PRELIMINARY CHARACTERIZATION OF L_g PHASE PROPAGATION FROM PEACEFUL NUCLEAR EXPLOSIONS IN SIBERIA

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ABSTRACT

In continuation of our study of L_g propagation from the peaceful nuclear explosions (PNEs) recorded along the Russian ultra-long refraction/reflection profile QUARTZ, we obtained four other PNE profiles: CRATON, KIMBERLITE, RIFT, and METEORITE. This acquisition extends our database to 17 PNEs. Together with QUARTZ, these profiles form a grid traversing the East European Platform, the Ural Mountains, the West Siberian Basin and the Siberian craton in two directions, and the Baikal Rift. The uniqueness of the obtained dataset is in linear, dense (~10 km station spacing), up to 10-min long 3-component recording of seismic phases to over 3000-km distances, with additional control provided by reversed PNEs. Pairs of subparallel and crossing profiles allow correlation of features of wave propagation observed on individual PNE records. The use of PNE profiles provides us with unique opportunities to study large-scale propagation effects of various seismic phases, and especially L_g, across geological and tectonic boundaries.

Preliminary examination of P_g, *S*-wave, and L_g phases in PNE shot gathers reveals strong variations in the character of the phases and poses a number of questions for further interpretation and modeling. L_g broadly varies in velocity (2.2 to 3.8 km/s), in amplitude (from lower to much stronger than the mantle *S* wave) and in propagation range (from around 1000 to 2200 km). Generally, L_g appears to be recorded better by the Siberian profiles than by the profile QUARTZ, where the PNE records show L_g at offset ranges 300-1200 km. Tentatively, these differences, together with the variations between the new PNEs currently being analyzed, can be attributed to the influence of the West Siberian Basin that appears to cause strong L_g attenuation. However, this conclusion requires further assessment of the dynamic character of the wavefield, its correlation with other seismic phases and with the available detailed information about the crustal structure.

This study demonstrates that Russian PNE data provide valuable information for the analysis of the propagation of L_g and other phases for their use in CTBT calibration studies.

Key Words: Nuclear Explosions, Russian Eurasia, Seismic Phase Propagation, L_g

OBJECTIVE

Over the past three decades, Russian scientists acquired a network of dense, linear, long-range, three-component Deep Seismic Sounding (DSS) profiles using conventional and Peaceful Nuclear Explosions (PNEs) over a large territory of Northern Eurasia. Within the framework of the Comprehensive Nuclear-Test-Ban Treaty, these historic data provide unique opportunities to calibrate existing seismic nuclear discrimination techniques by studying regional wave propagation through complex lithospheric structures.

Our work described below focuses on obtaining a representative set of PNE recordings along such profiles and on identification and characterization of the phases relevant for CTBT monitoring. The database of kinematic, spectral, and amplitude parameters of PNE recordings created in this study will result in development of robust amplitude measurement techniques and in correlation of its amplitude characteristics with the tectonic and geologic environment. Also, analysis of the profiles will allow an assessment of a realistic, 2- to 3-D, heterogeneous velocity and attenuation structure of the crust and upper mantle that would enable quantitative analysis of the amplitudes of regional seismic waves. Ultimately, the results of this effort should contribute to improvement of regional seismic event discriminantion techniques and should help calibrate the regional International Monitoring System (IMS) network (**Error! Reference source not found.**).

RESEARCH ACCOMPLISHED

This work continues our recent studies of the 3850-km long DSS profile QUARTZ (**Error! Reference source not found.**) which is one of the best-known profiles of the DSS program (Egorkin, A. V. and A. V. Mikhaltsev, 1990; Mechie et al., 1993). Our

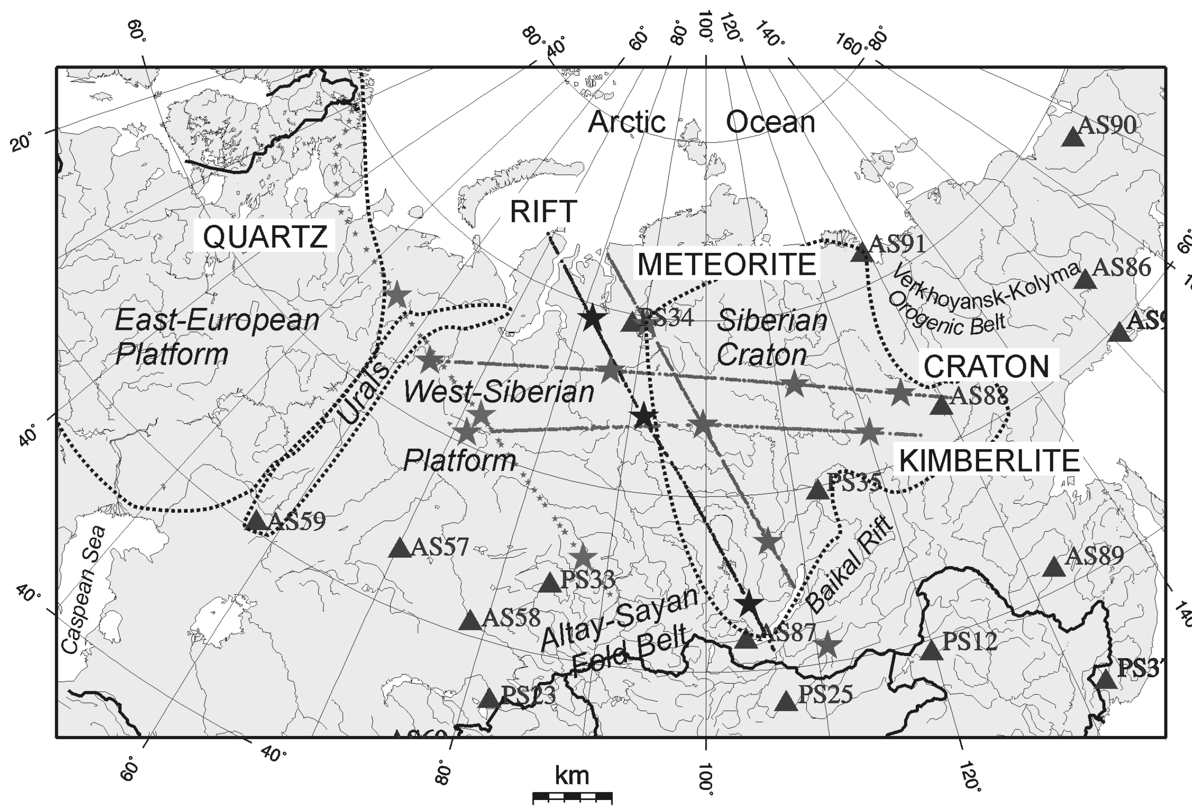

Figure 1 Five DSS PNE profiles under study at the University of Wyoming. Profile QUARTZ has been analyzed previously, profiles CRATON, KIMBERLITE, RIFT and METERORITE were obtained in this study. Large stars are the PNEs, small stars (for profile QUARTZ only) are the chemical explosions. The coordinates and other parameters of the PNEs used in these profiles were

reported by Sultanov et al. (1999). Major tectonic units are indicated. Note the extent of systematic, continuous profiling, with PNEs detonated at the nodes of a 2-D recording grid. Also note that the profiles are close to some of the IMS stations (labeled triangles).

recent, detailed analysis of both PNEs and chemical explosions reveals detailed images of seismic velocity and reflectivity of the crust and upper mantle (Schueller et al., 1997; Morozova et al., 1997 and in press), of seismic attenuation (Morozov et al., 1998b), and provides constraints on the propagation of lithospheric guided waves (Morozov et al., 1998a), and *S*- and *Lg* waves (Morozov et al., 1996, 1997).

Expanding our scientific cooperation with the Center GEON, Moscow, we obtained four other PNE profiles: CRATON, KIMBERLITE, RIFT, and METEORITE (**Error! Reference source not found.**). This acquisition extends our database from 3 to 17 PNEs. Together with the profile QUARTZ, these profiles form a grid traversing the East European Platform, the Ural Mountains, the West Siberian Basin, and the Siberian craton in two directions (**Error! Reference source not found.**). The uniqueness of the obtained dataset is in a linear, dense (~10 km station spacing), up to 10-min long 3-component recording of seismic phases to over 3000-km distances, with additional control on wave propagation provided by the reversed PNEs. Groups of parallel and crossing profiles allow us to correlate features of wave propagation observed on individual PNE records. The use of PNE profiles provides us with unique opportunities to study large-scale propagation effects of various seismic phases and especially L_g, across contrasting tectonic regions.

Our current efforts have concentrated on data reduction for the newly obtained profiles. The original analog recordings were digitized by GEON to the full length of the records of up to 600 s after the onsets of the primary *P*-wave phases. In order to extend the dynamic range of recordings, two sets of records were acquired and digitized at different amplification levels. Further data reduction was performed at the University of Wyoming, where the digital data were converted to a more flexible format used in our lab (Morozov and Smithson, 1997), and an extensive interactive editing of the records used a commercial seismic processing system PROMAX. Our current data editing procedure is based on selecting the best-quality recordings from each recording channel. As an additional data editing option, we are investigating a possibility for combining both low-gain and high-gain channels to increase the dynamic range of the signal while minimizing the instrument noise. This would imply switching from the low-gain channels for first arrivals to high-gain channels for the rest of the records. Such a procedure would correspond to the plotting techniques used at GEON; however, since we intend to preserve the available trace amplitude information, it would also pose a problem of consistency of these two groups of channels, and of their proper scaling in the resulting records.

The data reduction procedures outlined above are completed with an incorporation of the channel amplification information provided by GEON. Averaged spectra of the resulting records from two profiles are shown in Figure 2 and selected record sections of the cross-line component (this component was chosen as containing more *S*-wave energy) are presented in Figure 3.

Preliminary examination of P_g, *S*-wave, and L_g phases in PNE shot gathers reveals strong variations in the character of the phases and poses a number of questions for further interpretation and modeling. L_g broadly varies in velocity (from 2.2 km/s in some branches to 3.8 km/s), in amplitude (from lower to much stronger than the mantle *S* wave) and in propagation range (from around 1000 to 2200 km). Generally, L_g appears to be recorded better by the Siberian profiles than by the profile QUARTZ, where the PNE records show L_g at offset ranges 300-1200 km (Morozov et al., 1997). Tentatively, these differences, together with the variations between the new PNEs currently being analyzed, can be attributed to the influence of the West Siberian Basin that appears to cause strong L_g attenuation. However, this conclusion requires further assessment of the dynamic character of the wavefield, its correlation with other seismic phases and with the available detailed information about the crustal structure.

Recorded amplitude spectra exhibit peaks between 0.5 - 4 Hz, with steeply decreasing amplitudes at higher frequencies. In CRATON records, the usable frequency range is about 0.5 - 10 Hz, with power at 10 Hz about 15 dB lower than between 0.5 - 3 Hz. CRATON-3 shows a broader peak at lower frequencies whereas the white ambient noise appears much stronger (Figure 2). The records from PNE RIFT-1 have a particularly narrow low-frequency energy peak. The records from the profile KIMBERLITE appear most broad-band, probably usable to 20 Hz. Note that the relatively broad-band KIMBERLITE PNEs and CRATON-3 (Figure 2) also show the best recordings of mantle *S* waves (Figure 3).

Comparison of the observed spectra from the CRATON and KIMBERLITE PNEs detonated at (relatively) close locations suggests a limited correlation with the general tectonic character of the sites. The broad-band shots CRATON-3 and KIMBERLITE-3 and 4 were detonated within the Siberian craton while the low-frequency shots (with an exception of CRATON-4) were located within the West Siberian basin (Figure 1). However, the general difference between the spectra from these two profiles (Figure 2) also suggests a probable difference in the source conditions.

Examination of the *S*-wave and *Lg* phases in the shot gathers reveals strong variations in the character of the phases and poses a number of questions for further interpretation and modeling. *Lg* broadly varies in velocity (2.2 to 3.8 km/s), in amplitude (from lower to much stronger than the mantle *S* wave) and in propagation range (from around 1000 to 2200 km). Below, we present the most characteristic observations available to date.

Pg and *Lg* phases are clear in many of the Siberian PNE records. CRATON-4 shows a remarkably strong *S* wave (especially on component 2 - transverse to the profile), followed by diffuse *Lg* with group velocity of about 3.2 km/s. We can trace *Lg* to about 2000 km but it becomes very weak after about 1700 km. Note that the next shot to the west—CRATON-3 shows a very strong Lg, which becomes much slower (2.5 km/s) when it enters the West Siberian basin (Figure 3). Virtually no *S* wave is recorded to the east from CRATON-2 (Figure 3).

We observe a complex *Lg* pattern west from PNE CRATON-3 (Figure 2). The "primary" *Lg* phase is very strong and compact (~10 - 15 s in duration) throughout the entire offset range of 2200 km (this is the longest *Lg* propagation distance from DSS PNEs that we have observed so far). Two trains of energy appear to separate from *Lg* near offsets of 200 and (probably) 700 km, propagating at about 2.2 km/s apparently corresponding to the Rayleigh wave. To the east of this shot, a similar slow branch emerges near 300 km of offset but terminates near 700 km.

Records from CRATON-2 (and CRATON-4, not shown), show strong *Lg* that is more diffuse and can be traced to about 1500 km (Figure 3). The mantle S wave is not pronounced to the east of the shot but appears to be comparable in amplitude to *Lg* to the west (Figure 3). Strong crustal multiples follow the primary *P*-wave arrivals, but we cannot identify these multiples in the *Lg* wavetrains. *Pg* is also very strong to about 1500 km east of the shot.

CRATON-1 (not shown) generated little *S*-wave or *Lg* energy although its spectral content is not dramatically different from that of CRATON-3. However, this PNE also exhibits significant gaps complicating its interpretation.

The *Lg* from KIMBERLITE-1 (not shown in Figure 3; at the center of the West Siberian basin; Figure 1) to the east is very slow (about 2.4 km/s), reverberative and strong to about 500 km. After 500 km, it appears to decay quickly, similar to *Lg* phases from PNEs 213 (which is located close to KIMBERLITE-1) and from PNE 323 of the profile QUARTZ (Morozov et al., 1996, 1997). This slow propagation suggests that *Lg* in this area is dominated by relatively shallow S-wave phases propagating within the thick sediment cover of the basin.

KIMBERLITE-3 (Figures 1 and 3) shows good *Lg* and mantle *S* waves in both directions. *Lg* appears to be stronger than the *S* (unlike what we had observed from the southern PNE of QUARTZ profile (see Figure 1). *Pg* is strong to 1300 km offset to the east and to about 1000 km to the west. As in other PNE records, close examination of the records indicates strong *P*-wave crustal reverberations; such reverberations might contribute to the diffuse character of *Lg*.

KIMBERLITE-4 also shows strong *S* and *Lg* phases (Figure 3). *Lg* appears to carry somewhat more energy than the *S* wave. Both *S* and *Lg* waves are diffuse but the onset of S waves is clearly marked. As expected, *Lg* separates from *Sn* near 250 km of offset, where high amplitudes of the shear-wave arrivals indicate a near-critical *SmS* reflection.

RIFT data have narrower bandwidth and somewhat lower quality. Yet, *Lg* from RIFT-1 and RIFT-2 can be identified to offsets of about 1600 km, propagating at about 3.8 km/s. A mantle *S* wave, somewhat scattered in character, can be also observed (Figure 3). A notable difference in the relative amplitudes of the *Pg*, *S*, and *Lg* arrivals east of PNEs RIFT-1 and RIFT-2 (Figure 3) is not explained at present.

Due to instrumental problems, METEORITE recordings are limited in offset coverage (Figure 3). The *P*, *Pg*, *S*-, and *Lg* phases are strong and reliably observed to the ranges of 1200 - 1600 km.

CONCLUSIONS AND RECOMMENDATIONS

Preliminary examination of the newly obtained Russian PNE records from four Siberian DSS profiles demonstrates that the data provide valuable information for the analysis of the propagation of L_g and other phases for their use in CTBT calibration studies. Our further effort in analyzing the data will be focused on a detailed characterization and modeling of the *P*-, *S*-, and *Lg* wave phases critical for nuclear test discrimination.

In the records from the Siberian DSS PNE profiles, we generally find stronger *Lg* propagating to longer distances than recorded by the profile QUARTZ. At the same time, the propagation character of *S* waves and *Lg* shows high variability that is apparent across the contact between the Siberian craton and the West Siberian basin where the observations are more consistent with those from the profile QUARTZ.

In our ongoing research, we will substantiate and quantify these observations in more detail. As a first step, we will perform picking travel-times of the *P*- *S*- wave, *Lg*, and *Rg* seismic phases in the records; and checking for reciprocity between the reversed PNEs. During further stages of this work, we will proceed with further analysis of *Lg* phases, selecting noise correction approaches, spectral estimators, to examine offset dependence of the amplitudes and spectral ratios. This will result in a database of travel-time, velocity, amplitude, spectral, coda *Q*, and other parameters of these phases.

At later stages of this research, we intend to use crustal/uppermost mantle structural models to interpret the resulting database, associating the observed variations in propagation properties of *Lg* with the crustal structure and with the character of other seismic phases identified in the profiles. The crustal velocity and Moho models will be available from previous studies conducted at GEON. At this stage, we will model *Lg* propagation along the profiles in order to test hypotheses about the effects of the crustal and uppermost mantle structure on *Lg* and other regional phases.

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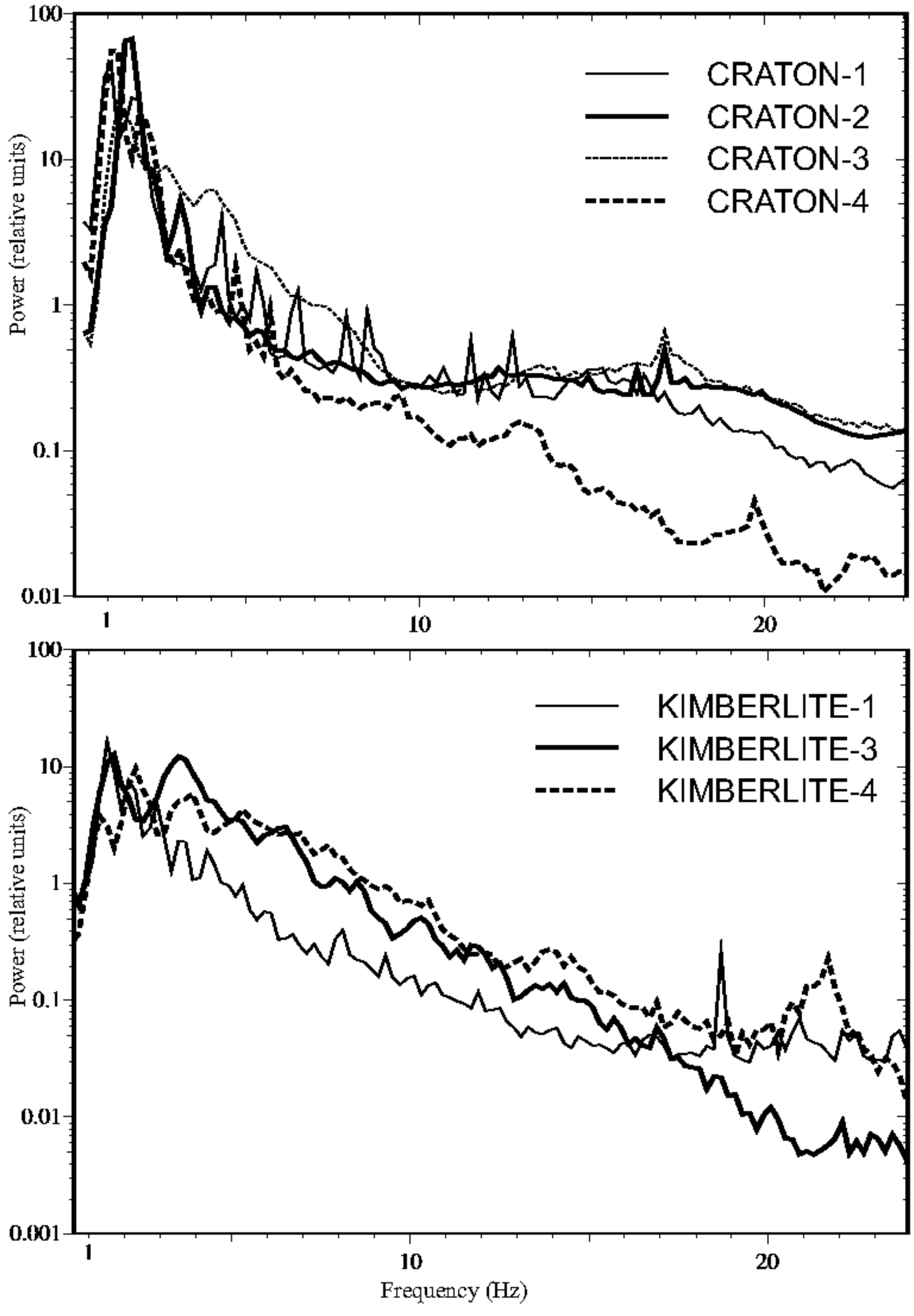


Figure 2. Averaged power spectra of the vertical-component records from profiles CRATON (top) and KIMBERLITE (bottom). To obtain these spectra, record sections were trace-normalized, and the resulting power spectra were averaged within 0.2 Hz intervals over the entire sections. The recorded spectra vary significantly between the shots and between the profiles; however, the PNEs in the cratonic areas (CRATON-3, KIMBERLITE-3 and 4; see Figure 1) generate more high-frequency energy.

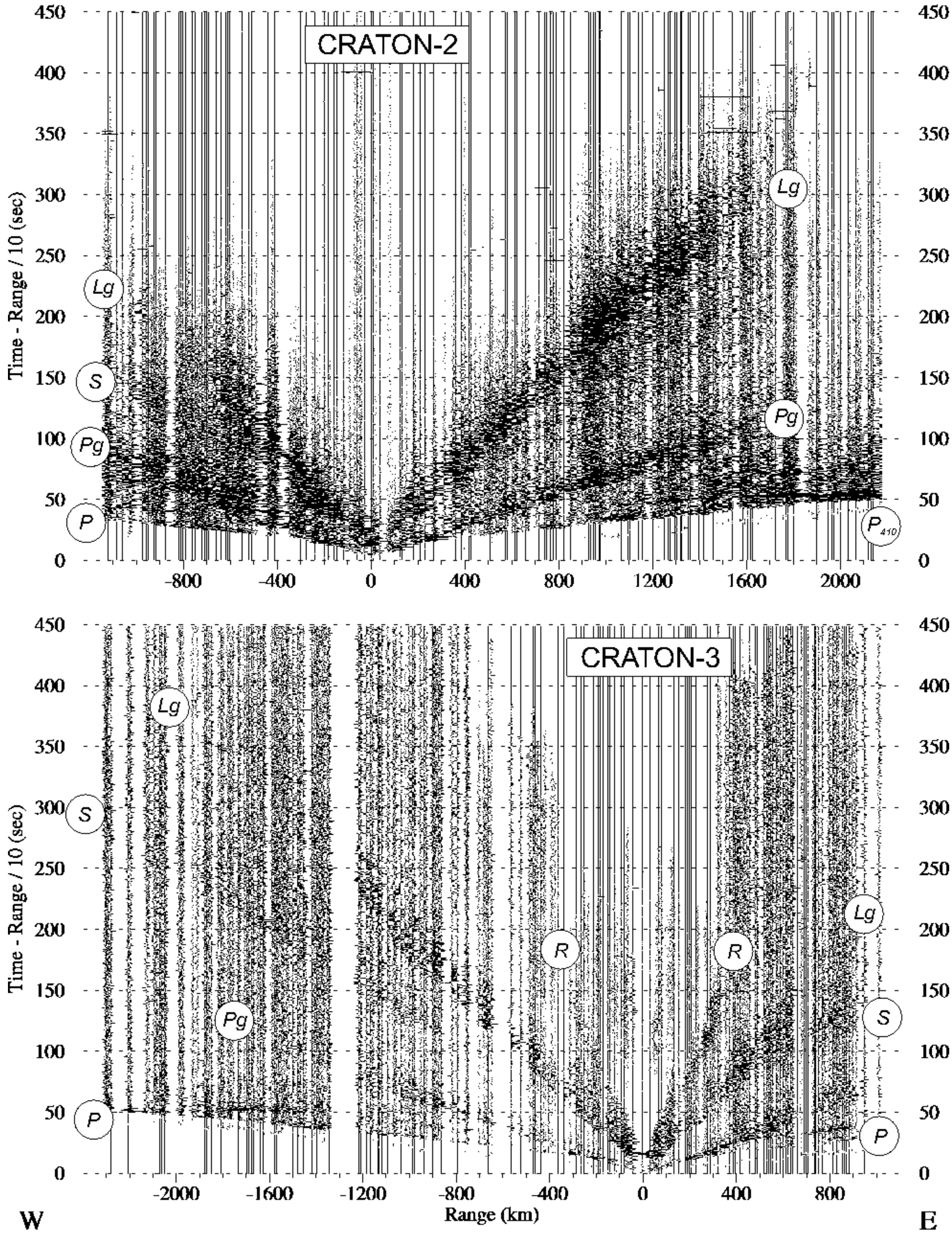
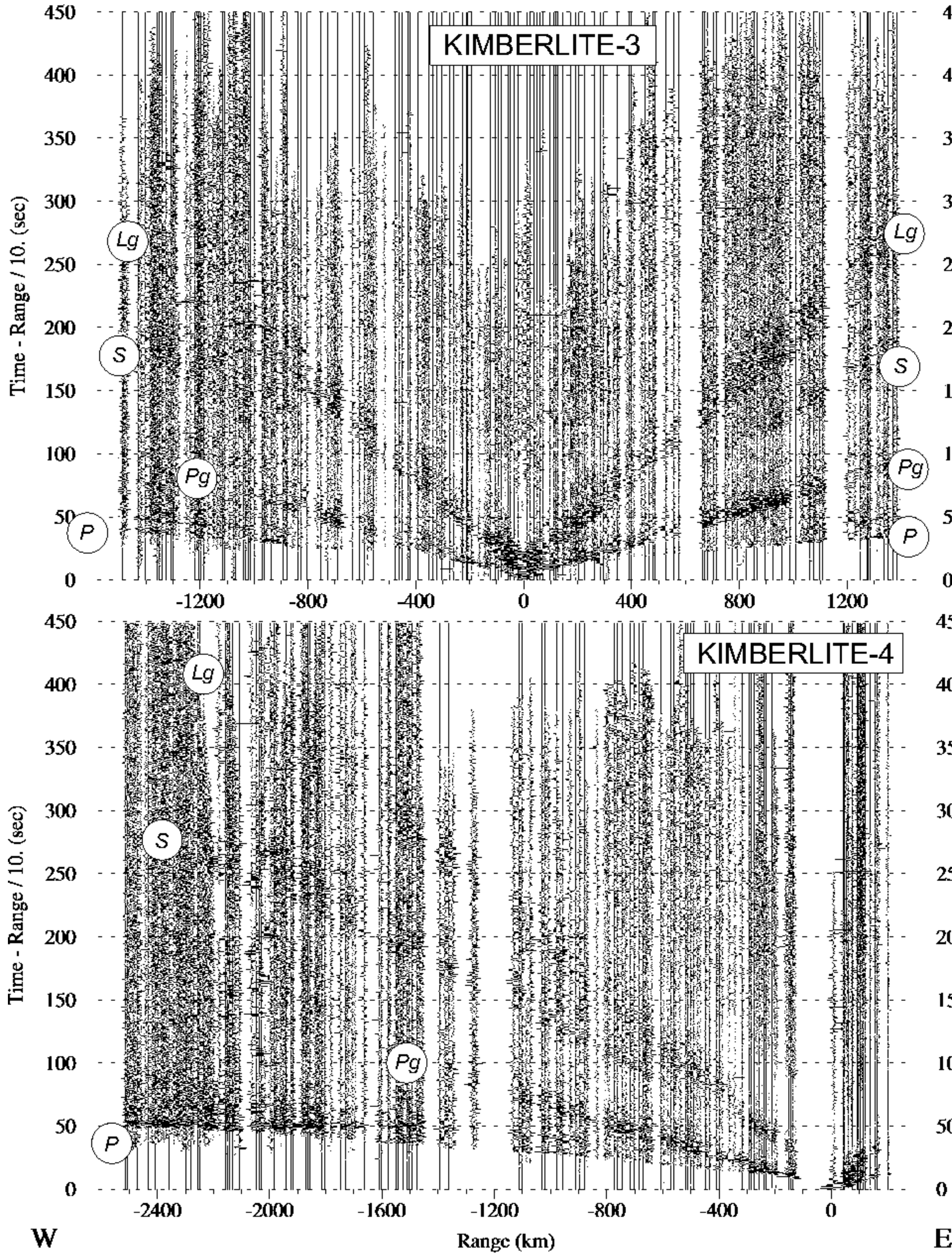


Figure 3. Horizontal component (transverse to the profiles) records from 2 PNEs from each of the newly obtained profiles (Figure 1). Automatic gain control within 100-sec window used for normalization. Note the strong and variable *S*-wave and *Lg* phases.



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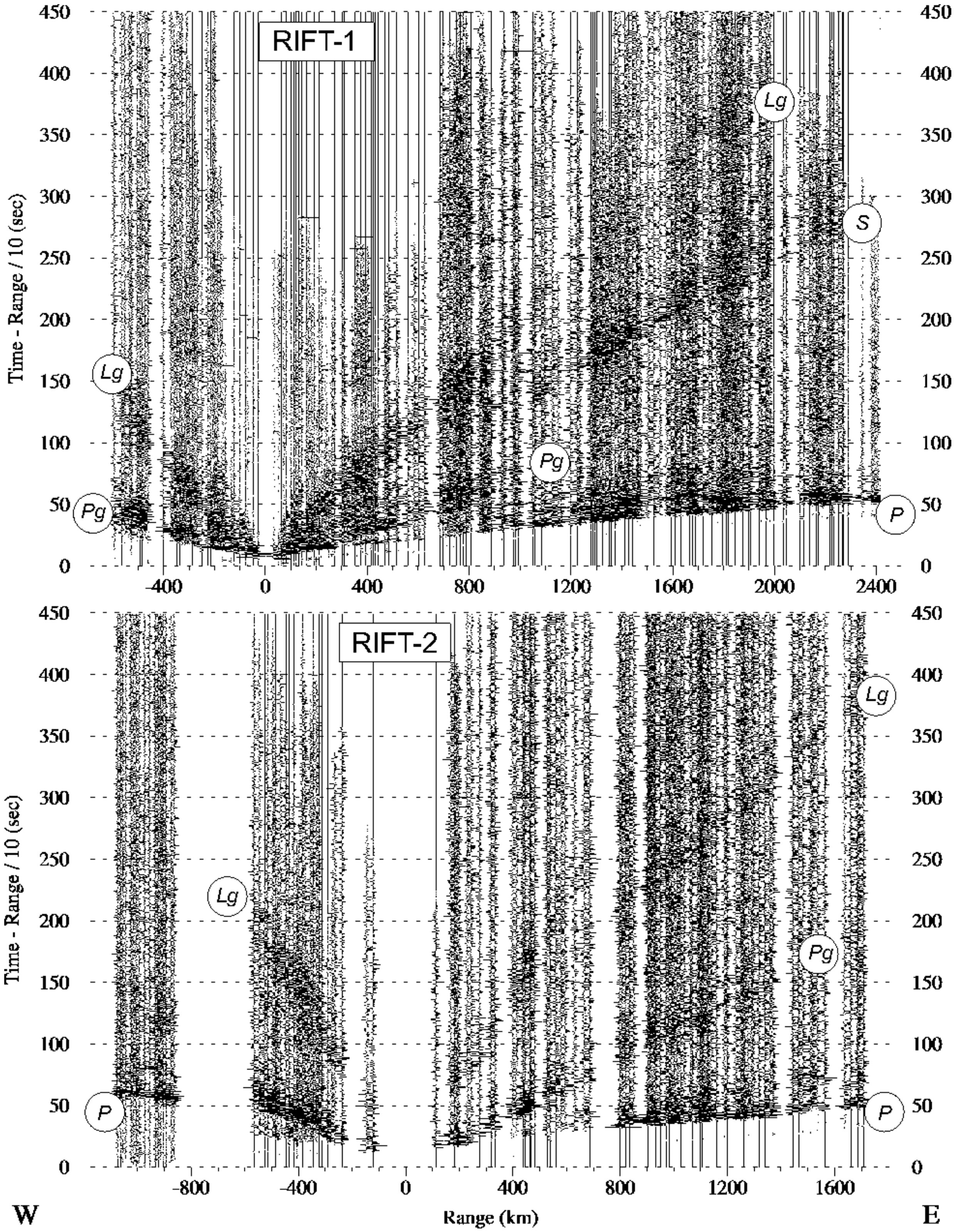

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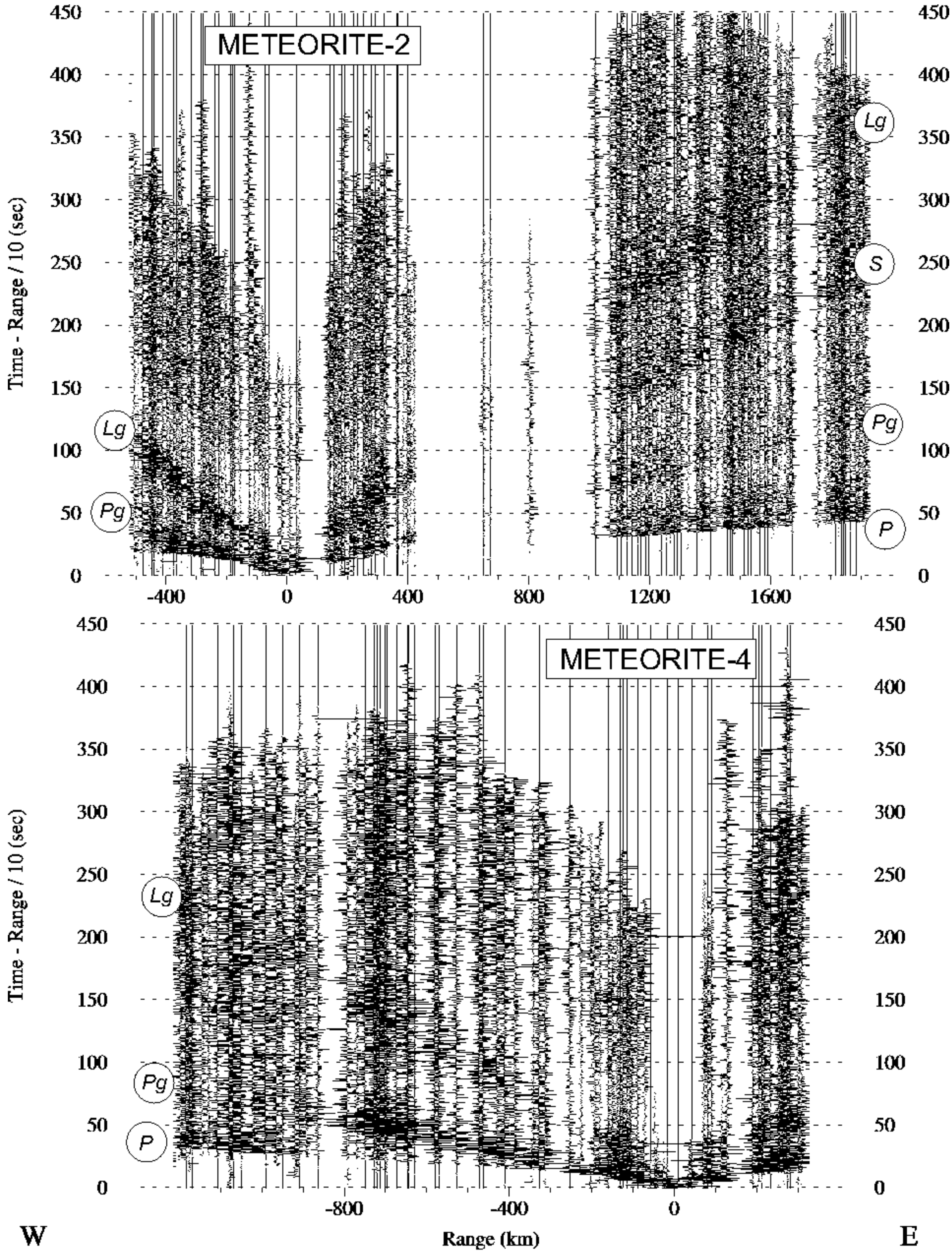

Figure 3 (continued).