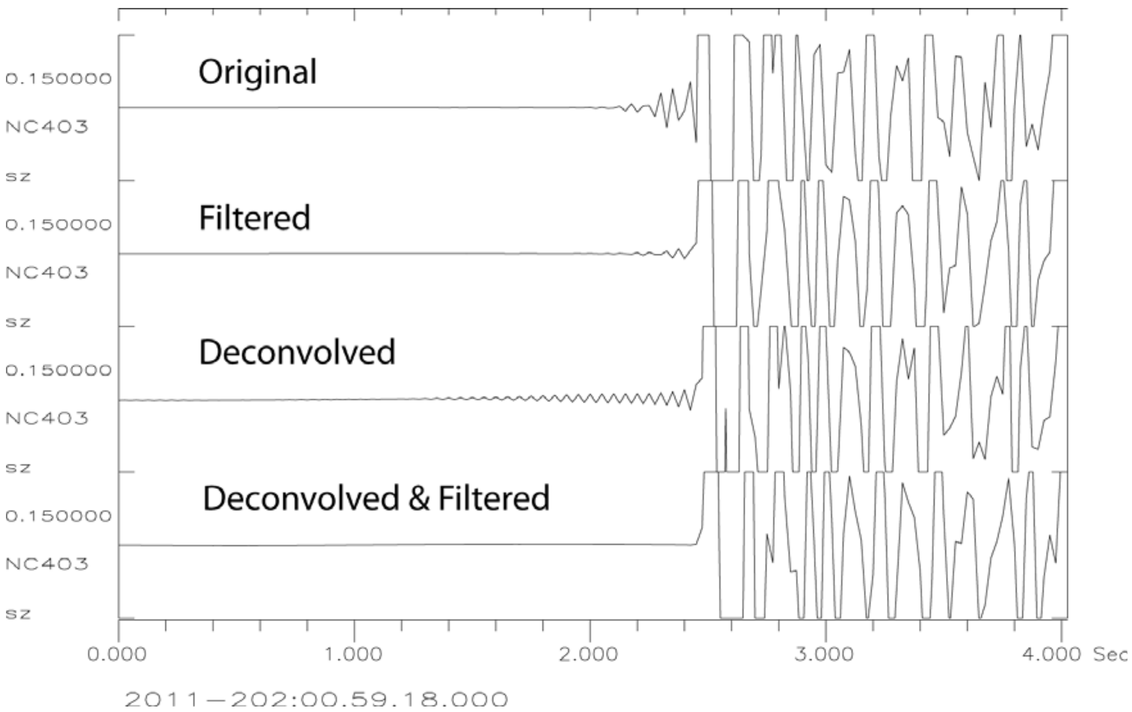

Fig. 6.3.2. First P-onset records of the 21 July 2011 earthquake at NOA site NC604. On top the original observations, as second trace a Butterworth bandpass 0.01 - 15 Hz filtered trace, as third trace the original trace deconvolved with the instrument and digitizer response, and on bottom the deconvolved trace additionally filtered with the Butterworth bandpass. All traces were normalized with the maximum P-wave amplitude.

The S-onsets could be read with an uncertainty of +/- 0.1 s on the rotated radial and transverse components at the 7 3-component NOA sites. S-onsets at the other NOA sites with vertical instruments only could be read with an uncertainty of +/- 0.3 s. For each of the 7 NOA subarrays, beams were calculated to estimate apparent velocities and backazimuths of the P and S onsets. With these 145 NOA observations plus some additional readings from the Hagfors array in Sweden, a seismic station at the University of Oslo and a test installation at NOA site NC6, altogether 165 observed parameters could be used to estimate the hypocenter (see also

Fig. 6.3.3). Fig. 6.3.4 shows a map of all stations, which have been used and the best achieved event location.

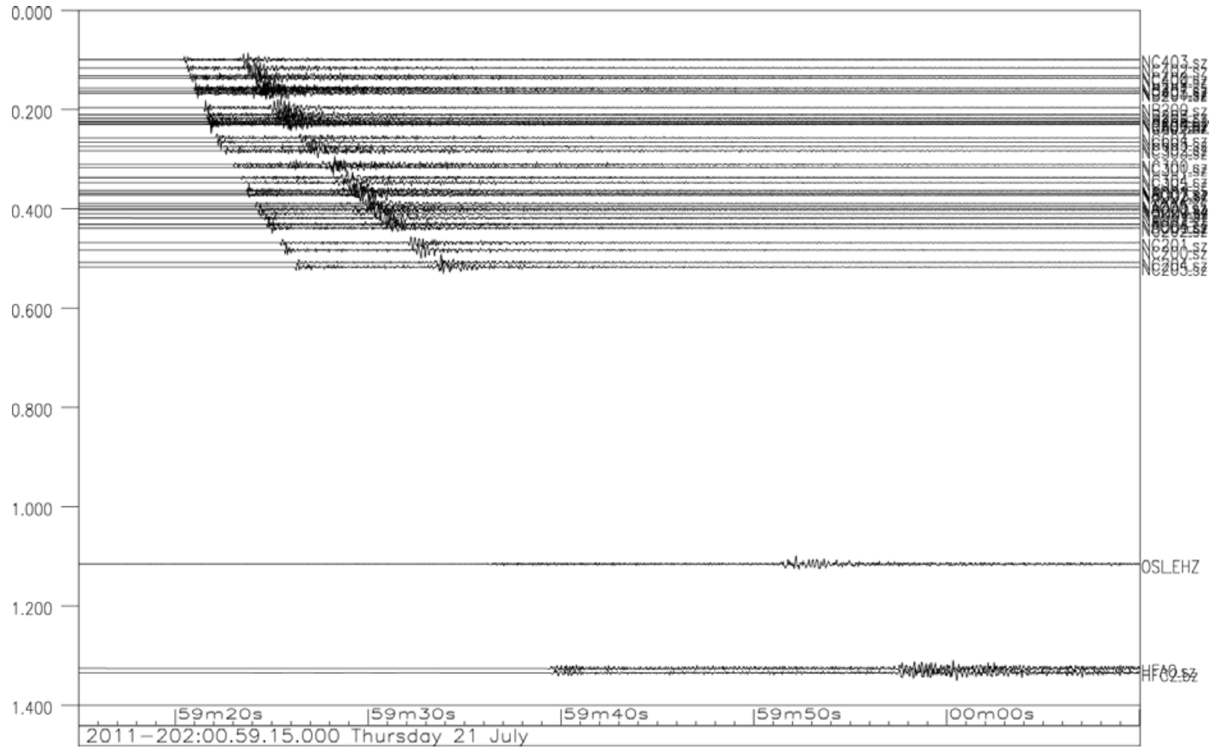

Fig. 6.3.3. All analyzed vertical traces used to locate the 21 July 2011 earthquake are shown as a function of epicentral distance. Normalized, unfiltered data are plotted.

6.3.3 The Elverum-Rena earthquake as ground-truth event

The 21 July 2011 earthquake was located using HYPOSAT (Schweitzer, 2001; 2002). The same velocity model as derived and systematically studied for the 7 April 2004 Flisa event could be used since the observing seismic stations are almost identical and the epicenters do not differ much; the seismic velocity model was published in Schweitzer (2005, Table 6.3.2 therein).

In Table 6.3.1 different locations for the 21 July 2011 earthquake are listed. All these locations with their error ellipses are plotted on the map of Fig. 6.3.4. All locations are very close to each other and their error bars overlap. The velocity model used had been defined by Schweitzer (2005) with discussing several parameters, which may influence the location (v_p/v_s velocity ratio and the depth of the main discontinuities Moho and Conrad). Applying this model for the 21 July 2011 event in the same larger source region together with only local and near regional observations gives very small (formal) location uncertainties and high confidence in the inversion results.

Although this event was not very large (reported magnitudes are between 3.3 and 3.8), it had been observed at local, regional, and teleseismic distances. With such a large number of close by seismic stations and observations, the GT level of this event is of interest. The given uncertainties for the location presented herein were calculated for 99.99% confidence limit. Based on these results, the epicenter can be addressed as a GT-1 event. With several NOA sites at epicentral distances of 10 to 20 km and in different azimuthal directions even the depth of the event is well defined with an uncertainty of less than +/-1 km.

Table 6.3.1. List of locations for the 21 July 2011 earthquake in Hedmark, Southern Norway.

Source	Origin Time	dTo [s]	Latitude [deg]	Longitude [deg]	Depth [km]	dho [km]	Error Ellipse			RMS [s]
							Major [km]	Minor [km]	Azimuth [deg]	
NORSAR (web info)	00:59:16	-	60.98	11.58	~10	-	-	-	-	
NORSAR (analyst reviewed)	00:59:15.73		60.9774	11.5882	13.68		3.7	3.4	146.5	2.11
IDC (REB)	00:59:15.79	0.52	60.9571	11.5708	16.2	5.8	7.0	4.3	99	0.77
University of Bergen (web info)	00:59:16.9	-	60.955	11.579	17.7	-	-	-	-	-
NORSAR (this study)	00:59:16.38	0.08	60.9642	11.5849	22.8	0.8	0.5	0.5	55	0.13

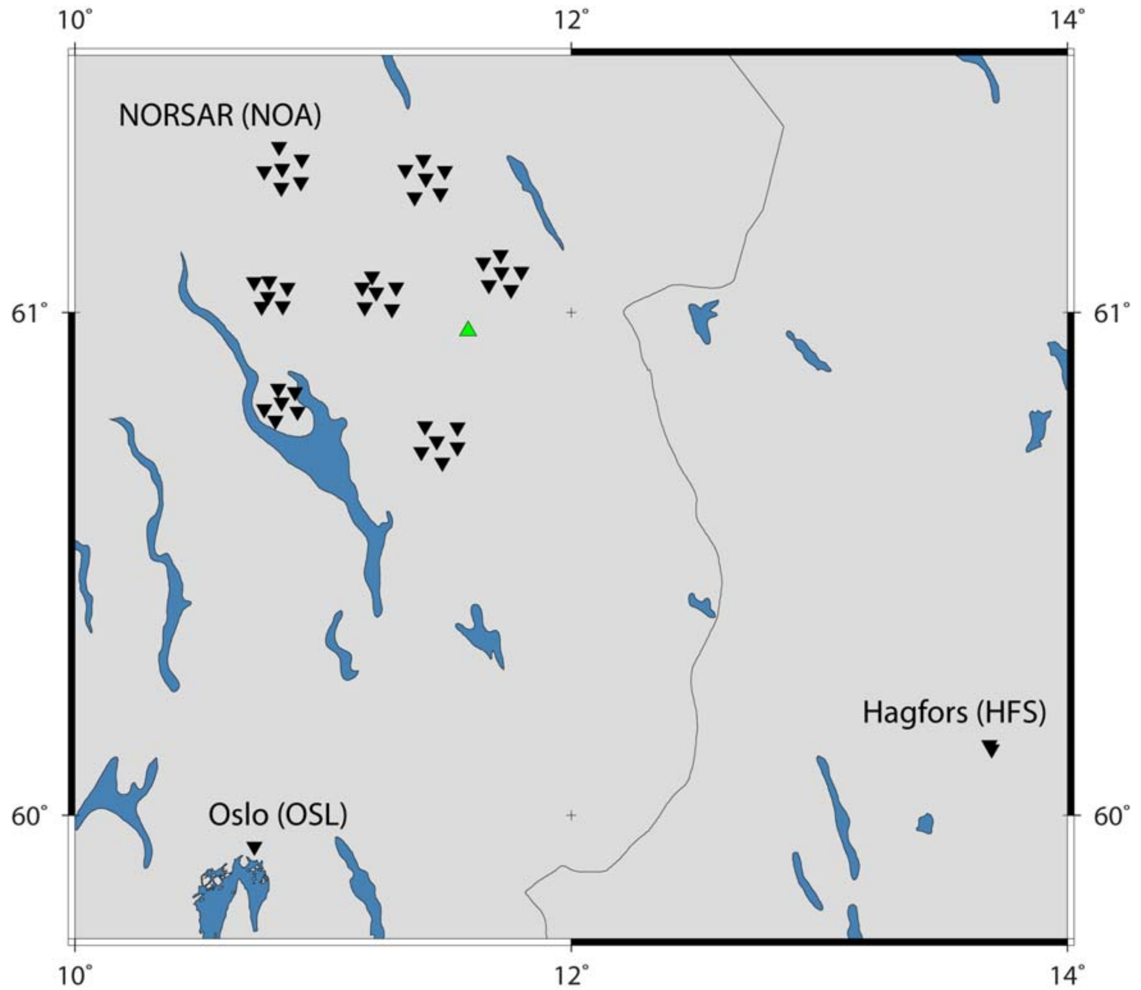

Fig. 6.3.4. Map of the new location of the 21 July 2011 (green triangle) and the seismic stations (black inverted triangles) used for its determination.

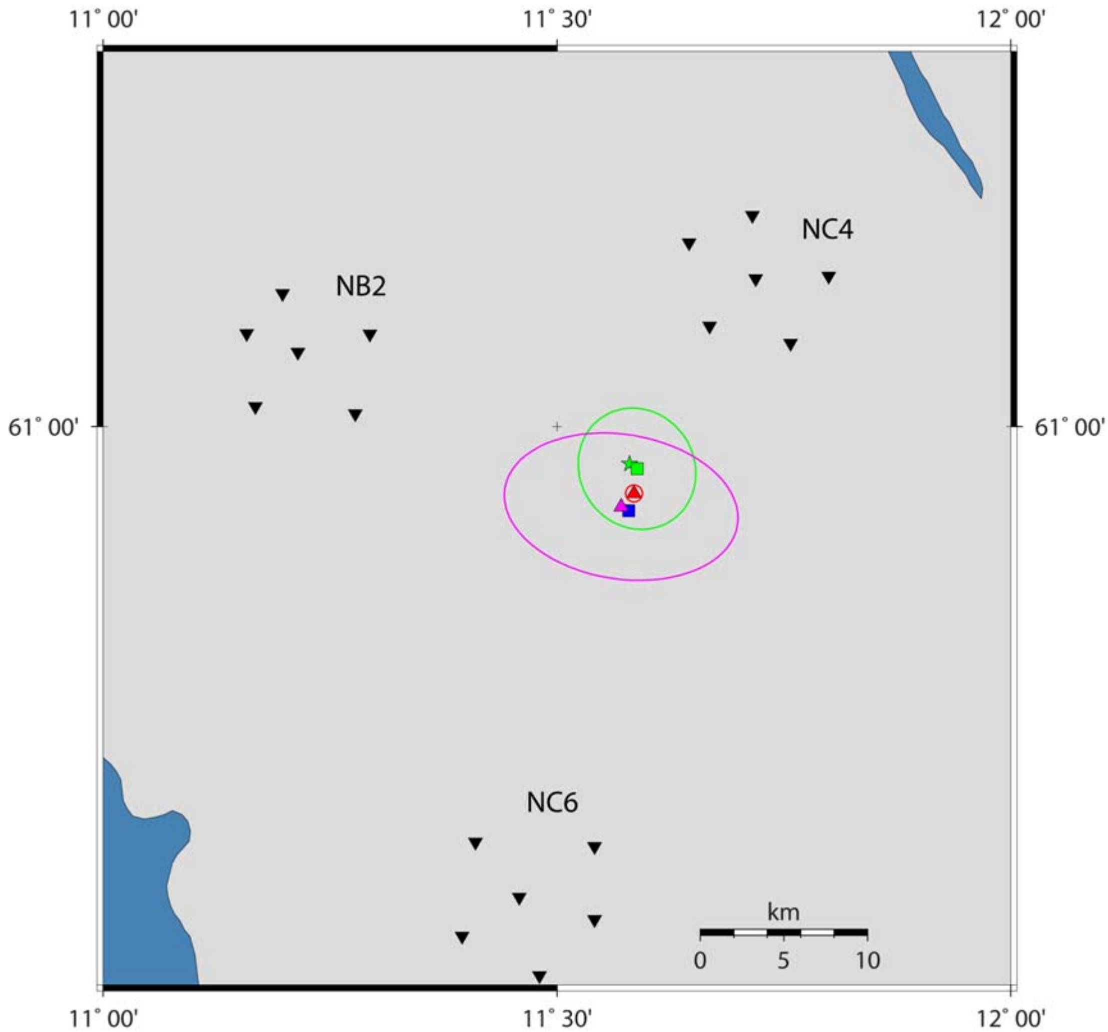

Fig. 6.3.5. Close up map with the different locations of the 21 July 2011 earthquake as listed in Table 6.3.1: NORSAR (Web info) green star, NORSAR (analyst reviewed) green square, IDC (REB) magenta triangle, University of Bergen (web info) blue square, NORSAR (this study) red triangle. Additionally, corresponding location uncertainty ellipses are shown, when available, as well as the nearest seismic stations of the NORSAR array.

6.3.4 Fault plane solution for the 21 July 2011 earthquake

At all stations used to locate the event and at a smaller number of stations at regional distances P-onset polarities and some SH and SV polarities could be read. In addition, some amplitude ratios between the P and the S (SV and SH) onsets were measured. All these data were inverted for the best fitting double couple solution. The FOCMEC inversion routine (Snoke, 2003) was applied to calculate all possible fault planes, which are in agreement with the observed data. The assumption for this type of inversion is that a single double couple can describe the source mechanism. Fig. 6.3.6 shows all observed P polarities and the results from FOCMEC. The triangles represent negative and the circles positive polarities. The B-axis, where the two possible fault planes intersect, is not very well defined due to station distribution and due to the fact that many stations in the South are located beyond the Teisseyre-Tornquist zone, which is known to block seismic wave propagation (Schweitzer, 1997). However, systematic search for more polarity data may constrain the solution better.

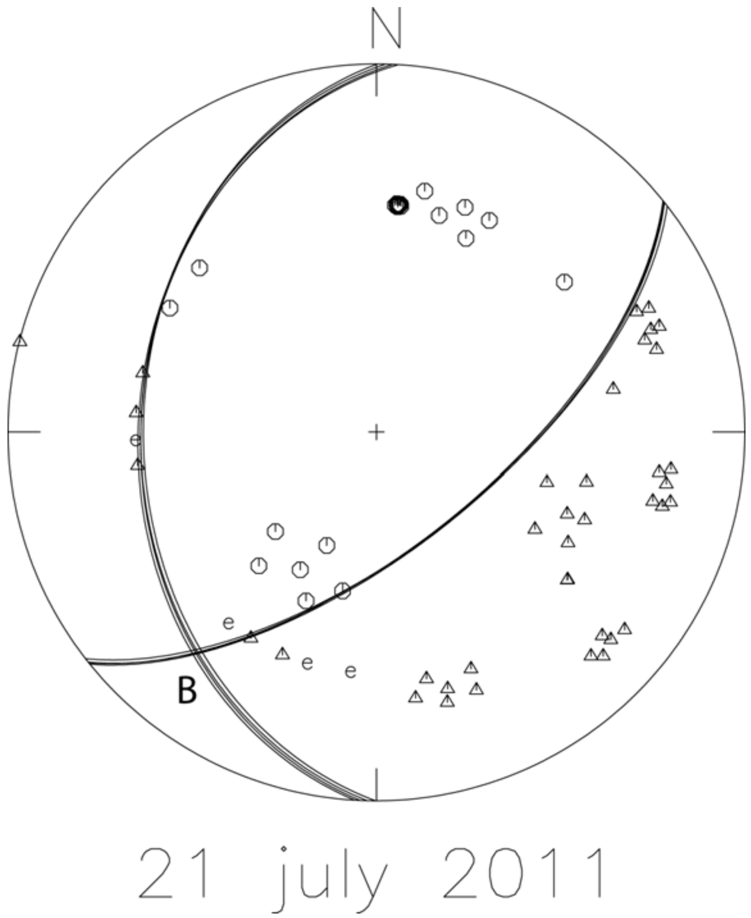

Fig. 6.3.6. The estimated fault plane solution for the 21 July 2011 earthquake and all P polarities (positive circles, negative triangles).

The presented double couple solution shows a reverse fault with a general NNE - SSW strike. This feature will also not change with a better defined solution. From the observed data, it is not possible to decide, which of the two possible planes is the actual fault plane.

However, many earthquakes in and around the Oslo Graben area show north-south striking fault planes with a large variation in the orientation of the auxiliary plane; almost every type of source mechanism can be observed: normal faulting, strike-slip movements, and reverse faulting (see e.g., Hicks et al., 2000; Lindholm et al., 2000).

Johannes Schweitzer

Acknowledgements

Thanks to the kind contribution of the station owners, seismic data from the Swedish Auxiliary IMS array Hagfors, the Norwegian National Seismic Network, the British Geological Survey, the University of Helsinki, the German Regional Seismic Network, the Geological Survey of

Denmark and Greenland, and the University of Oulu could be analyzed and were used to locate the event and to determine the focal mechanism.

References

Hicks, E. C. (1996). Crustal stresses in Norway and surrounding areas as derived from earthquake focal mechanism solutions and in-situ stress measurements. Cand. Scient. Thesis, University of Oslo, Norway, 164 pp.

Hicks, E.C., H. Bungum & C.D. Lindholm (2000). Stress inversion of earthquake focal mechanism solutions form onshore and offshore Norway. Norsk Geologisk Tidsskrift, **80**, 235-250.

Lindholm, C.D., H. Bungum, E. Hicks & M. Villagran (2000). Crustal stress and tectonics in Norwegian regions determined from earthquake focal mechanisms. In: Nottvedt et al. (eds). Dynamics of the Norwegian Margin. Geological Society London, **167**, 429-439.

Pirli, M. & J. Schweitzer (2007). Overview of NORSAR sytem response. NORSAR Sci. Rep., **1-2008**, 64-77.

Schweitzer, J. (1995). Blockage of regional seismic waves by the Teisseyre-Tornquist zone. Geophys. J. Int., 123, 260-276.

Schweitzer, J. (2001). HYPOSAT – An enhanced routine to locate seismic events. Pure Appl. Geophys., **158**, 277-279.

Schweitzer, J. (2002). PD11.1: User Manual for HYPOSAT (including HYPOMOD). In: Bormann, P. (ed.) (2002). IASPEI New Manual of Seismological Observatory Practice, GeoForschungsZentrum Potsdam, Vol. 2, 15 pp.

Schweitzer, J. (2005). The 7 April 2004 Flisa, Southern Norway earthquake sequence - eight hypocenter determinations and one focal mechanism. NORSAR Sci., **Rep. 1-2005**, 62-75.

Snoke, J. A. (2003). FOCMEC: FOcal MEChanism determinations. In: Lee, W. H. K., H. Kanamori, P. C. Jennings & C. Kisslinger (eds). International Handbook of Earthquake and Engineering Seismology. Academic Press, San Diego, Chapter 85.12.