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6.6 ARCES recordings of events from the Khibiny and Olenegorsk mines

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6.6.1 Introduction

The principal objective of this project is to develop and test a new advanced, automatic approach to seismic detection/location using array processing. Our aim is to obtain significantly improved precision in location of low-magnitude events compared to current automatic approaches, combined with a low false alarm rate. We plan to develop and evaluate a prototype automatic system which uses as a basis regional array processing with fixed, carefully calibrated site-specific parameters in conjunction with improved automatic phase onset time estimation.

The first step is to study the characteristics of selected mining explosions and attempt to identify systematic features of recordings from explosions in the same mine. This paper presents some initial results from the Rasvumchorr and Central mines in the Khibiny Massif, Kola Peninsula, and the five mines in the Olenegorsk group north of the Khibiny Massif.

6.6.2 Compact underground shots from the Rasvumchorr mine in the Khibiny Massif

The initial focus of research will be to develop algorithms for processing of mining events from the northern Fennoscandian region, using the ARCES array. As shown in Figure 6.6.1, there are several active mines in this region.

Since September 2001, an extensive collection of ground truth information on mining explosions in the Kola Peninsula has been conducted on the DoE funded contract entitled “Ground-Truth Collection for Mining Explosions in Northern Fennoscandia and Russia”. Our plan is to use the ground truth events for the one-year time period October 2001 - September 2002 for development and tuning of the algorithms, and to use events after September 2002 for evaluation.

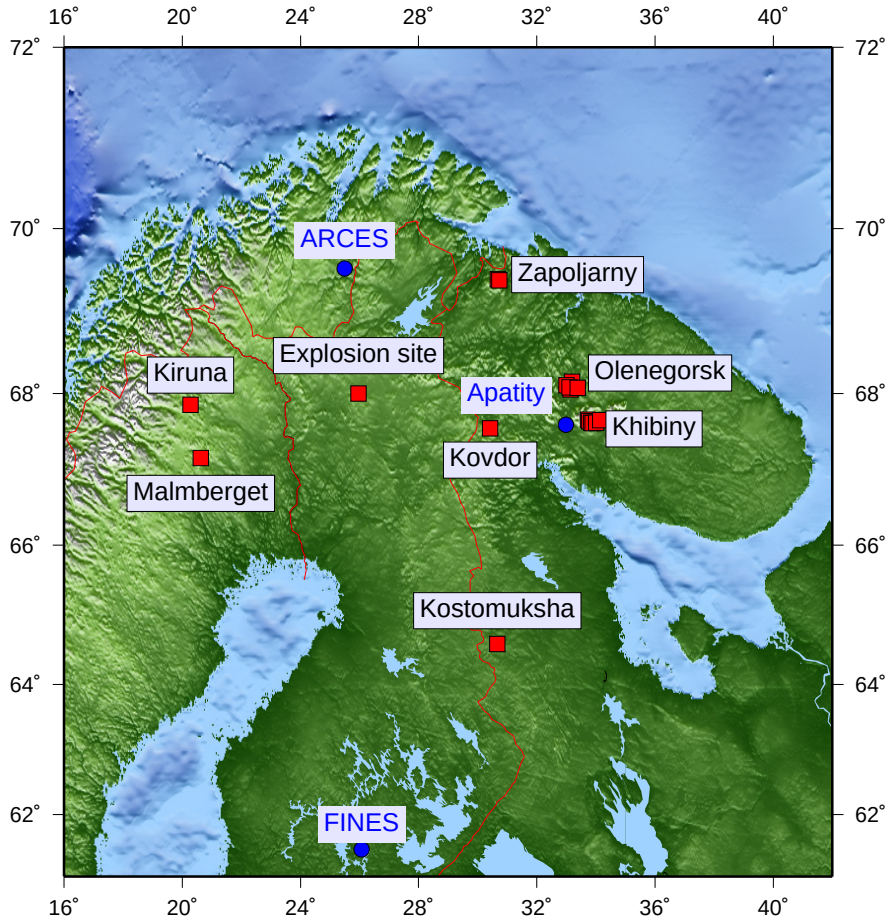

Fig. 6.6.1. *Locations of the main mining regions in NW Russia and Sweden, together with the location of a site regularly used by the Finnish military for destruction of ammunition. Also shown are the locations of the seismic arrays in the region (ARCES, Apatity and FINES).*

We have started to investigate in detail events from the Khibiny and the Olenegorsk mines (see Figure 6.6.2). Ground truth information (Harris et al., 2003) and earlier studies of mining events from this region (Gibbons and Kværna, 2002; Ringdal et al., 2003) have revealed that a wide range of source types are present at these mines. The blasts in the open-pit mines are usually large ripple-fired explosions, often detonated in several groups with some seconds delay. The regular blasts in the Khibiny Massif underground mines usually have yields between 120 and 240 tons with many delays of 20-35 milliseconds. So-called compact shots also detonated in these underground mines. The compact shots have yields between 1 and up to a few tons, having only a few delays, and provide the simplest source type available in these mines. The main purpose of the compact shots is to remove smaller parts of rocks remaining after the main underground explosion.

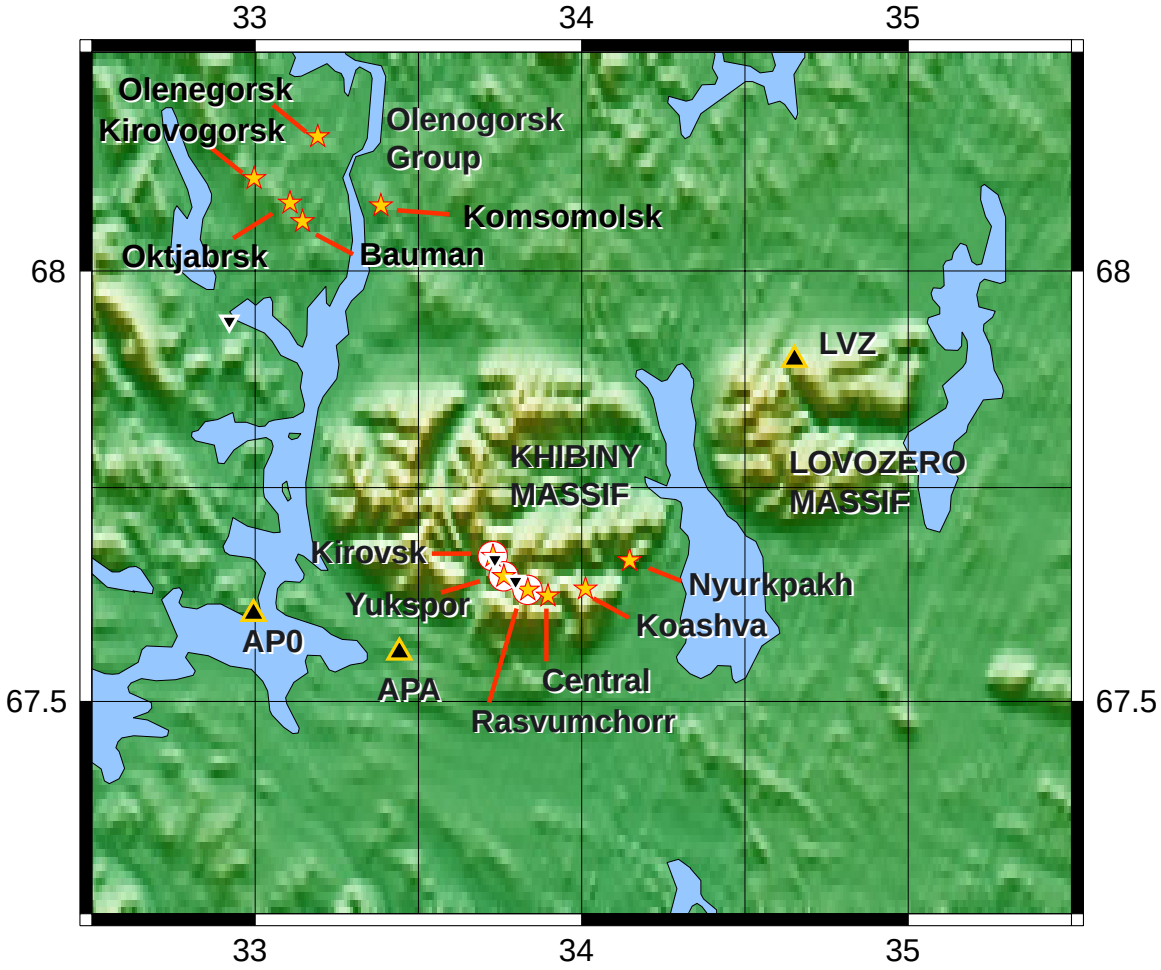

Fig. 6.6.2. *Locations of the mines (stars; circles indicate mines with both underground and surface facilities), permanent stations (triangles) and temporary stations (inverted triangles) in the vicinity of the Khibiny Massif. The five mines in the Olenegorsk group are all open-pit mines.*

In order to get an overview of typical seismograms observed at the ARCES array from explosions in the Khibiny and the Olenegorsk mines, we have taken a closer look at the compact shots from the underground Rasvumchorr mine in the Khibiny Massif. For each of the 99 events in the ground truth database (October 2001 - September 2002), we have calculated the Pn beam, the corresponding semblance coefficient, and the Pn beam weighted with the semblance coefficient. The frequency band used for this analysis was 4 - 8 Hz. The Pn beam was formed using the ARCES center instrument (A0), the C- and D-ring instruments steered with an apparent velocity of 7.5 km/s and a back-azimuth of 121.0 degrees. The semblance coefficients were calculated for 0.5 second window lengths with a 40 Hz sampling rate.

The 15 upper panels of Figure 6.6.3 show the results from semblance analysis of the first 15 events in the ground truth database. The events in the lower three panels are selected to illustrate the more complex signatures found among the ground truth events. The distance from ARCES to the center of the Rasvumchorr mine is 401 km and the back-azimuth is 118.3 degrees.

From these panels we can see that some of the events show a relatively simple source signature, whereas others have longer duration and consist of several pulses, which could be an effect of multiple seismic sources in combination with near-source scattering.

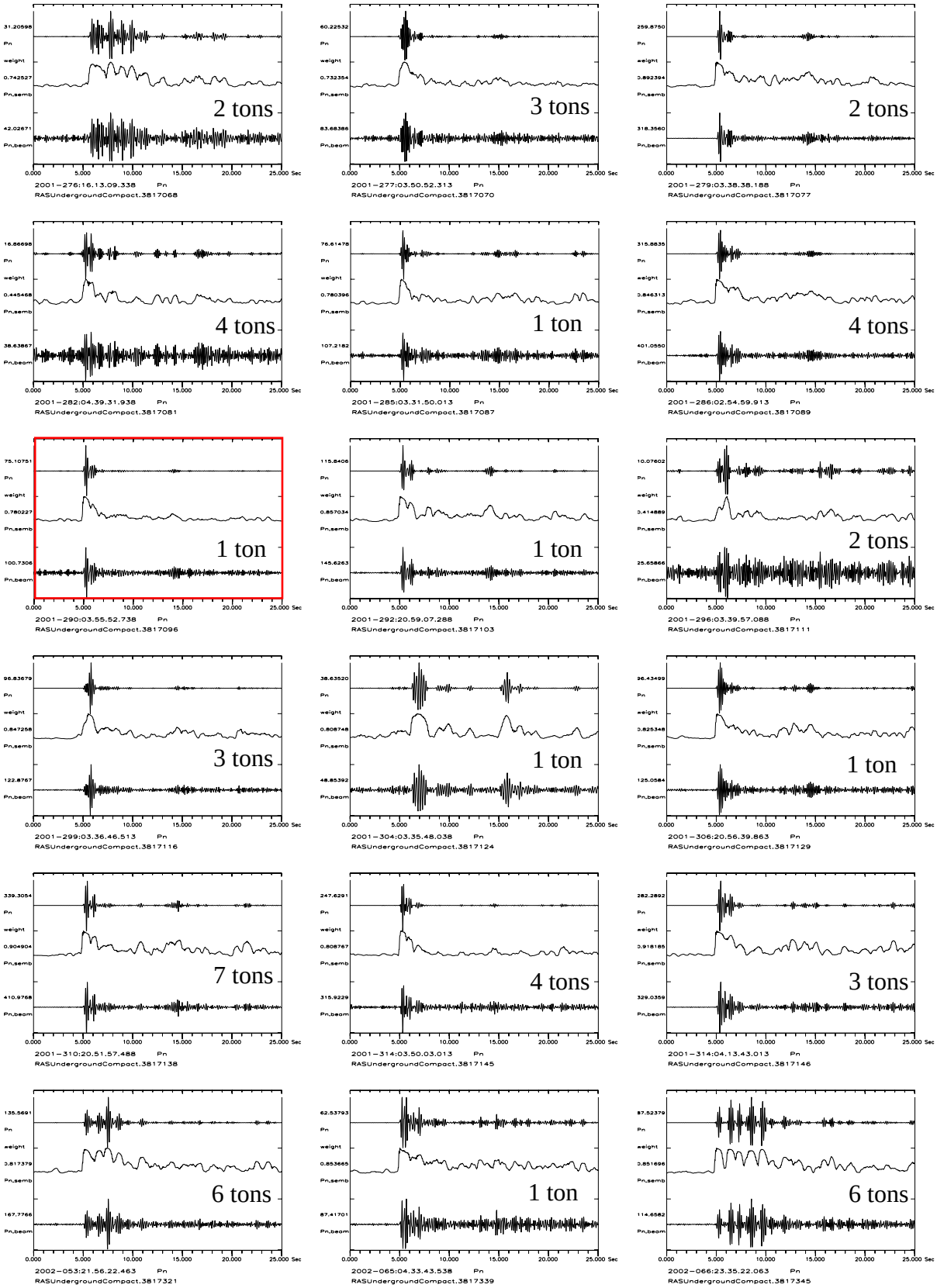

Fig. 6.6.3. *ARCES recordings of 18 compact shots in the underground Rasvumchorr mine in the Khibiny Massif. For each panel we show the 4-8 Hz Pn beam (bottom), the semblance coefficient (middle) and the Pn beam weighted with the semblance coefficient. The yields reported for each event are also given. The highlighted event, which has a relatively simple signature, is also used in Figure 6.6.4 and 6.6.5.*

For further investigating the source and propagation effects of events from the underground Rasvumchorr mine, we have stacked the ARCES Pn semblance coefficients of the 99 events in the ground truth database. The stacked semblance trace is shown on top of Figure 6.6.4, together with an event having among the simplest signatures at ARCES (highlighted red in Figure 6.6.3). We note the close similarity between the stacked trace and the "simple" waveform. In particular, the only secondary arrival on the stacked trace (arriving about 9 seconds after Pn), corresponds to the Pg phase on the "simple" waveform. Also the Pn phases are well correlated. For this frequency band (4-8 Hz), we can conclude that there are no other phases than Pn and Pg, that are expected to be found within this time window for events in this mine.

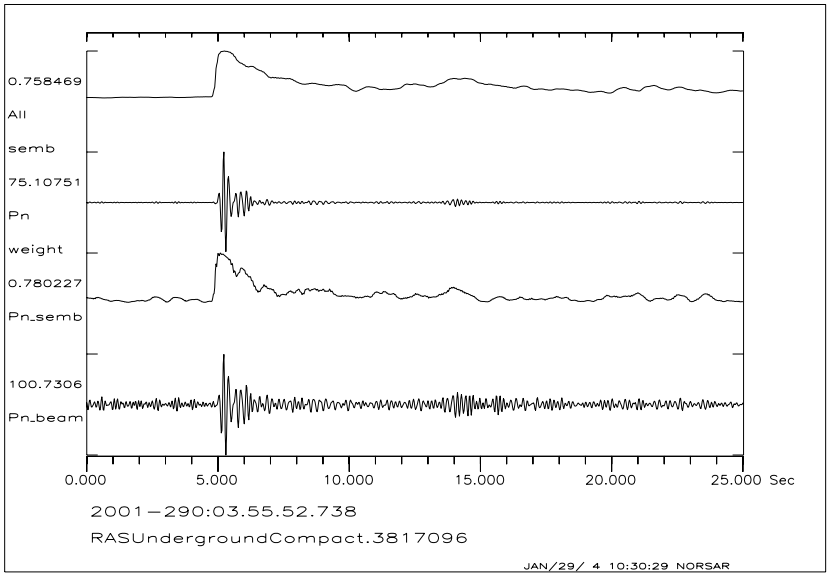

Fig. 6.6.4. *The upper trace shows the stacked ARCES Pn semblance coefficients of the 99 ground truth events of compact underground shots from the Rasvumchorr mine in the Khibiny Massif. For comparison, the three lower traces show the result from semblance analysis of an event having a simple signature at ARCES (highlighted red in Figure 6.6.3).*

Vespagram analysis can be efficiently used to find coherent signals arriving at a seismic array. Figure 6.6.5 show vespagrams in the 4-8 Hz and 2-4 Hz frequency bands for the compact shot displayed in Figure 4. For the 4-8 Hz band we can clearly observe the Pn phase arriving at about 20 seconds, a couple of coherent pulses in the P coda, some coherent Sn energy arriving at about 63 seconds, and some additional signals in the Lg wavetrain arriving at about 75 seconds.

In the 2-4 Hz band the phases Pn, Pg (arriving at about 29 seconds), Sn and Lg can be seen more clearly. The arrival time of these phase are in accordance with the theoretical arrivals of the so-called 'barey' crustal and upper mantle model (Schweitzer and Kennett, 2002).

Based on the overview gained from semblance analysis and visual inspection of ARCES data of 99 compact shots from the underground Rasvumchorr mine, we have found that the vast majority of these events are characterized by a single strong Pn pulse. For these events, it should be possible to detect and characterize the Pn, Pg, Sn and Lg phases at ARCES automatically.

However, for about 25% of the events, there are multiple pulses in the Pn-Pg time window, indicating separate explosions with time delays ranging from 1 and up to several seconds. Consequently, automatic processing of these events will be a more difficult task.

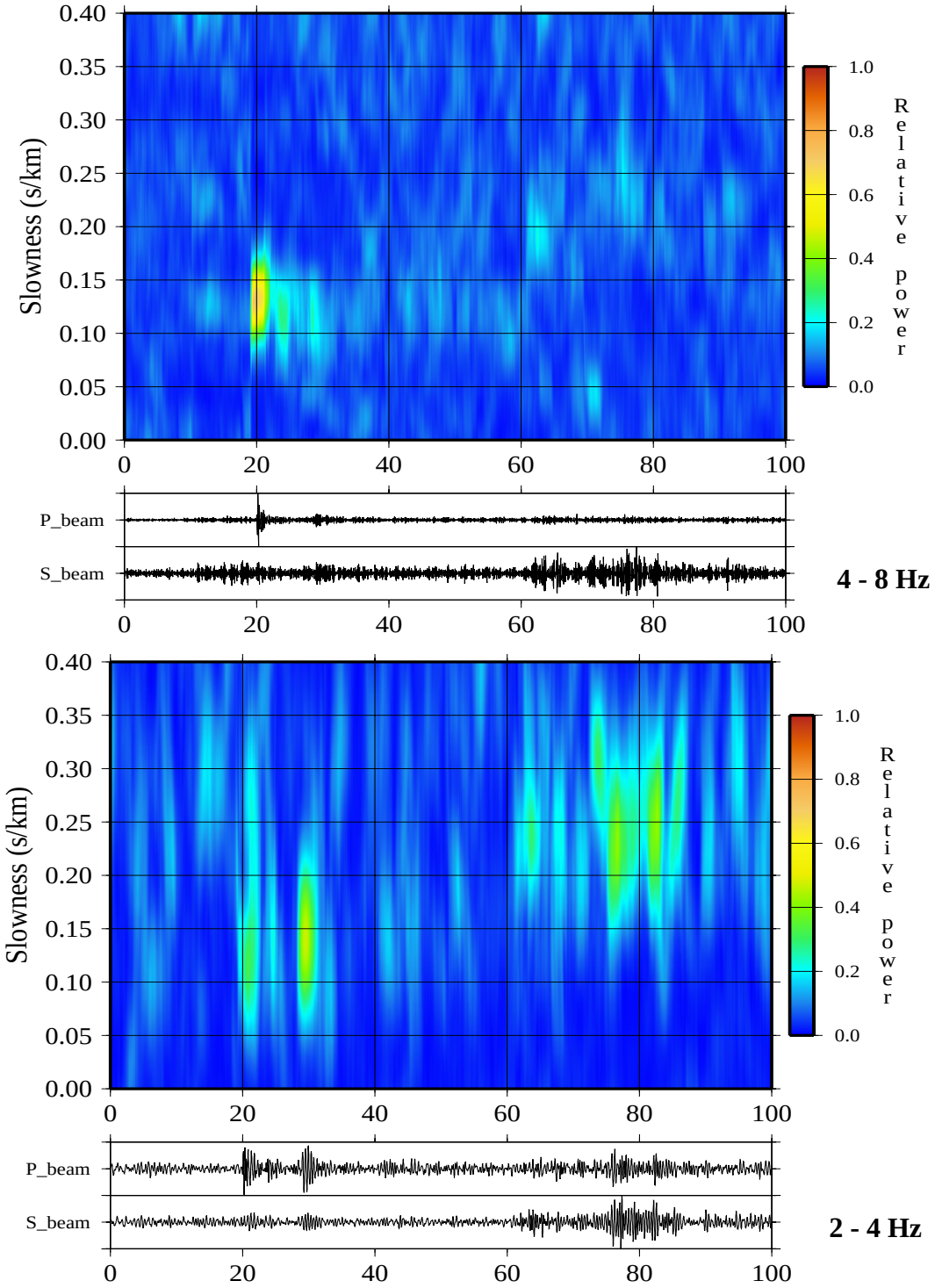

Fig. 6.6.5. *The upper panel shows a 4-8 Hz ARCES vespagram of the Rasvumchorr compact shot shown in Figure 6.6.4. The slowness space is scanned at a back-azimuth of 120 degrees, using a window length of 2 seconds sampled at 0.1 second steps. The ARCES center instrument (A0), the C- and D-ring instruments are used in the calculations. The P beam shown below the vespagram is steered with an apparent velocity of 7.5 km/s, and 4.3 km/s is used for the S beam. The lower panel show similar plots for the 2-4 Hz frequency band.*

6.6.3 Comparisons of ARCES recordings from different mines

We have also made similar semblance calculations for all ground truth events from the Khibiny Central mine (open-pit), as well as for the five open-pit mines in the Olenegorsk group. Panels with such plots are shown in Appendix A-F. In cases when more than 18 ground truth events are available, we show the first 18 events in the database.

The Khibiny Central mine is located very close to the underground Rasvumchorr mine (within 1-3 km), but visual inspection of the semblance plots (Appendix A) indicate quite complex wavetrains at ARCES as compared with the wavetrains from the compact underground shots at the Rasvumchorr mine (see Figure 6.6.3). From visual inspection of the semblance plots we found that more than half of the 48 ground truth Central mine events are multiple explosions with up to several seconds delay between each shot. However, by stacking of the semblance traces from the Central mine events, the random structure caused by differences in the shooting practice is averaged out, and we are left with the common properties for these events. The stacked semblance trace is shown in the upper panel of Figure 6.6.6, where we find that except for the first few seconds after Pn, the curve closely resembles the corresponding curve for the Rasvumchorr events.

The distance from ARCES to the Olenegorsk mines range between 341 and 350 km, spanning the back-azimuth range between 112.8 and 114.5 degrees. These mines are located 50-60 km closer to ARCES than the Khibiny mines. For the Olenegorsk mines (see Appendix B-F) the ARCES waveforms appear even more complex than for the Central mine events, and will be a real challenge for any automatic processing procedure. But again, by stacking of the semblance traces for each mine, the random structure caused by differences in the shooting practice is averaged out. The stacked semblance traces for these mines are shown in the lower five panels of Figure 6.6.6.

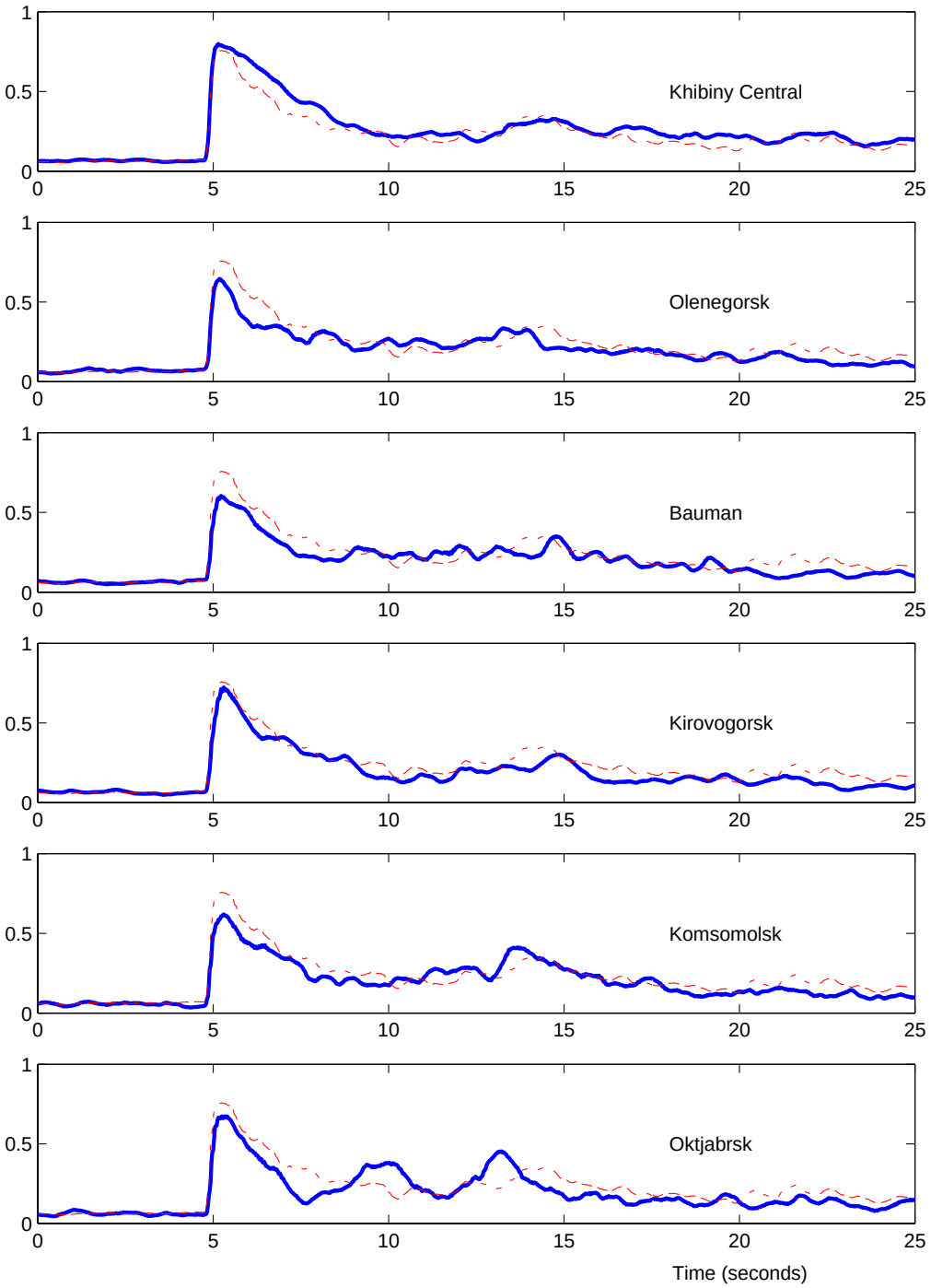

Fig. 6.6.6. *The blue curves show the stacked ARCES Pn semblance coefficients in the 4-8 Hz frequency band for the ground truth events in the Khibiny Central mine (upper trace), and for the mines in the Olenegorsk group (the lower five traces). The dashed red curve shows the stacked semblance coefficients for the compact underground shots in the Rasvumchorr mine.*

References

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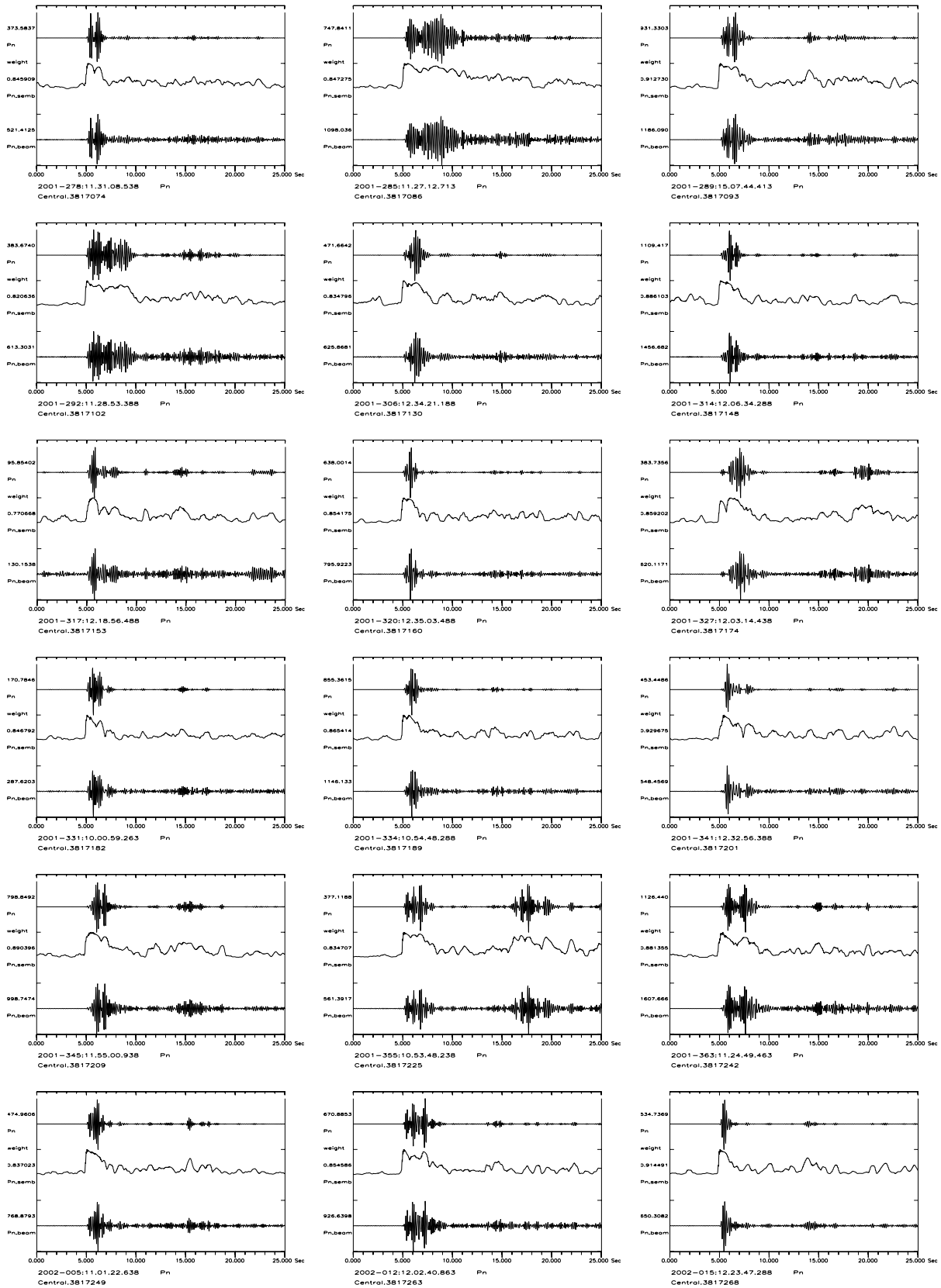
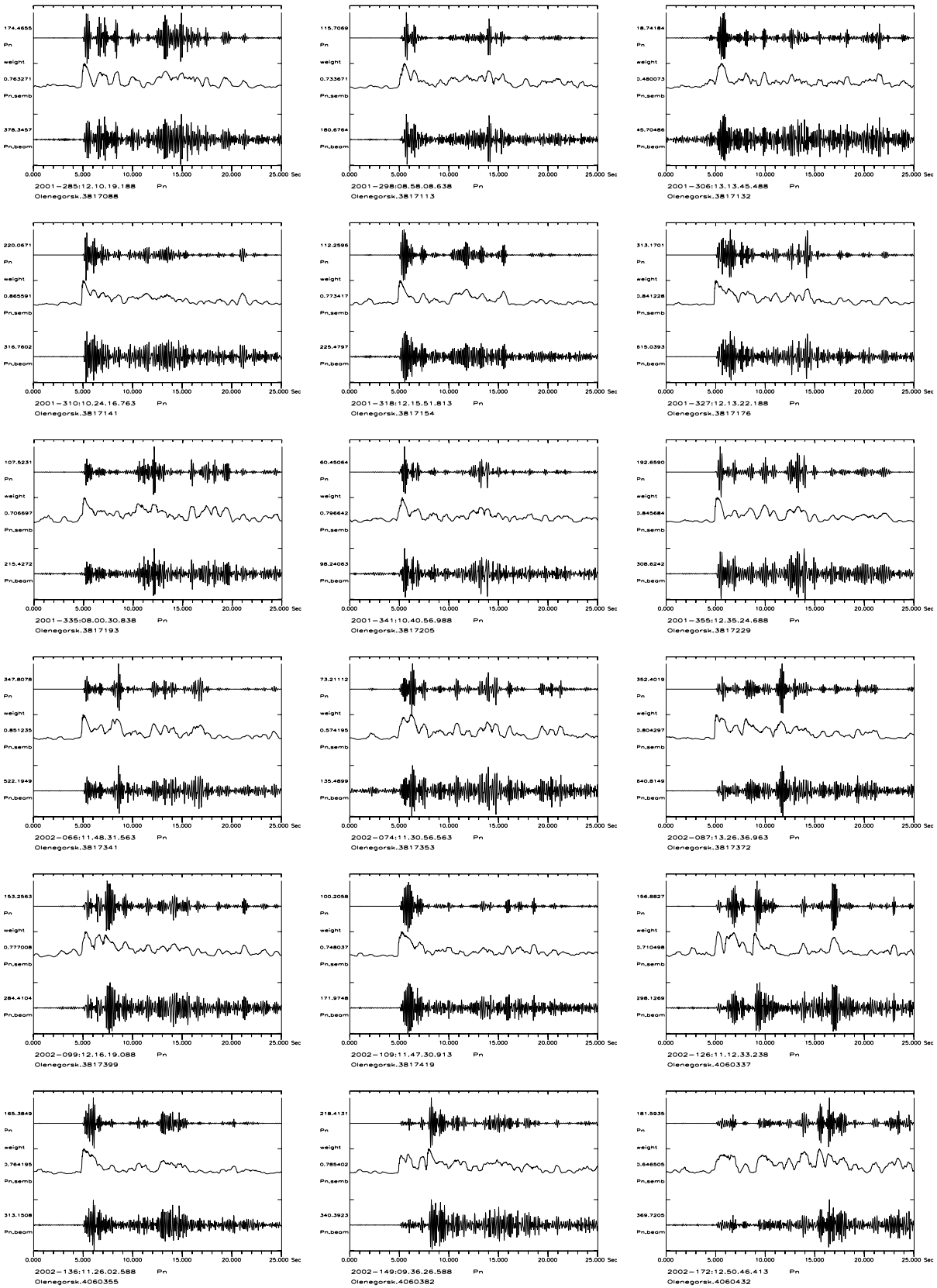
T. Kværna

Appendix A, Semblance analysis of events from the Khibiny Central Mine (4-8 Hz)



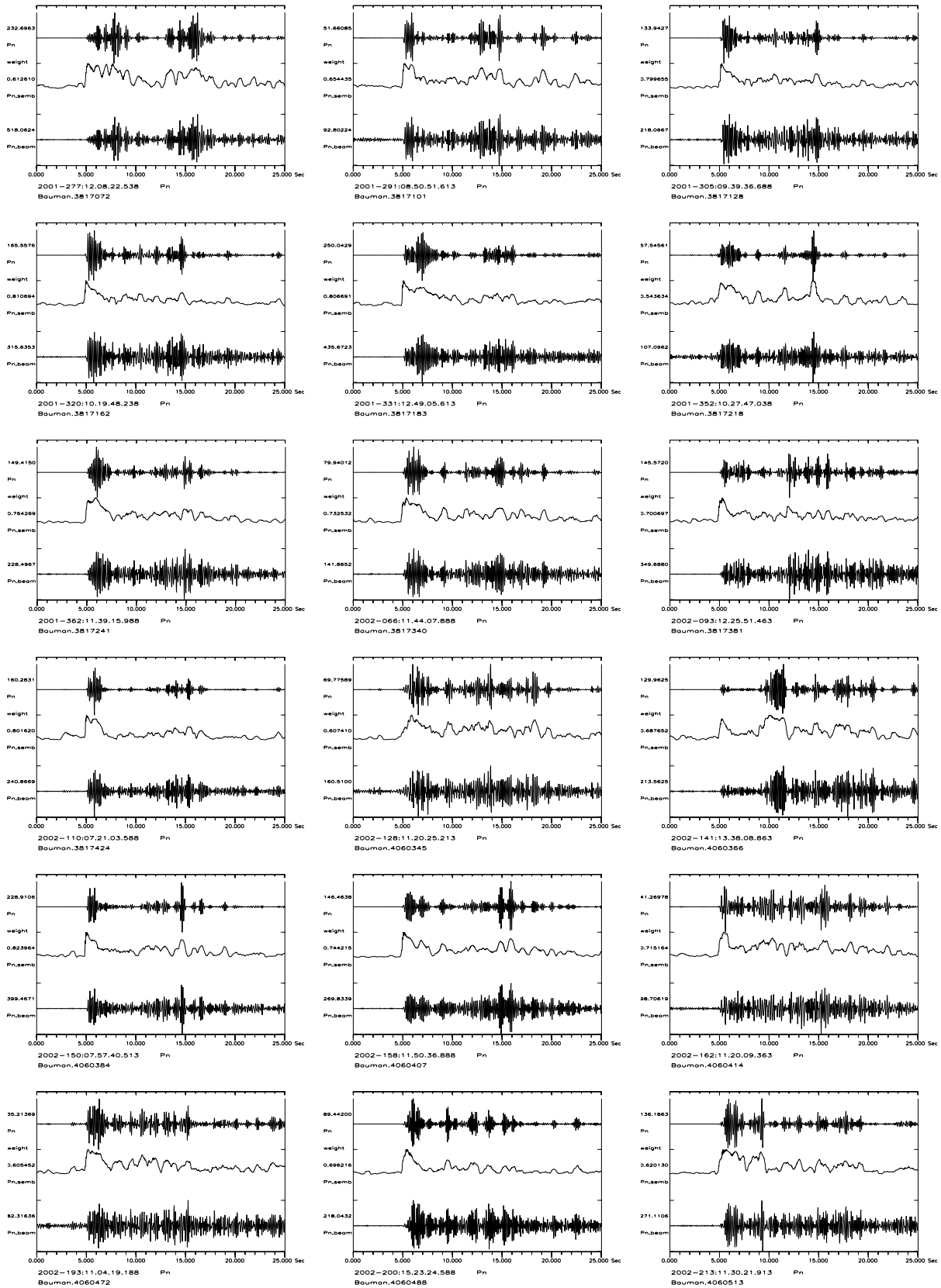
Appendix A. *ARCES recordings of 18 explosions in the Central open-pit mine in the Khibiny Massif. For each panel we show the Pn beam (bottom), the semblance coefficient (middle) and the Pn beam weighted with the semblance coefficient.*

Appendix B, Semblance analysis of events from the Olenegorsk Mine (4-8 Hz)



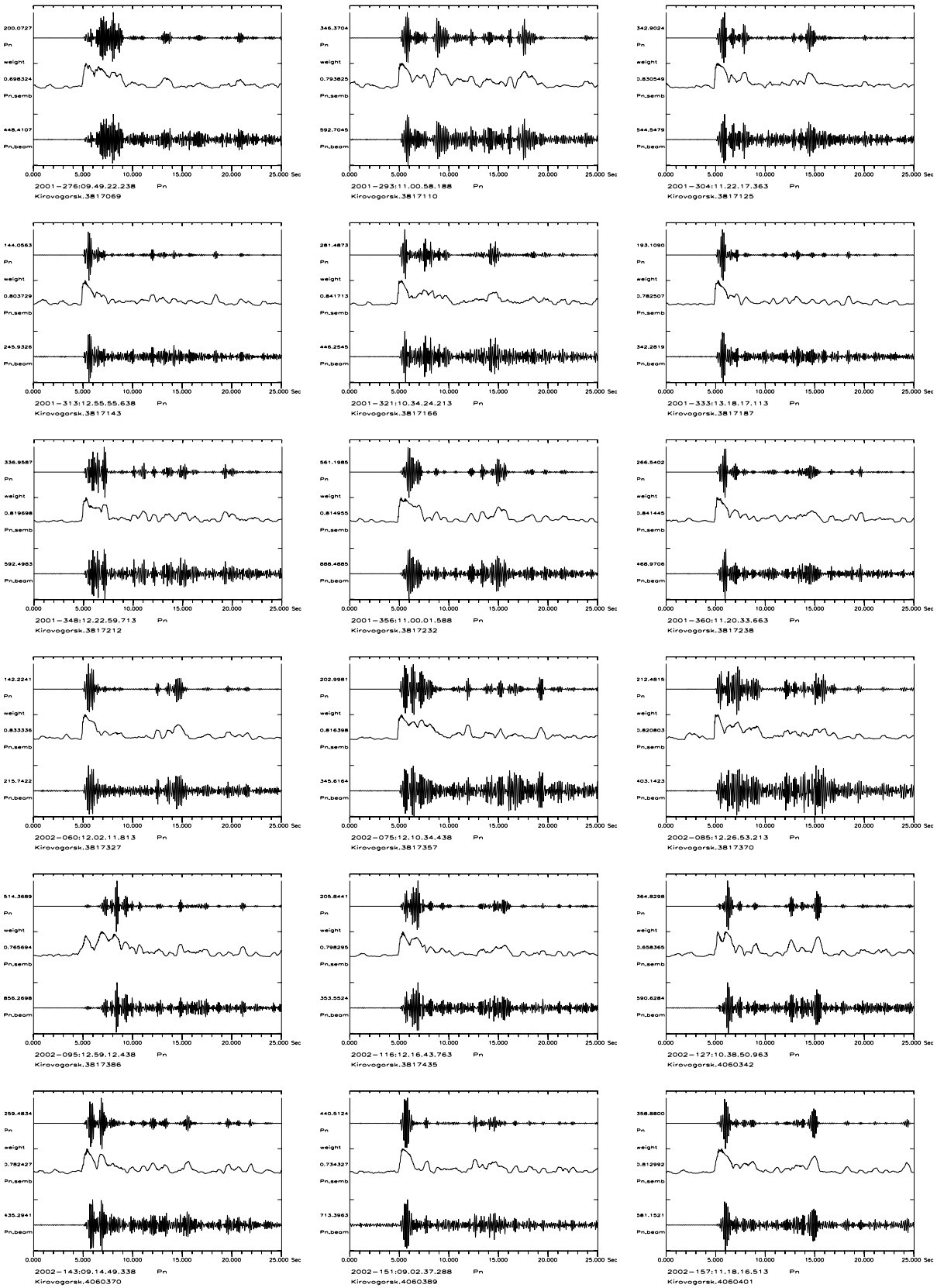
Appendix B. *ARCES recordings of 18 explosions in the Olenegorsk open-pit mine. For each panel we show the Pn beam (bottom), the semblance coefficient (middle) and the Pn beam weighted with the semblance coefficient.*

Appendix C, Semblance analysis of events from the Bauman Mine (4-8 Hz)



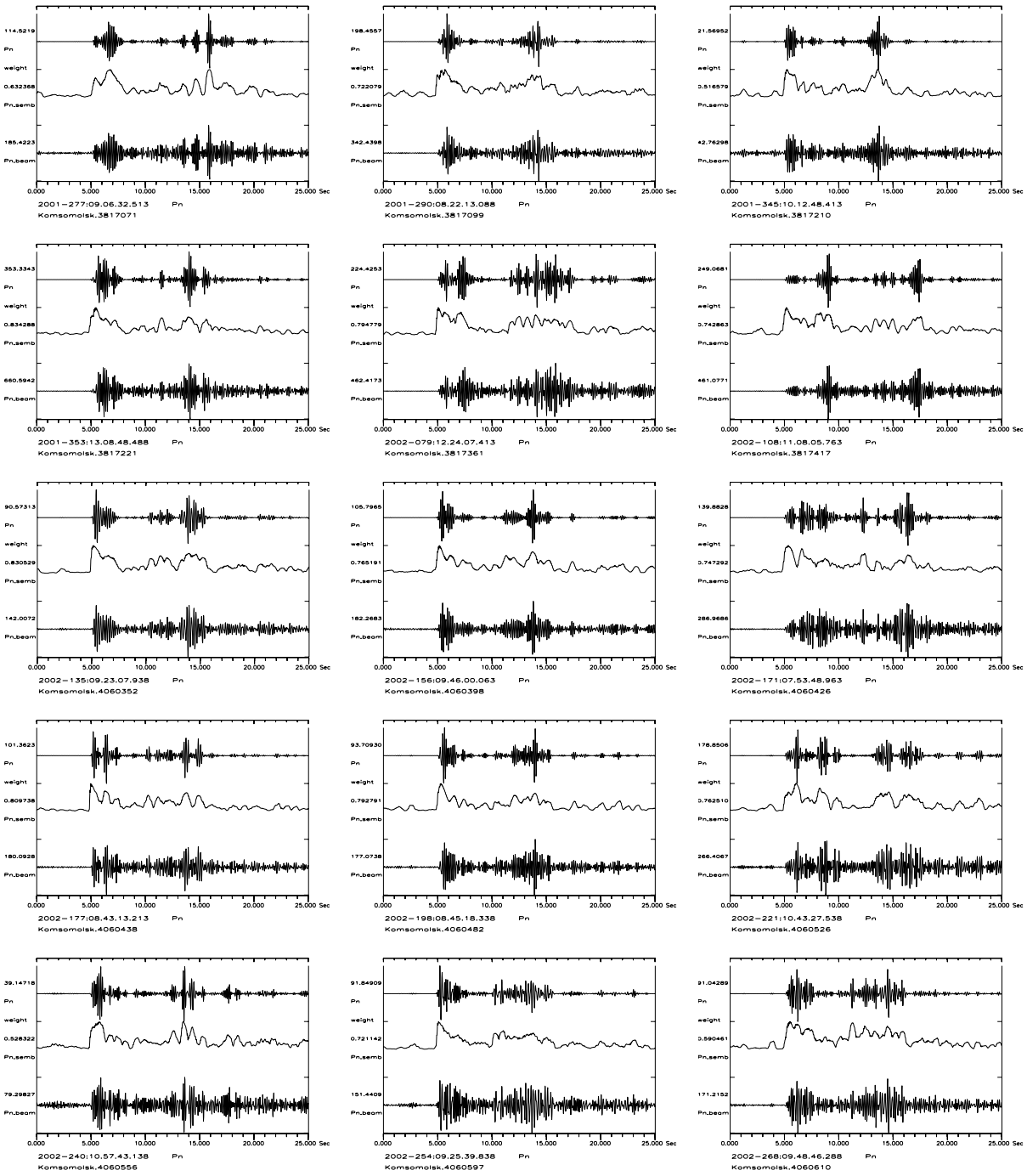
Appendix C. *ARCES recordings of 18 explosions in the Bauman open-pit mine. For each panel we show the Pn beam (bottom), the semblance coefficient (middle) and the Pn beam weighted with the semblance coefficient.*

Appendix D, Semblance analysis of events from the Kirovogorsk Mine (4-8 Hz)



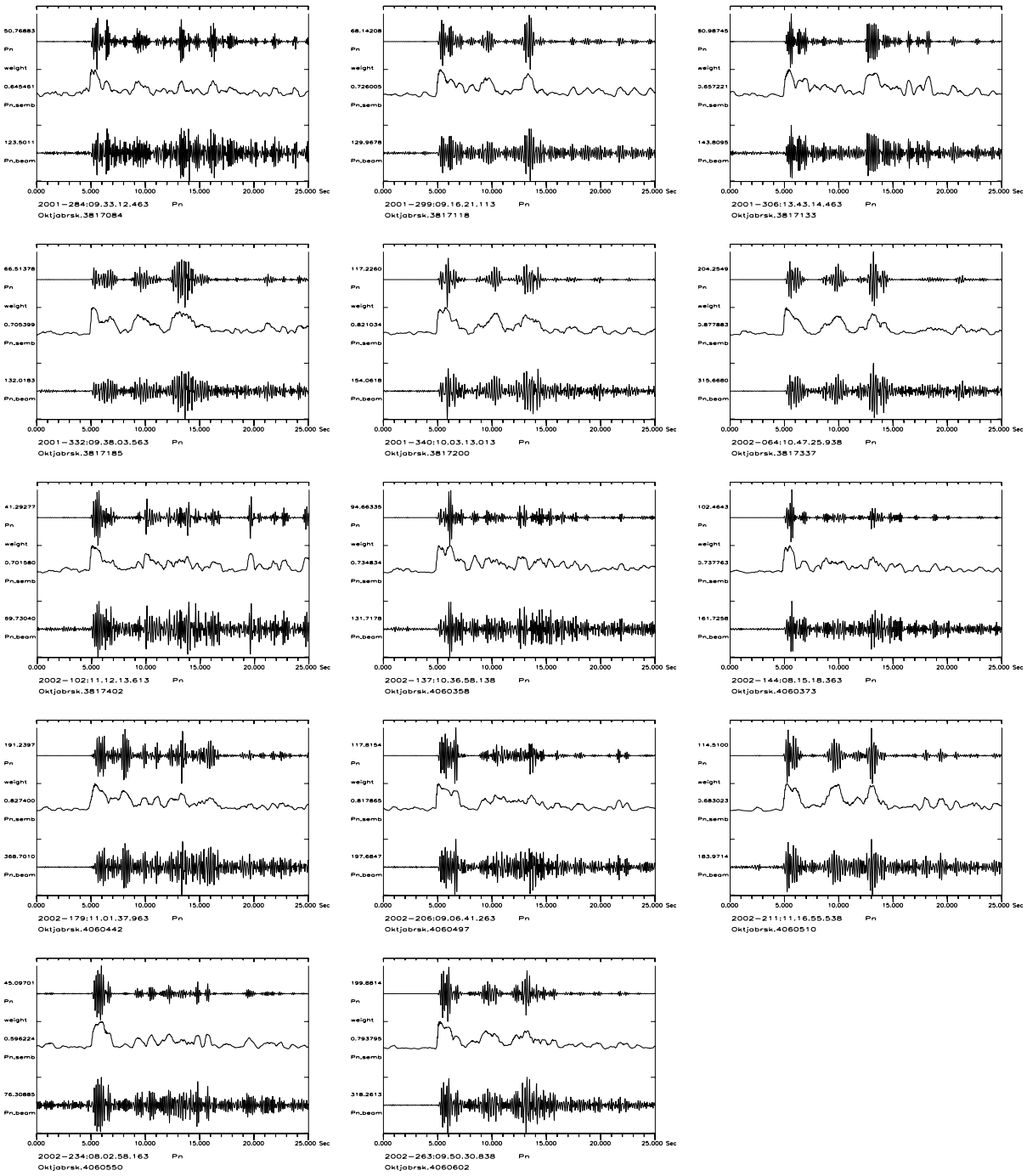
Appendix D. *ARCES recordings of 18 explosions in the Kirovogorsk open-pit mine. For each panel we show the Pn beam (bottom), the semblance coefficient (middle) and the Pn beam weighted with the semblance coefficient.*

Appendix E, Semblance analysis of events from the Komsomolsk Mine (4-8 Hz)



Appendix E. *ARCES recordings of 15 explosions in the Komsomolsk open-pit mine. For each panel we show the Pn beam (bottom), the semblance coefficient (middle) and the Pn beam weighted with the semblance coefficient.*

Appendix F, Semblance analysis of events from the Oktjabrsk Mine (4-8 Hz)



Appendix F. *ARCES recordings of 14 explosions in the Oktjabrsk open-pit mine. For each panel we show the Pn beam (bottom), the semblance coefficient (middle) and the Pn beam weighted with the semblance coefficient.*