Topic	Estimating the epicenters of local and regional seismic sources by hand, using the circle and chord method
Author	Peter Bormann, and K. Wylegalla (formerly GeoForschungsZentrum Potsdam, Telegrafenberg, D-14473 Potsdam, Germany); E-mail: pb65@gmx.net
Version	October 2001

1 Aim

The exercise aims at making you familiar with the basic “circle and chord” method for determining the epicenter of a seismic source. It is applied both to sources inside and outside of the recording networks.

2 Data

- Available are two sections of vertical component short-period records of stations of the former Potsdam seismic network from a local earthquake inside the network (see Figure 2) and a strong rock-burst in a mine located outside of the network (see Figure 3).

- Travel-time curves of the main crustal phases Pn, Pg, Sn, Sg and Lg from a near surface source up to an epicentral distance of 400 km (see Figure 4). These curves are reasonably good average curves for Central Europe. For any stations in this exercise at distances beyond 400 km, you may linearly extrapolate the curve without much error.

- Map with the positions of the recording stations and a distance scale (see Figure 5).

3 Procedure

- Identify the seismic phases in short-period records of near seismic sources.

- By means of local travel-time curves determine the source distance **d** from the best fit with the identified seismic phases.

- If no local travel-time curves are available, a first rough estimate of the hypocenter distance **d** or of the epicentral distance D (both in km) may be found using the following “rules-of-thumb”:

$$\mathbf{d \approx t(Sg - Pg) \times 8} \quad \text{or} \tag{1}$$

$$\mathbf{D \approx t(Sn - Pn) \times 10} \tag{2}$$

with t as the travel-time difference in seconds between the respective seismic phases. These rules are approximations for a single layer crust with an average Pg-wave velocity of 5.9 km/s and a sub-Moho velocity of 8 km/s and a velocity ratio $v_s/v_p = \sqrt{3}$. If in your area of study the respective average P- and S-wave crustal velocities

v_p and v_s deviate significantly from these assumptions you may calculate d more accurately from the relationship:

$$\mathbf{d = t(S_g - P_g)\ (v_p\ v_s)/(v_p - v_s)}. \qquad (3)$$

- Draw circles with a compass around each station $\mathbf{S_i}$, which is marked on a distance-true map projection, with the radius $\mathbf{d_i}$ determined from the records of each station.

- The circles will usually cross at two points, not one point (the thought epicenter) thus forming an area of overlap (see Figure 1, shaded area) within which the epicenter most probably lies.

- Usually, it is assumed, that the best estimate of the epicenter position is the "center of gravity" of this shaded area of overlap. The best estimate of the epicenter is found by drawing so-called "chords", i.e., straight lines connecting the two crossing points of each pair of circles. The crossing point (or smaller area of overlap) of the chords should be the best estimate of the epicenter (see Figure 1).

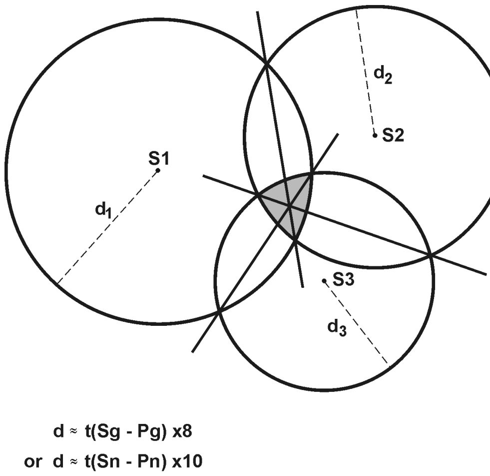

Figure 1 Principle of epicenter estimation by using the "circle and chord" method. S – station sites, d – distance of the event determined for each station according to travel-time curves (or "rules-of-thumb" as given in the figure).

Notes:

1) In the absence of independent information on the source depth and depth-dependent travel-times the distance d determined as outlined above is not the epicenter but the *hypocenter distance*. Therefore, for sources at depth the circles will necessarily overshoot, the more so the deeper the focus.
2) Also, an ideal crossing of circles at a point for a surface source requires that all phases are properly identified, their onset times picked without error and the travel-time curves/model for the given area (including the effects of lateral variations) exactly known. This, however, will never be so. Therefore, do not expect your circles to cross all at one point.
3) Despite note 2, the circles should at least come close to each other in some area, overlapping or not, within about 10 to 20 km at least, if the epicenter is expected to lie within the network and the hypocenter within the crust. If not, one should check again the phase interpretation and resulting distance estimate and also compare for all

stations the consistency of related estimates of origin time (see tasks below). Any obvious outliers should be re-evaluated.

4) For seismic sources outside the network the circle crossing will be worse, the error in epicenter estimation larger, particularly in the direction perpendicular to the azimuth between the network center and source; the distance control, based on travel-time differences S-P, is better than the azimuth control. Azimuth estimates are more reliable, if the source is surrounded by stations on three sides, i.e., with a maximum azimuthal gap less than 180°.
5) With only two stations one gets two possible solutions for the three unknowns (epicenter coordinates λ and φ and origin time OT) unless the source direction can be independently determined from polarity readings in three-component records of each station (see EX 11.2). If more than 3 stations are available, the estimates of both epi- and hypocenter will improve.

4 Tasks

4.1 Phase identification and travel-time fit

- Identify the main local phases Pn, Pg, Sn and/or Sg/Lg in the records of the Potsdam seismic network (Figures 2 and 3) by using the travel-time curves given in Figure 4.

- If possible use for it a 1:1 transparent sheet of the travel-time curve with the same time-scale resolution as the records (1 mm/s) and overlay it on the records. Take care that the distance abscissa D of the travel-time curves is strictly perpendicular to the record traces!

- Move the travel-time curves up and down until you find the best fit for the first arrival and the onsets of several later wave groups characterized by significant changes/increases in amplitude. Mark these best fitting onset times with a dot in the record together with the phase name.

Notes:

1) When searching for the best fit remember that the beginning of the later wave group with the largest amplitudes in the record is usually the onset of Sg, whereas in the early parts of the record it is Pg that is the largest wave. For distances < 400 km Pn is usually much smaller than Pg, although deeper crustal earthquakes with appropriate rupture orientation may be recorded with strong Pn too (see Figs. 11.44 to 11.46).
2) From the onset-time differences Sg-Pg or Sn-Pn you may roughly estimate the hypocenter distance d of the event by using the "rules-of-thumb" (see Equations (1) to (3) above). If your rough estimate is d < 150 km then the first arrival should never be interpreted as Pn but rather as Pg (unless it is a deeper crustal event or the crust is less than 30 km thick). If d > 150 km, try to get the best fit to the onsets by assuming that the first arrival is Pn, however remember that its amplitude is usually smaller than that of the following stronger Pg for d < 400 km.
3) The above said is true for near-surface events in a single-layer crust with average P-wave velocity of 6 km/s and sub-Moho velocity of 8 km/s. The **cross-over distance** $\mathbf{x_{co}}$ beyond which Pn becomes the first arrival is then approximately $\mathbf{x_{co} \approx 5\, z_m}$ with z_m as the Moho depth. In case of different average crustal and sub-Moho P-wave velocities, $\bar{v}_c$ and v_m, you may use the relation $\mathbf{x_{co} = 2\, z_m\{(v_m + \bar{v}_c)/(v_m - \bar{v}_c)\}^{1/2}}$ to

calculate the cross-over distance of Pn. However, be aware that for deeper crustal events Pn may over-take already at smaller distances!

4.2 Estimation of distance and origin time

- Write down for each station the distance corresponding to your phase interpretation and best travel-time fit. Mark on each record the estimated origin time which is the time of the abscissa position on the record time scale for your best phase-travel-time fit.

- Check, whether your marks for the estimated origin times are roughly the same (in vertical line) for all stations. This is a good check of the accuracy and reproducibility of your phase identifications and estimated distances. For any "outliers" check the phase identification and distance estimate again until you get agreement between the origin times within about ± 3s.

- Compare your best estimate of origin time OT (average of all your individual origin times determined from the records of each station) with the OT computer solution given in the head lines of Figures 2 and 3.

- If your average OT deviates by more than about 3 s from the computer solution reconsider your interpretation.

4.3 Epicenter location

- Take a compass and draw circles around each station position (see Figure 5) with the radius d_i in km as determined for the distance of the source from the station S_i. Use the distance scale given on the station map.

- Connect the crossing points of each pair of circles by chords. Estimate the coordinates λ and φ (in decimal units of degree) from the chord crossings.

- Compare your coordinates with the ones given in the headlines of Figures 2 and 3. If your solutions deviate by more than 0.2° for the earthquake within the network and by more than 0.4° for the mining rock-burst outside, reconsider your phase interpretation, distance estimates and circle-drawings.

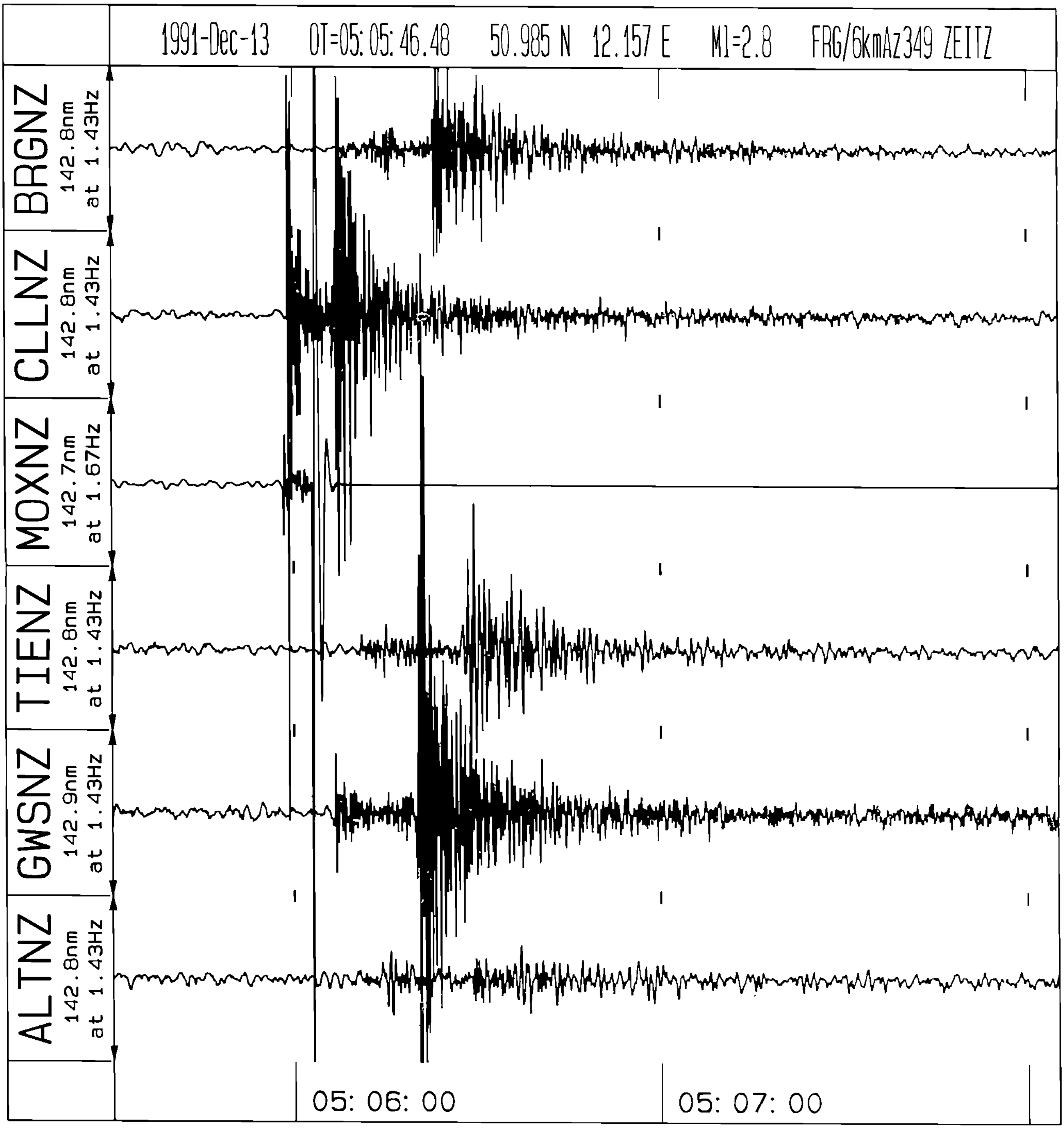

Figure 2 Recordings of a near earthquake situated within the seismic network of stations shown in Figure 5. The time scale is 1 mm/s. Note the second strong onset in the record of station MOX has a very different form and frequency than in any other record. It is not a natural wave onset but a malfunction of the seismograph, which responds to the impulse of the strong Sg with its own impulse response.

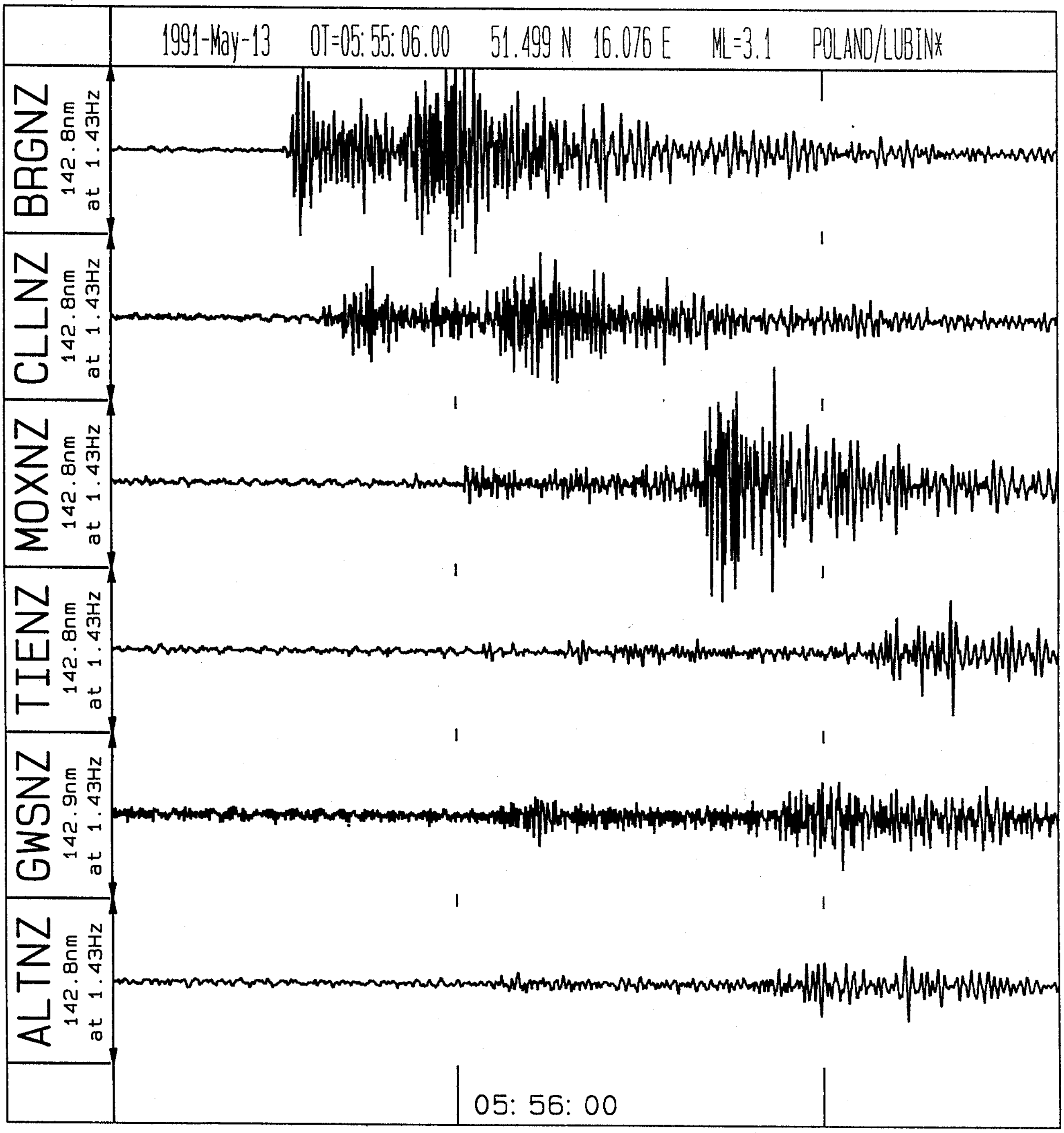

Figure 3 Recordings at regional distances from a strong mining rock-burst situated outside the seismic network of stations shown in Figure 5. The time scale is 1 mm/s.

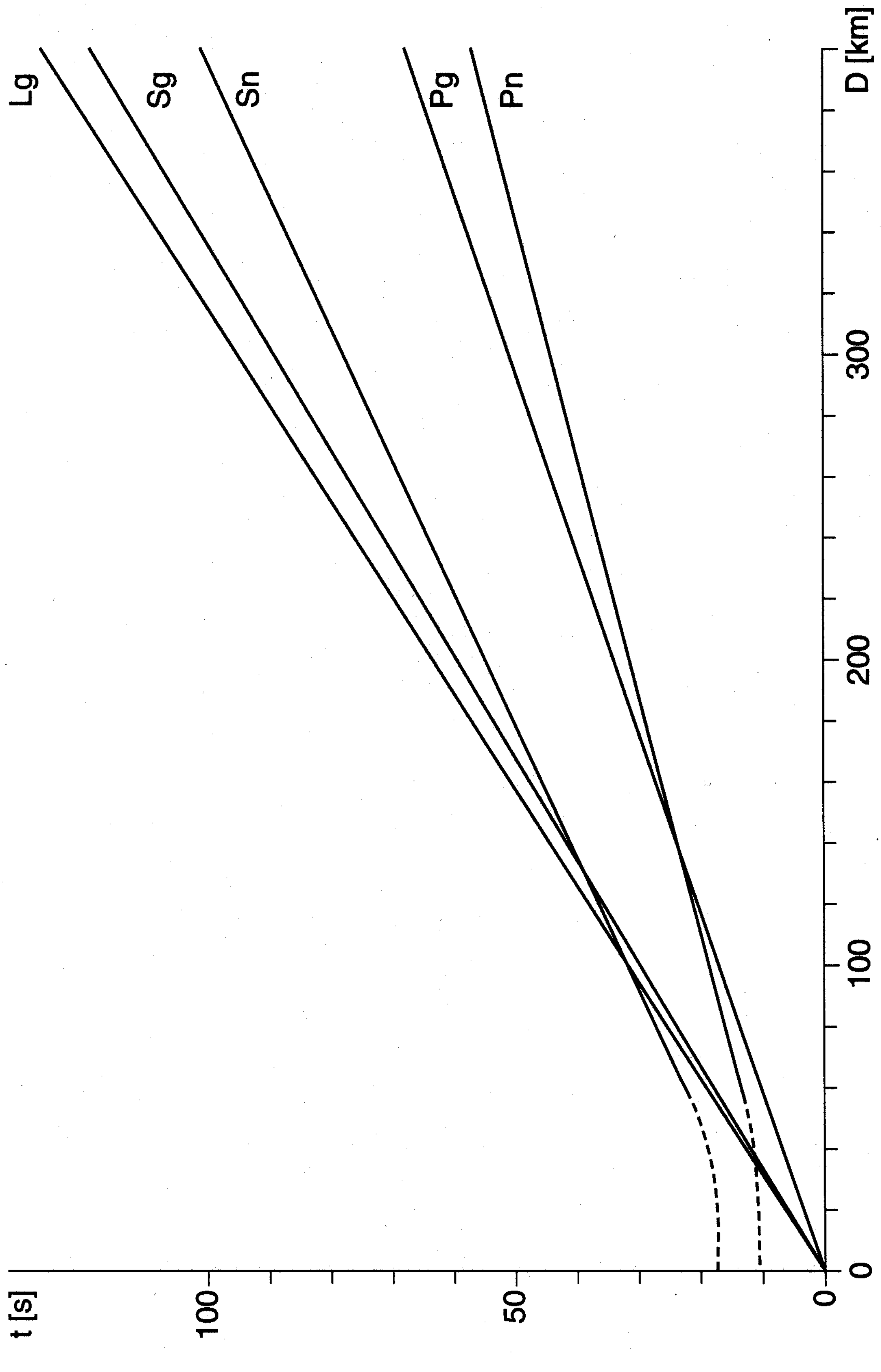

Figure 4 Travel-time curves for the main phases in seismic records of near-surface sources. They are good average curves for Central Europe with a crustal thickness of about 30 km.

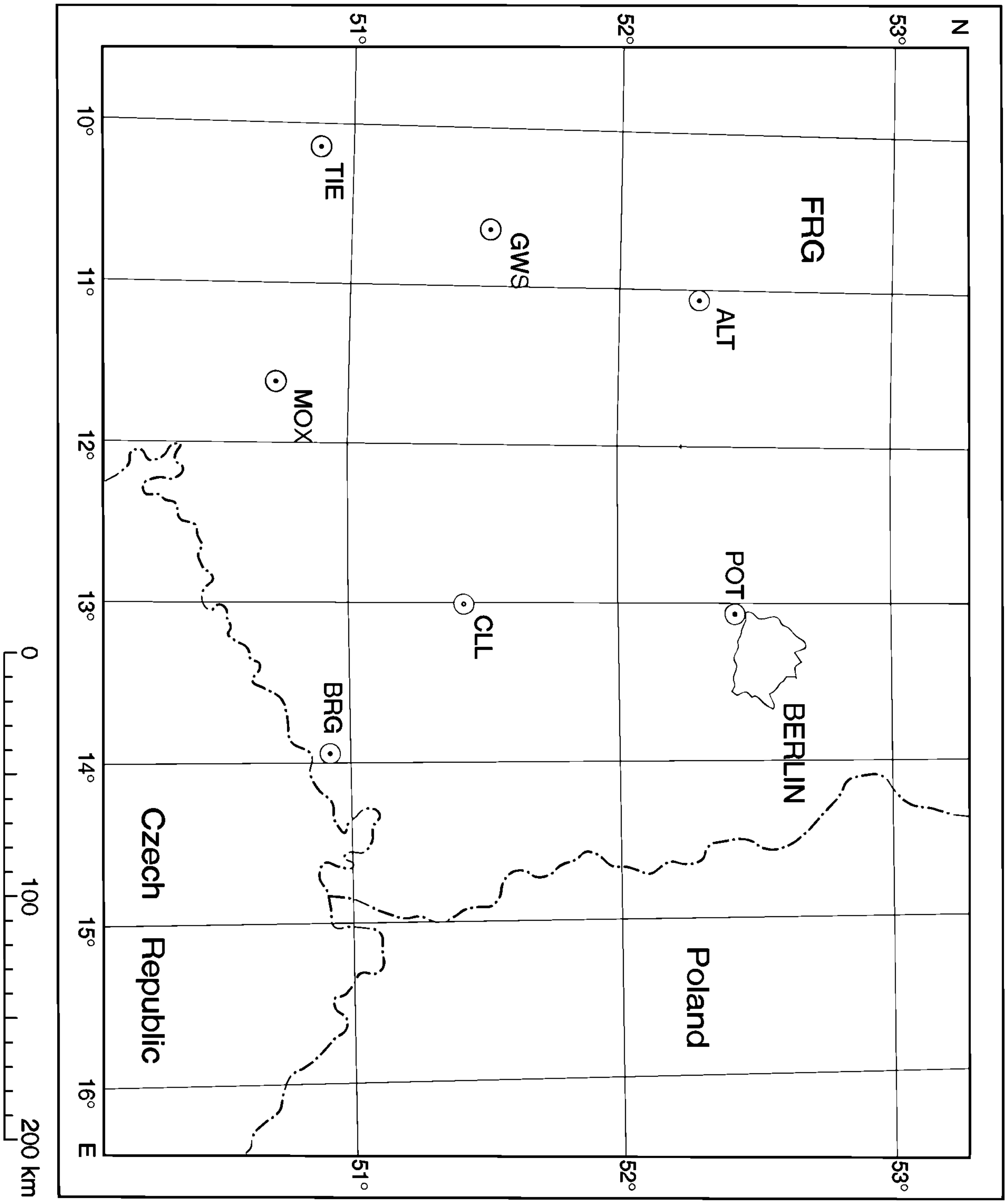

Figure 5 Map of parts of Central Europe with codes and positions (circles) of the seismic stations that recorded the seismograms shown in Figures 2 and 3 (on the map projection all distances are true).