Spectral characteristics of the 11 May 1998 Pokhran and 28 May 1998 Chaghai nuclear explosions

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The concept of spectral magnitudes and spectral seismograms, recently developed utilizing broad-band seismic data permits finer insight into the seismic-source processes. It has been observed that on a spectral seismogram display, nuclear explosions have peak energy content in higher frequencies compared to earthquakes of the same magnitude at similar distances. The broad-band GEOSCOPE seismic station (HYB) at NGRI, Hyderabad, recorded the Pokhran explosion of 11 May 1998 as well as the Chaghai explosion of 28 May 1998. These two explosive sources exhibit a distinct difference in the energy contents in various frequency ranges. The Chaghai source had more energy in lower frequencies compared to the Pokhran sources. To ensure that this observation is not specific to the recording site, we analysed records of the newly established broad-band seismic stations of the India Meteorological Department. The intrinsic differences in their spectral characteristics are confirmed by this comparative study. We note that energy from the Pokhran event peaked in the frequency range of 3.5 to 6 Hz compared to a range of 1 to 3 Hz for the Chaghai explosion.

THE 11 May and 13 May 1998 Indian explosions at Pokhran, Rajasthan, and the 28 May and 30 May 1998 Pakistan explosions at the Chaghai hills, Baluchistan, have evoked worldwide attention both from the media and the scientific community. The recent scientific publications[1–3] mostly dealt with the yields of these two explosions on the basis of their magnitude estimates. The conclusions reached in these papers remain questionable to a large extent, in view of the inadequacy of representing the size of an explosion merely on the basis of magnitude, in addition to the underlying uncertainties in the various magnitude-yield relationships. The present work however does not attempt to estimate the yields of these events.

In this article, we have reported our studies on the spectral characteristics of the 11 May and the 28 May events by analysing the digital data from the Geoscope seismic station at Hyderabad and the newly established IMD broadband stations in India. The concept of spectral seismogram[4] has been used to study the frequency-time history of the two explosions.

A spectral seismogram is a two-dimensional multicoloured time-frequency representation of the broadband seismogram. In this approach, a broadband seismogram is passed through a number of overlapping band pass filters to obtain the corresponding bandpass seismograms. Each of these seismograms is then Hilbert transformed to obtain the corresponding instantaneous amplitudes with respect to time, for each mid-frequency. The resulting amplitudes are then represented using a colour code to obtain a spectral seismogram. The spectral seismograms effectively exhibit the frequency contents of each identifiable seismic phase, which are not readily identifiable in the original broadband recording.

The spectral seismograms provide information regarding the distribution of energy in different frequency ranges for various seismic phases. They are particularly useful for discriminating nuclear explosions from earthquakes in terms of the absence of longer period P-waves in the former[4].

The Geoscope station (HYB) at NGRI, Hyderabad, situated directly on the Precambrian granitic basement, is capable of recording seismic signals over a wide range of 360–0.125 s, without any distortion. This station has clearly recorded both the 11 May and the 28 May explosions. Spectral seismograms of the P-wave portions of these events have been generated, and are shown in Figures 1 and 2. A conspicuous absence of energy below 1 Hz can be observed for the Pokhran event. On the other hand, the spectral character of the Chaghai event appears markedly different, with the energy distributed over a wide frequency range, down to 0.1 Hz. Also, frequencies higher than 2 Hz, are found to contain very low energy for the Chaghai event. This interesting observation prompted us to seek verification from the other broadband data, gathered from stations at regional distances.

The India Meteorological Department (IMD) has recently upgraded 10 seismological observatories of its national network, distributed over various geological terrains, with broadband seismographs conforming to the standards of the Global Seismograph Network. These stations are located at Ajmer (AJMR), Bhopal (BHPL), Bhuj (BHUJ), Bilaspur (BLSP), Bokaro (BOKR), Karad (KARD), Madras (MDRS), Pune (PUNE), Trivandrum (TRVM), Vishakapatnam (VISZ). The locations of these stations, including that of HYB, have been shown in Figure 3 along with the explosion sites. Both these explosions are well recorded by most of the IMD observatories.

For both the explosions, the spectral seismograms in the distance range of 2.5–11.4° show two prominent wave groups: one in the first 5 s and the other in the next 15 s (Figures 4 and 5). The first group consists of Pn and mantle P; the second group consists of Pg and

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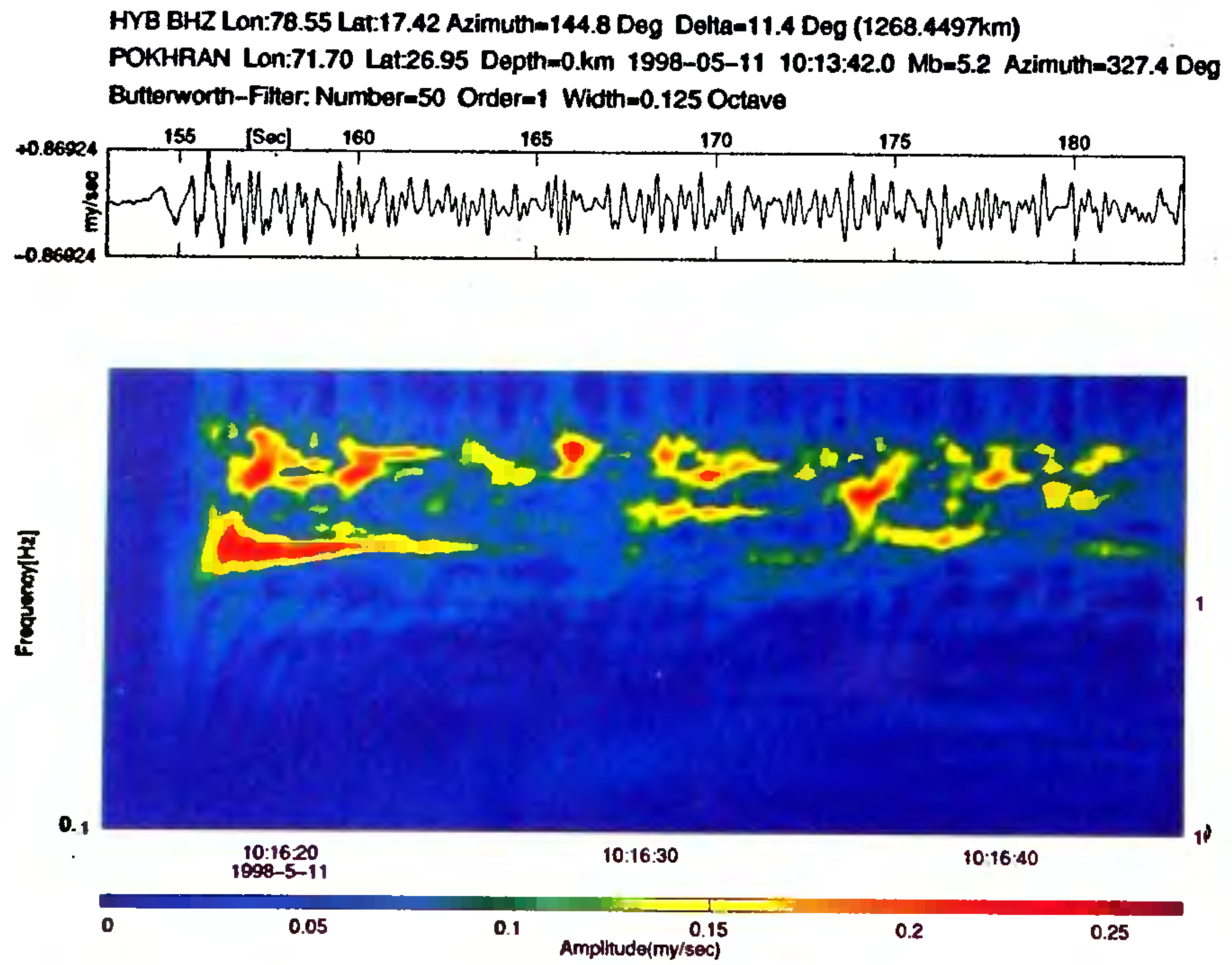

Figure 1. Broadband seismogram (top) and the corresponding spectral seismogram (bottom) at HYB of Pokhran (India) explosion.

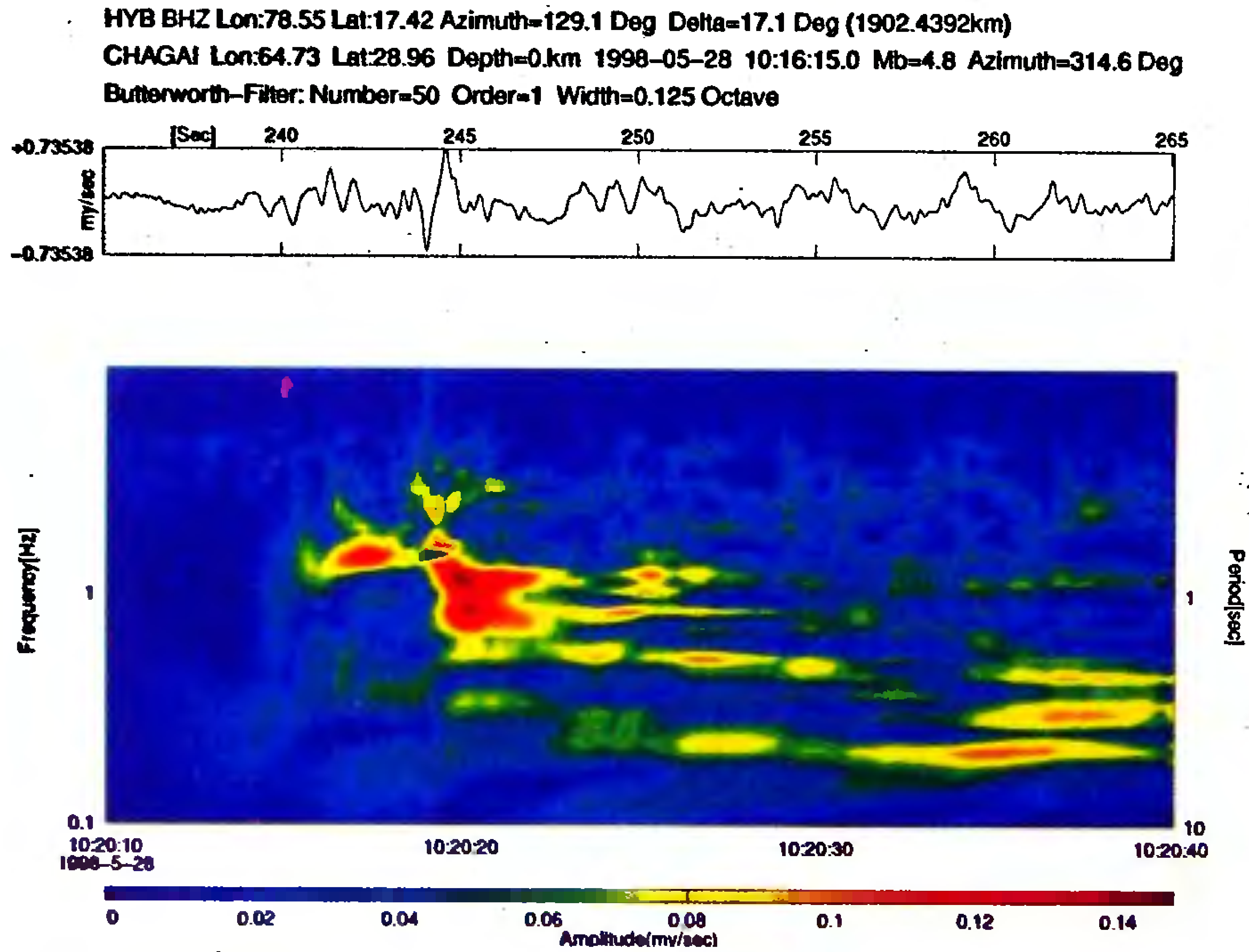

Figure 2. Broadband seismogram (top) and the corresponding spectral seismogram (bottom) at HYB of Chaghai (Pakistan) explosion.

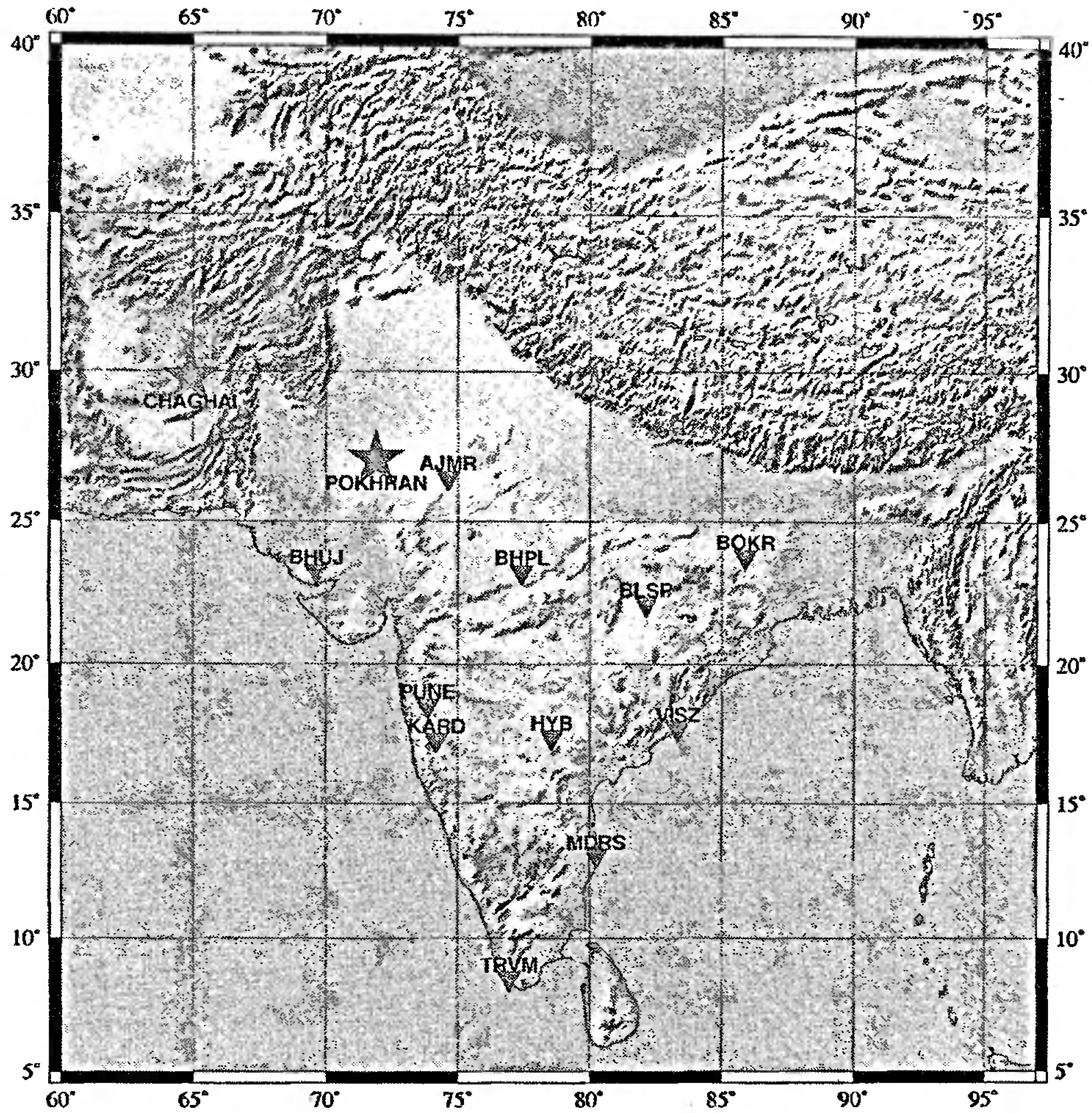

Figure 3. Locations of the broadband stations (triangle) in India and the sites of explosions (asterisk).

reflected and refracted P group. For the Pokhran explosion, both the wave groups have distinct differences in their spectral contents. The first group contains waves around 7 Hz, whereas the second group contains waves spread over a wider range of 1–7 Hz (Figure 4, for example). However, for the Chaghai explosion, the frequencies in both the wave groups range from 1–2 Hz (Figure 5, for example).

To quantify the above observations, we computed the P-wave energy in various frequency windows of 0.5 Hz width, from 0.5 to 8.5 Hz. The stations BHPL and BLSP were chosen for the Pokhran event. For the Chaghai event, we considered the stations BHUJ and AJMR, whose distances from the test site nearly agree with the distances used above for the Pokhran event.

It can be seen from Figure 6 that at AJMR and BHUJ stations the energy for the Chaghai explosion is concentrated in the frequency range of 1–3 Hz. On the other hand, the BLSP and BHPL records of the Pokhran explosion show energy concentration in a higher (3.5–6 Hz) frequency range. These observations are in conformity with those from the HYB broadband data that record the Indian explosion to consistently have higher frequency content compared to those of the Pakistan explosion.

Quantitative measures of the sizes of earthquakes and explosions are generally expressed in terms of magnitudes of various kinds: surface wave magnitude, body wave magnitude, moment magnitude, etc. calculated for waves with frequencies around 1 Hz, or lower. Various empirical relationships exist connecting these magnitudes with seismic energy release. However, theoretical relationships for computing seismic energy from spectral body wave magnitudes have also been determined using frequency-dependent magnitude calibration functions[5,6].

As has been earlier pointed out, the spectral seismograms of both the nuclear explosions under study show that the maximum energies are concentrated even at frequencies up to 7 Hz and not necessarily at 1 Hz. Hence, any type of magnitude, including m_b (the quantity often used in yield estimations), cannot measure the true size of the events, since the maximum energy concentrations are not represented. Computation of energy from such magnitudes and thereby estimating yields will therefore remain uncertain to a great extent. The spectral magni-

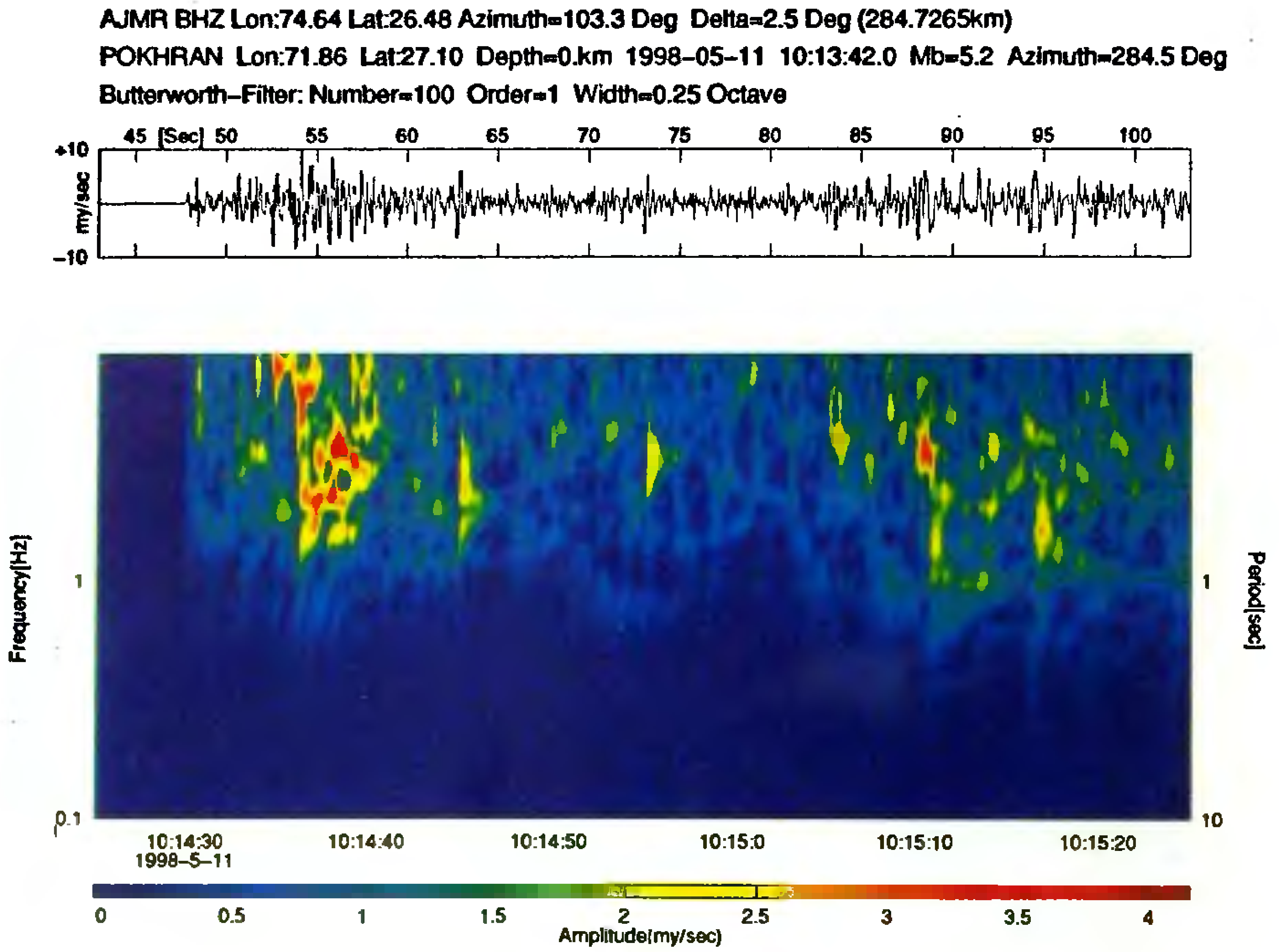

Figure 4. Broadband seismogram (top) and the corresponding spectral seismogram (bottom) at Ajmer of Pokhran (India) explosions. This is the nearest Indian broadband station from this test site.

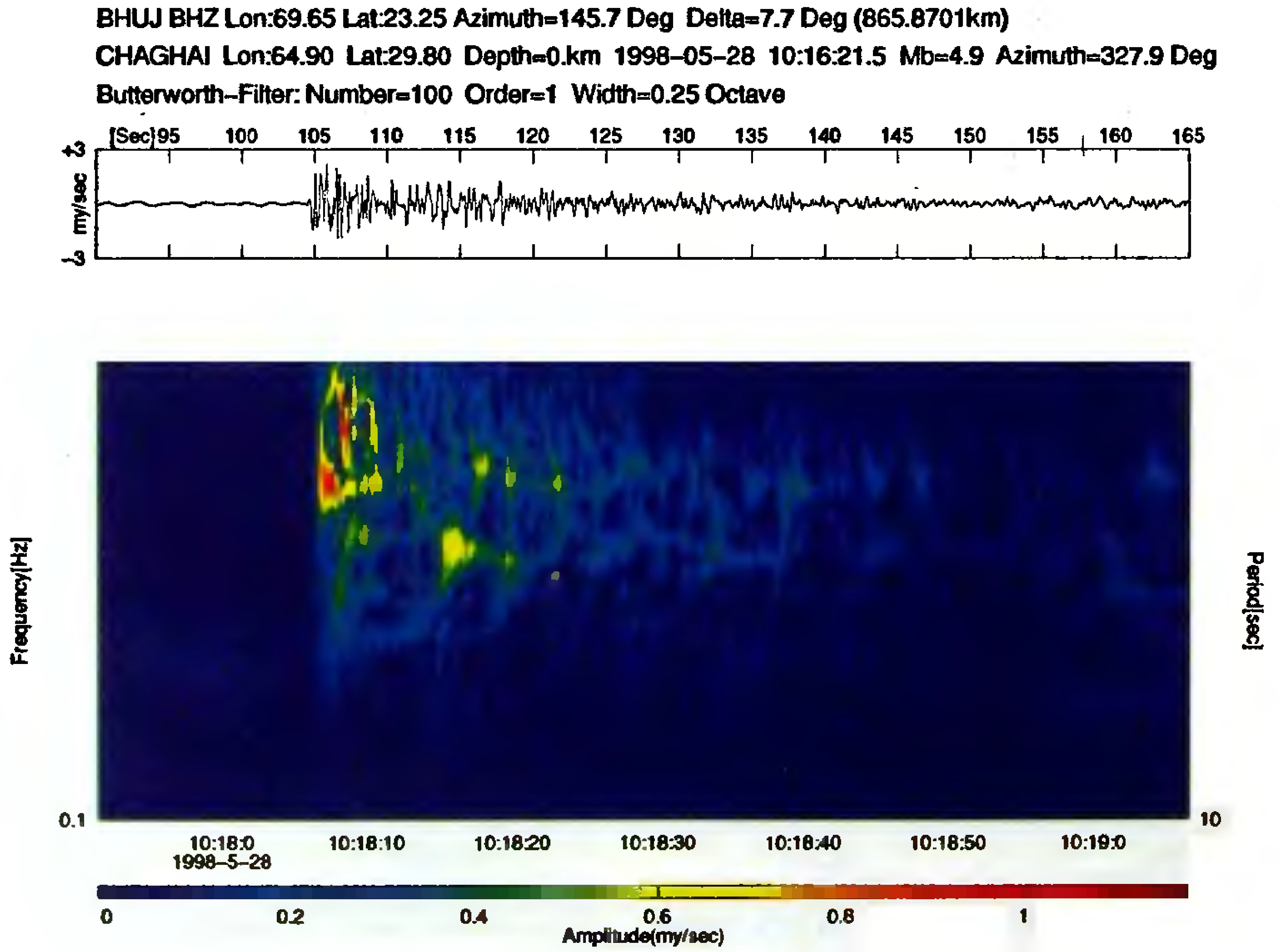

Figure 5. Broadband seismogram (top) and the corresponding spectral seismogram (bottom) at Bhuj of Chaghai (Pakistan) explosion. This is the nearest Indian broadband station from this test site.

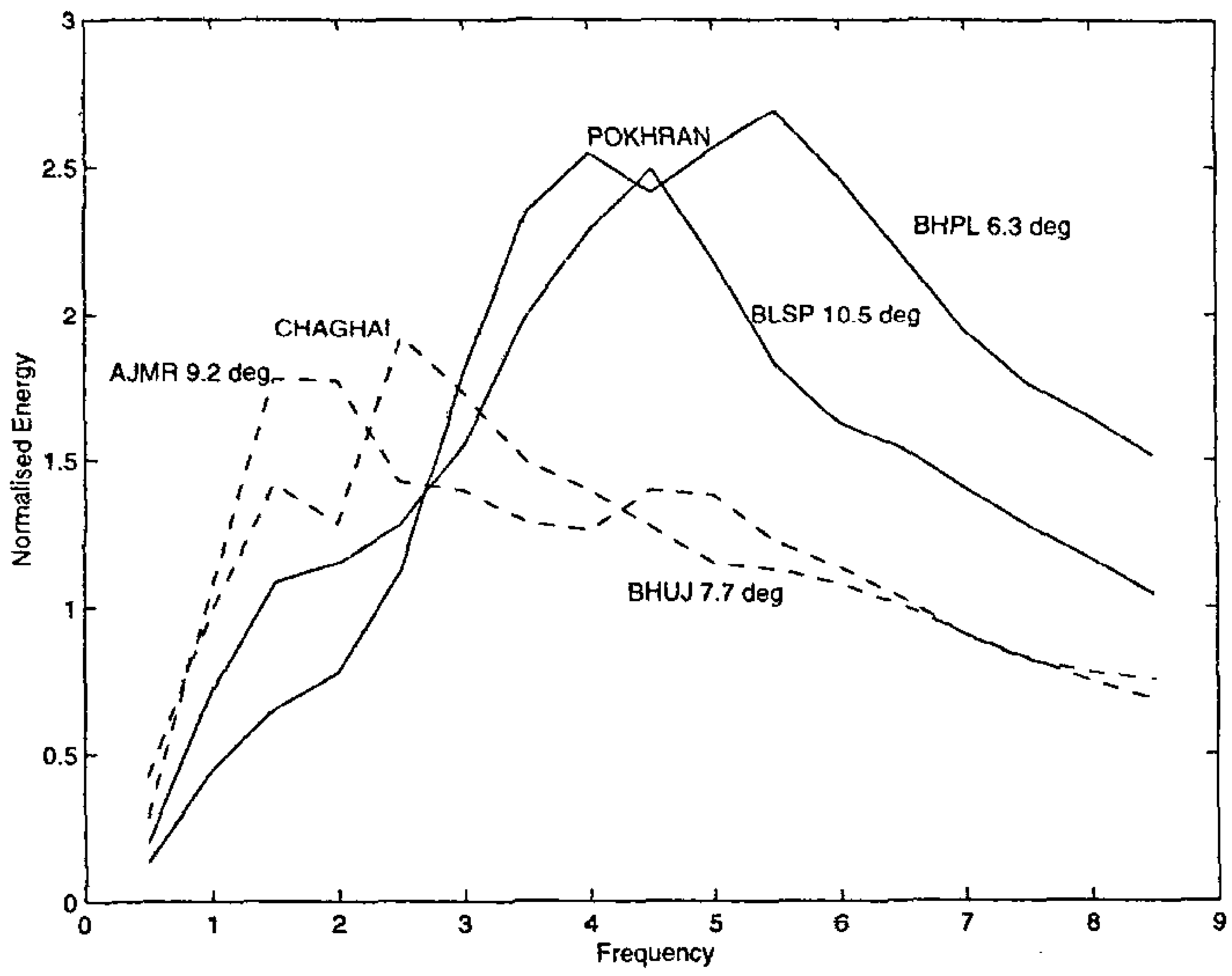

Figure 6. Comparison of spectral contents of Pokhran and Chaghai explosions at similar epicentral distances.

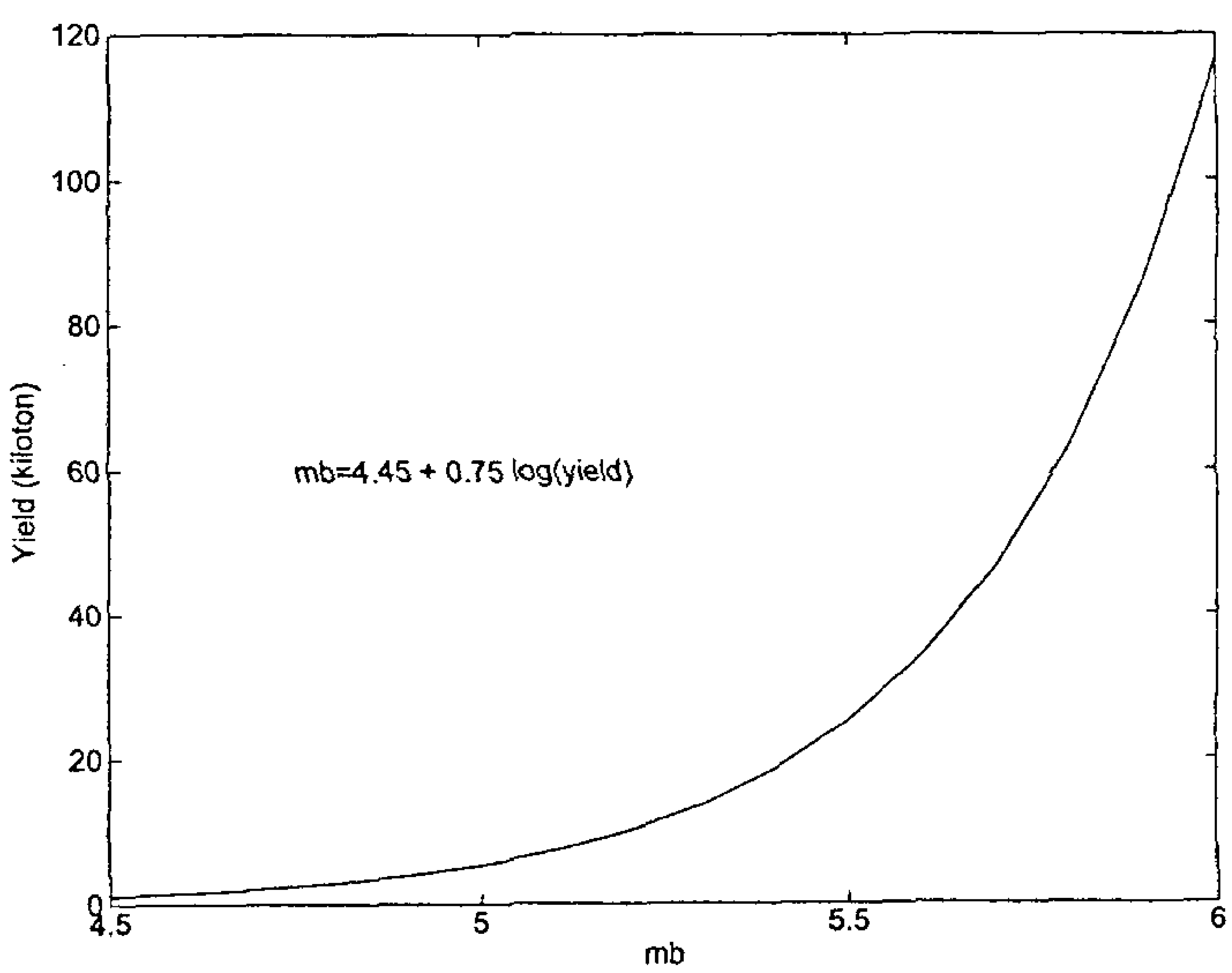

Figure 7. A typical magnitude-yield relation[3].

tudes do not offer a solution either, because the calibration functions are valid only in the teleseismic distances (> 20°), where frequencies greater than 1 Hz are almost completely attenuated. Also, direct estimation of yield of these explosions in our subcontinent from m_b values, using established m_b-yield relations, is not a correct approach. Such relations are understandably calibrated from a large number of known yield and m_b values of Nevada and Novaya Zemlya explosions, and we do not have any such data base to make a similar calibration applicable for the subcontinent. Moreover, the fact that the yield estimates are too sensitive to the magnitude values above a critical value (say, 5.6 in Figure 7), due to the exponential nature of the m_b-yield curve, complicates the issue further. This means that even if an 'appropriate' magnitude-yield relation is available, the yield estimates could lead to large errors due to slight variations in m_b determination, a situation very common. Hence, instead of trying to re-estimate the yields of these two explosions without having additional knowledge of the source details, we have attempted to find a possible explanation for the differences in their spectral characteristics.

Various studies on the mechanism of nuclear explosions[7,8] suggest that the release of elastic energy during an explosion can take place in the following ways:

i) as spherically symmetric compressional waves
ii) by wave conversion due to near-source inhomogeneities, including surface interaction
iii) owing to tectonic strain release consisting of cavity relaxation and discrete-triggered secondary source as a result of thrust faulting
iv) due to spall, where near surface compact crustal layers get parted.

Both (iii) and (iv) result in radiation of long periodic waves. These causes depend on the stress condition of the medium near the shot point, which in turn differs from site to site.

It may be noted that the Chaghai site is situated in a region of higher seismicity compared to the Pokhran test site. Also, the soil conditions at the two test sites are significantly different. While Pokhran is situated in the loose sands of the Thar desert, the Chaghai site is located in a relatively compact hilly terrain. Further, the Chaghai site is situated in a higher stress regime, being closer to a plate boundary. Since the spall effect is reported[9] to be predominant in the frequency range of 0.2–2 Hz, the long period energy from the Chaghai explosion appears to have been caused by secondary sources like spalling and tectonic stress release, the latter being caused by cavity relaxation[10].

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