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Report on detection and cross-correlation of quarry blasts and receiver functions

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1. INTRODUCTION

The purpose of this work consists in investigating the applicability of continuous monitoring for the purpose of detecting any possible variations in seismic wave velocity. The motivation of the approach is the dilatancy effect well investigated and fully documented in the literature by Crampin and colleagues (see references). The interpretations of the effect due to dilatancy is various (Crampin & Lowell, 1991). One interpretation assumes existing cracks in the fault zone that are filled by fluid, which are aligned due to the effect of local stress field. In this interpretation the angle of alignment is parallel to the direction of maximum stress, which is assumed to be horizontal in seismogenic crustal zones. This interpretation is referred as Extensive-Dilatancy Anisotropy model (EDA; see Crampin, 1978). The second interpretation relates the anisotropy to the intrinsic properties of the anisotropic material and therefore the direction of maximum velocity is independent of the stress conditions (Zinke & Zoback 2000). In this work the first model is assumed to be valid for the area under study.

2. METHOD

The primary goal in this study is not to reveal in full details the properties of the anisotropy in the fault zone in terms direction, amplitude, and local variations, although detailed work is already done in this direction (Eken et al, 2013). Instead, in situ variation of the seismic properties are expected to be monitored on a real time basis, in order to detect any significant changes in travel time properties of either P or S wave propagation. Many existing model of fracture mechanics assumes a rapid modifications of physical conditions of the fault zone prior to the final failure. These variations may be expected to be observed if sensitive measurements can be carried out at very close distances to the fault zones. Our goal in this study is directly linked to these expectations.

Our study is based on data provided by the PIREs Network (Prince Islands Realtime Earthquake Monitoring System) installed and operated by a cooperation of Bogazici University - Kandilli Observatory Earthquake Research Institute (KOERI) and GFZ (Germany). The PIREs (Prince Islands Realtime Earthquake Monitoring System) is an array of seismographs installed at the closest land site to the Marmara Fault Zone, namely on the Princes Islands . Two 5-seismograph seismic arrays are deployed on the two outermost Princes Islands, Sivriada and Yassiada, offshore İstanbul at only 3 km distance to the inferred Cinarcik Fault. Additional 6 stations are also installed on other islands thus enabling a very detailed monitoring of the western part of the Cinarcik Segment of the Marmara Fault. Two stations have broadband sensors while all the rest includes 3-D short period seismometers. Data is sampled at 500 Hz and realtime transmitted to the MARSITE Data Center since 2013.

Our major assumption is that since the seismic stations are located very close to the fault zone (within 3-5 km) it is expected that incoming waves cross the fault zones and therefore have the potential of carrying information related to the dilatancy effect. It is therefore expected that if any given seismic source is monitored throughout time, one can expect that any variations of phase arrivals can be directly explained by a variation of the seismic properties of the propagation medium, namely the fault zone. In this context the main difficulty is to find a unique seismic source that provides sufficient energy to monitor any possible variations of the phase arrivals over an extended period of time covering years, even decades.

In this work we have tested two types of seismic sources: the local quarry blasts and the teleseismic events. Both types of sources provides waves that travels close to the fault zones before being recorded at the PIREs stations. Both types of sources have both advantages and drawbacks of its own, and these are going to be discussed in the sequel.

3. QUARRY BLASTS

The quarry blasts that are recorded at the PIRES arrays are originated from different sources that are distributed at various azimuths and distances (see Figure 1). The location and timing of the quarry blasts are provided by UDIM (Kandilli Observatory Earthquake Research Institute, National Earthquake Monitoring Center). The locations are in general distributed around four main clusters: the Uskumrukoy quarries (most northern close to Black Sea coast), the Sultangazi quarries (the most western sources, close to Istanbul metropolitan area), Cekmekoy quarries (east of Bosphorus, on the Asian side), and the Gemlik quarries (south of the Marmara Fault, east Gemlik Bay). We have investigated all of these clusters.

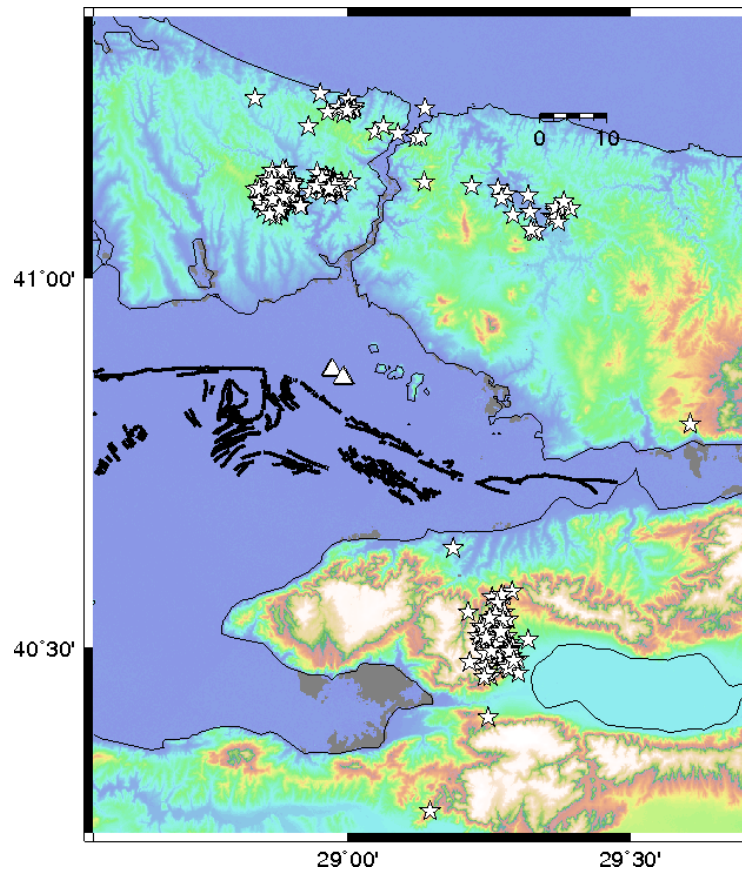


Figure 1 Location of quarry blasts (shown with white stars) around the Cinarcik Basin. The location and timing of the quarry blasts are provided by UDIM (Kandilli Observatory Earthquake Research Institute, National Earthquake Monitoring Center) based on conventional earthquake location procedures. The PIRES arrays (shown by single star on each island) at Sivriada and Yassiada. The locations of blasts are in general distributed around four main clusters: The Uskumrukoy quarries (most northern close to Black Sea coast), the Sultangazi quarries (close to Istanbul metropolitan area), Cekmekoy quarries (East of Bosphorus, on Asian side), and the Gemlik quarries (south of the Marmara Fault, east Gemlik Bay). The fault traces are taken from LePichon et al (2001).

We have first noticed that although the location of quarries were distributed over an expanded area the real situation was different. The source scattering is due to the indiscrepancies in hypocenter locations. This is to be expected since the signal from these sources are not recorded at far distances and at many stations, therefore the locations are subject to some error. In reality the number of quarries that provide these large blasts are quite few in numbers. This fact is verified by an inspection of satellite imagery trough Google Earth. In future we expect to investigate this issue more deeply on site, in order to determine which quarries are the ones providing these largest blasts. Nevertheless, we have selected in our analysis only blasts from the quarries that are located within a close distance to each other. We have carried out a finer analysis on the selected blasts from Sultangazi and Cekmekoy quarries. We have restricted the analysis only to the array stations located on the Sivriada and Yassiada Islands. Since the arrays on each islands have stations that are separated by about 200 m from each other, there is a possibility of stacking neighbouring stations which is expected to reduce the noise considerably and therefore improve the accuracy.

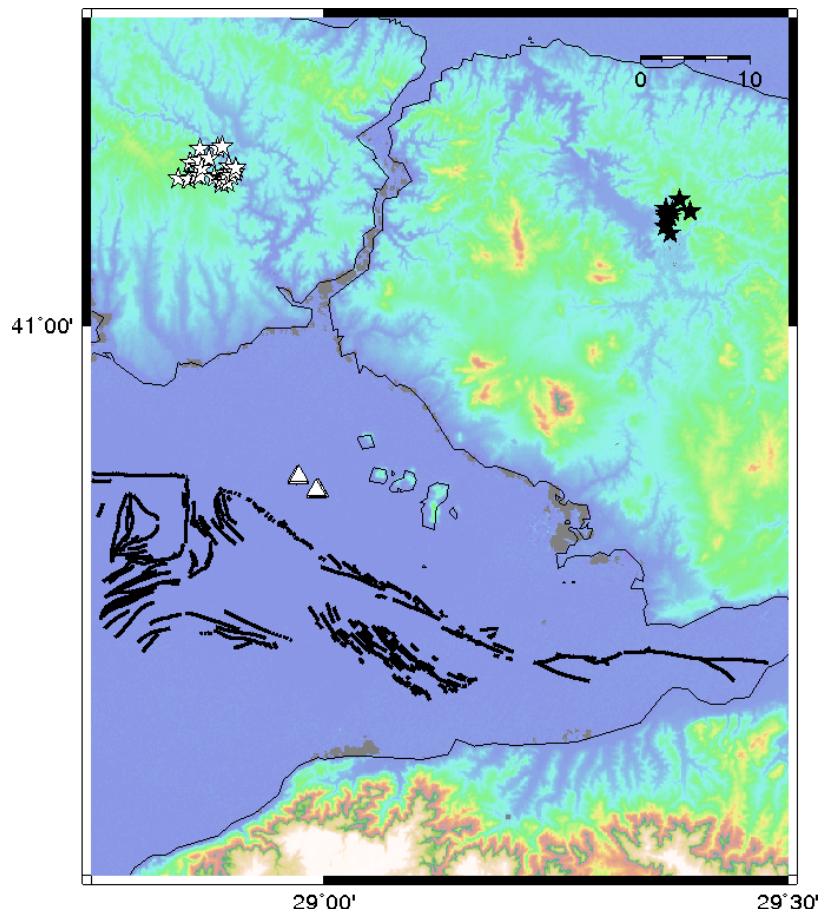


Figure 2 Location of quarry blasts (Sultangazi quarries :white stars, Cekmekoy quarries: black stars) on the north the Cinarcik Basin. The location and timing of the quarry blasts are provided by UDIM (Kandilli Observatory Earthquake Research Institute, National Earthquake Monitoring Center). The PIREs arrays at Sivriada and Yassiada are shown by single star each. The fault traces are taken from LePichon et al (2001).

A total of 243 blasts were recorded from Sultangazi Source area during the year Of 2013. The source area is located at a distance of 25 km from the PIREs arrays at an azimuth of 310° . This is closest of all sources and expected to provide the best SNR. Although the locations are scattered within an circle of 3.5 km of radius, in reality the quarries are located within a distance of 1-1.5 km within each other. Furthermore we have the impression that the largest blasts are originated from only a single quarry. The waveforms recorded at one the stations on Sivriada, namely POWD, are displayed in Figure 3. Starting time of the window correspond to the blasting time as estimated from the hypocenter determination process. The total time window corresponds to a duration of 30 second. It is not possible to detect any significant feature from this figure where waveforms are squeezed to a narrow amplitude. The P-wave arrivals are observed at about 6 sec from the start of the data window which roughly corresponds to the travel time from the source. We observe that there is a roughly observable second arrival, at about 4.5 second from the first arrival. This second arrival is likely to corresponds to either the S-arrival or to a reflection from the basin boundary which is roughly 5 km from the recording site. Theoretically speaking, we should not expect any S wave generation from a blasting source since it is mainly composed of isotropic component, and has no deviatoric part. Therefore a reflection from the basin boundary is also a strongly valid explanation. This issue is at the moment being investigated in more detail.

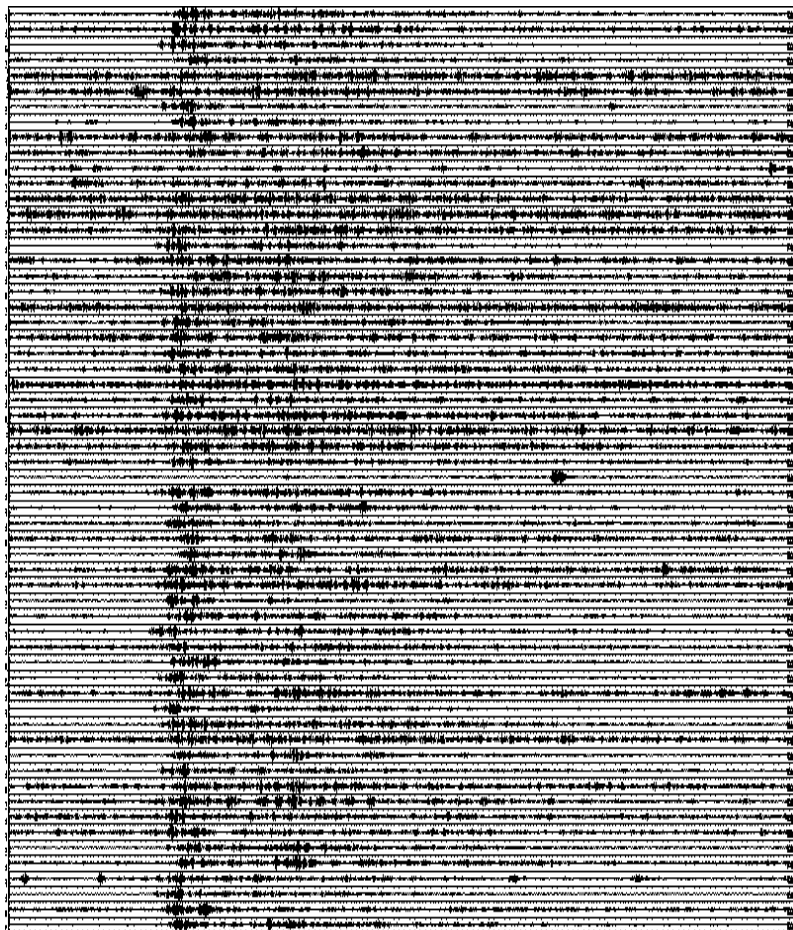


Figure 3 Waveforms recorded at POWD (Sivriada) for of quarry blasts of Sultangazi during the year 2013. The waveforms are of 30 second in length, starts at the time of blasting as estimated by UDIM.

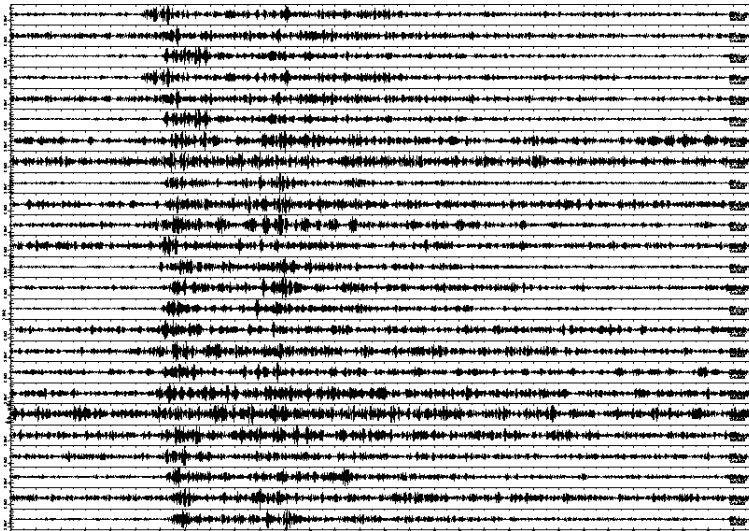


Figure 4 A selection waveforms recorded at POWD (Sivriada) for of quarry blasts of Sultangazi during the year 2013. The waveforms are of 30 second in length, starts at the time of blasting as estimated by UDIM. The first arrival occurs at about 6 s while a second arrival seem to be located at 10.3 s. The misalignment of the P-arrivals is due to the discrepancies in blast time estimations which are done using conventional earthquake locations procedures. The second arrival is better aligned which remains to be explained.

Figure 4 gives a selection of quarry blasts that are recorded at POWD (Sivriada) and originate from Sultangazi quarry. The waveforms are aligned with respect to time of blasts again as estimated using conventional earthquake location procedures. We note that the second arrivals are better aligned as compared to the first arrivals, which is a point to be investigated in the future works. We have cross-correlated the waveforms in order to detect if a reflection from basin boundary exist. We have not detected any secondary pulse, which weakens the reflection argument. We are also going to investigate other stations at different distances from the quarries, to see if the time difference between first and second arrival varies with to distance which will demonstrate that it corresponds to a shear energy produced at the source. The final approach will be to investigate particle displacements. However since the waveforms amplitudes are small and SNR is high, we do not expect a decisive contribution from this last analysis.

Figure 5 gives another selection of quarry blasts from Cekmekoy, recorded at station PIER on Yassiada which is the closest to the source location. We note that there is a strong emphasis on the second arrival on both three components, which strong asserts that it corresponds to a shear energy production at the source site. This observation is contradictory of what we know from the general modeling of explosive sources. However it will be a useful tool for investigating the dilatency effect since the final analysis will only be reduced to monitor the P-S arrival difference in a accurate manner. Note also the third arrival is observed on all records, at about 12 sec from the first P-arrival, which is an issue remains to be analyzed in the future.

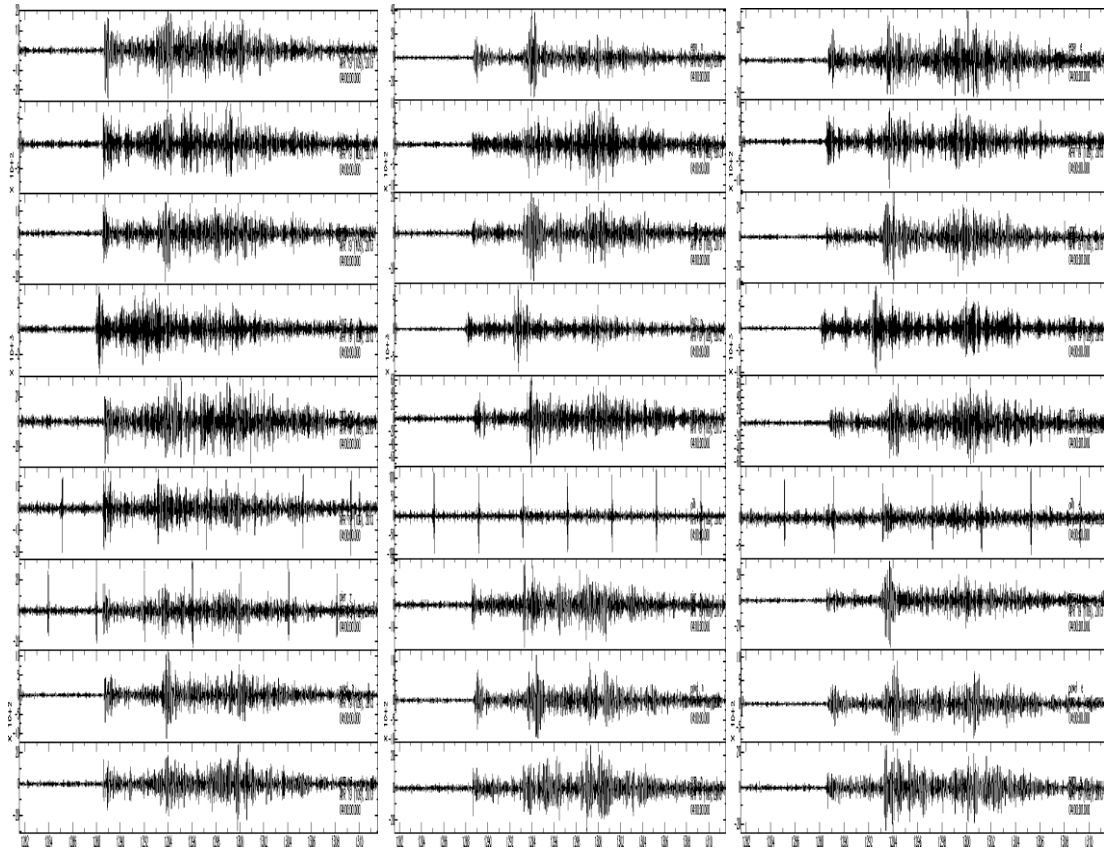


Figure 5 A selection waveforms recorded at PIER (Yasiada) for of quarry blasts of Cekmekoy during the year 2013. The vertical, EW, NS, components are aligned from left to right, respectively. The waveforms are of 30 second in length, starts at the time of blasting as estimated by UDIM. The first arrival occurs at about 6 s while other arrivals are observed at 10.3 s and 18 s. The first and second arrivals are much better aligned as compared to Sultangazi case.

We have also analyzed the blasts from the southern side of the Marmara Fault namely those from Iznik-Gemlik quarries. The vertical components of 18 blasts are displayed in Figure 6. Surprisingly we note that for all explosive sources coming from the southern side we do not observe the second arrival as in the case of northern blasts. This may be due to the strong attenuation of S-waves as it crosses the deep unconsolidated sediments of the Cinarcik Basin. On the other hand, this may also supports the idea that the second arrivals on the northern blasts may actually correspond to reflections from basin boundaries.

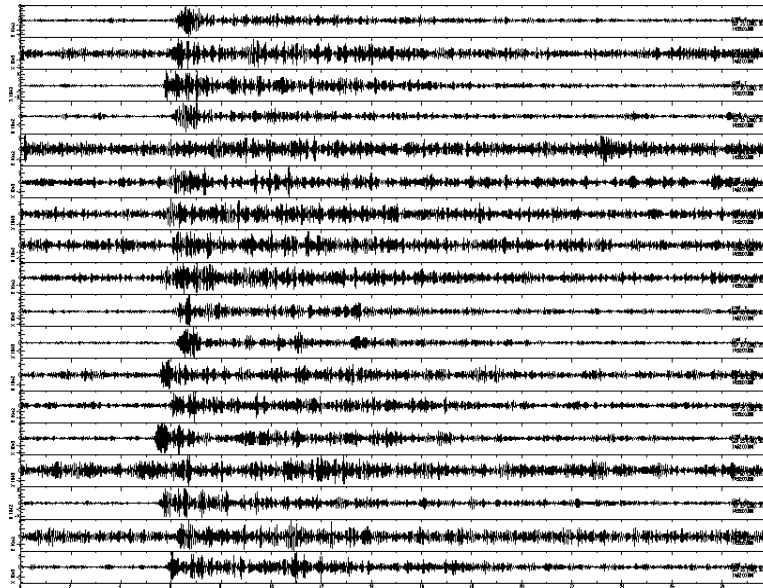


Figure 6 A selection waveforms recorded at POWD (Sivriada) for of quarry blasts of Gemlik-Iznik quarries, during the year 2013. The vertical, EW, NS, components are aligned from left to right. The waveforms are of 30 second in length, start at the time of blasting as estimated by UDIM. The first arrival occurs at about 6 s while other arrivals are not clearly observed as in the case of northern blasts.

4.RECEIVER FUNCTIONS FROM TELESEISMIC EVENTS

The receiver function analysis of the waveforms are considered to be at initial stages. The waveforms recorded during the year of 2013 which corresponds to the first year of the MARSITE Project are not complete. This is due to the fact that during the first year of the project the network were upgraded to real time data transmission and for a considerable time data were not recorded efficiently and were often lost. For a accurate analysis a more complete data set is required which in turn necessitates a longer observation period. We have still carried out some preliminary analysis on data recorded on earlier periods. A selection of P receiver functions on PIER (Yassiyada) is displayed in Figure 6. On the right hand side of the figure the dotted line shows the variation of the azimuth that the teleseismic event is originated. We observe that the majority of events are produced by eastern seismogenic zones, namely Japan and Sumatra. This is in a sense an advantage in our situation, since the wave arriving from east and in particular from Sumatra Zone sample well the Cinarcik fault zone. We observe a clear PS conversion at 4.5 second as often seen in many of the eastern Marmara stations. We note that the conversion arrival is well distinguished above the noise and is not much influenced by the azimuth change in particular for the eastern events. This observation clearly supports the idea of using teleseismic events for the purpose of monitoring S-wave velocity variations. A drawback of the receiver function approach for the S-velocity monitoring is the fact that the dilatency variations would be of the order of tents of millisecond while the frequency band of receiver functions are of the order of one seconds. We plan to improve on sensitivity by stacking events from various stations within the one array. We also plan to use cross correlation techniques for comparing converted time arrivals. Oversampling techniques will also be used to improve the resolution. It is however clear that sufficient number of waveforms are available before applying such techniques.

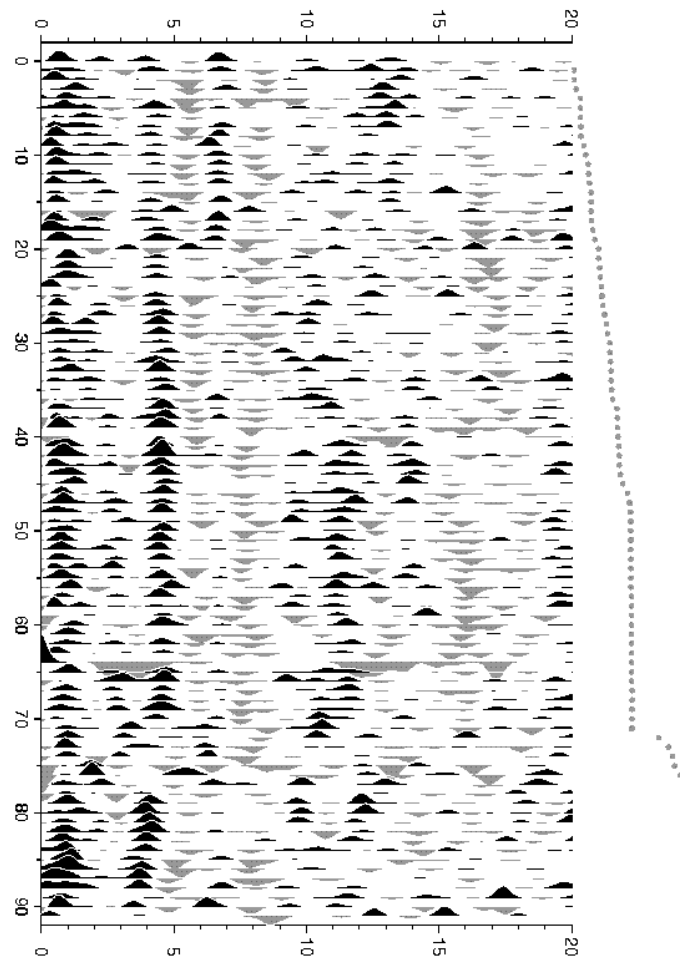


Figure 7 A selection of P-receiver functions at PIER (Yassiada) stations. The point on the rhs indicates the variation of the back-azimuth for the event used in calculating the receiver function. The first pulse at about 0.5 s corresponds to the main P arrival while the second pulse at about 5 s shows the PS conversion at the Moho.

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