550. 340

UPPER MANTLE STRUCTURE OF NORTHERN EUROPE FROM APPARENT VELOCITIES OF P WAVES

by

REIDAR KANESTRØM

Seismological Observatory
University of Bergen, Norway

A b s t r a c t

The velocity variation of P-waves in the upper mantle in Northern Europe is derived from direct measurement of $dt/d\Delta$ for the first arrivals. Data from 25 earthquakes with epicenters in the Norwegian Sea and the Arctic Ocean are used. The total number of seismic stations involved is 43. An abrupt change in the slope of the travel-time curve is observed at a distance of about 25°. This change is most probably caused by a second-order discontinuity and the depth is about 640 km.

Introduction

The upper mantle seems to be more complex in nature than earlier assumed, and it is very difficult to obtain detailed pictures of the more local structures. During the last ten years the seismological studies have been concentrated upon the structure of the upper mantle, but still a great number of problems are unsolved. The obtained results from different regions indicate lateral variations of the physical properties in the mantle. The main differences between the velocity-depth curves for different regions are caused by the existence or absence of low velocity layers and discontinuities. The velocities of P- and S-waves are the best known properties of the mantle. The velocities are obtained from studies

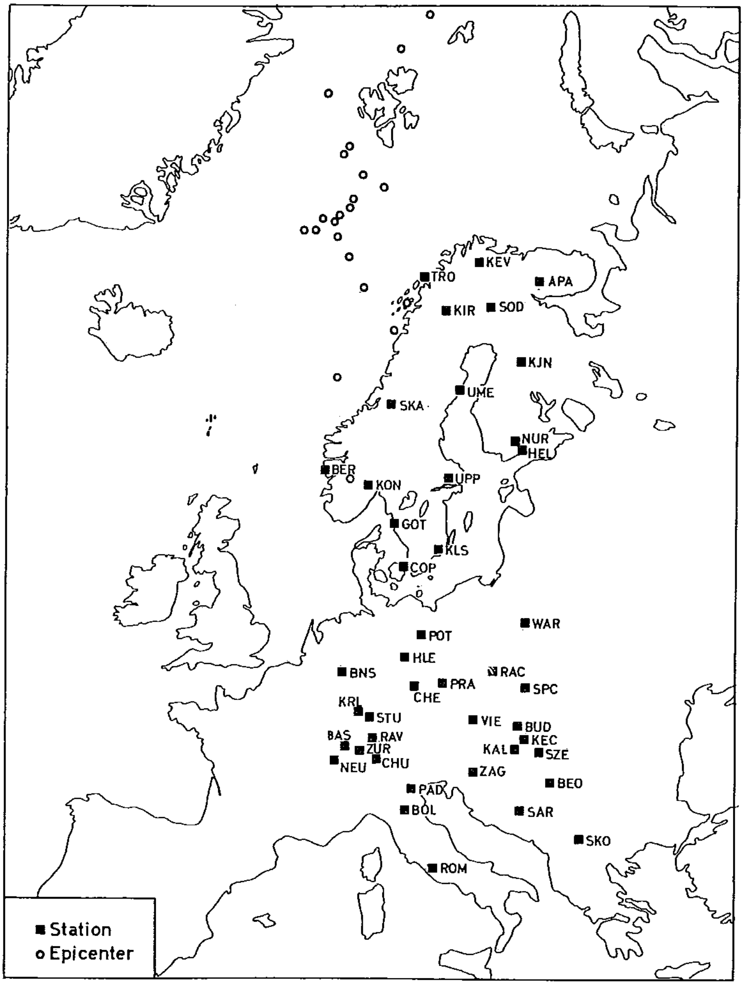

Fig. 1. Location of stations and epicenters.

of surface waves and the travel-times of the body waves, and it is a matter of fact that the observations allow different interpretations which lead to results differing significantly (LEHMANN [6]). Applications of large arrays can give valuable contributions to the efforts of revealing details of the velocity distribution in the upper mantle. Obviously a velocity-depth curve is valid only for the region where the observations of travel-times are made.

In the present study data from the 25 earthquakes with epicenters

Table 1. List of Earthquakes.

Date	Time (GMT) h m s	Geographic Coordinates N	E
10 15 45	18 24 42	78,5°	2,5°
2 18 48	18 20 47	82,5	41,5
8 23 48	23 11 50	72,7	3,6
11 22 48	22 23 32	82,5	41,5
7 8 49	18 18 04	72,2	0,5
6 20 50	14 11 42	75,1	10,3
9 13 50	11 59 35	76,7	7,8
10 16 51	06 54 33	76,7	7,8
2 10 52	06 10 06	72,2	0,5
4 28 52	01 15 16	73,9	8,5
4 24 53	02 09 44	76,7	7,8
1 6 54	15 53 57	76,3	7,0
2 22 56	00 07 36	73,5	7,9
5 10 56	18 11 59	79,5	2,2
6 22 57	08 59 57	68,5	16,0
12 5 57	14 04 30	72,0	6,0
1 23 58	13 35 03	65,0	6,5
1 29 59	23 24 30	71,0	8,0
8 1 59	12 14 14	61,7	29,0
9 28 59	01 11 20	81,5	26,0
2 28 60	07 26 37	69,5	10,0
5 20 61	07 06 51,5	73,2	6,4
5 20 61	17 23 27,6	74,5	14,4
5 20 61	17 47 19,3	72,9	5,6
8 1 62	13 55 33	60,0	8,0
12 15 62	03 48 34,8	67,36	13,90 (Sykes, 1965)

in the Norwegian Sea and the Arctic Ocean are used for determination of the velocity-depth curve for P waves in the upper mantle (Fig. 1). The arrival times for P waves are used for direct measurement of $dt/d\Delta$ and the Herglotz — Wiechert method is applied for the interpretation.

Analysis of data

The events used in this work are listed in Table 1. Origin times and epicenter coordinates are taken from I.S.S. except where other sources are quoted. The distribution of epicenters and stations is shown in Fig. 1. The epicentral distances range from 2° to 35°. As shown in Fig. 1, the epicenters and stations are mainly grouped in north—south direction,

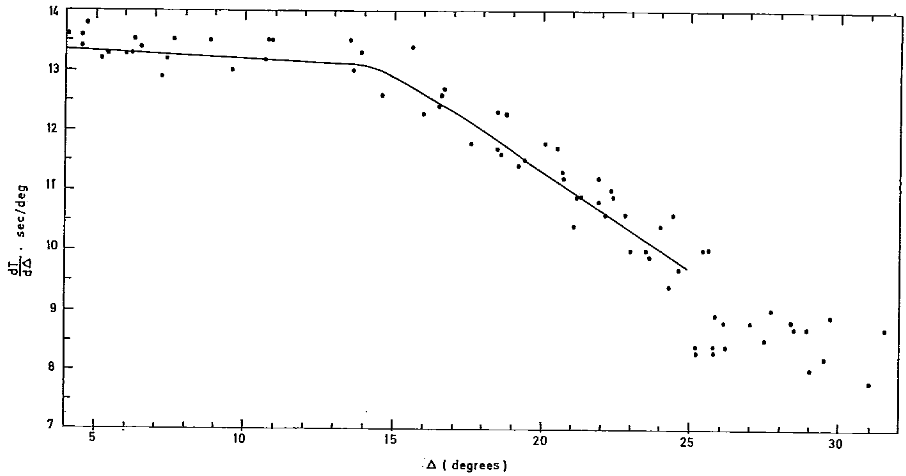

Fig. 2. Observed $dt/d\Delta$ versus distance.

but there is also an east—west extension of about 1000 km. The data therefore represent a region of the mantle rather than a well defined profile.

Before the measurement of the $dt/d\Delta$, the travel-time curve was constructed and examined for possible discontinuities in the mantle between Moho and 900 km depth. A marked change of the slope was observed at an epicentral distance of about 25°. Because of the non-linear distribution of epicenters and stations, it was impossible to obtain a sufficient number of $dt/d\Delta$ measurements in one specific direction to compute the velocity-depth curve. In the measurement of the slope of the travel-time curve the seismic stations are combined in different ways to obtain a number of arrays with aperture of about 200 km. It is then possible to obtain $dt/d\Delta$ for more than one epicentral distance from one earthquake.

Fig. 2 is a plot of the apparent reciprocal velocity. It shows a gradual decrease of $dt/d\Delta$ between 15° and 25°. The change of the slope at 15° is interpreted as being a continuous change in $dt/d\Delta$. The discontinuity at about 25° is earlier presented by others (Hales *et al.* [2]; Niazi and Anderson [7]; and Doyle and Webb [1]).

The present data are not accurate enough for obtaining the fine structure of the travel time curve to get detailed information of the

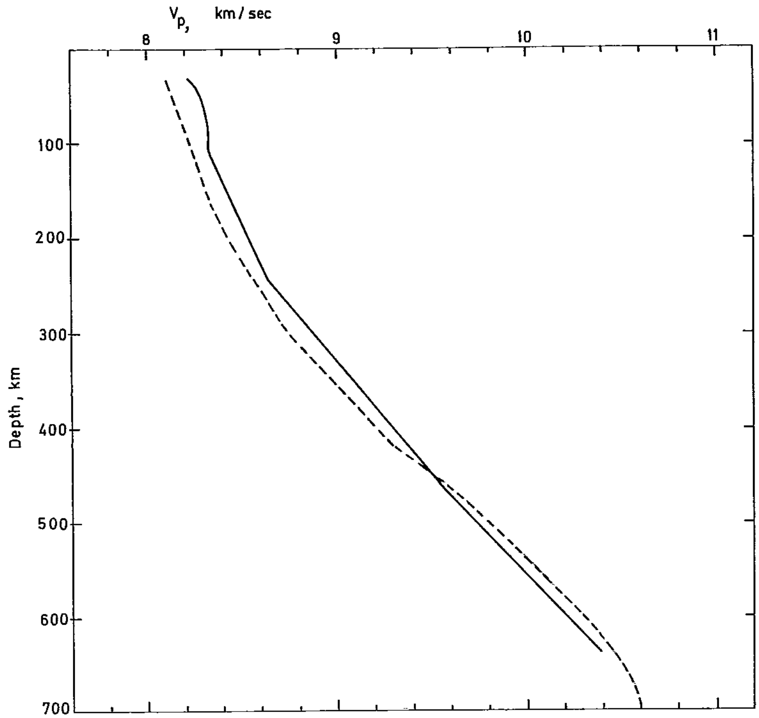

Fig. 3. Velocity — depth curves. The full line represents the velocities determined in this paper. The dashed line is the velocity-depth curve of JEFFREYS and SHIMSHONI [3].

variation of $dt/d\Delta$ at epicentral distances near 25°. Therefore, velocities and depths of rays emerging at epicentral distances greater than 25° are not computed.

The Herglotz — Wiechert formulas:

$$ln \frac{r_0}{r_1} = \frac{1}{\pi} \int_0^{\Delta_1} \cosh^{-1} \left(\frac{p}{p_1}\right) d\Delta \, , \frac{v_1}{r_1} = \frac{V}{r_0}$$

are used in the interpretation of the data. Here p is the ray parameter, v_1 the velocity at the deepest point (r_1) of the ray (with parameter p_1) emerging at an epicentral distance Δ_1. V is the apparent surface velocity at distance Δ, and r_0 is the radius of the earth.

In stripping the earth a single-layered crust of 33 km thickness with an average compressional velocity of 6.30 km/sec is assumed. The

Table 2. Velocity distribution.

Depth (km)	Velocity (km/sec)
33 Moho	8.22 (assumed)
40	8.26
50	8.28
60	8.30
80	8.32
100	8.33
110	8.33
150	8.42
200	8.54
250	8.66
300	8.88
350	9.09
400	9.30
450	9.50
500	9.74
550	9.97
600	10.21

velocity at the top of the mantle is taken to be 8.22 km/sec (PENTTILÄ [8]). The focal depths of the earthquakes is assumed to lie at the base of the crust. According to SYKES [9] the focal depths are confined to the upper 100 km of the earth for this region.

The variation of P-wave velocity in the uppermost 600 km of the mantle derived here and those obtained by JEFFREYS and SHIMSHONI [3] from data on P-wave amplitudes in European earthquakes are compared in Fig. 3. The velocity distribution is also given in Table 2. The travel-time differences between the computed first arrivals and the Jeffreys — Bullen's model and the computed first arrivals for the Jeffreys — Shimshoni's model are presented in Fig. 4. A small part of the travel-time residuals is caused by the difference in the crustal structure between the three models. The velocity distribution obtained here is in good agreement with that obtained by Jeffreys and Shimshoni.

Discussion

The values of $dt/d\Delta$ presented in Fig. 2 are quite scattered. Some scattering results from the fact that the crustal structure under the arrays differ and there may also be dipping boundaries in the crust.

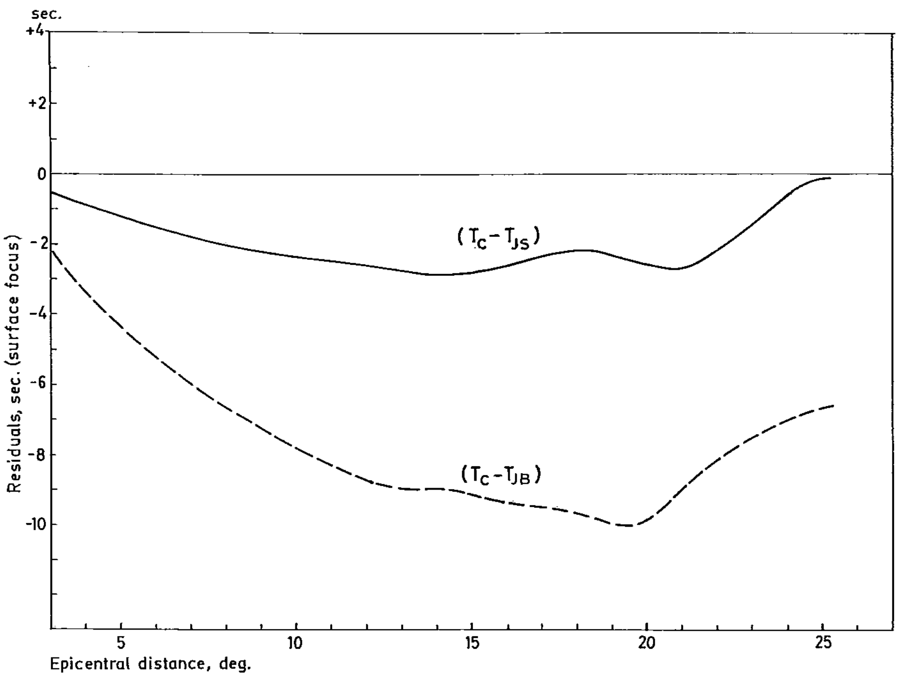

Fig. 4. Travel-time residuals from the Jeffreys — Bullen (JB) and Jeffreys — Shimshoni (JS) models for the new velocity structure.

This effect is most serious for small aperture arrays (KANESTRØM [4]). Values of $dt/d\Delta$ at about the same epicentral distance are often determined by different arrays and based on data from different earthquakes, and it is obvious that the errors in the position of the epicenters will contribute to the scatter. One may question the assumption that focus lies at the base of the crust. From a study of earthquakes off the west coast of Norway, the author found focal depths down to about 260 km (KANESTRØM [5]). Another factor is that large amplitude later arrivals may have been picked as first arrivals.

The large arrays (LASA and NORSAR) will be very useful tools in measuring travel-times and $dt/d\Delta$ for both first and later arrivals. This will be a new step towards a more detailed picture of the structure of the earth's interior. An important task in the future is to map the lateral variation in P- and S-velocities of both the upper and the deep mantle.

REFERENCES

1. DOYLE, H. A. and J. P. WEBB, 1963: Travel times to Australian stations from Pacific nuclear explosions in 1958, *J. Geophys. Res.* **68**, 1115–1120.
2. HALES, A. L., J. R. CLEARY and J. L. ROBERTS, 1968: Velocity distribution in the lower mantle, *Bull. Seism. Soc. Am.* **58**, 1975–1989.
3. JEFFREYS, H. and M. SHIMSHONI, 1966: The use of amplitudes in improving velocity distributions for Europe, *Geophys. J. r. astr. Soc.*, **10**, 515–524.
4. KANESTRØM, R., 1969: The dip of Moho under the NORSAR. *Scientific Report No. 3, ARPA Contract No F61052-68-C-0019, Seismol. Observ., Univ. of Bergen* (June 1969).
5. —»— 1969: Crustal structure and location of near earthquakes using NORSAR-data. Paper given at the *IASPEI's Congress, Madrid 1969.*
6. LEHMANN, I., 1966: On the structure of the upper mantle, *Bull. Seism. Soc. Am.* **56**, 1147–1152.
7. NIAZI, M. and D. L. ANDERSON, 1965: Upper mantle structure of western North America from apparent velocities of P-waves, *J. Geophys. Res.* **70**, 4633–4640.
8. PENTTILÄ, E., 1968: A report summarizing on the velocity of earthquake waves and the structure of the earth's crust in The Baltic Shield, *Geophysica*, **10**, 11–23.
9. SYKES, L. R., 1965: The seismicity of the Arctic, *Bull. Seism. Soc. Am.* **55**, 519–536.