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Analysis Summary of an Assembled Western U.S. Dataset

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INTRODUCTION

The dataset for this report is described in Walter et al. (2004) and consists primarily of Nevada Test Site (NTS) explosions, hole collapse and earthquakes. In addition, there were several earthquakes in California and Utah; earthquakes recorded near Cataract Creek, Arizona; mine blasts at two areas in Arizona; and two mine collapses in Wyoming. In the vicinity of NTS there were mainshock/aftershock sequences at Little Skull Mt, Scotty's Junction and Hector mine. All the events were shallow and distances ranged from about 0.1 degree to regional distances. All of the data for these events were carefully reviewed and analyzed. In the following sections of the report, we describe analysis procedures, problems with the data and results of analysis.

ANALYSIS PROCEDURES

Phase quality designations were assigned only to the most commonly recorded phases listed below. Two classification systems were used, alphabetic and numeric. The numeric system was applied only to the first arrivals with uncertainty of the pick less than o.5s. The alphabetic designations were applied to larger uncertainties for the first arrival and all secondary arrivals.

Pg, Pn, P	(A) 0 1 2 3 4 representing 0=<0.1s, 1=0.1s, 2=0.2s, 3=0.3s, 4=0.4s-<0.5s
	(B) 0.5s-1.0s
	(C) >1.0s-3.0s
	(D) >3.0s-5.0s
Sn, S	(A) <2.0s
	(B) 2.0s-4.0s
	(C) >4.0s-6.0s
	(D) >6.0s-8.0s
Lg	(A) <2.0s
	(B) 2.0s-4.0s
	(C) >4.0s-8.0s
	(D) >8.0s-12s

Phases were picked on unfiltered data if possible, otherwise pass-band filters were applied as necessary to enhance the signal-to-noise for each phase.

Later phases were added even if the first arrival could not be read.

Stations determined to have timing errors above 2s to 3s have first P arrivals identified with "CE"(clock error). No later phases were added in those instances. It should be noted that clock errors below about 2 seconds were difficult to confirm particularly if other stations had this problem for the same event. The occurrence of unusual outliers in travel times for similar paths might indicate timing problems.

A generic phase name (Px) was used for phases that were real but did not fit standard travel time branches. Real is defined as an arrival with fairly clear onset and significant SNR found to be consistent for other similar paths.

For simplicity, a number of crustal phases were labeled Pg when positive identification of the phase was not possible. Thus, no attempt was made to separately identify such phases as Pb, PIP, PmP unless they were unambiguous
(W. Walter, personal communication).

If the first arrival is Pg, the second arrival is labeled Sg not Lg.

For NTS events recording at station DAC about 1.4 degrees to 1.5 degrees distant, the Pg/Pn crossover was taken to be 140 km (Roller and Healy 1(963).

Very poorly recorded phases were not read. Such phases were generally very emergent, had indeterminate onsets and were mixed with either background noise or coda of previous phases.

All picked phase names and times can be found in the ARRIVAL database table.

DATA PROBLEMS

During analysis a variety of problems with the data were observed, and these are listed below followed by some examples. No attempt was made to record all of the possible problems for every event.

- Clock errors
- Glitches
- Data dropouts
- Clipped signals
- HF noise contaminating the signal
- Unknown instrument problems where the data was not readable
- One or more channels from 3-C stations missing

For some station/event combinations SHZ may be the only component available, while for others the vertical, radial and transverse channels only were available.

In some cases (e.g., PFO, ANMO) it was noted that there were possible reversals of instrument orientation. However, as mentioned above, there was no attempt made to thoroughly QC all the data.

For some of the events, several stations had multiple 3-C instruments available (i.e., bb, hf, vb). In all those instances the bb channels were offset by +0.1s to +0.2s from the other two (Fig 12a). In addition, there were instances where the horizontal channels were also offset by >= +0.1s from the vertical channel (Fig 12 b).

There were a number of cases where waveform segments did not include all the arrivals of potential interest. Some of the segments started after the expected first arrival, and others were truncated after the initial phase and did not include secondary arrivals.

The following table includes examples of some of the problems described above.

EVID	TYPE	STATION	COMMENTS
2022467	EQ	TPNV	A local event brackets predicted Pn arrival time, Lg only read.
1324942	WY Mine Collapse	TPNV	Horizontal channels down.
		GSC	A small local event records 2.6s after Pn.
		PFO	A small local event records 18s prior to Pn.
		YBH	A small local event records at the approximate time of predicted Lg.
		NEE	Segments contaminated by long bursts of HF (~0.15s) noise.
		MNV	Segments contaminated by long bursts of HF (~0.2s) noise.
1471866	EQ	SRU	Segments end 70s after Pn arrival.
609251	BARNWELL	LAC	A large 1s glitch occurs 13s prior to Pn arrival
616762	BULLION	MNV	Pg coda is clipped.
		ELK	bbe channel is down.
		ELK,KNB, LAC, MNV	A large 2s glitch occurs on ending LR codas.
612817	METROPOLIS	ELK	Segments contain numerous large glitches.
		COR	Appears to have ~ -60s clock error.

617078	AUSTIN	ELK	bbe channel down, a large 2.4s glitch occurs 17s after Pg arrival.
		LDS	A large 1s glitch occurs 4.5s after Pg and a second occurs 10.3s after Lg.
635527	HOYA	KNB	bbe has unknown type instrument problem.
2708586	GALENA	TUC	BHE channel is missing.
648221	VICTORIA	BMN	Initial P coda is buried in noise, Lg only added.
		LDS	Segments contaminated by many bursts of HF (~0.1s) noise, not readable.
643767	JUNCTION	MNV, KNB, LAC	Appear to have +2.5s to 3.0s clock errors.

ANALYSIS AND RESULTS

For the most part, this dataset includes readings of phases that would be typical for local and regional events in the Western US -- Pn, Pg, PmP, Sg, SmS, Lg and in some cases LQ and LR. Examples of these are shown in Figs 1-3. However, there are also cases of complex events, or phases that would be considered unusual, and these are discussed below. In addition, examples are presented which illustrate possible analysis dilemmas related to the identification of arrivals in the vicinity of the crossover distances.

In the figures that follow, the labels to the left of the traces have station/channel designation (top line), backazimuth for some (2nd line), distance in Km or degrees (next line), and filter band (bottom line). Some of the observations are:

- Poorly recorded Lg for NTS explosions -- see Figs 1 and 2.

- Unusual observations of high-frequency Sn – see Fig. 4

- Anomalous phases – see Figs. 5, 6, 7 and 8.

- Pn too small to read at distances beyond the Pg/Pn crossover – see Fig. 9

- PmP and SmS phases observed -- see Figs 10 and 11.

- Interference due to local earthquakes – see Figs 12 and 13.

- Multiple events -- Complications also arise for multiple events that occur at almost the same time. Examples of these are discussed below.

The Atrisco hole collapse was determined to be a double event based on signal character and Rayleigh
wave correlation. Phases were picked for both events

STATION	EVID 4361928	EVID 4361929
MNV	Pn, Lg	Lg
KNB	Pn	Pg, Lg
LAC	Lg	Pg, Lg
ELK	--	Pn, Sn, Lg

The Scotty's Junction mainshock, ML 5.8, was determined to be at least a double and possibly a triple rupture. The mainshock occurred about 2.6s after a smaller foreshock. Both of these events were read (Evid
1315772, and Evid 4361917). However, no readings were made for either past the Pg/Pn crossover distance because of possible ambiguities in assigning phases as belonging to one or the other event.

The Hector mine mainshock was also a possible multiple rupture. For consistency, Pg and Pn were picked on the first small arrival at all the available stations. No later phases were added.

• Possible timing issues between channels – see Figure 14.

REFERENCES

Roller, J. C. and J. H. Healy (1963). Seismic refraction measurements of crustal structure between Santa Monica Bay and Lake Mead, *J. Geophys. Res.*, *68*, 5837-5849.

Walter, W. R., K. D. Smith, J. L. O'Boyle, T. F. Hauk, F. Ryall, S. Ruppert, S. C. Myers, R. Abbot and D. A. Dodge (2005). An assembled western United States dataset for regional seismic analysis. *Lawrence Livermore National Laboratory Report UCRL-TR-206630*, 17pp.

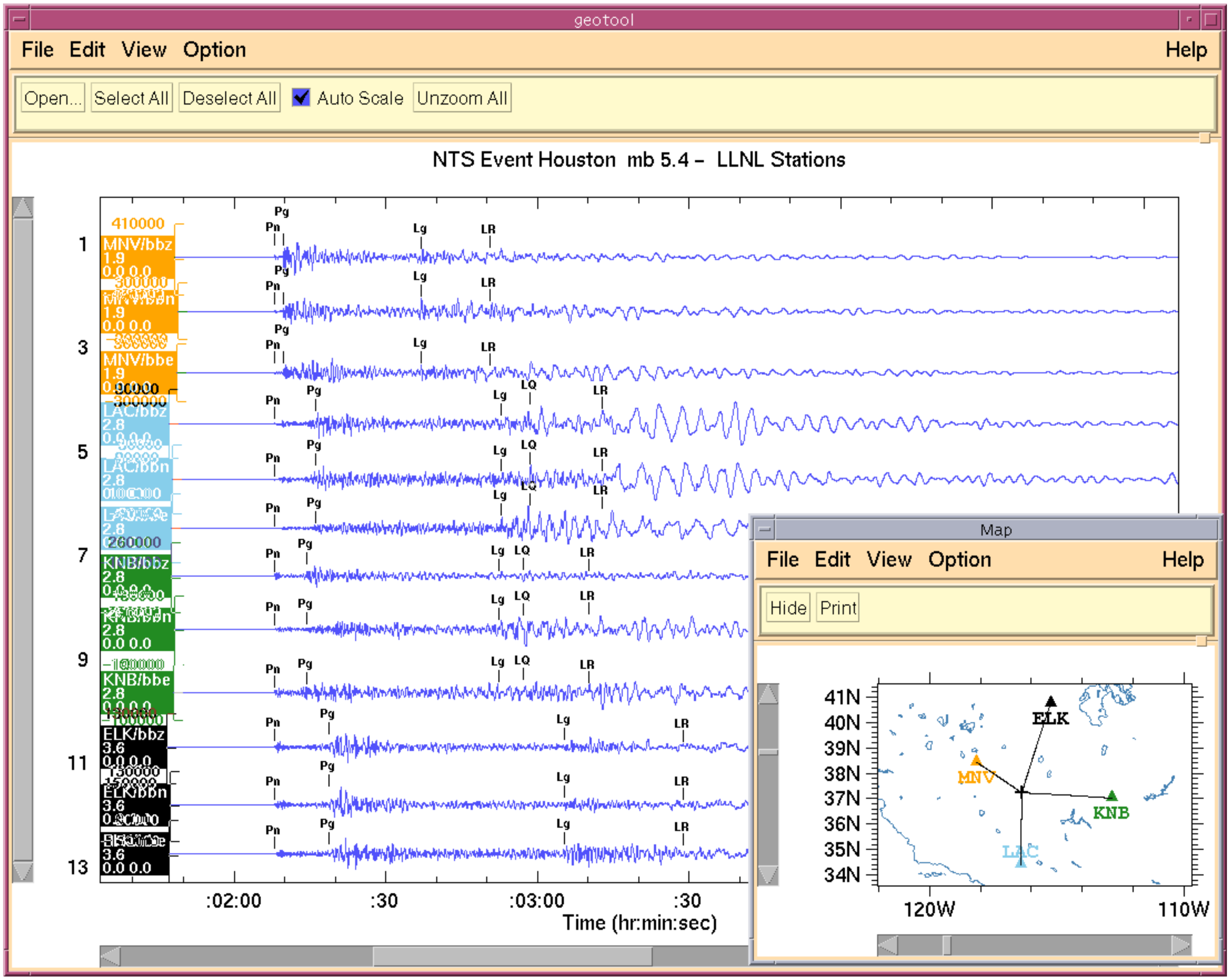

Fig. 1. Poorly recorded Lg -- In general, the phase Lg was poorly recorded for NTS explosions (see unfiltered waveforms on Figs. 1 and 2)

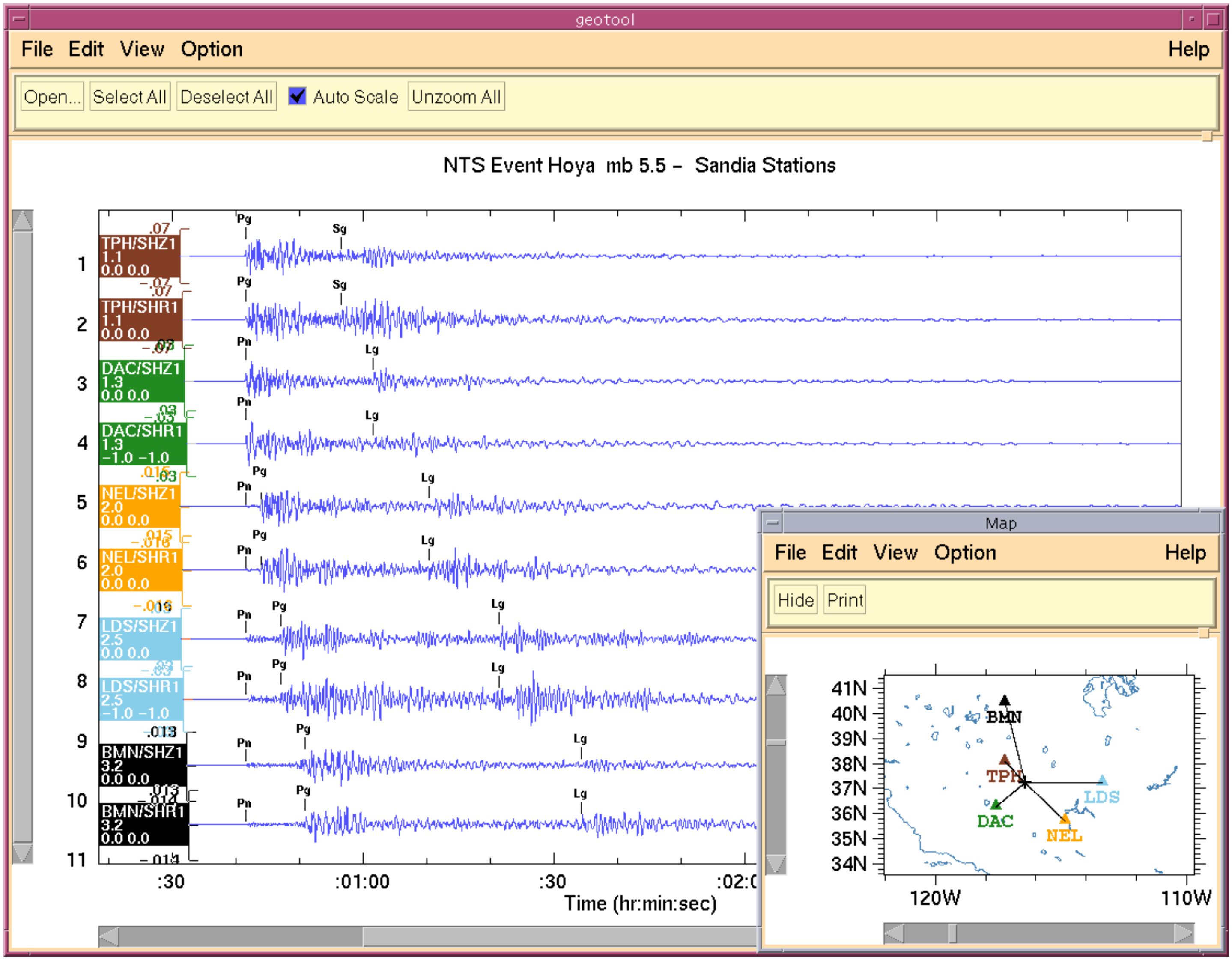

Fig. 2. An NTS explosion with analyst arrivals at the Sandia Leo Brady Network stations.

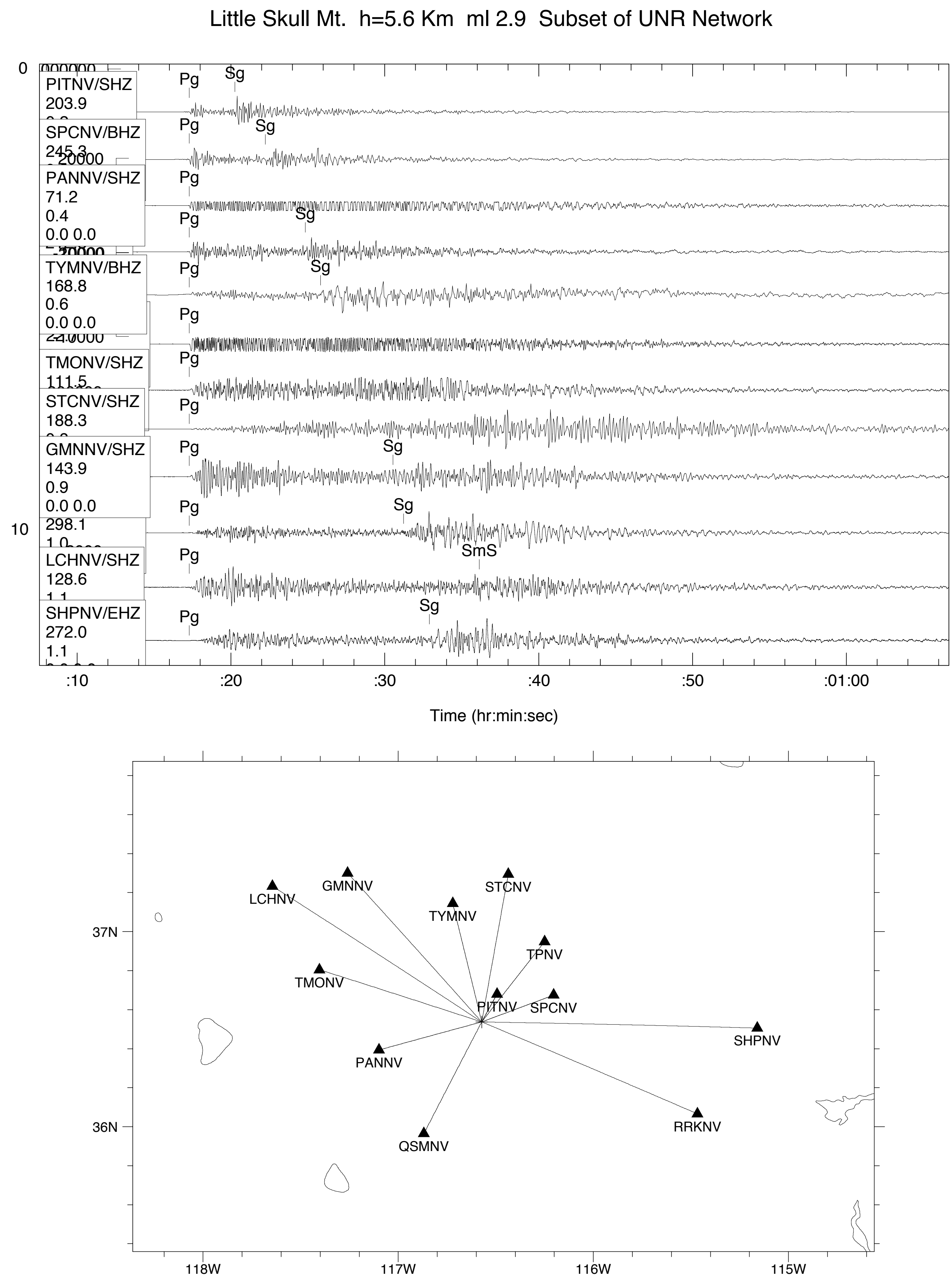

Fig. 3. Earthquake seismograms with analyst arrivals at some of the UNR Southern Great Basin Network stations.

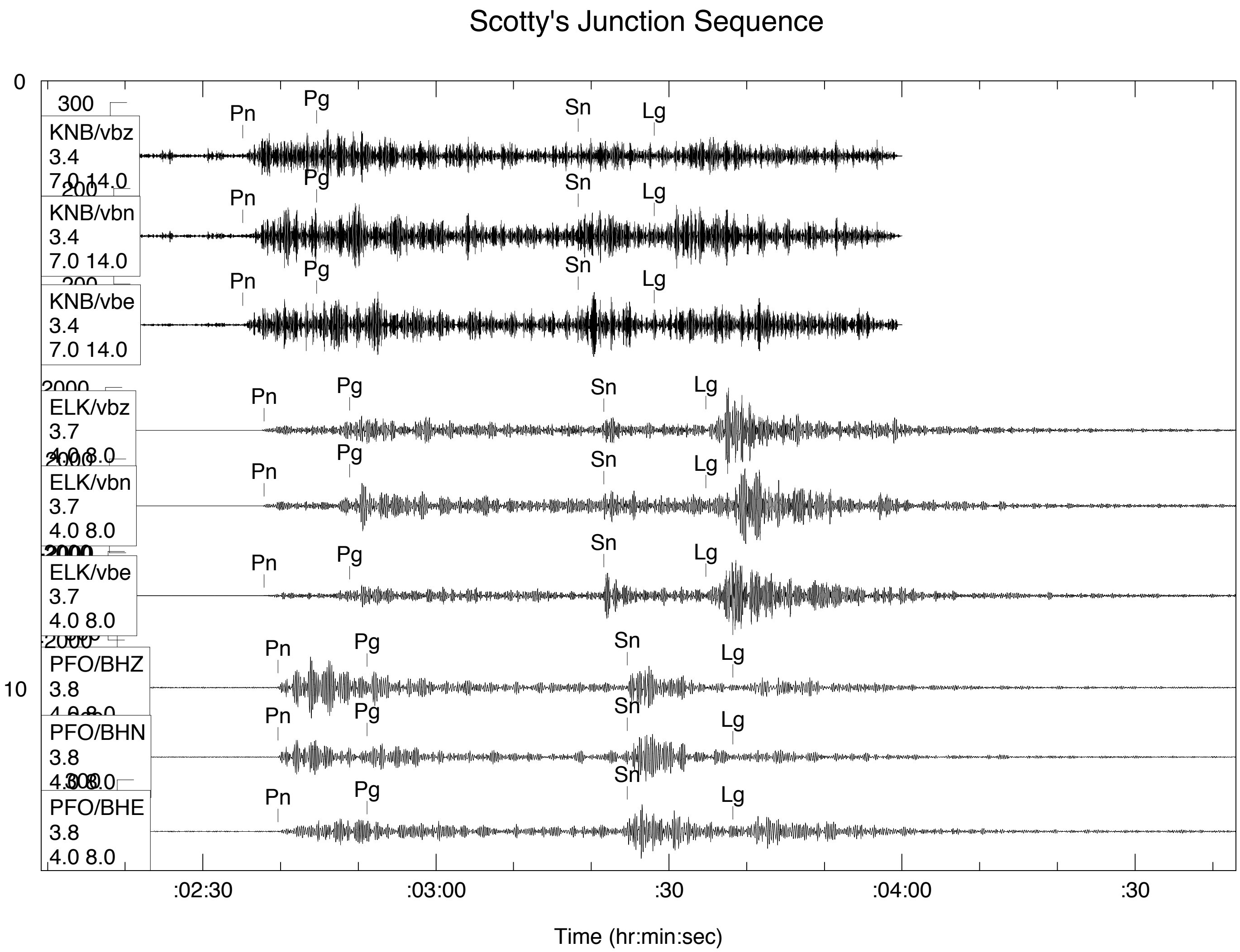

Fig. 4 shows unusual observations of high-frequency Sn at stations KNB, ELK, PFO. Station BMN not shown in this figure also had occasional recordings of HF Sn. This phase is not normally seen in the Basin and Range and recorded for both earthquakes and explosions. However, this phase did not consistently record for similar source/station paths. Waveforms were filtered in the band 4.0-8.0 Hz to enhance Sn arrivals.

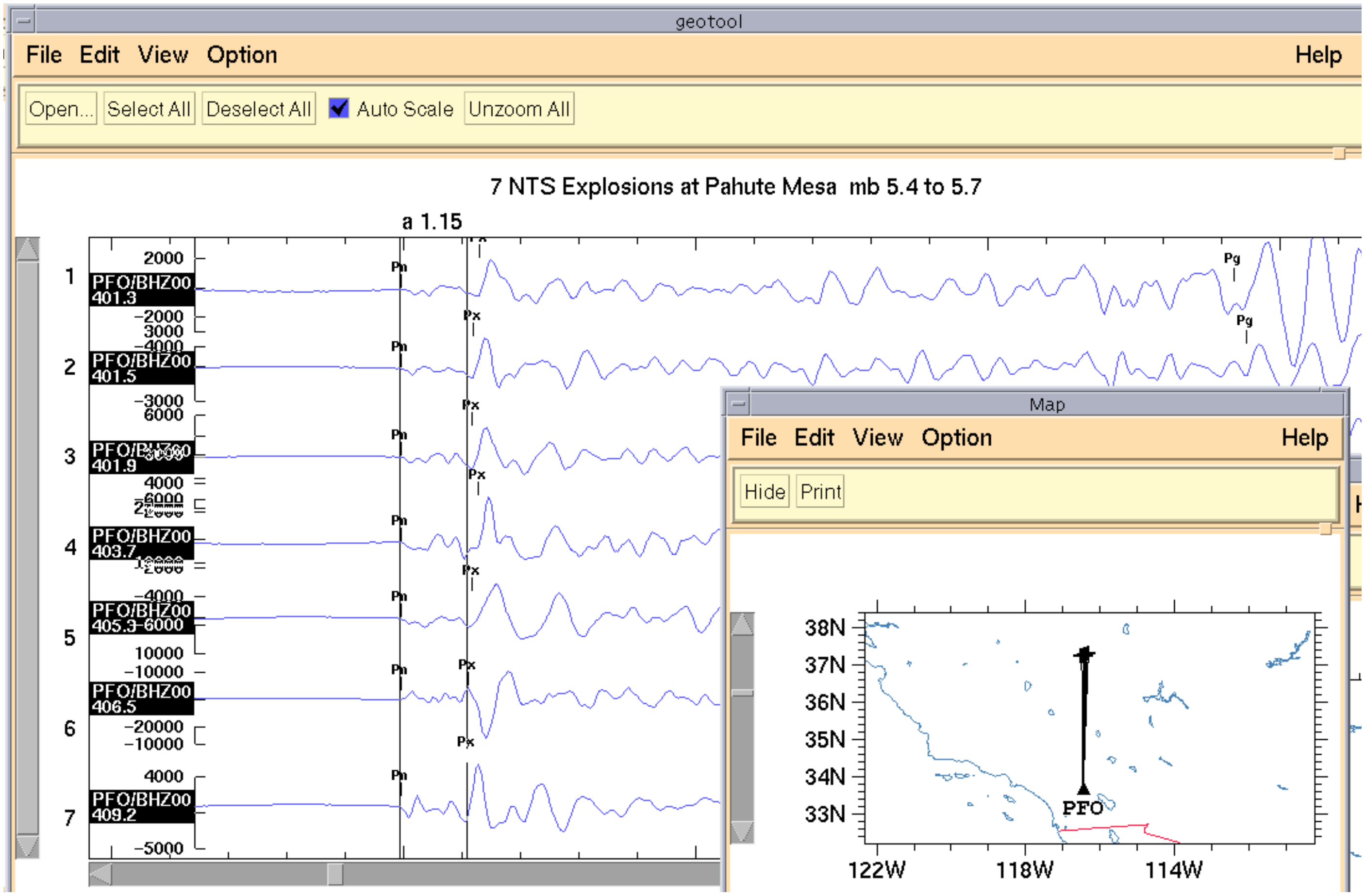

Fig. 5 shows seven NTS explosions at Pahute Mesa that record on the broadband vertical components of station PFO. Note the large arrival labelled Px that occurs about 1s after Pn. Px has a period of about 0.5s and also records for shots at Yucca and Rainier.
All traces are unfiltered.

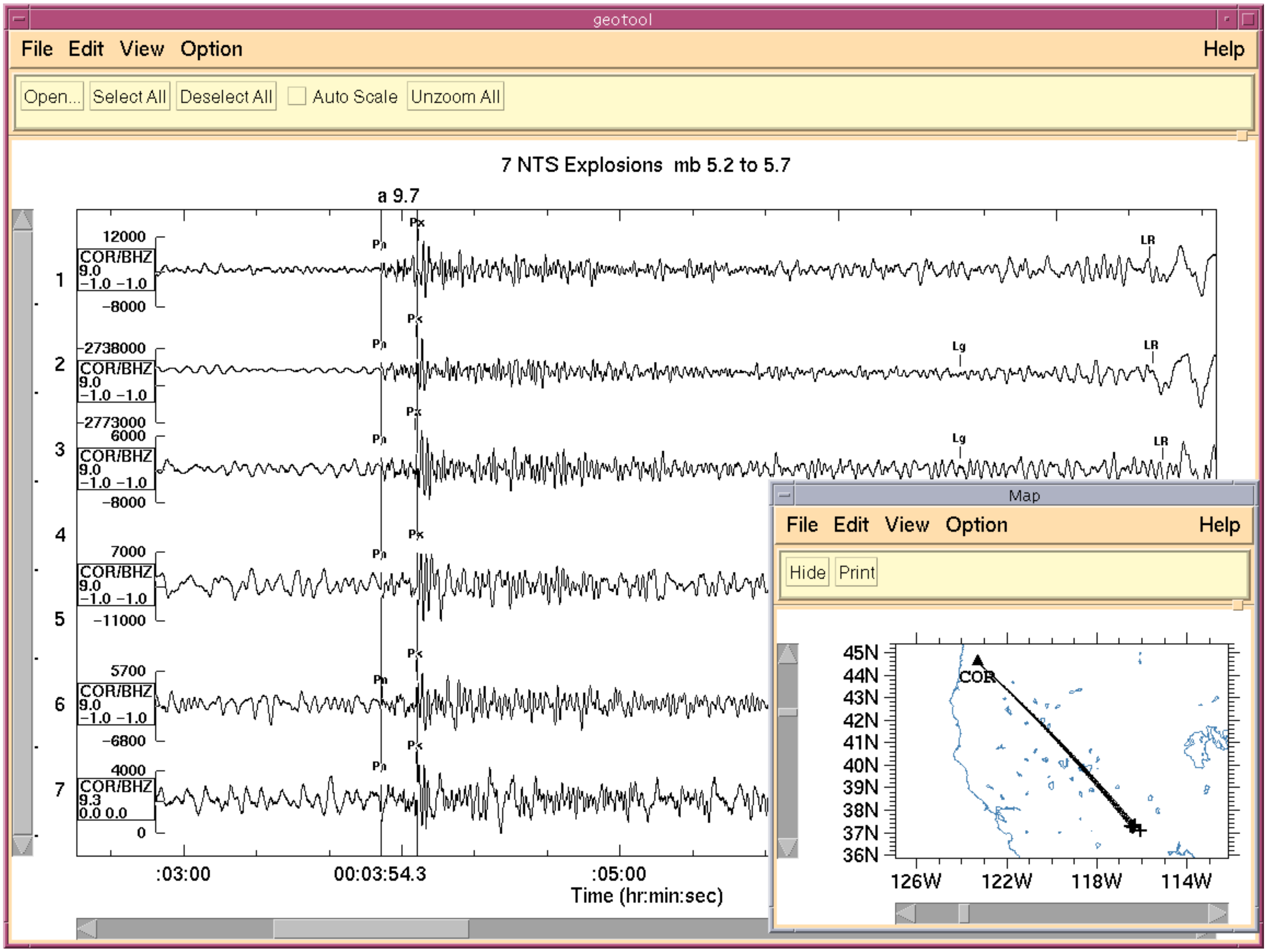

Fig.6 shows seven NTS explosions that record on the broadband vertical channels of station COR about 9 degrees distant. A prominent short-period (~1.5s) phase that arrives about 10s after Pn was labeled Px. This phase is close to the predicted arrival time for PnPn, but the difference in amplitude between Pn and Px, leave this possible interpretation open to question. All traces are unfiltered.

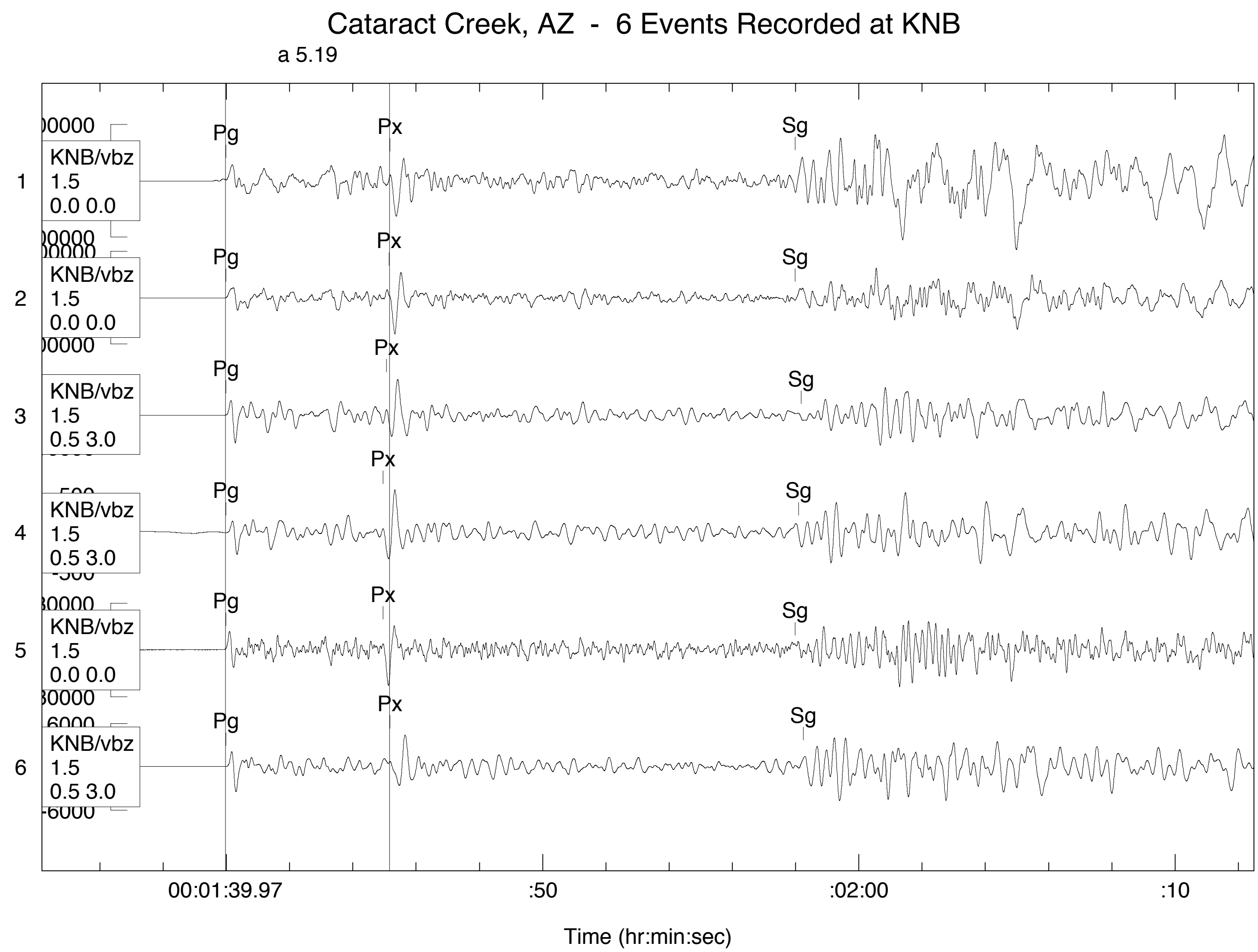

Fig. 7 shows six earthquakes located in Cataract Creek, Az that record on the vertical channels of station KNB, 1.5 degrees distant. A second large arrival labelled Px records about 5s after Pg and has a period of about 0.5s. Traces 1,2,5 are unfiltered, traces 3,4,6 are filtered in the band 0.5-3.0 Hz to enhance Px.

Cataract Creek, AZ events recording at PFO - trace1 ML 3.0; trace2 ML3.8; trace 3 ML 3.6

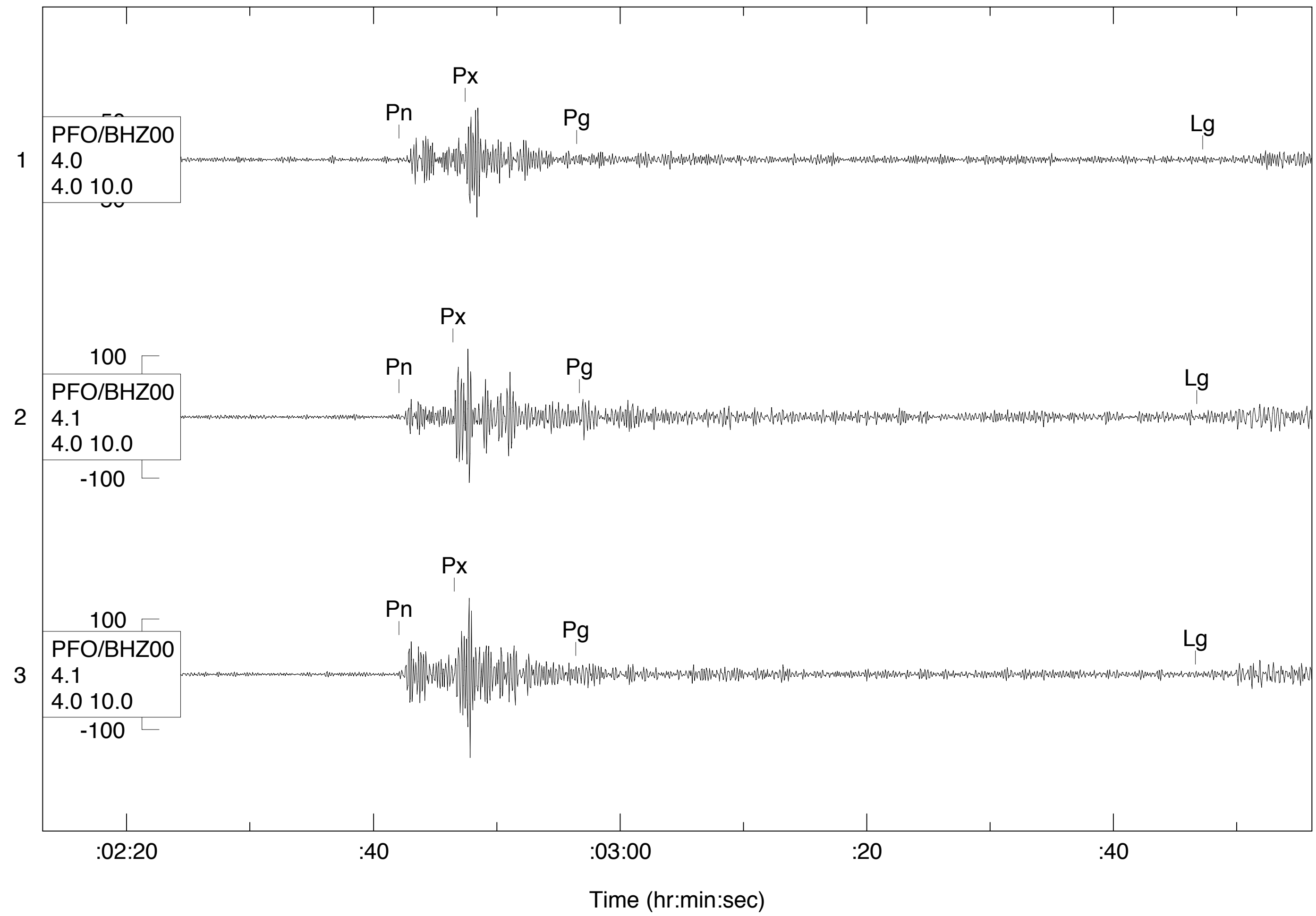

Fig. 8 shows shows three earthquakes located in Cataract Creek, AZ that record on the broadband vertical channels of station PFO, about 4 degrees distant.
A high-frequency (~0.25s) phase that records about 4.5s after Pn was labelled Px.
Note that this high-frequency signal might be mistaken for a local earthquake if it were observed for only one of these events.

Hector Mine EQs trace 5 largest of 6 events with mb 4.5

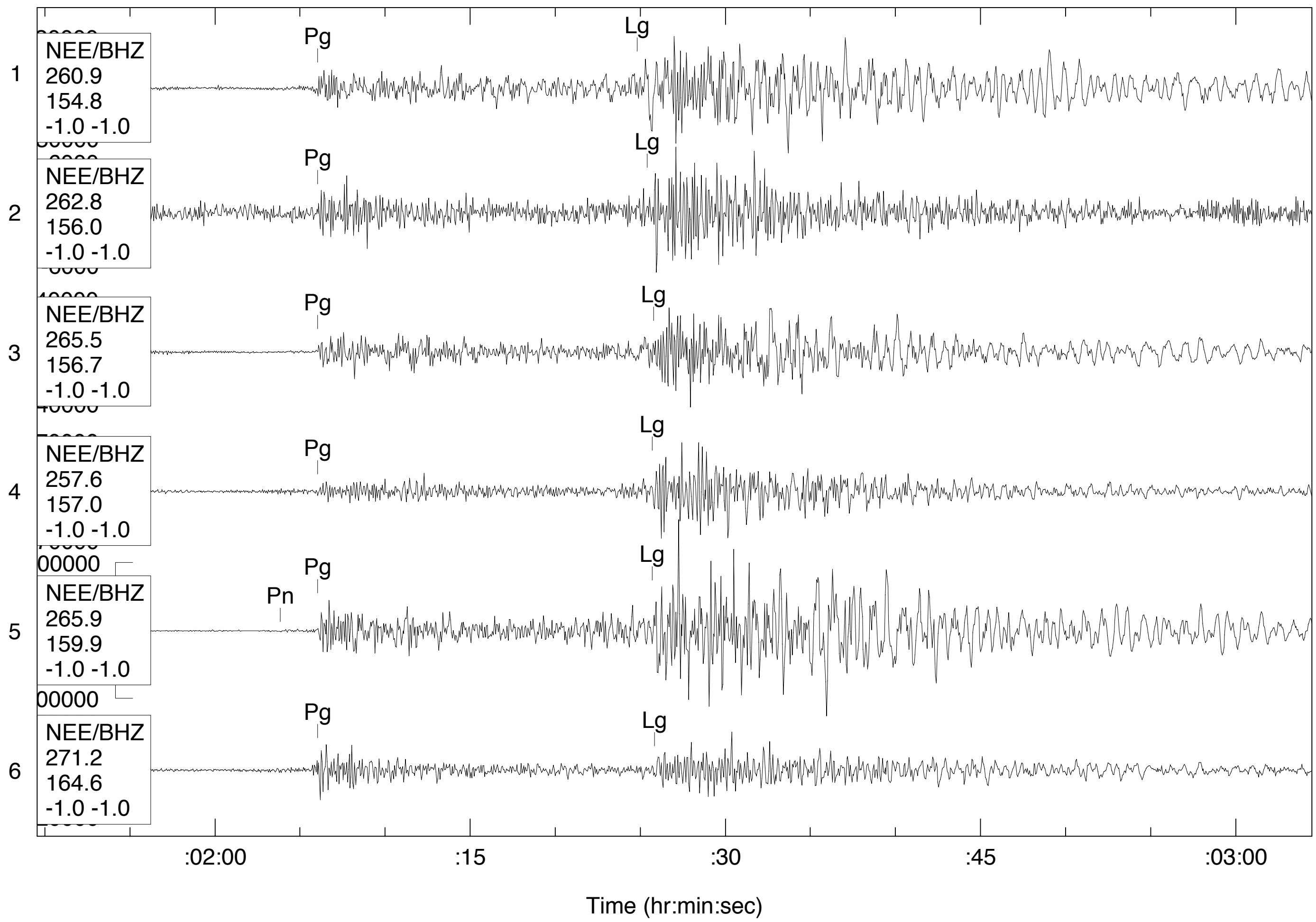

Fig. 9 illustrates a situation in which a small first arrival may be buried in noise and missed by the analyst, such that a second, larger phase may then be misidentified as the first arriving P-wave. This figure shows six Hector Mine earthquakes that record on the broadband vertical channels of station NEE, about 1.5 degrees distant. Trace 5 corresponds to the largest event (mb 4.5) in this group. Note that Pn and Pg were clear only for this event. The other traces show Pg as the first observable arrival, even though these events are located beyond the Pg/Pn crossover distance.

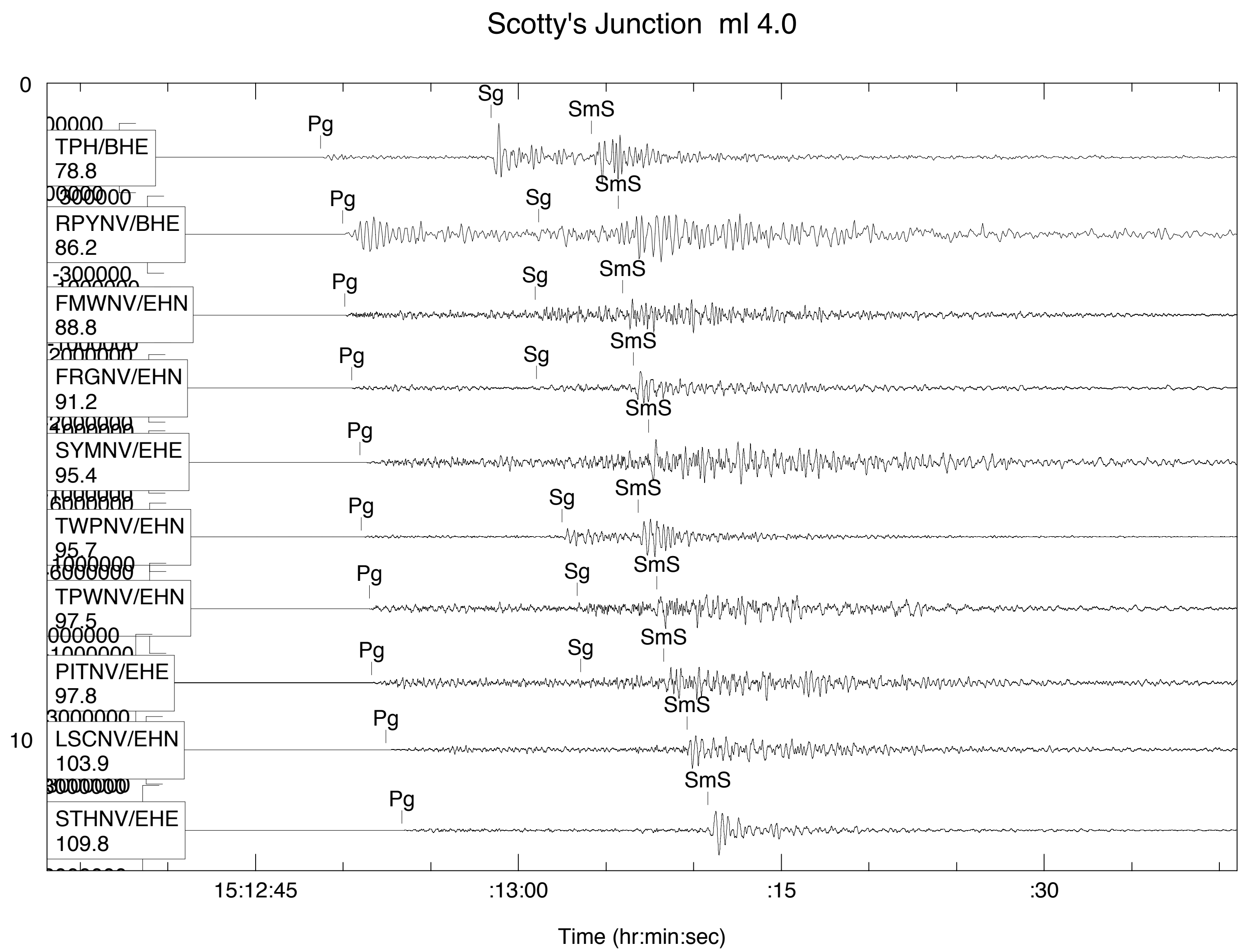

Fig. 10. Data from the UNR local network were available for earthquakes located at or near NTS. For these events, starting at a distance of about 80 Km large arrivals are commonly observed following Pg (and Sg) that we have identified as the mantle-reflected phases PmP (and SmS). In some cases such as the bottom traces above, Sg is too small to see above the preceding coda, and the only phase that appears is SmS; in such cases SmS could be mistaken for Sg during routine analysis.

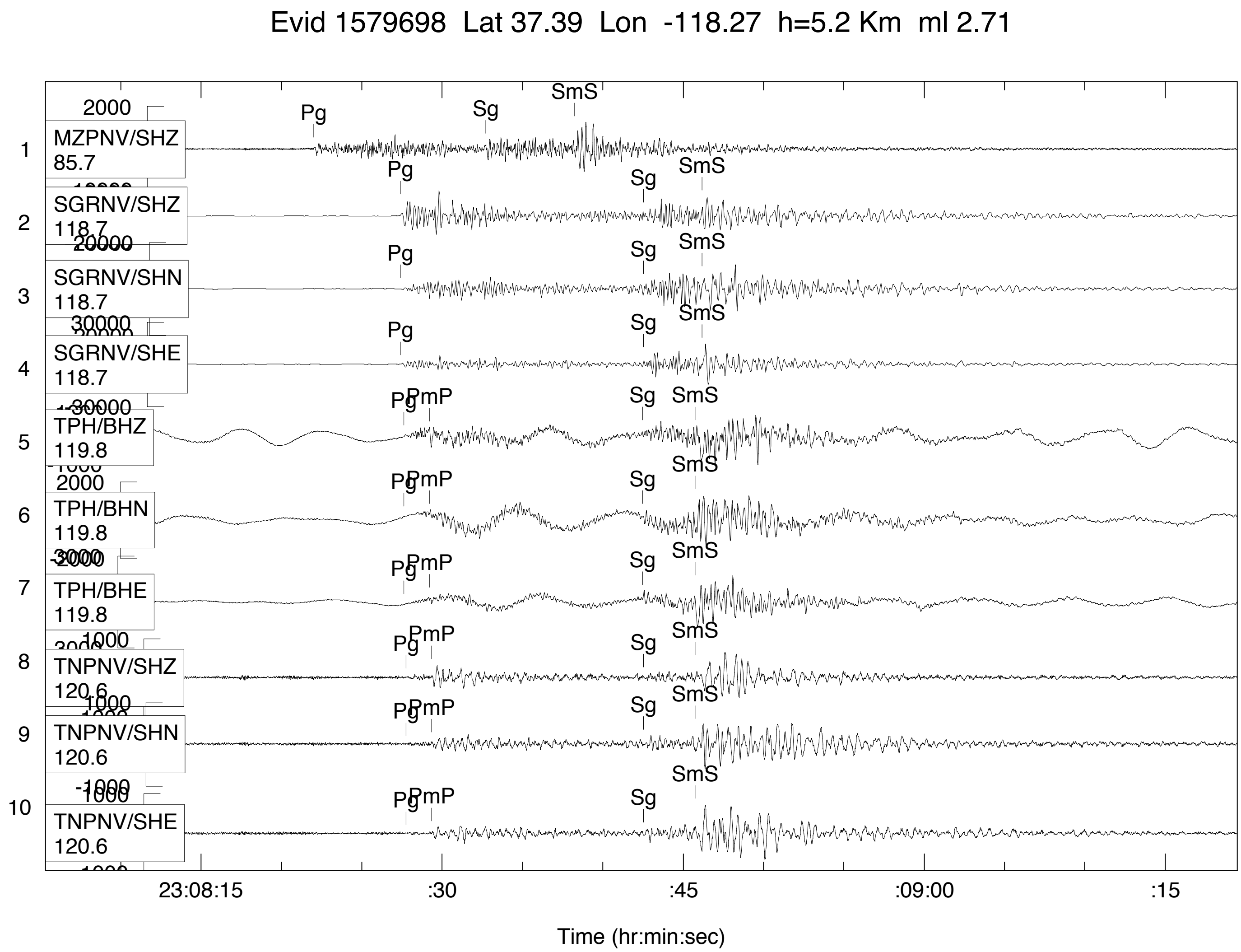

Fig. 11. Near the Pg/Pn (and Sg/Sn) crossover distance of about 120 Km we also see a small Pg (and Sg) phase followed by a larger arrival, and we have labeled the second phase PmP (SmS). Since Sn is not observed at stations in the southern Basin and Range region, this supports the identification of the two phases as Sg and SmS. This figure shows a small (ml 2.7) earthquake that that recorded at a subset of four UNR network stations The top trace in the figure is for a station at 85.7 Km distance, and it clearly shows Pg, Sg, and SmS phases. The other three stations are near the crossover distance of about 120 Km and the four recorded phases are labeled Pg, PmP, Sg and SmS. Again, this identification is supported by knowing that Sn is not observed in this region. However, a dilemma arises for the analyst if Sg is too small to be observed above the background, in which case the three phases could be identified as Pn, Pg and Lg.

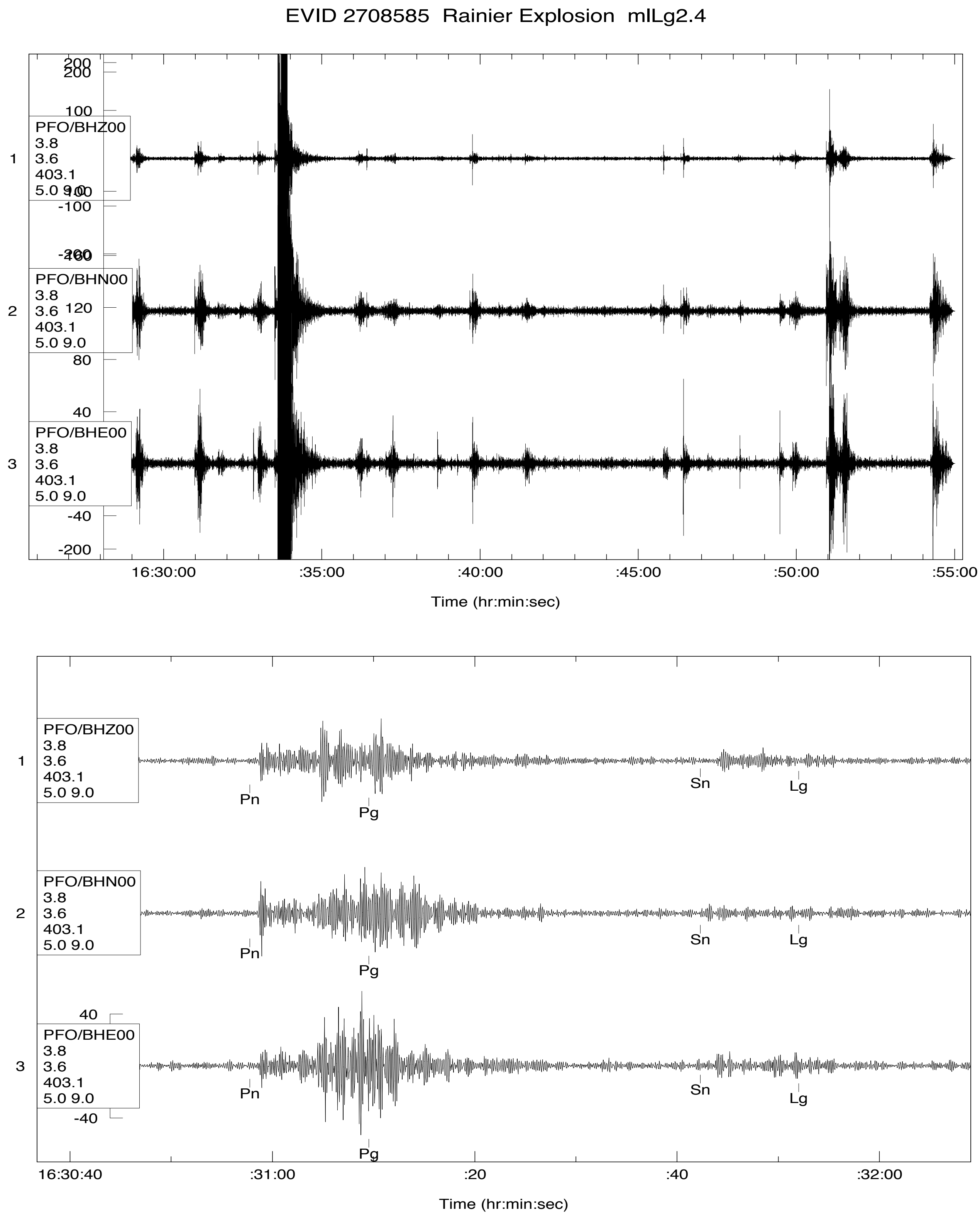

Fig. 12a. An example of interference by local earthquakes occurring near expected arrival times. The top plot shows a swarm of small local events that record at station PFO during the time of expected of arrivals for an explosion at Rainier Mesa. The bottom plot shows that one of these local events record at about the predicted Pn arrival time for this explosion. Theoretical arrivals Pn Pg Sn Lg are plotted beneath each of the 3-C channels.

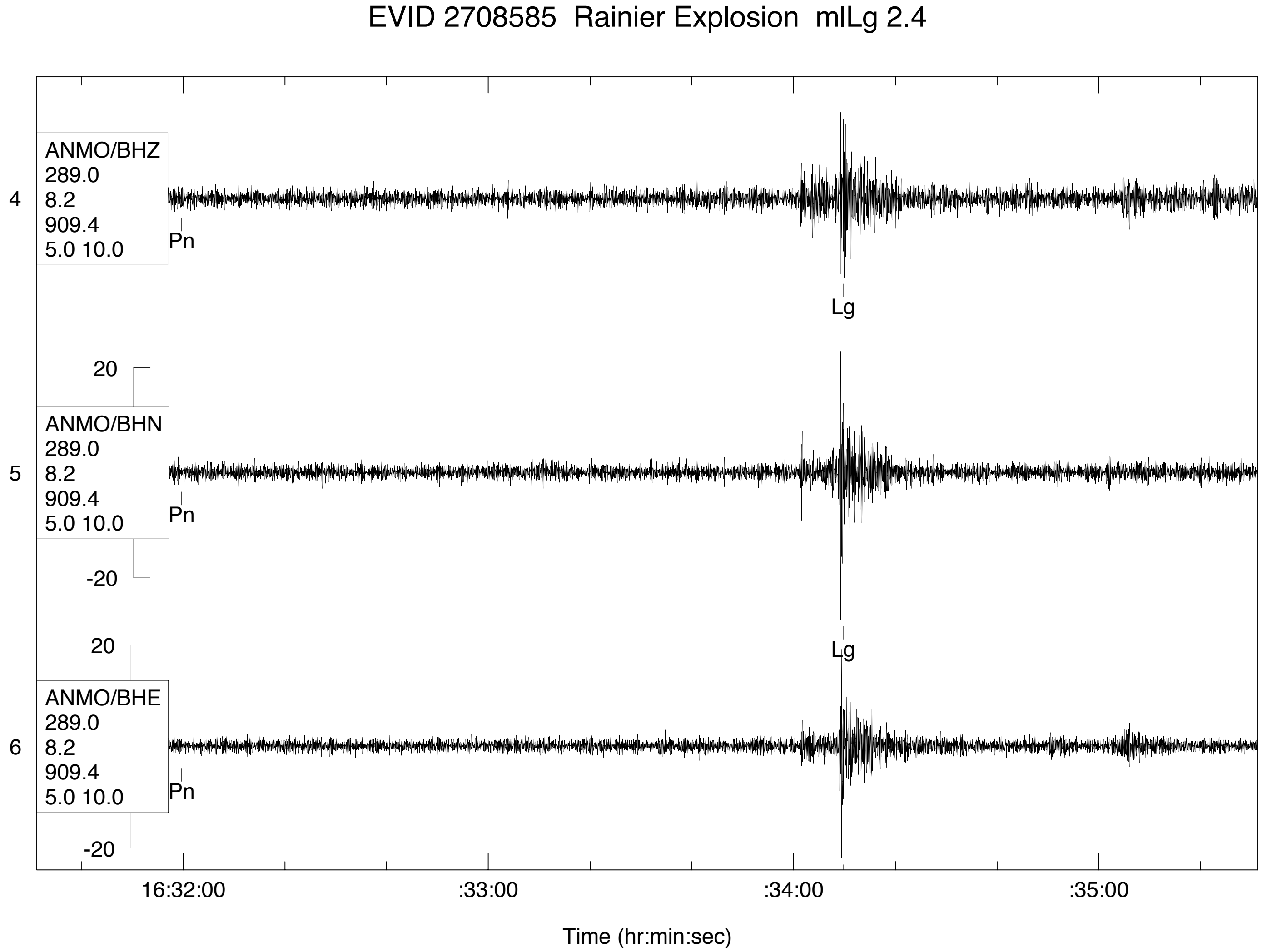

Fig 12b shows that coincidentally, station ANMO 8.2 degrees distant, records a small local event during the expected Lg arrival time for the same Rainier explosion as in Figure 12a. In any case, the event was too small to record at ANMO and probably at PFO also.

Evid 697661 traces 1-2; Evid 1324942 traces 3-8; small local events recording near phase arrival times

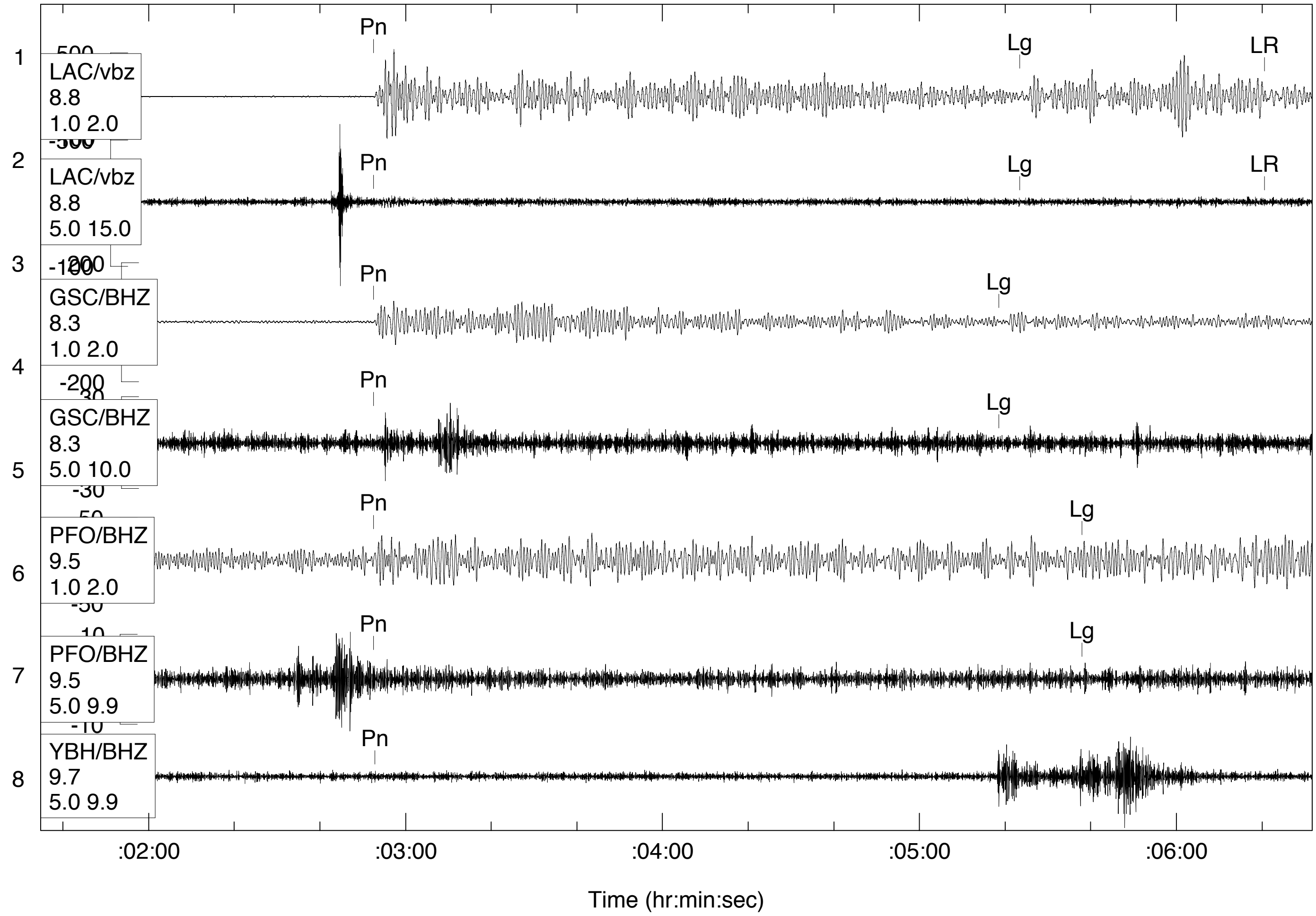

Fig. 13 shows a similar to Figure 12 interfering local event problem for four stations that recorded two Wyoming mine collapses. For each of the stations a short-period (1-2 Hz) filtered trace shows Pn and Lg phases from the collapses. However, a higher frequency (>5 Hz) band shows a number of local events that arrive near the times of these Pn or Lg arrivals at each of the stations.

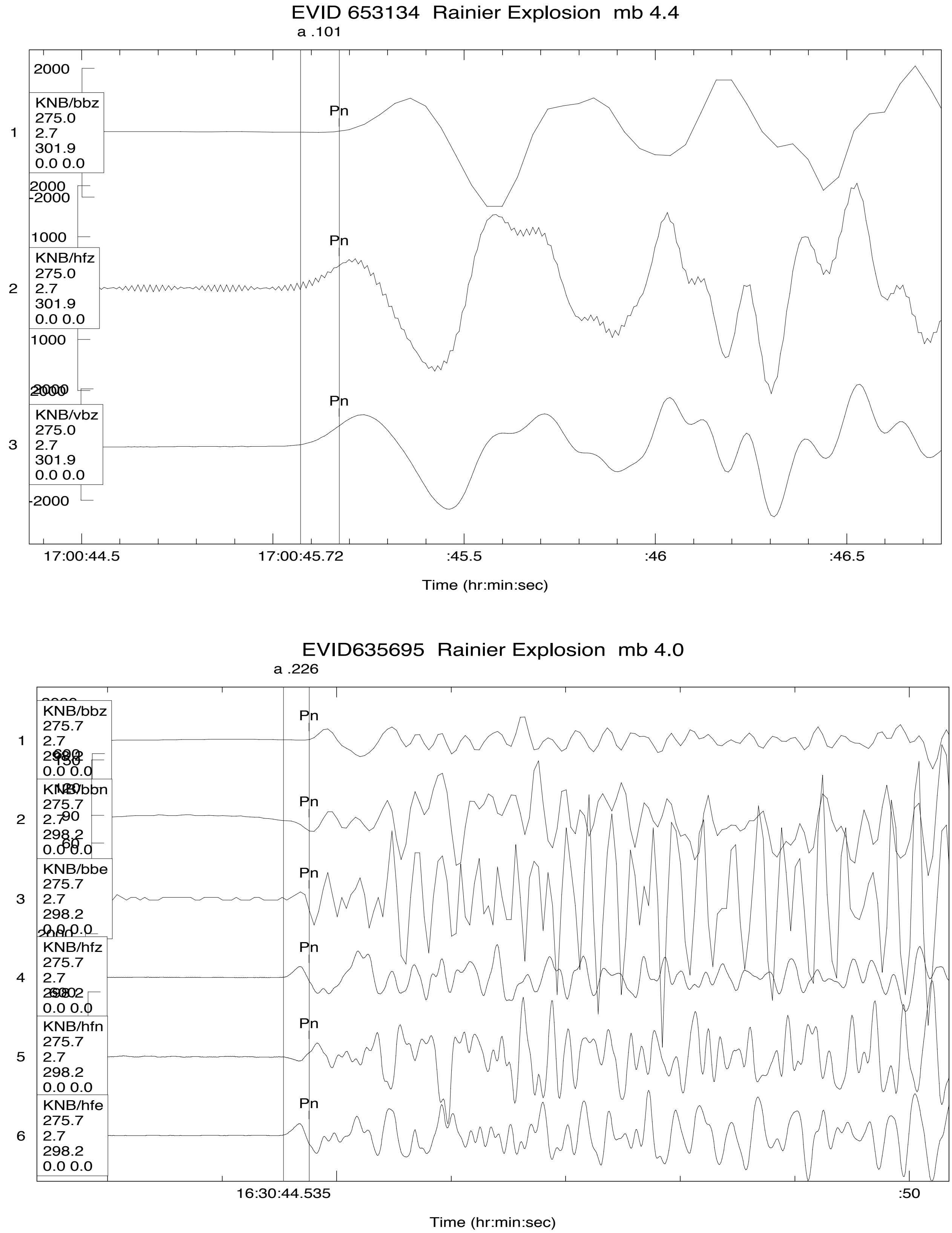

Fig 14. For some of the events, several stations had multiple 3-C instruments available (i.e., bb, hf, vb). In all those instances the bb channels were offset by +0.1s to +0.2s from the other two (top). In addition, there were instances where the horizontal channels were also offset by >= +0.1s from the vertical channel (bottom).