TWO STUDIES IN CENTRAL ASIAN SEISMOLOGY: A TELESEISMIC STUDY OF THE PAMIR/HINDU KUSH SEISMIC ZONE AND ANALYSIS OF DATA FROM THE KYRGYZSTAN BROADBAND SEISMIC NETWORK

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In memory of the victims of the Suusamyr earthquake.

It is my hope that perhaps this work may, in some small manner,

help alleviate the suffering from future catastrophes.

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Chong ragmad y'all!

Two studies in Central Asian seismology: A teleseismic study of the Pamir/Hindu Kush seismic zone and analysis of data from the Kyrgyzstan broadband seismic network

Robert J. Mellors

The thesis consists of two separate studies: (1) an analysis of lateral velocity variations associated with the Pamir and Hindu Kush seismic zones and (2) a study of the seismicity and tectonics of the Kyrgyz Tien Shan, with emphasis on a major earthquake and its aftershock sequence. In the first study, I used teleseismic arrival time data from analog seismic stations in Tadjikistan and northern Afghanistan to invert for velocity perturbations in the crust and upper mantle of the Pamir-Hindu Kush. The results show a strong (up to 6%) well-resolved zone of high velocities in the upper mantle at depths greater than 200 km, coincident with the location of the deep Hindu Kush earthquakes. No clear velocity perturbations are associated with the deep Pamir earthquakes. Above 200 km little correlation is observed between the velocity perturbations and the seismic zone, but indications of thicker crust under the Pamir and thinner crust under the Tadjik Depression are seen. I interpret these high velocities under the Hindu Kush as evidence of oceanic lithosphere at depth, possibly resulting from the subduction of an isolated section of oceanic lithosphere. The lack of velocity anomalies in the upper segments of the Hindu Kush and Pamir seismic zones may indicate the subduction of continental lithosphere.

The second study concentrated on data from the Kyrgyzstan broadband seismic network (KNET), which consists of 10 telemetered broadband seismometers installed in the area around Bishkek, Kyrgyzstan. In 3 1/2 years of operation it has recorded two nearby aftershock sequences, and numerous local, regional, and teleseismic events. Most local earthquakes are concentrated along the Kyrgyz Range in a diffuse pattern, suggesting that the seismicity occurs throughout a complex set of faults rather than on

one main range-bounding fault. Many quarry blasts were also recorded, which allowed calibration of velocity models for network locations. The high dynamic range and broadband response of the KNET seismometers permits observation of a range of phenomena seldom observed by conventional systems. These include: (1) a ramp-like phase between the P and the S wave arrivals that is observed on several dozen nearby (< 15 km distance) events. This ramp probably represents the effect of near-field source terms; (2) a pronounced vertical displacement signal that coincides with the arrival of the S wave for a number of high-amplitude local events. This displacement appears to be due to an instrumental or site effect; (3) strong variations in aftershock waveforms that appear to be dependent in part on source depth; and (4) variations in S wave amplitude across the network from regional events, especially those from the south.

The Ms 7.4 Suusamyr, Kyrgyzstan earthquake of 19 August 1992 was studied using aftershock data, a teleseismic body wave inversion, and field observations. The combined analysis defined a 50 km-long, east-west rupture zone that dips 50° to the south and extends to a depth of 18 km. The rupture originated at the eastern end at depth and propagated westward, and probably included at least one sub-event. The three large (Ms > 6.0) aftershocks that occurred immediately after the main shock also showed a progression with time from east to west. A strong correlation between the aftershock zone and topography was noted, suggesting that the topography is largely fault controlled. The Suusamyr event demonstrates that a large amount of current shortening is accommodated along high-angle reverse faults within the Tien Shan in addition to that occurring along the range-bounding fault systems. This event also clearly shows the 3-dimensional geometry of an active, basement-involved, intra-continental thrust.

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CHAPTER 1:

Introduction

Scattered all across Central Asia, from the dusty plains of Turkmenistan to the airy peaks of the Tien Shan, seismometers quietly record every bump and twitch of the earth. The first instruments to record and locate the earthquakes that strike this seismically active area were installed in the 1920s [*Galperin et al.*, 1986]. Since then, the sophistication of both seismic instrumentation and data analysis techniques has greatly increased. In this thesis I use seismic data to determine the structure of the crust and upper mantle under the Hindu Kush (Chapter 2), to examine the source parameters of a large and damaging earthquake (Chapter 4), as well as to determine earthquake locations (Chapters 3 and 4).

The purpose of these studies is twofold. First, to help understand the active tectonic processes in this complex and poorly understood area. Second, and more importantly, to aid in evaluating the potential seismic hazard in this region which has suffered many catastrophic earthquakes in the past.

In Chapter 2, I apply the technique of teleseismic arrival time tomography to study the deep structure of the Hindu Kush and Pamir seismic zones. These enigmatic and highly active seismic zones possess a dipping zone of earthquakes similar to many subduction zones, yet lack an obvious surface expression. Previous studies had indicated both high mantle velocities [e.g. *Vinnik and Lukk* , 1975] and low mantle velocities [*Roecker et al.*, 1982]. My study shows that the deep part of the Hindu Kush zone is closely associated with high mantle velocities. These anomalously high velocities suggest that part of the zone may be subducted oceanic lithosphere. These results help resolve the discrepancy between previous studies and put constraints on the tectonic history of the Hindu Kush seismic zone.

The third chapter describes a new seismic network (KNET) deployed around the city of Bishkek in northern Kyrgyzstan and presents an analysis of the local seismicity recorded by this network, with emphasis on the seismicity near the city of Bishkek. The seismicity near Bishkek helps to define the possible seismogenic structures near this large city and shows the seismic style of an active thrust belt. Chapter 3 also shows examples of data recorded by KNET including near-field effects and anomalous regional seismograms from the Hindu Kush zone.

The fourth chapter studies the Suusamyr earthquake, a large (Ms 7.4) earthquake that struck northern Kyrgyzstan on August 19, 1992. This destructive earthquake was not only first well-recorded large event in the northern Tien Shan but is also one of the largest well-recorded continental thrust events in the world today. Consequently, the study of this event yields information about active faulting in the region, seismic hazard and the geometry of thrust faults.

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Figure 1.1 (top) Map showing collision-induced tectonics of Central Asian region. Arrows indicate relative movement between regions. After Thomas et al., [1993]. **(bottom)** Map of same area showing earthquakes of magnitude 5.5 and above since 1977. Light gray represent elevations above 2000 m, darker gray is elevations above 4000m. The 'Hindu Kush' rectangle refers to the area studied in Chapter 1 while 'KNET' refers to the area covered in Chapter 2 and 3.