Royal Norwegian Council
for Scientific and Industrial Research
(NTNF)

NORSAR

NORSAR Scientific Report No. 2-87/88

Semiannual Technical Summary

1 October 1987 – 31 March 1988

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Kjeller, June 1988

VII.3 Surface topographic effects on arrays and three-component stations

A recent analysis of the location capabilities by the NORESS array and by the 3-component stations within the array has led to the following conclusions concerning 3-component slowness solutions for regional P waves (Kværna and Doornbos, 1986): 1) There is a relatively large scatter in the solutions for events from the same source region, and 2) there are significant differences between the solutions at the different stations. The differences are systematic, and for a proper evaluation of NORESS and similar arrays it is important to understand their cause. Here we report on an investigation of the effects of surface topography.

The usual correction for surface topography implies an arrival time correction for elevation, and possibly a particle motion correction for surface slope. These corrections are consistent with geometrical ray theory, which requires that topographic relief be smooth on the scale of a wavelength. If this is not the case, wave scattering by topographic relief will be important. We have digitized a topographic map of the NORESS array area. The data are displayed in the form of elevation in Fig. VII.3.1, and in the form of surface gradients in Fig. VII.3.2. These figures demonstrate that topographic relief is not smooth on the scale of the wavelengths involved ($\sim$ 2 km). To evaluate the scattering we have applied a recently developed multiple scattering method (Doornbos, 1988). For the present purpose, we need to determine only the displacement vector at the surface, say $\underline{u}$. In the above method, the solution for $\underline{u}$ is obtained recursively in wavenumber space. If the topography is described by a function $f(x,y)$, and $\underline{U}(k_x,k_y)$ is the Fourier transform of $\underline{u}(x,y)$, then a trial solution in the form of a perturbation series is

$$\underline{U}(k_x,k_y) = \sum_{n=0}^{\infty} \underline{U}^{(n)}(k_x,k_y)$$

and $\underline{U}^{(n)}$ is a function of $\underline{U}^{(n-m)}$, $1 < m < n$, of the surface topography $f(x,y)$, and of the surface gradients $\partial f/\partial x$, $\partial f/\partial y$. The zeroth order term $\underline{U}^{(0)}$ gives the conventional free surface response for a plane, the first order term $\underline{U}^{(1)}$ includes the Born approximation, and the higher order terms account for multiple scattering.

Kværna and Doornbos (1986) analyzed in detail the P waves from a suite of mining events in the same location near Leningrad. The slowness solution based on wide-band signals (2-4 Hz) from the complete vertical-component array, was very stable. The solution differs from that expected for P_n from this source region, but the difference cannot be attributed to near-receiver structure. Hence we associate the observed slowness with that of an incident plane P wave. Three-component slowness solutions were obtained at 4 sites. The average of solutions for the 4 sites coincides reasonably well with the array solution, but there are significant differences between the individual sites, and there is also a relatively large scatter in the solutions at each site. We have synthesized the free surface response in the frequency range 2-4 Hz, and applied Kværna and Doornbos' method to determine the apparent slowness of the synthetics. The procedure was applied to the 3-component sites A0 and C7. The other 3-component sites C2 and C4 are located too close to the boundaries of the available topographic map to yield reliable synthetics. The results for discrete frequencies between 2 and 4 Hz are displayed in Fig. VII.3.3 for station A0, and in Fig. VII.3.4 for station C7. The results show a significant variation with frequency, but the average over the frequency band explains about half of the observed anomaly. We speculate that shallow subsurface structure may enhance the surface topographic effect. The variation with frequency is in agreement with the notion of surface response as an interference pattern. One consequence is that the slowness solutions for P from two events will be different if the source spectra are different. This is in agreement with the observed scatter of 3-component slowness solutions at each site. We have calculated the response at 10 other array sites for which the topographic map provides adequate information, even though there are no 3-component stations at these sites. The results for all 12 sites are summarized in Fig. VII.3.5, in the form of average azimuth angle and incidence angle. The results suggest that the particle motion vector varies smoothly across the array. An important mechanism for the perturbation of particle motion is scattering into S motion, and this modifies especially the horizontal components. The vertical components are more stable. Since the array slowness solution is based on phase differences between stations, we have also calculated the vertical component phase perturbations due to topographic relief. The corresponding delay time perturbations are included in Fig. VII.3.5. These perturbations are negligible, hence the array slowness solution appears to be relatively insensitive to topographic relief.

In summary, our results suggest that surface topographic relief significantly perturbs the surface particle motion and hence 3-component slowness solutions. The perturbation varies from site to site within the NORESS array, and it also depends on details of the input signal spectrum. On the other hand, the array slowness solution based on vertical component phase delays is relatively stable since the additional phase perturbations are negligible.

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References

Doornbos, D.J. (1988): Multiple scattering by topographic relief, with application to the core-mantle boundary. Geophys. J., 92, 465-478.

Kværna, T. and D.J. Doornbos (1986): An integrated approach to slowness analysis with arrays and three-component stations. Semiannual Technical Summary, 1 October 1985 - 31 March 1986. NORSAR Sci. Rep. No. 1-85/86, Kjeller, Norway.

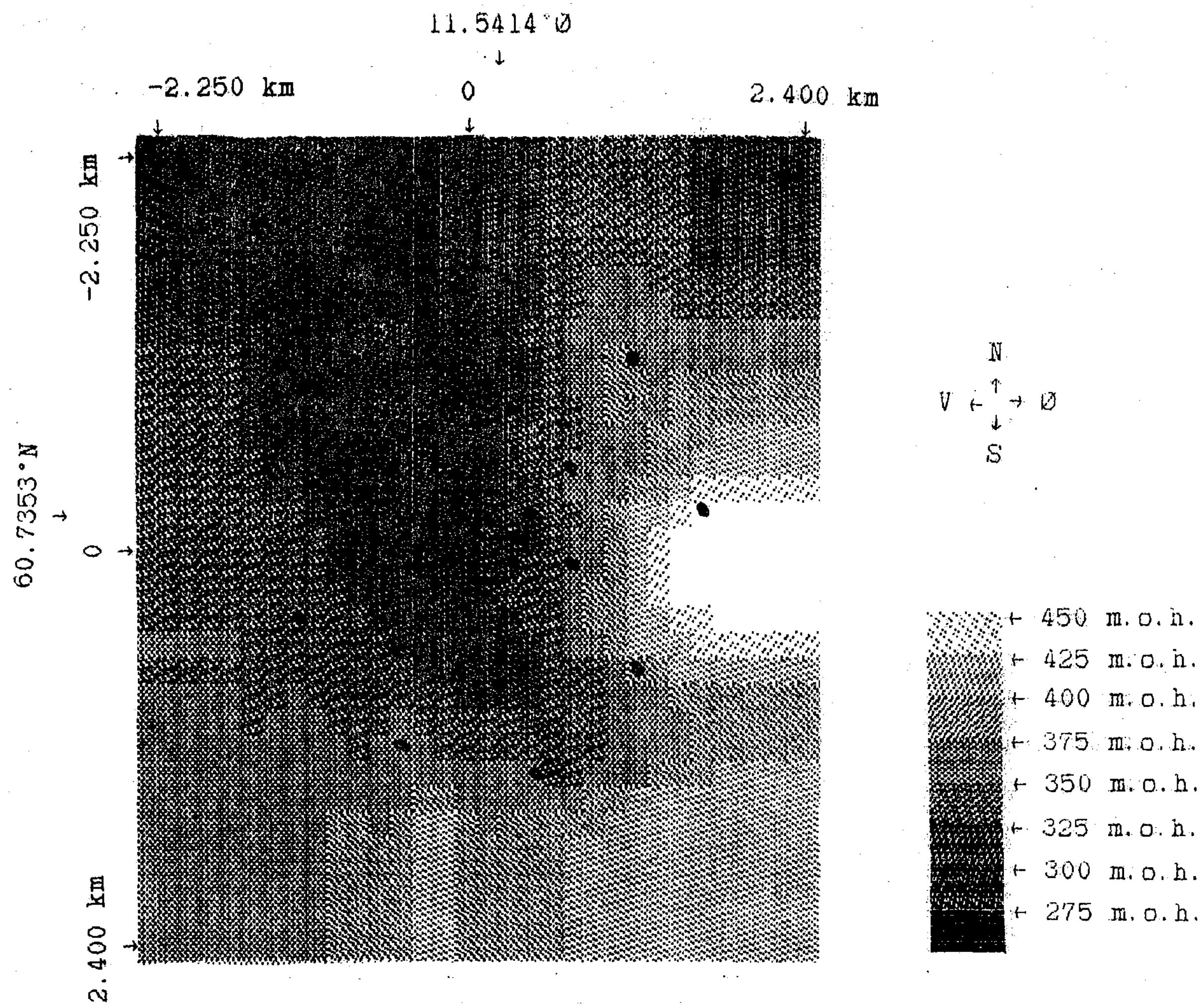


Fig. VII.3.1 Topographic map of the NORESS array area between 60.71 - 60.76°N and 11.50 - 11.58°E.

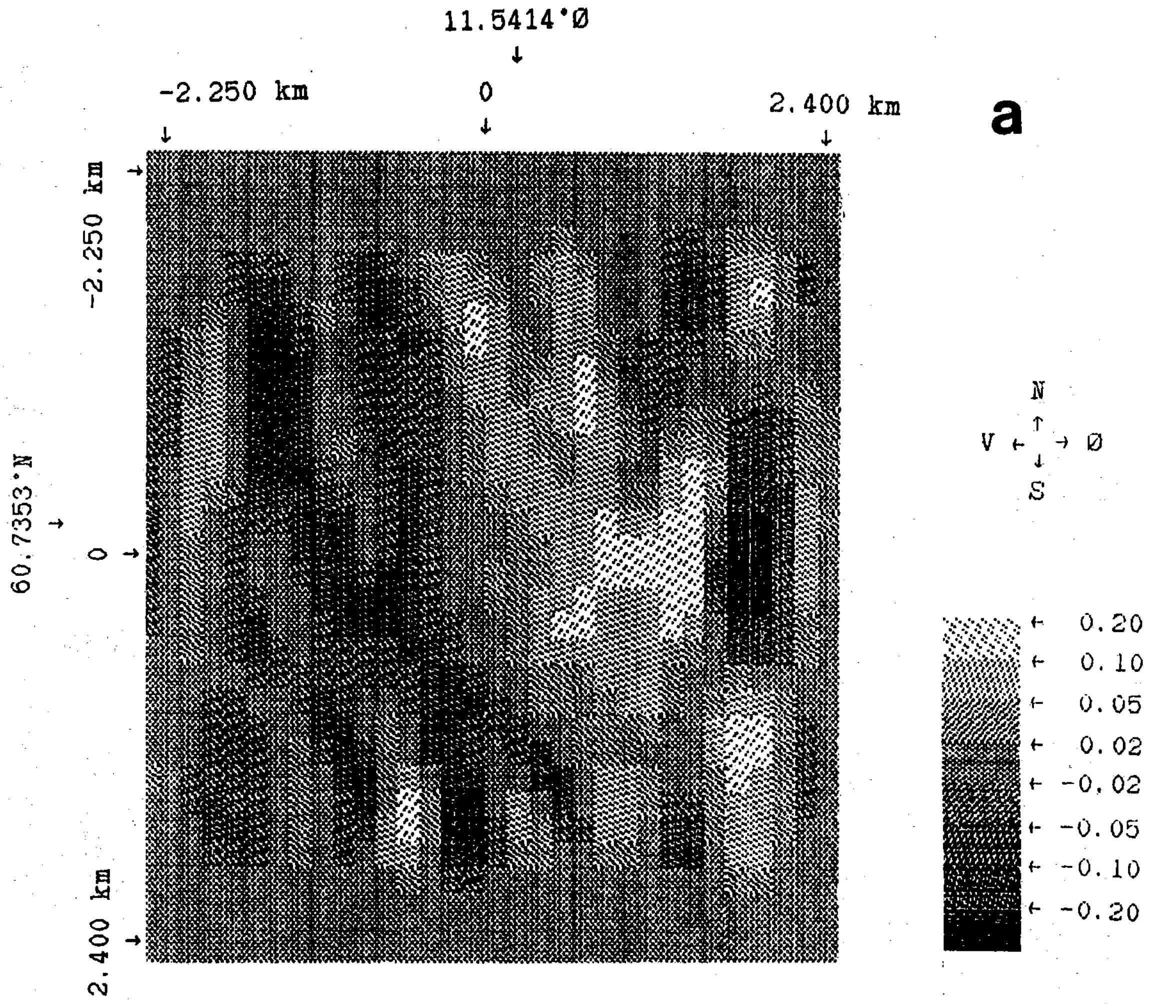


Fig. VII.3.2 Surface gradients of topography in Fig. VII.3.1. (a) Gradient toward East ($\partial f/\partial x$). (b) Gradient toward south ($\partial f/\partial y$). Here f(x,y) represents the topography.

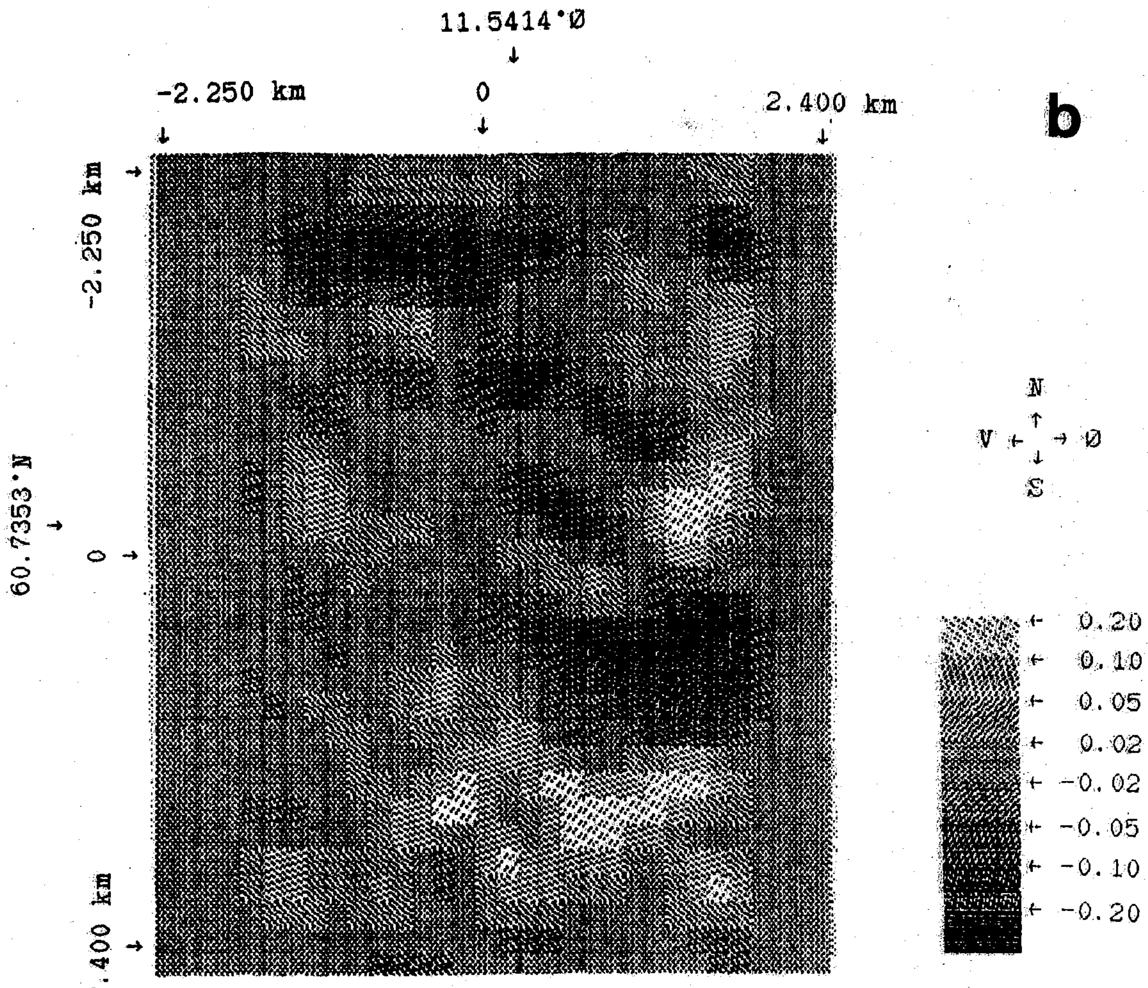


Fig. VII.3.2 (cont.)

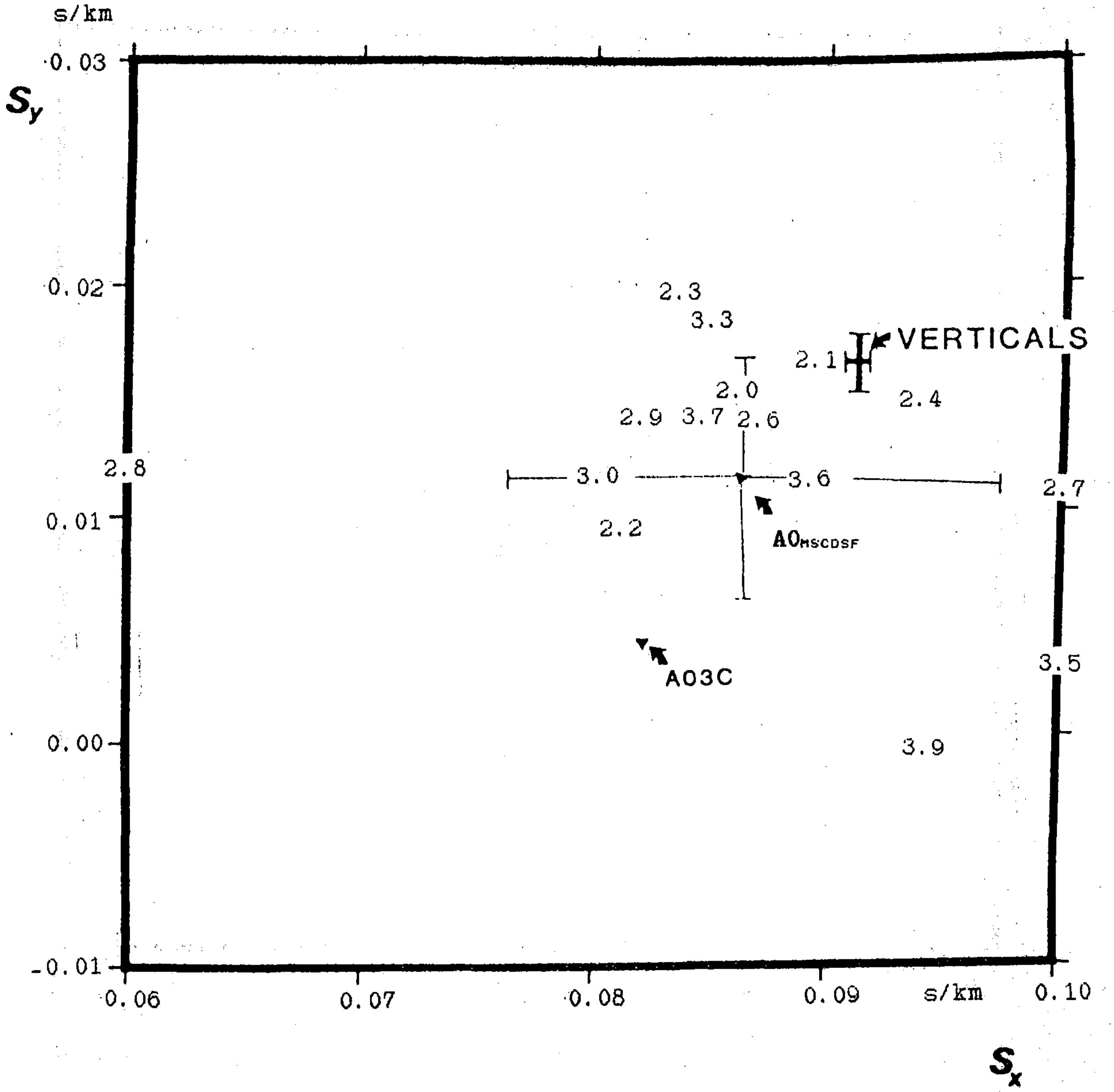


Fig. VII.3.3 Slowness solutions at site AO, based on synthetic response in the frequency range 2-4 Hz. Slowness components in s/km. The incident plane wave slowness is labelled "VERTICALS". Solutions at single frequencies are labelled by the frequency in Hz. The averaged solution over the band 2-4 Hz is labelled "AO" with standard deviations indicated. The averaged solution from real data is "AO3C".

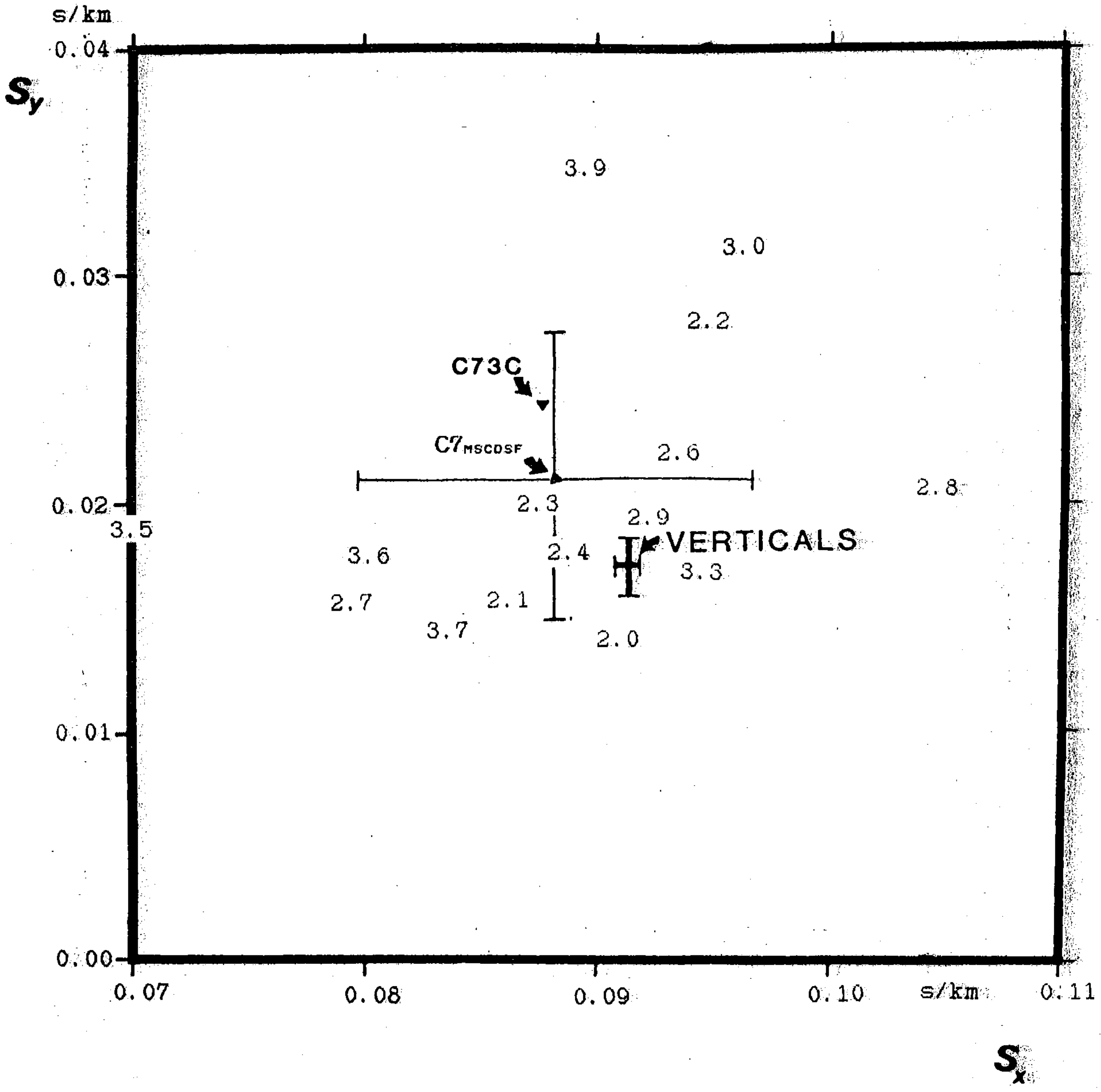
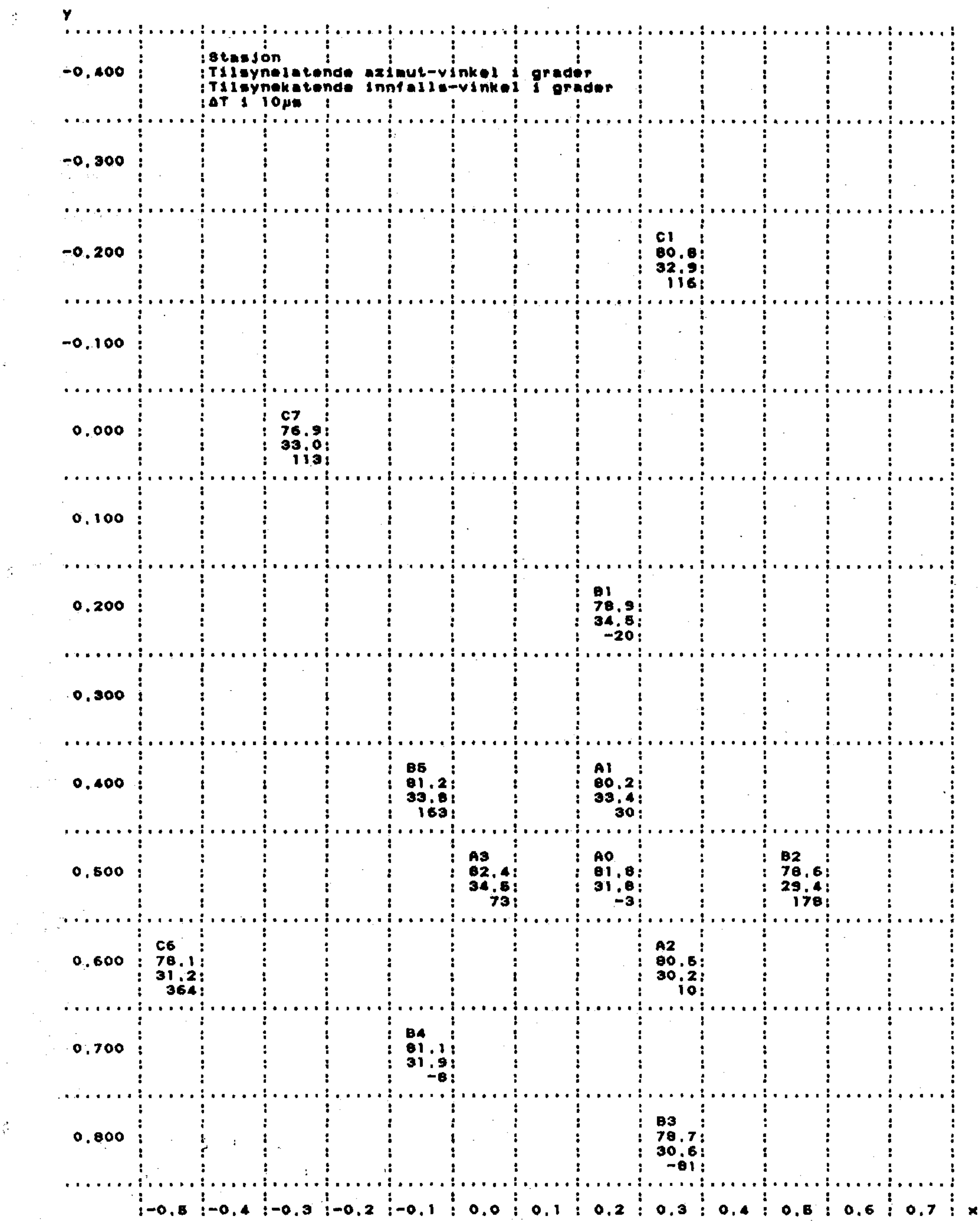


Fig. VII.3.4 Slowness solutions at site C7, based on synthetic response in the frequency range 2-4 Hz. Other details as in Fig. VII.3.3.



<u>Fig. VII.3.5</u> Synthetic particle motion direction and delay time perturbation at 12 sites within the NORESS array. The 3 numbers given for each site denote azimuth (in ^{o}), incidence angle (in ^{o}), and delay time perturbation (in units of 10 μs). The theoretical numbers for a plane surface are: azimuth 79.4^{o} and incidence angle 33.8^{o}.