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Linda Tronrud (ed.)

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VII.8 The New Regional Array: 1983 Vertical and Three-Component Instrument Field Experiments

Introduction

During the period June 10 - July 5, 1983, data were recorded of a 5-element array of three-component instruments. The geometry of that array is shown in Fig. VII.8.1. During this period a number of local events were recorded.

The new array to be installed in 1984 will initially comprise 4 three-component instruments, whereof one will be located in a borehole at the center of the array. A proposal for location of the remaining 3 sets of three-component instruments is the purpose of the document.

Preliminary work

Before an analysis of the recorded three-component data can be conducted, it is important to reconsider the design of the 21-element vertical instrument regional array installed during the summer of 1983. The array configuration (Fig. VII.8.2) was based on an idealized analysis of the presumed noise field structure conducted by Mykkeltveit et al (1983) thereby enabling more than $\sqrt{N}$ (N = number of sensors) reduction in noise by simple beamforming. However, Husebye et al (1984) reported that there may be a coherent component in the noise field, thereby reducing the effective gain attainable by simple beamforming to be considerably less than $\sqrt{N}$. This has prompted reanalysis of the vertical component array data.

To examine the tenet proposed by Husebye et al, the experiment performed by Mykkeltveit et al is repeated here, i.e., computing correlation curves as a function of inter-sensor spacing and frequency, but with two innovations:

- During the period February - March 1984, the gain of each array element was raised by 12 dB. Effectively, this implies that the noise analysis can be conducted to a maximum frequency of 7 Hz before discretization levels are reached. This is in contrast to the upper limit in frequency of 4 Hz imposed on the Mykkeltveit et al experiment.
- A search for the coherent and/or propagating component in the noise field is possible by beaming the array to orthogonal directions (e.g., 0°

and 90°), and to 3 velocities, say ∞, 8 and 4.2 km/s. The latter two velocities approximately correspond to the phase velocities of Pn and Lg. In addition, cohrence along the edge of a presumed propagating noise wave front is examined by considering correlations between sensors aligned approximately parallel and normal to the wavefront.

Computational details

The data consists of 5 noise samples, each containing 100 seconds sampled at 40 Hz. The data are selected from different days spanning a full day. The data are bandpass filtered in the ranges 0.5-2.5, 1.5-3.5, 2.5-4.5, 4.0-6.0 and 6.0-8.0 Hz. Normalized correlations were computed between pairs of the 21 instruments giving 210 values and then averaged over the 5 samples and inter-sensor distance intervals of 150 meters. Some of the results are given in Fig. VII.8.3.

Results

The essential results of Mykkeltveit et al are replicated for beam velocities ∞ and 8 km/s (Fig. VII.8.3a, b); negative correlation values are observed for inter-sensor spacings in the range 200 meters to 1 kilometer, depending upon frequency.

However, no such results can be corroborated for a beam velocity of 4.2 km/s; the distance to where negative correlations exist varies with frequency (as expected) and beam direction. For example, at all frequencies higher than 3 Hz, negative correlations are consistently observed at inter-sensor distances of at least 100 m less for beam velocity 4.2 km/s than for ∞ or 8 km/s. For the beam direction 90°, correlations remain strongly positive even for large inter-sensor spacings at high frequencies (Fig. VII.8.3d). This implies that the noise is propagating with a reasonable degree of coherency from the east.

The second part of this exercise examines correlations between pairs of sensors parallel and normal to the presumed noise wavefront. Specifically, Fig. VII.8.3e,f examines instrument pairings aligned approximately parallel and normal to the steering direction of 0^{o}, respectively. Beam velocity is 4.2 km/s. It can be seen that for this particular beam, the correlations are much as expected for the case of non-propagating, incoherent isotropic noise. However, there are some differences, particularly at inter-sensor spacings of less than 300 meters. This may be due, in part, to leakage of coherent noise from the source to the east of the array. Fig. VII.8.3g,h examines instrument pairing aligned approximately normal and parallel to the steering direction of 90^{o}, respectively. The strongly positive correlations at small inter-sensor spacings indicate that the noise wavefield is reasonably coherent both along the edge of the wavefront and in the direction of propagation from east to west. It is important to note that this is true for a wide range of frequencies, from 0.5 to 8 Hz, and so it is not simply noise propagating in a narrow pass-band. It is also likely that the source to the east of the array is non-transient, i.e., stationary, because of the wide time span sampled by the noise data.

The main conclusions to be drawn from this work are:

- A certain directability in the noise field is apparent for certain azimuth directions. In practice this gives reduced noise suppression capabilities or an equivalent higher false alarm rate on certain beams.
- Array configuration optimization; this is a problem if reasonable performance is desired over a relatively wide frequency range. Optimum processing schemes (Husebye et al, 1984) appear to be unavoidable here or the array must compromise on a duality in configuration.

Analysis of three-component data

The data consist of 5 noise samples, each containing 100 seconds recorded by the 5 three-component sets in the preliminary NORESS array. As before, the data are selected from different days spanning a full day. The data are bandpass filtered in the ranges 0.5-2.5, 1.5-3.5 and 2.5-4.5 Hz. Correlations were computed between pairs of the orthogonal components, and then averaged over the 5 samples. Standard deviations of correlation were larger for this exercise than for the vertical instrument array, because no averaging over inter-sensor spacing intervals was possible. This is reflected in the correlation plots (Fig. VII.8.4) where the curves appear quite jagged due possibly to incorrectly matched instrument responses.

Correlation curves for three components with beam velocities ∞ and 8 km/s (two steering directions, 0^{o} and 90^{o}) are shown in Fig. VII.8.4a,b,c. The curves exhibit the general properties for isotropic noise, as found in the preliminary work using the vertical instrument array. Fig. VII.8.4d,e shows the results for the beam velocity of 4.2 km/s. The poor correlations for beam direction 0^{o}, particularly in the higher frequency pass-band of 2.5-4.5 Hz, show that the noise is largely incoherent. For the beam direction 90^{o}, the noise exhibits a greater degree of coherence. This again indicates that there is a probable source of stationary noise to the east of the array.

Recommendations for deployment of three-component instruments

With one three-component instrument centrally located in the array, deployment of the three remaining instrument sets in the C-ring, specifically at site numbers 1, 12, 14 and 16 is advised. The minimum inter-sensor spacing for instruments deployed this way is about 700 meters which is perhaps the best compromise based on the noise correlation curves in this study and signal correlation curves from Mykkeltveit et al. Average inter-sensor spacings for instruments placed in the B-ring are 300 meters, and for the D-ring, 1500 meters. Clearly, however, much denser station spacing is required. It is imperative that an additional 3 or 4 sets of three-component instruments be considered for deployment in summer 1984.

The usefulness of an array of three-component instruments in detection and location modes has yet to be examined. Future areas of study include the use of sophisticated multivariate schemes such as principal-component analysis (of which polarization and particle motion studies are a subset). However, the initial deployment of only 4 three-component instruments will not create a sufficiently large data base for such studies, as can be seen from the considerable scatter in the correlation estimates of Fig. VII.8.4. Nevertheless, four sets of instruments will be useful for determining preliminary directions of future research.

S.F. Ingate

References

Husebye, E.S., S.F. Ingate and A. Christoffersson (1984): Optimum processing schemes in real-time analysis of array data, in Technical Means of Verification of Compliance with Arms Control Agreements (in press).

Mykkeltveit, S., K. Åstebøl, D.J. Doornbos and E.S. Husebye (1983): Seismic array configuration optimization. Bull. Seism. Soc. Am., 73, 173-186.

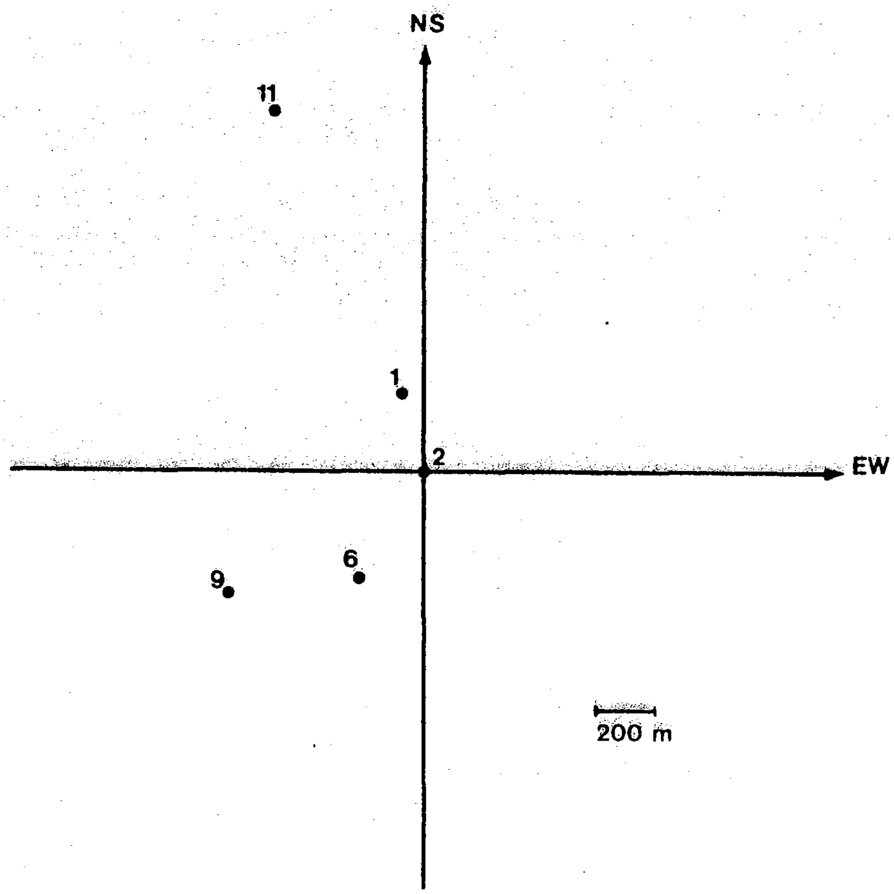

Fig. VII.8.1 Temporary 5-element, three-component short period seismometer experimental array, deployed June 10 - July 5, 1983.

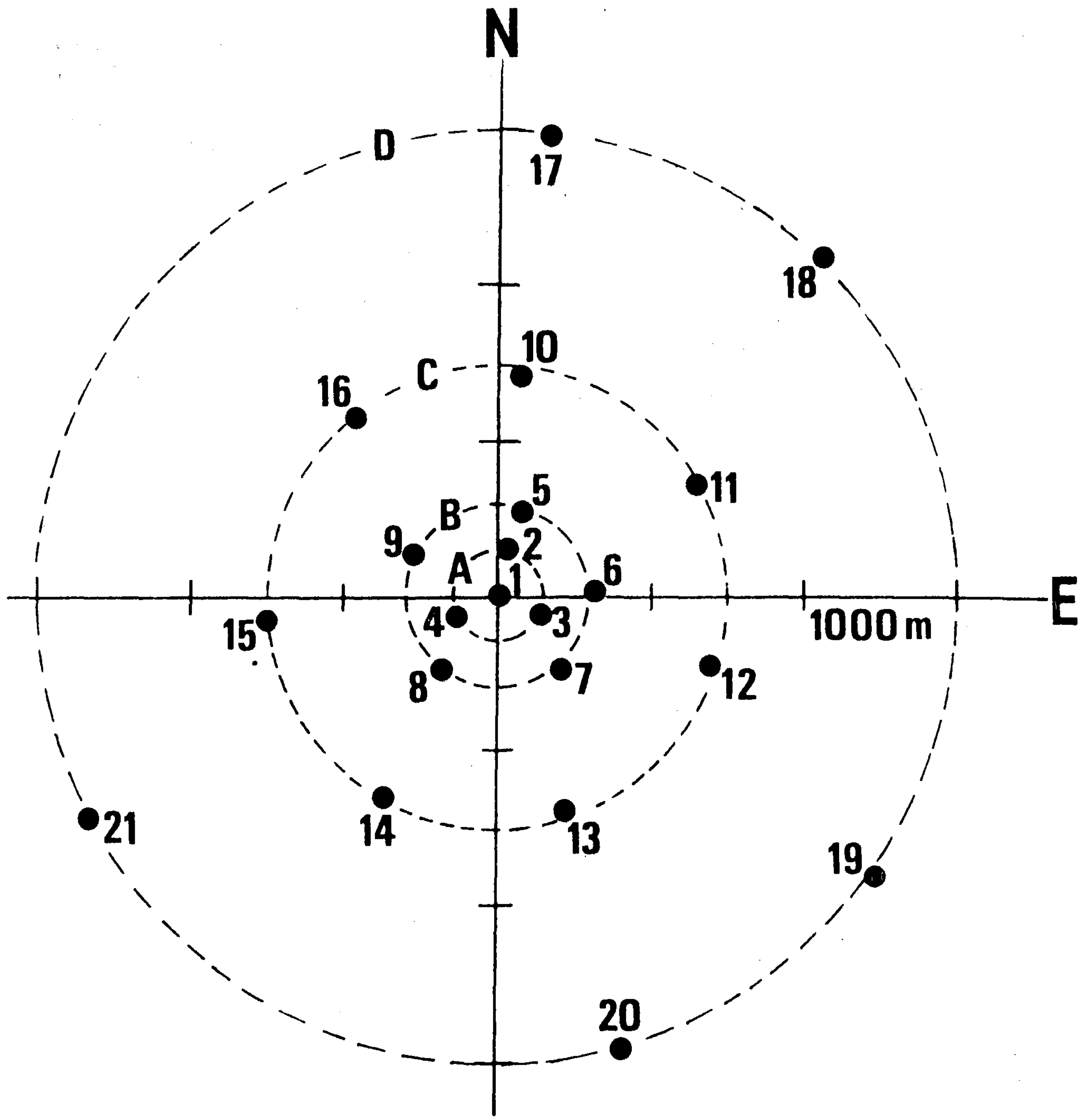

Fig. VII.8.2 The prototype 21-element vertical component short period seismometer array, with site numbering. Deployed summer 1983 to present.

Fig. VII.8.3 Correlation versus inter-sensor spacing for noise recorded on the prototype regional array. Five frequency bands are shown, 1 (0.5-2.5 Hz), 2 (1.5-3.5 Hz), 3 (2.5-4.5 Hz), 4 (4.0-6.0 Hz) and 5 (6.0-8.0 Hz). Each curve is based on measurements from 210 combinations of sensor pairs.

(a) Beam velocity = ∞ km/s.
(b) Beam velocity, direction = 8 km/s, 0°.
(c) Beam velocity, direction = 4.2 km/s, 0°.
(d) Beam velocity, direction = 4.2 km/s, 90°.
(e) Beam velocity, direction, alignment = 4.2 km/s, 0°, parallel to wavefront
(f) Beam velocity, direction, alignment = 4.2 km/s, 0°, normal to wavefront.
(g) Beam velocity, direction, alignment = 4.2 km/s, 90°, normal to wavefront.
(h) Beam velocity, direction, alignment = 4.2 km/s, 90°, parallel to wavefront.

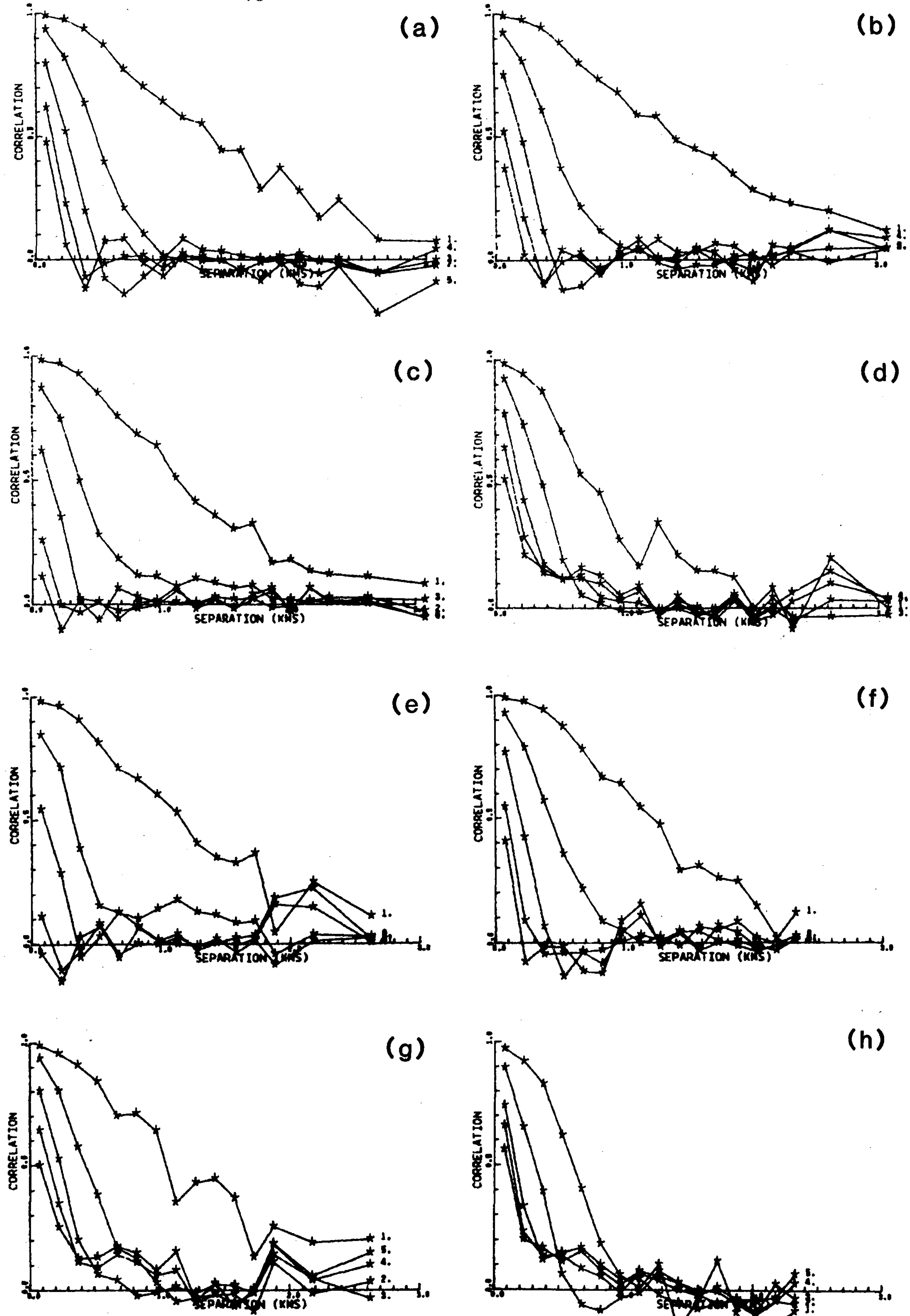

Fig. VII.8.3

Fig. VII.8.4 Correlation versus inter-sensor spacing for noise recorded on the temporary three-component seismometer array. Three frequency bands are shown, 1 (0.5-2.5 Hz), 2 (1.5-3.5 Hz) and 3 (2.5-4.5 Hz).

(a) Beam velocity = ∞ km/s.
(b) Beam velocity, direction = 8 km/s, 0^{o}.
(c) Beam velocity, direction = 8 km/s, 90^{o}.
(d) Beam velocity, direction = 4.2 km/s, 0^{o}.
(e) Beam velocity, direction = 4.2 km/s, 90^{o}.

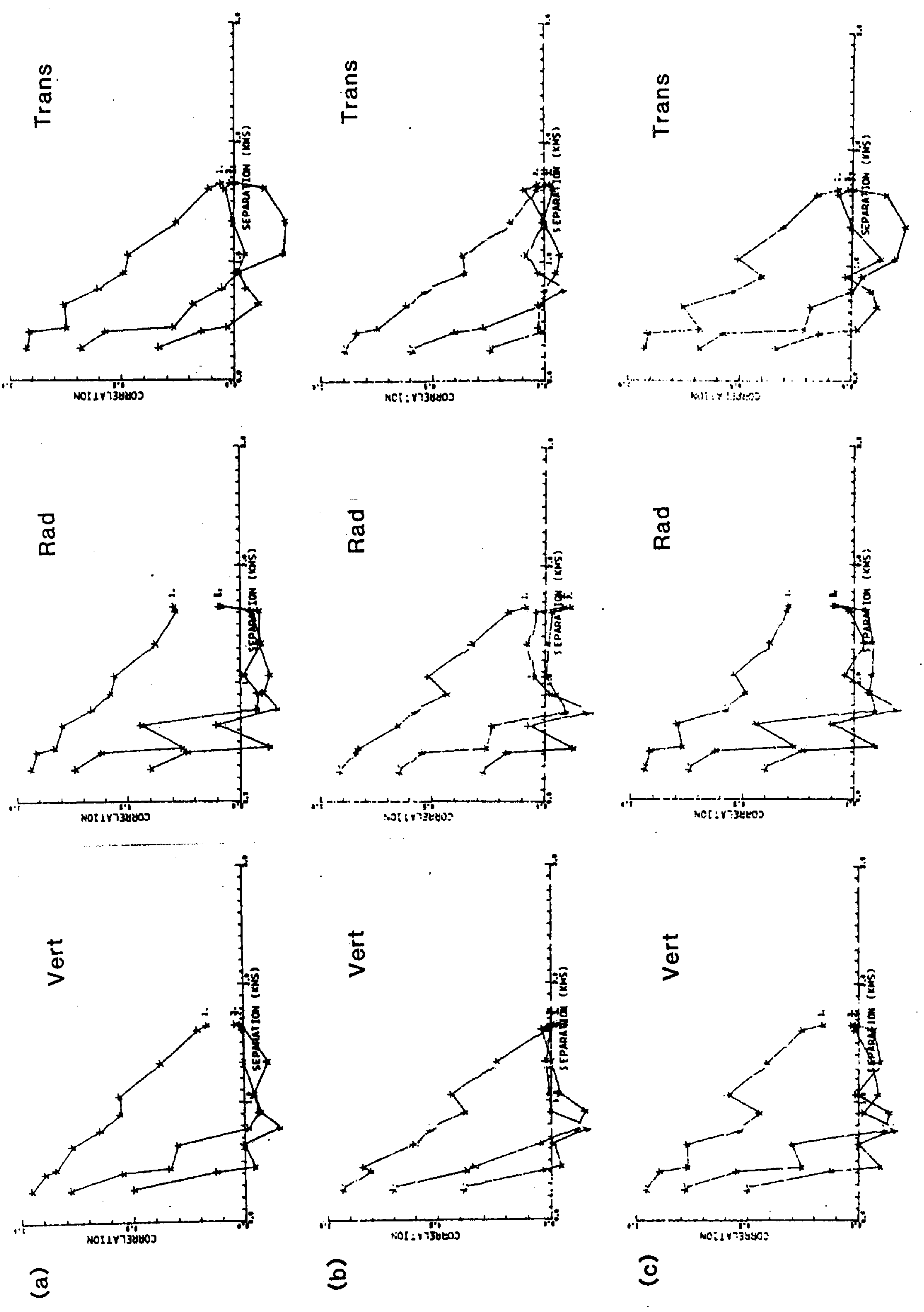

Fig. VII.8.4

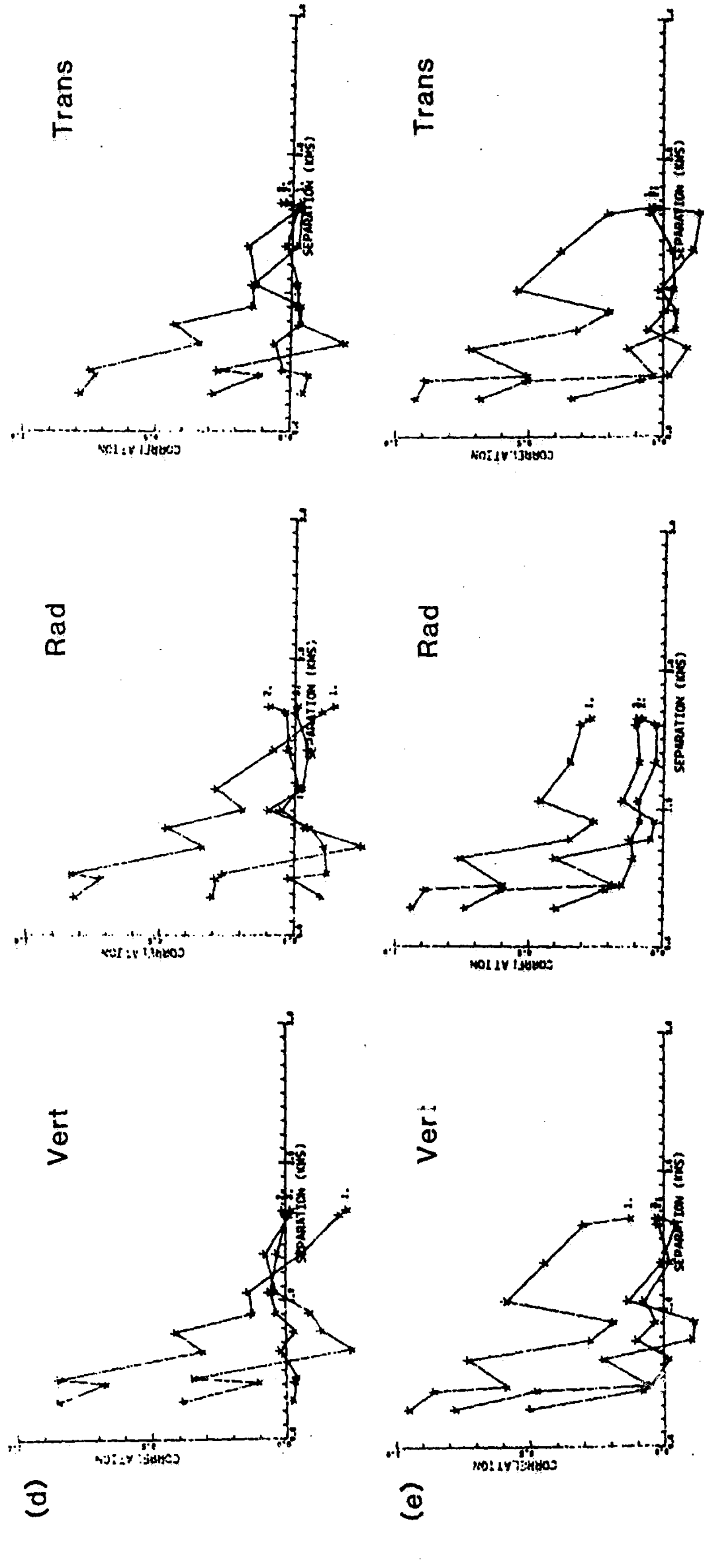

Fig. VII.8.4 (cont.)