Experiences From Shallow Reflection Seismics Over Granitic Rocks in Sweden

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ABSTRACT

The Department of Geophysics at Uppsala University has been carrying out seismic reflection experiments for nearly 12 years. Most of these experiments have been on a crustal scale (50- or 100-m spacing between geophones), but a number of these have also been high resolution surveys (5- or 10-m spacing between geophones) where the targets have been in the upper kilometre of the earth's crust. In those areas where we have focused on the more shallow crust we have often had access to boreholes for control of our interpretations.

This paper contains a brief review of results from five areas in Sweden (Figure 1), all of which are located in granitic rock type environments. Three of the surveys were carried out as what is generally considered to be high resolution surveys with station spacings of 5 or 10 m (Table 1) while the other two surveys were of a more regional character. The latter two were included because they provide good images on conditions at depths of less than 2 km, depths which are of interest for mining.

RESULTS

A very brief review of objectives and results from the selected areas is given below. All surveys were carried out over granitic type rock ranging in composition from granite to granodiorite. Results from the Siljan, Finnsjön and Dala Sandstone areas have previously been published. Data from the SW shear zones and Ävrö areas are still being processed, but preliminary results are presented here.

Siljan Ring

Seismic data were acquired in the Siljan Ring impact structure as part of the Swedish State Power Board's Deep Earth Gas Research program. The combination of numerous seismic lines (a total length in excess of 100 km) and two deep boreholes (c. 7 km) within the Siljan Ring area resulted in the calibration of both seismic reflection surveys and impact mechanic models (Juhlin and Pedersen, 1987; Juhlin, 1990; Juhlin and Pedersen, 1993; Papasikas and Juhlin, 1996). One result was the correlation of dolerites (diabases) drilled through in the Gravberg-1 deep borehole with high amplitude reflections on the surface seismic (Figure 2). Another result was consistent estimates of the size of the excavated crater during impact along two radial lines.

Finnsjön

One of the objectives of the profile was to image a known fracture zone with high hydraulic conductivity dipping gently to the west at depths of 100 to 400 m (Juhlin, 1995). The initial processing of the data failed to image this fracture zone; however, these data have now been reprocessed and a clear image of the gently dipping zone has been obtained (Figure 3). In addition, several other reflectors were imaged in the reprocessed section, both gentle and steeply dipping ones. It is likely that the origin of these reflections are also fracture zones.

Dala Sandstone

The purpose of this 2-km long profile was to test the capability of the seismic method to detect fracture zones which could contain mineralizations (Juhlin *et al.*, 1991). In order to calibrate the seismic results a ~700 m deep corehole was drilled. Correlation of surface seismic data with core data shows a dipping event at ~250 ms (700 m) originating from a fracture zone (Figure 4). Waveform analyses and modelling indicate a deeper event at below 600 ms to originate from a dolerite sill.

SW shear zones

The SW shear zone project is located on the border zone between the undeformed Transscandinavian granite porphyry belt (TGPB) and the Sveconorwegian domain. Rocks become progressively more deformed towards the west. The aim of the 17-km long survey was to study the structure of the upper 10 km of crust to help determine the deformation history of the area, in particular if shear zones observed on the surface developed during regional compression or extension. On the western end of the profile subhorizontal reflections are observed within the

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Table 1: ***Acquisition parameters for surveys presented in this paper. More than one line was shot in the Siljan and Ävrö areas.***

Area	Siljan	Finnsjön	Dala Sandstone	SW shear zones	Ävrö
Date acquired	Winter/Fall 1985	Summer 1987	Fall 1988	Summer 1996	Fall 1996
Spread type	Split/End-on	End-on	End-on	End-on/Shoot through	End-on/Shoot through
Number of channels	96/120	60	60	140	105
Near offset (m)	200/150	100	60	75	20
Geophone spacing (m)	50	10	10	25	5/10
Geophone type	Single 28 Hz	Single 28 Hz	Single 28 Hz	Single 28 Hz	Single 28 Hz
Shot spacing (m)	200/150	10	10	100	5/10
Charge type	5/10 kg dynamite	50 g dynamite	200 g dynamite	1 kg dynamite	100 g dynamite
Nominal charge depth (m)	10	2-4	2-3	3	2
Sample rate (ms)	1/2	1	1	2	1
Profile length (km)	25/16	1.7	2	17	1/1

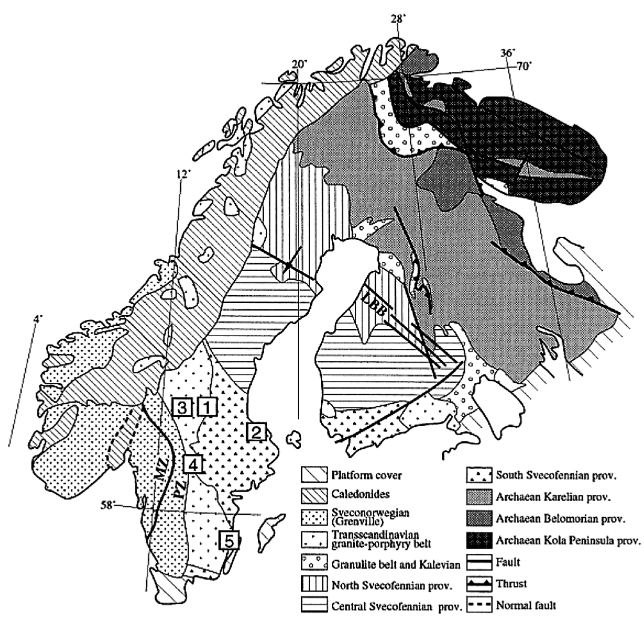

Figure 1: *Geological units of the Baltic Shield and location of the seismic surveys discussed in this paper. 1–Siljan, 2–Finnsjön, 3–Dala Sandstone, 4–SW shear zones, 5-Ävrö. Map after Weihed et al. (1992).*

upper 2 km which probably have as their source deformed mafic intrusions. Further to the east reflections become progressively steeper and can be traced to the near surface. These events are probably associated with shear or fracture zones.

Ävrö

A well-defined hydraulically conductive fracture zone between c. 400 and 500 m is present in the KAV01 borehole on the island of Ävrö, one of the Swedish Nuclear Fuel and Waste Management Company (SKB) study sites.

In order to study the 3-D orientation of this zone, two c. 1-km long crossing lines were shot over the borehole, an east-west line with a 5-m station spacing and a north-south one with a 10 m station spacing. Preliminary processing of the data indicates the zone dips to the west and surfaces about 1 km east of the borehole in the Baltic Sea.

DISCUSSION AND CONCLUSIONS

In granitic rock type environments in Sweden two predominant sources to seismic reflections are found, dolerite intrusions and fracture zones. Dolerites were found directly in the deep wells in the Siljan impact structure and were inferred to be present from the seismic data in the Dala Sandstone area. Similar subhorizontal reflections have been found below the Bothnian Sea and have also there been interpreted as originating from dolerite sills (BABEL Working Group, 1991). The dolerites represent high impedance layers in the host granitic rock and are subhorizontal to gently dipping. The fracture zones contain free water and, thus, represent low impedance layers in the granitic host rocks. They can be subhorizontal to steeply dipping and are generally less laterally

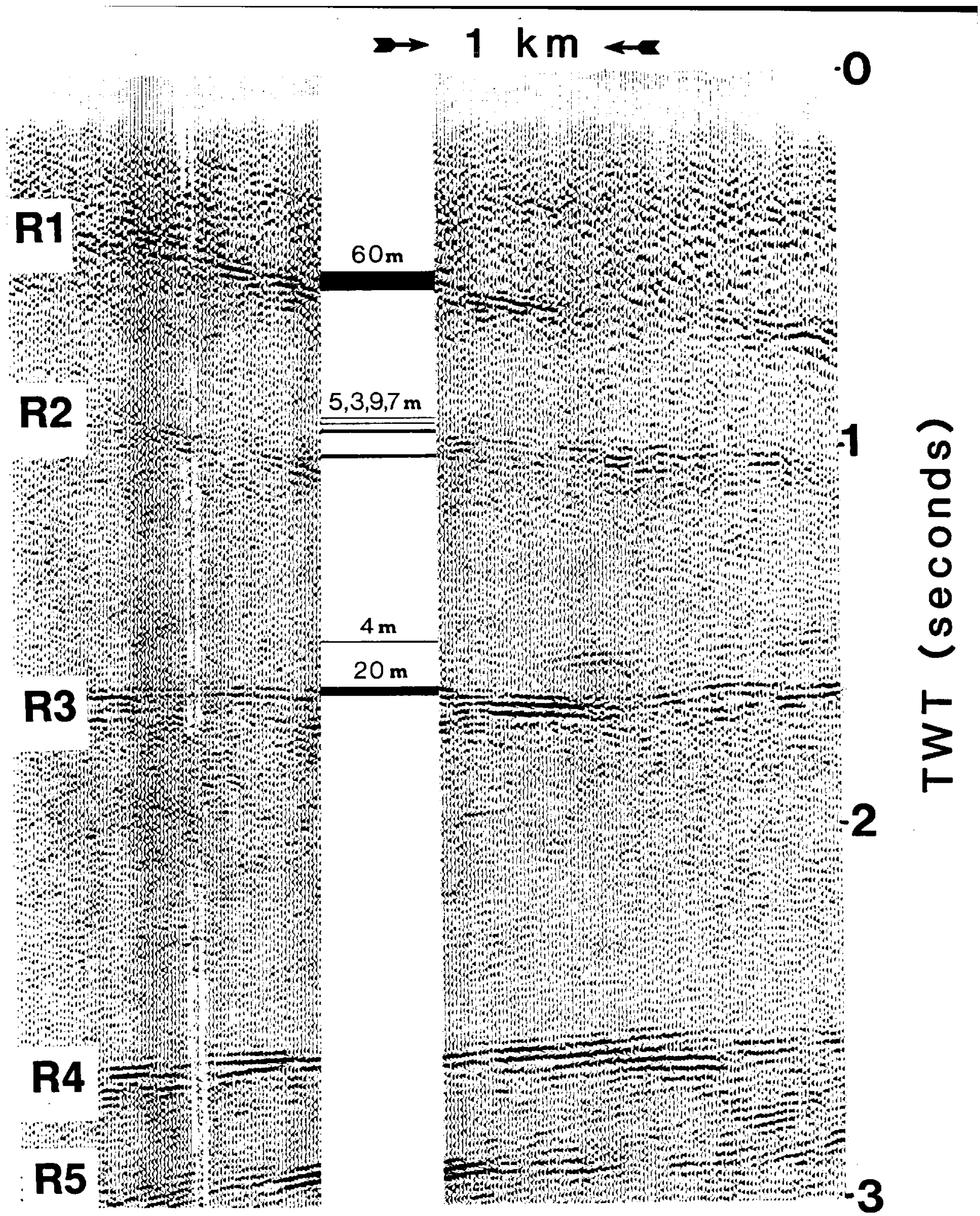

Figure 2: *Part of the stacked section from lines 5 and 7 (Juhlin, 1990) over the Gravberg-1 borehole in the Siljan impact structure. Dolerite sills with their respective thickness (greater than 3 m thick) are marked on the section.*

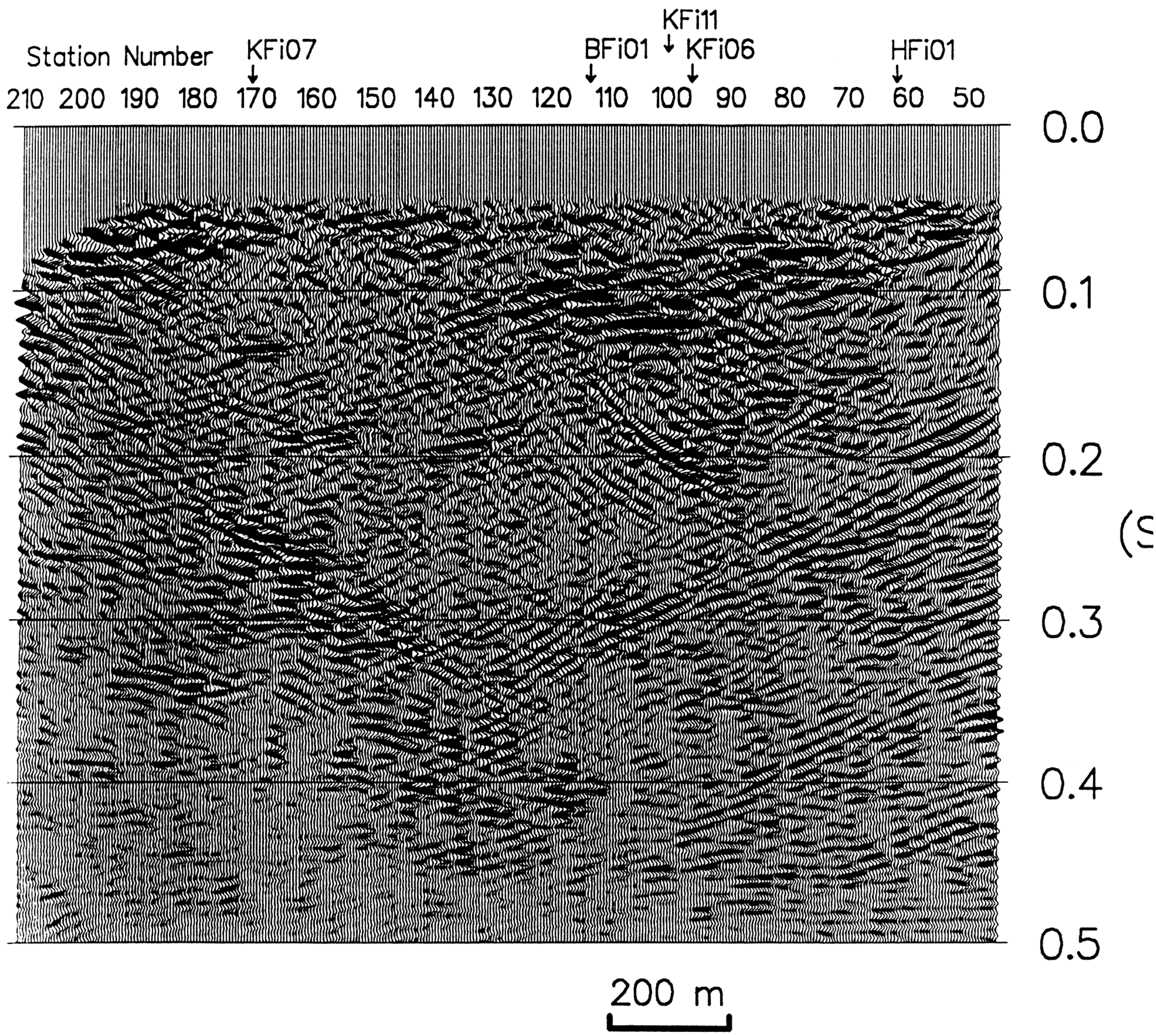

Figure 3: *Migrated section from the Finnsjön area. The subhorizontal event at about 0.1 s is an hydraulically conductive fracture zone as determined from surface boreholes (locations marked with arrows).*

continuous than the dolerites. Polarity analyses of the seismics can differentiate between dolerites and fracture zones in granitic rocks.

Several factors determine how shallow features in the crust can be imaged with the seismic reflection method. Some of the most important acquisition parameters are station and source spacing, number of channels, and source and geophone coupling. Important processing parameters are static corrections, spectral balancing and velocity filtering. The ability to differentiate direct S-waves from P-wave arrivals in the first 100 ms determines to a large extent if the upper 100 ms can be imaged.

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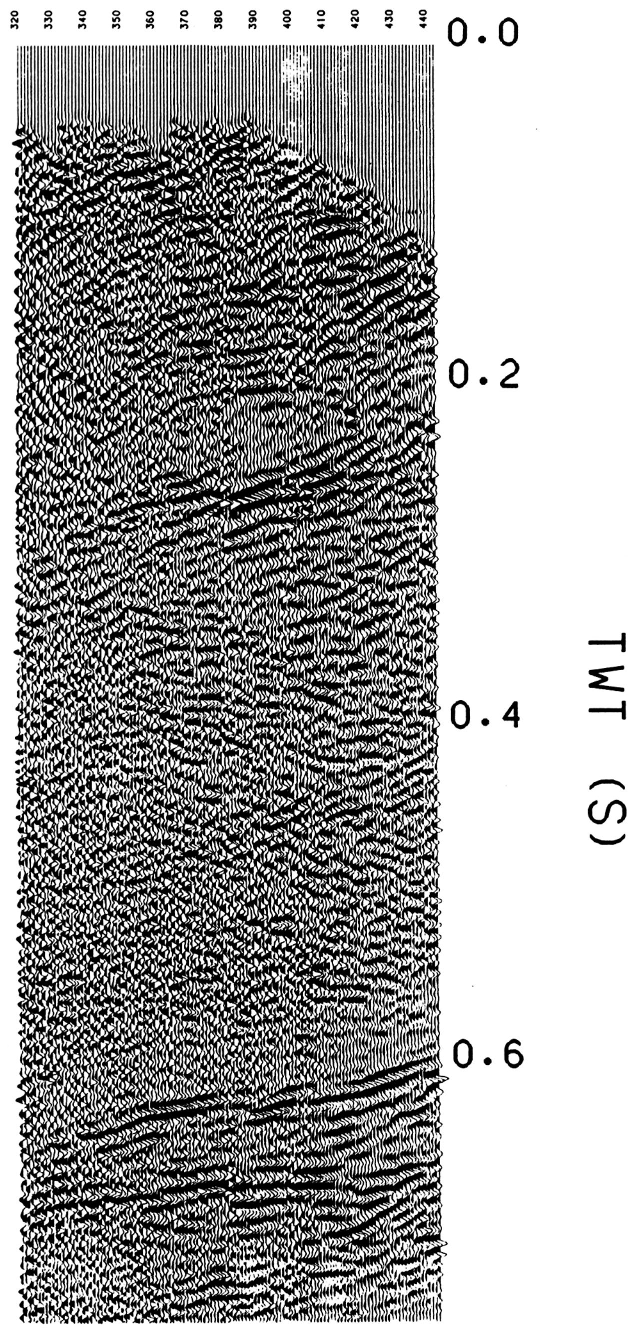

Figure 4: *Part of the stacked section from the Dala Sandstone area where borehole control exists (borehole located at trace 390). The reflection at c. 0.25 s is from a fracture zone confirmed by drilling. The reflections below 0.6 s are inferred from polarity analyses to be from dolerite sills (Juhlin et al., 1991). Trace spacing is 5 m.*

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