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VII.7 3-component seismogram analysis

A properly equipped seismograph station or array always includes 3-component instrumentation for the very simple reason that the seismic wavefield comprises vertical and horizontal ground motions and combinations thereof. Seismologists have for many years successfully exploited the information potential of 3-component records for wave propagation modelling, retrieval of structural information (tomography) and source parameters, but these efforts have mainly been tied to the low frequency part of the wavefield. Likewise, many efforts have been invested in extracting similar information in the high frequency range, say of 1-10 Hz, but in this case less successfully as judged from current literature. The reason for this appears to be twofold: i) high frequency records are rather complex due to scattering, mode conversions, multipathing and similar wave propagation effects and ii) the analysis techniques used fail to produce extracted wavefield parameters in an easily interpretable format. For example, a common procedure is to produce particle motion plots reflecting the structure in the wavefield, but since such plots generally are messy, the analysis is often left at that.

The problem addressed in this note is that of a new approach to extracting parameter characteristics, the wave field structure on the basis of a priori models for P, S, Love and Rayleigh wave particle motions. Special attention has been given to the problem of presenting results in an easily interpretable manner or extracting signal parameters convenient for a wide variety of research applications. These points will be amply demonstrated in the Results section.

3-component analyzing technique - wavefield modelling

Any approach to extracting signal parameters from a seismogram is based on certain assumptions or models regarding the signals or wavelets constituting the records and the background noise. In our case these are: i) noise is orthogonal between the 3-components (vertical, radial, transverse; or Z, E-W, N-S) and ii) particle motion is as derived from classical wave theory. The analyzing technique, as used in practice, is tied to the theoretically expected particle motion covariance matrix which is compared to that observed in given time and azimuth windows. Then using a max. likelihood formulation the primary result is simply the likelihood that a wavelet is either P, S, Love or Rayleigh against the null hypothesis of being noise. Concurrent with the likelihood estimation is that of extracting the axis of the particle motion ellipse (linear for body waves) which in turn can be converted into angle of approach of the incoming wavefront, that is, angle of incidence (azimuth is already known). Details on this particular particle motion analyzing technique is presented by Christoffersson et al, 1985. To summarize, wavefield information extraction from our 3-component signal analysis procedure is as follows:

- Likelihood of presence (0.4 triggering level) of P, S, Love and Rayleigh type of wavelets as a function of azimtuh (dAzi ~ 1 to 5 deg), and time (dT ~ 1 sec, updating interval 0.5 sec).

- Angle of incidence for triggered body wave type of wavelets.

As mentioned, special attention was given to results or extracted wavefield parameter presentations which presently are in the following forms:

i) Likelihood contouring as a function of azimuth (ranges typically 60-180 degrees) and time (ranges typically 20-50 sec).

ii) Particle motion filtering on the basis of the estimated likelihood function, that is, simply weighting the original records with the likelihood function and confining to an azimuth window of ± 30 to ± 40 deg relative "true" azimuth.

iii) Angle of incidence estimates converted to apparent phase velocity (so far for P only) via Herrin tables, and then plotted as a function of time and azimuth.

iv) Azimuth and incident angle of the very first P wavelet transformed to estimates of epicenter coordinates.

We remark that presently our work on 3-component seismogram analysis is just in a rather preliminary stage; the use of other types of ML-estimates has not been explored, nor the use of more complex particle motion models. Other types of problems are those of better handling interference phenomena typical of the Lg wavetrain and S-wave splitting, but a requirement here seems to be access to 5-component instrumentation (1 vertical and 4 horizontal). On the application side, we have not explored the possibility of coda decomposing in deterministic and random scattering contributions, and perhaps most challenging that of what we term earth fingerprinting. With this is meant that the large number of signal parameters extracted may exhibit stationary patterns reflecting structural heterogeneities characteristic of specific site and source regions.

It may also be appropriate with a few words on how our technique compares with others tied to analysis of 3-component data. The feature in common is that of estimating the axis of the particle motion ellipse, but to our knowledge nobody has tried to include model fit in probabilistic terms nor to use sliding time/azimuth windows permitting a rather comprehensive decomposition of the whole recorded wavetrain. The preliminary results to be presented stem from analysis of the 3-component recordings from the new NORESS array, and obviously some comparison has to be made between outcome of our decomposition technique and similar results obtained by f-k analysis using all 25 vertical components of the array. Without going into detail here, it suffices to state that 3-component results (single site) compare favorably to the f-k results; in fact quite often they do better in terms of improved time and azimuth resolutions. The reason for this is that f-k analysis requires longer time windows (a minimum of 2.5 sec is used) to account for move-outs across the array, and in case of interfering signals "averaged" results are produced. Not to forget, the consistency and stationarity of particle ground motion even for short wavelets are at least for us unexpectedly good.

Preliminary results

It has taken considerable time to program our 3-component analyzing technique; the first rough version became operational quite recently, so comprehensive analysis of many event recordings has not been completed yet. However, preliminary results from a few rather typical event recordings mostly from the NORESS 3-component station C2 will be presented in the following, so as to illuminate in our opinion the strength and potential of 3-component analyzing techniques. Results are presented event-wise (in appendices) using unfiltered data as standard recursive Butterworth filtering produces severe phase distortions. It should be added that so far mostly P-modelling has been attempted.

Case 1, Event No. 84301: Caspian Sea/W. Kazakh. Feature: travel time triplication(s).

Case 2, Event No. 84327: Local explosion. Feature: complex local record; energy migration.

Case 3, Event No. 84328: E. Kazakh event. Feature: triplication of wave train ?

Case 4, Event No. 85041: Semipalatinsk event. Feature: apparent velocity analysis of the first 25 sec of the record.

Case 5, Event No. 85060: "Leningrad" event. Feature: this is actually a double event easily separated by 3-component analysis.

Case 6, Event No. 85081: Finland/USSR event. Feature: worst case event with exceptionally poor SNR, but 3-component analysis still seems to work.

Concluding remarks

The preliminary results obtained from our variant of particle motion analysis of high-quality 3-component records from the new NORESS array in Norway are considered very encouraging and thus justify research on a broader scale into this kind of problems. Methodological problems are those of more eficient ML estimators, proper parameter settings including shorter updating rates, and potential for real-time event detection. In the latter case, fast algorithms are clearly needed. In fact, a solution of the latter problems has now been obtained, that is, the probability of P wave presence in the records estimated independently of azimuth. However, the associated calculations are rather demanding and indeed not considered justified. Our recommendation is to use a Walsh detector but using a low threshold (high false alarm rate) and then introducing 3-comp. analysis for testing precursor of P waves in an off-line mode.

Surprisingly, epicenter location capabilities appear to be relatively good, azimuth estimates so far seldom exceeded ± 5 deg (often around ± 2 deg), while distance is more problematic unless secondary phases (triplications) are clearly identified. In the same way as the azimuth angle is measured in the 3-comp. analysis, we can measure similarly for the angle of incidence in the vertical plane and then convert to epicentral distance via standard travel time tables. Experiments with a Semipalatinsk event gave worst-case distance error of 5 deg (see also Sec. VII.8). Another interesting aspect of 3-comp. seismogram analysis is that of identifying pP and thus significantly improving focal depth estimates which besides are highly diagnostic of source type.

A. Christoffersson, Uppsala Univ.
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S.F. Ingate, ERL, MIT

Reference

Christoffersson, A., E.S. Husebye and S.F. Ingate (1985): Phase identification on the basis of particle motion structure in 3-comp. seismograms. Manuscript in preparation.

CASE 1

Event No. 84301:

Caspian Sea/W. Kazakh

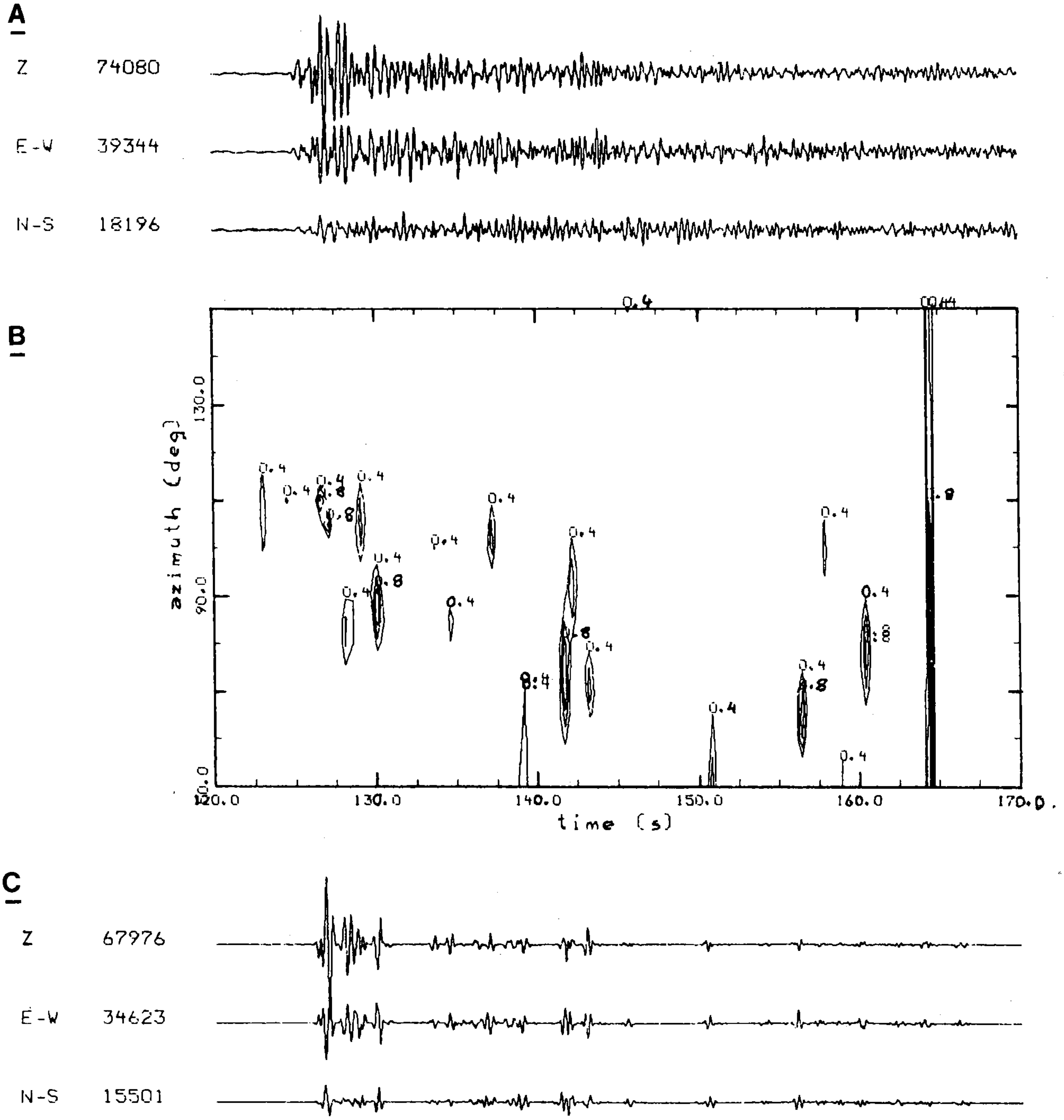
PDE azi: ~ 106^{o}, $\Delta \sim 25^{o}$

NORESS azi: = 110^{o}, vel. = 12.4 km/s

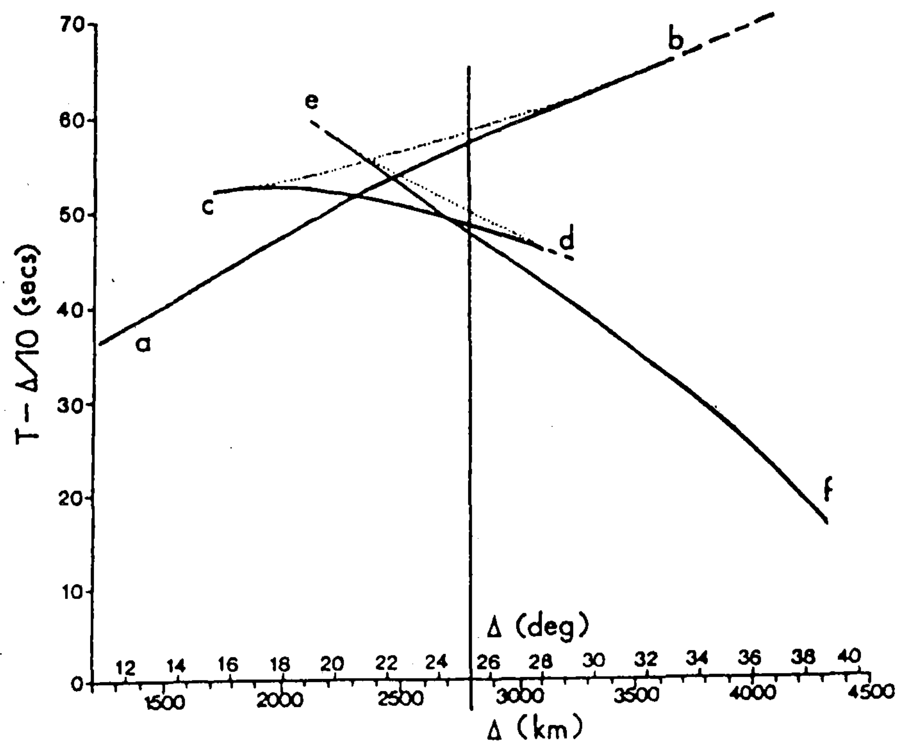
Note: Triplication features

Fig. A: Original unfiltered data
Fig. B: Probability of P-wave presence
Fig. C: Probability function of Fig. B used as a filter
Fig. D: King & Calcagnile travel time model; epicenter distance marked

Comments: The particle motion filter "produces" phase arrivals in very good agreement with expected travel time curves. The surplus arrival may be associated with a hypothesized discontinuity at ca 550 km depth. Epicenter locations better than 1 deg are deemed feasible in such cases, as triplications when identified give very precise distance estimates.


A
Z 74080
E-W 39344
N-S 18196
B
azimuth (deg)
time (s)
0.0
90.0
130.0
120.0
130.0
140.0
150.0
160.0
170.0
C
Z 67976
E-W 34623
N-S 15501

D



Travel-time distance curves for the KCA P-velocity model of the upper mantle beneath the Baltic Shield.

CASE 2

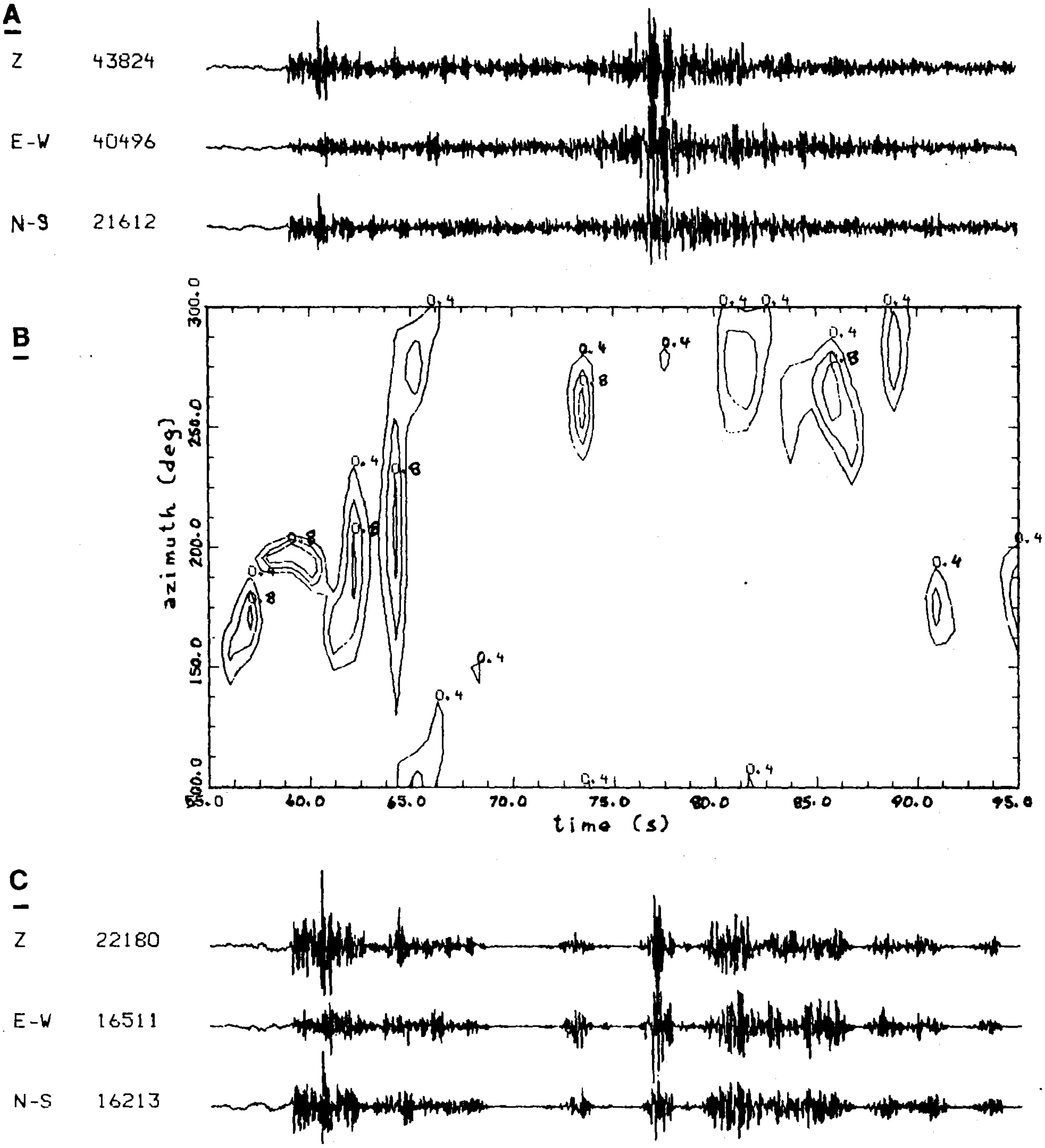
Event No. 84327:

Local explosion.

NORESS: Azi = "south"

Fig. A: Original data
Fig. B: Probability of P-wave presence; note trend of migrations in pattern
Fig. C: Particle motion filtered output

Comments: At a later stage filters based on S (SV & SH), SV, Love and Rayleigh presence will be introduced. The off-azimuth triggering at about 260-300 deg may reflect sort of side lobe effects. Anyway, 3-component filtering of complex local records seems clearly to be feasible.


A
Z 43824
E-W 40496
N-S 21612
B
azimuth (deg)
300.0
250.0
200.0
150.0
100.0
time (s)
35.0
40.0
45.0
70.0
75.0
80.0
85.0
90.0
95.0
C
Z 22180
E-W 16511
N-S 16213

CASE 3

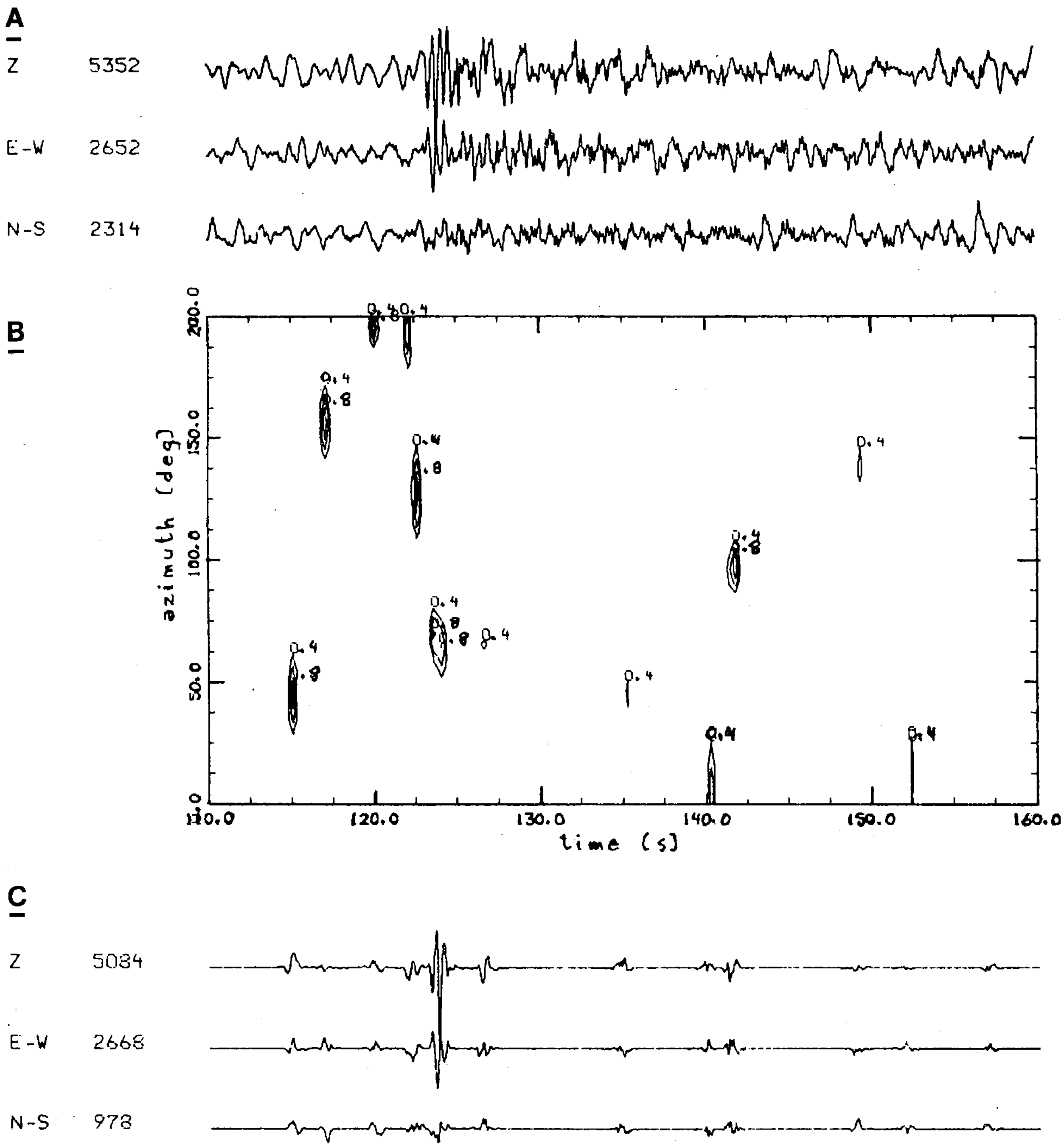
Event No. 84328:

Eastern Kazakh

NORESS gives location azi = 79^{o}, vel. = 13.8 km/s

Fig. A: Original, unfiltered data
Fig. B: Probability of P-wave presence; note triggering before main arrival
Fig. C: Filtered data; indications of triplication plus an unidentified precursory arrival

Comment: With practical experience, Fig. C filtered output may be associated with a specific siting area and/or distance range. Other problem, false alarm rate of probability triggering.


A
Z 5352
E-W 2652
N-S 2314
B
azimuth (deg)
time (s)
0
50.0
100.0
150.0
200.0
110.0
120.0
130.0
140.0
150.0
160.0
0.4
0.8
C
Z 5084
E-W 2668
N-S 978

CASE 4

Event No. 85041

Semipalatinsk

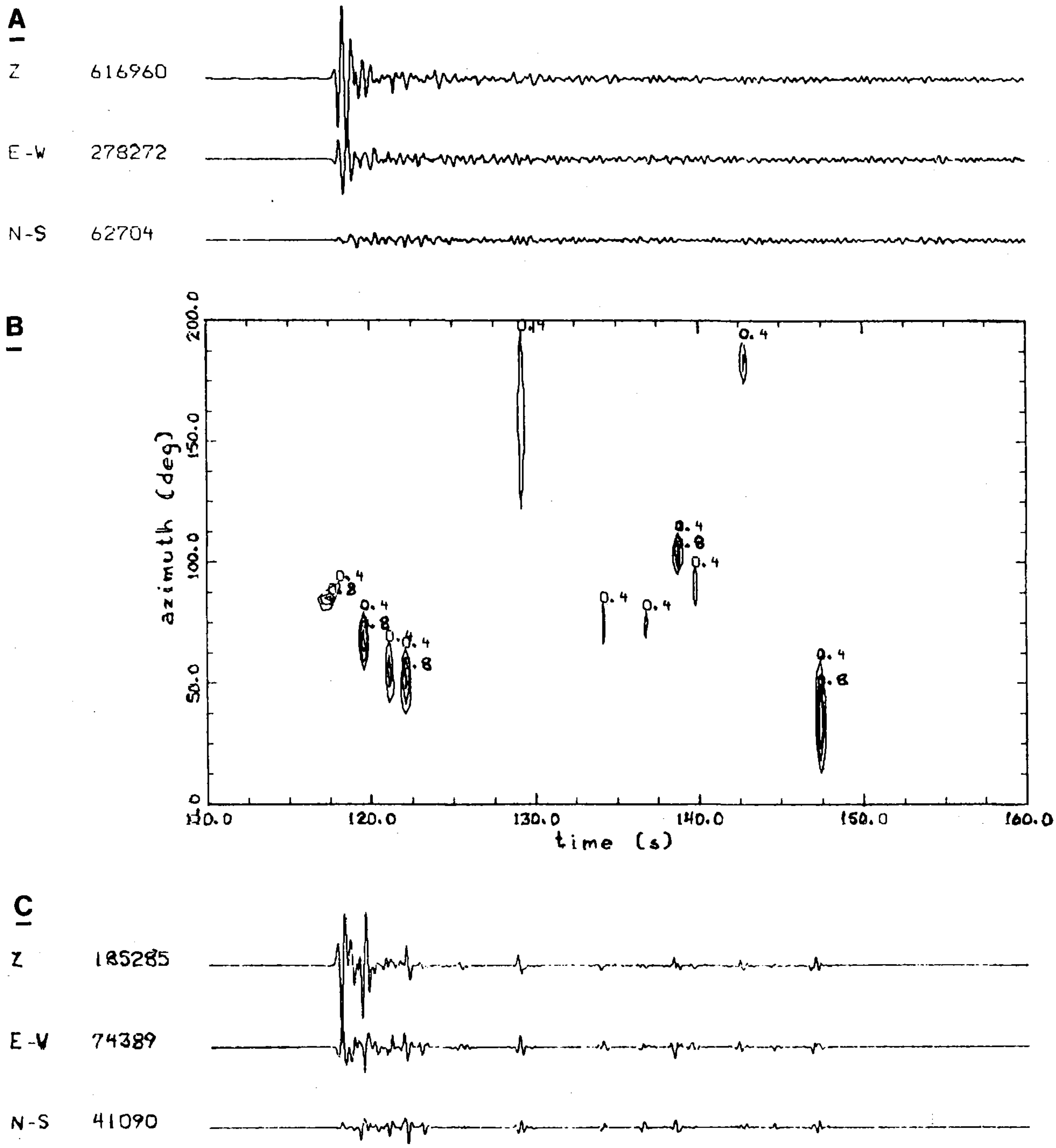
PDE azi = 74^{o}, $\Delta \sim 38^{o}$

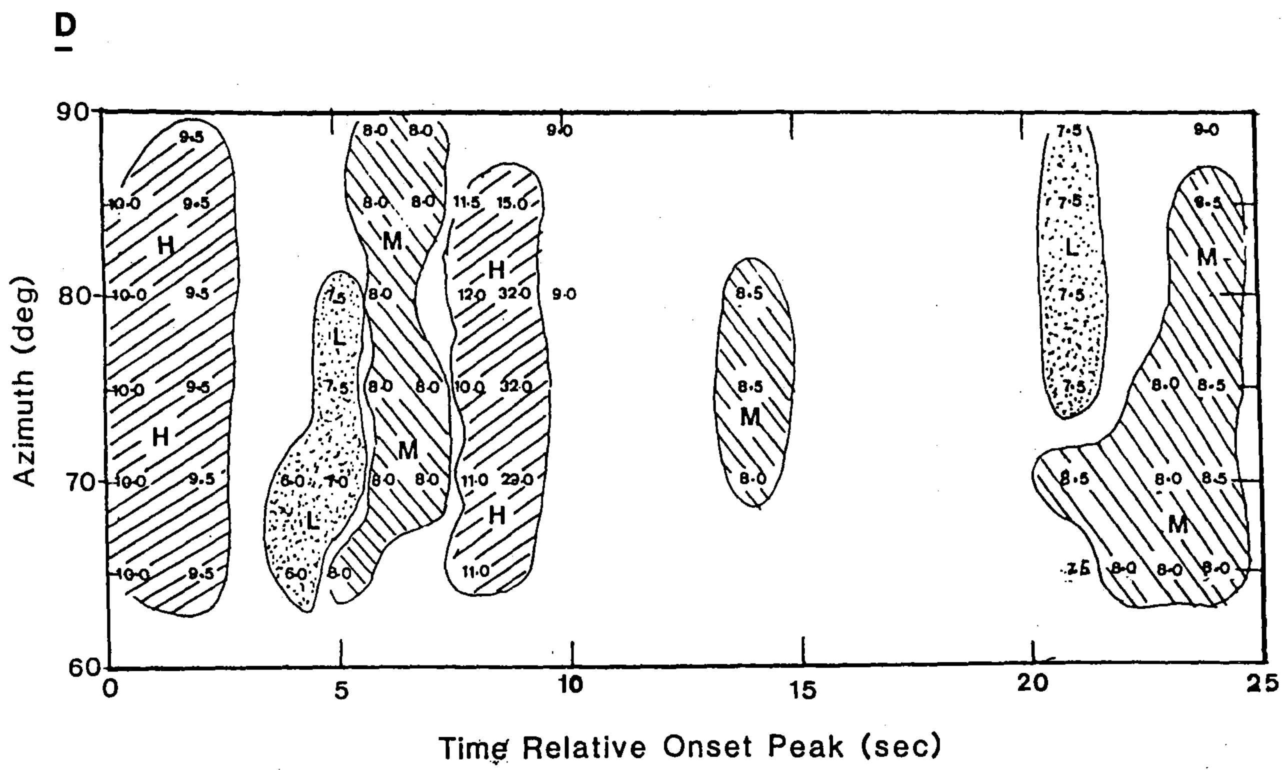
NORESS azi = 79^{o}, vel. 13.8 km/s

Note: Exceptionally clear records

Fig. A: Original, unfiltered records
Fig. B: Probability of P-wave presence; parameter setting extremely restricted so as to exclude secondary arrivals
Fig. C: Particle motion filtered output
Fig. D: Apparent velocity of detected P-wavelets under less severe triggering conditions - time interval 25 sec after first onsets

Comments: Fig. D demonstrates feasiblity of signal coda decomposition; results in good agreement with f-k analysis using all NORESS vertical sensors (Dr. A. Dainty, personal communication).


A
Z 616960
E-W 278272
N-S 62704
B
azimuth (deg)
0
50.0
100.0
150.0
200.0
110.0
120.0
130.0
140.0
150.0
160.0
time (s)
C
Z 185285
E-W 74389
N-S 41090



Velocity analysis as a function of time and azimuth after first P-wave onset of the data for case 4.

CASE 5

Event No. 85060

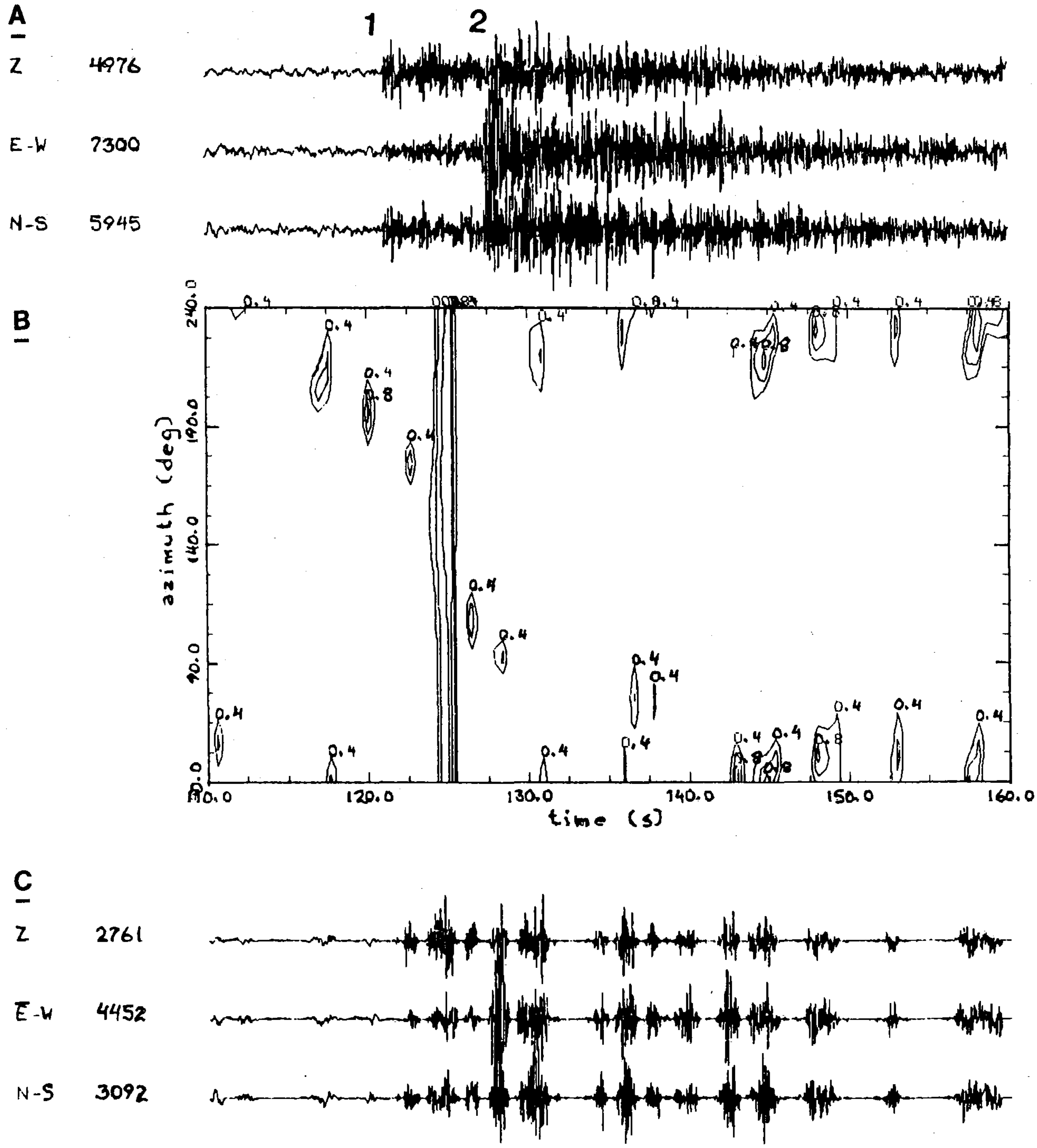
Leningrad event; azi. ~ 87^o, Δ ~ 8.8^o

NORESS: azi. ~ 87^o, vel. = 12.1 km/s

Note: This is actually a double event, the first arriving at approx. 120 sec, azi. ~ 200^o, and "Leningrad" at 127 sec, azi. ~ 90^o. Both seen in the 3-component analyzing results.

Fig. A: Original, unfiltered traces; the two arrival marked 1 and 2, respectively
Fig. B: Probability of P-wave presence
Fig. C: Particle motion filtered output

Comments: Our 3-component analyzing technique appears to have some potential for real-time event detection.


A
1
2
Z 4976
E-W 7300
N-S 5945
B
azimuth (deg)
time (s)
C
Z 2761
E-W 4452
N-S 3092

CASE 6

Event No. 85081

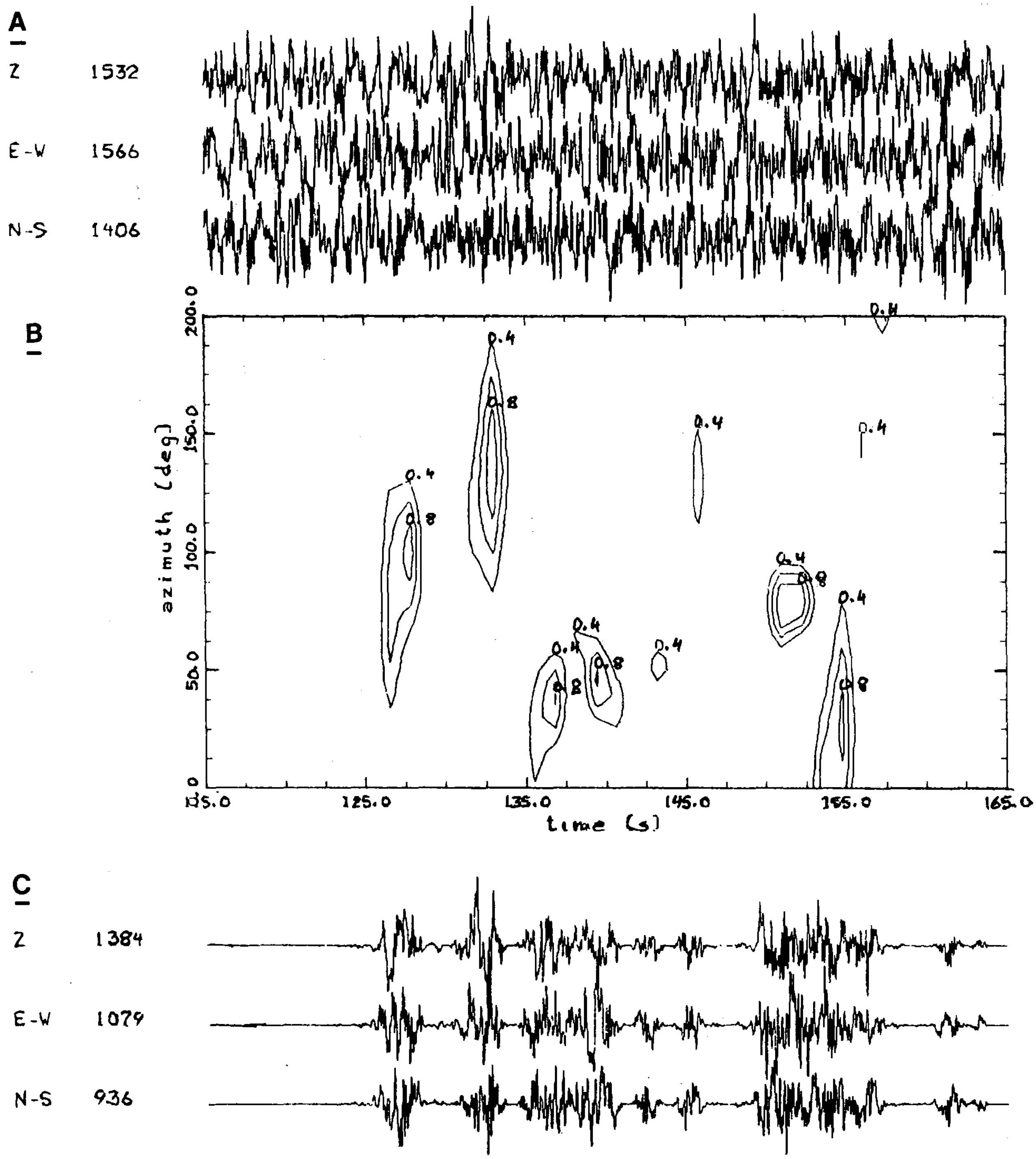
Finnish epicenter location at Finland/USSR Border gives azi. ~ 71°,
Δ ~ 9.8°

NORESS: azi. ~ 90°, vel. = 16.7 km/s

Note: The unfiltered data used in our analysis have exceptionally poor SNR; phase arrival(s) relatively clearly visible in full NORESS record display.

Fig. A: Original, unfiltered data
Fig. B: Probability of P-wave presence
Fig. C: Particle motion filtered record

Comments: P-wave particle motion structure appears to be preserved to some extent even for poor SNRs.


A
Z 1532
E-W 1566
N-S 1406
B
azimuth (deg)
time (s)
0.4
0.8
C
Z 1384
E-W 1079
N-S 936