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RELOCATION OF EARTHQUAKES IN WEST BOHEMIAN/VOGTLAND SUBREGIONS LAZY, KLINGENTHAL AND PLESNÁ USING THE MASTER EVENT METHOD

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ABSTRACT
The Master event location method (MEM) is used to relocate the earthquakes that occurred in the subregions Lazy, Klingenthal and Plesná of the West Bohemian/Vogtland earthquake swarms region during the second half of the 1990's as recorded by the seismic network Webnet. The crustal velocity in each of these subregions is modeled by a homogeneous layer, representative for the given subregion in the frame of 1-D models. The relocation in the subregion Lazy confirms the distribution of hypocenters obtained by the grid search (GS) location i.e. their division into two separated groups that might reveal the position of two almost vertical faults. These faults are in general agreement with faults shown on the geological map of this area. The relocated clusters of hypocenters in subregions Klingenthal and Plesná are almost identical with the corresponding GS location.

KEYWORDS: West Bohemian/Vogtland earthquake swarm subregions Lazy, Klingenthal and Plesná, seismic network Webnet, Master event location

INTRODUCTION

West Bohemian/Vogtland earthquake swarms are well known and intensively studied, see e.g. Procházková (Ed.), 1987, Procházková (Ed.), 1988, Nehybka et al. (1993), Klimeš (1995), Novotný (1996), Klinge et al. (2003). The region is covered by the joint seismic network Webnet (Horálek et al., 2000) of the Geophysical Institute and the Institute of Rock Structure and Mechanics, Acad. Sci. of the Czech Republic. This network recorded several swarms of earthquakes and microeartquakes in the past few years. The whole earthquake activity in the region is mostly concentrated in only several subregions that have been delineated by Horálek at al. (1996). Most of the earthquakes are concentrated in the main subregion Nový Kostel, that was studied in detail e.g. in Fischer and Horálek (2000), Fischer (2003) and Fischer and Horálek (2003). This paper is devoted to study of the marginal subregions, with lower seismic activity.

Three of these subregions are Lazy, Klingenthal and Plesná. There are 45 events at Lazy with 413 (203 P and 210 S wave) phase readings, 54 events at Klingenthal, with 327 (161 P and 166 S wave) phase readings, and 58 events at Plesná, with 565 (275 P and 290 S wave) phase readings, recorded on Webnet stations during the second half of the 1990's (Figure 1).

These events were recently used to find the optimal velocities V_P and V_S of the upper crust (for the Lazy, Klingenthal and Plesná subregions with respect to the Webnet network) in framework of homogeneous models (Janský et al., 2000). The grid search method (GS) was applied to locate the events and to determine the V_P and V_S that minimize the sum of the travel-time residuals in L_2 norm for the earthquakes in a given subregion. (The same data are used in the present paper. Let us mention that the accuracy of phase reading is 8 ms for P and 16 ms for S waves.)

In GS method a 3-D net was built with a chosen step in all three Cartesian coordinates that covered the given subregion. The hypocenter was represented by a net point with minimum of sum of squares of residuals. The origin time H at each grid point was estimated so that the sum of residuals over all stations for the given event was equal to zero. This minimizes the sum of squares of residuals as a function of H.

That study resulted in $V_P = 5.945$ and $V_S = 3.560$ km/s, $V_P = 5.370$ and $V_S = 3.315$ km/s, and $V_P = 5.810$ and $V_S = 3.489$ km/s, for the Lazy, Klingenthal and Plesná subregions, respectively. It was also found that 35-40 events are sufficient for such an estimation, and that optimal homogeneous models practically do not produce larger residuals than other, more complicated 1-D crustal models (several homogeneous layers, layers with constant velocity gradients), optimized in similar way (Janský et al., 2000, Janský, 2000).

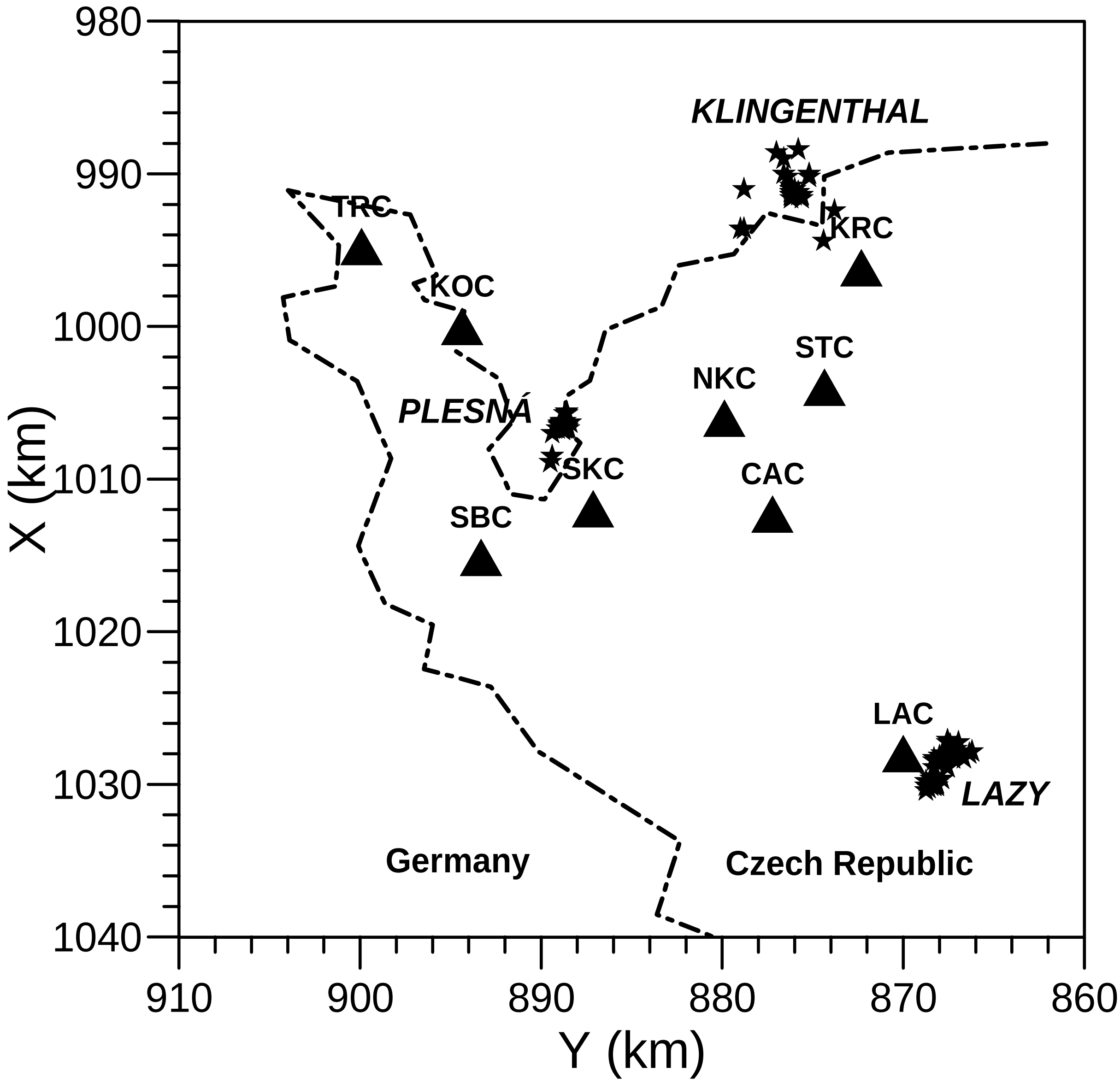


Fig. 1 Epicenters of sequence of 45 events in subregion Lazy, of 54 events in subregion Klingenthal, and of 58 events in subregion Plesná, located by grid search (GS) method (stars) and 9 stations (triangles) of Webnet network, that recorded the master events. Křovák's Cartesian coordinate system is used. For more details see text.

The epicenters of earthquakes in subregions Lazy, Klingenthal and Plesná, found by GS in the given homogeneous models, are shown in Figure 1 (in Křovák's coordinate system), together with the selection of Webnet stations that recorded the master events.

The subregions Lazy and Klingenthal are situated relatively outside of the Webnet network. Generally, lower accuracy of location can be expected under such conditions. In the present study we have therefore relocated the groups in Lazy and Klingenthal using the Master event location method with the aim to check the GS location and to find eventually a better relative locations. The subregion Plesná is situated inside the network, so one can expect sufficient accuracy by the grid search location. The relocation by the master event method serves in this case as a verification of the grid search location only.

CHARACTERISTICS OF THE MASTER EVENT METHOD

The relative Master event location method (MEM) has generally the advantage of partial elimination of the influence (on the location) of the difference between the true medium and its simplified model, e.g. inhomogenity under individual seismic stations (without introducing the station corrections). The results depend, of course, in the frame of a given model, on the quality of location of the selected master event. The master event method is effective especially in situation if distances between master and supplementary events are much smaller than the distances between hypocenters and stations.

The MEM of relative location developed by Zollo et al. (1995) was recently used with success by Fischer and Horálek (2000) for relocation of swarms in subregion Nový Kostel. It is used also in this paper. Its application is as follows: A 3-D net is built with a prescribed step in X, Y and Z coordinates around the hypocenter of the master event. In this net the hypocenter of the secondary event is searched as a point, that gives the minimum of the sum

$$\sum_i \left\{ \left(T_m^i - T_s^i\right)^{obs} - \left(T_m^i - T_s^i\right)^{cal} \right\}^2 ,$$

where T^i is the arrival time for the i-th station, the suffix m stands for the master event and the suffix s for the secondary event, *obs* stands for observed times and *cal* for calculated times. The sum is formed from all stations that recorded both the master and the secondary events.

APPLICATION OF THE MASTER EVENT METHOD TO THE LAZY DATA

The event that was recorded by the largest number of stations (8, i.e. by all stations given in Figure 1, with the exception of station SBC), on each of them with P and S onsets, was chosen as a master event for the MEM relocation. Its hypocenter was determined by the GS (see Figure 2).

From the original group of 45 events, only the secondary events with more than six onsets (P and/or S phase), recorded at the same stations as ME were chosen. Due to this condition the number of secondary events decreased to 33. The MEM uses the step of 0.15 km in the X and Y axes and 0.20 km in the Z axis. The model and step sizes are the same as in Janský et al. (2000) for GS location in Lazy subregion. The result of the MEM relocations is given by circles in the Figure 2, together with the corresponding GS locations (stars). (Note that some of the hypocenters are identical in the frame of our grid net).

The hypocenters are clustered into two groups, A and B. The group A (larger symbols) is situated about 2 km NE from the group B (smaller symbols) for both the MEM and as well as the GS locations. The A group of MEM relocation manifests significantly shallower depths Z as compared with the A group of GS location.

To demonstrate the stability of the MEM relocation, another event is used as the ME (see Figure 2). It is the event that is recorded by 7 stations (by stations given in Figure 1, with the exception of stations CAC and STC) and both P and S wave arrivals are available on each station. The hypocenters of the second MEM relocations are given in Figure 2 by squares. The second MEM relocation associated the events with the same groups A (larger symbols) and B (smaller symbols), as the previous locations.

But there is a slight shift in the epicenters and more pronounced shift in depth of the cluster events. To quantify the difference, we give in Table 1 the average values of X, Y and Z coordinates for group A and B and different locations, including their mean deviations. This Table so roughly illustrates the influence of the choice of the location method (GS versus MEM) and the influence of the choice of the ME on location of events in the subregion Lazy. (Note the significantly larger depth scatter for MEM No.1 group A).

An attempt to associate the groups A and B from Figure 2a to paths of tectonic faults in the detailed geological map (see References, Geological map of the Czech Republic) was not made because of dependence of their position on the location method used. (Generally on the geological map, in this locality more faults with NW-SE directions are marked.)

The shape of the misfit function of the GS location as compared to the MEM location is illustrated for one and the same event in Figure 3 for the GS location and in Figure 4 for the first MEM location. (The X, Y, Z coordinates and misfit values of the corresponding hypocentre are 1028.00 km, 867.85 km and 7.60 km and 0.0135 s^2 for the GS location, and 1028.60 km, 867.40 km and 6.60 km and 0.00484 s^2 for the MEM location, respectively.) The errors of the location can be estimated by the ratio between the maximum and minimum values of misfit function in the corresponding figure. The shape of the isolines, their "density" and the minimum misfit values gives the following order of increasing location error (method – axis): GS – Y, MEM – Y, MEM – X, GS – X, MEM – Z, GS – Z. The depth uncertainties are large in both methods. (Let us note that the misfit values for the MEM method are in principle smaller than the misfit values for GS).

APPLICATION OF THE MASTER EVENT METHOD TO THE KLINGENTHAL DATA

Similar method was applied to the Klingenthal data. (The position of the chosen master event for the MEM relocation is marked in Figure 5). Because the majority of the Klingenthal events were recorded only on three stations (KRC, NKC and KOC), only 3 P and 3 S onsets are available for ME. Just 44 secondary events satisfy the condition of being recorded at least with 6 onsets. The step size used in the MEM was 0.20 km in all three axes, the same as that in the GS location in Klingenthal subregion (Janský et al., 2000).

The result of the locations, using the Klingenthal crustal model is given in Figure 5 by smaller stars for the GS and by circles for the MEM location. This represents the first location of the Klingenthal data. To demonstrate the influence of crustal model on the

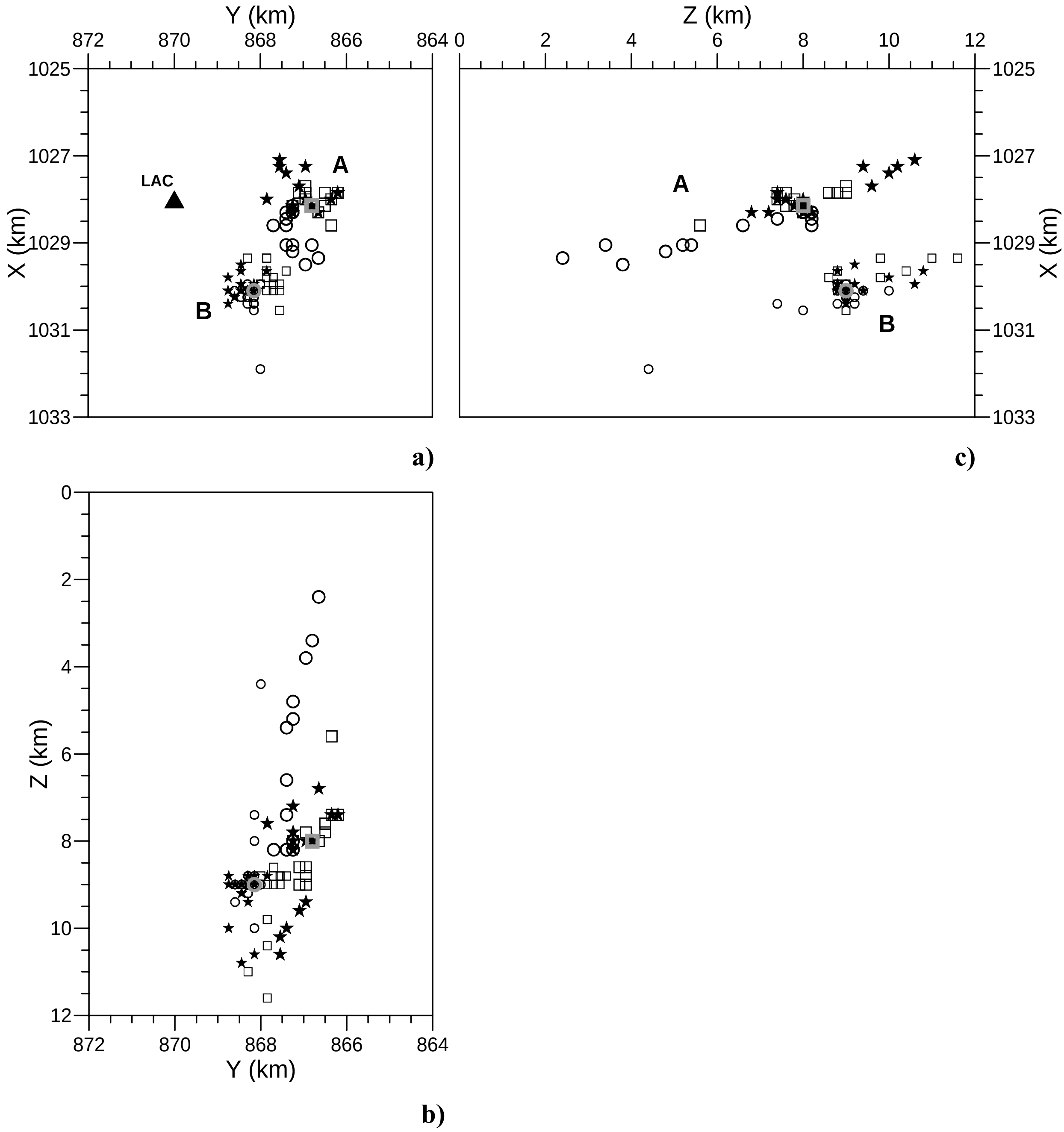


Fig. 2 Subregion Lazy. Hypocenters of group A (larger stars) and B (smaller stars), obtained by the GS location; hypocenters of group A (larger circles) and B (smaller circles), obtained using the first MEM relocation (ME marked by gray circle); hypocenters of group A (larger squares) and B (smaller squares), obtained using the second MEM relocation (ME marked by gray square). Groups A and B are formed by division of hypocenters according to their X, Y position. For more details see Table 1 and text. The triangle marks the position of station LAC. a) XY projection; b) YZ projection; c) XZ projection.

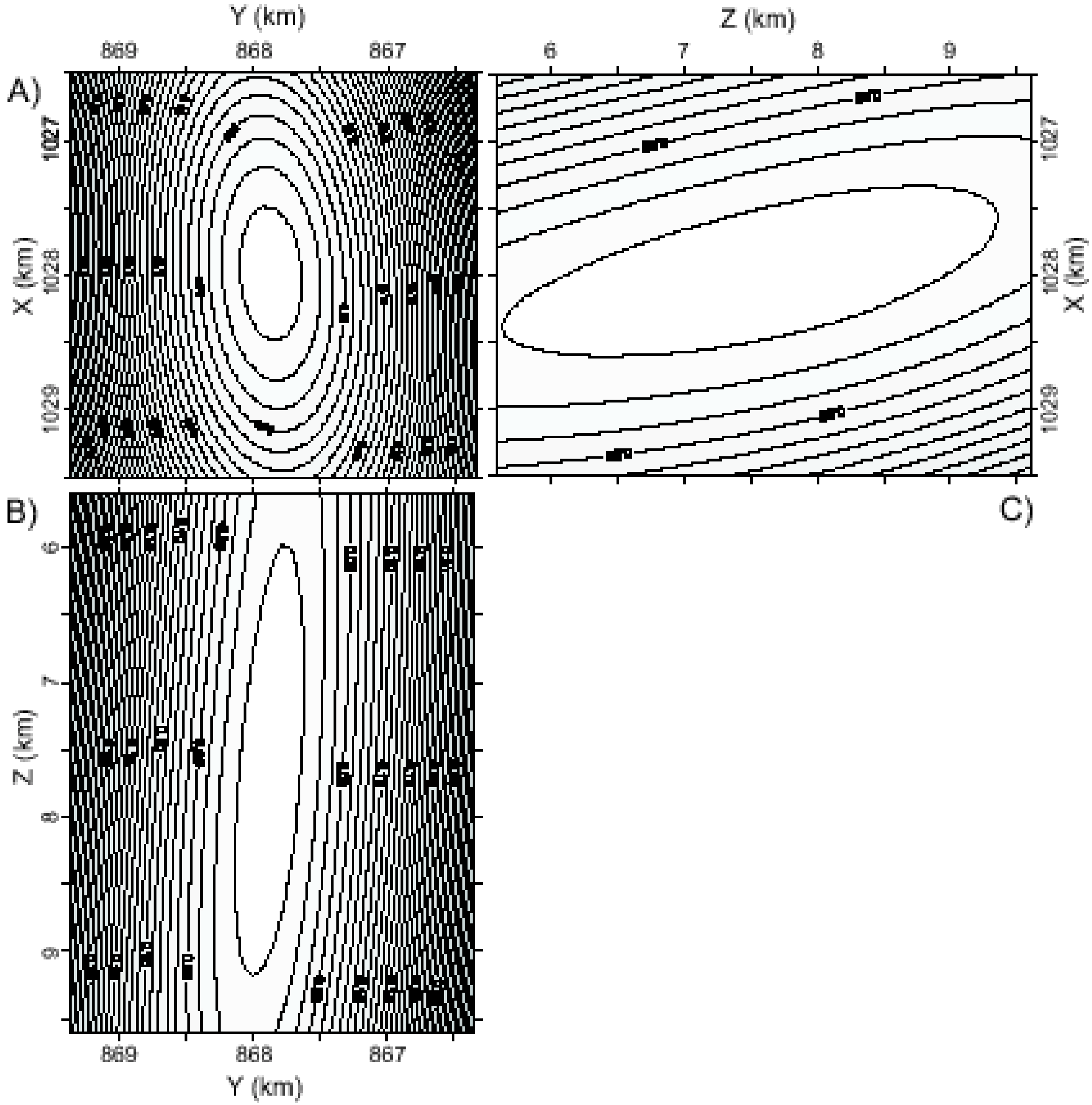


Fig. 3 Subregion Lazy. The form of misfit function in the vicinity of chosen hypocentre for the GS location. Coordinates of the hypocentre are given in text. a) XY crossection; b) YZ crossection; c) XZ crossection; all the crossections are going through the misfit minimum.

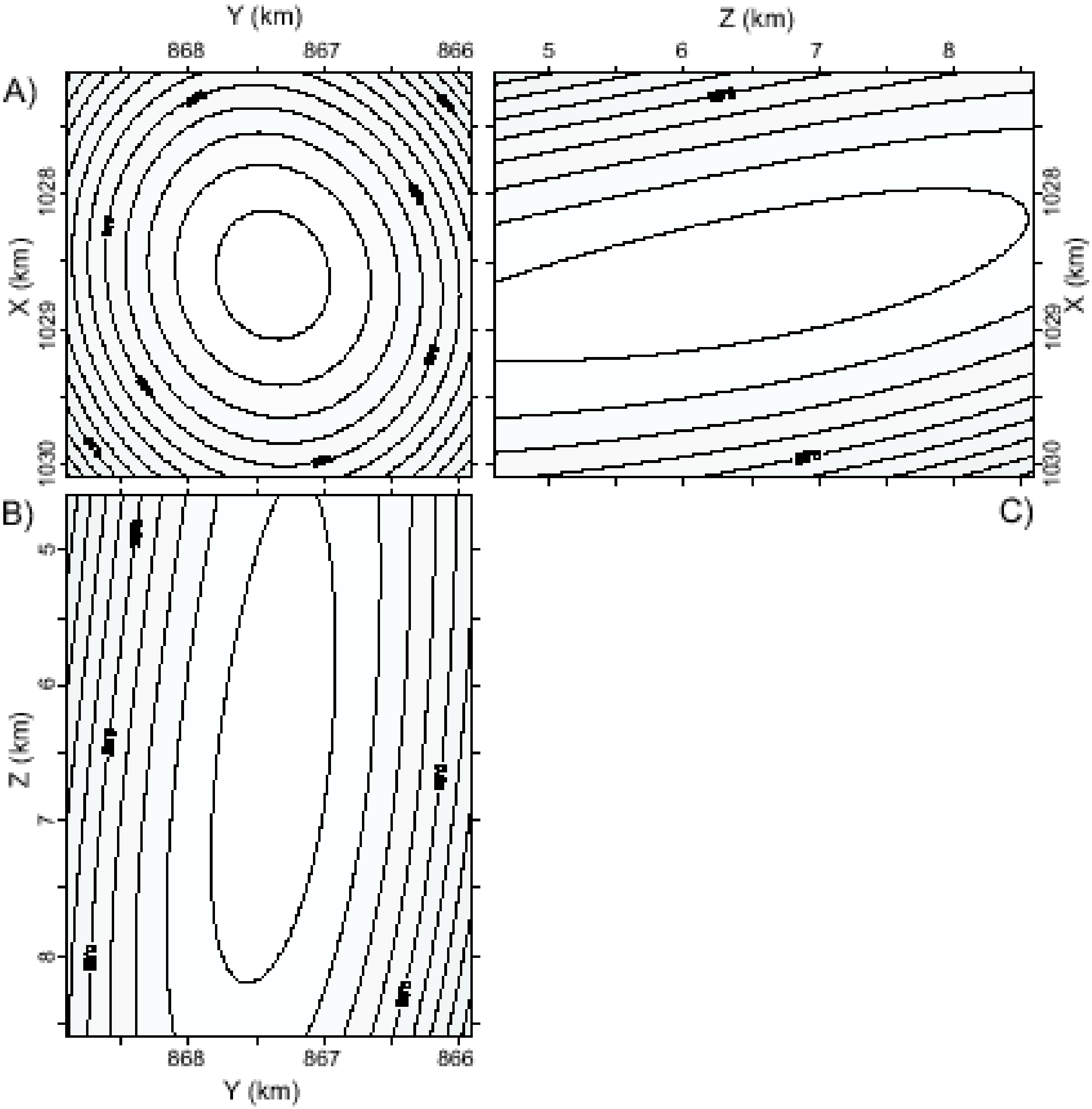


Fig. 4 The same as in Figure 3, but for the first MEM location.

Table 1 Average hypocentral coordinates X, Y, Z (km) of group A and B from Figure 2 for different locations of events in subregion Lazy and corresponding mean deviations (km) in parenthesis.

Location and group	X	Y	Z
GS A	1027.87 (0.36)	867.09 (0.35)	8.41 (1.03)
GS B	1030.00 (0.17)	868.36 (0.20)	9.23 (0.43)
MEM1 A	1028.71 (0.39)	867.24 (0.18)	6.40 (1.79)
MEM1 B	1030.31 (0.24)	868.26 (0.14)	8.67 (0.69)
MEM2 A	1028.02 (0.18)	866.74 (0.28)	7.95 (0.59)
MEM2 B	1029.88 (0.25)	867.78 (0.17)	9.34 (0.65)

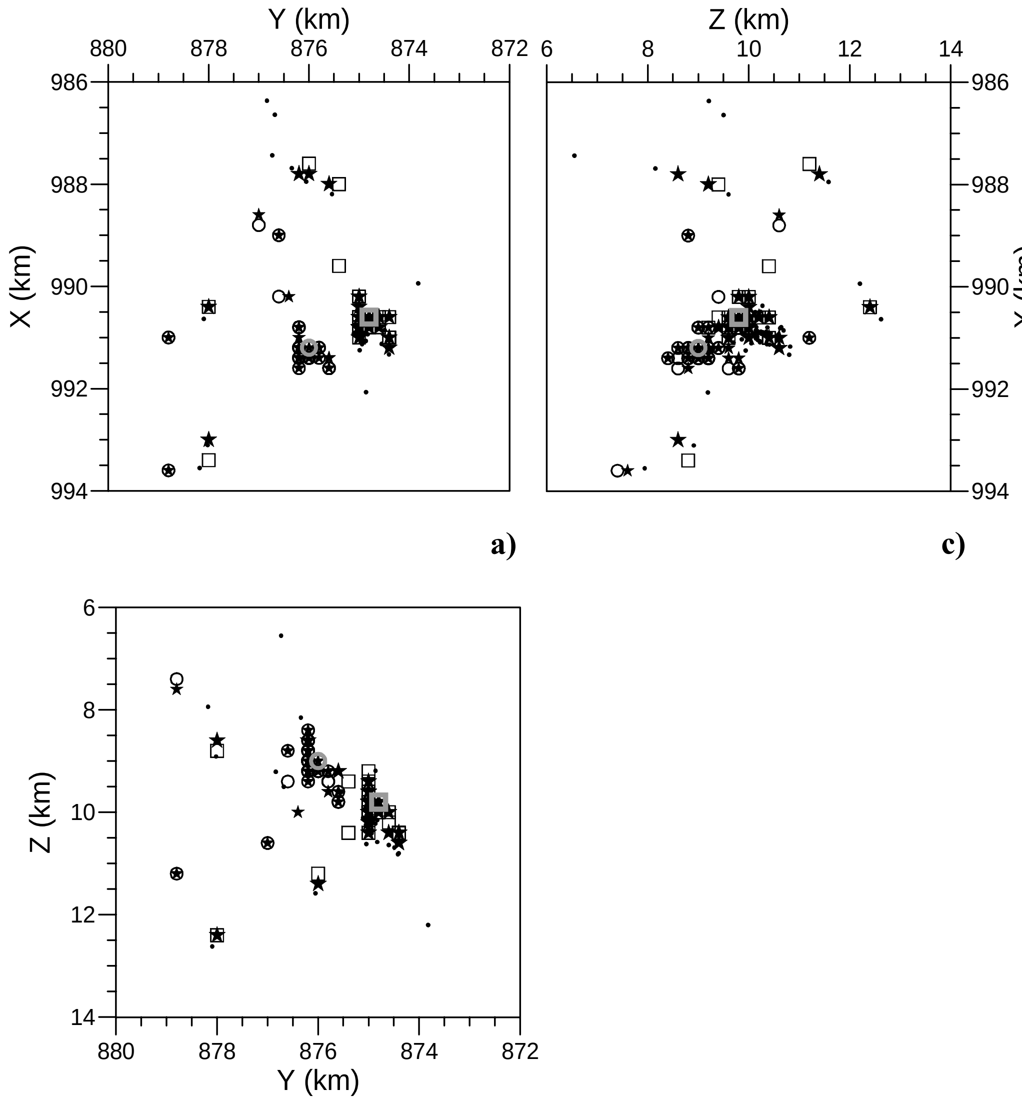


Fig. 5 Subregion Klingenthal. GS hypocenters (small stars) and MEM hypocentres (circles), obtained in the Klingenthal crustal model (the ME is marked by gray circle); GS hypocenters (larger stars and MEM hypocenters (squares), obtained in the average crustal model (the ME is marked by gray square). Dots show the FASTHYPO hypocenters in the average crustal model. a) XY projection; b) YZ projection; c) XZ projection.

Table 2 Average hypocentral coordinates X, Y, Z (km) of clusters from Figure 5 for different locations methods and different crustal model of subregion Klingenthal.

Location and model	X	Y	Z
GS Klingenthal	991.18	876.27	9.18
MEM Klingenthal	991.19	876.25	9.11
GS Average	990.58	875.10	9.98
MEM Average	990.60	875.08	9.98
FASTHYPO Aver.	990.75	874.97	10.25

location for given data, the location was run again in a changed model, which represents an average homogeneous model for all the 4 subregions (Nový Kostel, Lazy, Klingenthal and Plesná) together. Its P and S wave velocities are 5.84 and 3.58 km/sec, respectively. The hypocenters of this second location of Klingenthal data are given in Figure 5 by larger stars for the GS, and by squares for the MEM location. As can be seen from the Figure, the GS and MEM locations are near each other for the same model, whereas the influence of different model is more pronounced.

Figure 5 shows for comparison by dots also the corresponding hypocenters using the FASTHYPO location in the average crustal model. To quantify the difference between different location methods, we give in Table 2 the average values of X, Y and Z coordinates for GS and MEM location in the Klingenthal model and for the GS, MEM and FASTHYPO location in the average model. The Table 2 so roughly illustrates the influence of the choice of the location method and the influence of the crustal model on location of events in the subregion Klingenthal.

APPLICATION OF THE MASTER EVENT METHOD TO THE PLESNÁ DATA

The subregion Plesná is rather well surrounded by the Webnet network, as compared with the Lazy and Klingenthal subregions, see Figure 1. The hypocenters are therefore expected to be well located even using the standard (absolute) location methods, e.g. the GS. To verify this expectation, the data were relocated using the mentioned (relative) MEM.

The event of the Plesná sequence that was recorded on 7 stations, on each of them with the P and S wave onsets, was chosen as the first master event for the relocation. This event lies near to the center of the GS cluster (see Figure 6). Only 55 secondary events from the sequence satisfy the condition to be recorded at least with 6 onsets on stations that recorded the ME. The step size was 0.1 km in all three axes, i.e. the same as in the GS location.

The hypocenters obtained by the GS (stars) and by the first MEM (squares) are given in Figure 6. We see that the position of both clusters is almost identical. To check the stability of MEM location, we used as the second ME an event that lies rather outside of the GS cluster (see Figure 6). This event was recorded on 9 stations. Even in this rather extreme choice, the position of the relocated cluster (hypocenters are marked as circles) do not differ much from the previous one. But the similarity of the position of the whole cluster does not necessarily mean the similarity of position of the individual corresponding hypocenters. To show this, Figure 7a gives the difference in X, Y and Z coordinates between the GS and first MEM location, and Figure 7b the difference between the second and first MEM location.

CONCLUSION

In the subregion Lazy the GS and both MEM locations give two separated groups of hypocenters that might reveal position of two almost parallel faults. Both groups change slightly their position for different location method, but they agree with the set of NW-SE oriented tectonic faults given in geological maps for this area.

In the subregion Klingenthal the hypocentral clusters obtained by the GS and MEM location agree well with each other. This is valid both for the location in the Klingenthal crustal model, as well as for the average crustal model. The clusters are, of course, slightly different for different crustal models.

In the subregion Plesná the GS cluster agrees well with both clusters obtained by two MEM locations, despite the fact, that the ME for the second MEM location was chosen rather outside of the centre of the GS cluster. The similarity of position of the clusters does not generally mean the mutually close position of corresponding individual hypocenters.

The MEM relocation of events using different ME for all three subregions under study do not supply the same hypocenters. But considering the fact that the results of location are generally very sensitive to velocity model and also to some computation parameters (e.g. different first depth approximation, different phase weightings in HYPO-like location programs, or the choice of L_1 or L_2 norm in GS locations), the results of different MEM relocations can be regarded as similar. They generally do not differ significantly from the GS location.

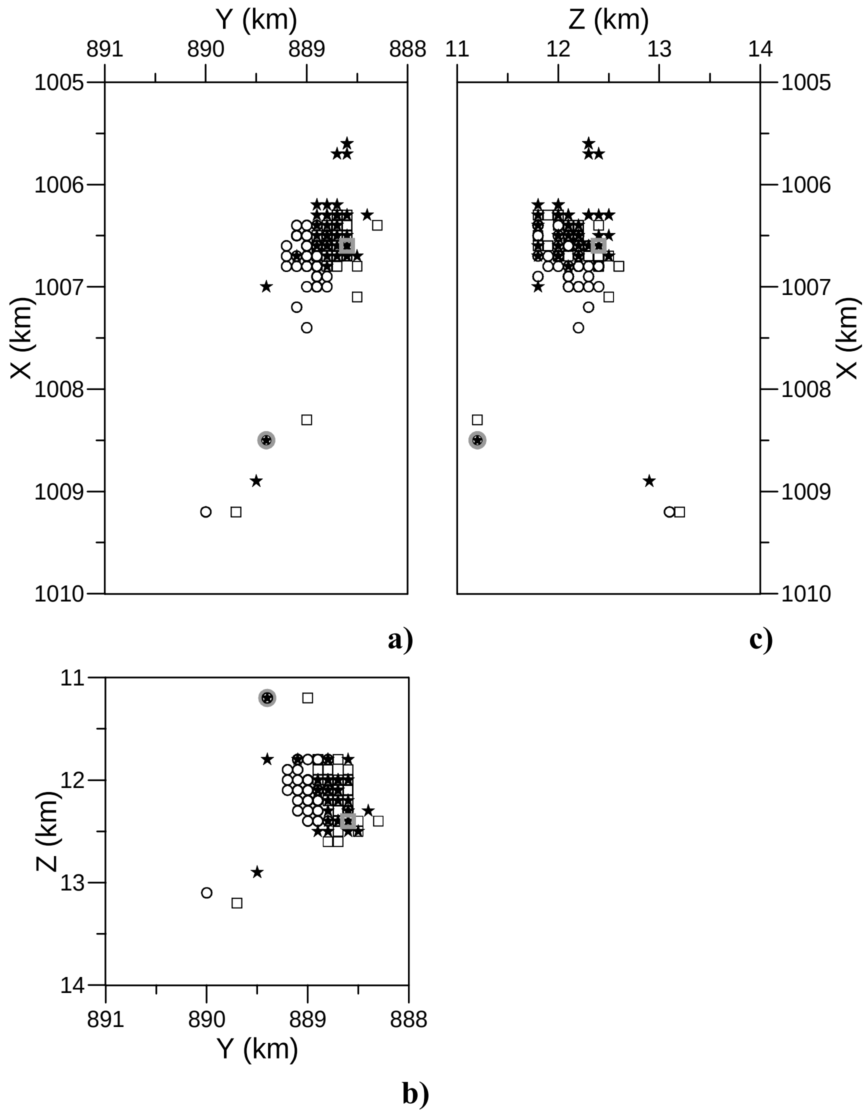
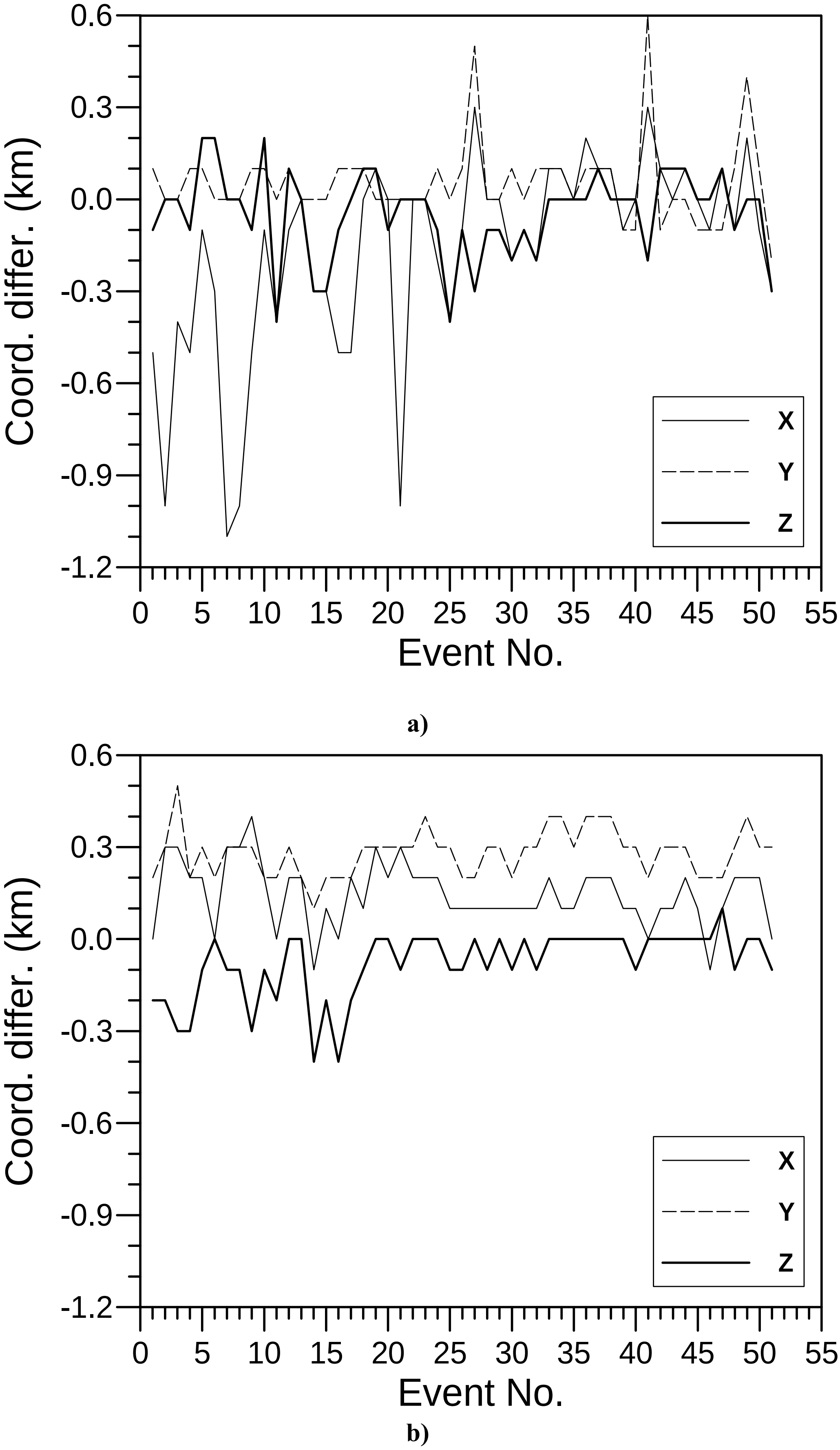


Fig. 6 Subregion of Plesná. Stars give the GS location, squares the first MEM relocation (the ME is marked by gray square). The circles give the hypocenters of the second MEM relocation (the ME is marked by gray circle). a) XY projection; b) YZ projection; c) XZ projection.



a)

b)

Fig. 7 Subregion Plesná. Difference in the X, Y and Z coordinates for individual corresponding hypocenters between: a) the GS and first MEM location; b) the second and first MEM location.

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