Royal Norwegian Council
for Scientific and Industrial Research
(NTNF)

NORSAR

NORSAR Scientific Report No. 2-90/91

Semiannual Technical Summary

1 October 1990 — 31 March 1991

Kjeller, May 1991

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

7.6 Crustal thicknesses in Fennoscandia — An overview

Background

Crustal studies became popular among seismologists in the Fennoscandinavian countries some three decades ago, and still remain so. The numerous seismic surveys conducted within this region are aimed at mapping crustal structures in ever-increasing detail. We have reviewed the knowledge accumulated from these studies and made a new crustal thickness map with contour intervals of 2 km for Fennoscandinavia. In some areas the sediment thicknesses exceed 10 km, so it is important to differentiate between Moho depths and the crust crystalline thicknesses. Hence for the southern parts of Fennoscandinavia, notably Denmark and adjacent seas, an additional map of crystalline crustal thicknesses was made. Below, we will present the major results from this crustal study, while for details we refer to a forthcoming paper by Kinck *et al* (1991).

Geological Framework

Geographically, the Fennoscandinavian part of the Baltic Shield comprises the Kola Peninsula (including the White Sea), Finland, the Scandinavian Peninsula, Denmark and adjacent seas (Skagerrak, Kattegat, the Baltic Sea and parts of the Barents Sea)In geological terms, this area (Fig. 7.6.1) exhibits a variety of different tectonic provinces, ranging in age from Archean to Permian. The more recent opening of the North Atlantic, commencing some 56 Ma ago, affected only peripheral parts of the shield, that is, the coastal areas of western and northern Norway.

Crustal profiling — Moho depth mapping

The principal aims of crustal profiling surveys are crustal thicknesses and velocity-depth distributions above and below Moho. The former parameter seems well constrained in view of small differences of the order of 2–3 km either between intersecting profiling lines or between reflection and refraction lines. Regarding velocity-depth distributions the reflection profiling data have poor resolution. The refraction profiling data have relatively good resolution although the inversion schemes in general use do not give unique results. It suffices here to mention that different groups of researchers using the same set of observational data seldom produce the same velocity-depth distribution. The inherent problem here is that the identification and picking of secondary phase arrivals often are difficult and hence the final solution is not well constrained. Kinematic ray tracing is not too helpful in this respect since amplitude information and scattering contributions are mostly ignored. Also, there appears to be a significant improvement in the published profiling results from the mid-seventies and onwards, reflecting better recording instrumentation (digital), denser sampling and the use of more sophisticated analysis and interpretational methods. These brief comments on the reliability of seismic reflection and refraction profiling results should be kept in mind when judging the major outcomes of our study (Kinck *et al*, 1991), namely, a Moho depth map for Fennoscandinavia, thicknesses of the crystalline crust in the southern parts of the region (Denmark and adjacent sea) plus a tabulation of P-velocity depth distributions for selected profiles.

Fennoscandinavian seismic profiling surveys

We have carefully screened the available literature for profiling surveys within Fennoscandinavia, and the outcome of these efforts is tabulated in Table 7.6.1 and displayed in Fig. 7.6.2. Note that data from some of the profiling lines have been reanalyzed and reinterpreted and with few exceptions we only refer to the latest publication in tis regard. A final remark here is that indeed much effort has been invested in the crustal mapping of Fennoscandinavia.

Results: Moho depth and crystalline crustal thickness maps for Fennoscandinavia

In Fig. 7.6.3 the Moho depth map is shown and in Fig. 7.6.4 the crystalline crustal thickness map (limited to Denmark and adjacent seas) are shown. A map similar to that in Fig. 7.6.4 was attempted constructed for the Kola Peninsula area, the White Sea and the western Barents Sea, but at present there are not enough data available for such a task. Anyway, the Moho map in Fig. 7.6.3 is rather detailed, in particular in the areas offshore Norway, as we have been able to incorporate recent results from marine seismic reflection surveys. The crustal thickening is in general perpendicular to the coastal areas of southern and western Norway, and the Kola Peninsula, but less so for the interplate Baltic Sea. In general, the oldest parts of the Baltic Shield (the major parts of the Fennoscandinavian region) exhibit the greatest crustal thicknesses. This may be expressed in the following form:

$$H = 17.3 log(T) - 10.2 \qquad (1)$$

where H in km is Moho depth and T is time in Ma.

The sediment thicknesses in the basin areas offshore Norway are often formidable with corresponding thicknesses of the crystalline crust of the order of 15–20 km. There is no obvious correlation with age between the crustal P-velocity depth distribution, although whether we have piecewise negative, zero or positive velocity gradients is likely to affect profoundly seismic wave propagation in the crust. Regarding lateral Pn and Sn velocity variations within Fennoscandinavia, this problem has been studied by tomographic techniques using local seismological bulletin data (e.g., see Bannister *et al*, 1991). Their major findings are that pronounced low velocity areas are associated with the Caledonide mountains of western Norway and the rift and basin areas offshore Norway. The central parts of the shield are rather homogeneous in this respect. A corresponding tomographic study of crustal velocity variations (Pg and Sg phases) was not attempted since the Pg/Sg ray paths cannot uniquely be determined.

Discussion

Compared to many other continental regions, the results displayed in Fig. 7.6.3 and 7.6.4 are indeed very detailed. On the other hand, structural details are very poorly resolved, which in turn reflects the data at hand; mainly, refraction profiling results. Although these results are not adequate for restraining hypotheses on the tectonic evolution of Fennoscandinavia, we do think that these results may be instrumental in providing a better understanding of seismic records at local and regional distances through synthetic seismogram analysis. In this respect we consider the 2D finited difference technique presented in Section 7.5 to be most suitable since we could incorporate a tilting Moho together with any kind of velocity gradient above and/or below Moho.

A final remark is that the Moho depth variation appears to have a counterpart in the spatial distribution of earthquakes within this region. As is well known, the seismicity is by far largest in the coastal areas of Norway, where the crust is exceptionally thin. Furthermore, all the largest earthquakes, including the historical ones, have taken place in areas where the crust is thin. In other words, stress accumulations within Fennoscandinavia appear to be insufficient for cracking or causing major earthquakes in areas with thick crust (H >40 km), which naturally is stronger than the thin crust in the coastal areas. Naturally, there are many areas, including Denmark, with thin crust but seismically quiescent.

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Mapref	Name - Location	References	Type
A	Central Graben	Barton and Wood, 1984	Refrac
B	Mobil Search, West coast of Norway	S. Deemer pers. comm., 1989	WRe/ Refrac
BALTIC	Baltic, Finland	Luosto et al., 1990	Refrac
C	Møre margin	Olafsson, 1988	ESP
D	Cannobe, South Norway	Cassell et al., 1983	Refrac
E1-E5	EUGENO-S, Denmark, Kattegat, SW Sweden	Eugeno-S Working Group, 1988; Lund et al., 1987	Refrac
F1-F3	Fennolora, Sweden	Clowes et al., 1987; Galson and Mueller, 1986	Refrac
G	Lappland, Sweden	Båth, 1984	Refrac
H	Trondheim-Sundsvall	Vogel and Lund, 1971	Refrac
I	Oslo-Trondheim	Kanestrøm, 1971	Refrac
J	Otta-Årsund	Mykkeltveit, 1980	Refrac
K	Flora-Åsnes	Sellevoll and Warrik, 1971	Refrac
L	Fedje-Grimstad	Sellevoll and Wårrik, 1971	Refrac
LOF 1	Lofoten, Norway	Sellevoll, 1983	Refrac
LOF 2	Lofoten, Norway	Drivenes et al., 1984	Refrac
M-N	Oslo Rift	Tryti and Sellevoll, 1977	Refrac
LA-LY	Larvik-Lysekil	Egilson and Husebye, 1991	Refrac
P1-P4	NSDP84-01:04, Viking Graben-North Sea	Fichler and Hospers, 1989 Hospers and Ediriweera, 1988	Reflec
POLAR	Polar, N.Sweden-Norw.	Luosto et al., 1989	Refrac

Table 7.6.1. Page of 2.

Mapref	Name - Location	References	Type
R	Blue Norma	Avedik et al., 1984	Refrac
S	Barents Sea	Davydova et al., 1984	Refrac
SVEKA	Sveka, Finland	Grad and Luosto, 1987	Refrac
LADOGA	Ladoga, Finland/USSR	Korhonen et al., 1990	Refrac
T1-T3	Western Barents Sea	Faleide et al., 1991	ESP/WRe
U1-U2	Baltic Sea-Poland	Grad et al., 1991	Refrac
Y1-Y2	Eastern Norwegian Sea	Planke et al., 1991	ESP/WRe
Z1-Z6	Kola, USSR	Glaznev et al., 1989	Refrac
NAO	Norsar, Norway	Berteussen, 1977	Spec.r.
COP HFS KEV KIR KJF KON KRK NUR SOD UME UPP	Copenhagen, Denmark Hagfors, Sweden Kevo, Finland Kiruna, Sweden Kajaani, Finland Kongsberg, Norway Kirkenes, Norway Nurmijärvi, Finland Sodankylä, Finland Umeå, Sweden Uppsala, Sweden	Bungum et al., 1980	Spec.r.
-	Balticum, USSR	Lubimova, 1980	Refrac
-	Siljan, Sweden	Lund et al., 1988	Reflec
-	Kattegat and S. Sweden	Kornfält and Larsson, 1987	Reflec

Table 7.6.1. Seismic profiling — crustal mapping studies within Fennoscandinavia. (Refrac = refraction profiling; W.Re = wide angle reflection profiling; Spec.r. = long period seismic spectral ratio technique; ESP = expanding spread profile). (Page 2 of 2)

Profile 5	
H (km)	P-Vel (km/sec)
0	2.0
1.5	4.5
5.2	5.6
15	6.2
27	6.3
27	6.7
34	7.0
34	8.1

(1)

Profile 23	
H (km)	P-Vel (km/sec)
0	6.2
20	6.5
32	6.8
32	7.2
45	7.2
45	6.8
50	7.4
50	8.0

(2)

Profile F3(G)	
H (km)	P-Vel (km/sec)
0	6.1
24	6.5
24	6.6
35	6.9
35	7.1
45	7.4
45	8.1
--	

(3)

Profile F3(F)	
H (km)	P-Vel (km/sec)
0	6.0
5	6.0
5	6.2
20	6.5
20	6.6
41	6.9
41	8.1
--	

(4)

Profile LOF2	
H (km)	P-Vel (km/sec)
0	6.1
12	6.1
12	6.5
19	6.5
19	7.1
23	7.1
23	8.4
--	
--	

(5)

Profile Sveka	
H (km)	P-Vel (km/sec)
0	6.0
30	6.5
30	6.8
40	6.8
40	7.3
52	7.3
52	6.8
55	6.8
55	7.9

(6)

Profile Baltic	
H (km)	P-Vel (km/sec)
0	6.0
18	6.7
30	6.7
30	7.1
42	7.2
42	8.1
50	8.2
50	8.4
--	

(7)

Profile Ladoga	
H (km)	P-Vel (km/sec)
0	6.0
12	6.0
12	6.2
30	6.5
40	6.8
40	8.3
--	
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--	

(8)

Profile I	
H (km)	P-Vel (km/sec)
0	6.0
14	6.3
14	6.7
36	6.8
39	7.3
39	8.0
--	

(9)

Profile L	
H (km)	P-Vel (km/sec)
0	6.3
17	6.3
17	6.4
33	6.8
33	8.1
--	
--	

(10)

Profile D	
H (km)	P-Vel (km/sec)
0	5.5
6	6.2
6	6.5
26	6.8
28	7.5
28	8.1
--	

(11)

Profile LA-LY	
H (km)	P-Vel (km/sec)
0	5.6
5	5.6
5	6.3
13	6.3
13	6.8
31	6.8
31	8.1

(12)

Table 7.6.2. Page 1 of 2.

Profile E3		Profile F2(L)		Profile F2(C)		Profile F2(B)	
H (km)	P-Vel (km/sec)	H (km)	P-Vel (km/sec)	H (km)	P-Vel (km/sec)	H (km)	P-Vel (km/sec)
0	6.1	0	5.8	0	6.1	0	6.1
16	6.4	6	6.0	20	6.2	20	6.2
24	6.5	16	6.3	20	6.7	20	6.7
30	6.7	18	6.5	35	6.7	27	6.3
33	6.9	34	7.0	3.5	8.0	33	7.0
39	7.1	43	7.4	--		33	8.0
39	8.1	48	7.9	--		--	
--		48	8.3	--		--	
(13)		(14)		(15)		(16)	

Profile U1		Profile F1		Profile E1		Profile E2	
H (km)	P-Vel (km/sec)	H (km)	P-Vel (km/sec)	H (km)	P-Vel (km/sec)	H (km)	P-Vel (km/sec)
0	2.2	0	5.2	0	4.1	0	4.0
1.5	2.5	4	5.2	10	5.9	4	5.5
2.5	5.2	4	6.0	21	6.5	8	6.0
2.5	6.0	12	6.0	21	6.7	13	6.3
19	6.5	12	6.7	31	6.8	18	6.7
31	6.9	32	6.7	31	8.0	30	6.9
42	7.2	32	8.0	--		30	8.0
42	8.2	--		--		--	
(17)		(18)		(19)		(20)	

Table 7.6.2. Tabulation of P-velocity distributions presumed representative for Fennoscandinavia. The profile notation of Table 7.6.1 is retained and the corresponding part of the respective profiles for which the velocity distributions are valid are marked by dots in Fig. 7.6.2. The sources are not necessarily coinciding with the listings of the original profiling references in Table 7.6.1, and are as follows: Profile S: Davydova *et al* (1985); Profile Z3, F3(G), F3(F), SVEKA, BALTIC adn LADOGA: Korhonen *et al* (1990); Profile LOF2: Drivenes *et al* (1984); Profile F2(E): Lund (1987); Profile F1, F2(B), F2(C): Clowes *et al* (1987); Profile U1: Grad *et al* (1990); Profile E1, E2, E3: Gregersen (1991); Profile LA-LY: Egilson and Husebye (1991); Profile D: Cassell *et al* (1983); Profile L, I: Kværna (1984). Note that for the two segments of the Fennolora profile F2 and F3, the letter indexing above is from south to north, i.e., F2(B), F2(C), F2(E), F3(F) and F3(G) – in Fig. 7.6.2 no such indexing. (Page 2 of 2)

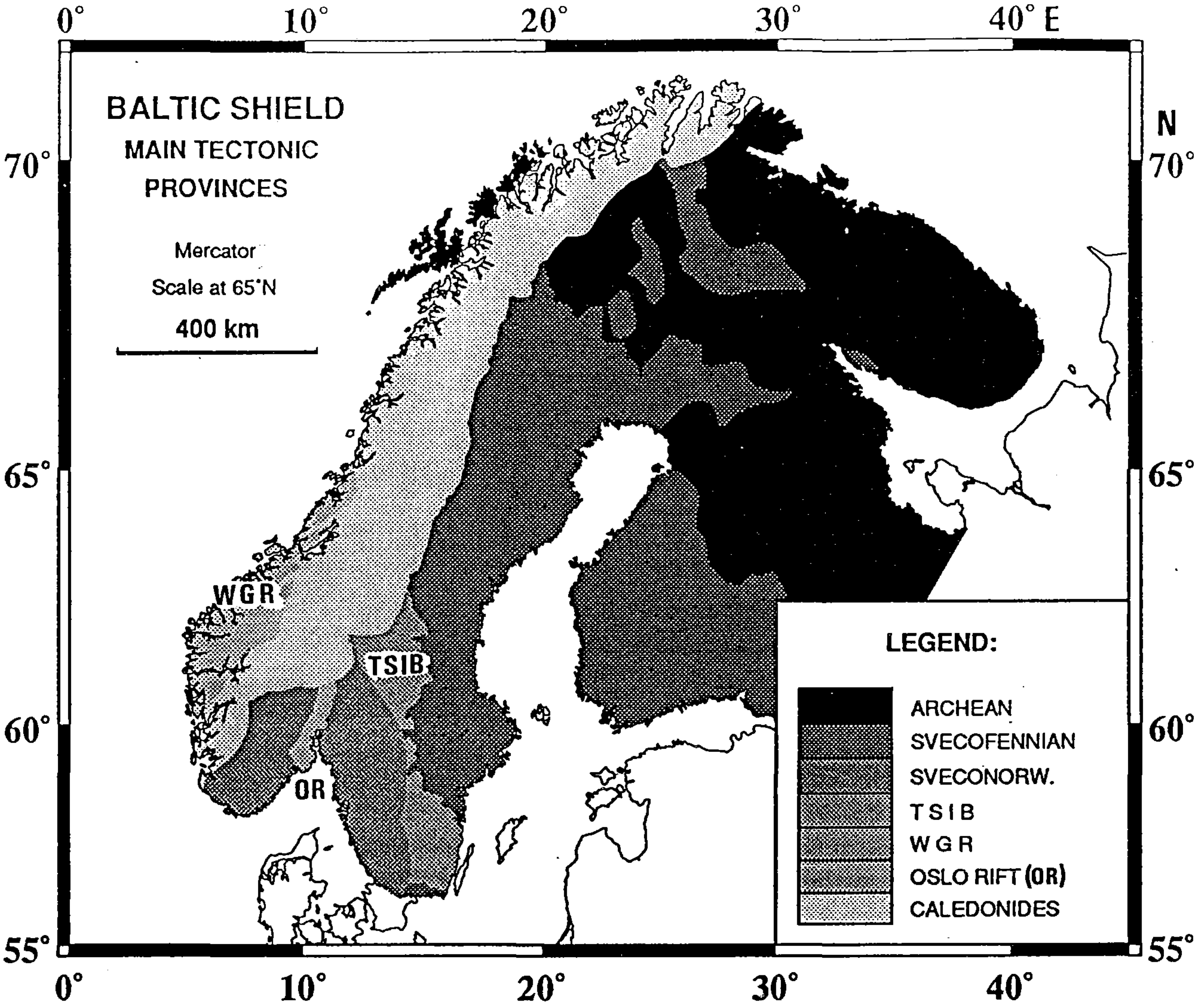

Fig. 7.6.1. Tectonic map of the Baltic Shield showing main age provinces. T.S.I.B.: Trans Scandinavian Igneous Belt. W.G.R.: Western Gneiss Region. Based on Gàal and Gorbatschev (1987).

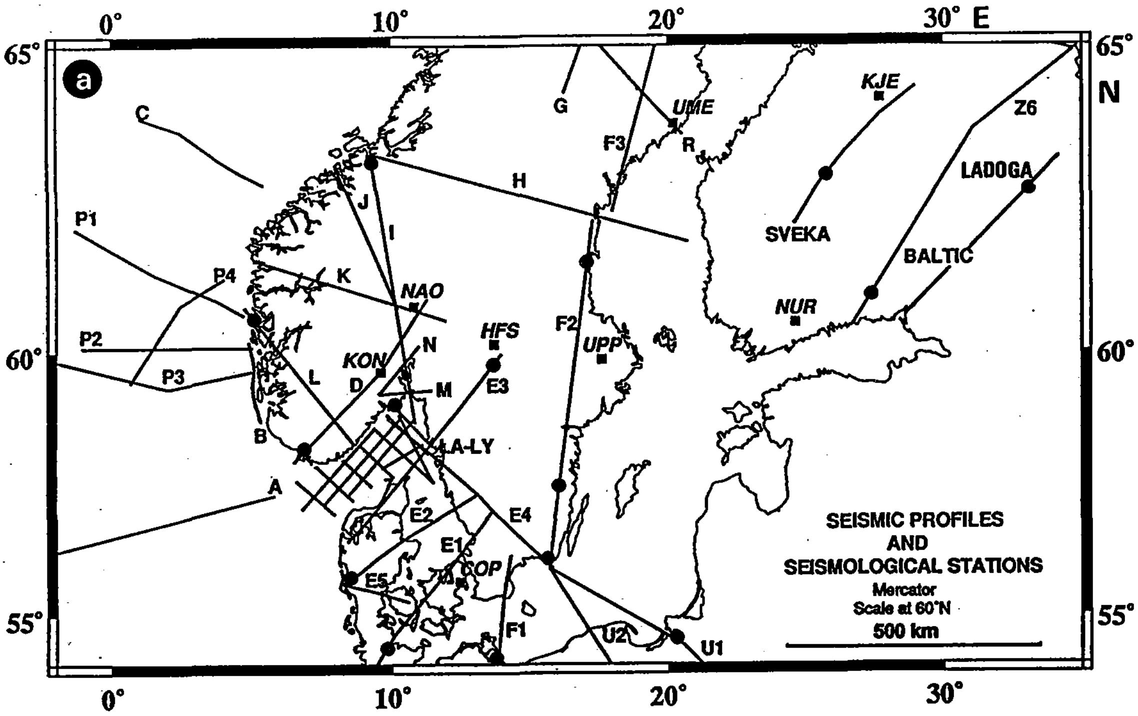

Fig. 7.6.2a. Seismic profiles and seismological stations (squares) in southern Fennoscandinavia. For references, see Table 7.6.1. The black dots mark small profiling areas for which P-velocity - crustal depth distributions are given in Table 7.6.2.

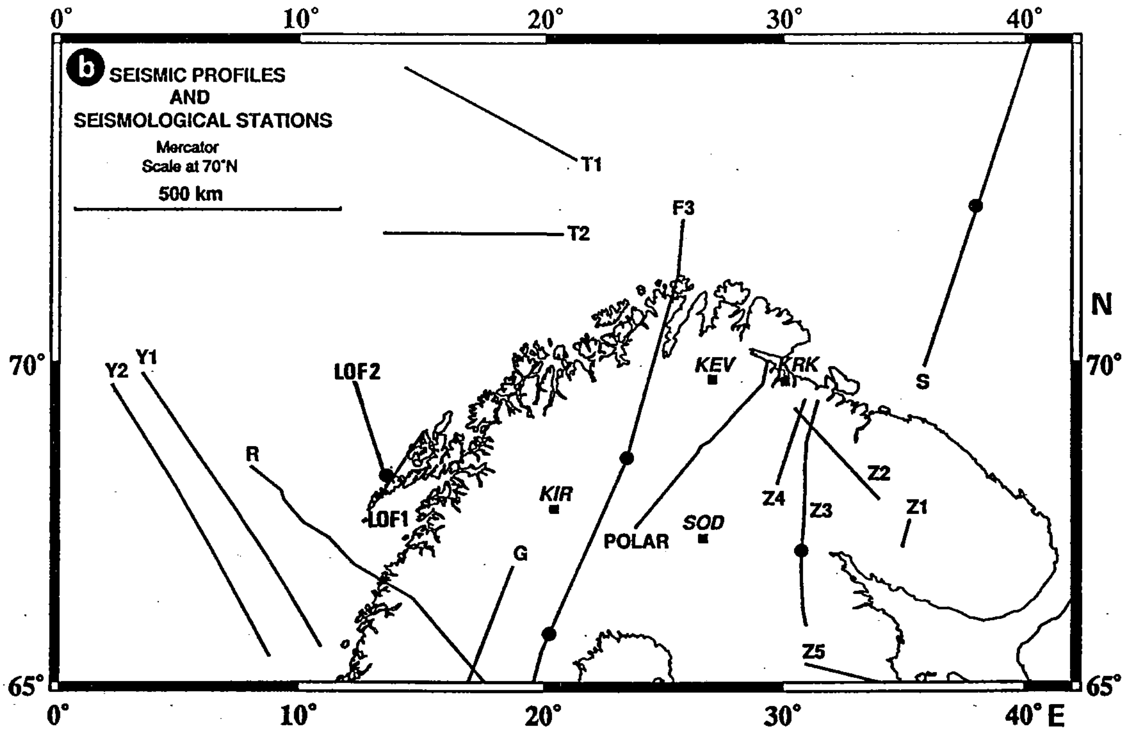

Fig. 7.6.2b. Seismic profiles and seismological stations (squares) in northern Fennoscandinavia. For references, see Table 7.6.1. The black dots mark small profiling areas for which P-velocity - crustal depth distributions are given in Table 7.6.2.

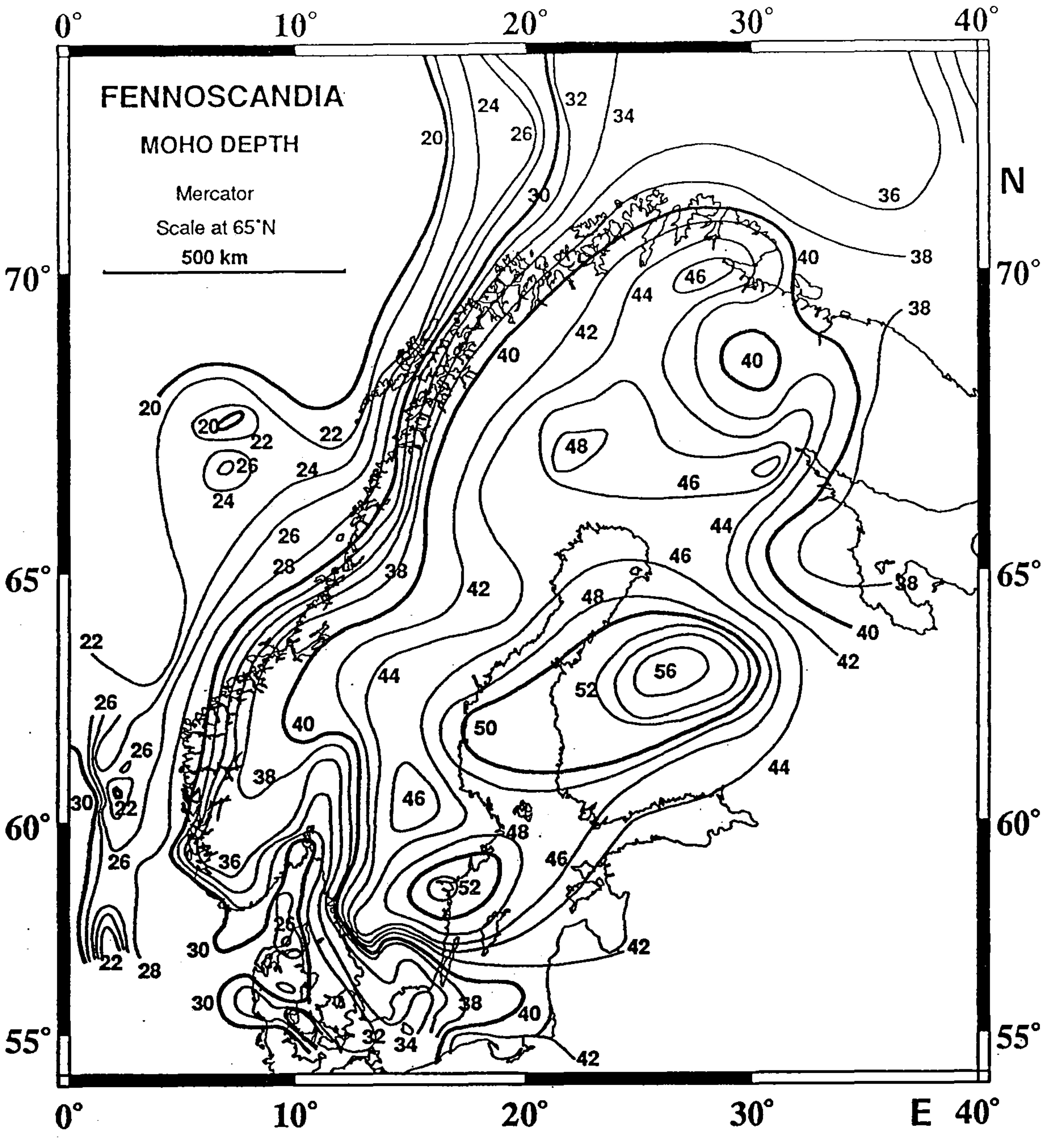

Fig. 7.6.3. Moho depth in Fennoscandinavia below sea level. A 2 km contour interval is used.

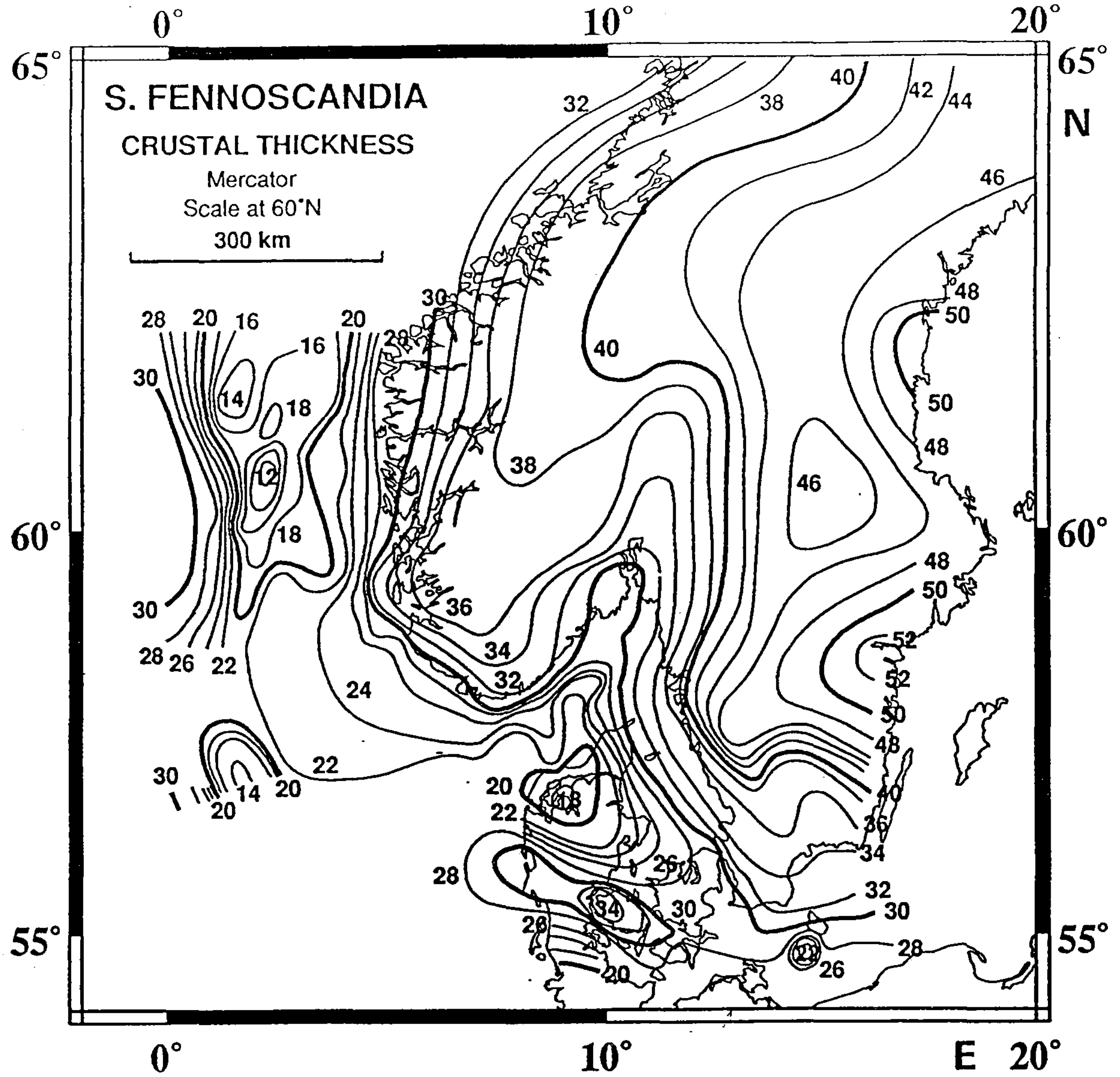

Fig. 7.6.4. Thickness of the crystalline crust in southwestern Fennoscandinavia where comprehensive sediment thickness data were available. A 2 km contour interval is used.