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HIGH RESOLUTION GROUP VELOCITY VARIATIONS ACROSS CENTRAL ASIA

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ABSTRACT

This study is a companion to another study in this volume (Levshin *et al.*, 1996). The companion study's purpose is to estimate a lithospheric shear velocity model across the entire continent of Eurasia with lateral resolutions lying between 500 - 750 km by using broadband (20 - 225 s) measurements of Rayleigh and (20 - 150 s) Love wave dispersion. The purpose of this study is to attempt to sharpen the focus further in the structurally complex regions of Central Asia (Iran, Afghanistan, Pakistan, southern republics of the FSU, and W. China) where significant off-pure-path propagation has degraded the resolution in the continent-wide study. This is accomplished in two ways. First, we use here much shorter paths which originate from smaller earthquakes ($Ms \geq 4.0$) and which have been recorded on regional arrays and networks (KNET, KAZNET, PASSCAL-Tibet, historical FSU-Mongolia) in addition to global stations (GSN/CDSN, GEOSCOPE). We have used 289 earthquakes from 1988 through late-1995 and 56 stations from these networks, all lying within 27 degrees of KNET (Kirghiz Telemetered Seismic Network). Counting all the KNET measurements for an event as a single path, the resulting data set comprises more than 1,000 paths with an average path length of 1,900 km (contrasted with the 6,000 km average path length in the companion study). Second, shorter path lengths have resulted in dispersion measurements in large numbers down to 10 s period. These shorter period measurements appear robust and provide enhanced radial crustal resolution in Central Asia.

We have constructed group velocity maps from 10 s - 60 s period for both Rayleigh and Love waves. Shown here are group velocity maps for Rayleigh and Love waves at three periods: 10 s, 20 s, and 40 s. Although there is substantial agreement with the general features of the continent-wide dispersion maps discussed in the companion study, significant improvement in resolution is apparent in Eastern Iran, Afghanistan, Pakistan, the Central Asian Republics of the FSU, and Western China. For example, the Tarim Basin in W. China appears much more sharply imaged as a low velocity feature on the short period maps (10 s, 20 s) here than in the continent-wide study. High velocities appear associated with Tibet at short periods indicating relatively high velocities near to the surface contrasted with the much lower velocities at depth. A low velocity feature is observed in Western Pakistan that appears to translate southward with depth in the crust. A linear low velocity feature is associated with the Elburz - Kopet Ranges in Northeastern Iran and Northern Afghanistan. As an indication of the resolution of the method, high near surface velocities associated with the the Pamir range (only a few degrees in diameter) are resolved in the short period maps. Other smaller amplitude features appear associated with known tectonic structures.

Key Words: Central Asia, Tarim Basin, Tibet, Iran, Afghanistan, Pakistan, Kirghizstan, Kazakhstan, surface wave dispersion, Rayleigh waves, Love waves, group velocity

OBJECTIVE

The purpose of this research is to investigate whether the resolution of lithospheric (in particular crustal) shear velocity models in the structurally complex regime of Central Asia (Iran, Afghanistan, Pakistan, southern republics of the FSU, and W. China) can be improved relative to that achieved in continent-wide studies (e.g., companion paper in this volume, Levshin *et al.*, 1996). To improve resolution, we have modified the observational protocol discussed in the continent-wide study in the ways listed below. Rayleigh and Love wave dispersion measurements are obtained:

- on a lowered period band (10 - 60 s period) which provides improved depth resolution;
- on shorter surface wave paths (average path length is less than 2,000 km contrasted with the 6,000 km average path length in the continent-wide study) which reduces uncertainties in path locations;
- from relatively small earthquakes ($M_s \geq 4.0$) more densely spaced in Central Asia than in the companion study;
- at regional networks and arrays (KNET, KAZNET, PASSCAL-Tibet, historical FSU-Mongolia) as well as global stations (GSN/CDSN, GEOSCOPE) in Central Asia.

A more sharply focused model of lithospheric shear velocities in Central Asia is useful in a variety of ways. Most significantly for a CTBT, accurate high resolution structural information is needed to improve location capabilities in the structurally complex regions of Iran, Pakistan, Afghanistan, Western China, and Northern India. Location error ellipses mainly quantify ignorance concerning the structure of the crust (sedimentary thicknesses and velocities, crustal velocities and Moho topography). Focused studies of intermediate period surface wave dispersion using regional earthquakes and seismic networks, such as the one described here, promise significantly improved crustal models on regional scales.

RESEARCH ACCOMPLISHED

As in the continent-wide study of Levshin *et al.* (1996), research to date has proceeded in three steps: (1) data acquisition and dispersion measurement, (2) determination of measurement reliability, and (3) group velocity map construction. We will discuss each of these steps briefly in turn.

Data Acquisition and Processing

The reader is referred to Ritzwoller *et al.* (1995) and Levshin *et al.* (1996) to find a discussion of the processing protocol of this study. This study differs from the continent-wide study of Levshin *et al.* (1996) by utilizing much shorter paths which originate from smaller earthquakes ($Ms \geq 4.0$) and which have been recorded on regional arrays and networks (KNET, KAZNET, PASSCAL-Tibet, historical FSU-Mongolia) in addition to global stations (GSN/CDSN, GEOSCOPE). The use of group times rather than phase times allows us to use earthquakes for which there is no detailed source information beyond a location estimate. Phase velocity measurements require moment tensor estimates. We have used 289 earthquakes (Figure 1) from 1988 through late-1995 and 56 stations (Figures 1 and 2) from these networks, all lying within 27 degrees of KNET (Kirghiz Telemetered Seismic Network). Counting all the KNET measurements for an event as a single path, the resulting data set comprises over 1000 paths (Figure 2) with an average path length of 1900 km (contrasted with the 6000 km average path length in the companion study). This information is summarized in Table 1.

Table 1. Origin of Data (All within 27° of KNET)

Network	*Number of stations*	*Number of events*
GSN	11 (3 CDSN)	97
GEOSCOPE	2	9
KNET	11	141
KAZNET	7	30
PASSCAL (Tibet)	11	21
FSU-Mongolia	14	21
Total	56	289

Data Reliability

A 'cluster analysis' similar to that described briefly by Levshin *et al.* (1996) has been performed. The reader is referred there for a discussion. The number of 'unique paths' as a function of period is shown in Figure 3a and the path number density is displayed in Figure 3b. Path number density peaks in Kirghizstan where KNET (e.g., Vernon, 1994; Pavlis *et al.*, 1994) is located, but is also quite good in Eastern Iran, Afghanistan, Pakistan, Northernmost India, and Western China. The existence of regional networks such as KNET and KAZNET (Kazakhstan Network, Kim *et al.*, 1995) allows for detailed reliability studies across the network to be performed which are impossible using global stations alone. Figure 5 illustrates the use of regional network data, KNET here, to estimate uncertainties in dispersion measurements.

Group Velocity Maps

All dispersion measurements have been weighted by results of the cluster and reliability studies discussed above, and have then been used to estimate the Central Asian group velocity maps. These maps represent the local group speed of a Rayleigh or Love wave propagating at a particular spatial point. Maps have been constructed for Rayleigh and Love waves ranging between 10 - 60 s period. Included here are maps at 10 s, 20 s and 40 s period shown in Figures 6 - 8, respectively. The features in Central Asia that appear on the group velocity maps in the continent-wide study of Levshin *et al.* (1996) are spatially much larger and more smeared, presumably due to off-pure-path propagation that manifests itself as a reduction in resolution in structurally complex regions such as Central Asia. The features comprising the maps shown in Figures 6 - 8 appear to be better resolved than in the continent-wide study and, as discussed in the next section, are correlated with known tectonic structures.

Cursory Interpretation

Levshin *et al.* (1996) briefly discuss how to interpret group velocity maps. This information illuminates the maps shown in Figures 6 - 8 here.

The map shown here that possesses the greatest depth penetration is the 40 s Rayleigh wave map. This maps exhibits very large amplitude variations due principally to Moho topography to which the shorter period waves are relatively insensitive. The shorter period maps display a number of features that are generally consistent with the continent-wide maps of Levshin *et al.* (1996) but are apparently in sharper focus. For example, the Tarim Basin of Western China is clearly seen as a low velocity feature on the 10 and 20 s maps. Tibet appears on these maps as a high velocity feature, to be contrasted with the longer period maps where it appears as a low velocity feature. Presumably, there are relatively high shear wave velocities in the upper crust underlying Tibet. A linear low velocity feature also shows up on the 10 and 20 s maps in Northwestern Iran and Northern Afghanistan associated with the Elburz - Kopet Ranges. The Kazakh Platform is fast on all the maps. The resolution of these maps is demonstrated by the fact that the Pamir Range (~38N, 73E) appears as a high velocity feature only a few degrees in diameter at both 10 and 20 s period.

CONCLUSIONS AND RECOMMENDATIONS

Regional scale surface wave dispersion studies, such as the study of the group velocity variability in Central Asia presented here, can be used to improve both lateral and radial resolution relative to continent-wide studies (e.g., Levshin *et al.*, 1996). This is particularly important in structurally complex regions such as Central Asia, since these regions significantly perturb wave paths propagating on continental scales (i.e., $\geq 5,000$ km). These perturbations create uncertainties about the location of wave paths that manifest themselves as regions of lowered resolution on group velocity maps and, ultimately, on continent-wide models of lithospheric velocity. Additionally, dispersion measurements on regional scales can be extended to shorter periods than continent-wide studies which provides improved radial resolution in the crust. These maps will be merged with those from the companion continent-wide study and then inverted for lithospheric shear velocity structure.

The principal recommendation that emerges from this study is that regional surface wave dispersion studies should be performed elsewhere in Eurasia, in areas of interest to CTBT monitoring that possess regional arrays or networks internal or peripheral to each area. One example is the Far East, centered on North Korea, where there is abundant well distributed seismicity and where GSN, GEOSCOPE, CDSN, POSEIDON, PASSCAL-Baikal, JNET, and DoD stations and arrays are located. The Middle East, centered on IRAN, is a similarly prime region for study, since it possesses well distributed seismicity and GSN, GEOSCOPE, Saudi Network, PASSCAL-Pakistan, and DoD stations provide fairly good peripheral coverage.

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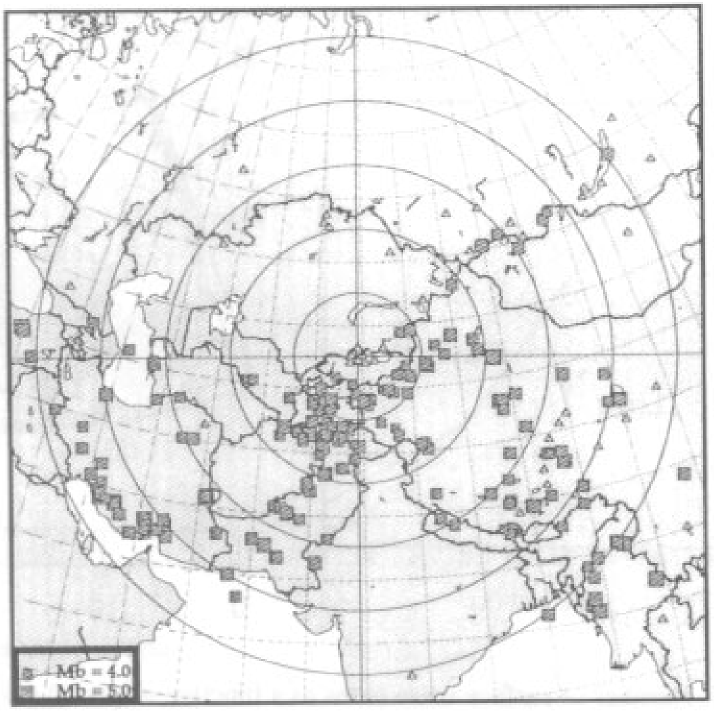

Figure 1. Distribution of sources (squares) and receivers from GSN, GEOSCOPE, KNET, KAZNET, PASSCAL & FSU networks used in the surface wave studies of Central Asia

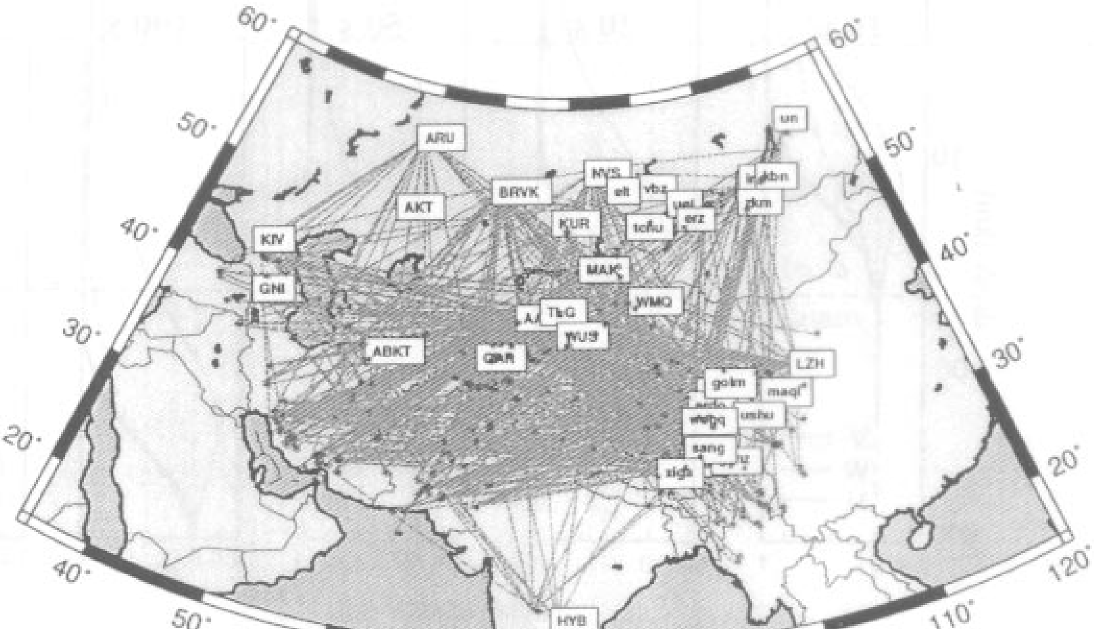

Figure 2. Source - station paths used for tomographic inversion of Central Asia group velocity data

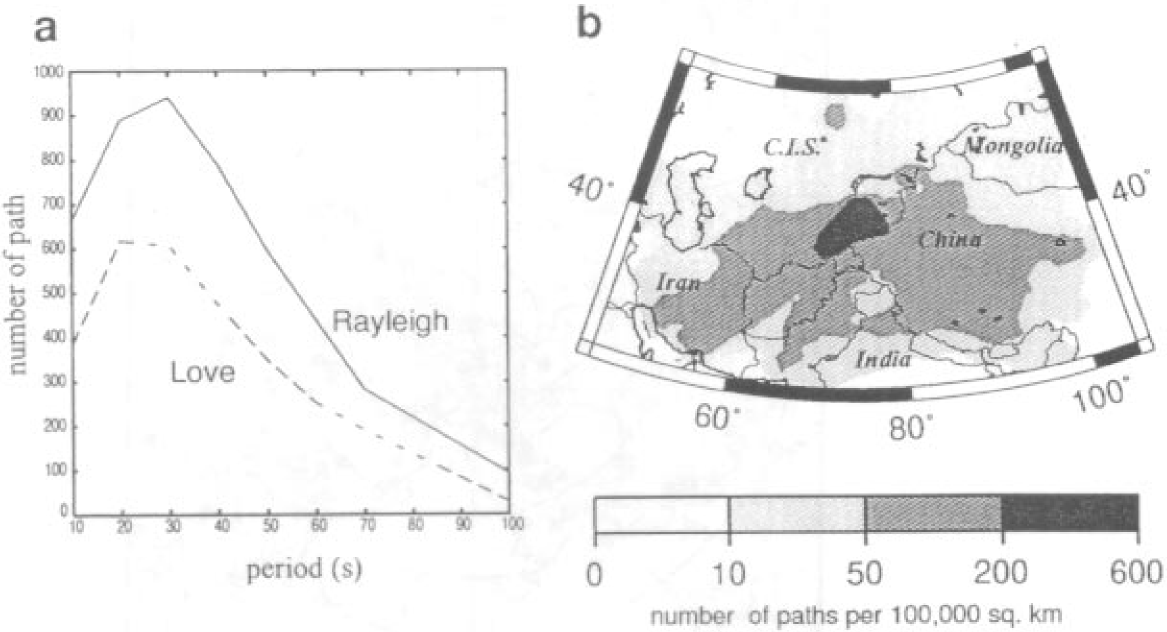

Figure 3. Number of surface wave paths as a function of period (a), and the path density for 30 s period (b).

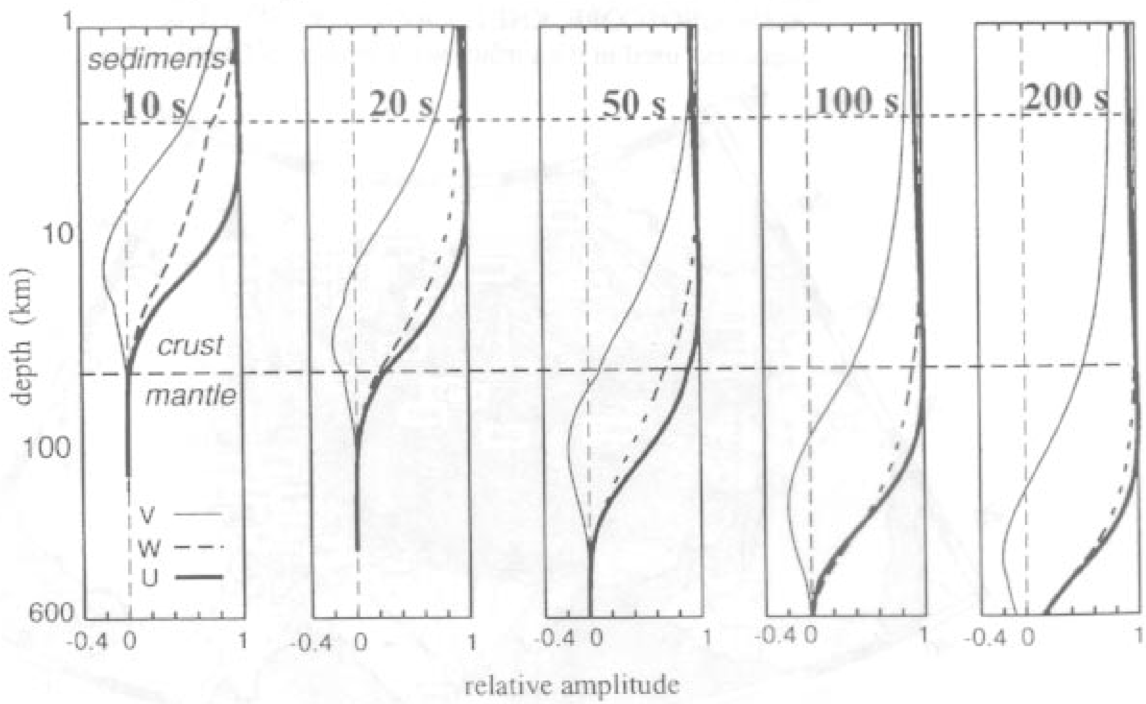

Figure 4. Eigenfunctions of Rayleigh (U, V) and Love (W) waves for different periods in the continental Earth model.

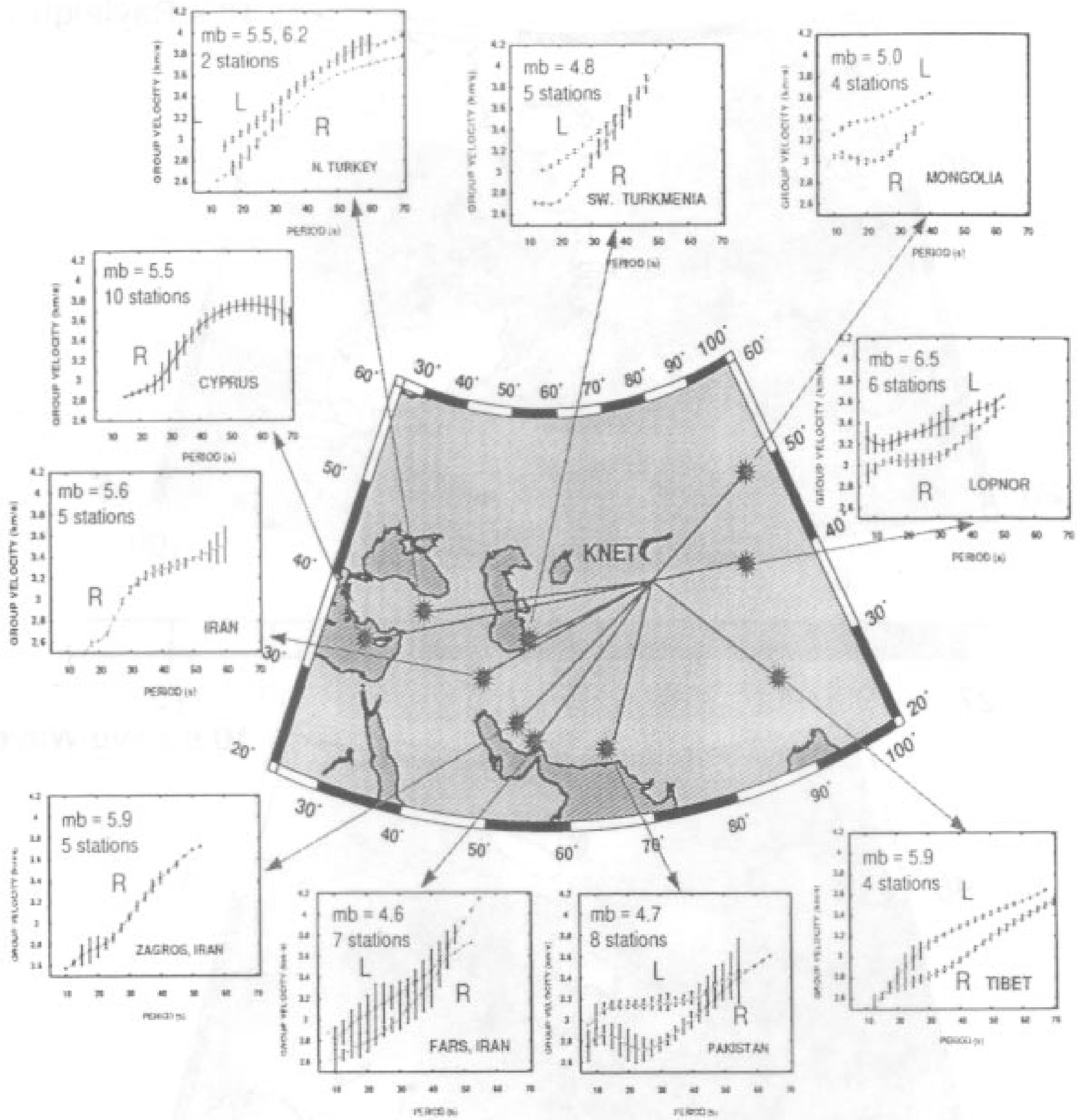

Figure 5. Group velocity variability across KNET is presented for Rayleigh (R) and Love (L) waves. One standard deviation 'error bars' are shown at periods where measurements from at least 3 stations exist, in order to represent variability observed for a variety of source regions around Central and Southern Asia.

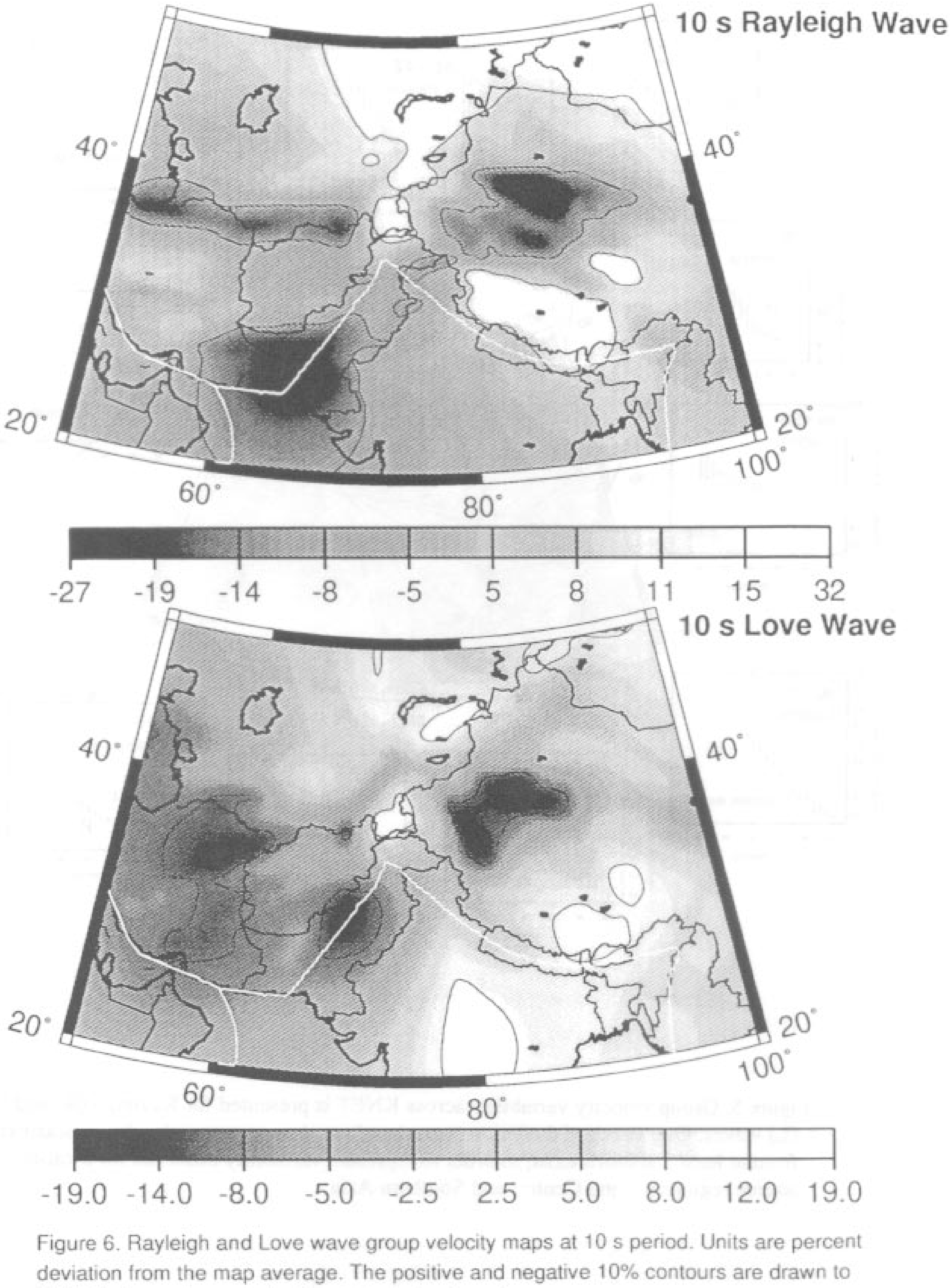

Figure 6. Rayleigh and Love wave group velocity maps at 10 s period. Units are percent deviation from the map average. The positive and negative 10% contours are drawn to highlight the regions of significant deviation from the map average.

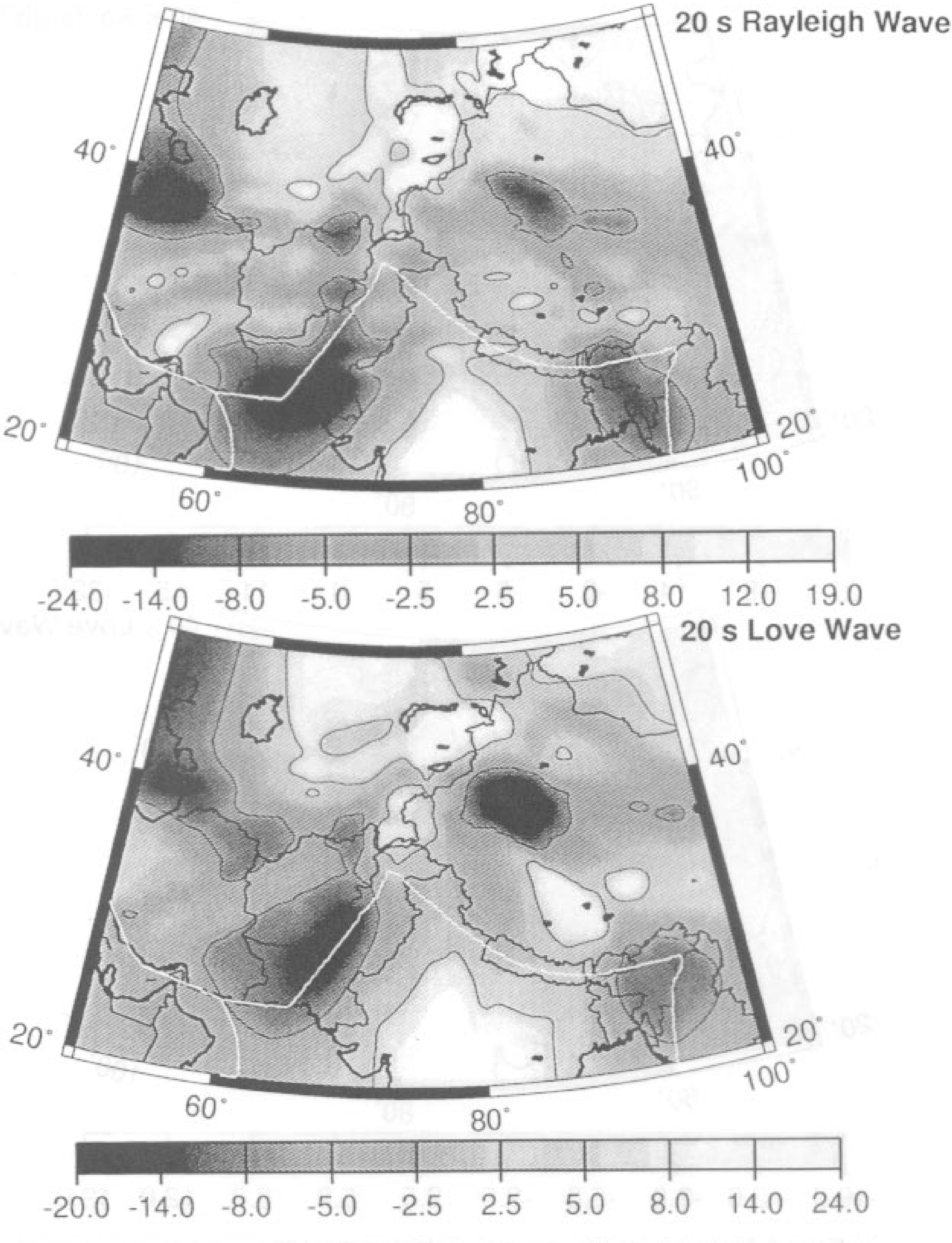

Figure 7. Rayleigh and Love wave group velocity maps at 20 s period. Units are percent deviation from the map average. The positive and negative 6% contours are drawn to highlight the regions of significant deviation from the map average.

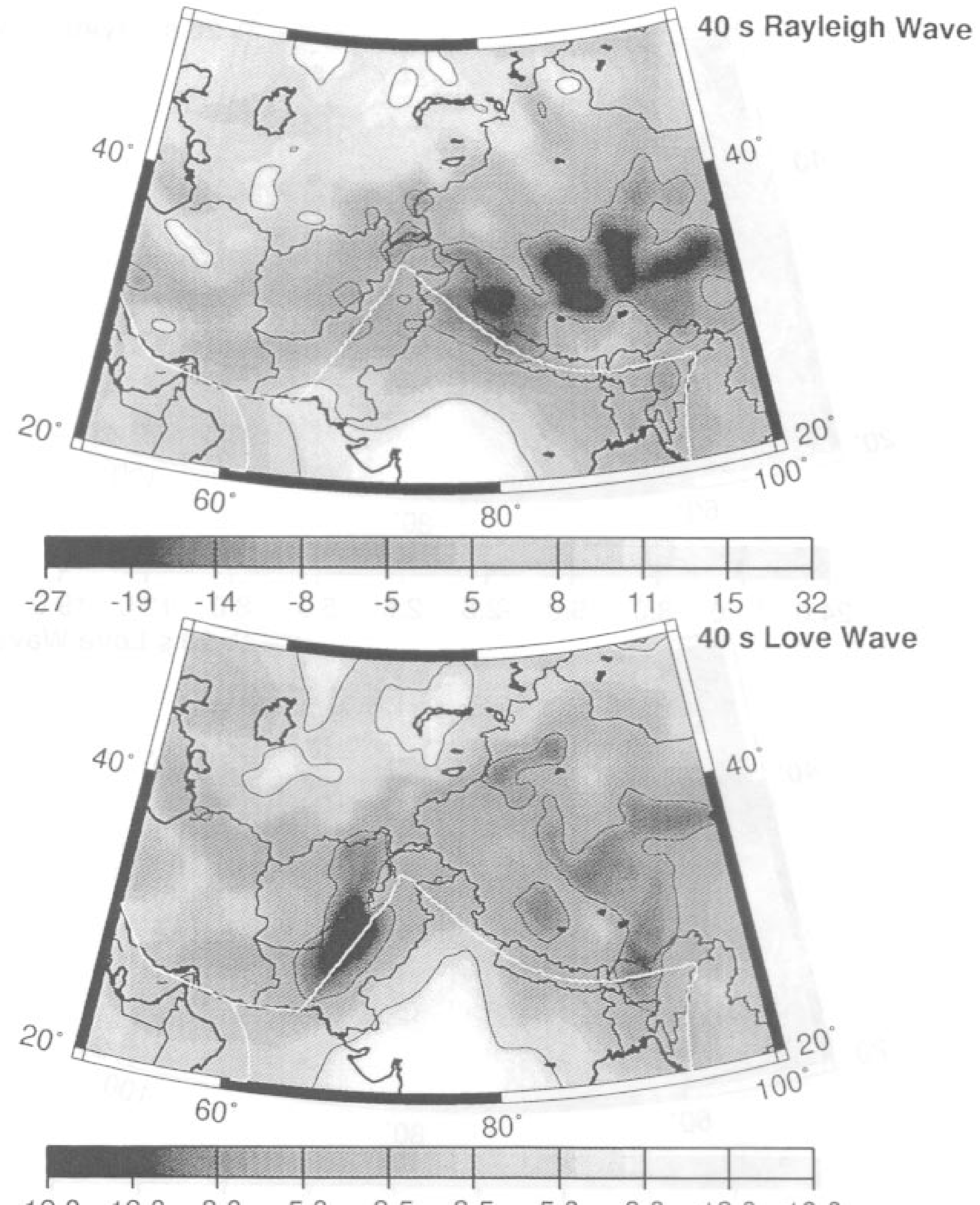

Figure 8. Rayleigh and Love wave group velocity maps at 40 s period. Units are percent deviation from the map average. The positive and negative (10%, 6%) contours are drawn on the (top, bottom) figure to highlight regions of significant deviation from the map average.