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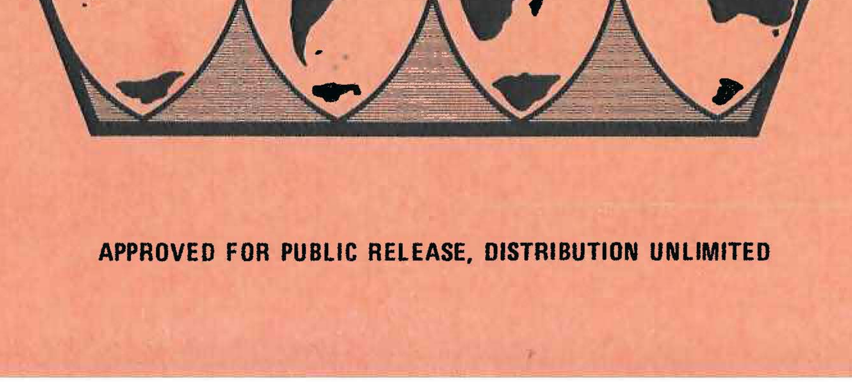

VII.3 Long Period P-Wave Spectra as a Tool for Studies of Local Structure

The vertical (Z) and horizontal-radial (R) signal spectra for a body wave may be written

$$Z = S \cdot H_Z \cdot I + N_Z \tag{1}$$

$$R = S \cdot H_R \cdot I + N_R \tag{2}$$

where S is the source and the source-side effects, $H_Z (H_R)$ is vertical (horizontal) transfer function of the crust and upper mantle on the receiver side, I is instrument response and N_Z (N_R) is noise on the vertical (horizontal) component. All the above parameters are a function of the angular frequency. Assuming $N_Z = N_R = 0$ one may form the ratio

$$G = Z/R = H_Z/H_R \tag{3}$$

Phinney (1964) originally proposed the idea of dividing the spectra of the vertical component of a recorded P-wave with that of the horizontal radial component in this way, thereby obtaining a ratio which does not depend on the spectrum of the original incident pulse. These ratios are then compared with theoretical layered models using the Haskell (1953)-Thomson (1950) matrix theory. This 'spectral ratio' method has since been used by a large number of authors.

The aim of this work (Berteussen, 1976a) has been to find out what type of information one may expect to get about the structure under a station (having a three-component long period instrument set) by applying this spectral ratio method. To do this we have used only simulated data, while we in a later work (Berteussen, 1976b) also will try real data from the three-component long period instruments at the Norwegian Seismic Array (NORSAR).

Simulating a number of different models, we have found that by far the most pronounced effect on the spectral ratio is caused by the Moho boundary. For this boundary the effect of, for example, changing the depth is very obvious and can easily be seen on the simulated ratios. Other interfaces may complicate the picture, like for example enlarging one of the peaks caused by the Moho boundary, but it is extremely difficult without other evidence to assign these additional effects to a particular model (Fig. VII.3.1 and VII.3.2). For example, interfaces at 10 km depth and 30 km depth can give rise to almost the same set of peaks. Compare trace 4 from top on Fig. VII.3.1) with traces 4 and 6 on Fig. VII.3.2. Structures below Moho may give a large number of additional smaller peaks (top traces Fig. VII.3.4), but neither of these structures seem able to change drastically the spectral ratio generated by the Moho boundary. Also it may be difficult even for a one-layer case to discriminate between a deep crust with high velocity and a shallow one with lower velocity (Fig. VII.3.3). By taking into account also the size of the spectral peaks, this should, however, be possible although the peak sizes are easily affected by noise.

When using Fourier theory to estimate the vertical and horizontal spectra, we will have to use a time window of a certain length. The estimated ratio is then (a star means convolution)

$$\hat{G} = \frac{Z*W}{R*W} = \frac{(S\cdot H_Z\cdot I+N_Z)*W}{(S\cdot H_R\cdot I+N_R)*W} \qquad (4)$$

Since convolution is an integral operation, we can in general not cancel the common terms in the numerator and denominator in Eq. (4), even if we assume $N_Z=N_R=0$. In the practical estimation of the spectral ratios, one has to ensure that a long enough window is used in the calculation of the spectra (see Fig. VII.3.4). For the type of instruments used at NORSAR this means 50 seconds or longer, but with other instruments with a flatter response curve a somewhat shorter window may be used, although as demonstrated a 20 second window is surely too short. If one would like to see the full effect of the upper mantle on these ratios, a window of up to 180 sec is needed. There are several other factors to be aware of. One needs signals with very good signal-to-noise ratio, and the signal should be as pulse-like as possible. A very deep source is to be preferred (one thereby may avoid any source-side depth phases), but is not a completely necessary requirement. It is found that depth phases are only a problem when they are so strong and arriving so late that they may be seen on the record. By selecting only simple pulse-like signals one therefore can avoid this problem.

In short, from the simulations performed we conclude that one can use the spectral ratio method to find the depth to Moho if proper care is taken in the data processing. We do not believe that it is possible to find a more detailed model, at least not without any other evidence.

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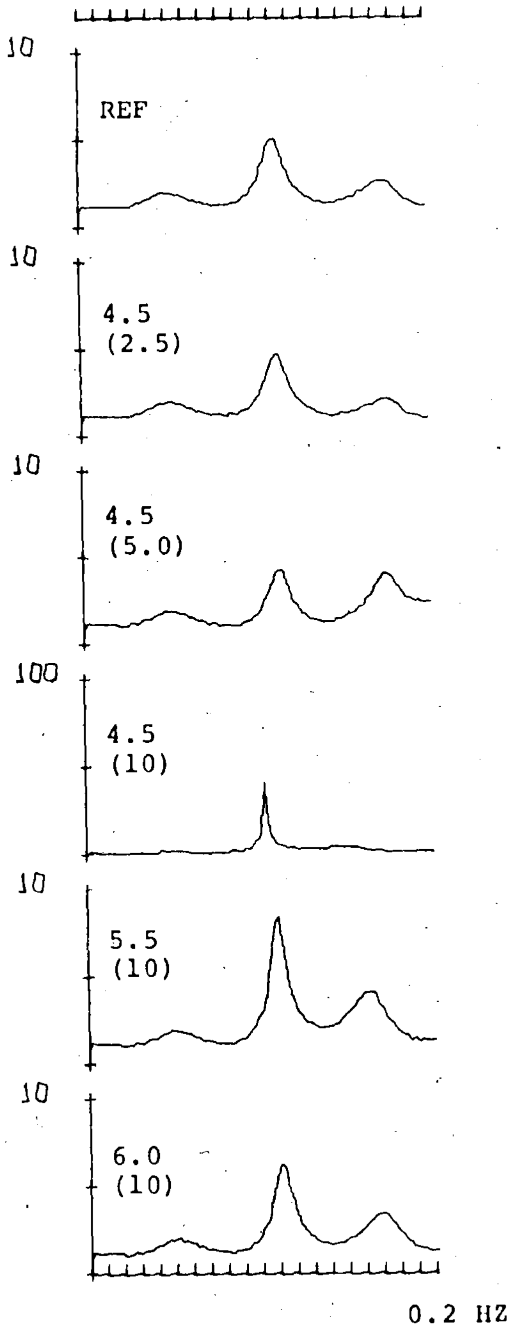

Fig. VII.3.1 Illustration of the effect on the theoretical spectral ratio of low velocity surface layers. In the first trace is plotted the ratio for a one-layered reference model with crustal P-velocity equal to 6.6 km/sec and Moho depth 35 km. In the following cases are then plotted the ratios for different cases of surface layers. The thickness of the layer and its P-velocity (in brackets) is written on the figures.

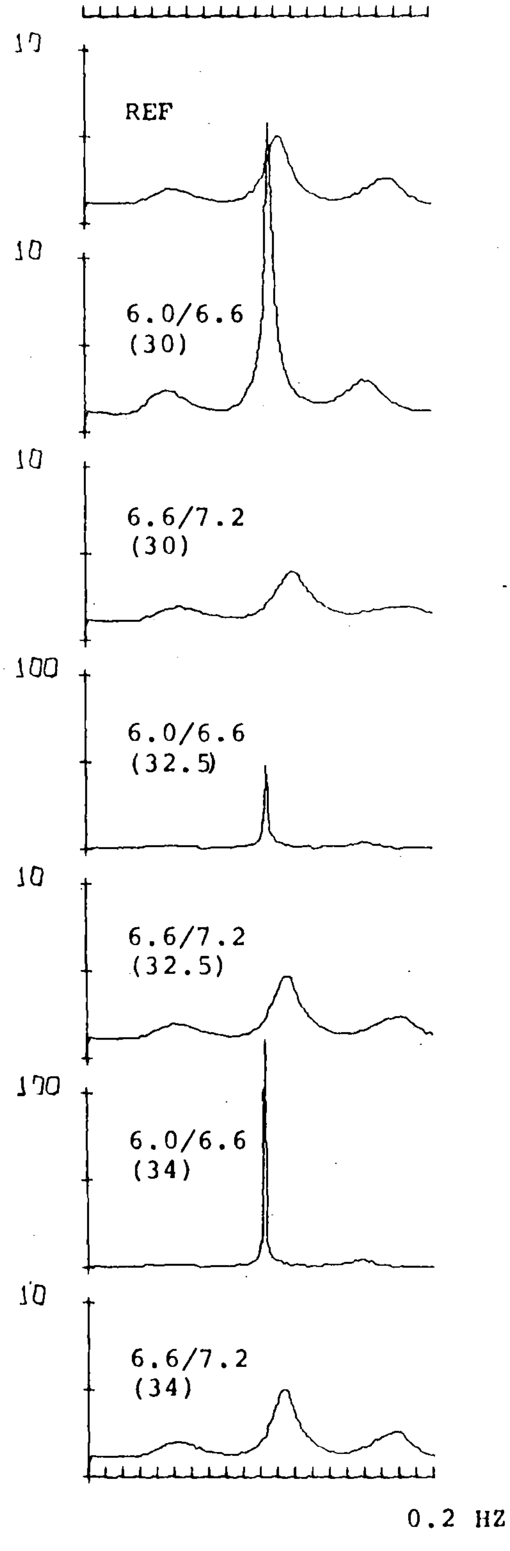

Fig. VII.3.2 Illustration of the effect on interfaces in the deeper part of the crust. As before the upper trace is the spectral ratio for a one-layered 35 km thick reference model, while the other traces are for different types of two-layered models. The depth (in brackets) of the intermediate interface and the P-velocity above and below it are given on the figure.

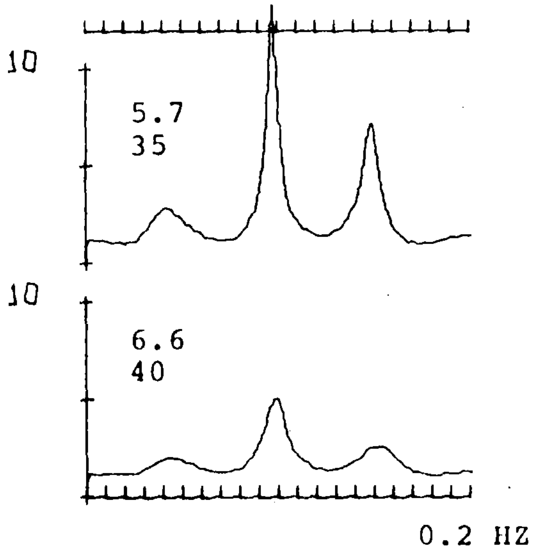

Fig. VII.3.3 Illustrating the fact that a deep crust with high velocity and a shallower crust with lower velocity will have the peaks in the theoretical spectral ratio at the same frequencies. In the upper case the Moho depth is 35 km and the crustal P-velocity is 5.7 km/sec, while in the lower case the corresponding numbers are 40 km and 6.6 km/sec.

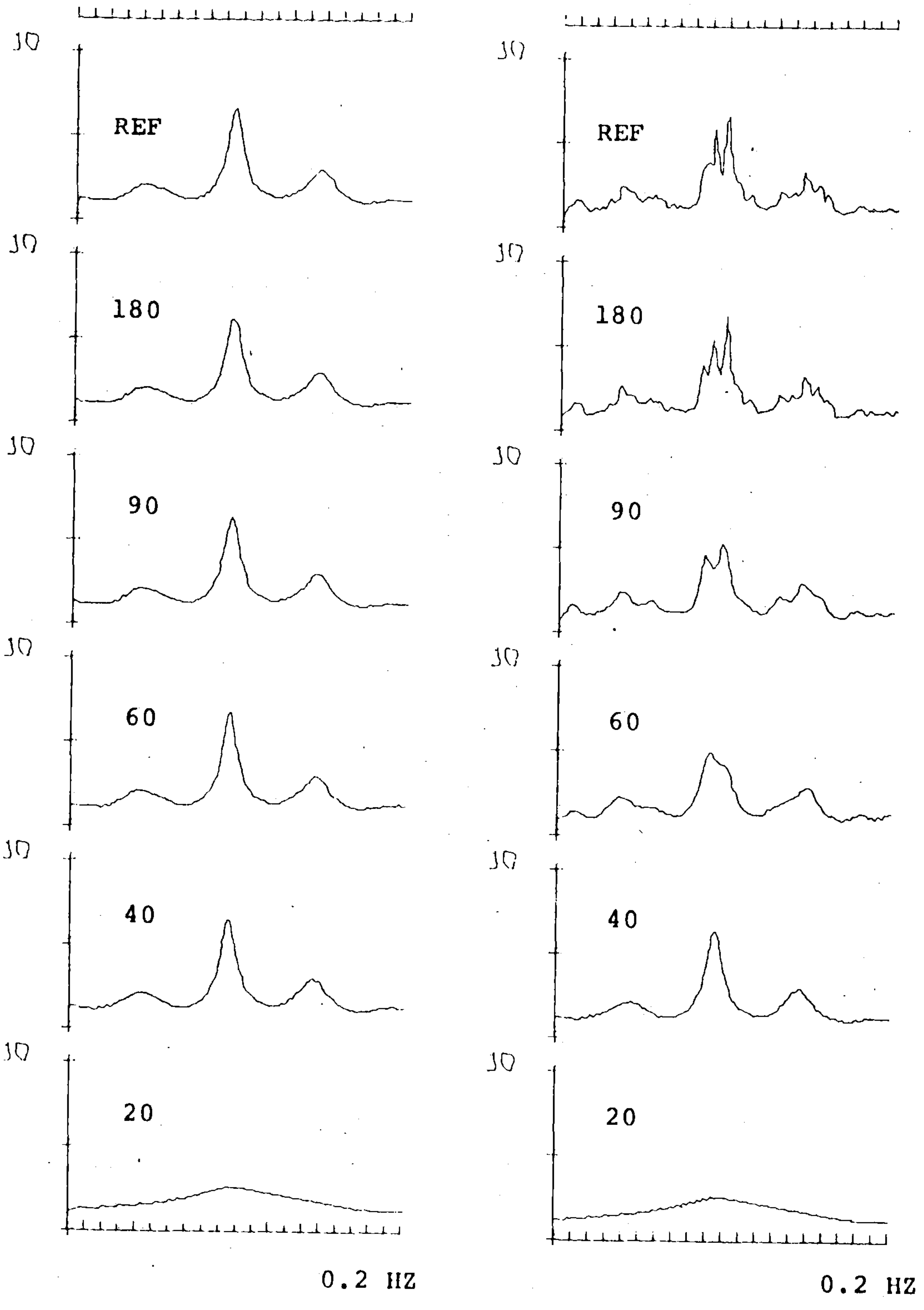

Fig. VII.3.4 Illustration of the effect of different window length in the calculation of the spectral ratio. The model used is the crustal model (left panel) and the whole crust and upper mantle model of King and Calcagnile (1976). The top trace in both cases is the theoretical ratio, while the other traces give the ratio that will be observed for different lengths of the Fourier window. Window length in seconds is given on the figure. The source function, the source-side crust response the effect of the mantle as well as the effect of the instrument response have been ignored in the calculations.