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GÖTEBORGS UNIVERSITET

Torbjörn Andersson

EARTH SCIENCES CENTRE
GÖTEBORG UNIVERSITY
A35 1998

PROBING CRUSTAL STRUCTURES IN SOUTHWESTERN SCANDINAVIA: CONSTRAINTS FROM DEEP SEISMIC AND GRAVITY OBSERVATIONS

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GÖTEBORG 1998

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Probing crustal structures in southwestern Scandinavia: Constraints from deep seismic and gravity observations

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ABSTRACT

Within the Sveconorwegian Province post-orogenic granites are abundant. Their ages coincides with the late extensional stage of the Sveconorwegian-Grenvillian orogen. Seismic and gravity data suggest that the Bohus granite in Sweden continues seaward in the Skagerrak Sea, for at least 80 km. A distinct reflection pattern is observed where the inferred seaward extension of the Bohus granite is intersected by a seismic profile. A large Moho offset is seismically observed beneath the modelled granite. It is proposed that this offset is related to Sveconorwegian crustal underthrusting and that the granite melt could have formed by anatexis of mid-crustal rocks downthrusted to greater depths in the vicinity of the Moho offset.

Further west in the Skagerrak Sea, seismic mapping suggests a complex area of Moho offsets and sub-Moho reflectors, associated with the Sorgenfrei-Tornquist Zone. Here, flexural subsidence of the shield-edge appears to have occurred during the Mesozoic without substantial thinning of the crust. On the basin side, the thinned crust together with the uppermost mantle appears to have been rigid enough to support segmentation and rotation of crustal blocks. The Fjerritslev Trough, observed to contain approx. 15 km of sediments, is interpreted as a pull-apart basin created by transtensional movements along the Tornquist Zone. The presence of Paleozoic sediments in the Fjerritslev Trough indicates that the Tornquist Zone was active also during this period.

The wide-angle seismic EUGENO-S profiles 1 and 4 belonging to the European Geo-Traverse project, have been reinterpreted into new P-wave velocity models. Perturbations in the Conrad- and Moho discontinuities are mapped within the Ätran and Idefjorden terranes of the Sveconorwegian Province. Seismically observed deep crustal segments are suggested to outline a continuous belt, at least 120 km in length, located in the Ätran terrane. A regional positive gravity anomaly, the Falkenberg Gravity High (FGH), spatially coincides with the Southwest Swedish Granulite Region, affected by Sveconorwegian high-grade metamorphism. A connection between the FGH and the granulite region is proposed, and the gravity high is suggested to be caused by granulitic rocks located within the upper crust.

Keywords: deep reflection seismic profiling; gravity anomalies; wide-angle seismics; Sveconorwegian Province; Skagerrak Sea; Bohus granite; Sorgenfrei-Tornquist Zone; Moho discontinuity; P-wave velocity structure.

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Andersson, M., Lund, C.E. and Lind, G. Crustal inhomogeneties in SW Sweden. Results from wide-angle seismic and gravity data. *Manuscript.*

Probing crustal structures in southwestern Scandinavia: Constraints from deep seismic and gravity observations

INTRODUCTION

During the last two decades, geophysical surveys have been performed in order to investigate the lithotectonic evolution of the Baltic Shield and its surroundings. For this purpose, multi-national projects such as the European Geotraverse (EUGENO-S Working group, 1988), the FENNOLORA (Prodehl and Kaminski, 1984; Guggisberg, 1986), MONA LISA (MONA LISA Working Group, 1997) and the BABEL deep seismic survey (BABEL Working Group, 1990) have been set up (Fig. 1) and vast amounts of data have been collected. The most recent, the EUROBRIDGE project was launched in the mid-nineties; a multidisciplinary research project, designed to image the Trans-European Suture Zone, separating mobile Phanerozoic terranes from the Precambrian East European craton. The results reported from these projects have greatly enhanced the understanding of the deep crust and upper mantle and its significance for plate tectonic development and surface geology expression.

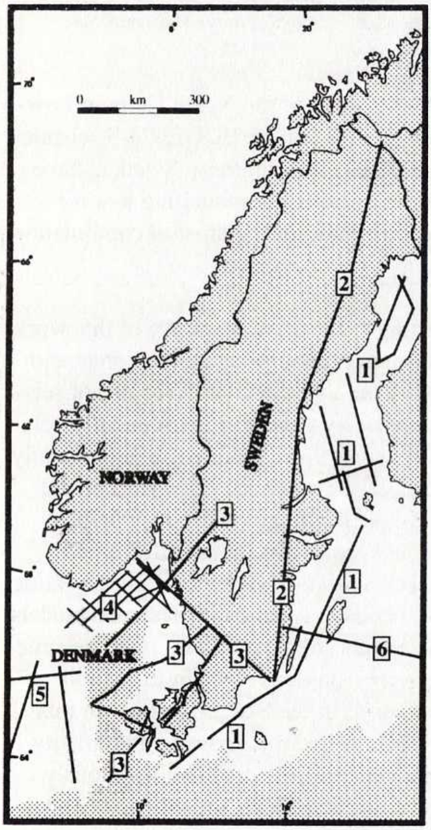

Figure 1. Map of Scandinavia, showing the locations of geophysical surveys for lithosphere research undertaken during the last few years. ***1:*** *Deep reflection seismic profiles of the BABEL Project 1989.* ***2:*** *Refraction seismic data collected in 1979 along the FENNOLORA line.* ***3:*** *EUGENO-S wide-angle seismic profiles, belonging to the EGT-project (1984).* ***4:*** *The Mobil Search deep seismic profiles in the Skagerrak Sea. Survey performed in 1987.* ***5:*** *Deep seismic survey undertaken by the MONA LISA Working Group 1993 in the eastern North Sea.* ***6:*** *The planned deep seismic reflection survey of EUROBRIDGE, continuing into the interior of the East European craton. For references, see text.*

In 1987, deep seismic reflection data were recorded in the Skagerrak Sea by the R/V Mobil Search ("The Mobil Search Cruise", see e.g. Husebye et al., 1988) as part of the Norwegian Lithosphere Programme (for profile locations, see Fig. 2). The record lenght was 16 s. two-way-time (TWT), equivalent to a vertical penetration depth of approx. 50 km. Also, the shot-receiver configuration chosen was optimum for seismic mapping of deep crustal structures. A dual recording system with sampling intervals of 4 and 8 ms was used. The 8 ms data were processed onboard, and later, processing of the 4 ms data was made of the upper 6 s. TWT to improve the imaging of the upper sedimentary

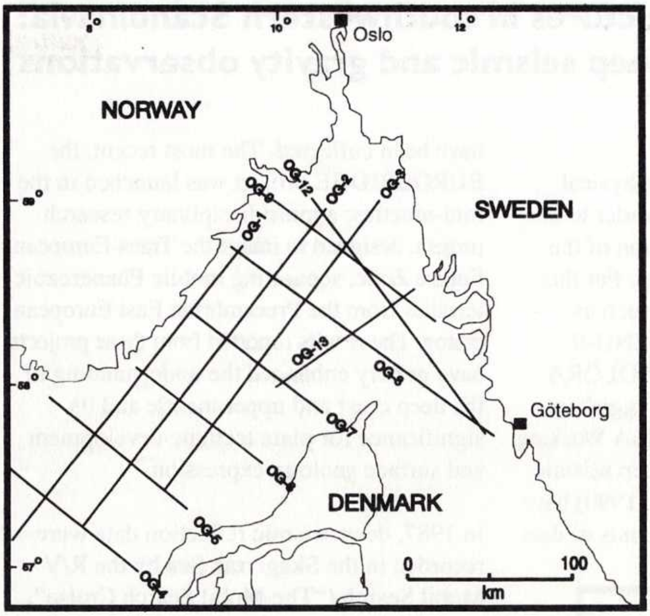

Figure 2. Location of the Mobil Search deep seismic and gravity profiles in the Skagerrak Sea.

column. Finally, the 8 ms data were migrated and reprocessed (e.g. Lie and Husebye, 1993) (for acquisition details, see Fig. 3 and 4). In addition, gravity observations were collected during the Mobil Search cruise along the deep seismic profiles. Although the seismic data have been used in the Skagerrak research projects since 1988, the marine gravity observations have not been accessible until recently. Together with the deep seismics, the gravity data displays a valuable complement for interpretation of basin and crust development of southwestern Scandinavia. These offshore seismic and gravity data constitutes a major part of information used in this work. In addition to this, seismic wide angle reflection and refraction profiles from the EUGENO-S project (EUGENO-S Working Group, 1988) have been studied. As a part of the multi disciplinary European Geo Traverse, this extensive assignment was designed to examine the transition from the Precambrian crust of the Baltic Shield to the Caledonian crust of the North German Lowlands. Here, two of the EUGENO-S seismic profiles transecting southern Sweden, have been reinterpreted, by modelling P-wave velocity structure of the crust in combination with gravity observations.

Accordingly, the main objective of this work has been to present models of the crust and crustal elements basically by the use of seismic and gravity data, and consequently, to check whether these models are geologically feasible. Objects of both Precambrian and Phanerozoic origin are mapped, which is natural in view of the investigated area, located close to the border zone of the Baltic Shield. In *paper 1* and *2* the presented models are the results from interpretation of seismic and gravity data derived from the Mobil Search cruise in the Skagerrak Sea. In this case, where reflection seismics and gravity observations are collected simultaneously along the same profiles, the inferred crustal

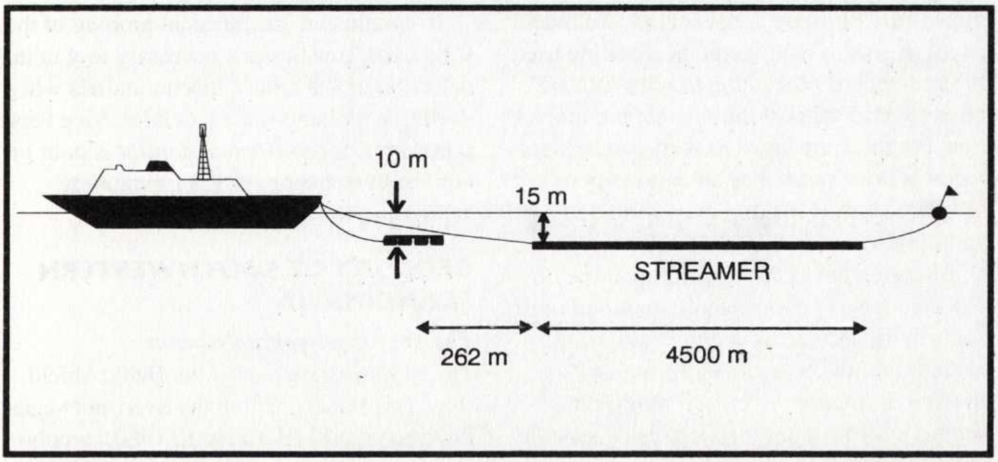

Figure 3. *Acquisition of the Mobil Search deep seismic survey*

RECORDING PARAMETERS
THE MOBIL SEARCH CRUISE SURVEY 1987
SKAGERRAK SEA

Record length	16 seconds
Sample rate	8 milliseconds
Traces/record	90
Filter	Lowcut 5.3 Hz Highcut 45 Hz
Hydrophones/group	32
Group interval	50 meter
Number of groups	90
Streamer length	4500 meter
Streamer depth	15 meter
Offset	262 meter
Tuned wide air gun array	
Array dimensions	59 x 75 m (l x w)
Number of sub-arrays	4 x (12 guns over 59 meter)
Sub-array spacing	25 meter between strings
Pressure/capacity	1800 psi/7200 cubic inches
Towing depth	10 meter
Shotpoint interval	50 meter
CDP spacing	25 meter
Fold	45

Figure 4. *Recording parameters of the Mobil Search deep seismic survey.*

models are far more consistent as two independent geophysical methods are being used. In the standard procedure, gravity data are often used to support the seismic interpretation, but there are cases as well, where significant gravity anomalies are not imaged seismically, thus making gravity modelling still more valuable.

Attention has been focused upon specific objects such as post-orogenic granitoid intrusions in the Skagerrak region and tectonic evolution of the Sorgenfrei-Tornquist Zone. Moreover, in *paper 3,* crustal models of southern Sweden are mapped, using seismic wide-angle and gravity data. Here, interest is focused on the Paleo- to Mesoproterozoic crust of the Sveconorwegian Province and in particular, its southwestern part. Lithotectonic structural framework with attention to variations in crustal thickness are highlighted, together with inferred crustal inhomogeneties arisen from orogenic events during the Sveconorwegian orogeny.

A more detailed and consistent understanding of the Baltic Shield crustal development is successively being improved, particularly with respect to the increasing amount of well-constrained isotopic age determinations. Gaál and Gorbatschev (1987) outline the evolution of the Baltic Shield and distinguish four main periods of orogenic activity, ranging from 3.5 to 1.5 Ga, with a generalized younging from northeast towards southwest. This zonation, largely based on geochronological data, is in some places supported by geophysical observations. One example here is the inferred 1.9 Ga suture zone that was seismically imaged by the BABEL Working Group (1990) in the Bothnian Bay (location, see Fig. 1), which also provided evidence for Early Proterozoic plate tectonic processes. For geophysical evidence of early plate tectonics; see also Calvert et al. (1995) and Warner et al. 1996).

In conclusion, geophysical probing of the solid earth constitutes a necessary tool in the detection of subsurface discontinuities when dealing with large-scale tectonics. Vice versa however, if the *geological control* is poor or non-existent, geophysics is figuratively working in the dark.

GEOLOGY OF SOUTHWESTERN SCANDINAVIA

The Sveconorwegian Province

The southwestern part of the Baltic Shield (Fig. 5) is situated within the Sveconorwegian Province (SNP) (Berthelsen, 1980); a polymetamorphic gneiss complex, considered a continuation of the North American Grenville belt (Gower, 1990). The Sveconorwegian-Grenville orogeny is bracketed within the 1.15-0.9 Ga time interval. However, in southwestern Sweden the major part of the crust may have been created earlier, during the Gothian orogeny (1.75-1.55 Ga) (Gaal and Gorbatschev, 1987). In southern Norway the SNP is obscured by Caledonian nappes in its northern part, and divided into the Telemark sector, consisting of reworked gneisses of both plutonic and supracrustal origin (Falkum, 1980), and the high-grade metamorphic gneisses of the Bamble and Kongsberg sectors (Starmer, 1991; 1993). These two supergroups are separated from the Telemark sector by the Bamble Fault and the Kongsberg Fault respectively. The SNP is truncated by the Late Paleozoic Oslo Rift; an extensional rift system, extending into the Skagerrak Sea forming the Skagerrak Graben (Neumann et al., 1986; Ro et al., 1990a; Sundvoll et al., 1990). At the Swedish Skagerrak coast Mesoproterozoic gneisses were intruded by the post-Sveconorwegian Bohus granite, dated to 922 Ma (Eliasson and Schöberg, 1991). Several granitoids of the same generation are present in southern Norway within the SNP (Eliasson and

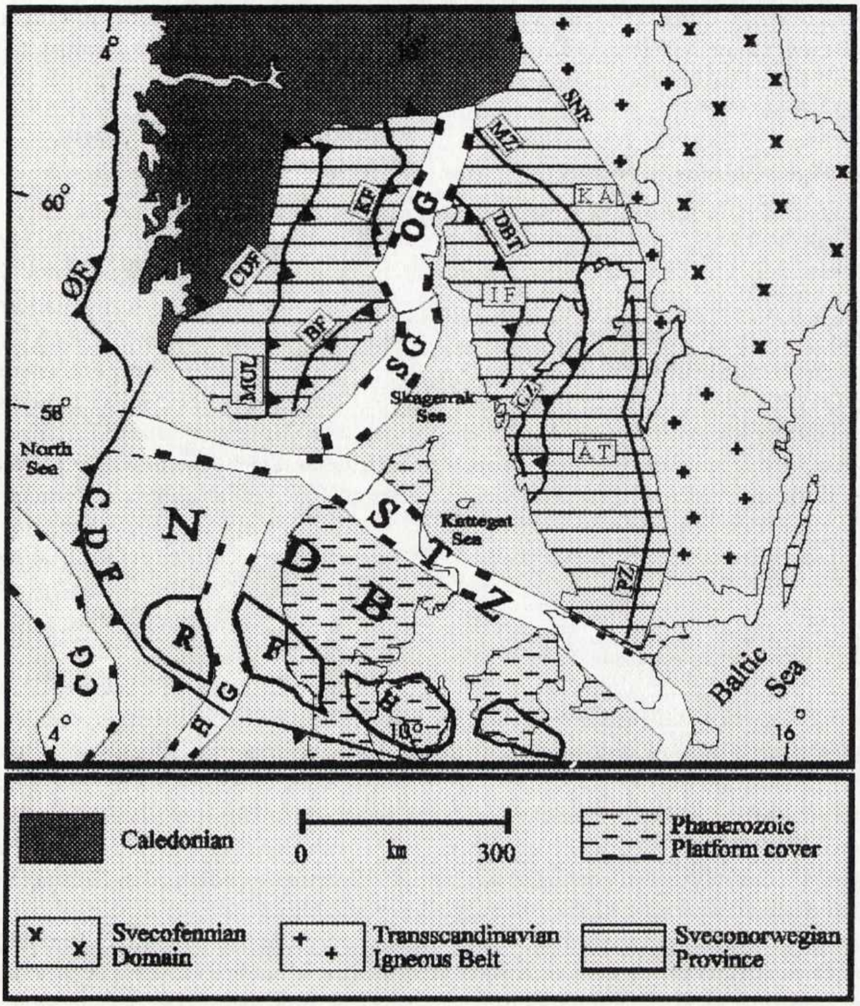

***Figure** 5. Tectonic map of southern Fennoscandia. The most prominent structural elements are shown. **ÄT:** Ätran terrane of the Sveconorwegian Province. **BF:** Bamble Fault. **CDF:** Caledonian Front. **CG:** Central Graben. **DBT:** Dalsland Boundary Thrust. **GZ:** Göta älv Zone. **HG:** Horn Graben. **IF:** Idefjorden terrane of the Sveconorwegian Province. **KÄ:** Klarälven terrane of the Sveconorwegian Province. **KF:** Kongsberg Fault. **MUL:**Mandal Ustaoset Line. **MZ:** Mylonite Zone. **NDB:** Norwegian Danish Basin. **ØF:** Øygaarden Fault. **OG:** Oslo Graben. **PZ:** Protogine Zone. **RFH:** Ringkøbing-Fyn High. **SG:** Skagerrak Graben. **SNF:** Sveconorwegian Front. **STZ:** Sorgenfrei-Tornquist Zone. Modified after EUGENO-S Working Group (1988) and Åhäll and Gower (1997).*

Schöberg, 1991; Starmer, 1993). In *paper 1*, the post-orogenic plutonism is linked to seismically observed deformational structures within the crust.

The gneiss complex within the Sveconorwegian Province of southern Sweden is divided into mega-segments, separated by large N-S trending tectonic zones (Berthelsen, 1980) (Fig. 5). Åhäll and Gower (1997) reevaluated the regional subdivision of the Sveconorwegian Province, based on recent geological data. The Ätran terrane, separated from the Idefjorden terrane by the Mylonite Zone, is distinguished from the latter by its more high-grade rocks and absence of supracrustals. A charnockitic complex and associated granulites are formed in the Varberg area.

The major crust forming events in the Sveconorwegian Province are recorded at c. 1.7 to 1.6 Ga (Gorbatschev and Gaál, 1987). This magmatism has a calk-alkaline to alkali-calkic signature and may be related to Gothian subduction processes (Larson, Göteborg, pers. comm. 1997). The grouping of rocks of a calk-alkaline signature to the west and more alkali-calkic to the east in southwestern Sweden, suggests a subduction to the east consistent with a younging of rocks towards the west (Åhäll and Gower, 1997). During the Sveconorwegian orogeny the southern part of the Ätran terrane experienced a granulite metamorphic overprinting associated with crustal thickening and eastward thrusting (Johansson et al., 1991; Gorbatschev and Bogdanova, 1993; Wang et al., 1996). Subsequently, rapid uplift followed, possibly induced by extensional tectonics (Park et al., 1991; Johansson and Kullerud, 1993). Results from P-T estimates made by Johansson et al. (1991) imply a considerable Sveconorwegian crustal thickness in the order of 70 km, supporting Sveconorwegian collisional processes.

PHANEROZOIC TECTONIC FRAMEWORK

The Sorgenfrei-Tornquist Zone

The Skagerrak Sea is situated at the borderzone between the Precambrian Baltic Shield and the sedimentary basins and platforms of continental Europe, created through Phanerozoic times (Fig. 5). These are separated from each other by the NW-SE trending Sorgenfrei-Tornquist Zone (STZ). The Tornquist Zone, by the EUGENO-S Working Group (1988) divided into the Sorgenfrei-Tornquist Zone (NW segment) and the Tornquist-Teisseyre Zone (SE segment), is regarded as the southwestern margin of the Precambrian Fennoscandian-East European platform (Pegrum, 1984).

South of STZ in the Norwegian-Danish Basin (NDB, Fig. 5), the stratigraphic sequence is complex; sediments are affected by halokinetic movements in response to Zechstein salt (Ro et al., 1990b) and the thinner crystalline crust shows a different style of deformation compared to the shield-crust, north of STZ.

The STZ in itself delimits a chain of Mesozoic troughs extending from southern Sweden to the North Sea. Its evolution is characterized by tensional and dextral wrench movements in Late Paleozoic times (Ziegler, 1982). In the Late Cretaceous – Early Cenozoic transtensional stresses induced subsidence of rift basins and inversional structures resulted from transpression (Liboriussen et al., 1987). The Fjerritslev Fault, located within the northwestern segment of the STZ, is responsible for creating the Fjerritslev Trough at the faultbend, where the strike changes from SE-NW to E-W.

The Skagerrak Graben

One of the most prominent structural elements in the Skagerrak Sea is the Skagerrak Graben. It coincides with the Norwegian Channel (considered a glacial erosion structure) and runs parallel to the coast of southern Norway (e.g. Sellevoll and Aalstad, 1971). Geophysical data suggest that the Skagerrak Graben is an offshore continuation of the Late Paleozoic Oslo Rift (Ramberg and Smithson, 1975; Ro et al., 1990a). According to seismic studies by Lie and Husebye (1994), the Graben system inherited a structural fabric created during the Sveconorwegian orogeny, something that would explain the deformation style and the lack of magmatism that otherwise characterises the onshore part of the Oslo Rift. In Cambrian-Silurian, formation of a sedimentary basin preceded the following rifting phase (Bjørlykke, 1983), indicating an early stage of crustal thinning (Ro et al., 1990b).

Sedimentary sequence

The Mesozoic platform sediments north of the Sorgenfrei-Tornquist Zone (STZ) are mainly undisturbed and terminate in a wedge-shaped manner beneath the Skagerrak Sea (Sellevoll and Aalstad, 1971). As demonstrated by Flodén (1973) on shallow seismic sections, the sediments are deposited on the gently SW-dipping Precambrian basement. Further south in the Kattegat Sea, Mesozoic sediments thin out towards east as the crystalline basement rises (EUGENO-S Working group, 1988). No Tertiary sediments are reported from the Skagerrak Sea north of the STZ (Sellevoll and Aalstad, 1971). In Fredrikshavn, northern Jutland, a borehole reached Precambrian basement at c. 1300 m. (Sorgenfrei and Buch, 1964). Lower Paleozoic sediments of both continental and marine origin are preserved in the Oslo Rift (Ramberg and Speldnæs, 1978). In the Skagerrak Graben, Cambrian-Silurian sediments are unconformably overlaid by the Mesozoic, indicating Late Paleozoic movements within the graben structure (Ro et al., 1990a; Lie et al., 1993).

SEISMIC AND GRAVITY INTERPRETATION

The gravity observations recorded by the Mobil Search Cruise, and data from the Danish Geodetic Survey, have been processed and compiled in Norway by AMAROK A/S (presently Nopec). Gravity data were collected along the 11 Mobil Search profiles in the Skagerrak Sea, 1 observation/ 50 m. The complete marine gravity record comprises 14,600 measurements. In Fig. 6 and 7 the gravity maps of the Skagerrak Sea and southern Sweden are shown. Gravity data of both the Mobil Search survey and observations collected along the EUGENO-S profiles of southern Sweden, have been interpreted using 2.75D cross-section models. This implies that the lithotectonic elements have been modelled as polygons, given a finite length in the apparent strike-direction, perpendicular to the modelled section. The vertical extent of the gravity modelling is chosen to approximately 50 km (in the Skagerrak Sea corresponding to the deep seismic penetration depth). To avoid edge effects, the modelled units have been extended approx. 50 km on both sides of the section. Although discrepancies are unavoidable, the aim has been to correlate seismic and gravity interpretations where this was possible. The ambiguity when creating gravity models is greatly reduced because of the seismic image at hand, making it possible to outrule models that are seismically unlikely. Where the inferred Moho reflections are well defined, the density boundary associated with the crust-upper mantle transition has been vertically fixed, only minor adjustments have been

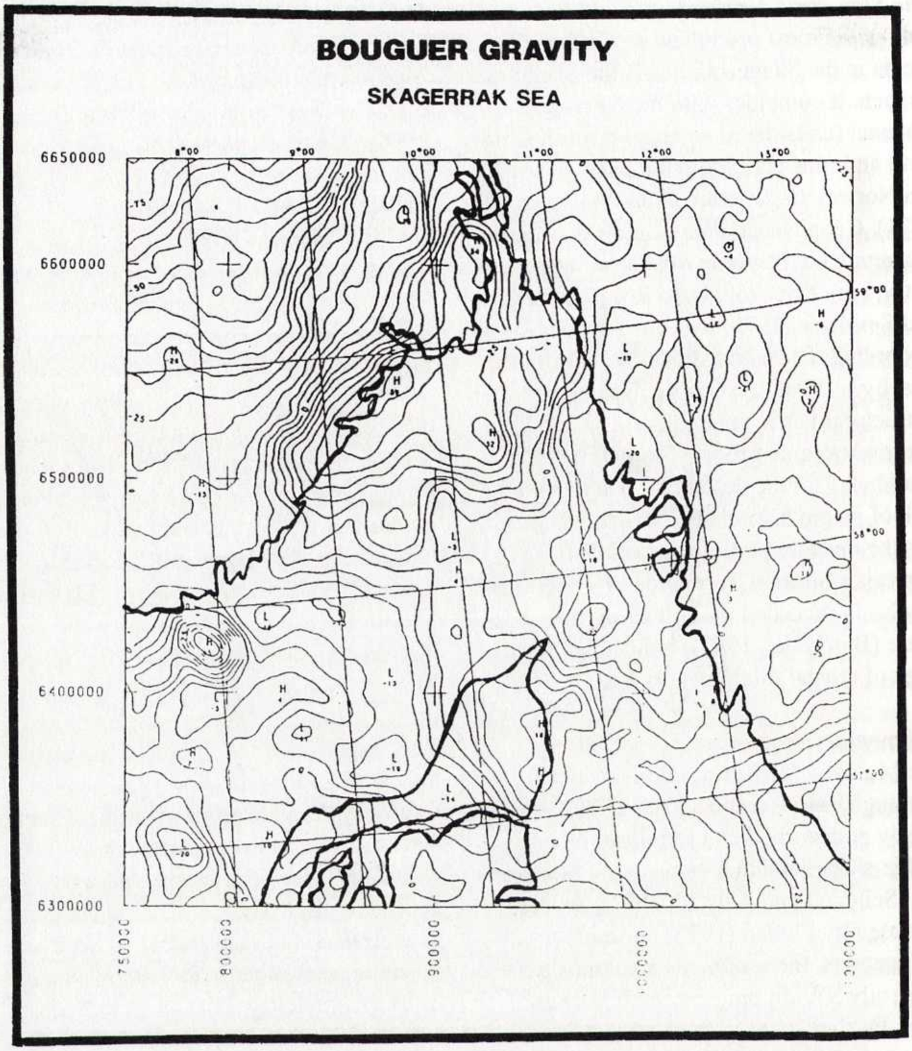

Figure 6. Bouguer gravity map; Skagerrak Sea. 5 milligal contours. Data collected during the Mobil Search survey, together with data from the Danish Geodetic Survey. Processed and compiled by AMAROK A/S (now Nopec A/S, Norway).

made (max. ±1.0 km). However, there are segments within the seismic sections where the Moho is poorly resolved and could thus not serve as a guideline in the gravity modelling. Moreover, since modelling comprises the whole crust and the lateral extent is in the order of hundreds of kilometers, minor lithological elements mapped in outcrops have been left unmodelled. The consequence to this is demonstrated by the smooth character of the calculated gravity curves and the absence of short wave-length anomalies compared to observed gravity.

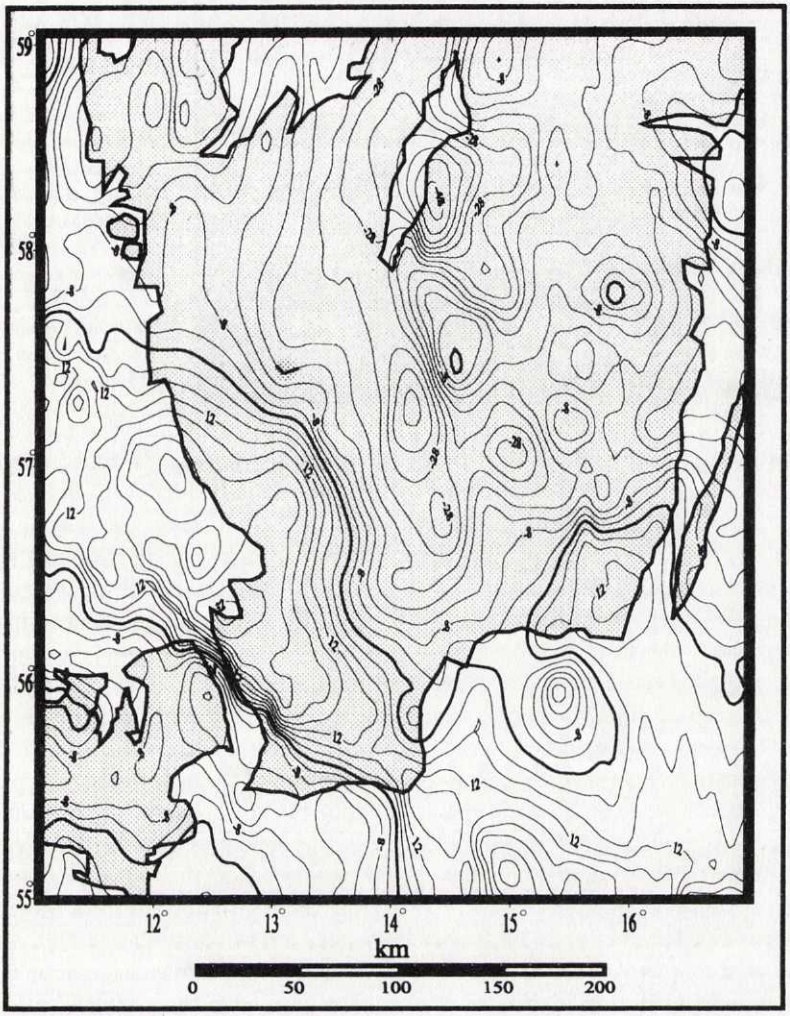

Figure 7. Bouguer gravity of southern Sweden. Contour interval 4 milligal. The map is based on data from the EGT project (Blundell et al., 1992).

Rock density

Geological boundaries, seismic reflectivity patterns, velocity structure and rock densities are the parameters used in gravity modelling. In the cases dealt with here, the calculation of Bouguer anomalies involves the whole crust as well as the upper mantle. Since absolute measurements of geometry and density are impossible at these depths, the resulting models are more or less ambiguous. Here, we have to rely on indirect determinations such as composition of deep crustal and mantle xenoliths, and the seismic velocity - density relationship. A vast amount of data

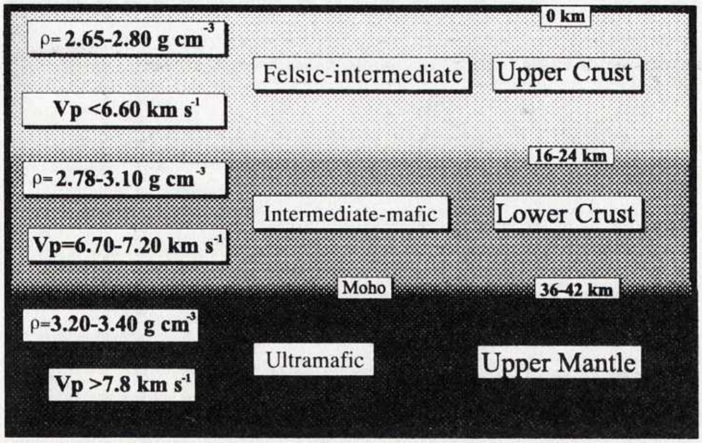

Figure 8. *Simplified model of the crust. The density-velocity distribution, together with depths, are considered average values for a Precambrian continental shield environment. Stepwise changes in P-wave velocity is often observed at the mid crustal boundary (the Conrad disc.). This relationship is even more pronounced at the Moho discontinuity. Based on calculations by Christensen and Mooney (1995).*

on this subject exists; some of the most well-known reports are made by Nafe and Drake (1957), Birch (1961) and Wollard (1969). A very thorough petrophysical compilation has been made by Carmichael (1989). Although seismic velocities could be translated into a limited spectrum of densities and rock types, this relationship provides a necessary assessment of systematic density distribution. Caution should be considered, however, in certain cases. Remarkable differences exist in the velocity-density relation between oceanic and continental rocks (Kern, 1978), and in areas with high heat flow, normal relations do not exist (Drummond, 1988).

In southern Sweden, the varying composition and banded character of certain gneisses are reflected in the scattering of rock density, thus making gravity modelling less constrained. In Fig. 8, a generalized model of the continental crust is shown, based on world-wide compilations of seismic velocities and densities made by Christensen and Mooney (1995).

Density and reflectivity patterns

There is no unique correlation between seismic reflectivity and density boundaries, as clearly demonstrated in the papers included in this work. Intracrustal reflectivity boundaries are most often less well-defined than the Moho-interface, where the seismic velocity-contrast is high, usually close to 1 km s^{-1}. Density of the crystalline crust increases vertically with depth, as deduced from the density-seismic velocity relationship. Apart from the inferred (Conrad) discontinuity, separating the upper brittle crust from the lower ductile crust, this increase in density is not shown in terms of reflectivity patterns within the crust. This must imply that petrological boundaries as viewed in a vertical perspective from the top to the bottom of the crust, are not sharply defined. Moreover, as pointed out by Austrheim (1991), it might be relevant to take into consideration not only lithological boundaries, but also metamorphic transitions as candidates for seismic reflection patterns.

SUMMARY OF RESULTS

Paper 1: Deformational structures within the deep crust and post-orogenic granitoid emplacement

The Post-orogenic Bohus granite exhibits a negative density contrast of 80 kg m^{-3} to the surrounding gneisses belonging to the Østfold-Marstrand Belt (Lind, 1982). On the

SE segment of the Mobil Search deep seismic and gravity profiles OG-8, OG-9 and OG-12 (Fig. 2), a Bouguer gravity low of approx. -20 mgal is observed, suggested to be caused by the Bohus granite. This inferred offshore continuation of the granite has been modelled as a body given a vertical thickness of approx. 3.5 km and 25 km width (Fig. 8, *paper 1*). In addition, the gravity interpretation is supported by a reflective pattern (approx. 1.6 s. TWT) on the seismic section OG-8 (profile location, Fig. 2), taken to image the granite/gneiss interface. The granite itself appears seismically transparent. Beneath, a large offset in the Moho reflector is observed, here denoted the Bohus Moho Offset (BMO). A casual connection between the granite intrusion and the BMO is proposed. During the E-W compressional phase (c. 1100 Ma) of the Sveconorwegian orogeny (Starmer, 1993), large-scale deformation structures like the BMO were created. Since the Bohus granite has a crustal origin (Eliasson, 1992), it is considered viable that the granitic melt formed by anatexis of mid-crustal rocks downthrusted to large depths in the vicinity of the Moho offset. The subsequent post-orogenic extensional regime could enable magma to ascend. An analogous scenario between seismically observed Moho offsets and post-orogenic granitoids in southern Norway is also discussed.

Paper 2: The Sorgenfrei-Tornquist Zone; development of a shield-basin transition

The Mobil Search deep seismic sections (location, Fig. 2) show that the Sorgenfrei-Tornquist Zone (STZ) in the western Skagerrak Sea represents the boundary between the thick crystalline crust of the Fennoscandian Shield and the thinner crust beneath the Norwegian Danish Basin (Fig. 5). The STZ marks a distinct change in crustal thickness, and is observed to affect the entire crust and upper mantle. The transitional zone is associated with complex lower crustal reflectivity, discontinuous Moho and Upper Mantle reflectivity. Flexural subsidence of the shield-edge appears to have occurred along the STZ without significant crustal thinning. In contrast to the BABEL deep seismic profile that crosses the STZ north of Bornholm (BABEL Working Group, 1990) (Fig. 1), no signs of Mesozoic inversion structures or uplift of the lower crust and Moho can be observed on the Skagerrak profiles (see Figs. 3-6, *paper 2*).

The profiles OG-1 and OG-5 (Fig. 4a and 5, *paper 2*; profile location, Fig. 2) show that the STZ does not terminate at the Oslo-Skagerrak Graben system, as previously suggested by Ziegler (1982) but continues farther to the west, bounding the Farsund Basin. According to seismic data even further west (Klemperer and Hurich 1990), the STZ is suggested to reach the Øygaarden Fault Zone (Fig. 7, *paper 2*) which is considered the present shield-basin boundary along the Norwegian west coast.

The deep seismic profiles indicate differences in subsidence between the shield and basin-crust during the Mesozoic, with the STZ acting as a discontinuity between the two tectonic regimes. On the basin side of the STZ (Fig. 4, *paper 2*), the Base Zechstein Unconformity (BZU) and Moho reflectors are observed to be parallel within segments which are tilted relative to each other. It therefore appears that during the Mesozoic, the crust and upper mantle together were rigid enough to allow for segmentation and rotation of lithospheric mega-blocks.

On the OG-3 deep seismic profile a thick sequence of Phanerozoic sediments is observed; the Fjerritslev Trough (Fig. 6a-b, *paper 2*). This narrow and deep structure is interpreted as a pull-apart basin created by transtensional movements along the STZ, and located where the STZ changes orientation from NW-SE to E-W. Previously the STZ has been interpreted mainly as a Mesozoic structure (EUGENO-S Working Group, 1988). However, the thick wedge of Early Paleozoic sediments within the trough indicates that strike-slip movements also occurred during this period.

Paper 3: Geophysical mapping of the crust in SW Sweden: Observational results from wide-angle seismic and gravity data

As part of the multi-disciplinary European Geo-Traverse carried out in the mid-eighties, the wide angle seismic EUGENO-S Profiles were shot in southern Sweden (for details, see the EUGENO-S Working group, 1988). The EUGENO-S profile 4 is situated in a NW-SE direction from the Skagerrak Sea to the Baltic Sea offshore Blekinge on the south coast of Sweden (Fig. 1, *paper 3*). Seismic data derived from explosive shotpoints on land and airgun shots at sea have been recorded. The EUGENO-S Profile 1 is SW-NE oriented and starts from the north German lowlands, across Sealand and the Kattegat Sea, before it ends up in southern Sweden (location, Fig. 1). In *paper 3,* new crustal velocity models together with gravity observations are interpreted along the EUGENO-S Profiles 1 and 4, and adjacent areas. Perturbations in the Conrad discontinuity and great variations in thickness of the crystalline crust, varying between 32 and 48 km are seismically indicated. On the EUGENO-S Profile 1 (Fig. 7, *paper 3*), the lower crust is considerably thickened, from approx. 13 km beneath the Norwegian Danish Basin, to c. 27 km within the shield area. Observed Moho depressions are located in the southern part of the Ätran terrane. In this interpretation, the trough-like structures have been linked into a continuous belt, approximately N-S oriented, and modelled as high density elements (i.e. mafic composition), to explain the absence of corresponding negative gravity anomalies. The Falkenberg Gravity High, situated in the southern part of the Ätran terrane, is proposed to be caused by unexposed, high-density rocks within the upper crust, and related to the Southwest Swedish Granulite Region.

SUGGESTIONS FOR FUTURE RESEARCH

Seismic indications of metamorphic transitions

Deep seismic data can provide useful information concerning metamorphic transitions within the lower crust and upper mantle. These issues are notable when dealing with continental collision zones and deep crustal processes resulting from orogenic activity. Rather than metamorphic transitions, reflections from the lower crust have mostly been interpreted as lithological boundaries (Austrheim, 1991). This is consistent since e.g. eclogite transitions occur over a broad P-T interval and should thus not be attributed to represent distinct reflections from the lower crust. However, recent findings in western Norway give field-evidence of sharp metamorphic transitions (granulite-eclogite) as they follow shear zones and fluid fronts, and cut across lithological boundaries (Austrheim et al., 1997). As concluded by Fountain et al. (1994), such shear zones exhibit excellent deep crustal reflectors in regions where high-pressure metamorphism has been active. The seismic Moho may in some places be due to mineral transitions causing abrupt changes in density and rheology (Austrheim et al., 1997 and references therein). Generally speaking, granulites could be converted to eclogites – phase transitions controlled by kinetics/fluids, and resulting in a density increase by 0.2 g cm^{-3} (Austrheim, Oslo, pers. comm., 1997).

Apart from metamorphic transitions, deep crustal reflectors have been viewed as candidates for high-strain mylonite zones (Smithson et al., 1979) – another aspect that may also be considered in the mapping of deep crustal reflections in the Skagerrak Sea.

Occurence of Phanerozioc volcanism in the Skagerrak Sea

As described above, volcanic structures inferred from gravity and magnetic mapping have been reported from the Skagerrak Sea (Åm, 1973), interpreted to be Tertiary in age. In addition, basaltic rocks have been dredged from the Skagerrak sea floor (Noe-Nygaard, 1967) and magnetic anomalies in the same area indicate structures that may be related to volcanism or magmatism. A so far unreported observation is a short-wave gravity anomaly along the deep seismic profile OG-7 in the western Skagerrak Sea (Fig. 9). This anomaly is situated at the northern slope of the Skagerrak Graben. A probable source candidate for this anomaly would be a structure similar to that of the Kristiansand volcano (Fig. 4a; *paper 2*), though smaller.

Hence, the seismic and gravity data do provide useful clues in the mapping of Phanerozoic tectonic evolution and magmatism in SW Scandinavia.

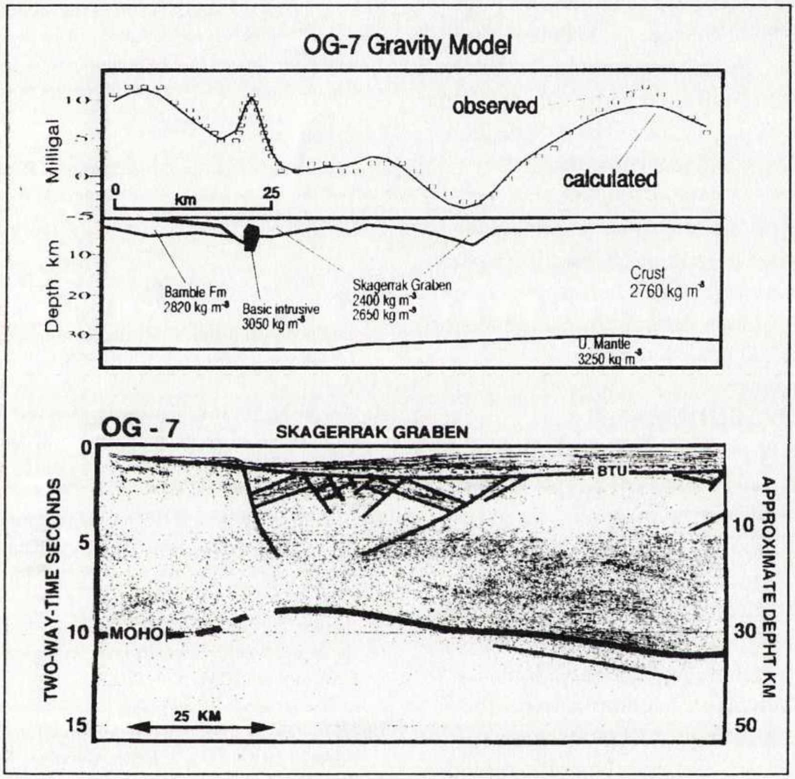

Figure 9. *Interpreted section of the deep seismic profile OG-7, together with a gravity model (location, Fig. 2). A short-wave gravity anomaly is observed at the NW edge of the Late Paleozoic Skagerrak Graben, here interpreted as a basic intrusive body, intruded into the graben.* ***BTU:*** *Base Triassic Unconformity.*

The Falkenberg Gravity High

Up to now, no investigations whatever have been made regarding the significance of the Falkenberg Gravity High (FGH). The results in *paper 3* are preliminary and do not cover the complete feature. Bearing in mind that FGH is one of the largest positive gravity anomalies in Sweden, the need for future examination should be motivated. A first step to take when continuing the close-up investigation, would be to examine the role of surface geology. This work may start with measurement of rock density of samples collected from outcrops. Along relevant segments of the EUGENO-S profiles, seismic data should be checked whether low V_p/V_s ratios could be detected, as this may provide clues about mineral composition. Today, magnetic data, collected and compiled by the Geological Survey of Sweden, cover the FGH, and might be testable against the gravity observations. In conclusion, integrative studies, involving relevant disciplines should be undertaken to evaluate the southern part of the Ätran terrane, its lithotectonic components and possible structural relations to the adjacent shield border zone.

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