A Seismic Refraction Line across the Seiland Igneous Province, Northern Norway

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A seismic refraction line across the Seiland igneous province suggests that the igneous complex is not rooted locally in the underlying mantle, but is probably restricted to the upper crust and underlain by a major thrust.

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The Seiland igneous province in the Caledonides of northern Norway comprises numerous mafic and ultramafic intrusions of Caledonian age and associated metasediments with a complex deformational and metamorphic history (Hooper 1971a, 1971b, Sturt 1971, Ramsay & Sturt 1963). The area is characterised by a positive Bouguer anomaly, which has an amplitude of about 90 mgal over the island of Sørøya (Brooks 1970) (Fig. 1). Various plate tectonic environments have been adduced to explain the geology of the Seiland province, in terms of proximity to an oceanic (Harland & Gayer 1972), marginal ocean (Ramsay 1973) or continental margin (Dewey 1969, Robins-Gardner 1975) suture.

The gravity anomaly centred on Sørøya has been used to derive information on the distribution of igneous material at depth, but there is an inherent problem of ambiguity in the interpretation. The anomaly has been attributed either to a massive sheet of mafic and ultramafic rock extending and thickening westwards above a major thrust cropping out to the east (Brooks 1970, Chroston 1974), or to numerous mafic intrusions extending upwards from the lower crust (Brooks 1970). The anomaly has been compared with the large Lofoten-Vesterålen anomaly about 300 km to the southwest (Brooks 1970), but the two areas are geologically dissimilar and the causes of the anomalies are probably not directly comparable (Brooks 1971).

The seismic line

In an attempt to resolve the problem of the deep structure, a long seismic line was established across the southwestern flank of the Sørøya anomaly (Fig. 1). Preliminary results and interpretation are presented here. The

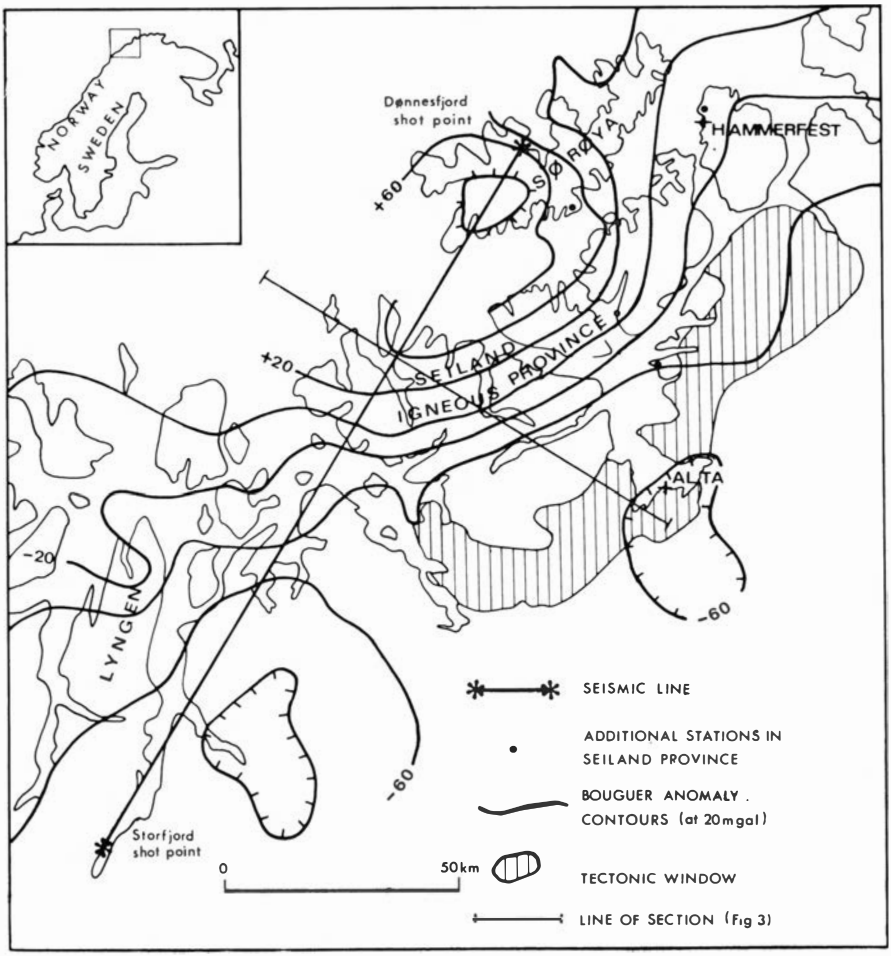

Fig. 1. Location of seismic line in relation to the Bouguer anomaly field and geological provinces.

seismic line was planned to allow a satisfactory station density along most of its length with reasonable lines of communication, and to cross the peak of the gravity anomaly which lies northwest of the main surface outcrop of mafic intrusions. At the south end of the line allochthonous Cambro-Silurian metasediments probably overlie a shallow Precambrian basement. The basement depth increases northwards but the structure under Sørøya is very uncertain. The length of the line, which runs parallel to the NNE–SSW regional trend of the Caledonides, is 180 km. Seven recording stations were moved systematically along the line at approximately 3.5 km intervals, occupying a total of 47 sites. Four other recording sites were established elsewhere in and around the Seiland province (Fig. 1).

Each recording station consisted of three HS-10 (2 Hz) seismometers and a Lennartz FM recording system. Timing was achieved by firing the shots at the start of 30-second time signals broadcast by Norwegian Radio. Charge

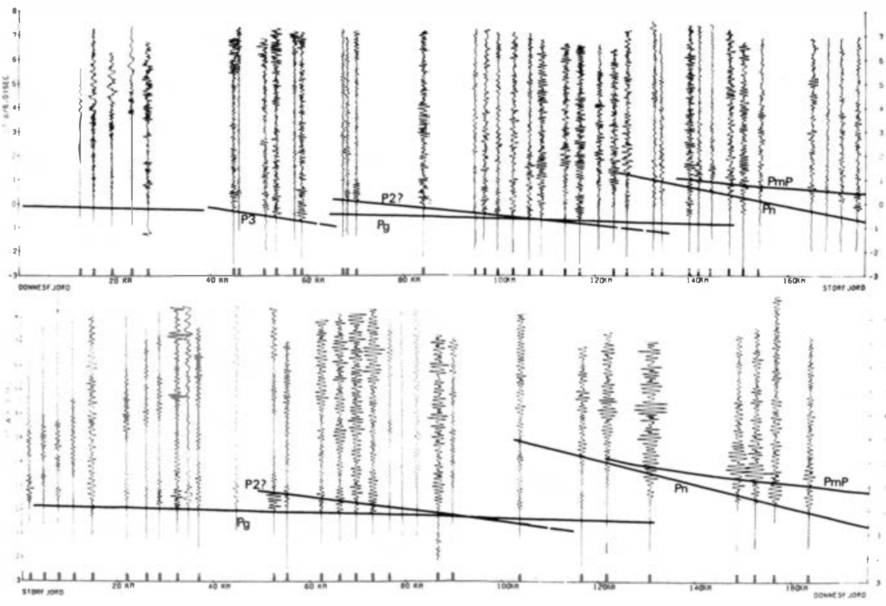

Fig. 2. Seismogram montages for shots from Dønnesfjorden and Storfjorden.

sizes ranged from 75 kg to 150 kg of 'Dynamit' fixed on the sea bed in 50 m of water in Dønnesfjorden (north shot point) and Storfjorden (south shot point) (Fig. 1). In general, records were of good quality but poor weather conditions during part of the experiment and breakdowns in automatic stations resulted in a loss of about 15 per cent of the records. Fig. 2 shows reduced time-distance curves superimposed on filtered seismograms for Dønnesfjorden and Storfjorden shots.

Seismic layers

The first arrival along the main length of the line is interpreted as Pg with a velocity of 6.18 ± 0.04 km/s. There are, however, some complications in the analysis of Pg which will be discussed below. Pn and PmP phases have also been recognised from both ends of the line, but as it was not possible to establish a line over 180 km long, second and later arrivals had to be used to determine the estimated Pn velocity of 8.21 ± 0.20 km/s. A Pb phase with a velocity of about 6.5–6.7 km/s is typical of many parts of Scandinavia (Sellevoll 1973) and its local equivalent may be the uncertain P_2 phase (Fig. 2) which has a velocity of 6.94 km/s. There are other distinct later arrivals, but these cannot be correlated across more than a few records, suggesting a heterogeneous crystal structure.

A simple two-layer crustal model based on Pg, P_2, and Pn time-distance curves indicates a crust thinning northwards along the line from 45 km to

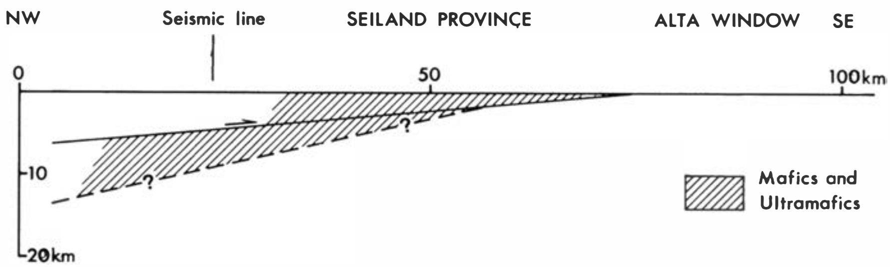

Fig. 3. Sketch structural section across the Seiland igneous province.

38 km. This model is probably oversimple for two main reasons: firstly, if the regional gravity anomaly closely reflects crustal thickness the crust does not thin uniformly along the line; secondly, Pn and P_2 may be arriving early because of mafic and ultramafic rocks in the upper crust under the northern part of the line (see below), in which case the crust will be slightly thicker overall than is indicated above. Assuming density contrasts of 400 kg/m^3 between basal crust and upper mantle, and 200 kg/m^3 between the two crustal layers, the calculated crustal model implies an increase of gravity of 140 mgal northwards along the line compared with an observed increase of about 100 mgal after removal of the Sørøya anomaly.

Possibly the most significant result of the study relates to the Pg phase. Although the average upper crustal velocity is 6.18 km/s, there are significant local variations. In particular, out to a range of 25 km at the northern end of the line Pg arrives with normal velocity, but stations in the range between 40 km and 60 km show early first arrivals defining a segment (P_3) with an apparent velocity of 7.29 km/s. Some of these stations were located on gabbro, others on metasediments. These early arrivals may be attributed to concealed igneous rocks of the Seiland province in the form of either a layer underlying the entire northern end of the line, in which case the high-velocity segment represents arrivals refracted from this layer, or a near-surface block commencing about 35 km down-range, through which the Pg phase is locally accelerated. The varied geology of the recording sites supports the first alternative and a simple horizontal layer interpretation yields a depth of 5.8 km to the main igneous mass. In either case, the igneous mass must wedge out southwestwards so that only diffracted waves are transmitted through it into the surface layer beyond the igneous province: in that section of the line there is an abrupt step back of first recorded arrivals (Fig. 2) and an associated reduction of velocity to 6.18 km/s. This continuation of the Pg segment must be attributed to waves that have effectively circumnavigated the high velocity wedge.

Geological interpretation

The wedge itself probably represents the deeper equivalents of surface intrusions in the Seiland province. The top surface of the wedge is interpreted here as the major thrust which crops out 50 km to the southeast, where it separates rocks of the igneous province from autochthonous or parautochthonous Precambrian rocks in the Alta-Kvænangen tectonic window (Figs. 1 and 3). The lower surface of the wedge may be a normal contact between the igneous complex and underlying country rock but may alternatively represent a thrust boundary with, possibly, autochthonous basement beneath. Such a structure cannot be correlated with any known surface structure in the region but may everywhere be concealed beneath the surface nappe containing the Seiland province.

In the absence of any indication of a culmination in the lower crust under the Seiland province, the seismic results suggest that the Sørøya anomaly is caused by near-surface mafic and ultramafic rocks. This model is similar to a gravity interpretation model discussed by Brooks (1970), in which all the anomalous mass was assumed to occupy the same nappe as the surface rocks of the Seiland province. The seismic results suggest, however, that the main source of gravity anomaly is located in an underlying tectonic unit (Fig. 3). In order to account for the gravity anomaly, the concealed mafic and ultramafic rocks must be several kilometres thick.

These results necessitate changes in existing plate tectonic models of the Seiland province (Harland & Gayer 1972, Ramsay 1975, Dewey 1969, Robins & Gardner 1975). Such models, in line with a preferred interpretation of the Sørøya gravity anomaly (Brooks 1970), view the province as the upper part of a large intrusion complex extending into the underlying mantle and derived from a deeper Benioff zone dipping eastwards under west Finnmark. In fact, the province appears not to be rooted in the local mantle but to owe its position to large-scale overthrusting from the west or northwest.

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