CHAPTER I

INTRODUCTION

This thesis demonstrates an attempt to investigate the complex structure of the northern European lithosphere and upper mantle from northern Germany to central Finland. Towards this aim I have used the receiver function methodology and utilized the teleseismic earthquakes recorded by two of the largest temporary seismic networks in Europe− TOR and SVEKALAPKO and those by the stations of German Regional Seismic Network (Fig. 1.1 & Fig. 2.1).

Receiver function method, past and present

The idea of using spectral ratio technique for isolating the crustal response function at a recording station was put forward in the mid 60's (*Phinney 1964*). However, It was in the end of 70's when Langston (*Langston 1979, 1981*) formulated and named receiver function methodology for exploring crustal structure through isolating conversions from the discontinuities whereas *Vinnik* (*1977*) had taken similar approach to detect upper mantle discontinuities by introducing delay and sum techniques.

The development of the method took a new turn as high quality broadband data were used for inverting the receiver functions for crustal velocities (e.g. *Owens et al. 1984*). The early euphoria followed by widespread usage of the inversion technique was subdued though as attentions were drawn to nonuniqueness nature of the results (e.g. *Ammon 1990*). Many attempts have been made so far to improve on strong dependence of final results of inversion on starting velocity models, but it seems that independent sources of velocity structures such as those obtained by surface wave and/or body wave tomography are needed for more reliable starting models and thus better outcome.

A major breakthrough has occurred as various techniques usually used in multichannel data processing of seismic explorations profiles, such as move−out correction (*Gurrola et al. 1994, Yuan et al. 1997*) and migration (e.g. *Kosarev et al. 1999*) were successfully applied to array and network data and produced detailed information on crustal and upper mantle structures. In its present form the receiver function method has emerged as a standard and reliable routine in any seismological investigation of the crust and upper mantle carried out using deployment of temporary seismic networks. Rather than as an alternative to costly active seismic measurements it could be envisaged as an integral part to such surveys.

Geologic and tectonic setting of the studied region

Northern European continent from the southernmost edge of the TOR profile (North German Lowlands) to the northernmost corner of the SVEKALAPKO network (central Finland) is considered seismically inactive and tectonically stable (Fig. 1.1). The lack of macroseismic activity in the region can be attributed, according to plate tectonic theory, to the absence of active seismic boundaries. Geologic and geophysical evidences, however, are abundant for the existence of some ancient plate boundaries which divide Phanerozoic, Proterozoic, and Archean basements of Europe as we traverse from northern Germany to the Baltic Shield.

From southwest to northeast along the extent of TOR and SVEKALAPKO networks the following structural and geological units are observed (as labeled in Fig. 1.2):

The North German Basin: The deeply buried caledonides of North German Lowland extend from North Sea to Poland. In northern Germany they are covered by more than 10 km of Devonian and younger sediments. There are up to 12 km of deposits in Schleswig−Holstein which according to borehole information (*Frost et al. 1981, Ziegler 1982, Liboriussen et al. 1987*) overlie the metamorphosed Caledonian basement. The Elbe line to the south marks the boundary between the North German Basin and the Cadomian Lüneburg massif. To the north the Trans−European Fault cuts through the the Avalonian accretion belt which is apparently juxtaposed with the Avalonian caledonides along the Caledonian Front.

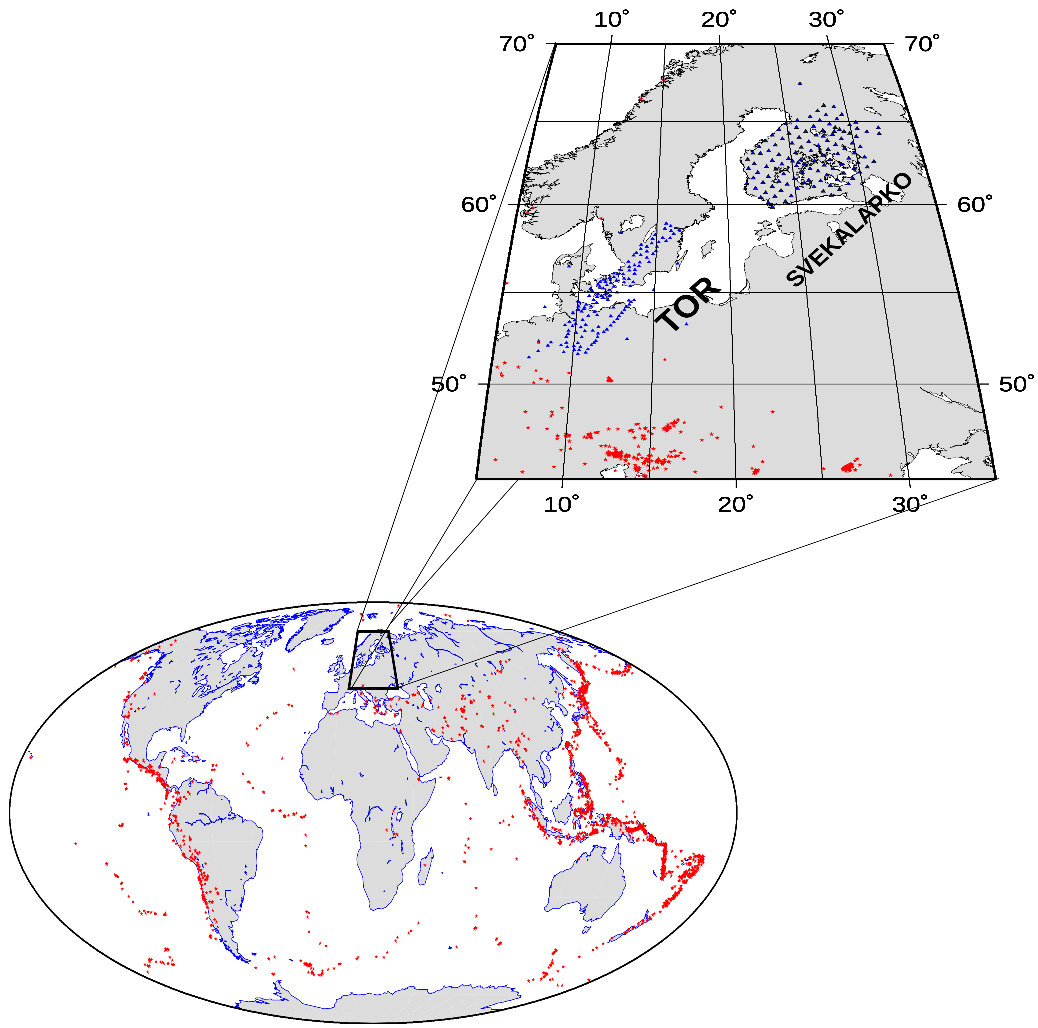

Fig. 1.1 Location map depicting the distribution of TOR and SVEKALAPKO stations (blue and black triangles, respectively) on the background of macroseismic activity (earthquakes with magnitudes greater than 3.5, shown as red stars) for the time period of 1973−2002 (source: USGS PDE Bulletin). The lack of seismic activity throughout the extent of both networks is an evidence for the absence of active plate boundaries. The only macroseismic activities observed south of the TOR profile is related to the Rhein Graben. The red stars on the globe represent world seismicity with earthquakes greater than 5.9 for the time period of 1991−1999 (source: USGS PDE Bulletin).

The Ringkøbing–Fyn High: consisting of a series of elevated basement blocks which appeared as a result of uplift during Carboniferous–Early Permian time and was first recognized by *Sorgenfrei & Buch (1964)*. Thin sedimentary cover and a gravity high characterize this structure.

The North Danish Basin: A 100–200 km NW–SE trending basin extending from the North Sea to the Polish Trough filled with about 5 km thick sediments dating from Permian to Cenozoic time that overlie a Precambrian basement. Radioactive dating of the core samples from basement under the North Danish Basin, north of the Ringkøbing–Fyn High, shows Proterozoic age (880–900 Ma) (*Larsen 1971*).

The Tornquist Zone: The ancient boundary between Phanerozoic and Precambrian Europe is defined by Trans–European Suture Zone (TESZ), the largest tectonic lineament in northern Europe, which extends from the Black Sea to the British Isles. The northwestern segment of the TESZ in northwest Europe is called Tornquist Zone and marks the suture of the Avalonia (present central Europe) and Baltica (present day Scandinavia and Finland) as the closure of the Tornquist Sea was followed by the collision of the two plates in Silurian (*Blundell et al. 1992)*. Unlike in Poland where the TESZ marks the boundary between Precambrian foundation and Paleozoic crustal domains, in northern Germany and Denmark the boundary between the two provinces lies in the vicinity of the Caledonian Deformation Front (Fig. 1.2).

Present day Tornquist Zone is an intensely faulted zone which is characterized by its late Cretaceous–Early Tertiary inversion structures, a result of the collision of Africa with Europe during the Alpine–Carpathian Orogeny (*Ziegler 1982*). It seems that the inversion did not fully compensate the crustal thinning caused by Permian and Mesozoic rifting and basin development (*Ziegler 1982, BABEL Working Group 1991*).

The Baltic Shield: There is a general age zonation from Proterozoic provinces in the southwest to the Archean Nucleus in the northeast. The two main Proterozoic provinces, the Svecofennian, and the Sveconorwegian are in fact structural domains named after the last episode of orogeny that has deformed them during 2100−1750 Ma and 1050−950 Ma, respectively (*Thybo 2000*). It is proposed that the Proterozoic provinces have been successively added to the Archean Nucleus by a series of crustal accretions accompanied by extensive orogeny, subductions and magmatism. The end of Precambrian deformations is marked by Caledonian orogeny (around 950 Ma ago) which created the northwestern Border (*EUGENO−S Working Group 1988*) (Fig. 1.2).

The Archean−Proterozoic Suture Line also known as Luleå−Kuopio suture zone marks the boundary between the Svecofennian (southwest) and Kola−Karelian (northeast) orogens as indicated by outcropping rocks, changes in intensities of aeromagnetic anomalies (*Windley 1992*) and chemistry changes in the composition of granitoids (*Öhlander et al. 1993*) on both sides of the suture. It represents the collisional tectonics with NE directed subduction occurred in in early Proterozoic (*BABEL Working Group 1991*).

The Kola−Karelian Province represents the Archean nucleus of the Baltic Shield with most of the rocks formed at about 2.8 Ga ago (*Gaál and Gorbatschev 1987*) but underwent structural deformation and amalgamation of several terranes during Early Proterozoic.

Previous studies

Tornquist Zone has been the focus of intensive geological and geophysical research specially in the projects like EGT (**E**uropean **G**eo**T**raverse, e.g., *Blundell et al. 1992*), EUGENO−S (**EU**ropean **GE**otraverse **NO**rthern Segment, **S**outhern part, e.g., *EUGENO−S Working Group 1988*) and BABEL (**BA**ltic and **B**othnian **E**choes from the **L**ithosphere, e.g., *BABEL Working Group 1993*).

As a follow−up to previous studies of tectonic evolution of northern Europe two major projects, namely TOR (Teleseismic Tomography **TOR**nquist, *Gregersen et al. 1999)* and SVEKALAPKO (**SV**ecofennian **KA**relian−**LA**pland−**KO**la Transect, *Hjelt & Daly 1996*) with special emphasis on the structure of the Tornquist Zone and the evolution of the Baltic Shield

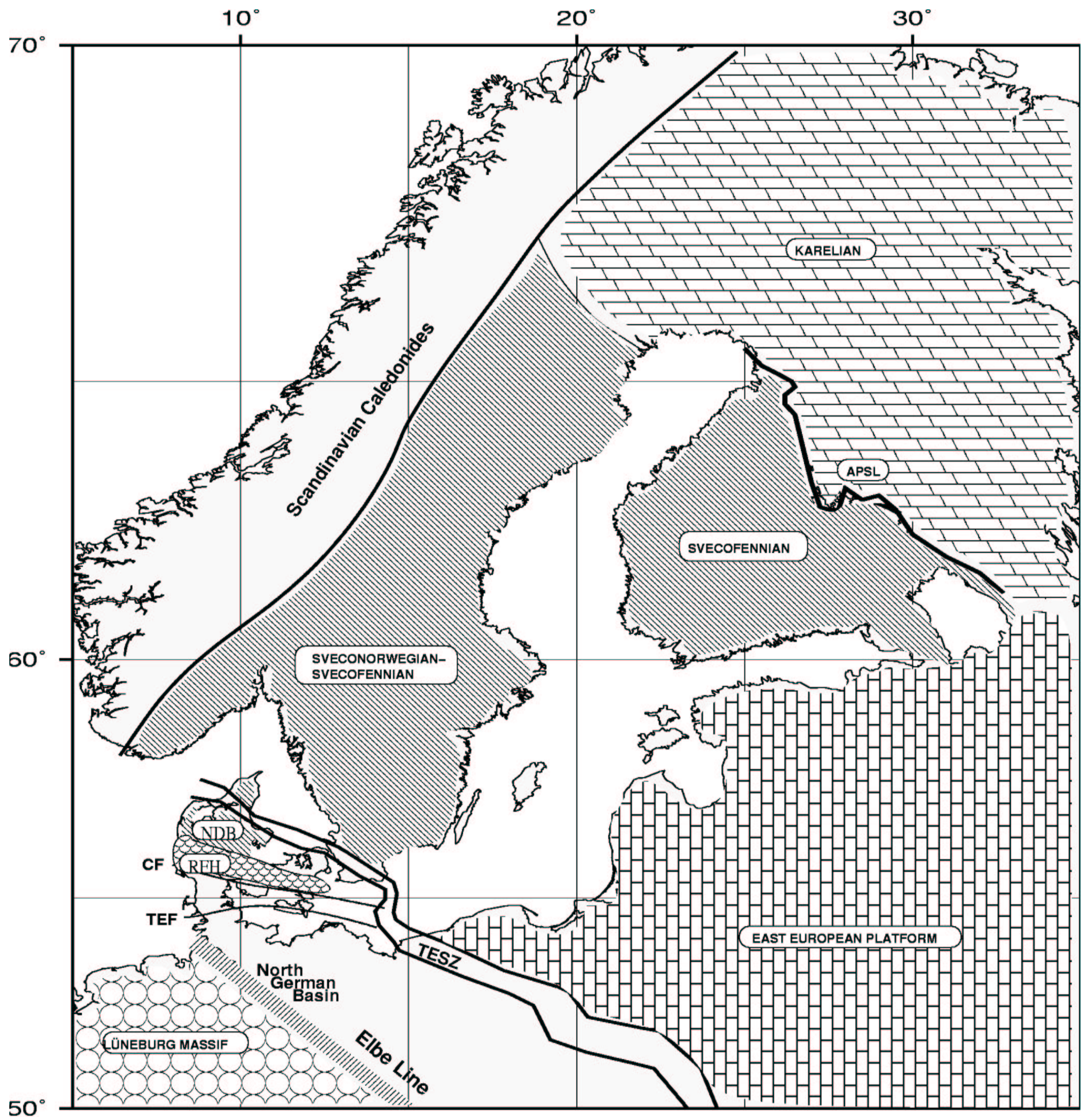

Fig. 1.2 A simplified map of the studied region showing major structural units (after *Berthelsen et al. 1992* and *EUGENO−S Working Group 1988*). Abbreviations: **TESZ** −Trans−European Suture Zone which in the southeast marks the boundary between the Precambrian East European Platform and Paleozoic North German−Polish Basin. **TEF** −the Trans−European Fault; **CF** − the Caledonian Front, and **APSL** − The Archean−Proterozoic Suture Line (which is also called Luleå−Kuopio suture zone in some literature), **RFH**− Ringk⌀bing−Fyn High; **NDB**− North Danish Basin.

were designed. In the framework of these projects two major temporary seismic networks, TOR and SVEKALAPKO were deployed to probe into the crust and upper mantle from the Proterozoic North German Basin in the south to the Archean Baltic Shield in the north and to provide comparison of the results achieved by active and passive seismic methods.

The TOR profile (*Gregersen et al. 1999*) with its elongated geometry and consisting of more than 140 broadband and short period stations (Fig. 1.1) provided the opportunity to study several tectonic lineaments (see e.g., *Gossler et al. 1999, Arlitt et al. 1999 and Wilde−Piorko et al. 2002*) which are highly controversial in terms of the roles geologists and geophysicists attach to them.

Adopting the approach taken in design and deployment of TOR network and bringing it into a broader perspective the SVEKALAPKO seismic network (*Bock et al. 2001*) was devised and over 120 boradband and short period stations were deployed in Finland and Karelian Russia, spreading over the Proterozoic and Archean Baltica across their suture zone. This configuration has provided a unique opportunity for broader and deeper investigation of the crust and upper mantle of the Baltic Shield than what had earlier been done by the controlled seismic source studies (e.g. *BABEL Working Group 1990, Luosto* 1997 *and Heikkinen et al.* 1999*)*.

The approch of this work

By combillning three large databases, namely TOR, GRSN and SVEKALAPKO, I have tried to take a unified approach towards unraveling the complexities of structures in Paleozoic and Precambrina provinces in northern Europe. By stretching the receiver function methodoloy to the very limit of its resolution power I attempted to look for answers to questions like these:

What are the characteristics of the Tornquist Zone? Where is the zone of transition between Paleozoic and Precambrian Europe actually located? Are there deep−seated differences between the two provinces?

What is the nature of the transition zone from Proterozoic and Archean orogenies in the Baltic Shield? Is there a collisional tectonics involved?

Chapther **II** introduces the data set. As it will be discussed in detail teleseismic earthquakes recorded by TOR, SVEKALAPKO, GRSN and GEOFON stations have been used in this study. Discussions on the characteristics of each data set with diagrams showing the signal quality of some sample stations are presented.

Chapter **III** discusses receiver function methodoly as it has been used and developed for this study. Synthetic receiver functions calculted using reflectivity method (*Kind 1985*) have been used to highlight different aspects of the steps taken to process the data.

Chapter **IV** presents the results of this investigation in terms of maps of Moho delay times, crustal thickness and and Vp/Vs values along with detailed images of crustal structures and upper mantle 410 km and 660 km discontinuities along selected profiles. Discussions are brought up to interpret the results with respect to their geological and geophysical significances and the implications they make to tectonic evolution of European continent.

The concluding remarks are in chapter **V** which is followed by additional information on the events and instrumentation used, in appendices **A** and **B**.

And, finally a brief account of the results achieved by application of receiver function method to data from two stations in northern Iran is presented in Appendix **C** that draws this treatise to an end.