



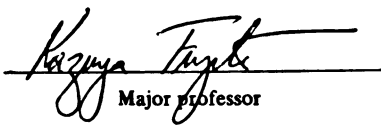


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CRUSTAL THICKNESS OF NORTHEAST
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CRUSTAL THICKNESS OF NORTHEAST RUSSIA

By

Kevin George Mackey

A THESIS

**Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of**

MASTER OF SCIENCE

Department of Geological sciences

1996

ABSTRACT

CRUSTAL THICKNESS OF NORTHEAST RUSSIA

By

Kevin G. Mackey

The first order crustal structure of the Magadan region and northeast Sakha Republic (Yakutia), northeast Russia, is obtained by simultaneously inverting for origin times and travel time curves. As an average, a 37 km thick, 5.992 ± 0.007 km/sec crust overlying an 7.961 ± 0.015 km/sec mantle provides an excellent fit to phase data listed in the *Materialy po Seismichnosti Sibiri* bulletin. Travel-time curves for individual stations are very close to this average, though there are some variations in both crustal thickness and velocities; upper mantle velocities and crustal thickness appear to increase along the southern edge of the Okhotsk-Chukotka volcanic belt and decrease in the upper Kolyma River basin and along the trace of the proposed Moma Rift. Crustal thickness is greatest at Khandyga, on the Siberian platform, and lowest at Yubileniya, which may lie within the currently active Laptev Sea rift system.

ACKNOWLEDGEMENTS

First, I would like to thank Kaz Fujita for all the support and guidance over the past two years, without which this project would not have seen completion. Secondly, I would like to thank my parents for their love, support, and understanding during the past several years. A million thanks to Trent Faust who slaved for weeks typing and checking phase data used in this study (I'm glad I did not have to do all of it). Dr. Larry Ruff deserves credit and thanks for the use of, and assistance with 'SQUINT', his travelttime inversion program. The University of Michigan Seismological Observatory provided the computer resources for running 'SQUINT'. I thank Boris Koz'min and Dima Gunbin for station information and discussions of data processing methods used in the former Soviet Union. I also thank the Yakut Science Center and World Data Center B for providing seismological bulletins. Thanks to Boris Koz'min from Yakutsk, and Valentin Kovalev from Magadan, who provided earthquake data and helpful comments on their respective regions. Thanks to David Stone, Pavel Minyuk, Valentin Kovalev, the Gunbin family, and the Koz'min family who made my stay in Russia educational, eventful, and fun. Larun Izmailov was especially helpful in Magadan with Russian Customs, and in getting me the nicest hotel room in the city (sorry Kaz). I thank Bill Cambray and Hugh Bennett for stimulating discussions and serving on my guidance committee. I also thank Tom Vogel for discussion on some of my ideas. Diane Baclawski, the librarian has been most helpful in finding sources for research. I thank Steve Riegel and all those before me for building the foundation for this study. Many thanks to Diane and Cliff Gray, who

provided transportation and a different perspective of Fairbanks. Thanks to Michelle, who has done a great job of keeping me sane. This work is part of an ongoing cooperative research program between the University of Alaska Fairbanks, Michigan State University, the Yakut Institute of Geological Sciences, and the Magadan Experimental Methodological Seismological Division to study the tectonics and seismicity of northeast Russia. This project was funded by the Incorporated Research Institutions for Seismology Joint Seismic Program (IRIS-JSP), and by National Science Foundation (NSF) grants OPP #92-24193 and OPP #94-24139. Additional funding and support for this project and myself was provided by a Michigan State University teaching assistantship, the Michigan State University College of Natural Sciences, the University of Alaska Geophysical Institute, and the Scottish Rite Masons.

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Introduction

In this study the first order variations in crustal structure in northeast Russia are investigated using seismic wave travel time data from regional seismic events published in Russian seismic bulletins. Northeastern Russia is a region presently under compression and uplift as a result of the convergence of the North American and Eurasian plates (e.g., Naimark, 1976; Cook et al., 1986; Riegel et al., 1993). This region is composed of a series of exotic terranes which accreted in the Mesozoic (e.g., Parfenov, 1991) and then participated in an apparently extensional episode in the Pliocene which resulted in the formation of the Moma rift system (Grachev, 1973; Fujita et al., 1990a). This study is confined to the areas best covered by the Magadan and northern Yakut regional seismic networks from the late 1970s to early 1990s. This region lies approximately between 57-70°N and 125-163°E and includes the Chersky seismic belt (CSB), the eastern portion of the Siberian Platform, the Kolyma gold mining belt and the region around Magadan (Fig. 1; q.v., Koz'min, 1984; Parfenov et al., 1988; Fujita et al., 1990b). The study area is centered approximately at the junction between the North American plate, the Eurasian plate, and Okhotsk microplate or block. In the southern region, the Okhotsk microplate is undergoing deformation as it is compressed and extruded as a result of the convergence of the North American and Eurasian plates (Riegel et al., 1993; Riegel, 1994). The deformation within the Okhotsk block results in a geographically large area of seismic activity. Figure 2 shows the trends of microseismic activity within the study area. Microseismicity within the CSB is heaviest in the vicinity of Susuman; but levels may

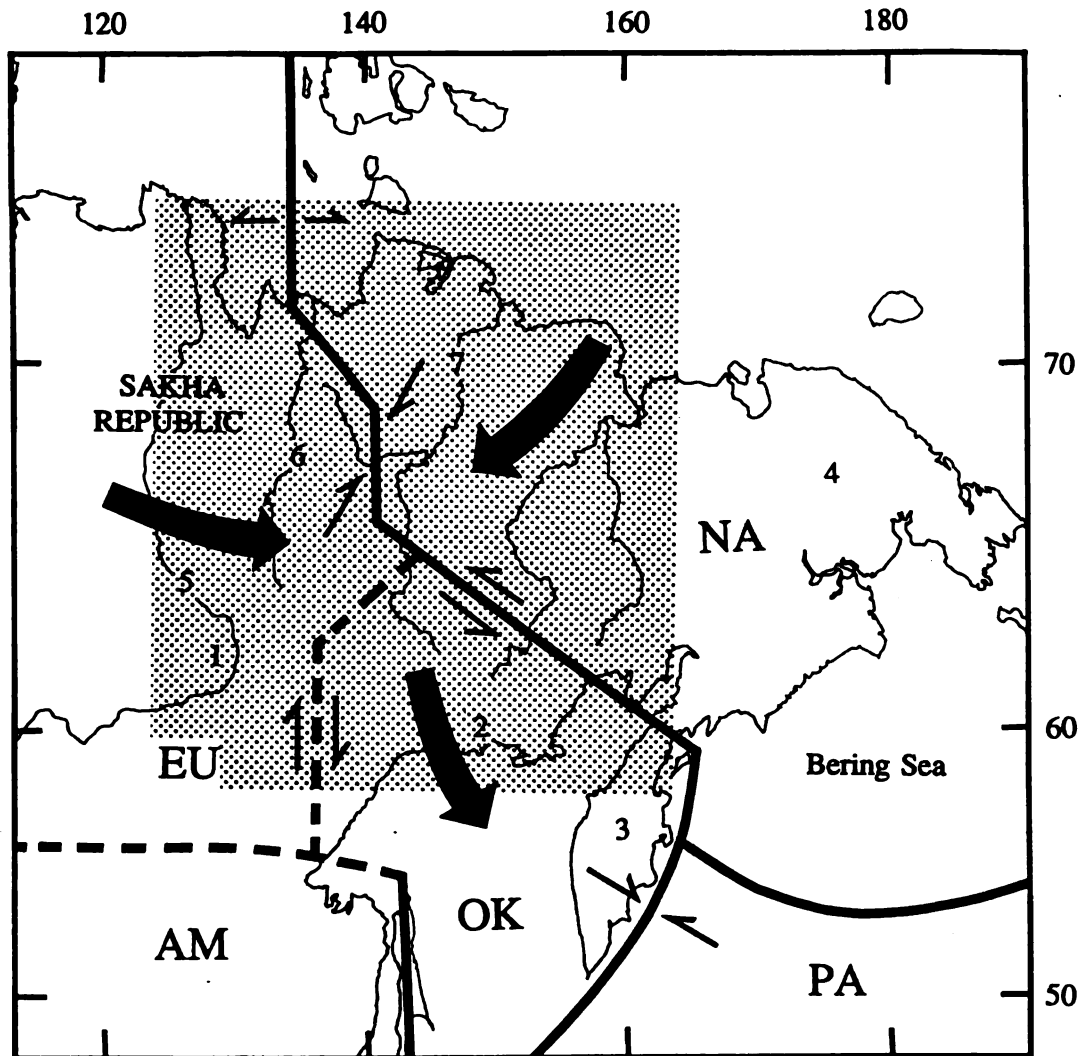


Figure 1. Plate configuration of northeast Russia, showing boundaries between the Eurasian (EU), North American (NA), Okhotsk (OK), Pacific (PA), and Amur (AM) plates. Solid lines denote established boundaries, while dashed represent diffuse or inferred. Large arrows represent relative motions between plates, and small show relative motion along individual boundaries. Stippled area covers the region considered in this study. 1 = Yakutsk, 2 = Magadan, 3 = Kamchatka Peninsula, 4 = Chukotka 5 = Lena River, 6 = Yana River. Adapted from Riegel (1994).

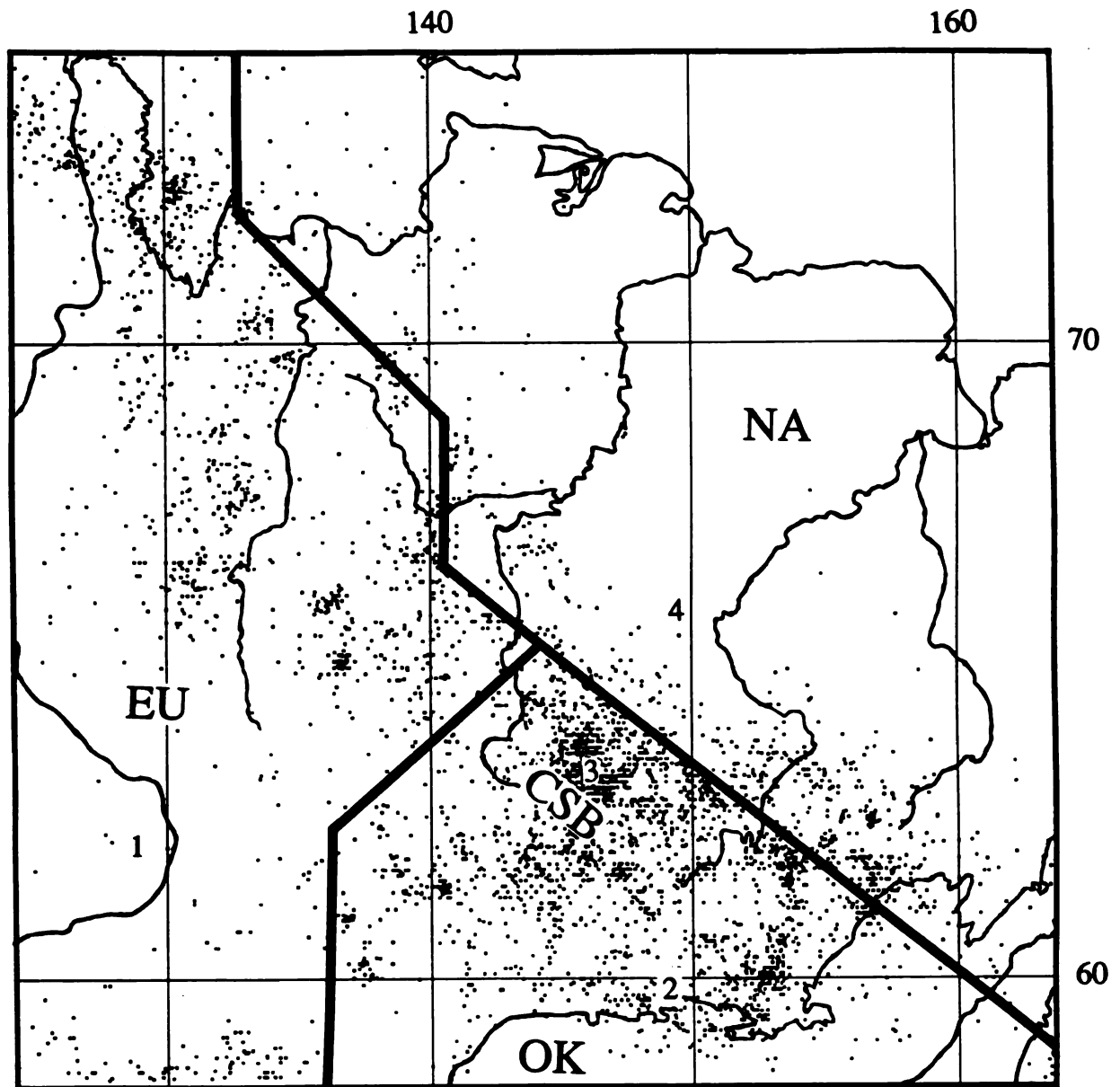


Figure 2. All known locatable seismicity within the study area. Seismicity shown ranges from approximately $M_b = 2.0$ to greater than 6.0. Seismicity is due to interaction between the North American (NA), Eurasian (EU), and Okhotsk (OK) plates. Highly seismic area represents the Cherskii Seismic Belt (CSB). 1 = Yakutsk, 2 = Magadan, 3 = Susuman, 4 = Zyryanka. Data from *Materialy Po Seismichnosti Sibiri*, years 1976-1991, and *Zemletryaseniya V SSSR*, years 1962-1989. Additional data supplied by B. Koz'min for Sakha Republic (Yakutia; personal communication, 1994), and L. Gunbina for Magadan (personal communication, 1995).

be inflated due to mining. Since the mid 1960s, when seismic networks were first opened in the area, approximately 5,000 CSB earthquakes have been catalogued and located. North of the CSB, microseismicity declines rapidly. This may be partially due to station distribution, but Riegel (1994) notes that the installation of a station at Zyryanka (Fig. 2) has not altered the microseismicity distribution.

The central portion of the study area is currently under transpression along the North American and Eurasian plate boundaries. However, in the Pliocene this region apparently underwent extension, forming the Moma rift system (Fig. 3). Within the past 0.5 m.y., the pole of rotation for the NA-EU plate is suggested to have moved north and extensional activity along the Moma rift cease (Cook et al., 1986). The northern portion of the study area includes the Laptev Sea rift system. The Laptev Sea rift system is the extension of the Arctic Mid-Ocean Ridge onto the Siberian continental shelf, expressed as a system of grabens (Fig. 4; Kim, 1986; Fujita et al., 1990a). Within the Laptev Sea rift system, Kim (1986) suggests the Omoloi graben is the presently active zone of extension. Drachev (1994) indicates extensional features throughout the southern portions of the Laptev Sea. Microseismicity levels are highest along the southern edge of the South Laptev basin (Fig. 4), although larger events are located both here and along the Omoloi graben. Fewer microseismic locations in the Omoloi graben is likely a result of seismic station distribution. The western portion of the study area contains the eastern portions of the Siberian platform. The Siberian platform generally consists of a flat lying Precambrian basement overlain by a few kilometers of Riphean, Cambrian, and Jurassic sedimentary materials (Parfenov, 1991). Topographically, the Siberian platform is

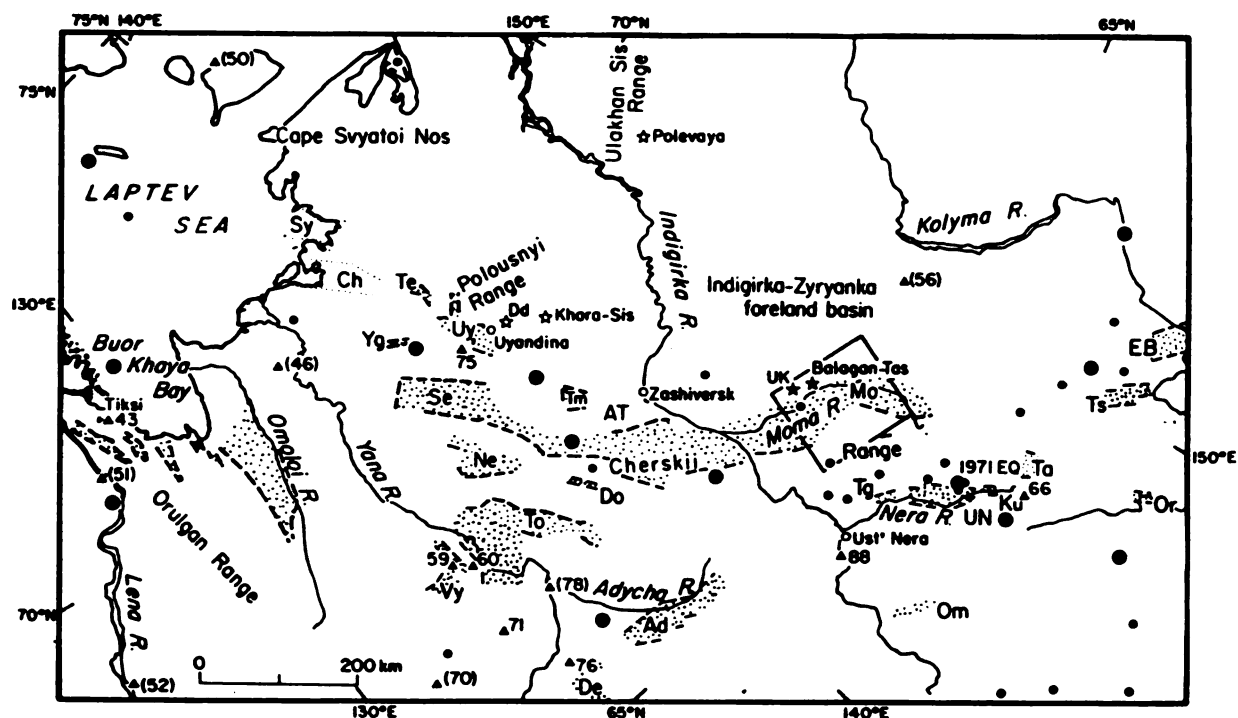


Figure 3. Map of the Moma rift system. Dashed lines show faults bounding grabens and half grabens, dotted where based on geophysical data. Cenozoic basins are stippled. AT denotes the Andrei Tas Range; UK the Uruga-Khaya dome and Dd the D'akhtardaakh volcano. Other letter pairs label grabens: Ad=Adycha; Ch=Chondon; De=Derbeke; Do=Dogdo (Darpir); EB=El'gen (Seimchan) - Buyunda; Ku=Khudzhakh; Mo=Moma; Ne=Nenneli; Om=Oimyakon; Or=Orotuk; Se=Selennyakh; Sy=Sellyakh Gulf; Ta=Talon; Te=Tenkeli; Tg=Tagyn'ya; Tm=Tommot; To=Toustakh; Ts=Taskan; UN=Upper Nera; Uy=Uyandina; Vy=Verkhoyansk (Upper Yana). Dots denote teleseismic earthquakes. Triangles represent heat flow measurements in mW/m^2 . Stars indicate volcanoes: white for Late Cenozoic, black for Quaternary. From Fujita et al. (1990a).

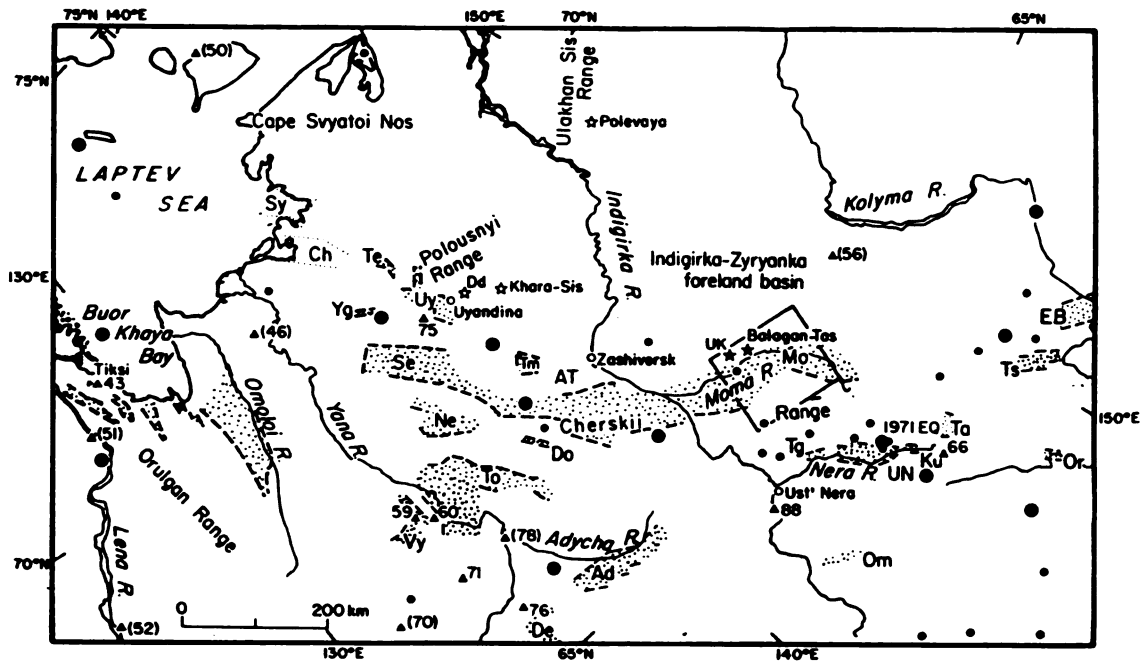


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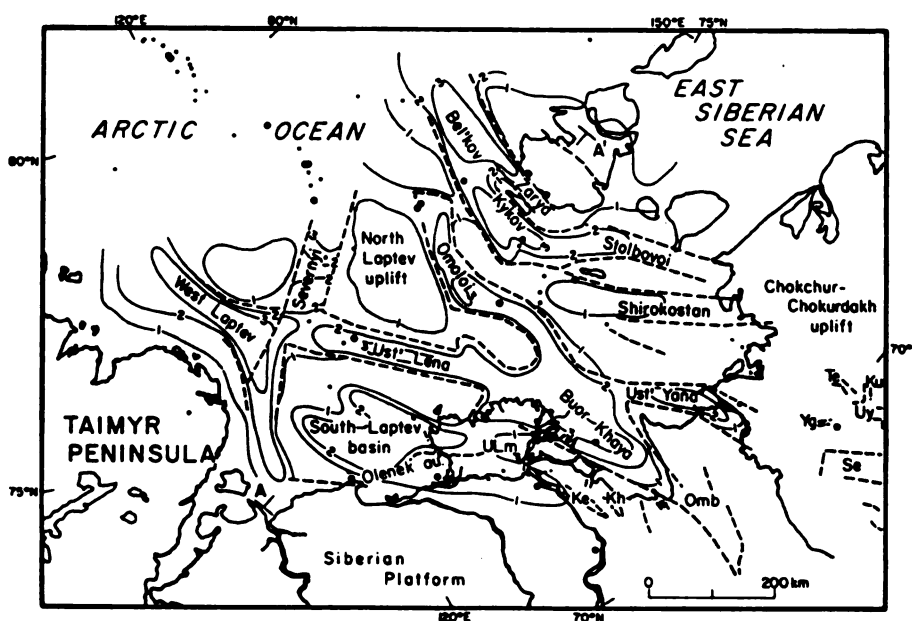


Figure 4. Map of the Laptev Sea rift system. Dashed lines indicate faults, primarily geophysically determined, and contours are for sediment thickness in km. Two letter abbreviations denote Cenozoic grabens: Ke=Kengdei; Kh=Khopto; Ku=Keranak; Se=Selennyakh; Te=Tenkeli; Uy=Uyandina; Yg=Yglan. Omb identifies the Omoloi basin. From Fujita et al. (1990a).

relatively flat.

Considering the regional tectonics, the crustal structure of the study area is expected to be very complex. Due to its general inaccessibility, however, few seismic studies have been conducted in northeast Russia; the few available studies are based on isolated seismic refraction profiles, converted phases, and differential travel-times. None of the long-distance refraction lines conducted throughout the Siberian platform reached (Razinkova, 1987) this area. Thus, the crustal structure is poorly known and some of the studies have resulted in contradictory results. The resolution of crustal thickness in this area contributes to the understanding of the present-day tectonics of the area, the extent of rifting during the development of the Pliocene Moma rift, and on the nature of the North America-Eurasia plate boundary.

In addition to the resolution of crustal thickness in northeast Russia, this study was also used to test the 'SQUINT' travelttime inversion program with application to a wide network. The 'SQUINT' program was originally developed for use with a small local network, and has never been applied to a large area with a regional network (Ruff et al., 1994).

The Chersky seismic belt region was selected for study because of the relatively dense network of seismic stations, which should result in better focal parameters, the great number of earthquakes, and the presence of a 350 km long, deep-seismic sounding (DSS; refraction) line conducted in 1959 between Magadan and Ust' Srednikan on the Kolyma River (Magadan-Kolyma DSS profile; Davydova et al., 1968; Ansimov et al., 1967). This line can be used to calibrate crustal studies.

PREVIOUS STUDIES

Several previous studies have considered this region. The earliest study of large scale crustal structure in this region was the Magadan-Kolyma Deep Seismic Sounding (DSS) profile conducted in 1959. This profile was conducted along the Magadan - Ust' Srednikan highway for a total distance of 350 km between end shot points with observations covering 156 km (Fig. 5). The profile indicates a crustal thickness of 31 km near Stekolnyi increasing to 38 km in the north (Davydova et al., 1968; Ansimov et al., 1967). According to Ansimov et al. (1967), the profile shows a 15 km thick granitic layer with velocities ranging from 6.0 km/sec to 6.5 km/sec. Beneath the granitic layer lies a 15-16 km thick basaltic layer where velocities are between 6.5 km/sec and 7.0 km/sec (Ansimov et al., 1967). The Moho, with a velocity of 8.1 km/sec underlies the basaltic layer (Ansimov et al., 1967). Velocities shown on figure 5, also from Ansimov et al. (1967) are not consistent with his text. Unfortunately, no direct data is available beneath Magadan; however, by extrapolation with an offshore refraction line, a depth of 29-30 km is inferred (Fig. 5: Ansimov et al., 1967).

The most comprehensive crustal structure study in the area was by Suvorov and Kornilova (1986). This study used Russian bulletin data and travel time differences between seismic stations for common events to study crustal thickness and crustal and mantle velocities. Their method initially assumes a homogeneous crustal strata and that the refracted phase for individual events travels along a flat underlying boundary (Suvorov and Kornilova, 1985). Consistent changes in travel times for certain regions

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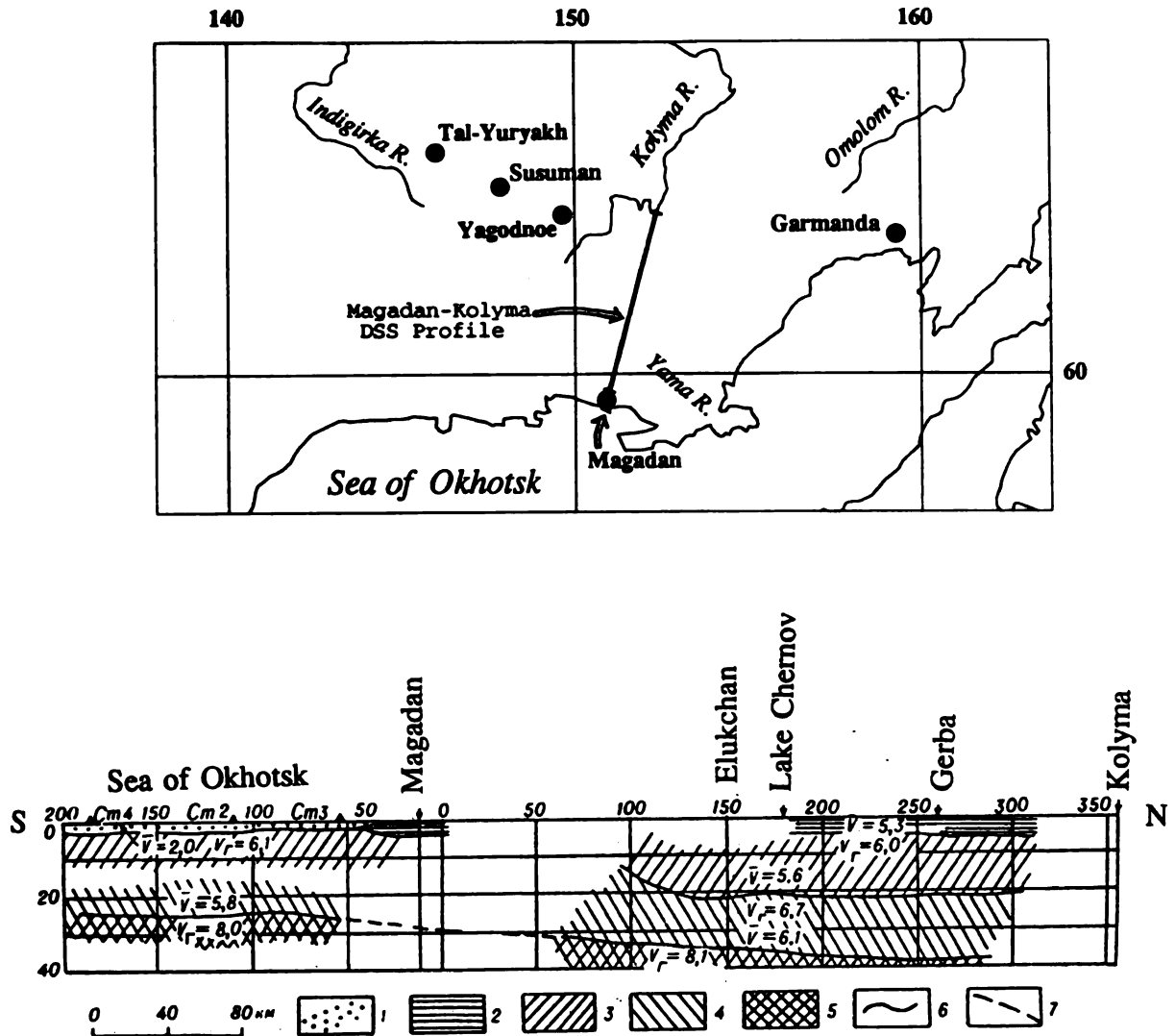


Figure 5. The Magadan-Kolyma Deep Seismic Sounding (DSS) profile and location map. Left portion of figure shows a portion of a DSS profile from the sea of Okhotsk. Magadan is located at the 0 km point. 1 - sediments with velocities up to 2.5 km/sec; 2 - sediments with velocities from 2.5 km/sec to 6.0 km/sec; 3 - granitic layer with velocities from 6.0 km/sec to 6.5 km/sec; 4 - basaltic layer with velocities from 6.5 km/sec to 7.0 km/sec; 5 - subcrustal layer with velocities above 8.0 km/sec; 6 - deep boundaries according to DSS data; 7 - deep boundaries in region of interpolation. From Ansimov et al. (1967).

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Crustal studies using P to Ps conversions were first utilized for this area by Mishin and Dareshkina (1966). For the study, the crustal velocity structure used was that determined by the Magadan-Kolyma DSS profile. For consistency, only earthquakes at teleseismic distances were utilized (Mishin and Dareshkina, 1966). The original Mishin and Dareshkina (1966) study calculated depths for only four of the stations used in this study. It should be noted that only 6 earthquakes per station were used for the Mishin and Dareshkina (1966) study. A later paper by Mishin et al. (1979) adds additional data for stations Seimchan and Susuman. Their studies yield a generally thin crust in the Kolyma gold belt, between 30 and 34 km, which increases in the north to 50 km at Susuman. Belyaevsky (1974) attributes data identical to that of Mishin to Nikolaevsky. Belyaevsky (1974) includes data beyond the Mishin and Dareshkina (1966) paper, including a Moho depth of 43 km for Debin and 34 km for Garmanda (near Evensk; Fig. 5). A P-Ps converted wave study by Belyaevsky and Borisov (1974) report generally

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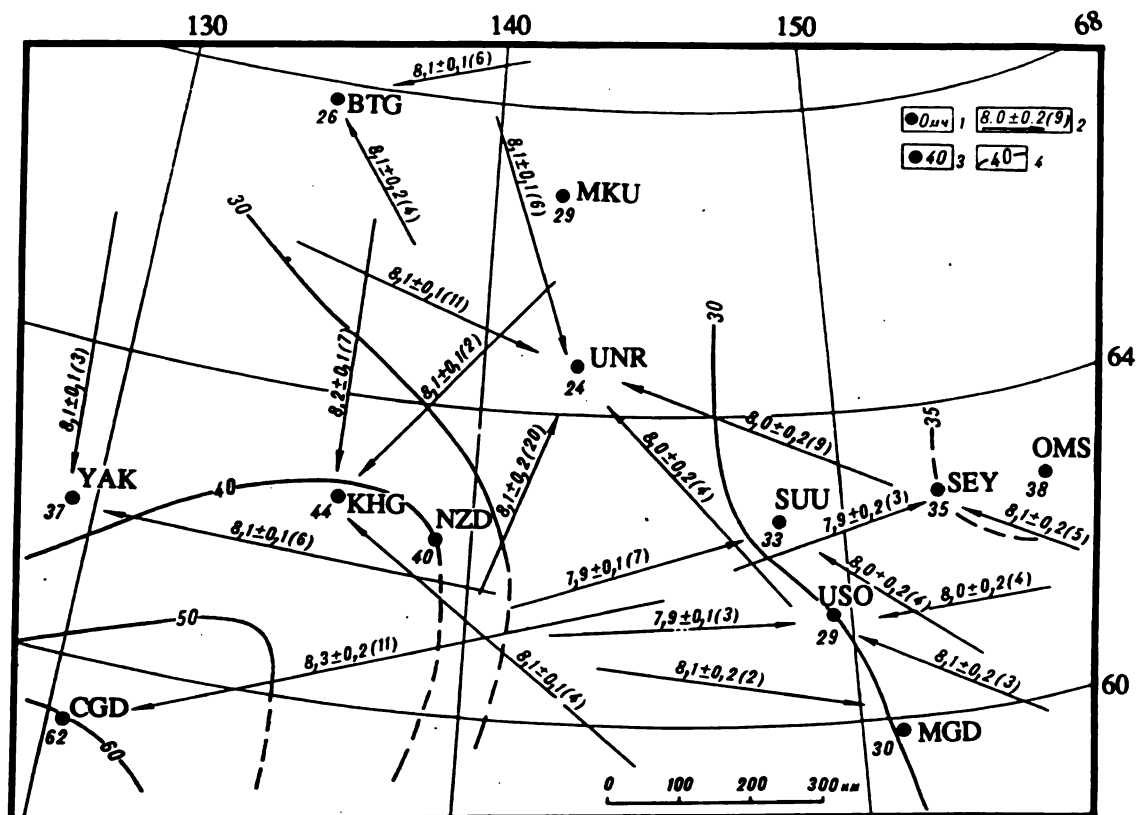


Figure 6. Results from Suvorov and Kornilova (1986) crustal structure study. Dots represent seismic stations (1) and associated numbers are depths in kilometers (3). Arrows indicate trends of Moho velocity, in km/sec (2). Numbers in brackets indicate the number of events used in the determination of velocity (2). Contours show general trend of crustal thickness (4). From Suvorov and Kornilova (1986).

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higher values of crustal thickness approaching 40 km. Vaschilov (1979) cites data from Mishin and Dareshkina (1966), including a depth for Garmanda identical to that cited in Belyaevsky (1974) (this station does not appear in Mishin and Dareshkina (1966)). Vaschilov (1979) recalculates the crustal depths using a different formula. Crustal depths generally increase about 2 km from the Mishin and Dareshkina (1966) values (Vaschilov, 1979).

The most recent study using P-Ps converted waves computes crustal thicknesses at 43 permanent and temporary seismic stations throughout eastern Siberia (Bulin, 1989). The velocity structure used in the study was also from the Magadan - Kolyma DSS profile and other DSS profiles in adjacent areas. In addition, the regional near surface geology was taken into account for individual stations (Bulin, 1989). Values computed by Bulin (1989) are consistently 1.5-3.0 km thinner than those computed by Mishin. This is generally due to increasing the V_p/V_s ratio from 1.73 used by Mishin to greater than or equal to 1.8 (Bulin, 1989), which seems a bit high. The justification for this ratio change is not clear. In direct contrast to Suvorov and Kornilova (1986), Bulin has determined a thick crust reaching 40 km at Ust' Nera, under the Chersky Range, and 40+ km in the Okhotsk-Chukotka volcanic belt (Bulin, 1989). Unfortunately, Bulin (1989) does not list data for all the seismic stations used in his study.

Sedov and Luchnina (1988) used mine blasts along a profile between Tal-Yuryakh and Susuman to determine seismic velocities and layer thicknesses. The velocities obtained are somewhat different from the other studies cited above; a 5.5-5.6 km/sec upper crust overlying a 6.5-7.3 km/sec lower crust and an apparent Moho refraction of

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10.6 km/sec. The high Moho velocity is attributed by them to a thinning of the crust in the direction of the profile; this end of the profile was not reversed. In a continuation of this study, Sedov (1993) conducted DSS profiling along the central Kolyma Highway including the Susuman - Maisky - Myaudzha and Susuman - Neksikan - Kadykchan branches. This DSS profile indicates a crustal thickness of 41.5 km at Susuman, decreasing to 37.1 km at Yagodnoe in the east and increasing to 43 km in the northwest at Tal-Yuryakh (Sedov, 1993; Fig. 5).

In the northern portion of the study area, Avetisov and Guseva (1991) used the Method of Reflected Wave Sounding (MRWS) to construct seismic profiles of the Earth's crust in the Omoloi graben. A crustal thickness of 29 - 31 km was established for the southern portion of the graben, in the vicinity of station Naiba (Avetisov and Guseva, 1991). This thickness is supported by a DSS profile in the southern Laptev sea (Kogan 1974) and a compilation of previous work (Avetisov, 1983) which indicate a crustal thickness of 29 - 30 km overlying a mantle with a velocity of 7.5 km/sec.

Neustroev and Parfenov (1985) have found a correlation between thickness of the Earth's crust and thickness of platform cover deposits from deep seismic sounding profiles. From this correlation, correction factors were introduced into the Bouger anomalies to remove the effect of the platform cover. Using several DSS profiles, gravimetric maps, and a 1:2,500,000 map of topography of the crystalline basement, a map of crustal thickness was produced for the eastern Siberian platform. Of relevance to this study, the crustal thickness was determined to be 42 km at Yakutsk and Khandyga, and 40 km at Nezhdaninskoe (Neustroev and Parfenov, 1985). Neustroev and Parfenov

(1985) indicate anomalies due to thick platform cover are sufficient to mask any anomaly resulting from variations in crustal thickness. This calls into question previous methods which have determined crustal thicknesses in the Siberian platform using gravity.

Intracrustal structure, based on gravity variations, has been extensively studied using the method of Vashchilov (1984) for the entire region. Bobrobnikov and Izmailov (1989) use gravity data to suggest 30-35 km crustal thicknesses for the study area, increasing to as high as 60 km southwest of the study area. Deep seismic sounding is reported to have obtained a crustal thickness of 38 km in the upper Yama River valley (Bobrobnikov and Izmailov, 1989; Fig. 5).

Methodology and Regional Crustal Model

For this study, a data base of travel time data from over 850 regional events occurring in the Magadan region, Sakha Republic (Yakutia), and the Laptev Sea was created. Data from 1976 to 1990 are taken from *Materialy po Seismichnosti Sibiri* and covers both the Magadan region and Sakha Republic (Yakutia). From 1991 to 1994, additional unpublished data was provided by B. M. Koz'min for the Yakut network (Personal communication, 1994) and by L. Gunbina for the Magadan network (Personal communication, 1995). These data were supplemented by phase data for approximately 50 events reported in the *International Seismological Center Bulletin* and the *Obninsk Seismological Bulletin* for stations in northeast Russia. The study area was selected based on the distribution of the regional seismicity and the location of seismic stations. Figure

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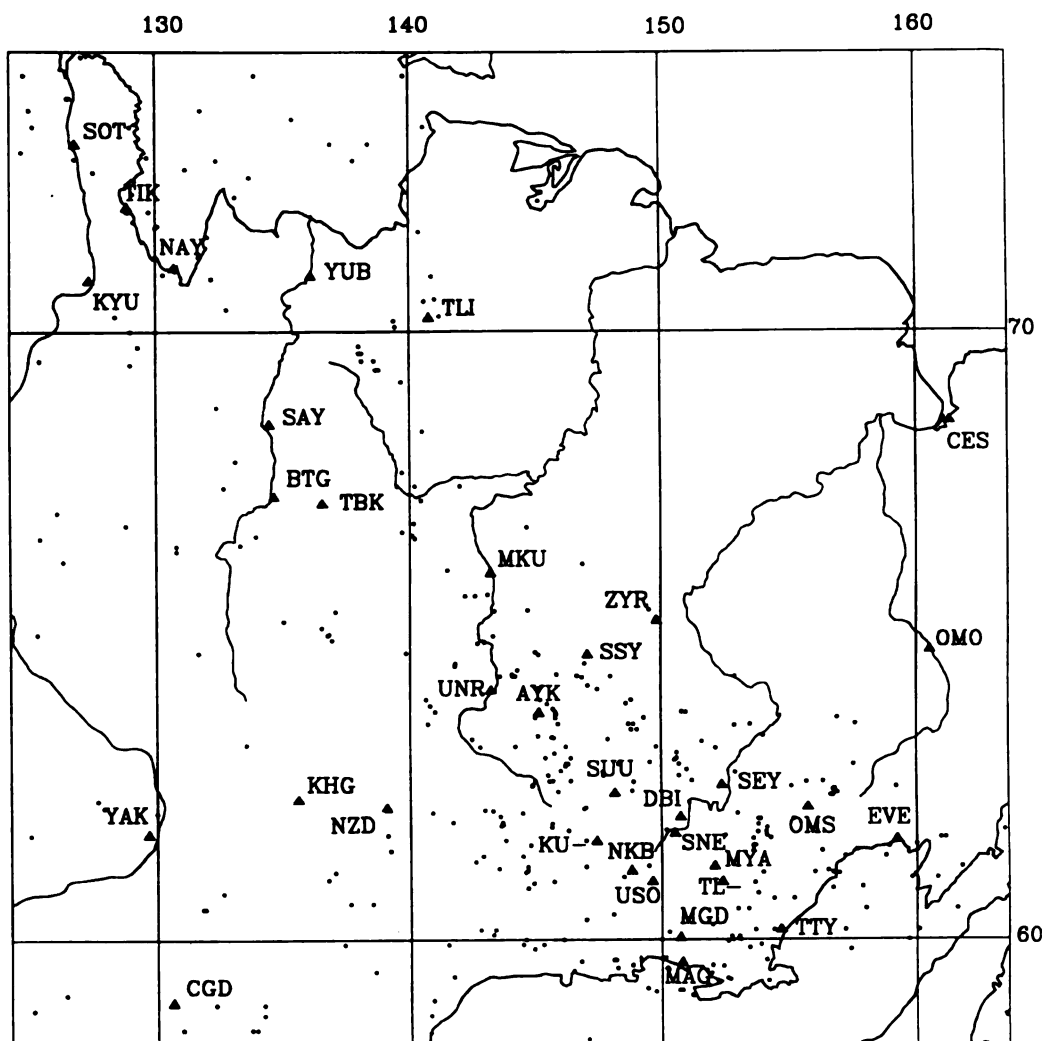


Figure 7. Study area showing seismic stations and epicenters of earthquakes used in the study. MAG = Magadan, TTY = Takhtoyamsk, MGD = Stekolnyi, EVE = Evensk, OMS = Omsukchan, TL- = Talaya, MYA = Myakit, USO = Ust' Omchug, NKB = Nelkoba, SNE = Sinegor'e, DBI = Debin, SEY = Seimchan, OMO = Omolon, KU- = Kulu, Suu = Susuman, CGD = Chagda, YAK = Yakutsk, NZD = Nezhdaninskoe, KHG = Khandyga, AYK = Artyk, UNR = Ust' Nera, SSY = Sasyr', ZYR = Zyryanka, MKU = Moma (Khonou), CES = Cherskii, TBK = Tabalakh, BTG = Batagai, SAY = Saidy, TLI = Tenkeli, YUB = Yubileniya, KYU = Kyusur, NAY = Naiba, TIK = Tiksi, SOT = Stolb.

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7 shows the boundaries of the study area as well as seismic stations and epicenters of events considered in the study. In total, 441 events from the original data set fall within the study area.

All events were relocated using Pg arrivals only, assuming a 6.00 km/sec crustal layer, as well as first arrivals (Pg or Pn) using Jeffreys-Bullen travel-times (Appendix A). Events with fewer than four arrivals were not possible to locate. In the relocation process, many misidentified phase arrivals were discovered. A Pn arrival misidentified as a Pg arrival stands out in a Pg location with a large negative residual. Likewise, a Pg arrival misidentified as a Pn arrival shows clearly in a Pn location with a large positive residual. In such cases, the phase of the arrival was corrected, and the event relocated. For events with large residual arrivals which did not correspond to any possible misidentified phases, the anomalous arrival was removed from the relocation process. During the 1980s, most of the stations in this region used the "*Mayak*" timing system with an accuracy of about 0.3 sec; combined with reading uncertainties, errors of 0.4-0.5 sec are expected; no attempt was made to reduce statistical residuals below this level. The most recent determinations of station coordinates and their elevations were used in the relocations. For Yakutian stations, new coordinates and elevations were determined from 1:200,000 topographic maps with assistance from B. M. Koz'min (Appendix B; Personal communication, 1994).

In the relocations, most epicenters moved only 1-20 km relative to those given in Russian bulletins. For events in which five or more arrivals were used in the relocation, change in epicenter vs. year was plotted (Fig. 8). There is no evidence that the Russian

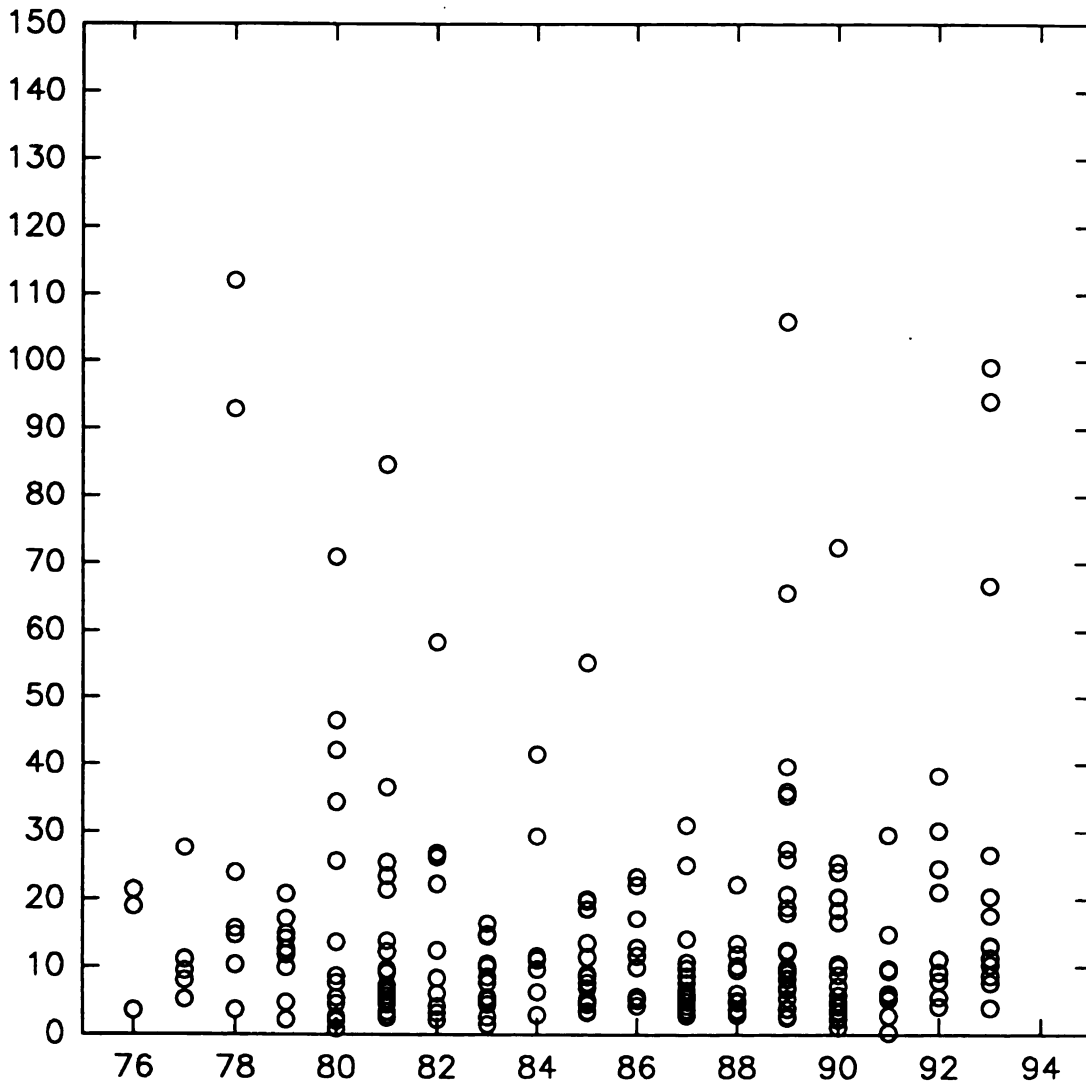


Figure 8. Year vs. change in kilometers of relocated epicenters for events shown in Fig. 7. Relocations computed with Pg phase only, assuming a single layer crust of velocity 6.00 km/sec. Lack of systematic trend through time indicates that the quality of original locations has remained consistent. Original epicenters taken from *Materialy Po Seismichnosti Sibiri*.

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epicenters improve in later years, even with better station distribution and presumably more accurate timing. There is evidence for systematic mislocations in the Russian data set. Relocations computed with Pg arrivals show a strong tendency to move south, and to a lesser extent north, relative to the *Materialy* reported epicenter (Fig. 9). This is likely due to a difference in the crustal velocity used in the different locations, and is discussed below. Relocations using first arrivals show no systematic trend (Fig. 10). Many events reported in the Russian bulletins report a calculated depth. In most cases, I was unable to calculate depths in the relocation process. For events where a shallow depth was determined, there is no consistent correlation with the Russian bulletin reported depths. Thus, for this study, most depths were confined to 10 or 15 km. Relocations computed early in the study used a confining depth of 15 km, while more recent determinations use 10 km. In general, this change seems to have little effect in the relocation process.

The Pg relocated epicenters were plotted on a simplified fault map of the study area (Fig. 11). Fault locations are from Imaev et al. (1994), as well as lineaments visible on landsat images. Activity on many of these faults is restricted to smaller events than those locatable with phase data in *Materialy po Seismichnosti Sibiri*, thus faults known to be active may not show activity on this map. Relocated epicenters correspond well to several of the mapped faults, such as the left-lateral Ulakhan fault (Imaev et al., 1994). For events believed associated with the Ulakhan fault, the bulletin epicenters and relocated epicenters were plotted on 1:500,000 scale topographic maps in an attempt to determine whether or not the relocated epicenters show an improved correlation with the

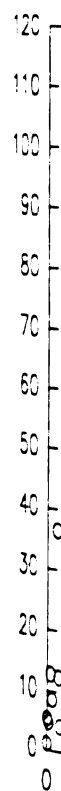
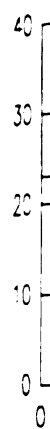


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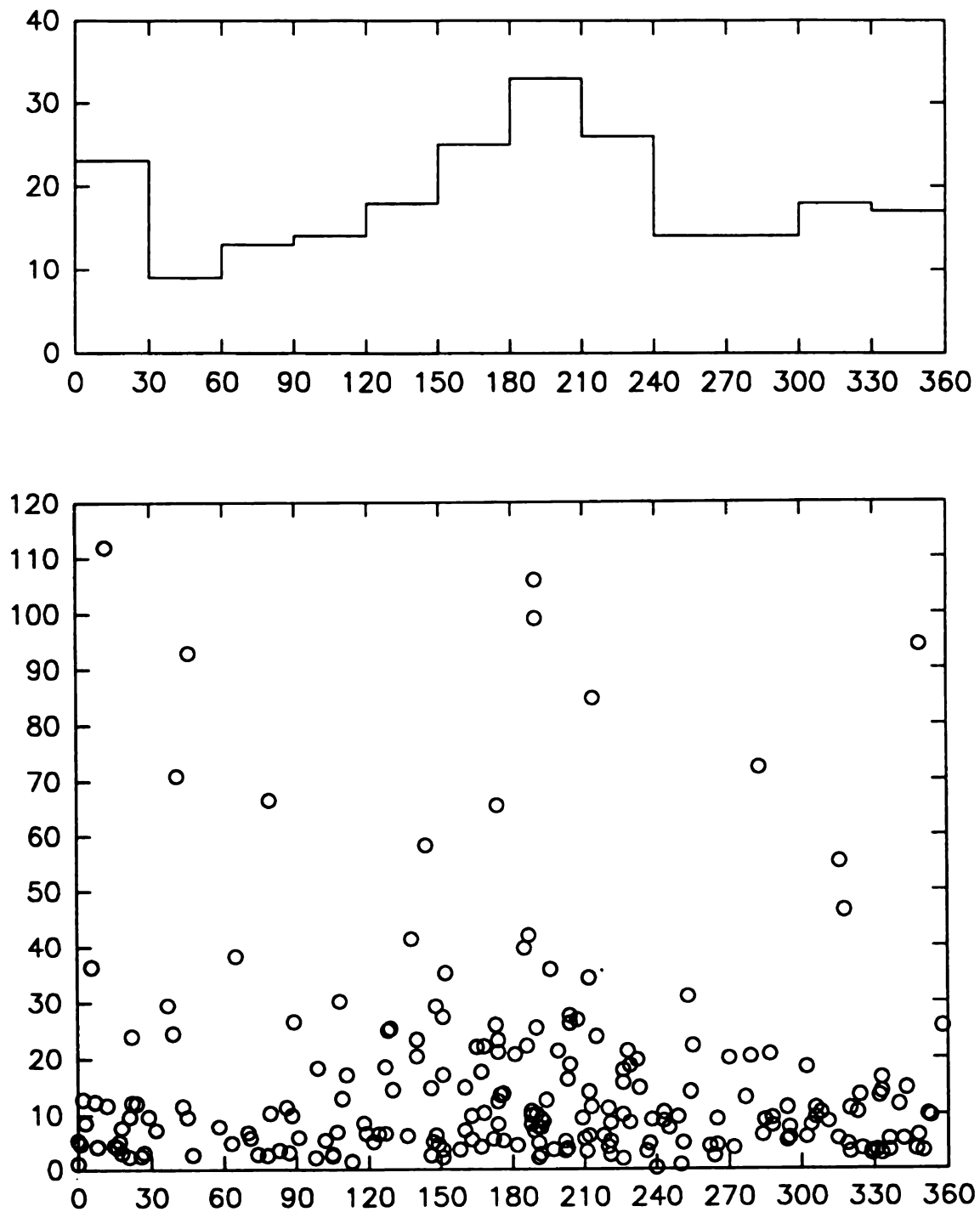


Figure 9. Azimuth from original to Pg data relocated epicenter vs distance of epicenter change (in km). As shown in the upper portion of the figure, epicenters tend to move south, indicating a systematic error in the original locations. Original epicenters taken from *Materialy Po Seismichnosti Sibiri*.

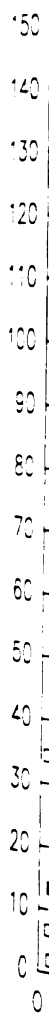


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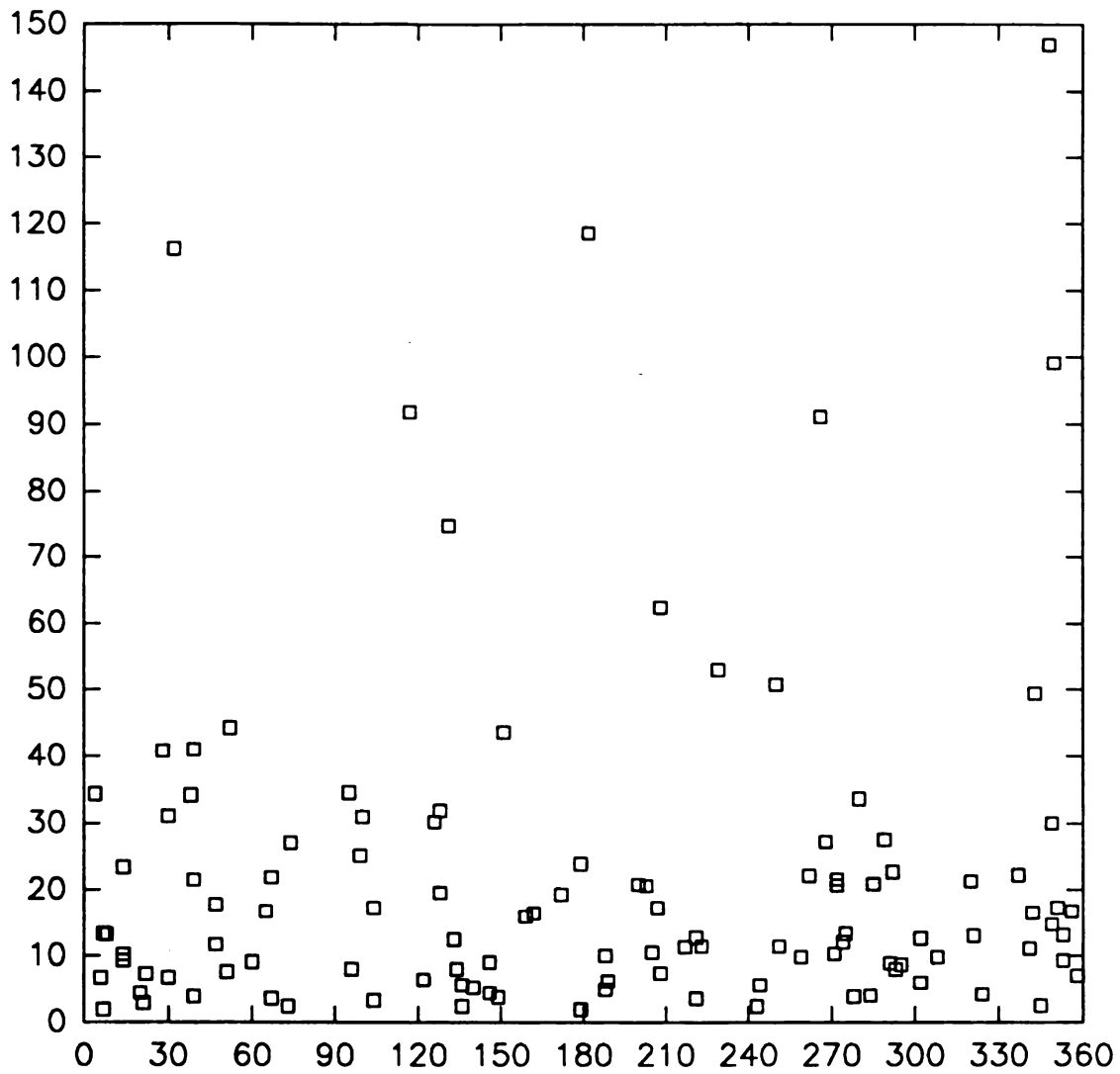


Figure 10. Azimuth from original to Pn data relocated epicenter vs distance of epicenter change (in km). Epicenters show no systematic direction of change. Original epicenters taken from *Materialy Po Seismichnosti Sibiri*.

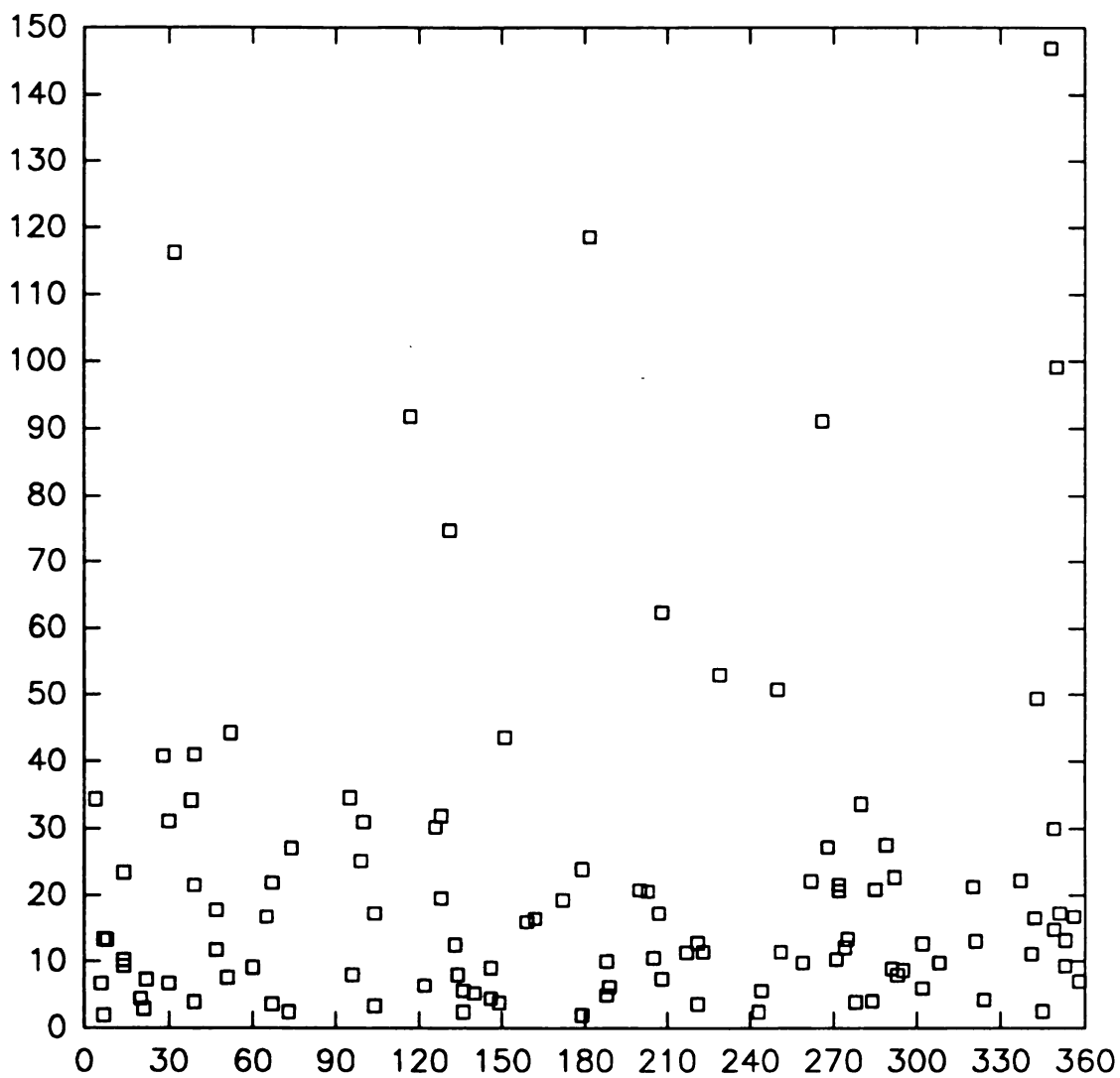


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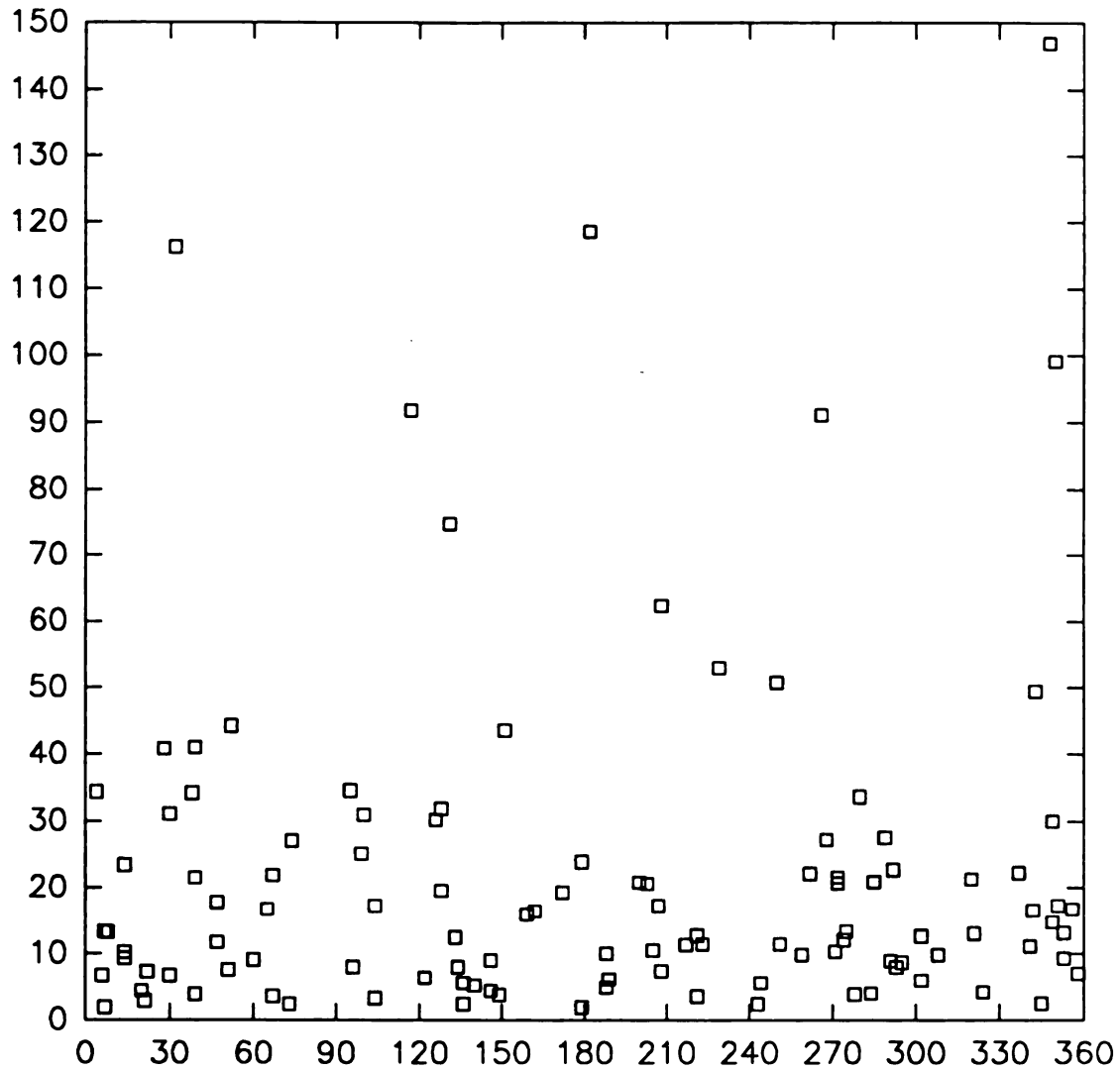


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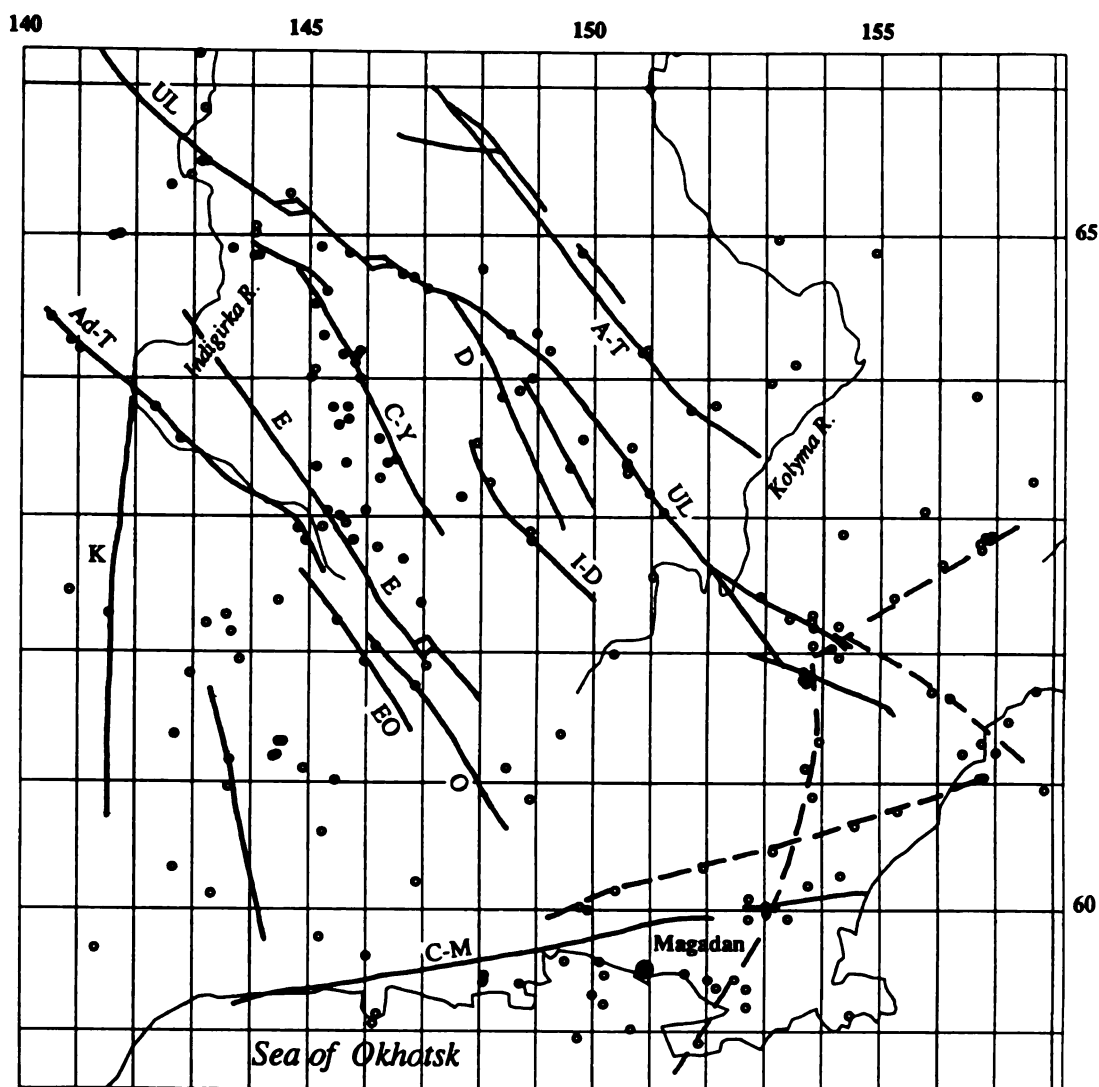


Figure 11. Map of major faults in the southern portion of the study area and their relations to relocated epicenters. Solid lines represent faults mapped in Imaev (1994), as well as those visible as lineaments on satellite images. Dashed lines represent faults inferred from linear trends in relocated epicenters. UL denotes the Ulakhan fault; A-T the Arga-Tas; D the Darpir; I-D the In'yali-Debin; E the Elgin; O the Oimyakon; EO the Eastern Okhotsk; C-Y the Chia-Yureya; C-M the Chelomdzha-Yama; K the Ketanda; Ad-T the Adycha-Taryn.

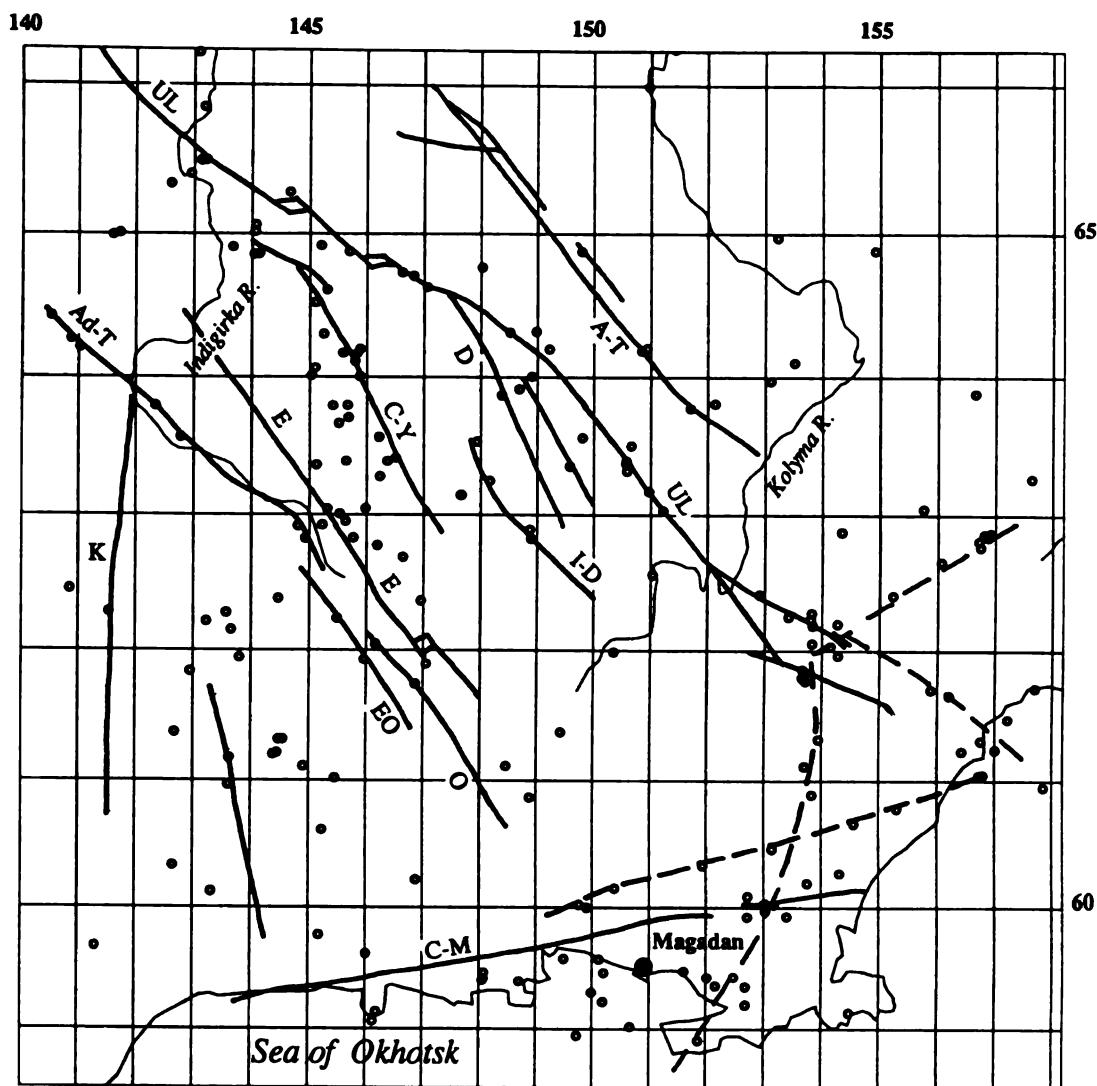


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fault trace. There is no apparent improvement in the correlation between relocated epicenters and the Ulakhan fault trace relative to the Russian determined epicenters. This may be a result of the lack of knowledge regarding the structure of the Ulakhan fault at depth, and poor depth control for both the relocated and bulletin reported epicenters. Some of the events plotted may actually occur on unrecognized faults in the vicinity of the Ulakhan. For many of the events, the Ulakhan fault trace is within the location errors as discussed below.

The best located 75 events were selected for the determination of crustal structure. Several criteria were established for selecting these events (Fig. 12). First, events were required to contain seven or more arrivals used in the Pg relocation. Fewer arrivals than seven causes individual stations to be weighted heavily, thus one mispicked arrival could result in considerable error in the relocation. Secondly, the azimuthal coverage had to exceed 130° . For events where the range of azimuths was less than 130° , the event could simply be moved towards or away from the recording stations, trading off only with origin time, and having little effect on the residuals. Lastly, the difference in epicenters between the Pg relocation and the first arrival relocation should not exceed 15 km, and the difference in origin times should be less than 2.0 sec. These criteria were intended to select events where the first arrival times were compatible with the Pg relocated epicenter, thus increasing the likelihood of good data. Because of the poor distribution of recording stations, the first two criteria were difficult to meet for events near the edge of the study area, or away from the network. This was particularly true for events in the Laptev Sea. In an effort to use a widely distributed data base, these criteria were

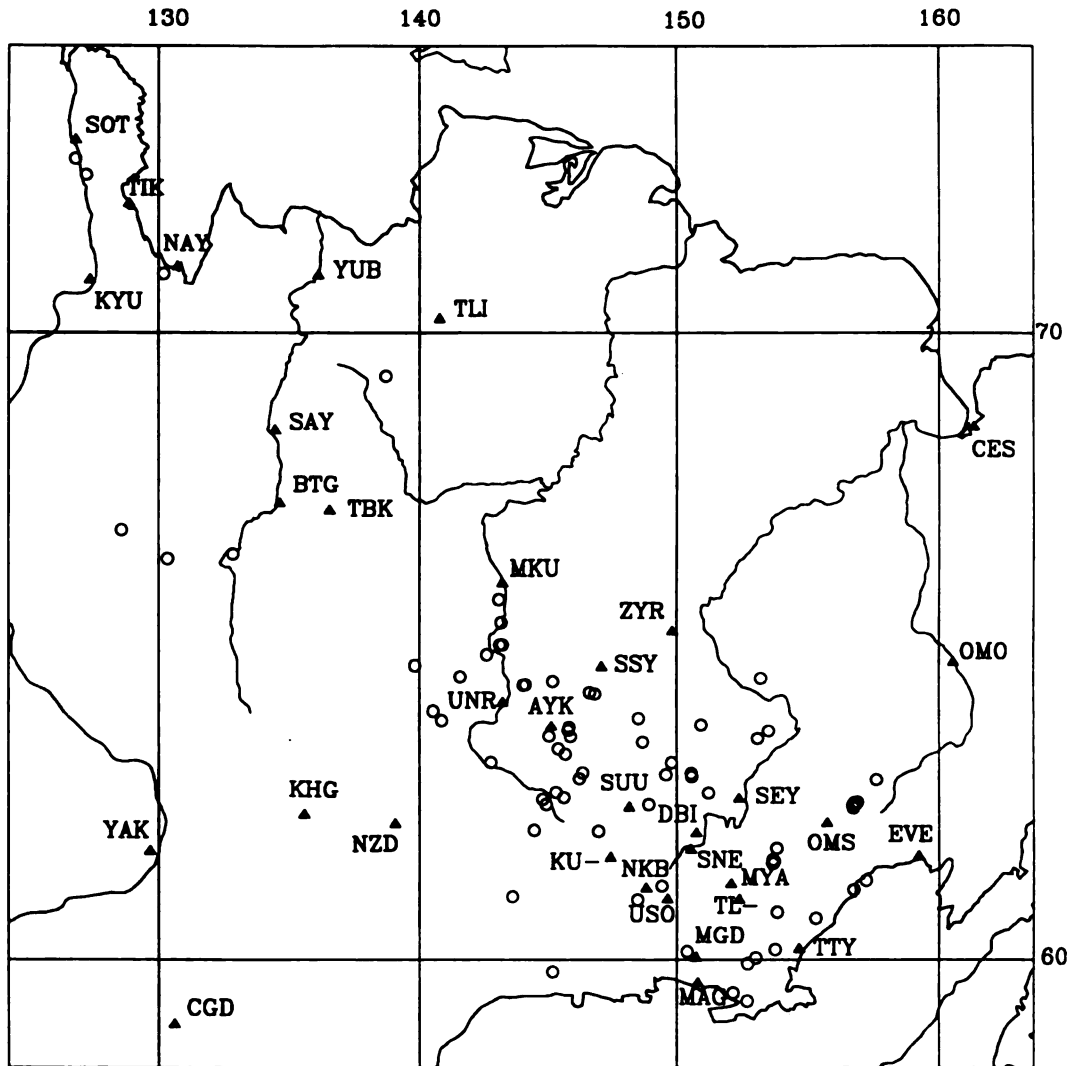


Figure 12. Relocated epicenters of the selected best 75 events in the study area. These events used in the determination of crustal thicknesses. Seismic station codes as noted in Fig. 7.

somewhat lessened for outlying events.

For the best 75 events, relocated epicenter errors range from ± 1 to ± 8 km, averaging ± 3 km. It was noted that for events occurring from 1991 to 1993, average errors for the relocations increased slightly to ± 4 km. The calculated errors on the relocated epicenters are less than the location errors reported in the *Materialy* bulletin. Bulletin reported epicentral errors average about ± 10 km for these 75 events.

To assess the precision of the epicenters reported in *Materialy* and compare them with the Pg relocations, the travel-time data for the 75 selected events was plotted. Looking at the Pg data, there is a significant reduction in scatter of the arrival times using the Pg relocation epicenter and origin time compared to those reported in *Materialy* (Figs. 13 and 14). This suggests problems with the reported epicenters.

A significant reduction in scatter of the Pn data is also observed when plotted with the Pg relocation parameters and compared with the plot using the *Materialy* parameters (Figs. 13 and 14). Sg and Sn data are also plotted using Pg location parameters, though they show a lesser reduction in scatter when compared to the data plotted with the *Materialy* epicenter and origin time (Figs. 15 and 16). For all phases, the use of the Pg phase relocated epicenter and origin time in place of those from *Materialy* results in a reduction of scatter in the plotted travel time curves. Therefore, my relocations using only Pg data are most certainly an improvement on the Russian locations.

Comparing the Pg travel time curves, it is apparent that the Russian locations are determined with a higher Pg velocity. A velocity of 6.10 km/sec fits the Pg travel time curve derived from the original Russian locations (Fig. 13). This is consistent with the

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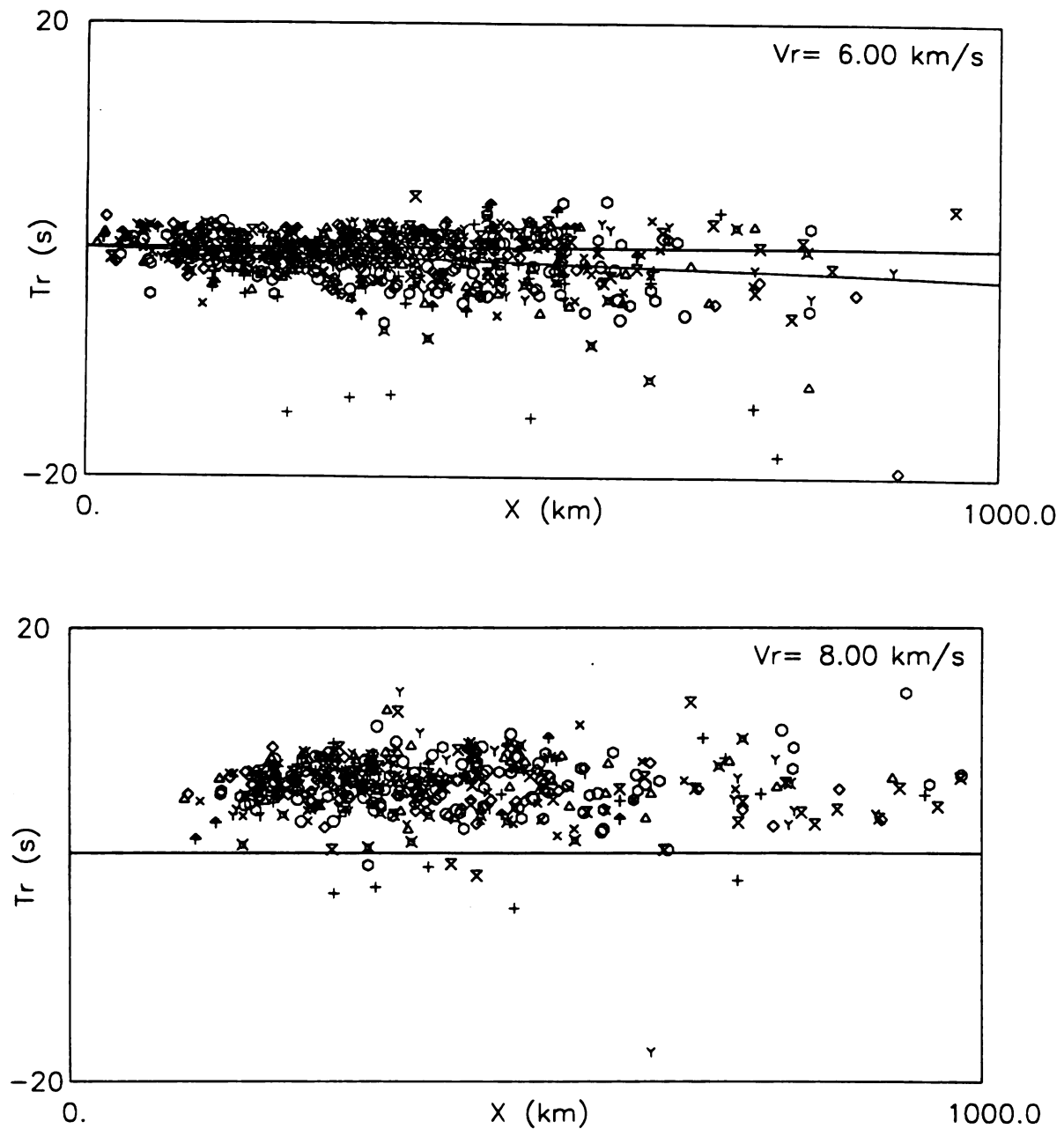


Figure 13. Reduced traveltime curves for Pg (A) and Pn (B) data of selected best 75 events using epicenters and origin times reported in *Materialy po Seismichnosti Sibiri*. Reduction velocities are noted on figures. For Pg data, the best fit velocity is 6.10 km/sec (optically determined). Individual events are represented by different symbols.

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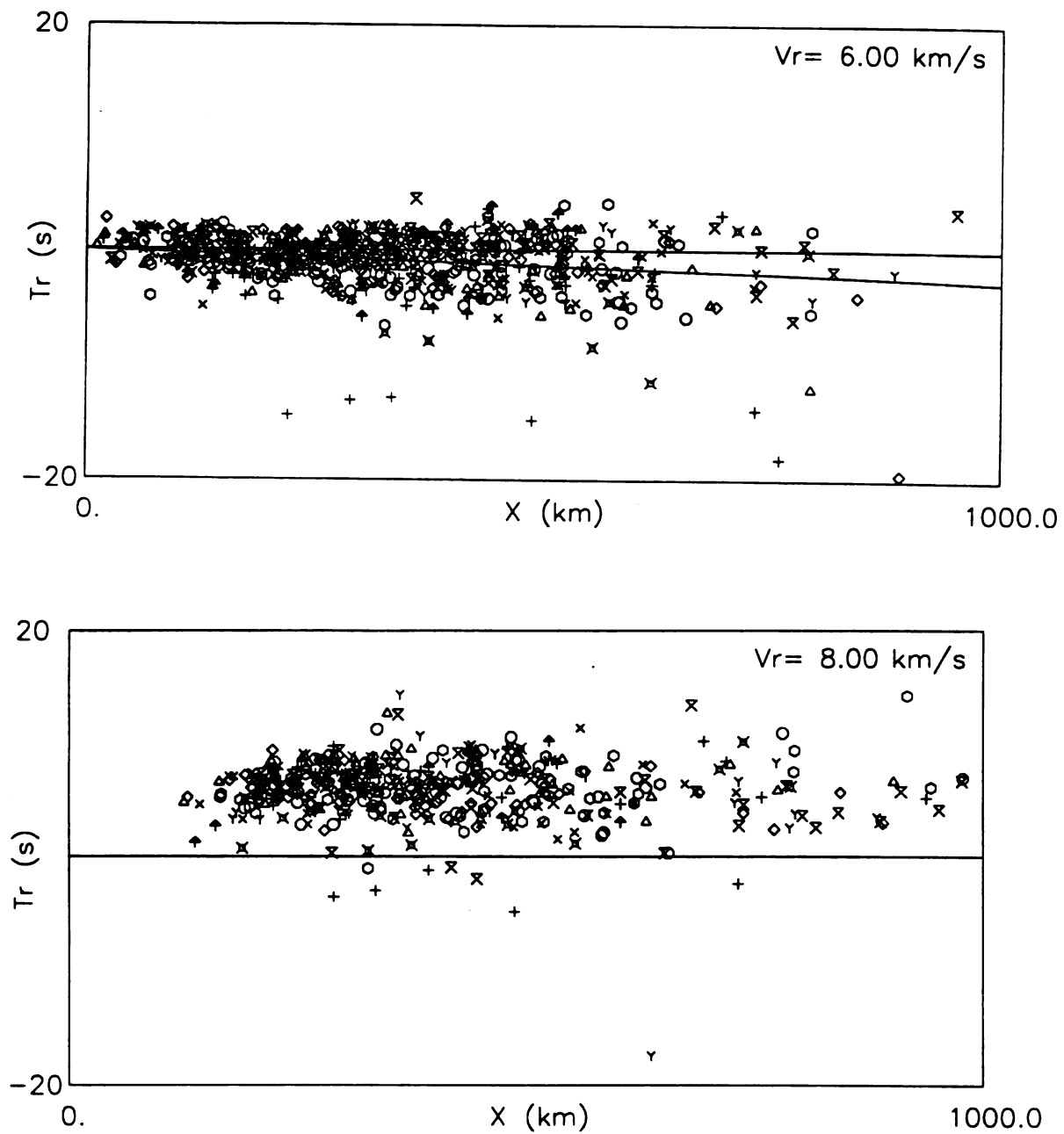


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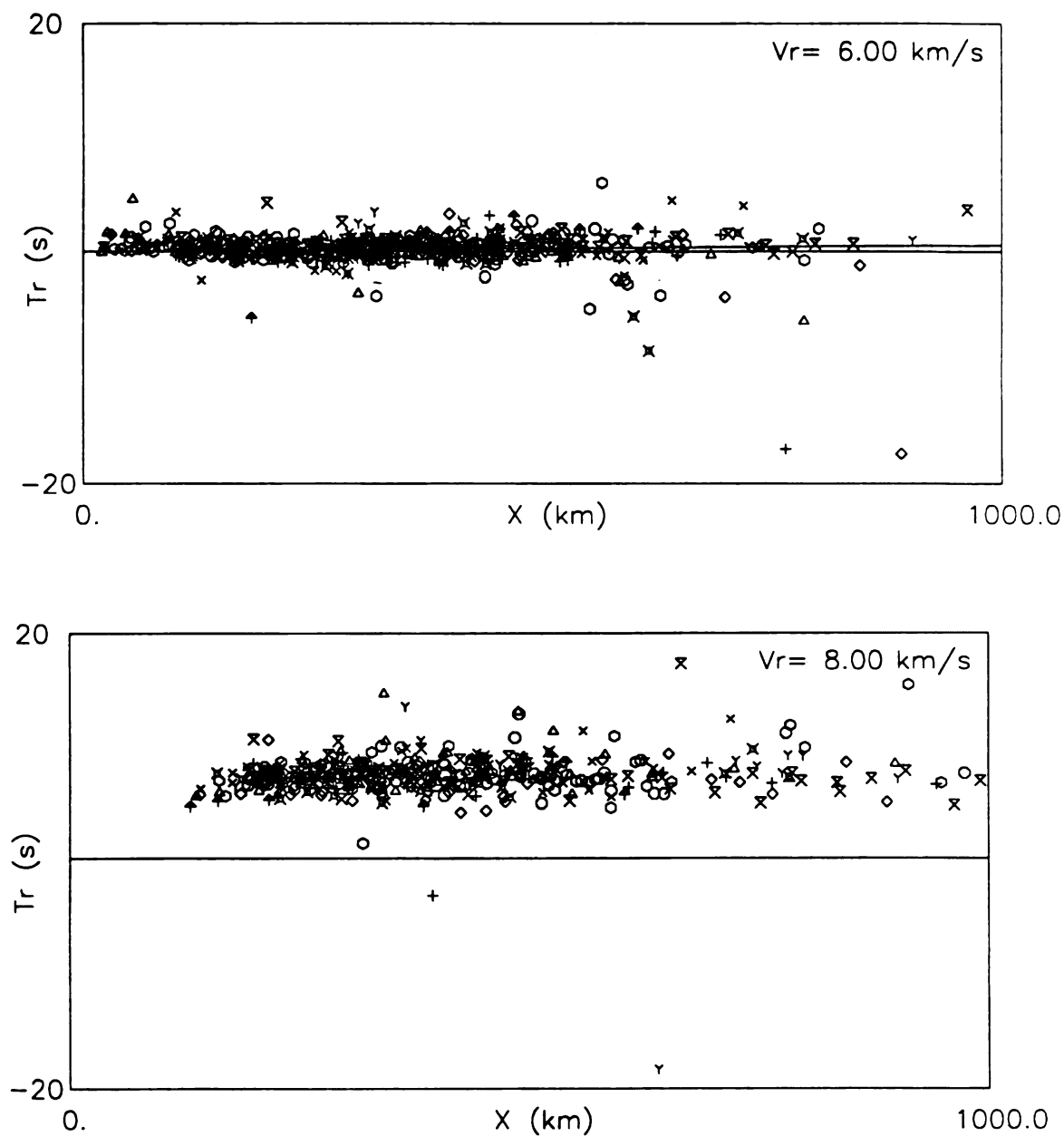


Figure 14. Reduced traveltime curves for Pg (A) and Pn (B) data of selected best 75 events using epicenters and origin times determined from relocations using Pg data. Reduction velocities are noted on figures. Individual events are represented by different symbols.

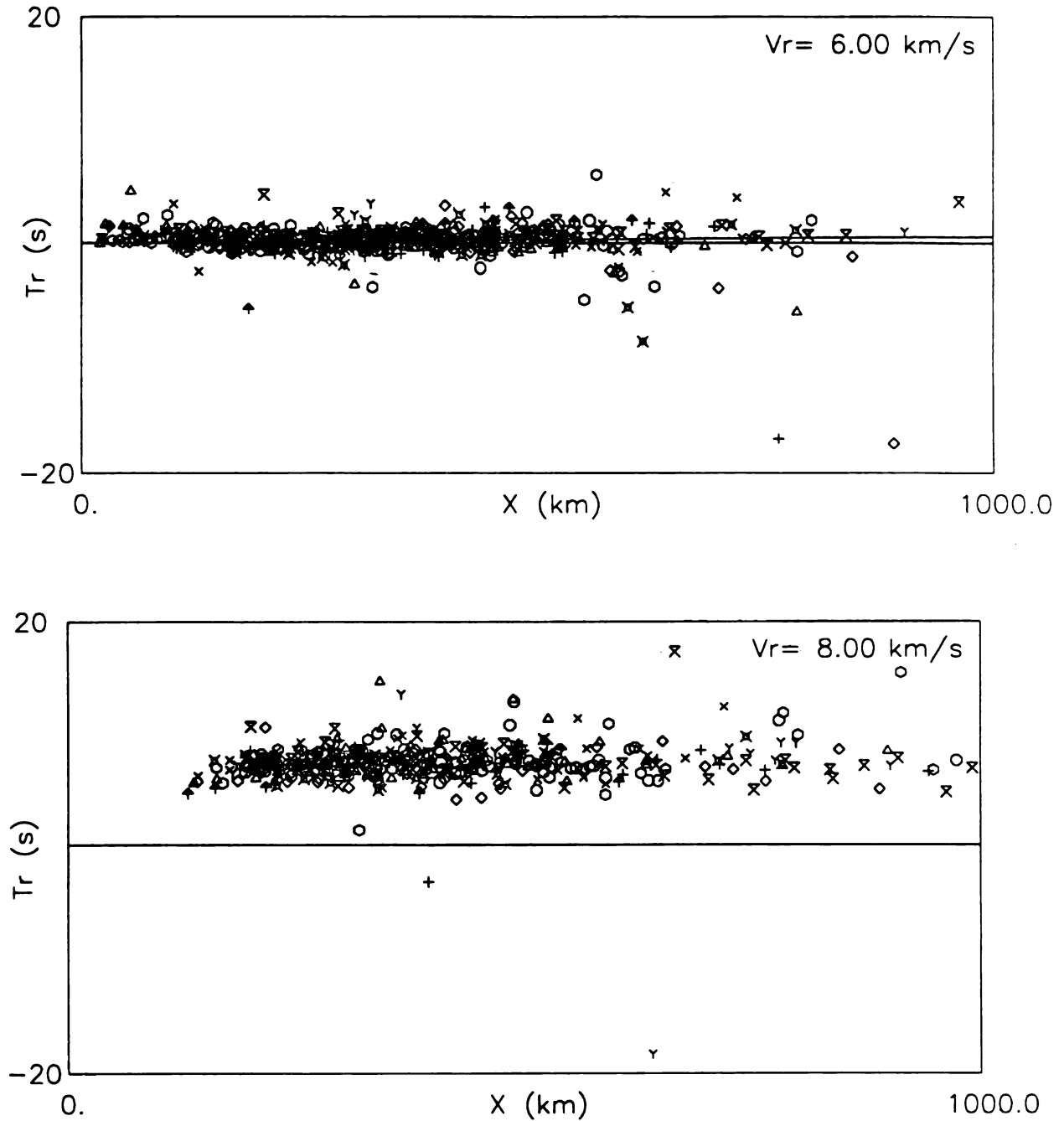


Figure 14. Reduced traveltime curves for Pg (A) and Pn (B) data of selected best 75 events using epicenters and origin times determined from relocations using Pg data. Reduction velocities are noted on figures. Individual events are represented by different symbols.

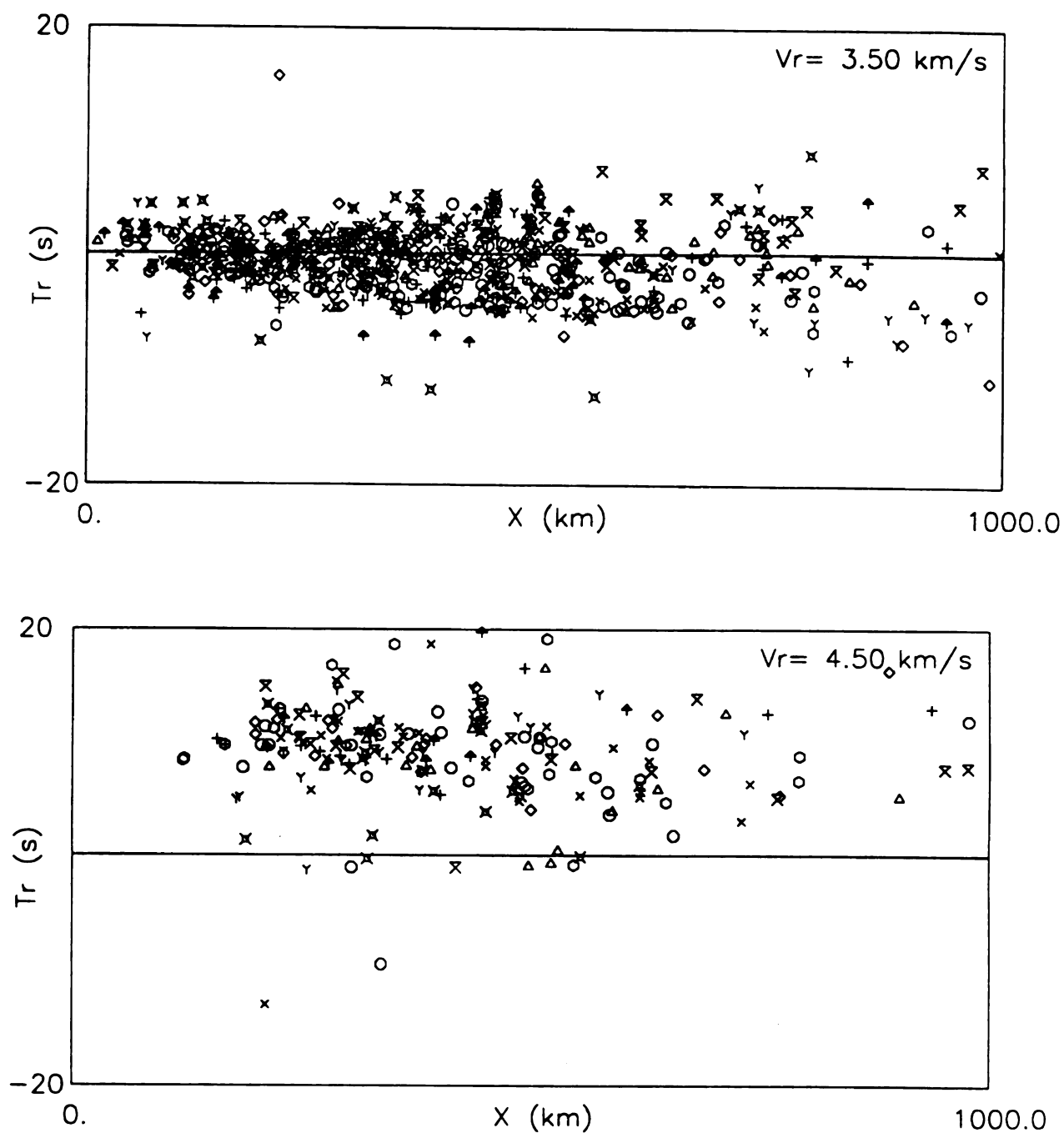


Figure 15. Reduced traveltime curves for Sg (A) and Sn (B) data of selected best 75 events using epicenters and origin times reported in *Materialy po Seismichnosti Sibiri*. Reduction velocities are noted on figures. Individual events are represented by different symbols.

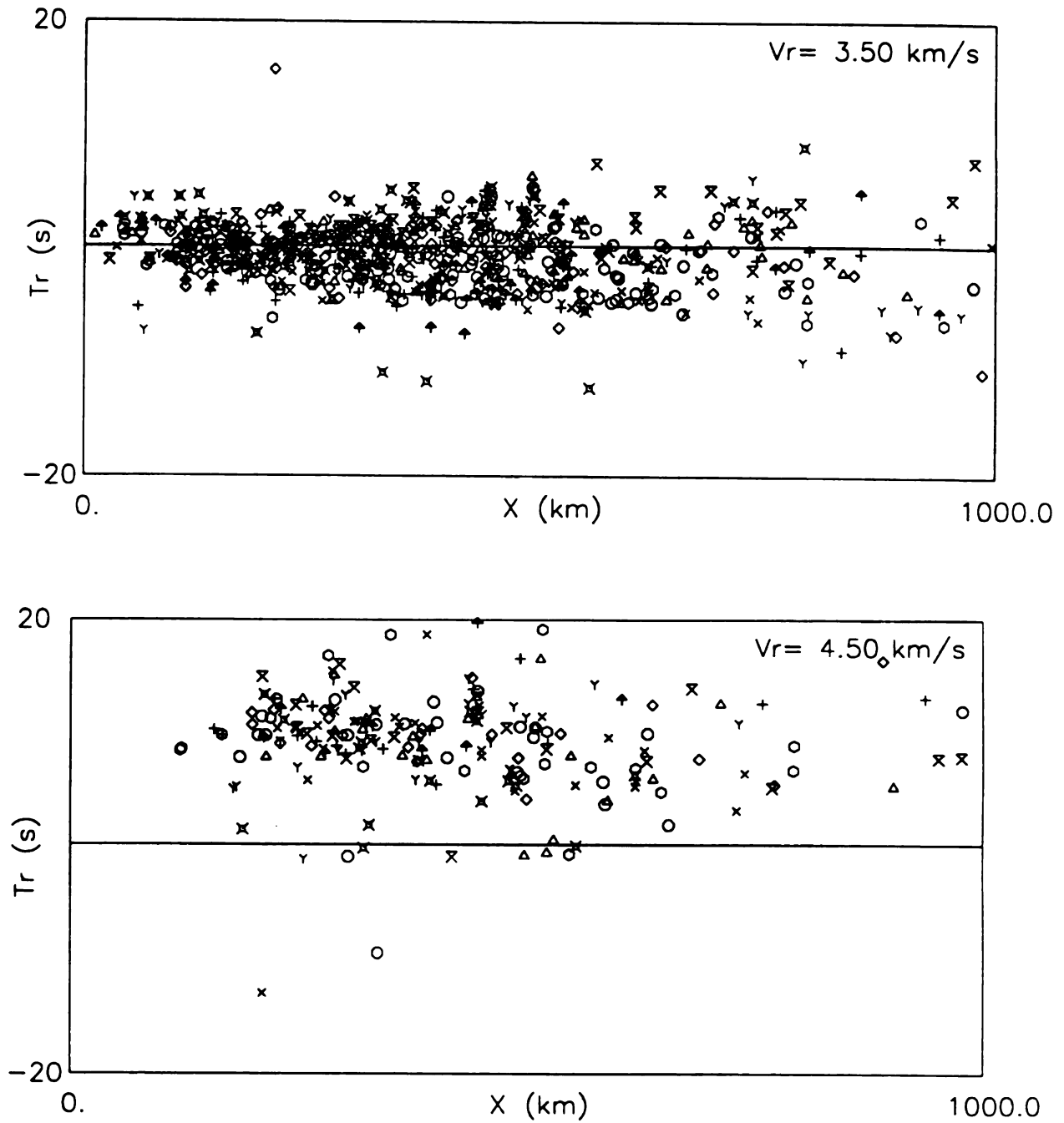


Figure 15. Reduced traveltime curves for Sg (A) and Sn (B) data of selected best 75 events using epicenters and origin times reported in *Materialy po Seismichnosti Sibiri*. Reduction velocities are noted on figures. Individual events are represented by different symbols.

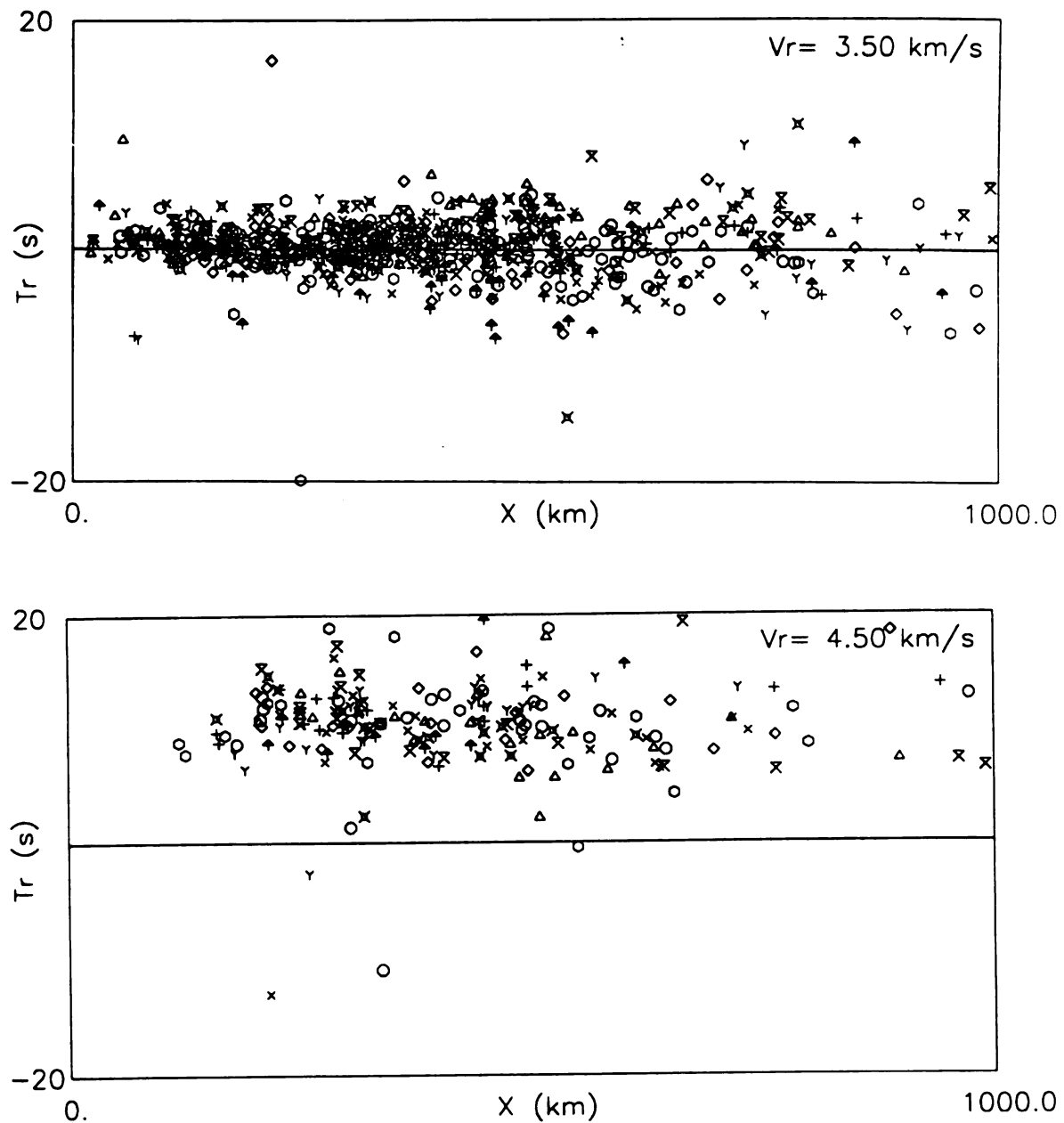


Figure 16. Reduced travel time curves for Sg (A) and Sn (B) data of selected best 75 events using epicenters and origin times determined from relocations using Pg data. Reduction velocities are noted on figures. Individual events are represented by different symbols. Note reduced scatter in data when compared Fig. 15.

travel time curve used in Magadan, which assumes a 6.1 km/sec crustal layer, according to D. Gunbin (Personal communication, 1995), and Andreev, (1984). The different Pg velocities used can account for the systematic change in epicenters that are apparent in the relocations (Fig. 9). The tendency for epicenters to move south is also evident when looking only at the selected events, although to a lesser degree (Fig. 17). In locating earthquakes, if one uses too high a velocity for Pg, but a correct velocity for Sg, the Pg-Sg time interval will be increased for any given distance. Thus, when using such a travel time curve, the apparent distance between epicenter and station will be decreased, and the origin time will be late. Note on figures 15 and 16 that a velocity of 3.50 km/sec fits the Sg data equally well using the bulletin or relocated epicenters. If the station distribution around the epicenter is not symmetric about 360° (which is the case for virtually all events in the study area), the epicenter will move toward the majority of the recording stations. Using a slower Pg velocity, the Pg-Sg time intervals will decrease for a given distance. In this case, the epicenter will move away from the recording stations, and origin time will be earlier. This occurs with the Pg arrival relocated epicenters. Figure 18 shows the azimuth from epicenter to station, relative to azimuthal change in epicenter for the relocation, using 26 events randomly selected from the best 75. For these events, there are a total of 230 Pg arrivals. I found that the epicenters moved away from the recording station in 142 of the arrivals (61.7%) and moved towards the recording station in 88 arrivals (38.3%). For the best 75 events, the origin times shifted an average of 1.16 sec earlier. In total, 56 events shifted to an earlier time, 19 shifted later, and one remained constant. With the above evidence, and considering the reduction of scatter of

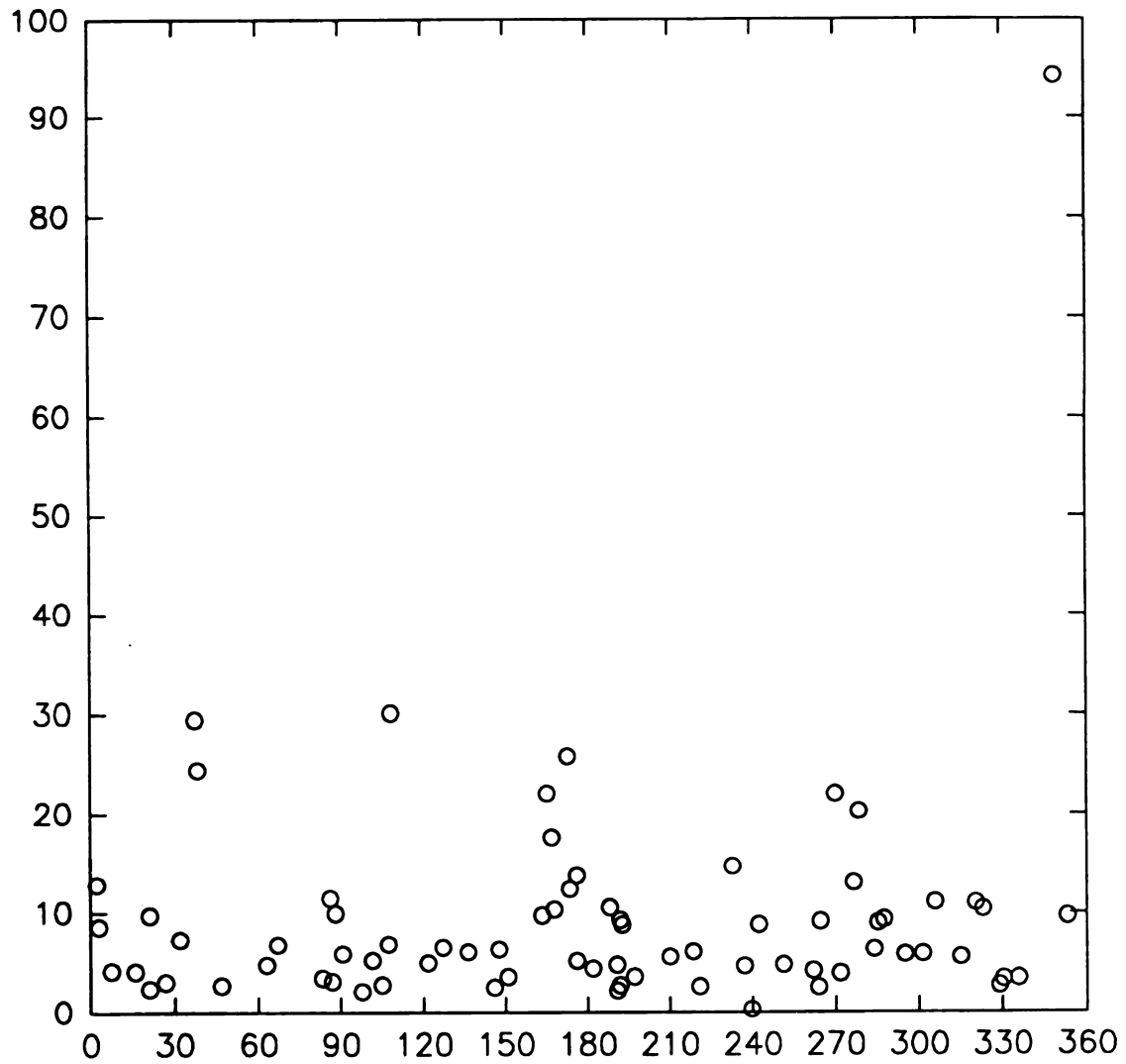


Figure 17. For selected best 75 events, azimuth from original to Pg data relocated epicenter vs. distance of epicenter change (in km). Epicenters tend to move south, indicating a systematic error in the original locations. Original epicenters taken from *Materialy Po Seismichnosti Sibiri*.

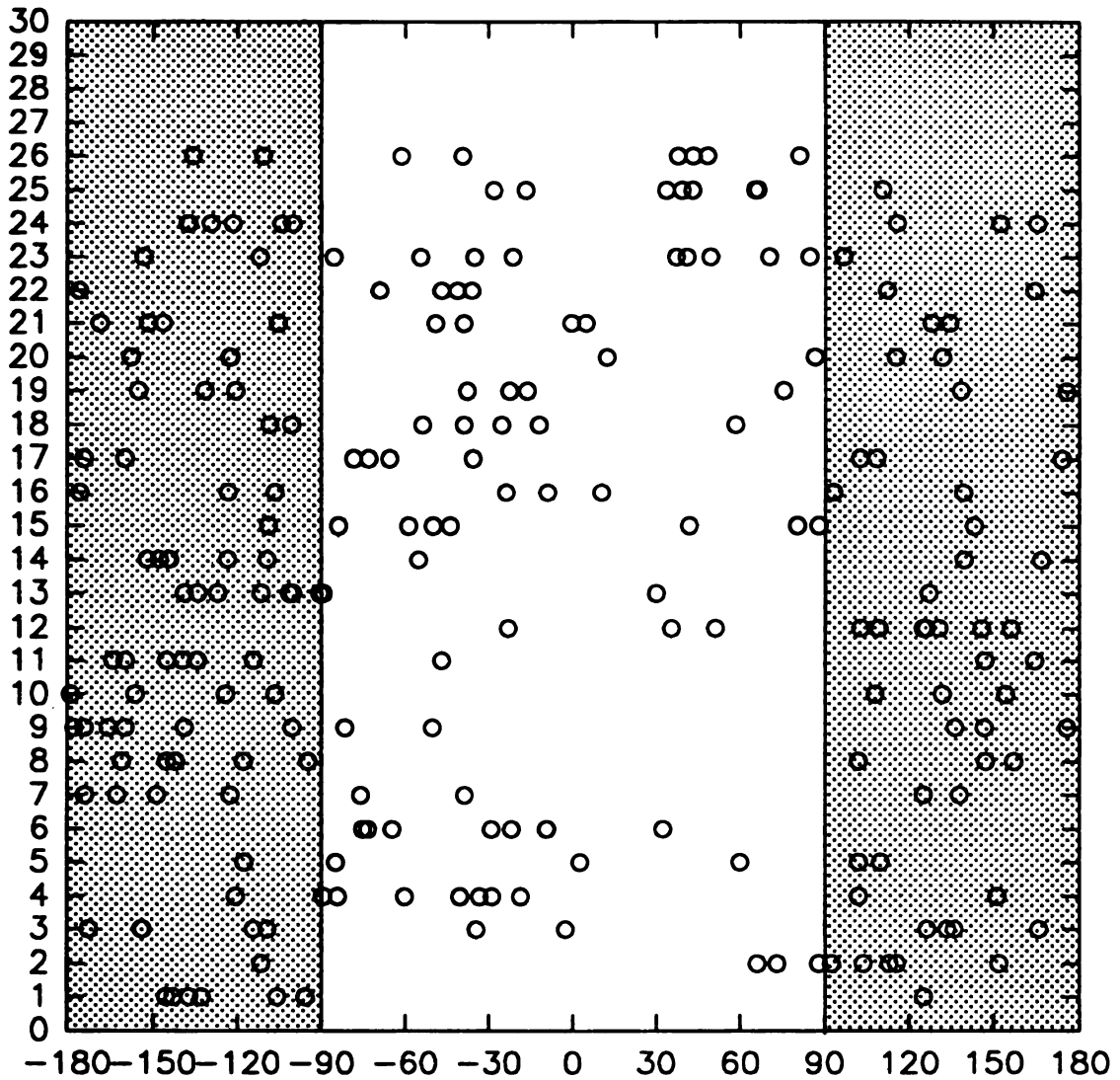


Figure 18. Angle between azimuth from relocated epicenter to station and azimuth from original epicenter to relocated epicenter for 26 of the selected best 75 events. This figure illustrates that the relocated epicenters tend to move away from the bulk of the receiving stations. Relocation moved the epicenter away from the recording stations in 142 out of 230 arrivals, denoted by the shaded regions of the plot.

data for all phases when plotted with the Pg relocations, I conclude that the 6.1 km/sec Pg velocity used to determine locations listed in the *Materialy* catalog is too high. Research by D. Gunbin (Personal communication, 1995) also indicates improved locations when a slower crustal velocity of 6.0 km/sec is used for the Magadan region.

The method of earthquake location used for most of the epicenters reported in *Materialy* may also contribute to errors in the epicenters. Earthquakes in the Sakha Republic (Yakutia) are still located by drawing arcs on large scale (approximately 1:8,000,000) paper maps. Considering the scale of the maps and thickness of the pencil line being drawn, errors of several kilometers may be introduced into the location process. These errors would probably be random with respect to azimuth.

In order to determine the first-order crustal structure, the method of Ruff et al., (1994) 'SQUINT' is used. This method assumes that regional travel time curves for multiple earthquakes can be approximated with a regional average crustal model. Given a set of earthquakes, the Pg travel time data are simultaneously inverted, solving for the best fit velocity for the set of events, and new origin times for individual events, assuming fixed hypocenters. For a given station, any systematic variation from the regional average should be a result of local variations in crustal structure. The Pg data was initially inverted with all spurious arrivals included (Fig. 19). Although this results in an increase in data scatter compared with the non-inverted data, it allows easy identification of dubious arrivals, which are then removed. Following the removal of spurious data, the data were again inverted for the determination of new origin times and regional crustal velocity (Fig. 20). The origin times of most events were moved 0.2-0.3

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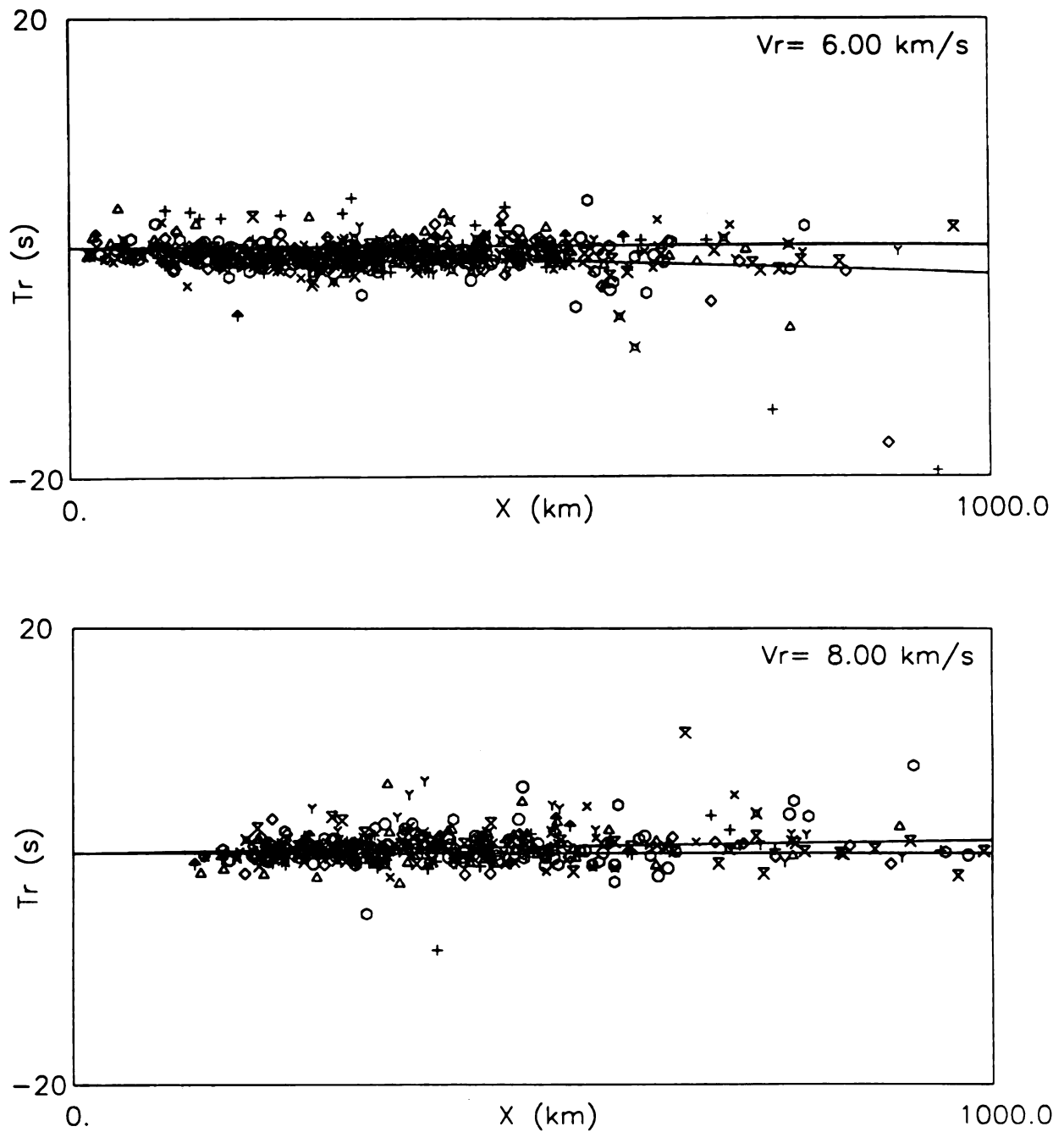


Figure 19. Reduced traveltime curves for Pg (A) and Pn (B) data of selected best 75 events using relocated epicenters and origin times determined from the 'SQUINT' inversion program. All data was included for this inversion trial. Individual events are represented by different symbols.

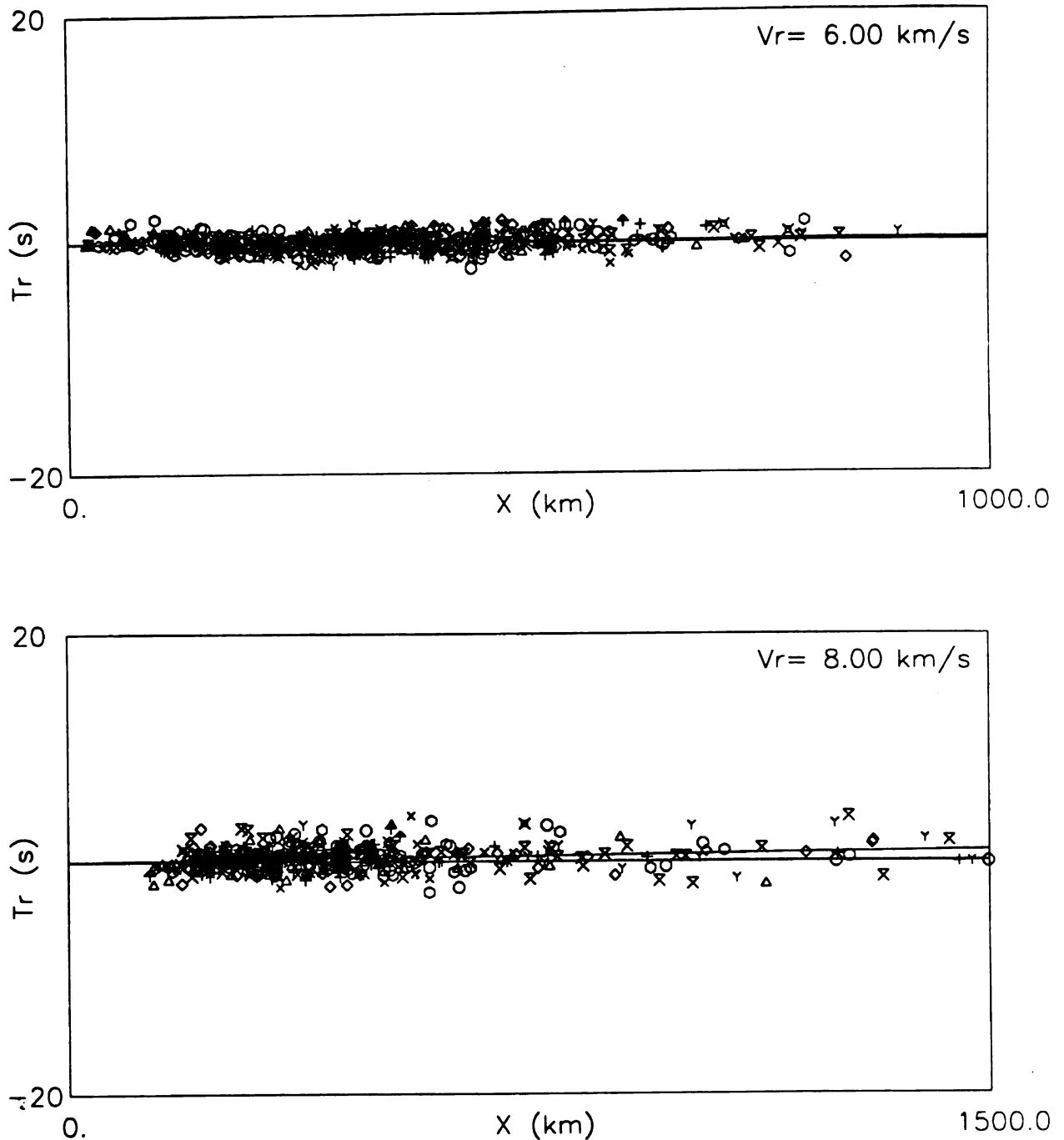


Figure 20. Reduced traveltime curves for Pg (A) and Pn (B) data of selected best 75 events. Epicenter relocations used are computed with Pg data, while origin times determined from the 'SQUINT' inversion program after high residual arrivals were removed. These traveltime curves indicate a Pg velocity of $5.992 \pm 0.007 \text{ km/sec}$ and a Pn velocity of $7.961 \pm 0.015 \text{ km/sec}$. Reduction velocities are noted on figures. Individual events are represented by different symbols.

seconds later from the origin time determined in the Pg relocation (Table 1). The reason for the consistent shifts in origin times is not clear, though may be related to incorrect assumptions about source depth. Using the Pg relocation epicenter, the Pn data were also inverted, first for identification of spurious arrivals (Fig. 19), which were subsequently removed. The Pn data were again inverted to determine the regional Pn velocity. Although inversion of the Pn data reveals nothing with respect to origin time, it does allow the best determination of the regional Pn velocity. Knowledge of the regional Pn velocity is necessary for the interpretation of the regional crustal structure.

As a result of this inversion the apparent velocities and crossover distance, and thus approximate crustal thickness are obtained for the study area as a whole (Fig. 21). Results for the Magadan region and Sakha Republic (Yakutia) indicate a simple structure with a 5.992 ± 0.007 km/sec layer overlying a 7.961 ± 0.015 km/sec layer. Average thickness is about 37 km. Data at shorter epicentral distances (< 260 km) suggest a slightly higher Pg velocity; the reason for this is likely related to misidentification of phases at the crossover distance. This apparent slightly higher crustal velocity is visible on the regional crustal travel time curve as a slight downwarp in the data (Fig. 20). I do not believe this downwarp to be caused from a 6.7 km/sec intermediate layer as reported by Ansimov et al. (1967). The existence of a 6.7 km/sec refracting intermediate layer should cause a significant number of mispicked Pg and Pn phases at distances greater than the crossover, which is not evident on any plotted traveltime curve.

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**Table 1. New origin times for the selected best 75 events, computed by 'SQUINT'.
Relocation origin times from Pg phase relocations.**

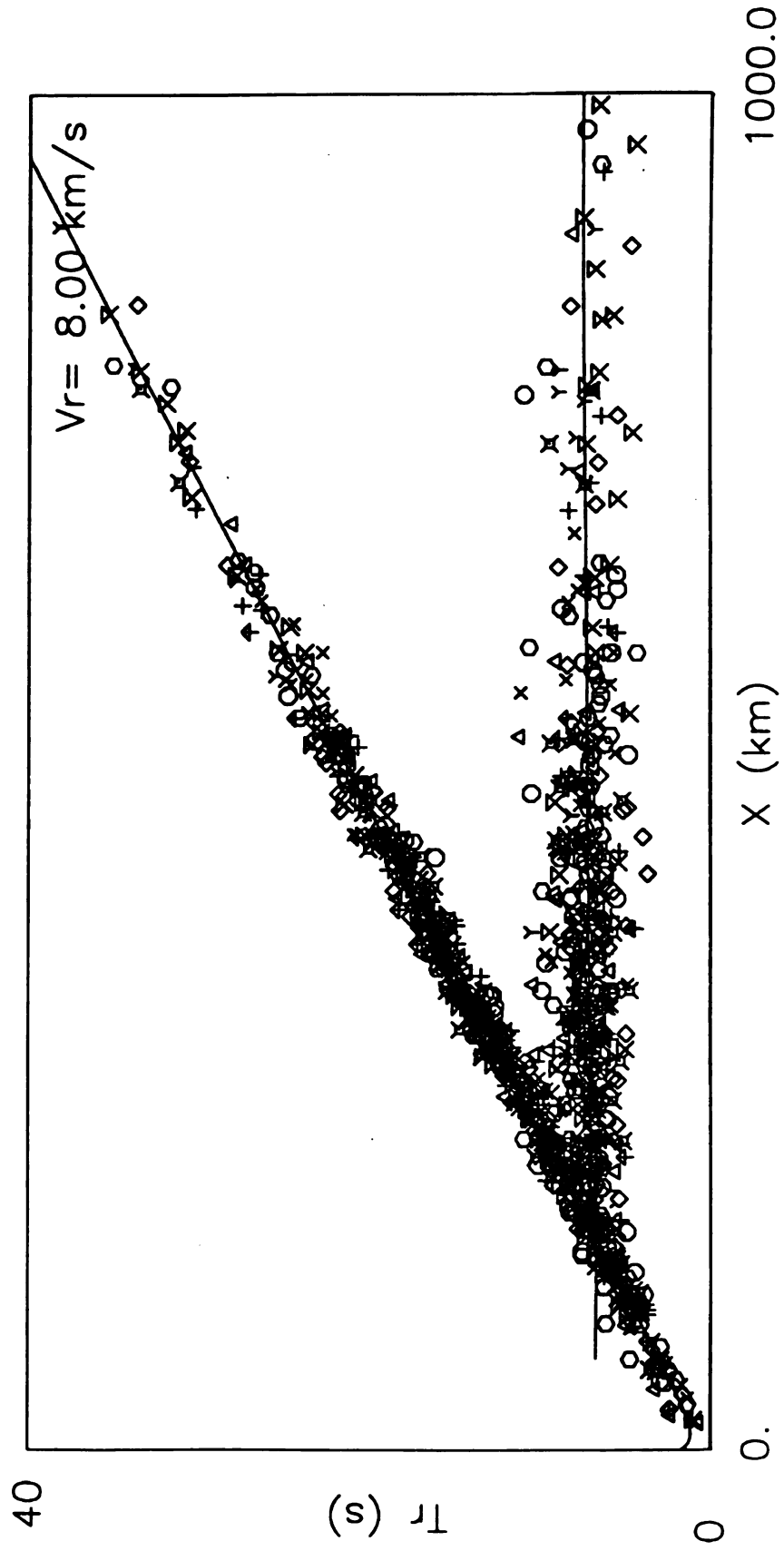
TABLE 1

DATE	RELOCATION O.T.	TIME SHIFT (S)	NEW O.T.
81-02-02	19:15:15.5	+0.19	19:15:15.69
81-05-10	18:08:25.8	+0.28	18:08:26.08
81-11-08	21:56:08.9	+0.28	21:56:09.19
81-11-10	10:54:15.5	+0.20	10:54:15.70
81-11-11	14:22:18.5	+0.22	14:22:18.72
81-12-08	10:57:20.6	+0.26	10:57:20.86
82-04-06	14:41:13.9	-0.38	14:41:13.52
82-08-04	20:17:03.5	+0.27	20:17:03.77
82-12-22	15:47:03.6	+0.22	15:47:03.82
83-03-12	11:55:11.7	+0.09	11:55:11.79
83-03-25	10:36:55.1	+0.19	10:36:55.29
83-05-09	16:48:05.3	+0.29	16:48:05.59
83-10-25	19:44:59.9	+0.17	19:45:00.07
84-08-21	17:41:02.7	-0.23	17:41:02.47
84-12-02	08:35:45.1	+0.35	08:35:45.45
84-12-02	18:17:54.9	+0.23	18:17:55.13
85-01-21	18:03:50.4	+0.25	18:03:50.65
85-01-24	20:26:33.2	+0.28	20:26:33.48
85-01-29	00:36:06.2	+0.02	00:36:06.22
85-03-08	22:24:37.8	+0.32	22:24:38.12
85-06-02	04:08:08.8	+0.31	04:08:09.11
85-11-28	08:38:20.5	+0.20	08:38:20.70
86-01-18	13:13:22.0	+0.28	13:13:22.28
86-02-15	20:30:26.3	+0.20	20:30:26.50
86-03-07	23:28:08.2	+0.23	23:28:08.43
86-04-06	01:27:20.5	+0.22	01:27:20.72
86-12-18	18:04:11.2	+0.27	18:04:11.47
86-12-26	03:21:04.5	+0.31	03:21:04.81
87-02-11	00:58:19.8	+0.26	00:58:20.06
87-02-11	01:03:08.0	+0.19	01:03:08.19
87-02-11	01:09:50.8	+0.28	01:09:51.08
87-02-11	06:19:16.3	+0.40	06:19:16.70
87-02-11	07:28:17.5	+0.17	07:28:17.67
87-02-11	11:36:16.1	+0.19	11:36:16.29
87-03-04	00:09:28.0	+0.39	00:09:28.39
87-04-13	21:20:12.8	+0.18	21:20:12.98
87-09-09	04:43:22.8	+0.30	04:43:23.10
88-02-19	00:04:04.0	+0.23	00:04:04.23
88-02-19	23:50:24.9	+0.18	23:50:25.08
88-04-03	02:01:28.6	+0.16	02:01:28.76
88-05-25	16:55:43.7	+0.05	16:55:43.75
88-06-09	13:37:32.9	+0.17	13:37:33.07
88-06-14	14:44:44.1	+0.24	14:44:44.34
88-10-17	00:27:59.2	+0.26	00:27:59.46
89-01-29	23:23:01.6	+0.23	23:23:01.83
89-03-21	10:53:05.1	+0.16	10:53:05.26

Table 1 (continued)

89-04-09	04:16:23.0	+0.43	04:16:23.43
89-06-16	07:36:08.5	+0.16	07:36:08.66
89-07-07	10:51:43.1	+0.14	10:51:43.24
89-07-09	18:11:49.0	+0.21	18:11:49.22
89-10-04	20:56:47.2	+0.52	20:56:47.72
90-03-29	20:47:29.7	+0.11	20:47:29.81
90-05-30	11:56:45.1	+0.27	11:56:45.37
90-06-25	07:33:51.7	+0.21	07:33:51.91
90-07-12	02:22:50.5	+0.18	02:22:50.68
90-08-24	01:04:44.6	+0.28	01:04:44.88
90-11-01	13:42:06.1	+0.27	13:42:06.37
90-11-02	21:54:03.2	+0.31	21:54:03.51
90-11-22	19:36:25.1	+0.28	19:36:25.38
90-12-13	21:34:39.1	+0.26	21:34:39.36
91-02-10	18:16:32.3	+0.13	18:16:32.43
91-03-01	01:57:04.1	+0.38	01:57:04.48
91-07-02	13:43:45.0	+0.27	13:43:45.27
91-07-31	01:44:02.7	+0.32	01:44:03.02
91-08-04	10:08:05.9	+0.25	10:08:06.15
91-08-04	19:14:40.6	+0.17	19:14:40.77
91-08-26	09:35:49.0	+0.40	09:35:49.40
92-01-22	06:29:16.1	+0.33	06:29:16.43
92-02-12	17:14:51.2	+0.28	17:14:51.48
92-06-28	23:53:17.4	+0.23	23:53:17.63
92-11-17	07:55:13.8	+0.22	07:55:14.02
93-03-05	04:21:05.1	+0.20	04:21:05.30
93-03-22	18:14:06.8	+0.21	18:14:07.01
93-03-24	16:18:05.9	+0.27	16:18:06.17
93-08-30	07:56:34.9	+0.37	07:56:35.27

Figure 21. Reduced traveltime curve for combined Pg and Pn data. All data plotted use the Pg data relocated epicenter and origin times from the 'SQUINT' inversion program after high residual arrivals were removed. The Pg-Pn crossover point is consistent with a regional crustal thickness of 37 km (optically determined). Pg velocity plotted is 5.99 km/sec, and Pn velocity is 7.96 km/sec. Reduction velocities are noted on figures. Individual events are represented by different symbols.



Individual Stations

I next examined the travel time data for individual stations. A best-fit crustal structure was estimated based on travel time curves derived from relocated epicenters and inverted origin times. Best-fit lines to the data were determined optically. The use of seventy five events in the analysis results in a lack of data at some outlying stations, and thus poorer determinations of velocities and crustal thickness. This primarily affects the stations in northern Yakutia. This problem is more serious for the mantle refraction, Pn. Sufficient data were available for 27 stations, and present data suggests that structural variations between stations in the study area are resolvable with this method. Based on final results, the errors in determining crustal thickness appear to be $\pm 4\text{--}5$ km, Pg velocities, ± 0.03 km/sec, and Pn velocities, ± 0.1 km/sec. In general, Sg velocities appear to be 3.5 ± 0.04 km/sec, while Sn velocities are generally unobtainable. There is some trade off between Pn velocity and crustal thickness; higher velocities usually result in greater thicknesses. The use of a computer data-fitting routine will improve these determinations. The use of additional data, particularly from outlying regions would also improve the crustal parameter determinations.

The results (Tables 2 and 3) suggest that velocities and thicknesses are very close to those determined to be the regional average. Most stations are fit well with a 6.00 km/sec Pg velocity, a 7.99 km/sec Pn velocity, and a 37 km depth. Magadan (Fig. 22) and Takhtoyamsk (Fig. 23) appear to have greater thicknesses of 40 km, although both are constrained by a small number of observations. Significantly, both of these stations

Table 2
COMPARISON OF CRUSTAL THICKNESSES

Code	Station	Belyaevsky (1974) ¹	Belyaevsky and Borisov (1974)	Bobrobnikov and Izmailov (1989) ²	Suvorov and Komilova (1986)	Vaschilov (1979) ³	Mishin and Dareshtina (1966)	Bulin (1989)	Neustroev and Parfenov (1985)	This Study
BTG	Bagai				26±3					32
DBI	Debin			43.0						37
EVE	Evenak	34 ⁴	40 ⁴			33.8 (36.0)			42	37
KHG	Khandyga				44±8					44
KU-	Kulu		38							30
MAG	Magadan				30±2 ⁴					40
MKU	Moma				29±7					35
MYA	Myakit									37
NAY	Naiba									29
NKB	Nelkoba	39	40	38.9		38.9 (41.2)	38.9			35
NZD	Nezhdaninskoe				40±4			37	40	39
OMO	Onolon	38	38			38.9 (40.1)	38.9			37
OMS	Onsukchan	30	35	30.2	38±3	30.2 (31.8)	30.2			36.5
SAY	Saidy						40			35
SSY	Sasyr									37
SEY	Seimchan			34.0	35±13					37
SNE	Sinegore									37
MGD	Stekolnyi	31	37	31.0		31.0 (32.9)	31.0			37
SUU	Susuman		45 (7)	50.0	33±3			40		35
TBK	Tabalakh									34
TTY	Takhtoyamak									40
TL-	Talaya									38
UNR	Ust' Nera				24±3			40		34
USO	Ust' Onchug				29±3				42	35
YAK	Yakutsk				37±6					38
YUB	Yubileinaya									19
ZYR	Zyryanka							41		47

¹Attributed to work by Nikolaevsky.

²Values reported by Bobrobnikov and Izmailov (1989) attributed to Mishin and Dareshtina (1966). Bobrobnikov and Izmailov (1989) consider the value for Debin to be an error.

³Data from Belyaevsky (1974) and Belyaevsky and Borisov (1974) for Garmanda, about 20 km north of Evenak.

⁴Suvorov and Komilova (1986) used Magadan as a calibration point based on the 1959 deep seismic sounding line.

⁵First column is attributed to Mishin and Dareshtina (1966), while values in brackets are from P-S conversions determined with a different formula.

Table 3

PN AND PG VELOCITIES

Station	Pg This Study	Pn This Study	Pn Suvorov and Kornilova (1986)
Batagai	5.97	7.94	8.1
Debin	5.99	7.97	
Evensk	6.01	8.07	
Khandyga	6.00	8.10	8.1-8.2
Kulu	5.98	7.73	
Magadan	6.01	8.00	
Moma	6.03	7.98	8.1
Myakit	5.99	7.90	
Naiba	5.96	7.70	
Nelkoba	5.97	7.87	
Nezhdaninskoe	5.98	7.98	
Omolon	5.98	7.98	
Omsukchan ¹	5.99	8.00	
Saidy	6.01	8.04	
Sasyr	5.98	8.00	
Seimchan	5.98	8.00	7.9-8.1
Sinegore	6.00	8.00	
Stekolnyi	5.98	8.04	
Susuman	6.00	7.96	7.9-8.0
Tabalakh	6.01	7.94	
Takhtoyamsk	6.02	8.10	
Talaya	5.96	8.10	
Tenkeli	5.98		
Ust' Nera	5.99	7.95	8.0-8.1
Ust' Omchug	6.05	7.90	7.9-8.1
Yakutsk	6.03	8.00	
Yubileinaya	5.96	7.49	
Zyryanka	5.98	8.22	
REGIONAL	5.99	8.00	

¹ Mishin and Dareshkina (1966) calculated a Pg velocity for Omsukchan of 6.02 km/sec by the method of Gaiskii.

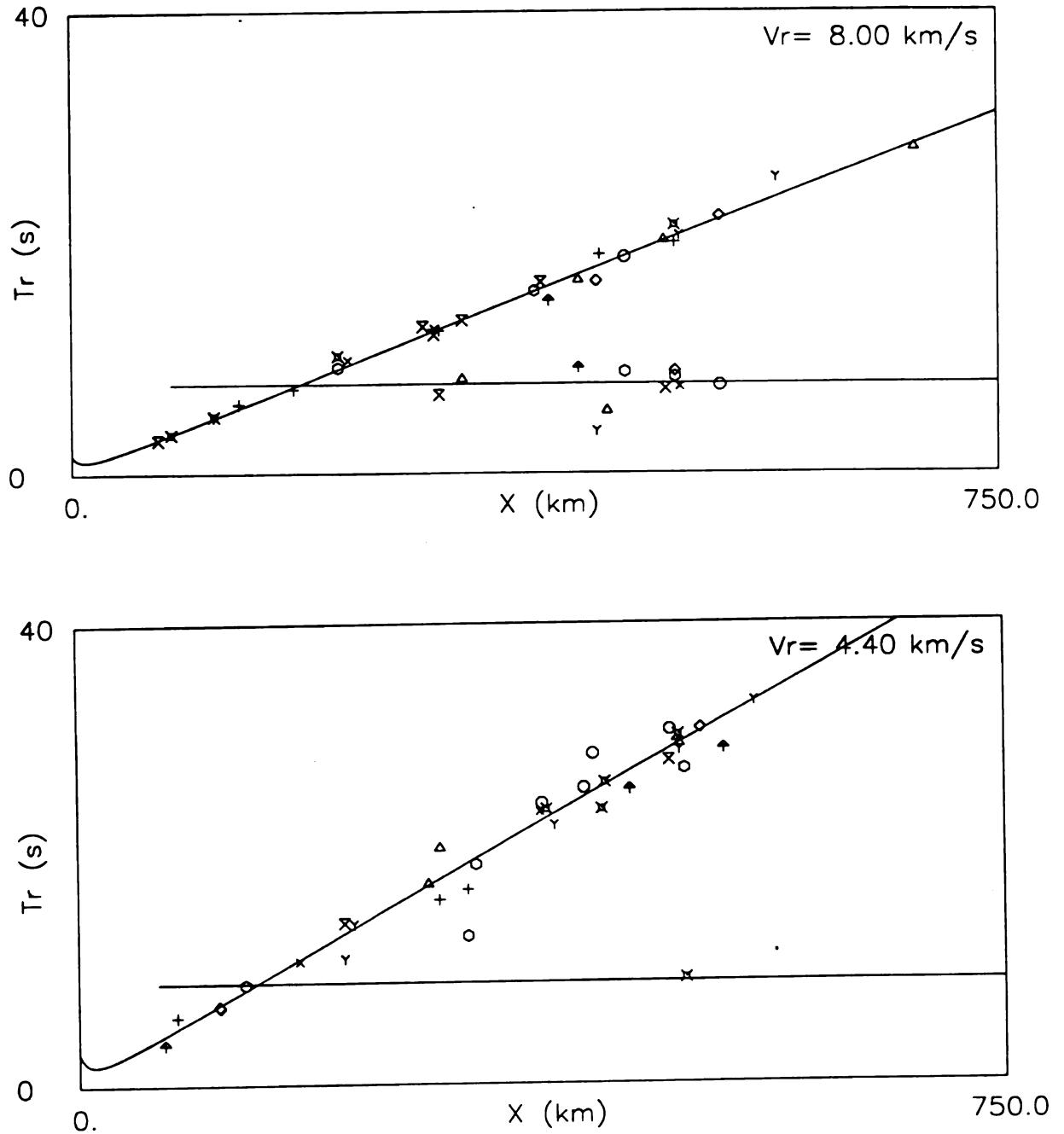


Figure 22. Magadan station traveltime curves and crustal model. Upper plot shows Pg and Pn data with velocities of 6.01 km/sec and 8.00 km/sec respectively. The Pg-Pn crossover point is consistent with a crustal thickness of 40 km. Lower plot shows Sg and Sn data. Sg data is best fit with a velocity of 3.50 km/sec. No attempt was made to fit Sn data. All velocities and crustal thickness were fit optically. Reduction velocities are noted on figures. Individual events are represented by different symbols.

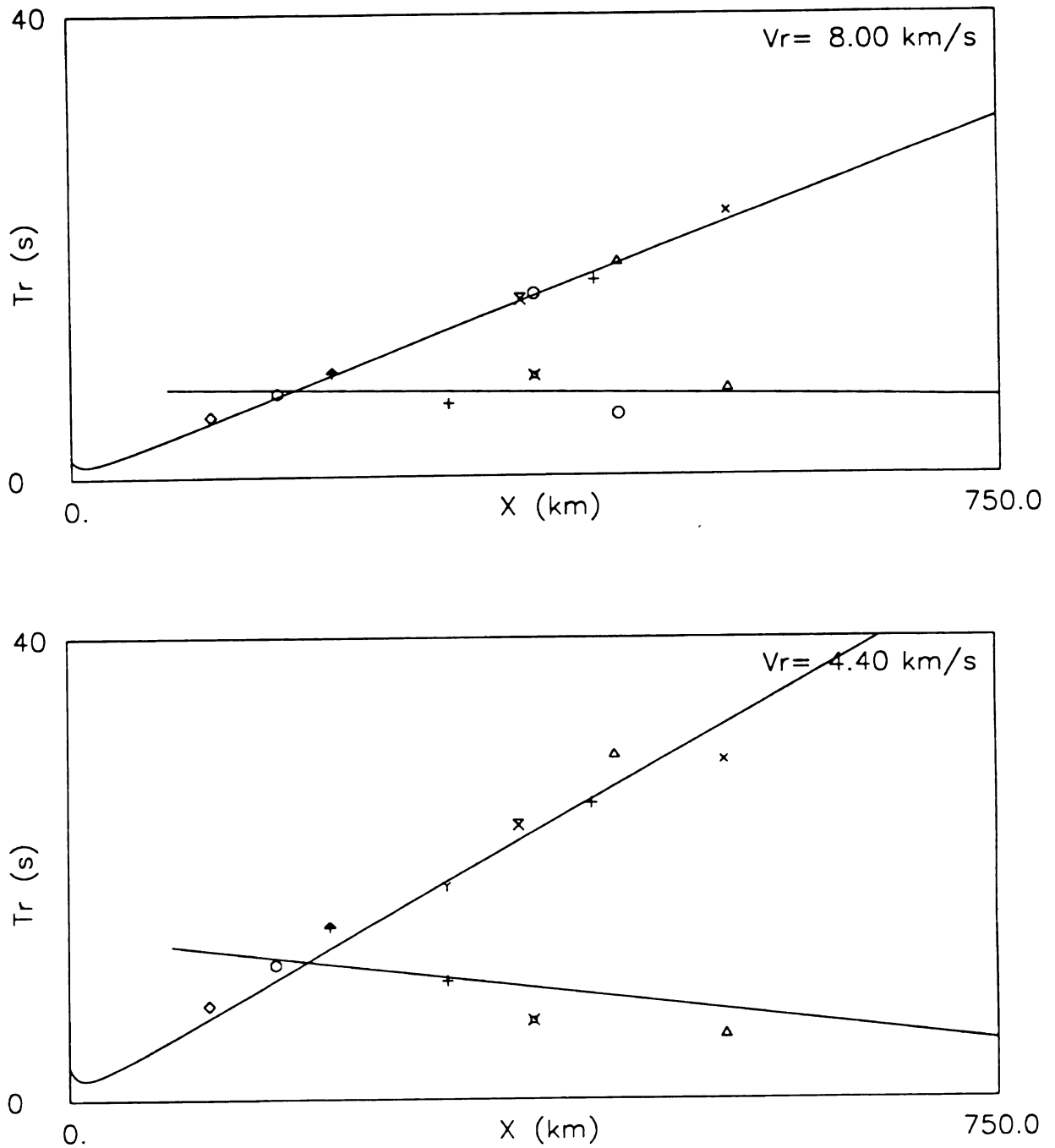


Figure 23. Takhtoyamsk station reduced traveltime curves and crustal model. Pg velocity 6.02 km/sec, Pn velocity 8.10 km/sec, and crustal thickness 40 km. Sg velocity 3.47 km/sec. Conventions as in Figure 22.

are located on the southern edge of the Okhotsk-Chukotka volcanic belt. In the region of Magadan and Takhtoyamsk, the Okhotsk-Chukotka volcanic belt overlies the Kony-Murgal terrane. The Kony-Murgal terrane is composed primarily of an accreted sequence of island arc volcanic, plutonic, and related sedimentary rocks dating from Late Jurassic to Early Cretaceous (Nokleberg et al., 1994; Watson and Fujita, 1985). Results are also in good agreement with the deep seismic sounding results from the upper Yama River valley, also near this suture, reported by Bobrobnikov and Izmailov (1989). By extrapolation of the Magadan-Ust' Srednikan DSS profile, the crustal thickness at Magadan is estimated to be approximately 30 km (Davydova et al., 1968; Ansimov et al. 1967; Suvorov and Kornilova, 1986). However, Magadan is located on a separate terrane from the area actually covered by DSS profiles, and no data is available directly under Magadan. Therefore, it may not be a valid assumption to extrapolate for crustal thickness and velocities. It should be noted that for both Magadan and Takhtoyamsk, the Pn data are sparse or scattered, with only one or two points controlling Pn velocity and crustal thickness. Both crustal thickness and Pn velocity could be affected significantly by alteration of only one data point in each plot. The Pg data for Magadan and Takhtoyamsk fit well with velocities of 6.01 km/sec and 6.02 km/sec respectively. There is no clear evidence in the data to support a 6.7 km/sec lower crust as observed along the Magadan - Ust' Srednikan profile (Ansimov et al., 1967).

Stekolnyi is located approximately 70 km north of Magadan within the Viliga terrane. This terrane consists primarily of a thick section of Carboniferous, Permian, Triassic, and Jurassic marine clastic rocks with some intermixed volcanics (Nokleberg et

al., 1994). This study derives a crustal thickness of 37 km for Stekolnyi, with Pg and Pn velocities of 5.98 km/sec, and 8.04 km/sec respectively (Fig 24). S wave data are fit well with Sg and Sn velocities of 3.48 km/sec and 4.6 km/sec, with a crustal thickness of 38 km. The Sn data show considerable scatter, thus the Sn velocity and thickness are unreliable. The crustal thickness here is in good agreement with the P-Ps conversion study by Belyaevsky and Borisov (1974), which indicates a 37 km thick crust. The thickness determined in this study is a bit higher than the 31-32 km indicated by the DSS line. The data for Stekolnyi are considered good, as the velocities are constrained by many points.

To the north of Stekolnyi, within the Viliga terrane, are the stations Debin, Myakit, Omsukchan, Seimchan, and Sinegor'e. These stations are all within a 200 km radius, and are fit well with a thickness of 37 km and Pg velocity of 5.98-6.00 km/sec (Figs 25-29). Mishin and Dareshkina (1966) calculated a Pg velocity for Omsukchan of 6.02 km/sec using the "method of Gaiskii". Pn velocity is 8.00 km/sec for these stations, with the exception of Myakit and Debin, where velocities are 7.90 km/sec and 7.97 km/sec respectively. Sg velocities are also well constrained at 3.52 km/sec for Seimchan and Omsukchan and 3.50 km/sec for Debin. The scatter in the Debin Pn data are considerable, while Myakit and Sinegor'e have Pn data over a short epicentral distance, thus Pn velocities have large error bars. For both Seimchan and Omsukchan, the velocities and thickness are well constrained. There are no previous velocities or thickness reported for Sinegor'e or Myakit, and only Belyaevsky (1974) reports a thickness for Debin, at 43 km. Bobrobnikov and Izmailov (1979) believe the 43 km figure for Debin to be in error. Previous determinations for crustal thickness at

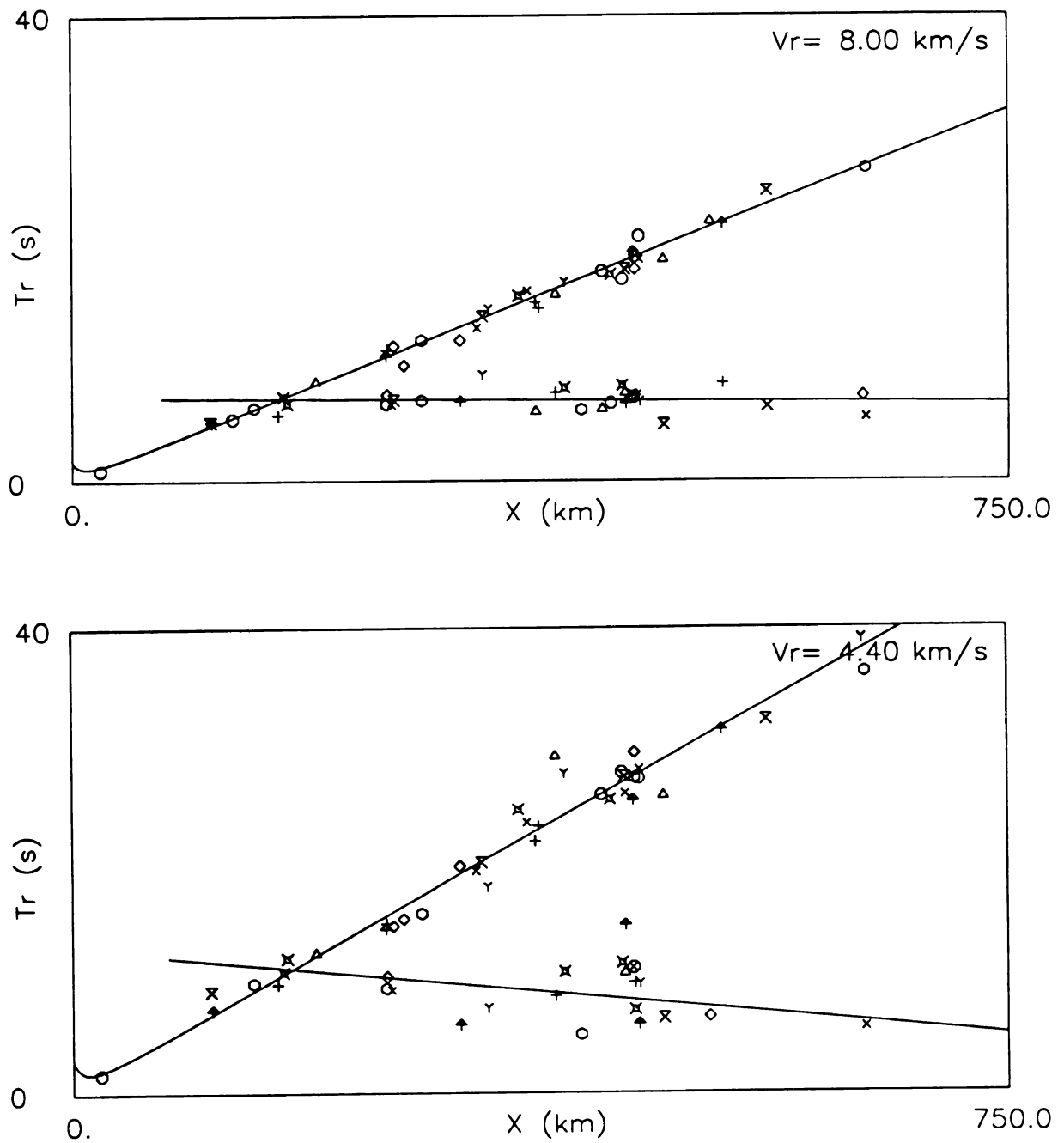


Figure 24. Stekolnyi station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 8.04 km/sec, and crustal thickness 37 km. Sg velocity 3.48 km/sec. Conventions as in Figure 22.

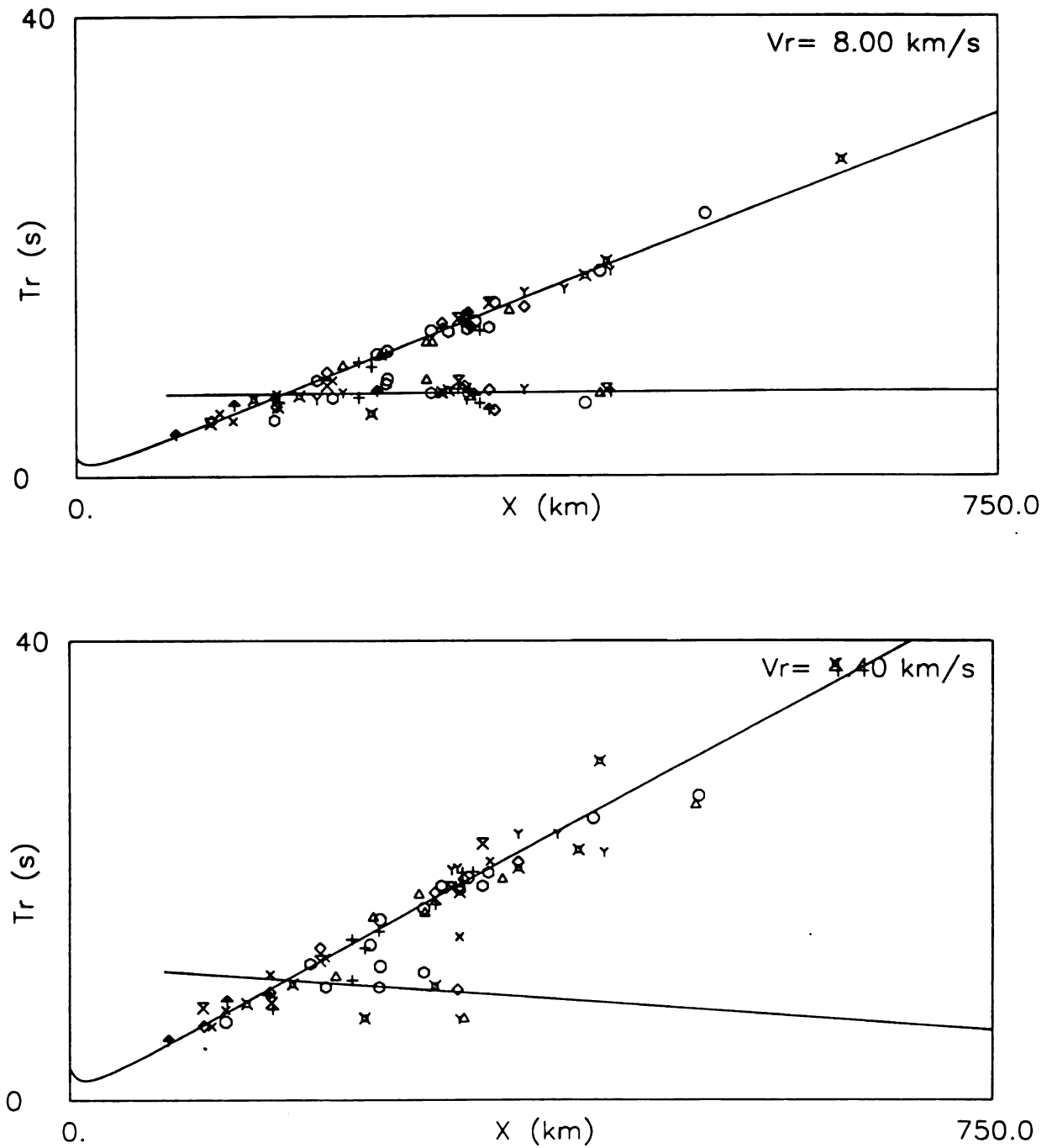


Figure 25. Debin station reduced traveltime curves and crustal model. Pg velocity 5.99 km/sec, Pn velocity 7.97 km/sec, and crustal thickness 37 km. Sg velocity 3.50 km/sec. Conventions as in Figure 22.

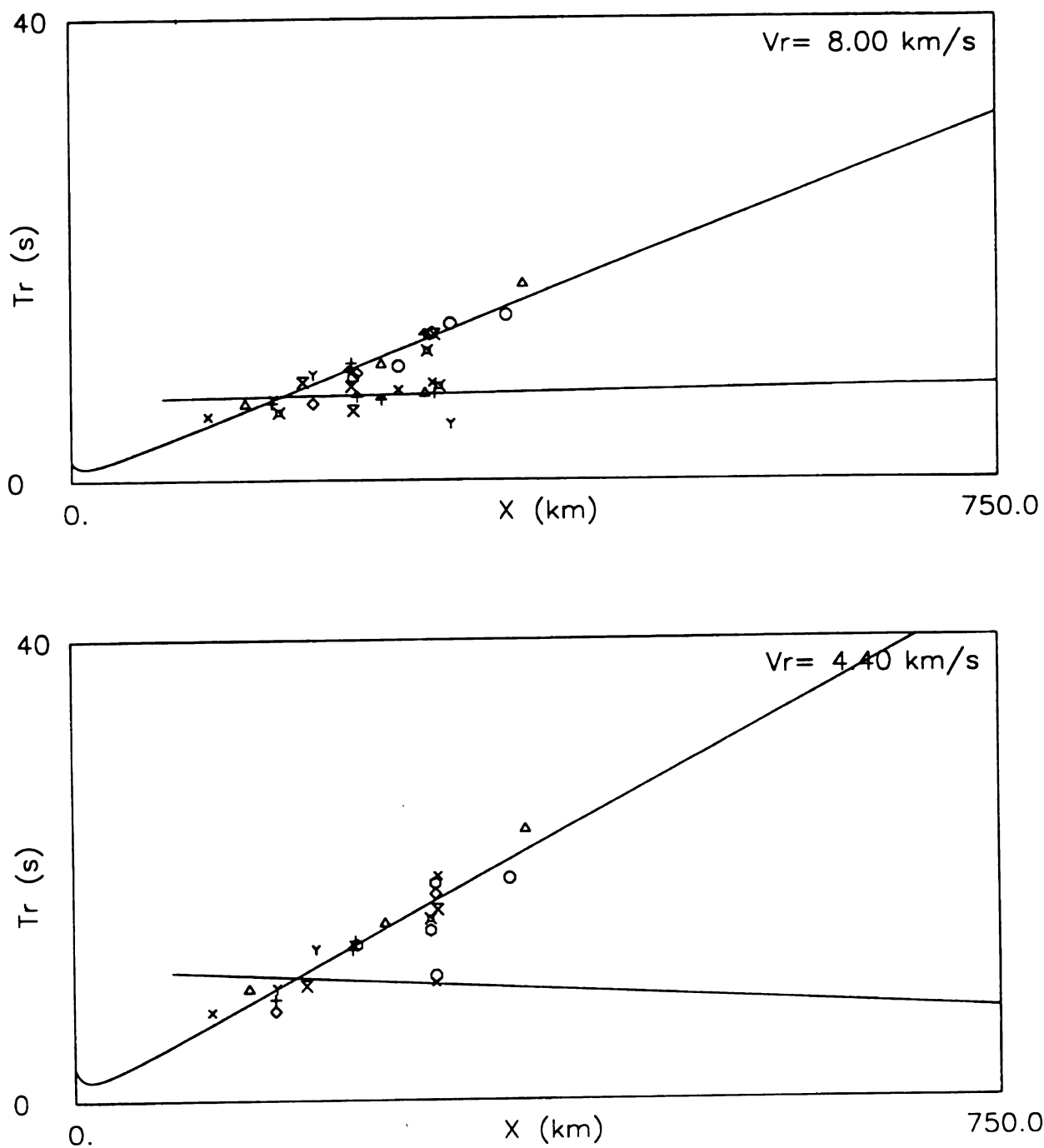


Figure 26. Myakit station reduced traveltime curves and crustal model. Pg velocity 5.99 km/sec, Pn velocity 7.90 km/sec, and crustal thickness 37 km. Sg velocity 3.50 km/sec. Conventions as in Figure 22.

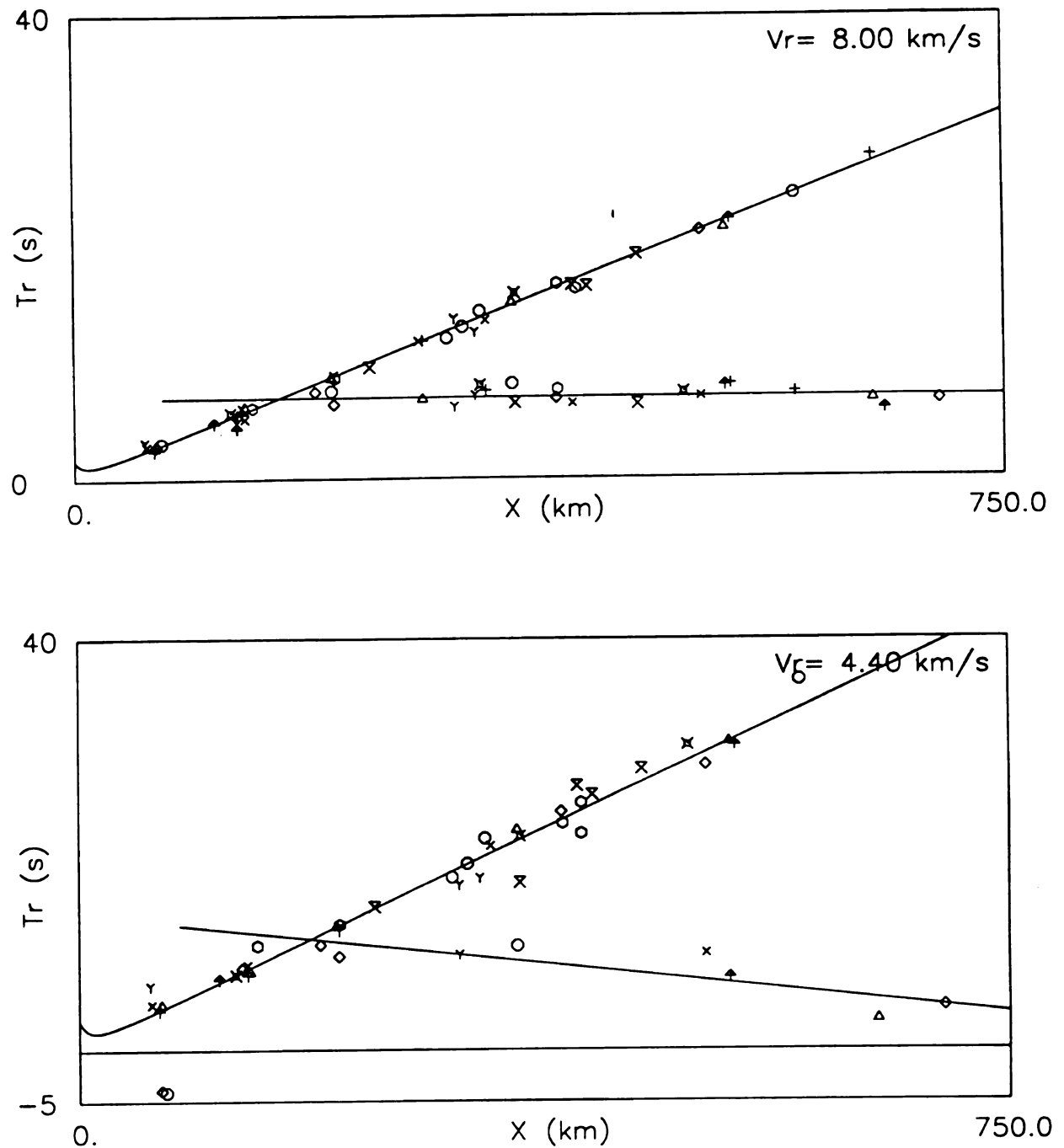


Figure 27. Omsukchan station reduced traveltime curves and crustal model. Pg velocity 5.99 km/sec, Pn velocity 8.00 km/sec, and crustal thickness 36.5 km. Sg velocity 3.52 km/sec. Conventions as in Figure 22.

40

T_r (s)

0

4

T_r (s)

0

Fig
5.9
km

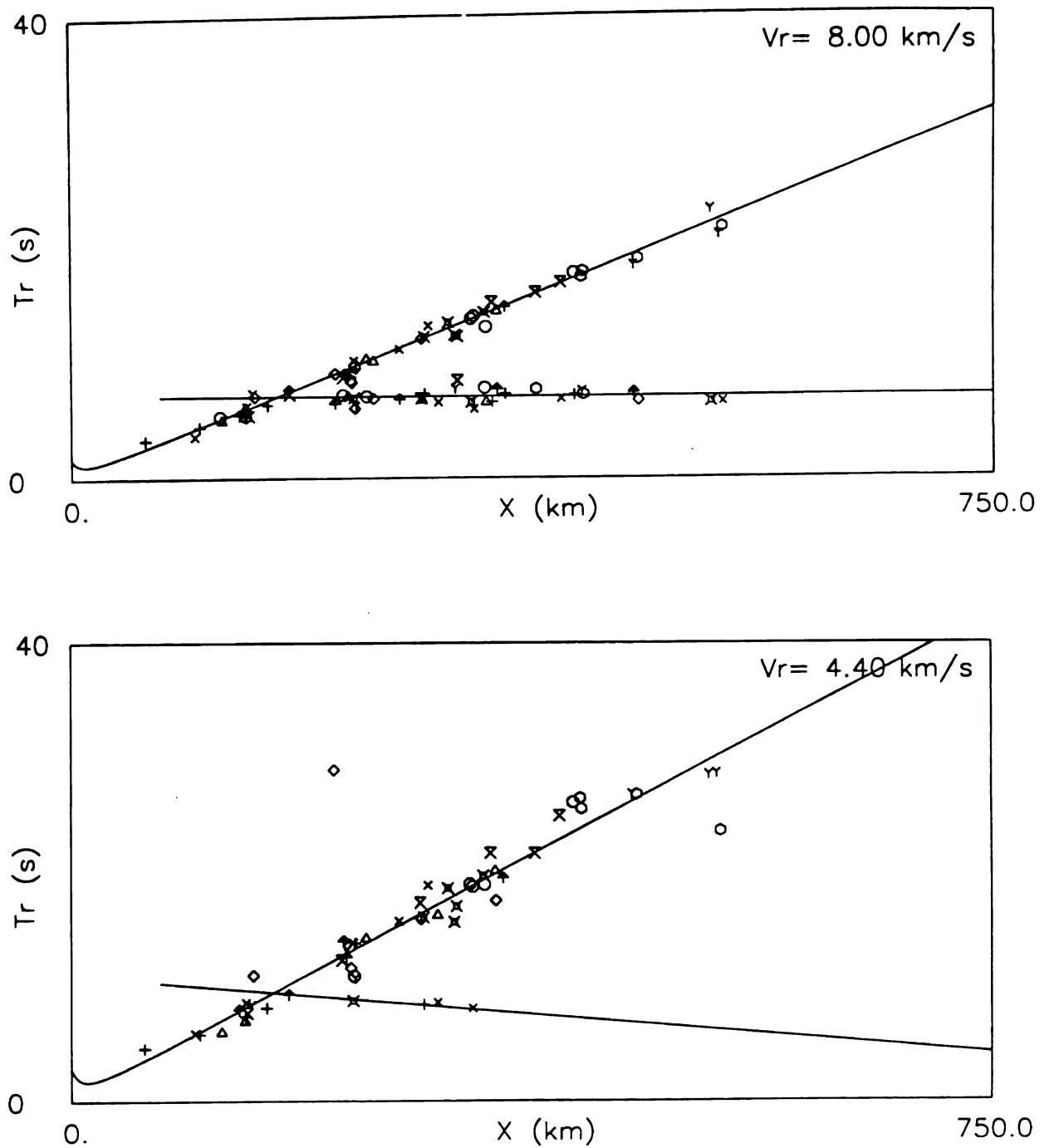


Figure 28. Seimchan station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 8.00 km/sec, and crustal thickness 37 km. Sg velocity 3.52 km/sec. Conventions as in Figure 22.

40

t_r (s)

0

40

t_r (s)

0

Figure
6.00
km/s

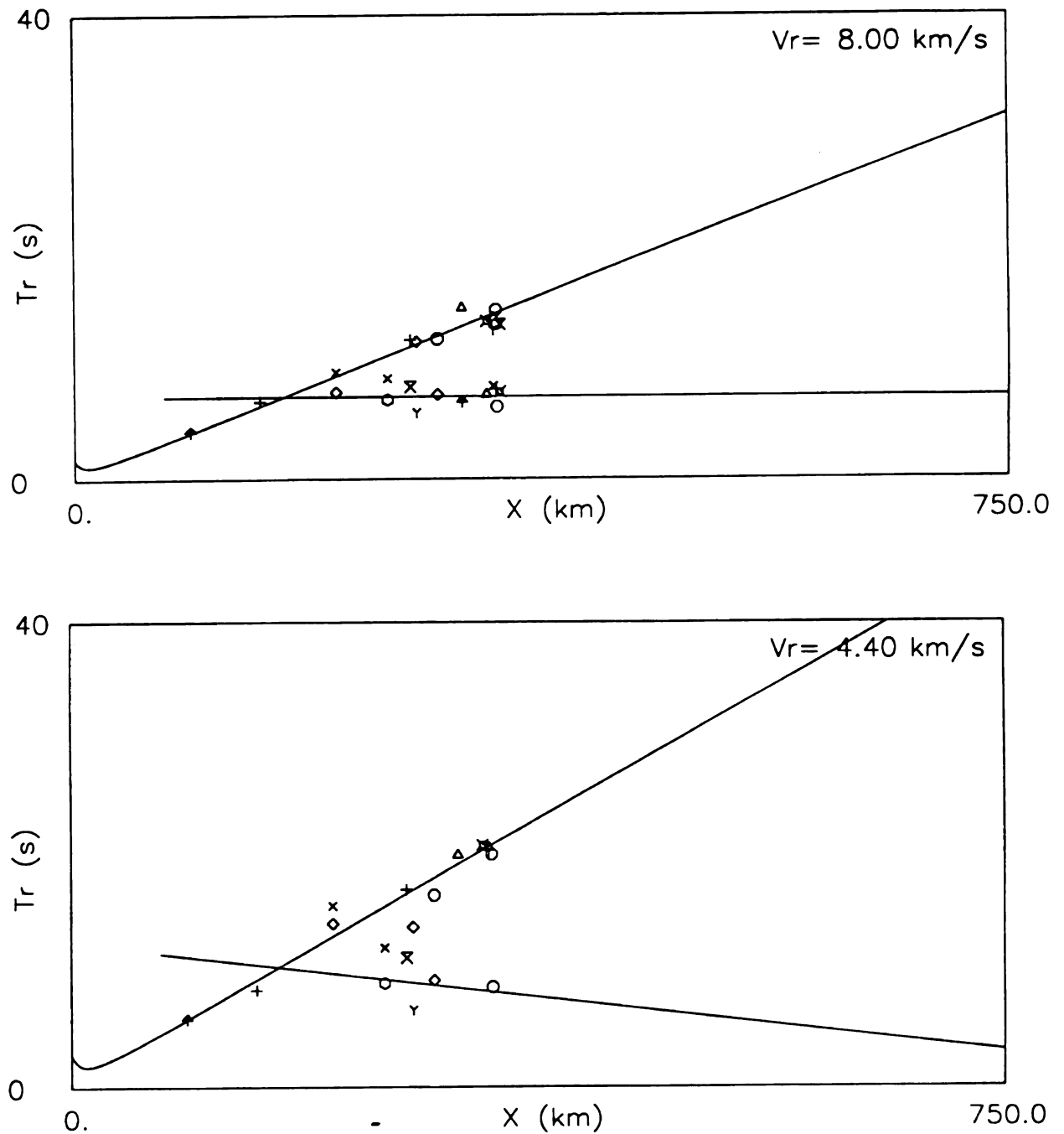


Figure 29. Sinegor'e station reduced traveltime curves and crustal model. Pg velocity 6.00 km/sec, Pn velocity 8.00 km/sec, and crustal thickness 37 km. Sg velocity 3.53 km/sec. Conventions as in Figure 22.

Omsukchan range from 30 km (Belyaevsky, 1974) to 38 km (Suvorov and Kornilova, 1986). The thickness determination for Omsukchan in this study falls in between at 36.5 km. For Seimchan, this study determines the thickness to be 2-3 km greater than previous studies. For this study, I estimate crustal thickness errors for Seimchan and Omsukchan to be 2 km. Bulin (1989) has also determined this region of the study area to have a homogeneous crustal structure, which is consistent with my results.

Talaya may also fit within this homogeneous region, although Pg and Sg velocities for Talaya are lower than the above discussed region at 5.96 km/sec and 3.48 km/sec, respectively, both being fairly well constrained (Fig. 30). A crustal thickness of 38 km is calculated for Talaya, although Pn data are sparse. This crustal thickness would be consistent with a thickening of the crust toward the south, as indicated by Magadan and Takhtoyamsk.

The area immediately east of the homogeneous region discussed above contains Kulu, Susuman, Nelkoba, and Ust' Omchug stations, all showing a slightly reduced crustal thickness (Figs. 31-34). Crustal thicknesses range from 30 km at Susumam to 35 km at the other stations. In addition, all stations indicate reduced Pn velocities ranging from 7.73 km/sec at Kulu to 7.96 km/sec at Susuman. For these stations, there is no consistent velocity change for either Pg or Sg phases. It should be noted that values for Ust' Omchug have large error bars due to limited data. The previous estimates of crustal thickness for Ust' Omchug are 29 km by Suvorov and Kornilova (1986), and an estimate of 36 km from the Magadan-Ust' Srednikan profile. Previous estimates for Susuman are inconsistent, with values ranging from 33 km (Suvorov and Kornilova, 1986) to 50 km

4

Q

P

C

A

N

A

C

F

S

K

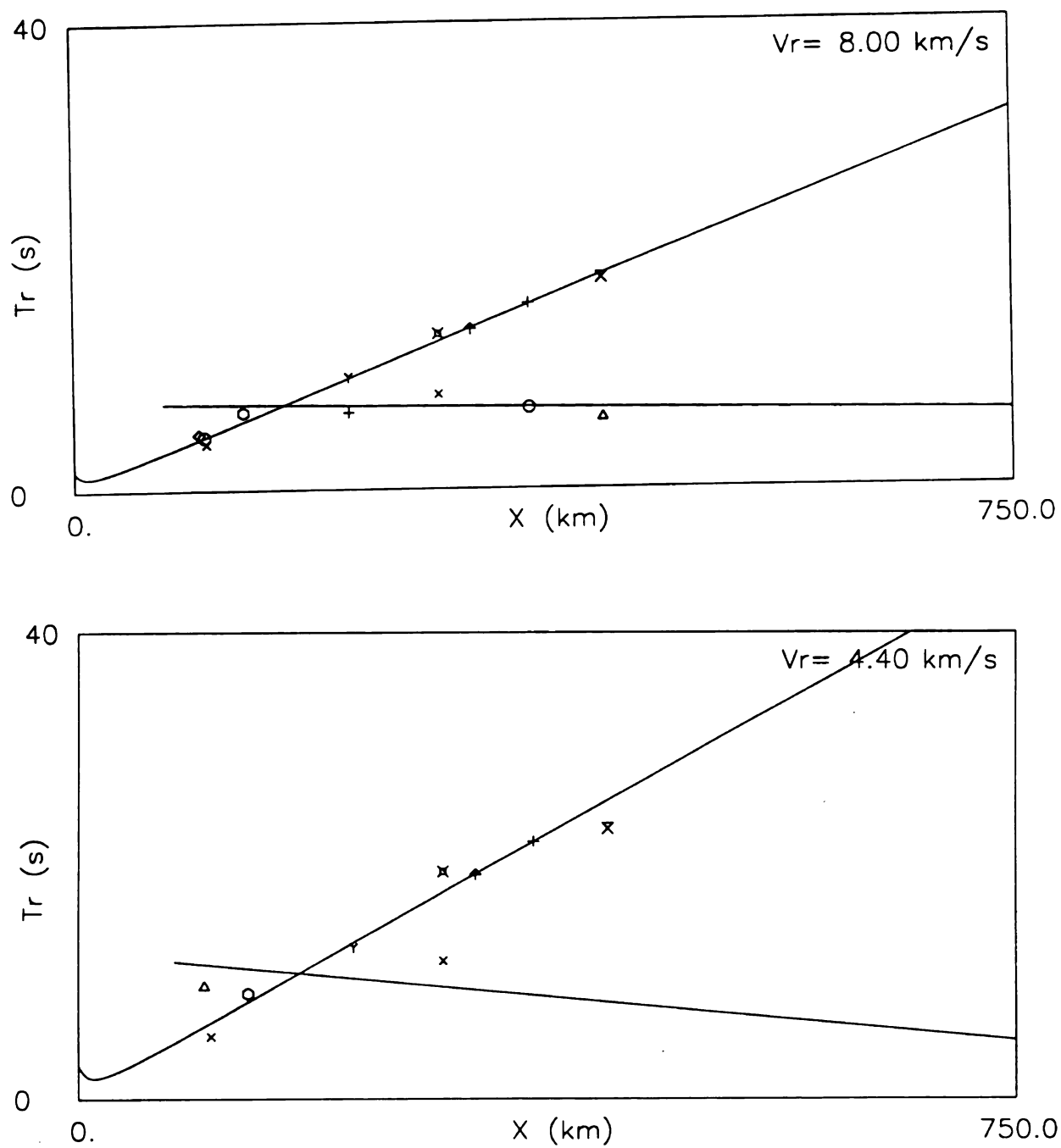


Figure 30. Talaya station reduced traveltime curves and crustal model. Pg velocity 5.96 km/sec, Pn velocity 8.10 km/sec, and crustal thickness 38 km. Sg velocity 3.48 km/sec. Conventions as in Figure 22.

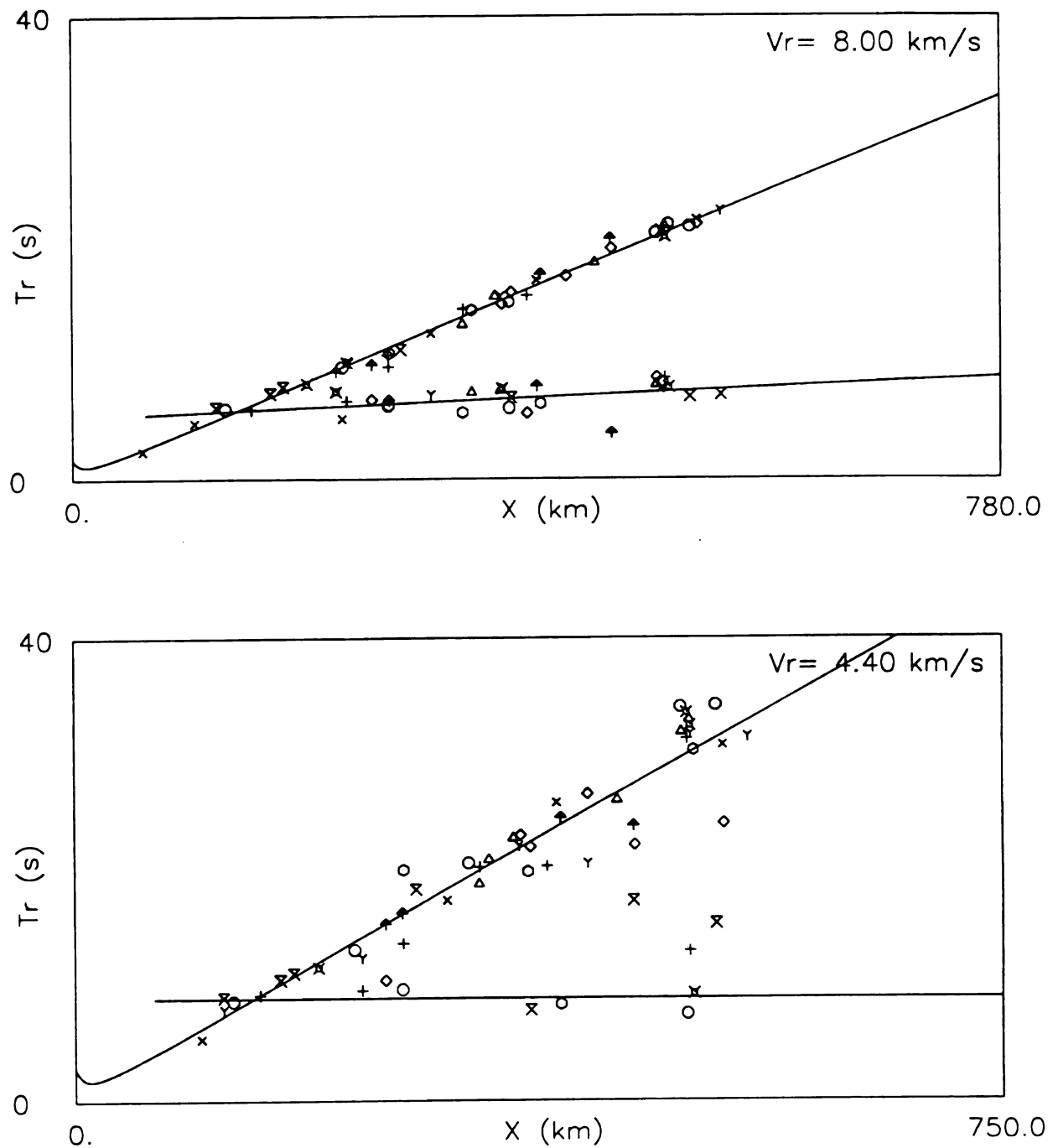


Figure 31. Kulu station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 7.73 km/sec, and crustal thickness 30 km. Sg velocity 3.48 km/sec. Conventions as in Figure 22.

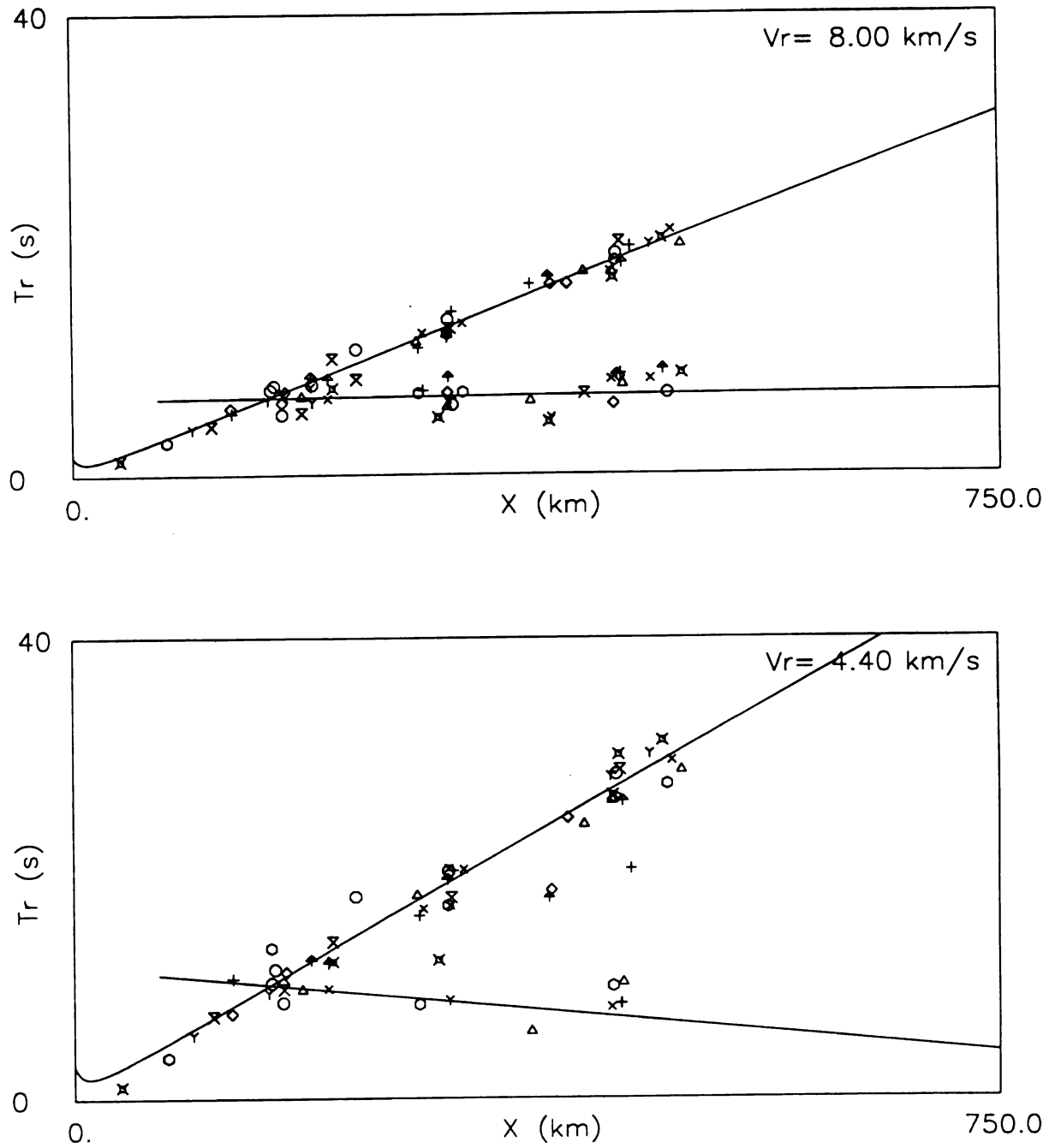


Figure 32. Susuman station reduced traveltime curves and crustal model. Pg velocity 6.00 km/sec, Pn velocity 7.96 km/sec, and crustal thickness 35 km. Sg velocity 3.47 km/sec. Conventions as in Figure 22.

40

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0

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Figure
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km/sec

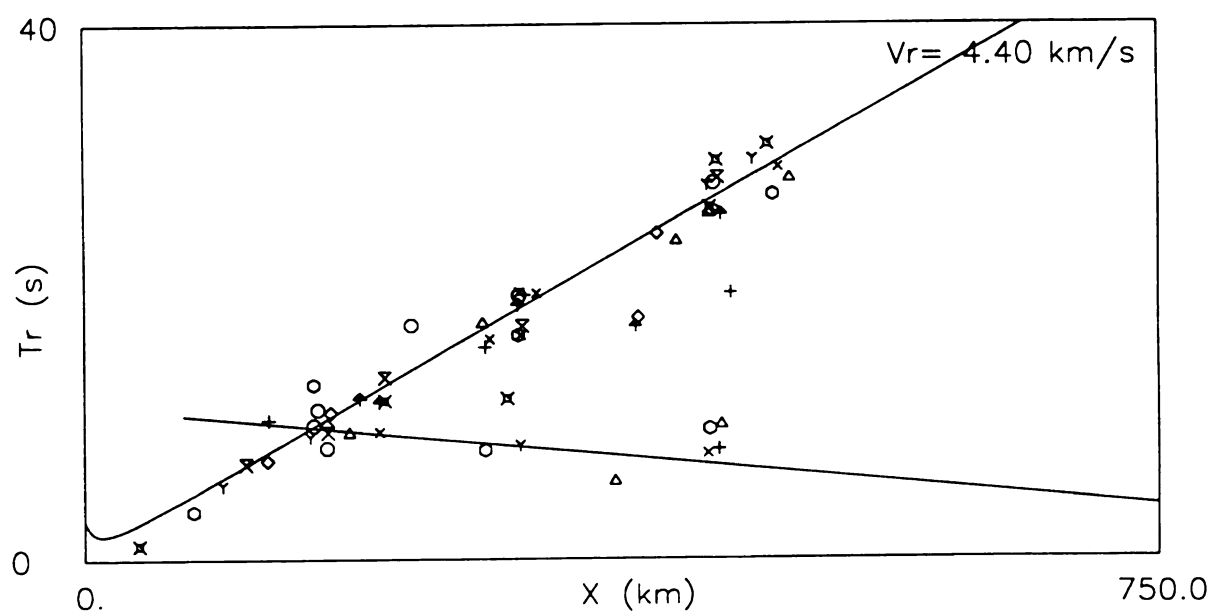
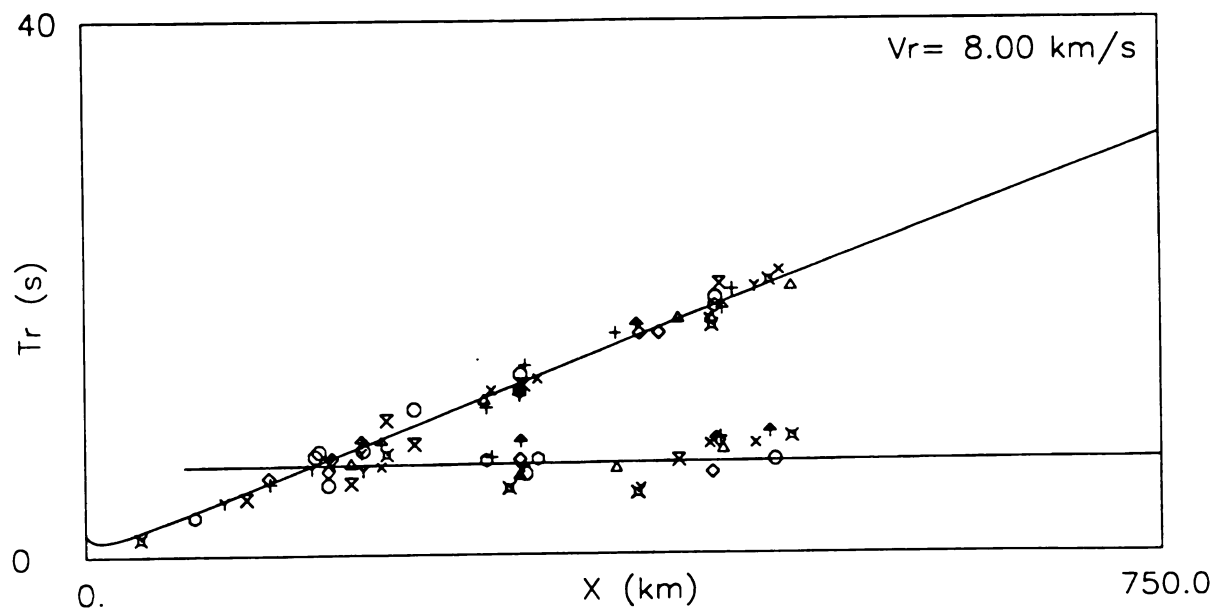


Figure 32. Susuman station reduced traveltime curves and crustal model. Pg velocity 6.00 km/sec, Pn velocity 7.96 km/sec, and crustal thickness 35 km. Sg velocity 3.47 km/sec. Conventions as in Figure 22.

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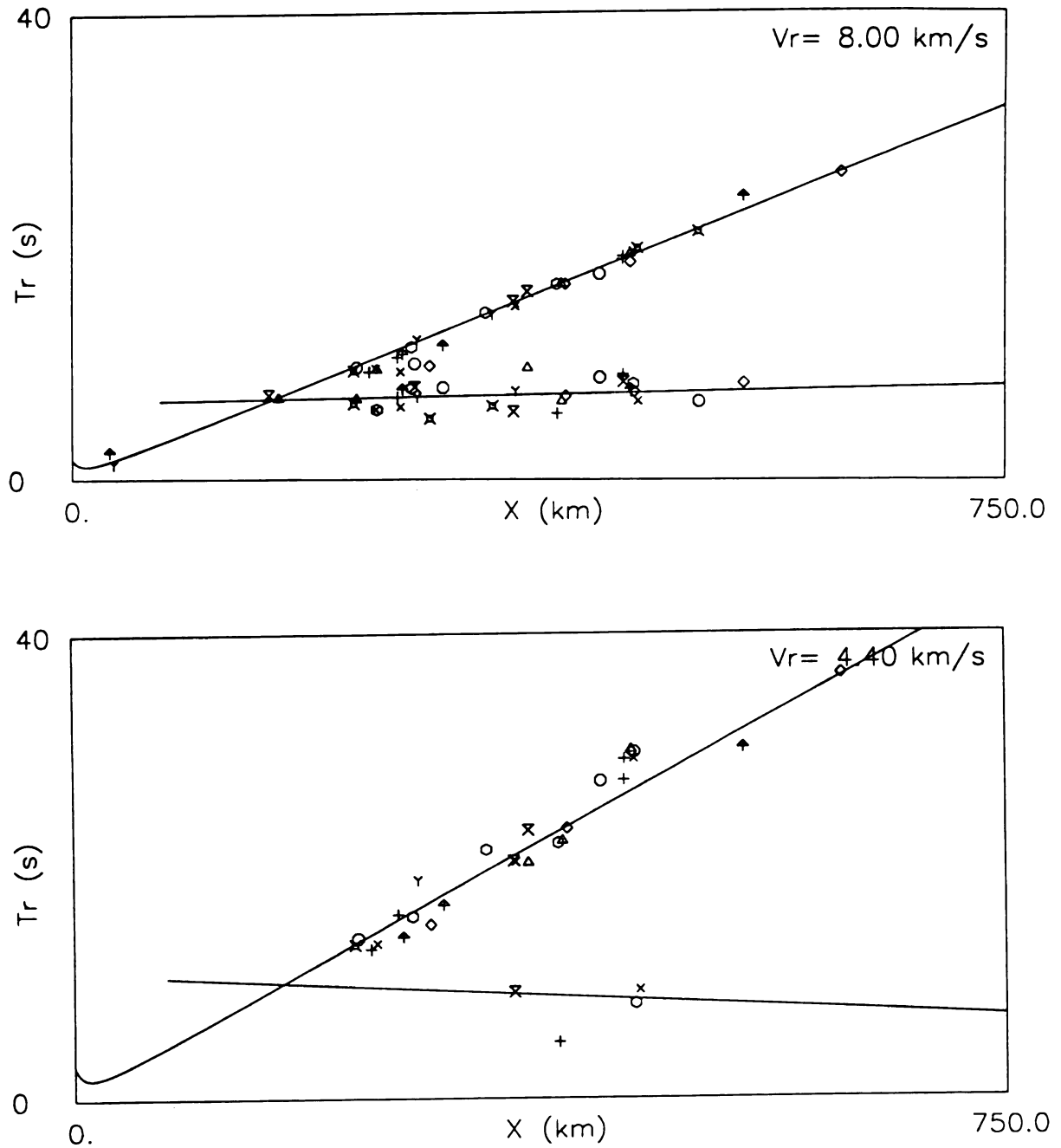


Figure 33. Nelkoba station reduced traveltime curves and crustal model. Pg velocity 5.97 km/sec, Pn velocity 7.87 km/sec, and crustal thickness 35 km. Sg velocity 3.50 km/sec. Conventions as in Figure 22.

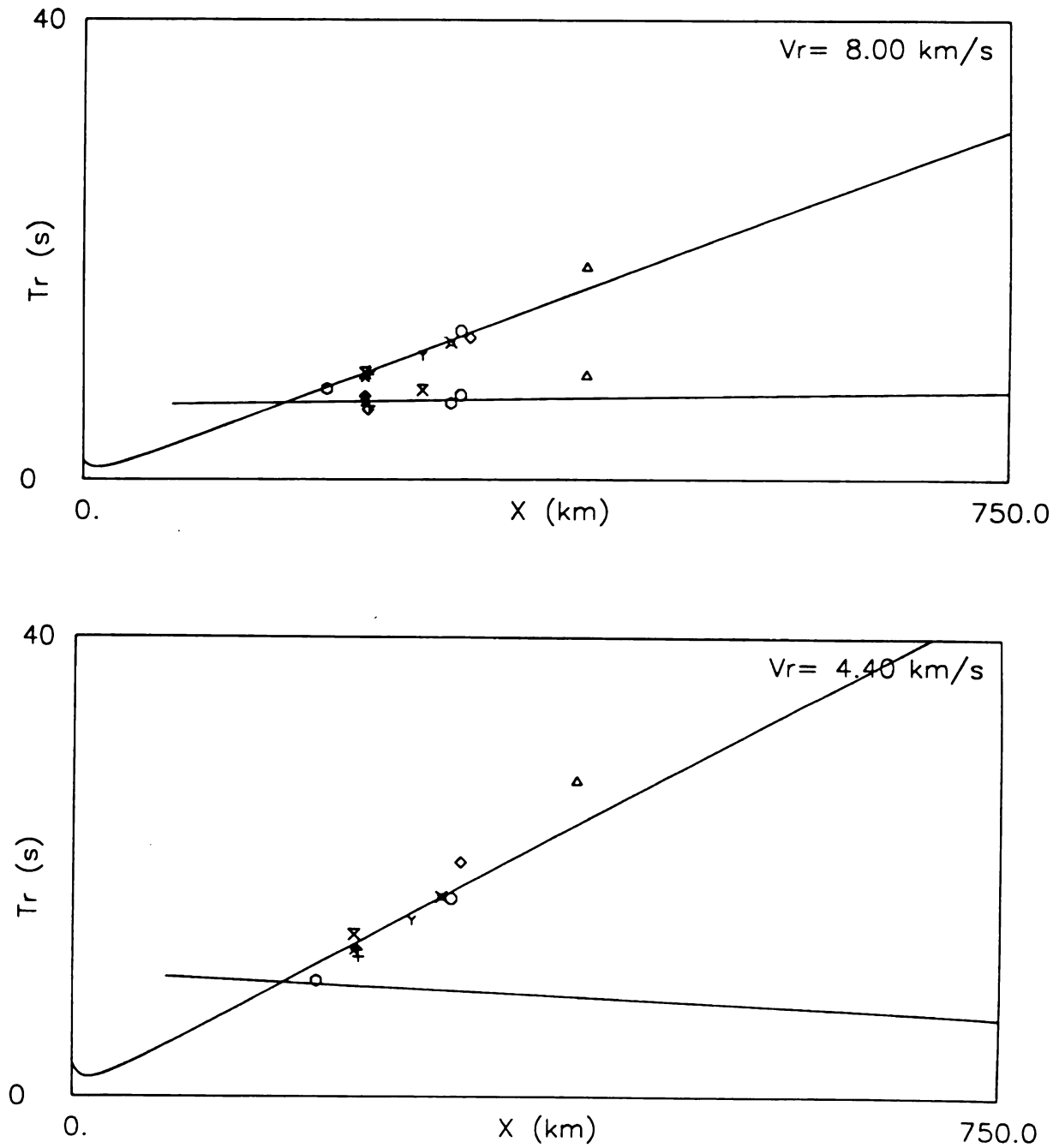


Figure 34. Ust' Omchug station reduced traveltime curves and crustal model. Pg velocity 6.05 km/sec, Pn velocity 7.90 km/sec, and crustal thickness 35 km. Sg velocity 3.51 km/sec. Conventions as in Figure 22.

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(Belyaevsky, 1974). Given the 2 km difference between the Suvorov and Kornilova estimate and my estimate, I believe the Belyaevsky (1974) estimate to be in error. Previous studies on Nelkoba indicate a thickness of 39-40 km. It is not possible for me to increase crustal thickness by the required 4-5 km to agree with previous studies without ignoring a significant portion of my data. No previous studies have considered the crustal structure at Kulu.

Ust' Nera and Moma (Khonu) are located to the northwest of Susuman, continuing the trend of a slightly elevated Moho at 35 km and reduced Pn velocities (Figs. 35 and 36). For Ust' Nera, Pn velocity is 7.95 km/sec, with Pg velocity at 5.99 km/sec and Sg at 3.53 km/sec. For Moma, Pn velocity is 7.87 km/sec, while Pg and Sg velocities are 6.03 km/sec and 3.55 km/sec respectively. Previous estimates of crustal thickness at Ust' Nera range from 24 km (Suvorov and Kornilova, 1986) to 40 km (Bulin, 1989). The data set for Ust' Nera is one of the best in terms of epicentral distance coverage, and scatter of data are acceptable, thus I feel the 35 km crustal thickness is reasonable. There are no previous velocity or thickness determinations for Moma. The slightly reduced crustal thickness and reduced Pn velocity are consistent with a region which has recently undergone an extensional event, and thus may represent a relic of the Moma rift system. The station at Moma is within the Moma rift proper, as defined by Fujita et al. (1990a). Although this region is presently under compression, caused by extrusion of the Okhotsk block (Riegel et al., 1993; Cook et al., 1986) the region was recently under extension. The transition from extension to compression occurred as a result of the migration of the North American-Eurasian pole to the north as recently as 0.5 Ma (Cook et al., 1986).

43

11 (s)

0

45

11 (s)

0

Fig
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km/s

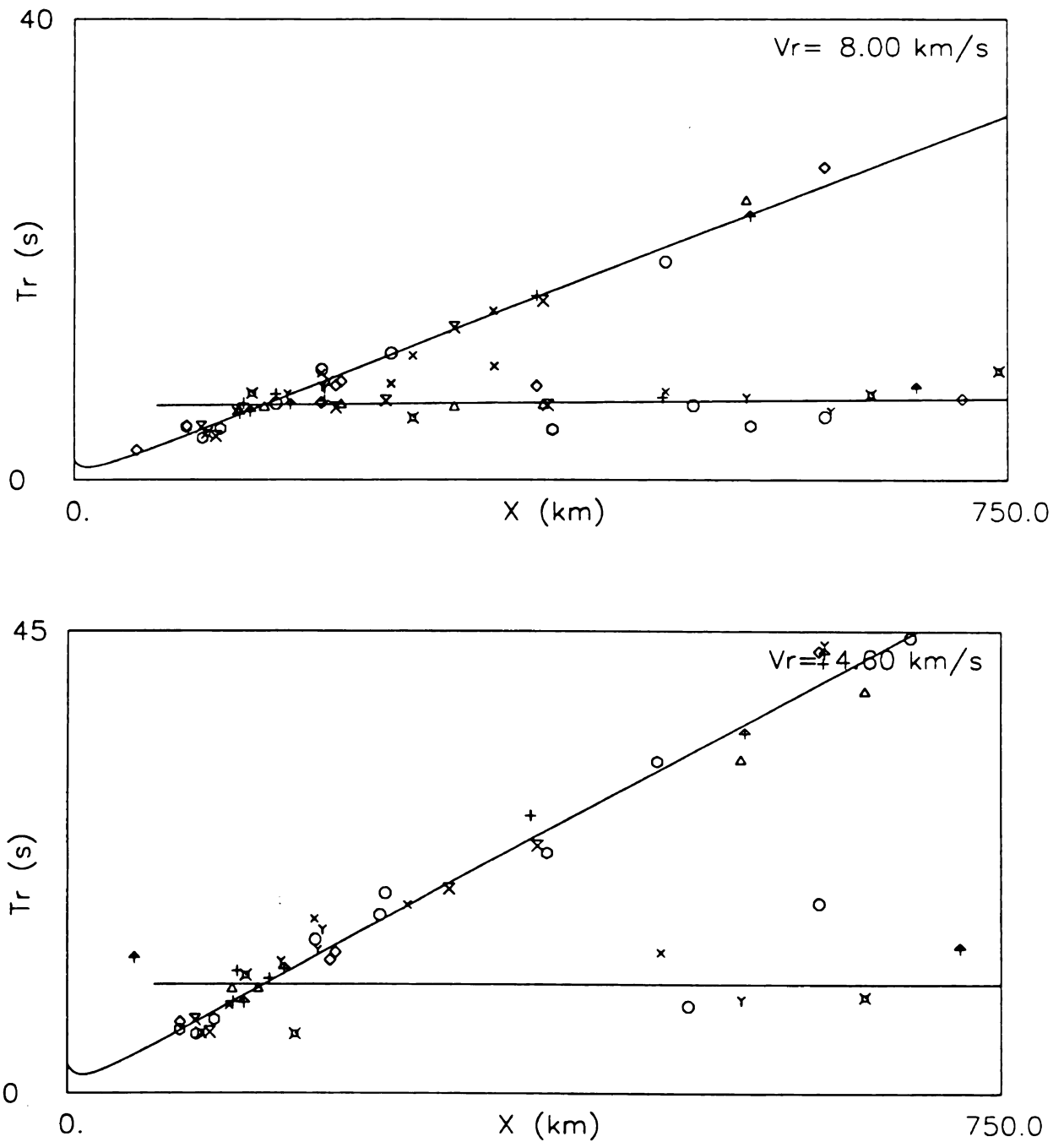


Figure 35. Ust' Nera station reduced traveltime curves and crustal model. Pg velocity 5.99 km/sec, Pn velocity 7.95 km/sec, and crustal thickness 34 km. Sg velocity 34 km/sec. Conventions as in Figure 22.

40

T_r (s)

C

40

T_r (s)

C

Figure
6.03 k
km/sec

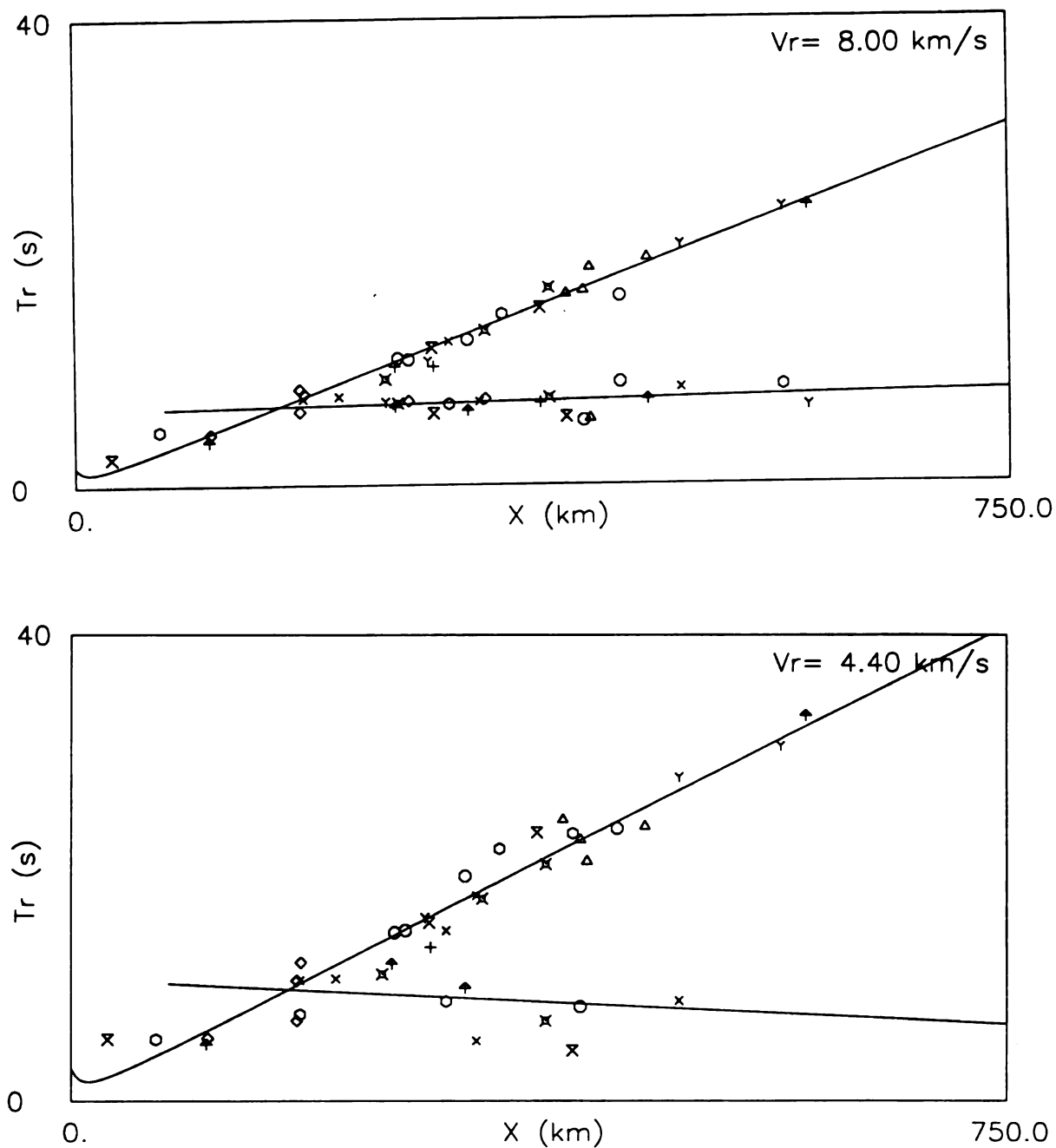


Figure 36. Moma station reduced traveltime curves and crustal model. Pg velocity 6.03 km/sec, Pn velocity 7.87 km/sec, and crustal thickness 35 km. Sg velocity 3.55 km/sec. Conventions as in Figure 22.

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Given the recent transition to compression, the former extensional regions may still be reflected in an elevated Moho and reduced Pn velocity.

Northeast from Ust' Nera are stations Sasyr' and Zyryanka. Both stations show an increased crustal thickness, at 37 km for Sasyr', and 47 km for Zyryanka (Figs. 37 and 38). Velocities are close to regional averages with the exception of an 8.22 km/sec Pn velocity at Zyryanka. Station Sasyr' has been considered in previous studies. Bulin (1989) reports a thickness of 41 km for Ugol'naya (Zyryanka), and a thickness at Zyryanka of 35-45 km is possible (Suvorov and Kornilova, 1986).

Continuing northwest along the trend of thinner crust, are the stations Tabalakh, Batagai, and Saidy. Saidy is within the region encompassed by the Toustakh graben, a portion of the Moma rift, while Batagai and Tabalakh lie immediately to the south (Fujita et al., 1990a). Of the three stations, Batagai shows the thinnest crust at 32 km, followed by Tabalakh at 34 km and Saidy at 35 km (Figs. 39-41). Both Batagai and Tabalakh show reduced Pn velocities of 7.94 km/sec while Saidy has an elevated velocity of 8.04 km/sec. Compared to Batagai and Tabalakh, Saidy shows a higher Pn velocity and slightly thicker crust.

Stations Naiba and Yubileniya are in the northern portion of the study area. Naiba is located on Buor Khaya Bay, off the Laptev Sea, and Yubileniya is approximately 100 km south of the Laptev sea along the Yana river. The crustal thickness determinations for these stations are among this study's most interesting results. The Naiba data indicate a thin crust at 29 km, with a reduced Pn velocity of 7.70 km/sec (Fig. 42). Geologically, Naiba is located on the western edge of the Omoloi basin, the southern extension of the

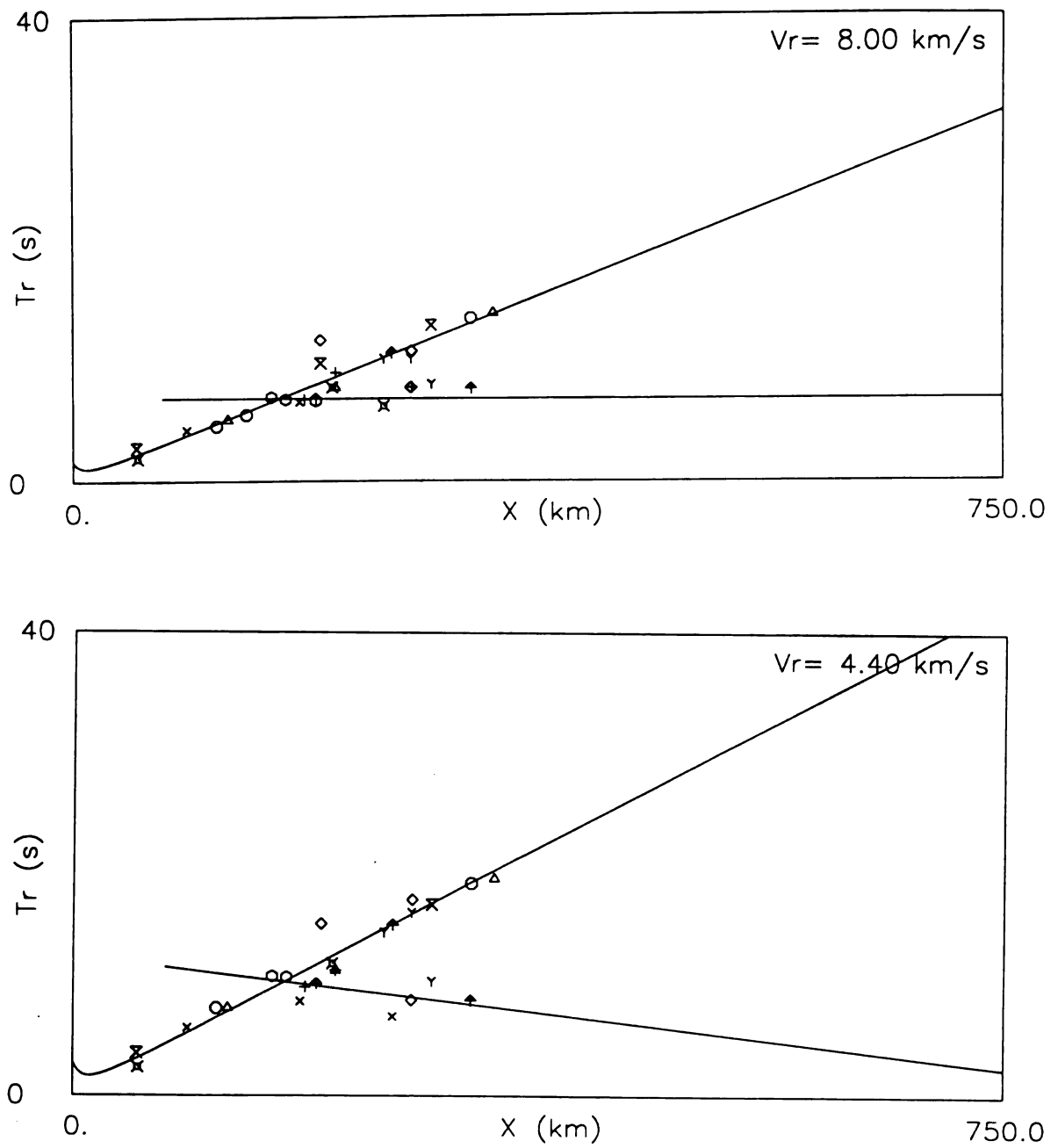


Figure 37. Sasyr' station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 8.00 km/sec, and crustal thickness 37 km. Sg velocity 3.52 km/sec. Conventions as in Figure 22.

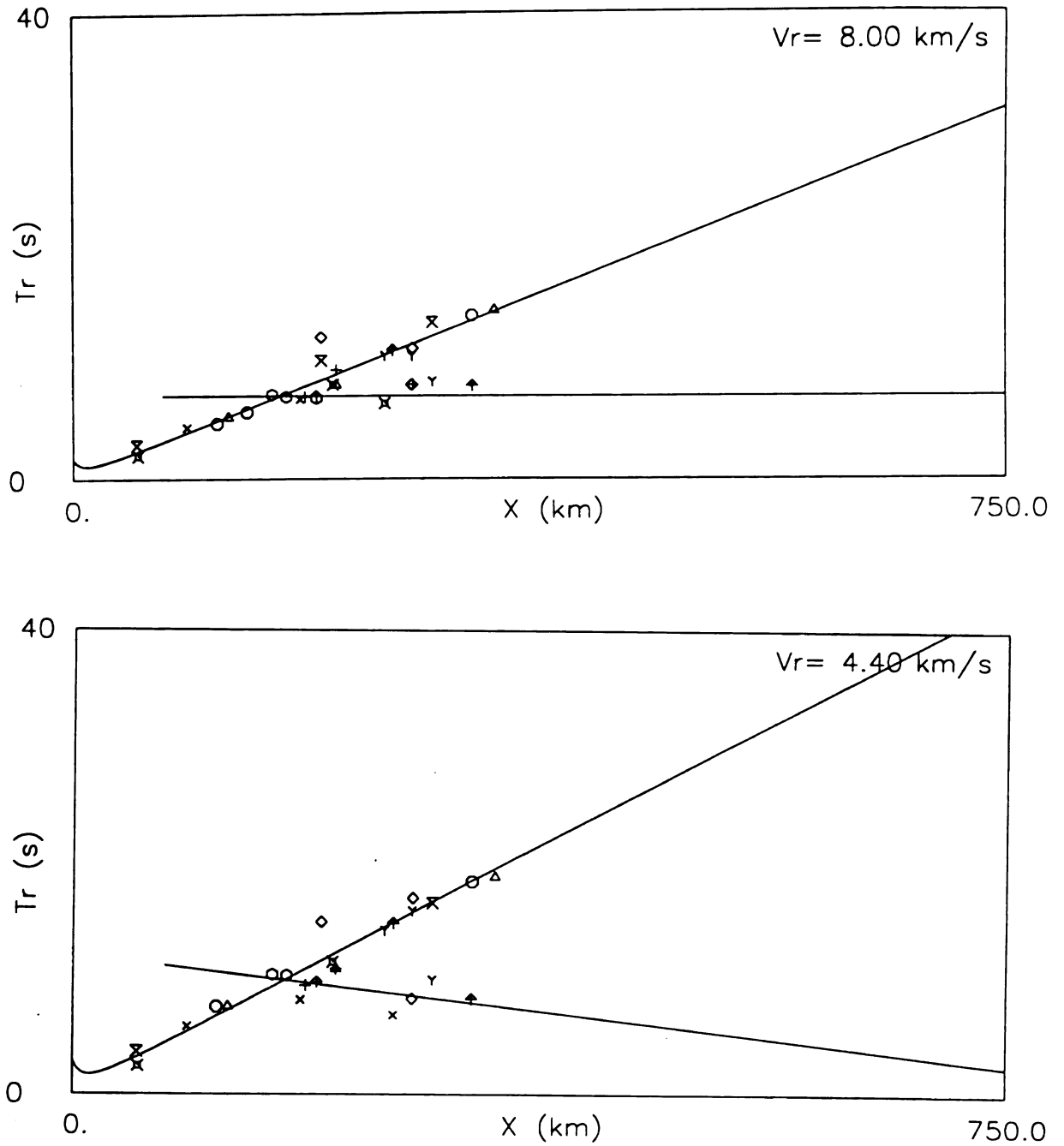


Figure 37. Sasyr' station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 8.00 km/sec, and crustal thickness 37 km. Sg velocity 3.52 km/sec. Conventions as in Figure 22.

40

T_r (s)

0

40

T_r (s)

0

Figure
5.98
km/s

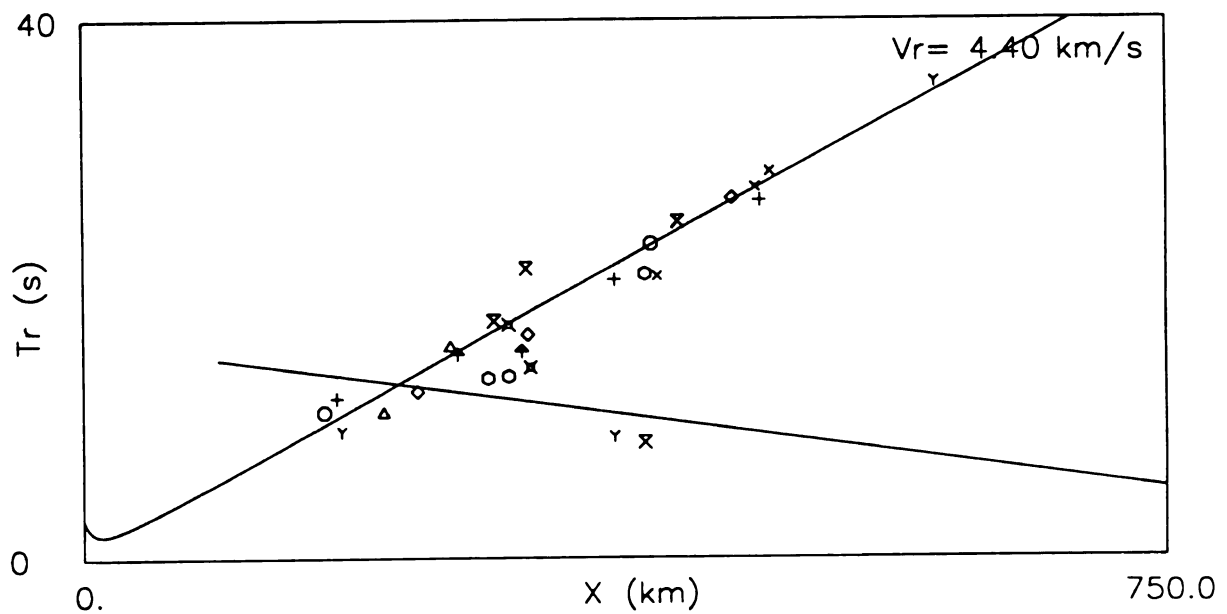
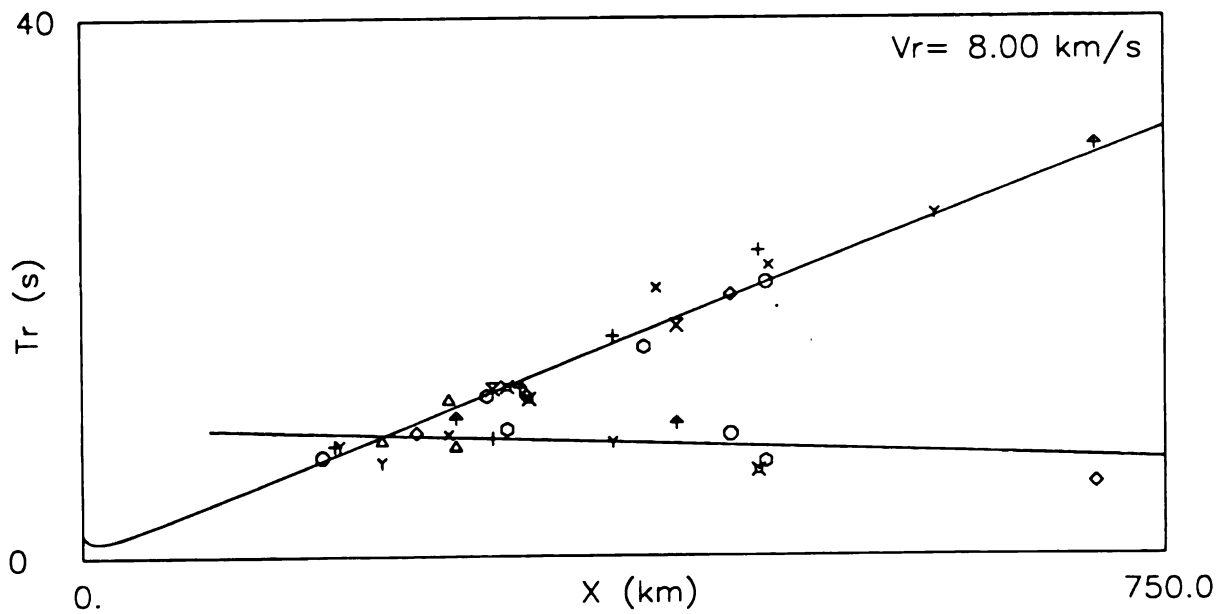


Figure 38. Zyryznka station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 8.22 km/sec, and crustal thickness 47 km. Sg velocity 3.50 km/sec. Conventions as in Figure 22.

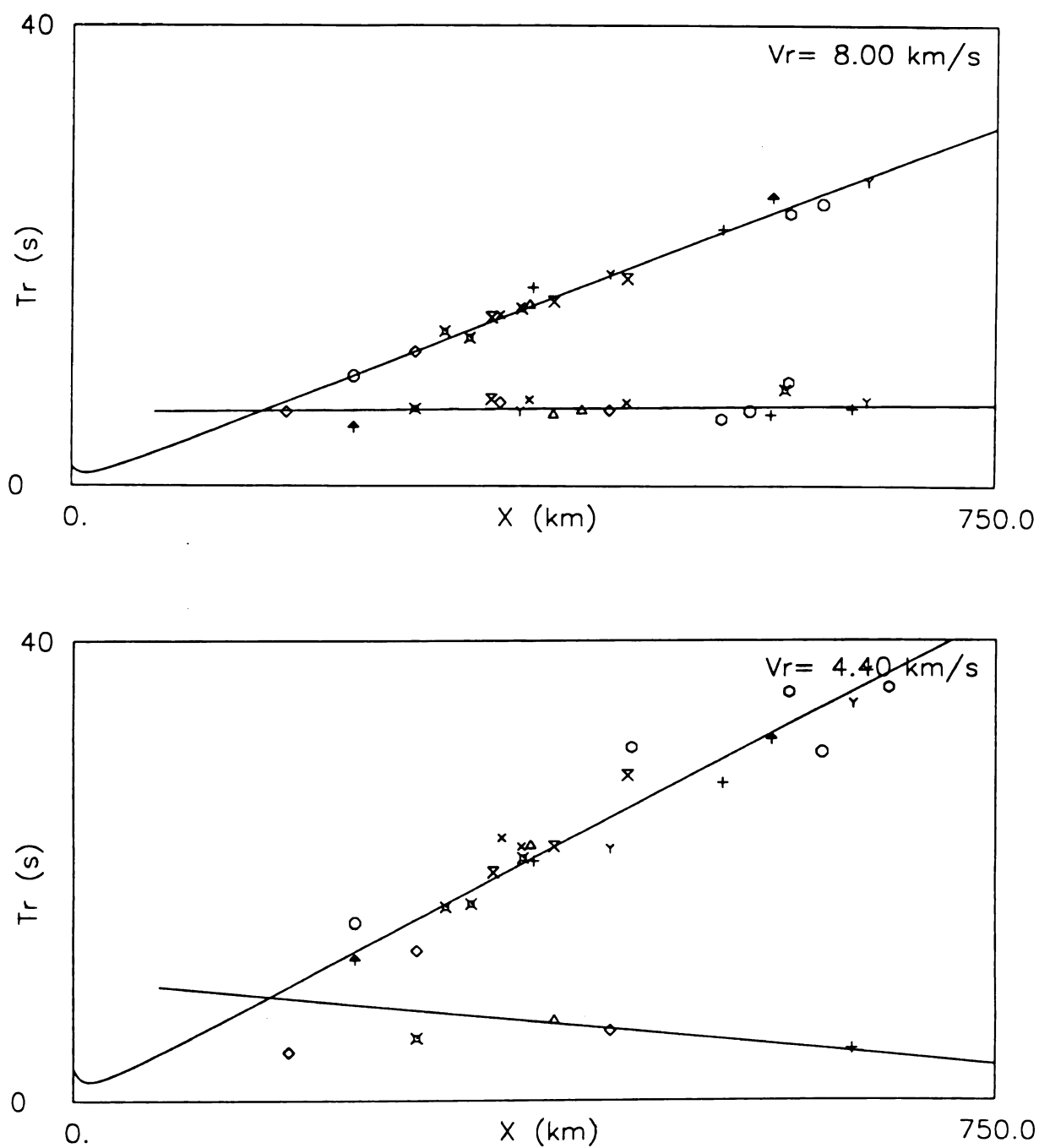


Figure 39. Tabalakh station reduced traveltime curves and crustal model. Pg velocity 6.01 km/sec, Pn velocity 7.94 km/sec, and crustal thickness 34 km. Sg velocity 3.53 km/sec. Conventions as in Figure 22.

40

T_r (s)

0

40

T_r (s)

0

Figure
5.97
km/s

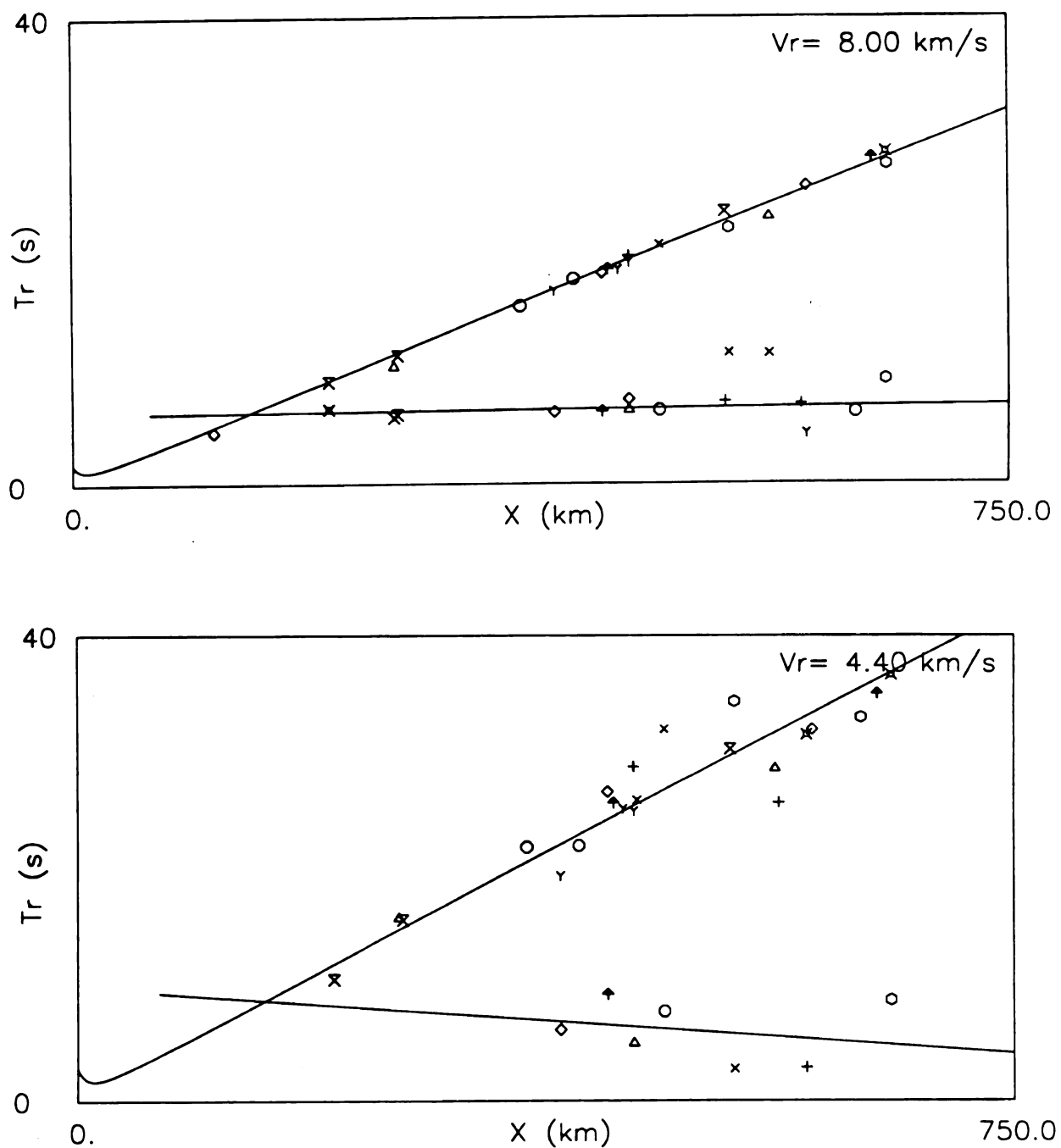


Figure 40. Batagai station reduced traveltime curves and crustal model. Pg velocity 5.97 km/sec, Pn velocity 7.94 km/sec, and crustal thickness 32 km. Sg velocity 3.53 km/sec. Conventions as in Figure 22.

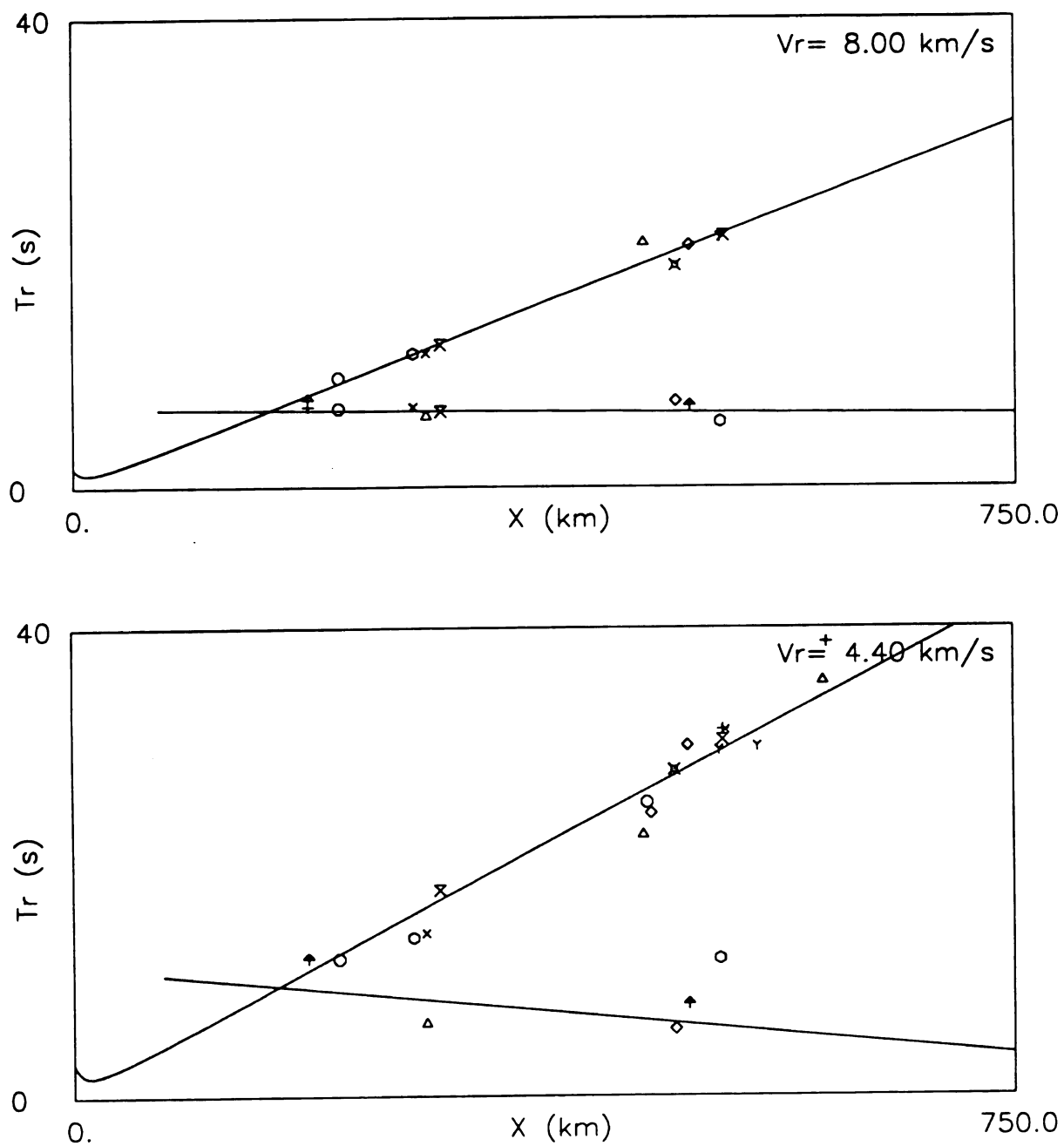


Figure 41. Saidy station reduced traveltime curves and crustal model. Pg velocity 6.01 km/sec, Pn velocity 8.04 km/sec, and crustal thickness 35 km. Sg velocity 3.52 km/sec. Conventions as in Figure 22.

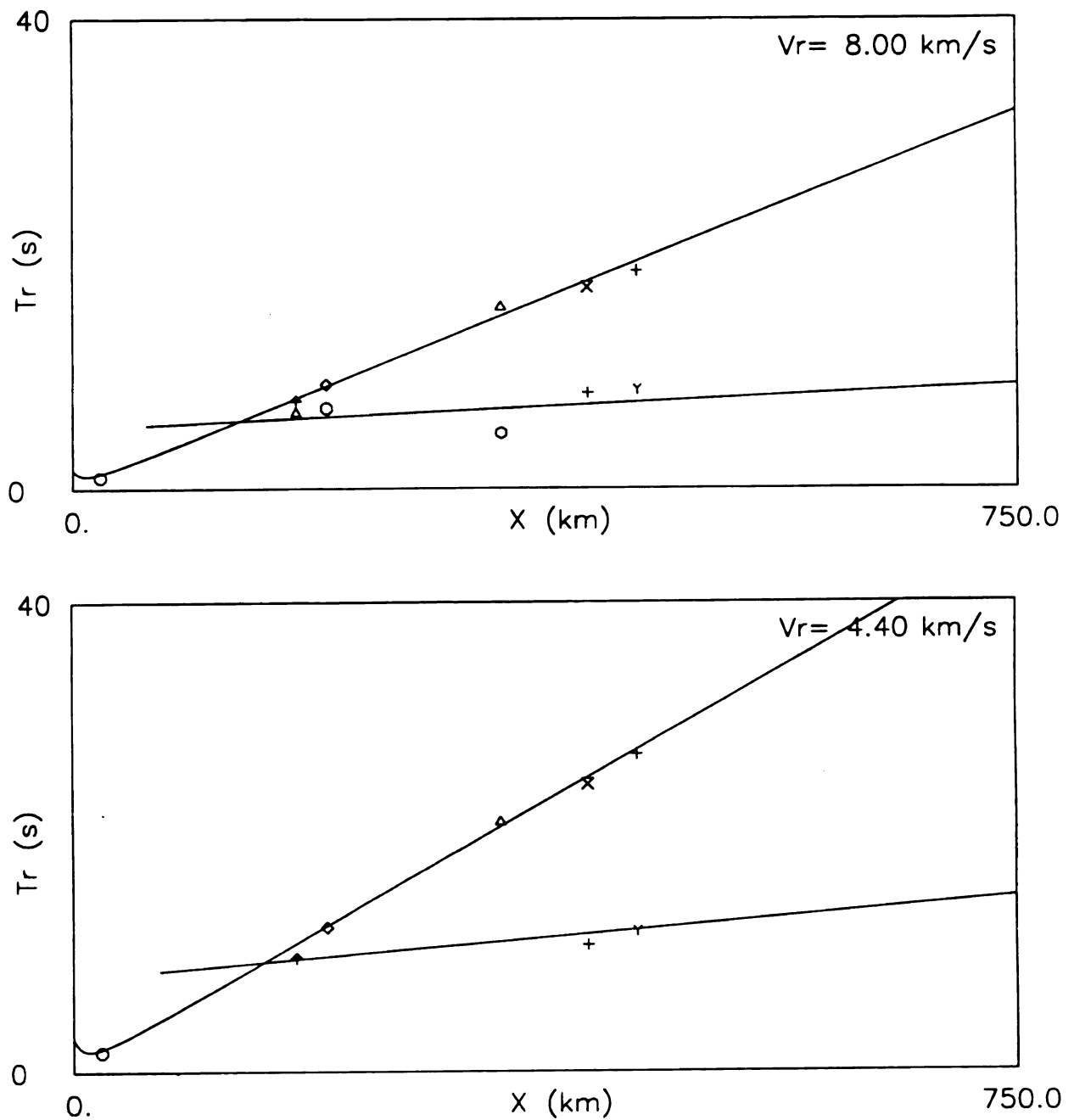


Figure 42. Naiba station reduced traveltime curves and crustal model. Pg velocity 5.96 km/sec, Pn velocity 7.70 km/sec, and crustal thickness 29 km. Sg velocity 3.47 km/sec. Conventions as in Figure 22.

Omoloi graben (Fig. 4). This study shows Yubileniya to be located above a zone of anomalously thin crust at 19 km (Fig. 43). For Yubileniya, Pn velocities are significantly reduced at 7.49 km/sec, while Pg velocities are near normal at 5.96 km/sec. Note that the data supporting such a thin crust contains minimal scatter, and is not constrained by any single point. Yubileniya is located in the southern end of the Ust' Yana graben (Fig. 4). For both stations, local grabens from regional extension seem to be the controlling factor in thinning of the crust. These stations indicate clear evidence of anomalously thin continental crust in the southern portion of the Laptev rift system. Thin crust and low Pn velocities are supported by DSS profiles in the south Laptev sea (Avetisov and Guseva, 1991; Avetisov, 1983; Kogan, 1974). A reflection profile 30 km east of Naiba indicates a crustal thickness of approximately 28km (Avetisov and Guseva, 1991).

Located east of Yubileniya, station Tenkeli is located in the vicinity of Tenkeli basin (Fig. 4), where an elevated Moho and reduced Pn velocity could be expected. Unfortunately, Tenkeli results are inconclusive due to Pn data scatter and lack of close in data. For Tenkeli, acceptance or rejection of a single datum can vary crustal thickness from 24 km to 42 km (Fig. 44). Crustal velocity is constrained at 5.98 km/sec.

The southwest portion of the study area contains stations Yakutsk, Khandyga, and Nezhdaninskoe. These stations are located within the eastern Siberian platform. These stations evidence a generally thickened crust of 44 km at Khandyga, 39 km at Nezhdaninskoe, and 38 at Yakutsk (Figs. 45-47). Pn velocities are near average, except Khandyga where the Pn velocity is 8.10 km/sec. Pn velocity and crustal thickness are poorly constrained for Yakutsk. Previous studies are in good agreement with these

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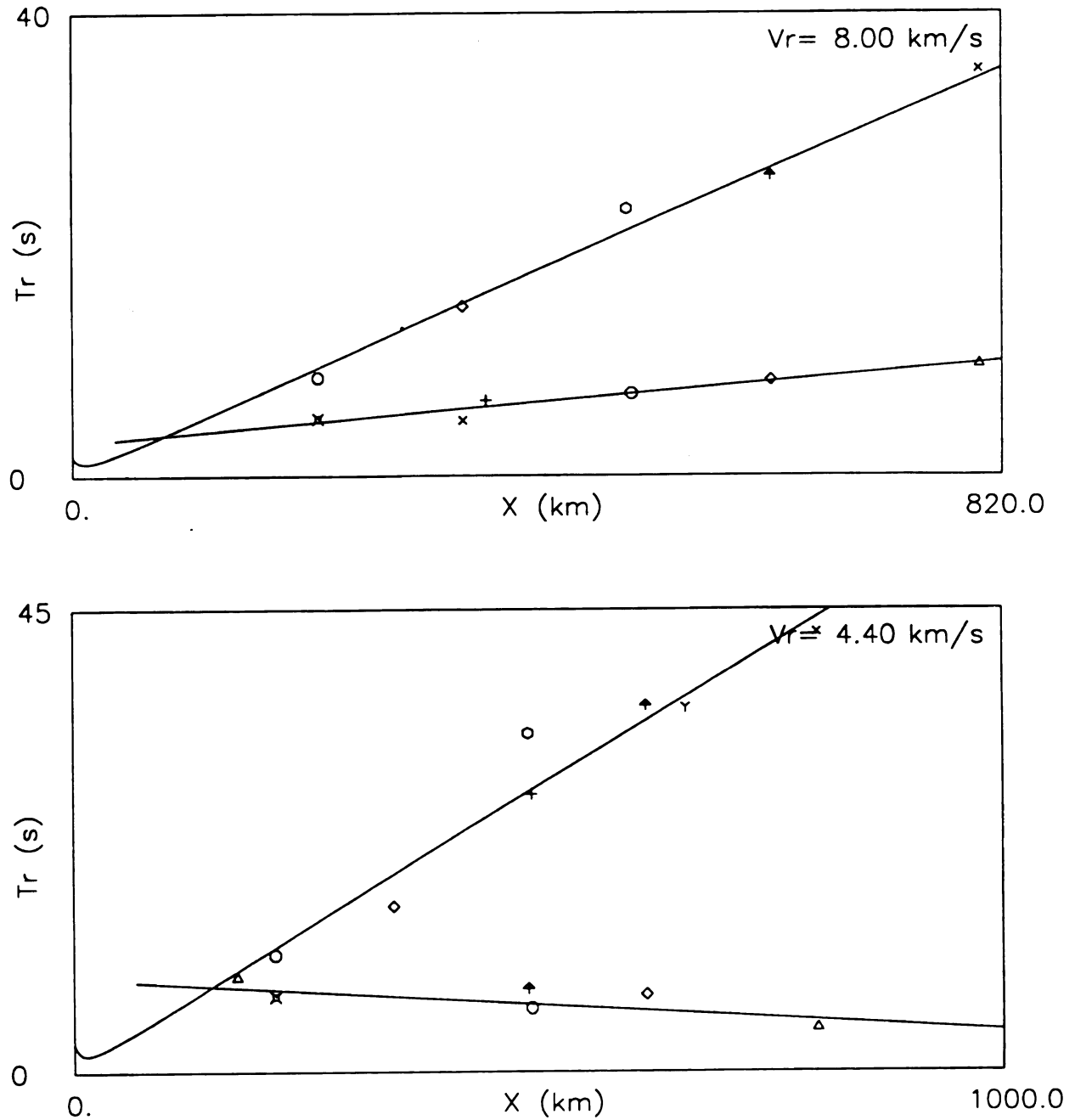


Figure 43. Yubileniya station reduced traveltime curves and crustal model. P_g velocity 5.96 km/sec, P_n velocity 7.49 km/sec, and crustal thickness 19 km. S_g velocity 3.54 km/sec. Conventions as in Figure 22.

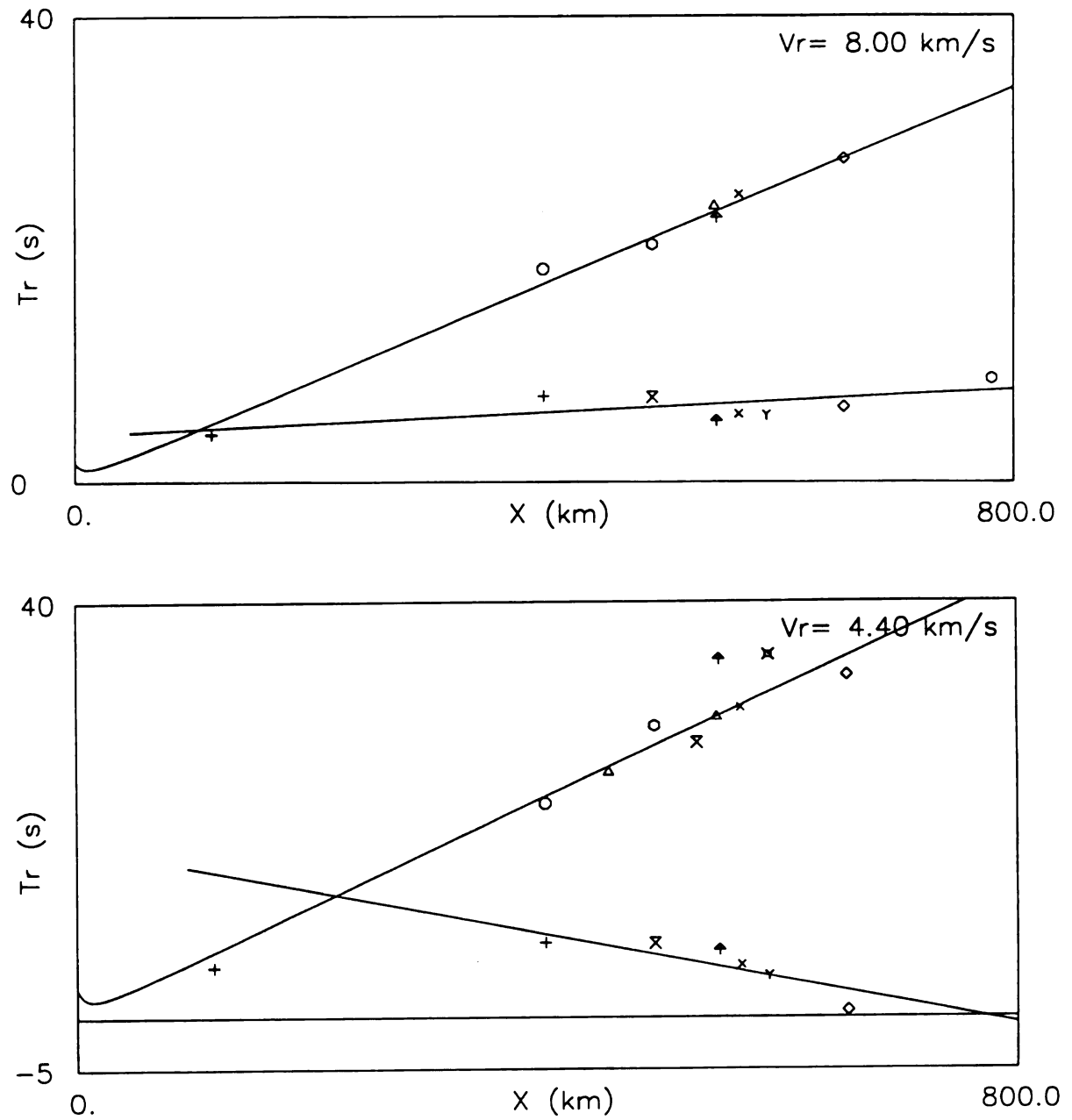


Figure 44. Tenkeli station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 7.70 km/sec, and crustal thickness 24 km. Sg velocity 3.57 km/sec. Conventions as in Figure 22.

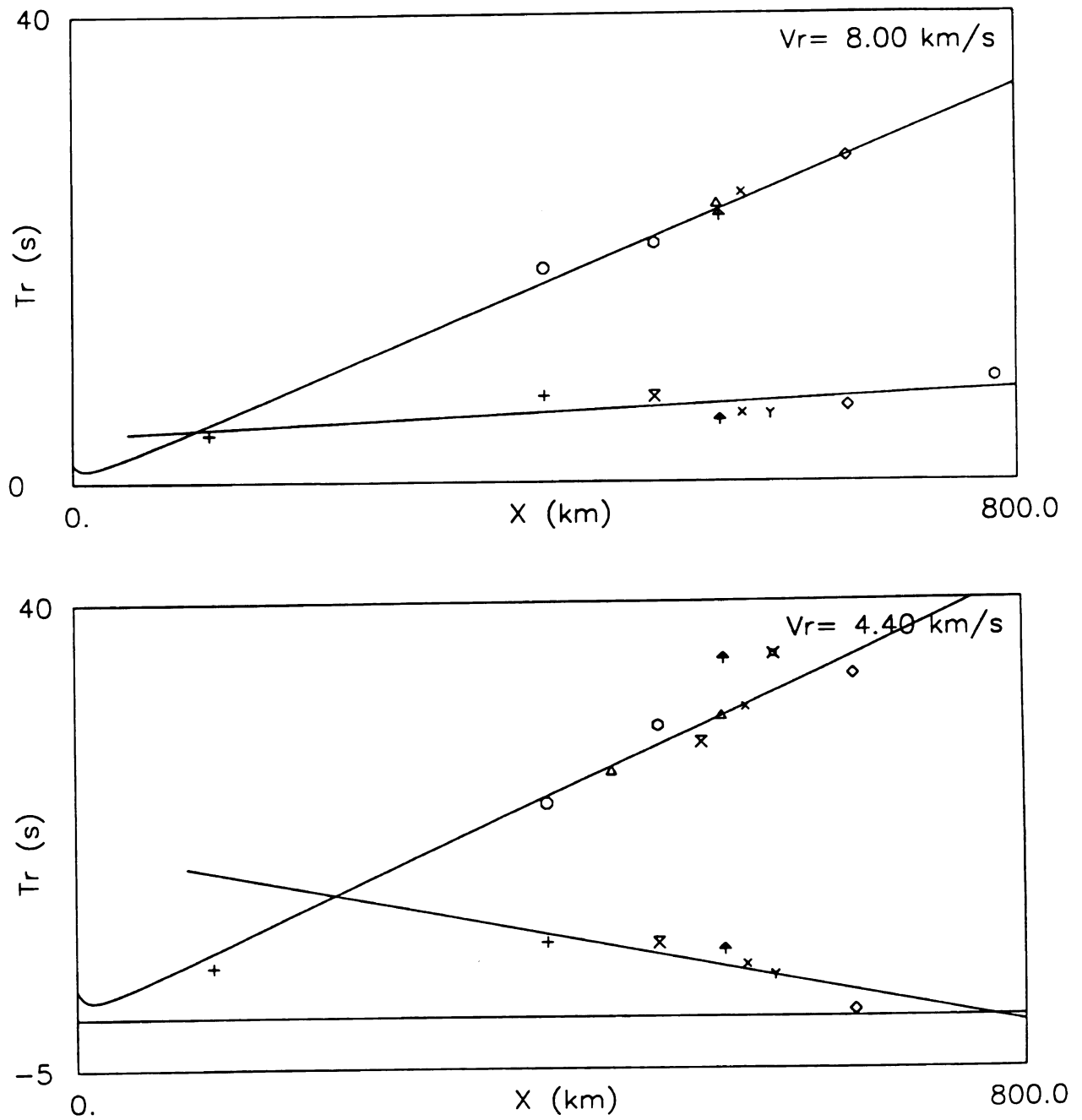


Figure 44. Tenkeli station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 7.70 km/sec, and crustal thickness 24 km. Sg velocity 3.57 km/sec. Conventions as in Figure 22.

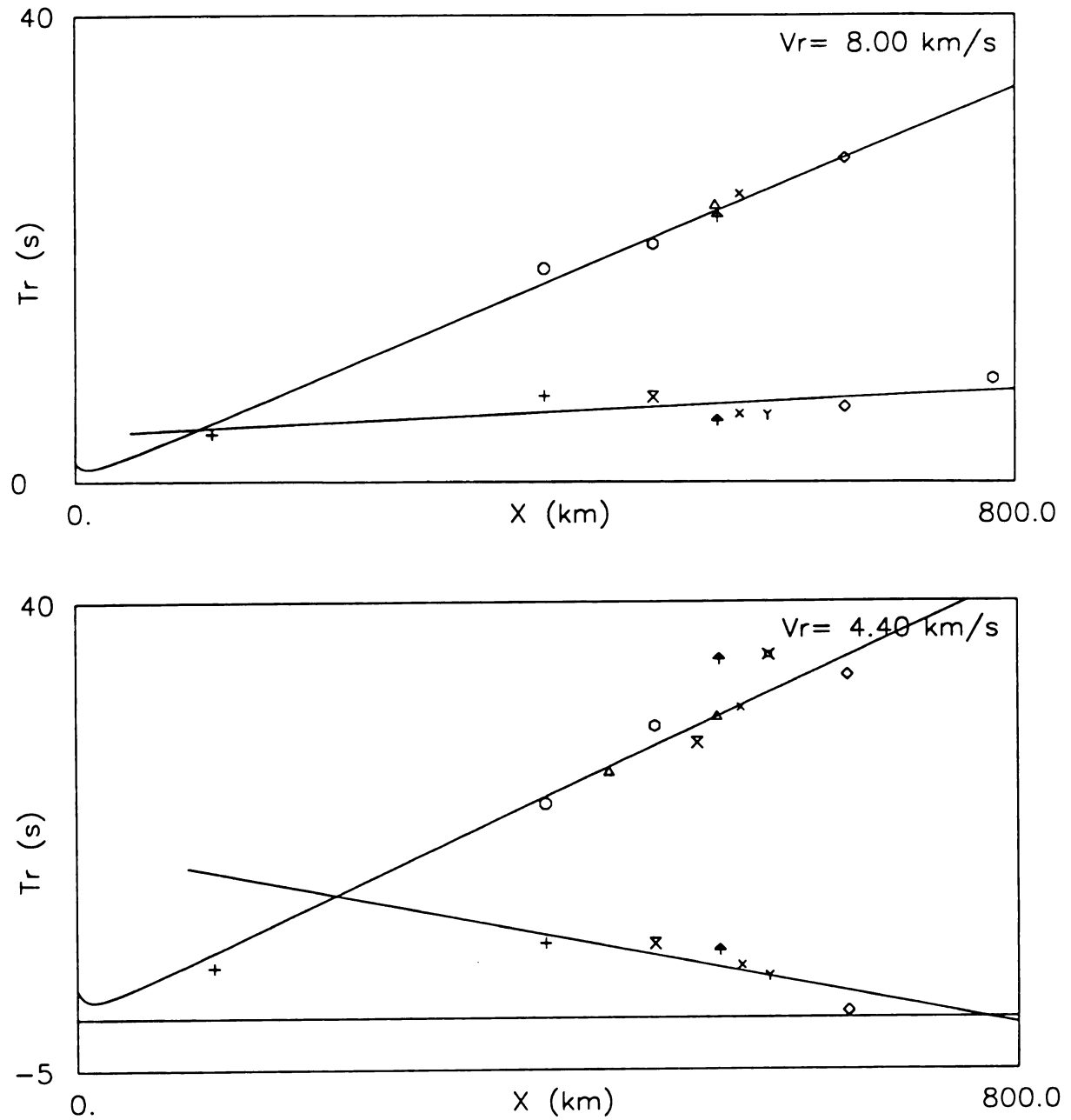


Figure 44. Tenkeli station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 7.70 km/sec, and crustal thickness 24 km. Sg velocity 3.57 km/sec. Conventions as in Figure 22.

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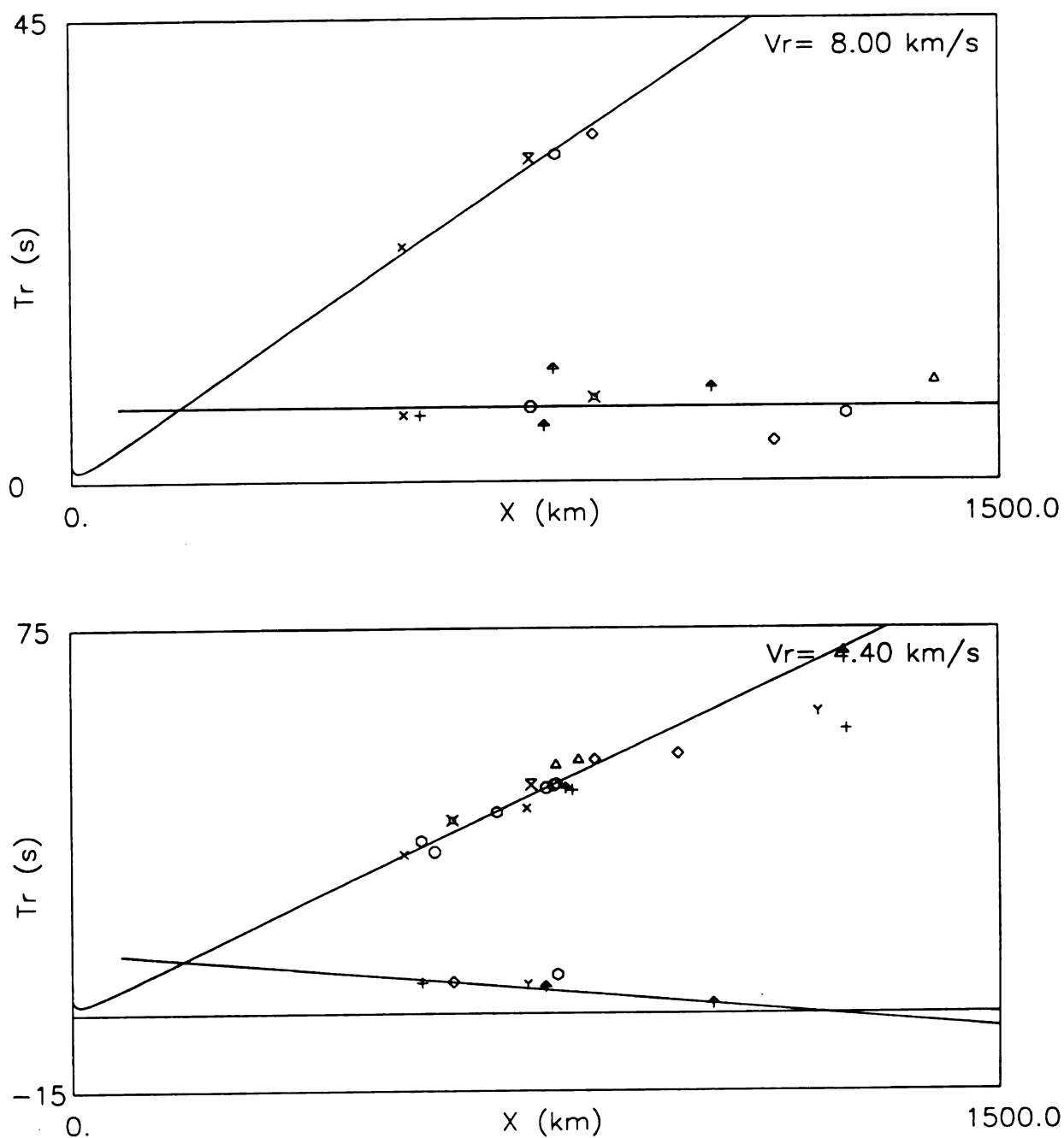


Figure 45. Yakutsk station reduced traveltime curves and crustal model. Pg velocity 6.03 km/sec, Pn velocity 8.00 km/sec, and crustal thickness 38 km. Sg velocity 3.52 km/sec. Conventions as in Figure 22.

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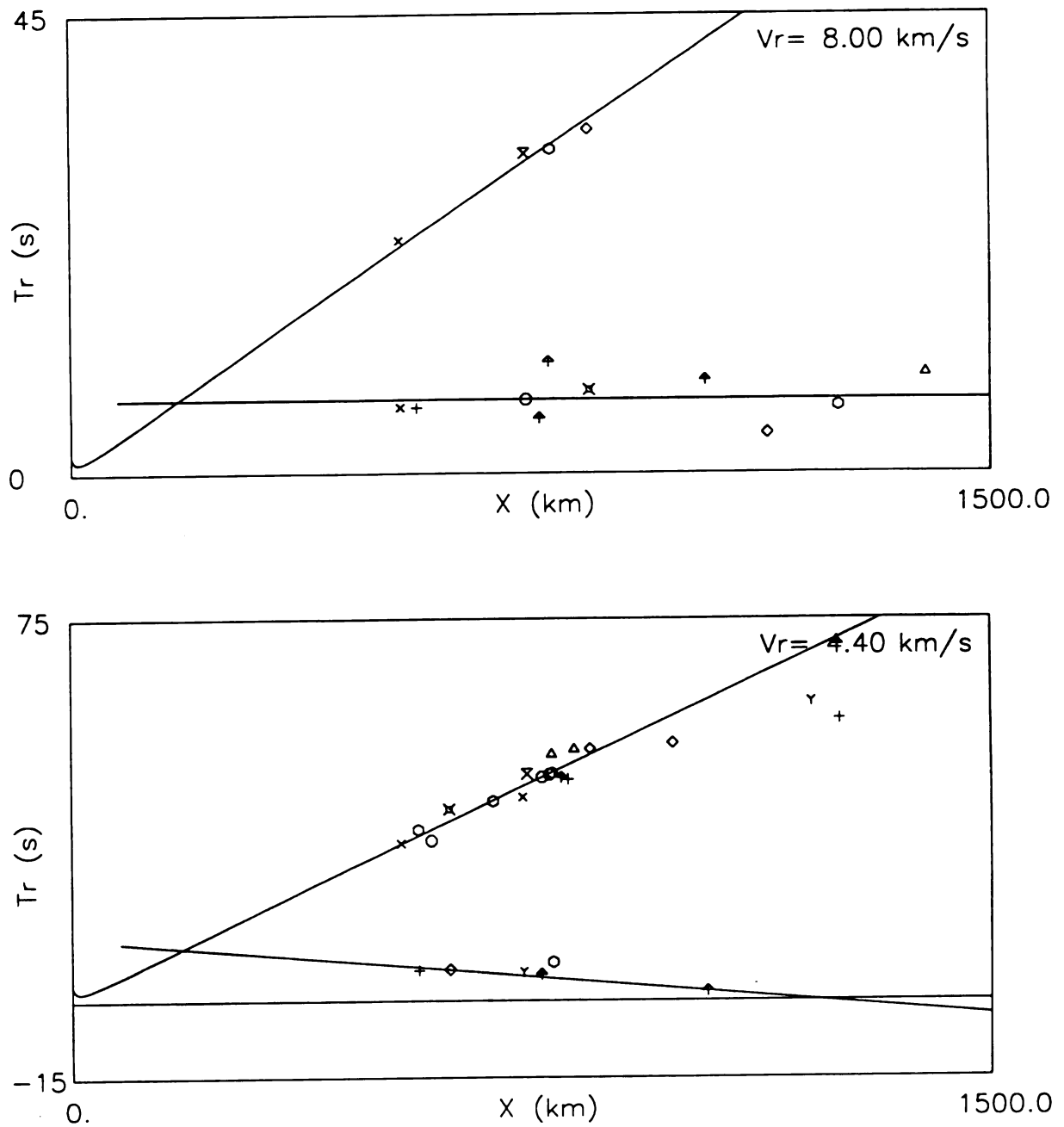


Figure 45. Yakutsk station reduced traveltime curves and crustal model. Pg velocity 6.03 km/sec, Pn velocity 8.00 km/sec, and crustal thickness 38 km. Sg velocity 3.52 km/sec. Conventions as in Figure 22.

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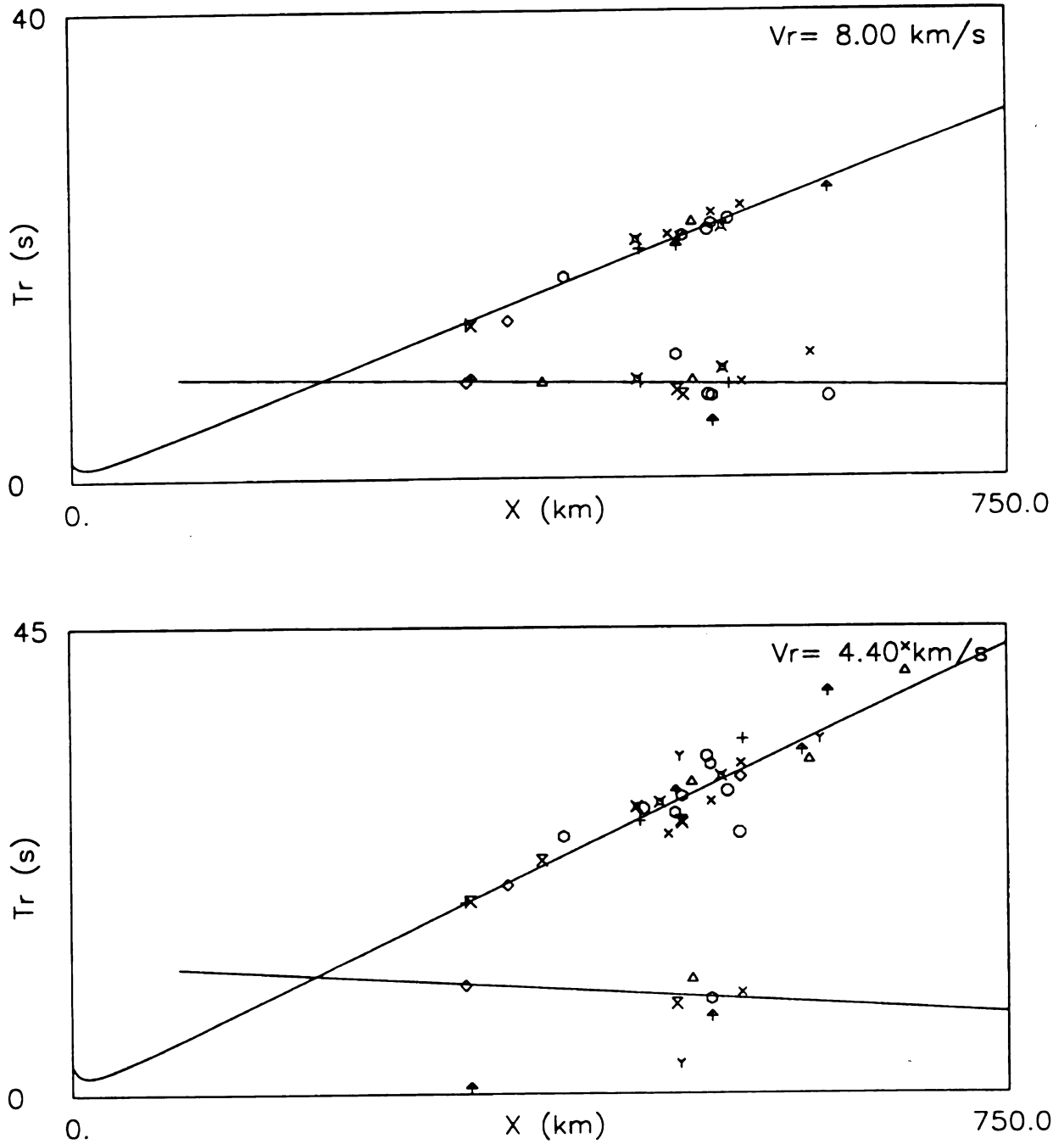


Figure 46. Khandyga station reduced traveltime curves and crustal model. Pg velocity 6.00 km/sec, Pn velocity 8.10 km/sec, and crustal thickness 44 km. Sg velocity 3.51 km/sec. Conventions as in Figure 22.

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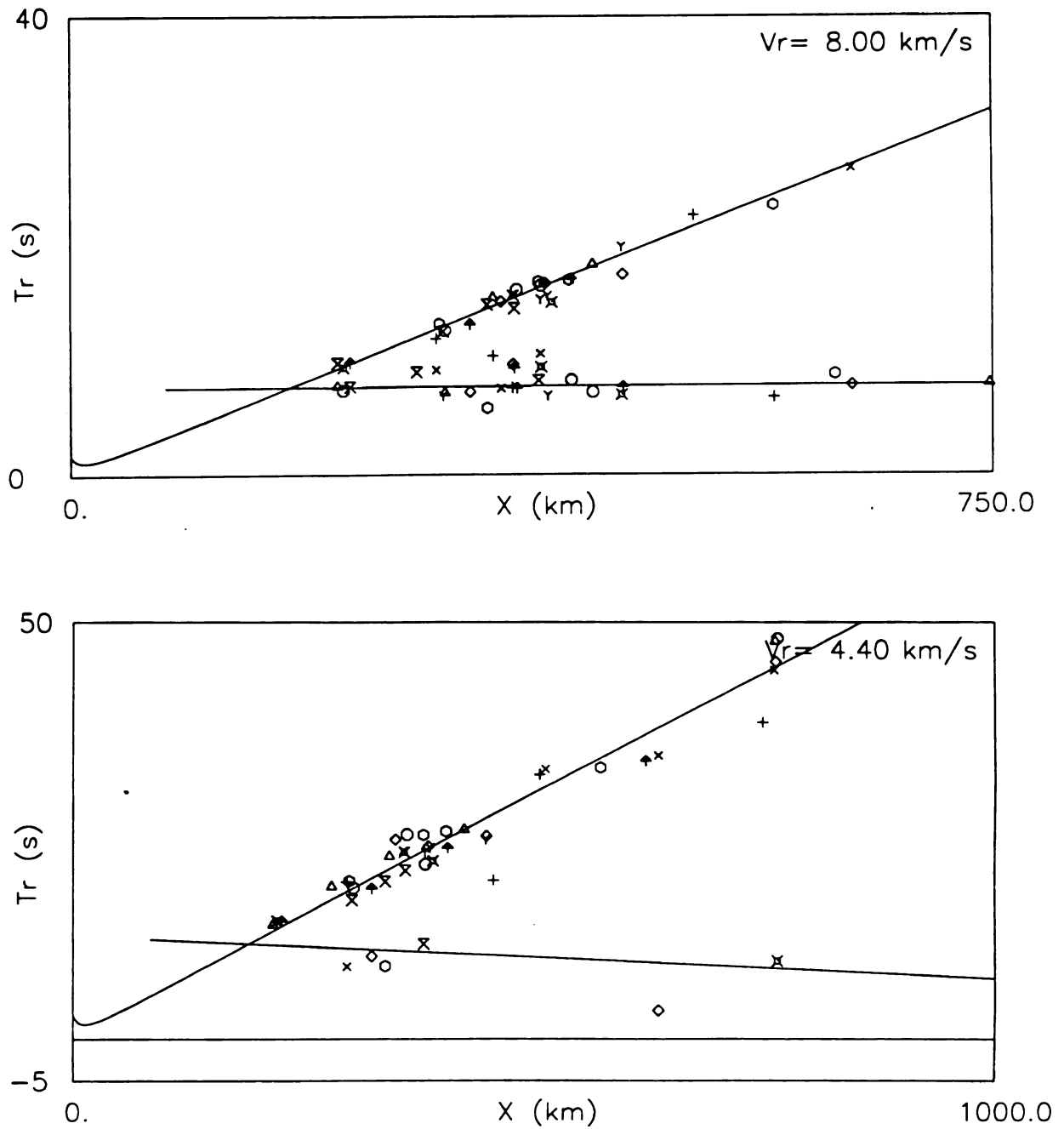


Figure 47. Nezhdaninskoe station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 7.98 km/sec, and crustal thickness 39 km. Sg velocity 3.50 km/sec. Conventions as in Figure 22.

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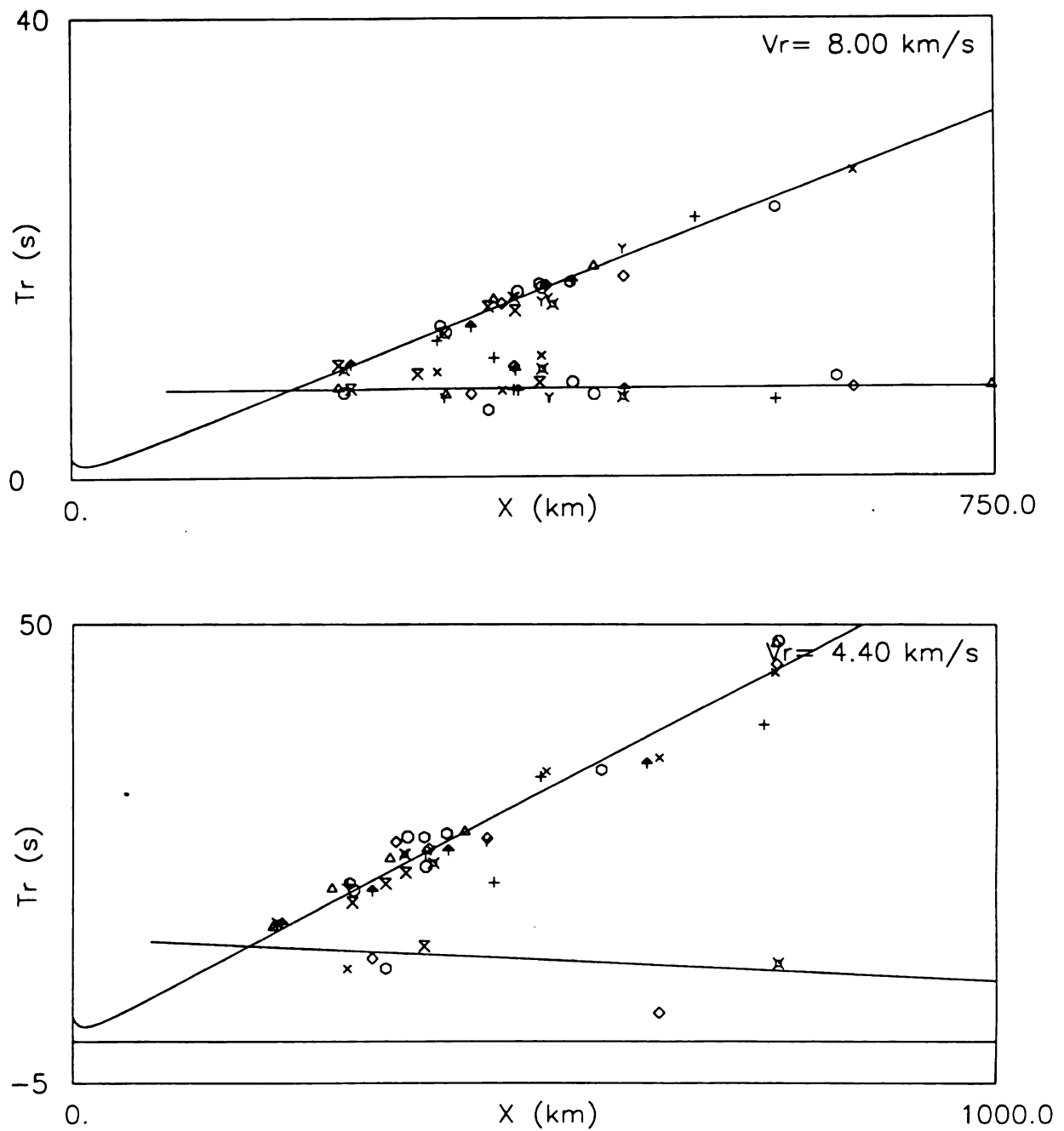


Figure 47. Nezhdaninskoe station reduced traveltime curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 7.98 km/sec, and crustal thickness 39 km. Sg velocity 3.50 km/sec. Conventions as in Figure 22.

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results. Suvorov and Kornilova (1986) indicate a crustal thickness of 44 km at Khandyga, 40 km at Nezhdaninskoe, and 37 km at Yakutsk. However, data from their study indicate somewhat higher Pn velocities. Neustroev and Parfenov (1985) have also calculated crustal thicknesses for the eastern Siberian platform, indicating 42 km for Khandyga and Yakutsk, and 40 km for Nezhdaninskoe. Bulin (1989) indicates a crustal thickness of 37 km for Nezhdaninskoe.

Evensk, on Shelikhov Bay, is located on the Avekova terrane. The Avekova terrane is composed of Proterozoic gneiss, crystalline schist, and metamorphosed carbonates. Younger units are primarily marine, with minor volcanics (Nokleberg et al., 1994). Evensk data indicate a normal crustal thickness of 37 km, but slightly elevated Pg and Pn velocities at 6.01 km/sec and 8.07 km/sec (Fig. 48). Sn velocities are slightly below normal at 3.48 km/sec. Crustal thickness for Evensk is within 3 km of all other determinations, falling near the center of the field of previous values. There are no other published velocities for Evensk, thus it is not possible to verify the slightly increased velocities.

Omolon is located north of Evensk, near the center of the Kolyma-Omolon superterrane (Nokleberg et al., 1994). Station Omolon lies on the Omolon block of the Kolyma-Omolon superterrane. In this study, aside from stations on the Siberian Platform, Omolon is probably the only station which lies on ancient Precambrian continental crust (Nokleberg et al., 1994). Crustal data for Omolon are well constrained and indicated a normal crustal thickness of 37 km, but slightly reduced P velocities (Fig. 49). A Pg velocity of 5.98 km/sec and Pn velocity of 7.98 fit the data well. A slightly reduced Sg

results. Suvorov and Kornilova (1986) indicate a crustal thickness of 44 km at Khandyga, 40 km at Nezhdaninskoe, and 37 km at Yakutsk. However, data from their study indicate somewhat higher Pn velocities. Neustroev and Parfenov (1985) have also calculated crustal thicknesses for the eastern Siberian platform, indicating 42 km for Khandyga and Yakutsk, and 40 km for Nezhdaninskoe. Bulin (1989) indicates a crustal thickness of 37 km for Nezhdaninskoe.

Evensk, on Shelikhov Bay, is located on the Averkova terrane. The Averkova terrane is composed of Proterozoic gneiss, crystalline schist, and metamorphosed carbonates. Younger units are primarily marine, with minor volcanics (Nokleberg et al., 1994). Evensk data indicate a normal crustal thickness of 37 km, but slightly elevated Pg and Pn velocities at 6.01 km/sec and 8.07 km/sec (Fig. 48). Sn velocities are slightly below normal at 3.48 km/sec. Crustal thickness for Evensk is within 3 km of all other determinations, falling near the center of the field of previous values. There are no other published velocities for Evensk, thus it is not possible to verify the slightly increased velocities.

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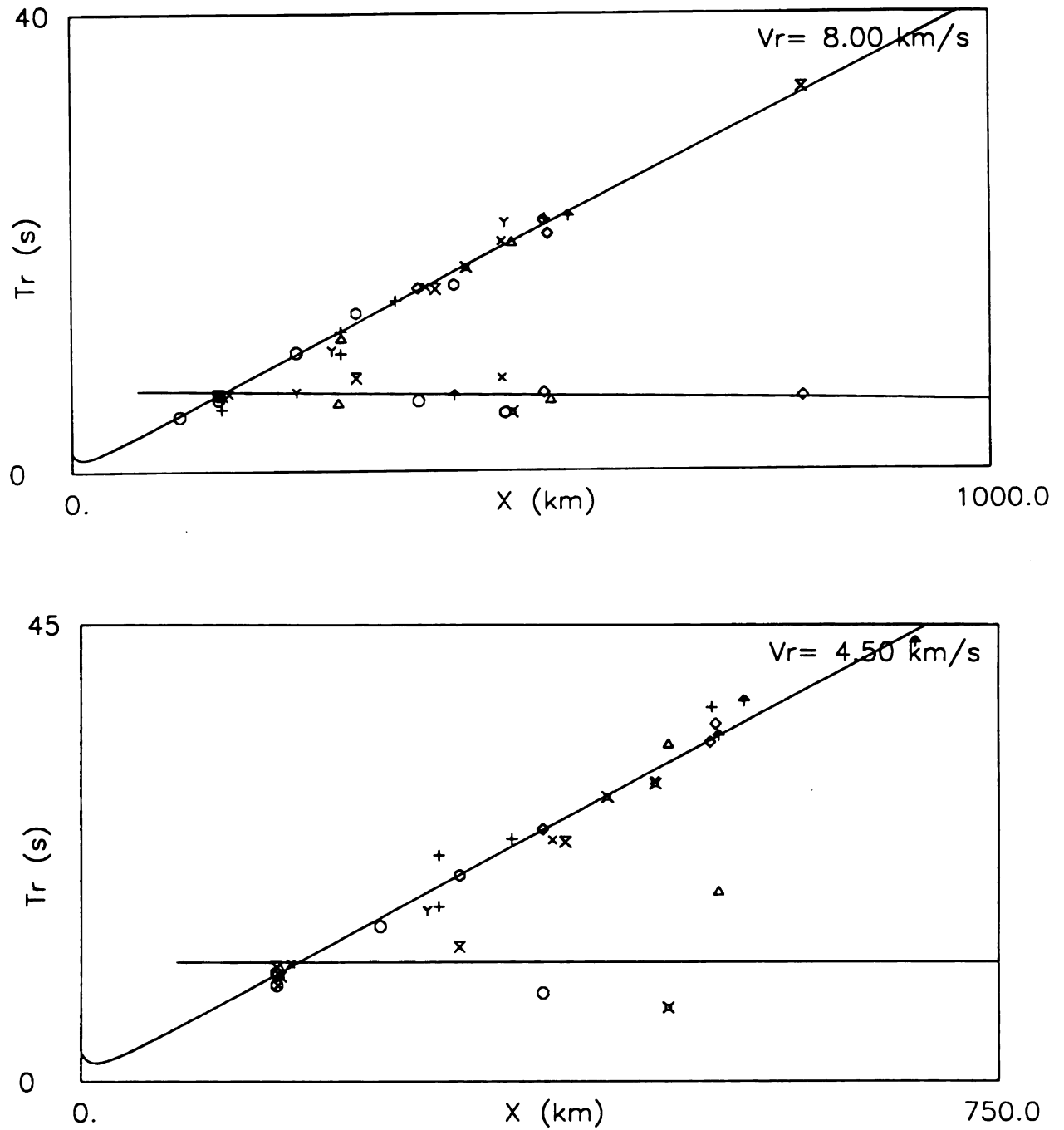


Figure 48. Evensk station reduced traveltime curves and crustal model. Pg velocity 6.01 km/sec, Pn velocity 8.07 km/sec, and crustal thickness 37 km. Sg velocity 3.48 km/sec. Conventions as in Figure 22.

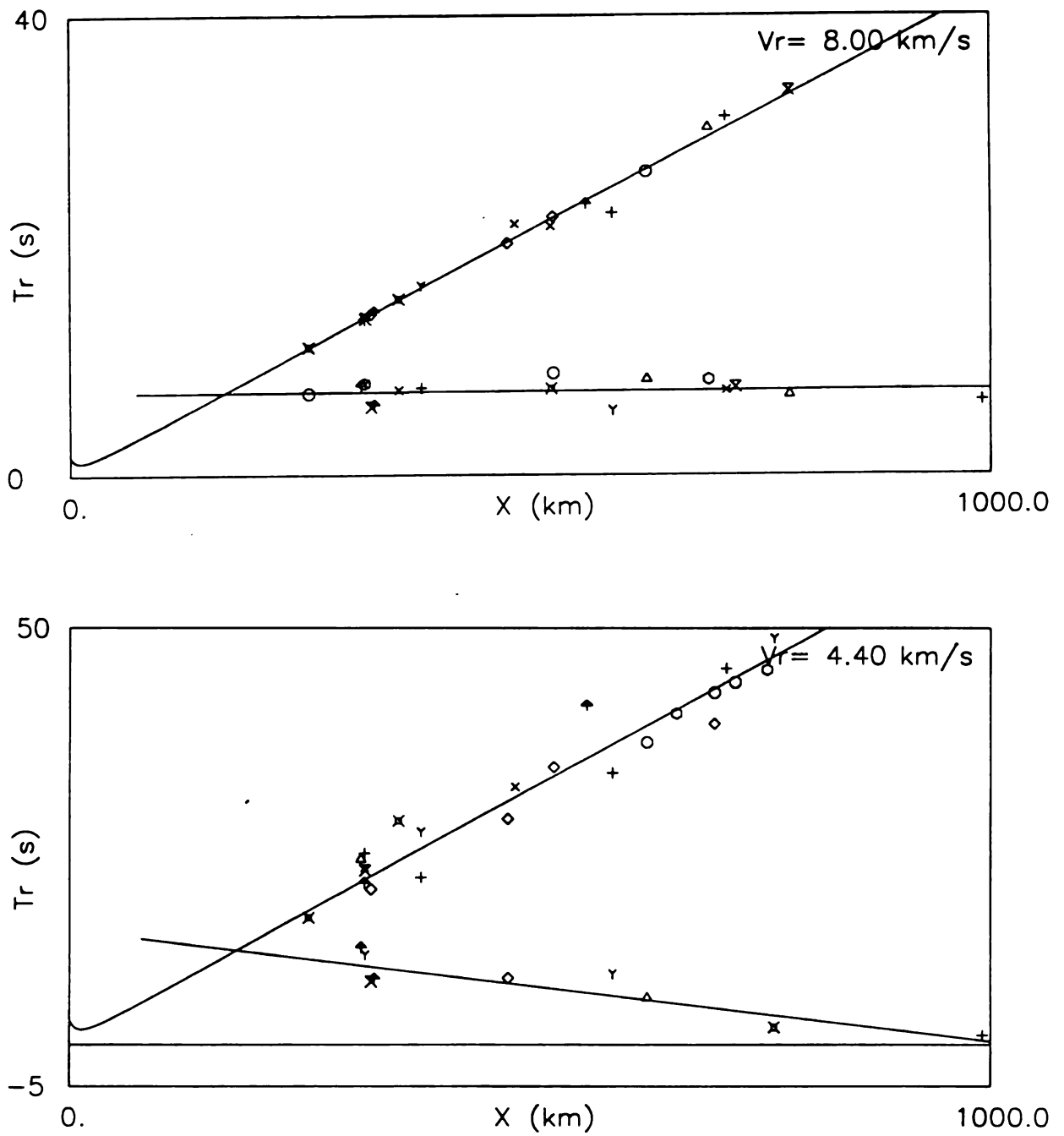


Figure 49. Omolon station reduced traveltimes curves and crustal model. Pg velocity 5.98 km/sec, Pn velocity 7.98 km/sec, and crustal thickness 37 km. Sg velocity 3.47 km/sec. Conventions as in Figure 22.

velocity of 3.47 km/sec is also observed for Omolon. Crustal thickness for Omolon is in agreement with previous studies, where values of 38-40 km have been determined.

All crustal thickness values determined in this study are plotted and contoured in figure 50. As a consequence of these results, it is apparent that additional data is necessary for some stations, while for other stations additional work to eliminate spurious and misidentified phases would be beneficial. For all stations, it will be necessary in the future to obtain better quantitative fits to the data. However, this method does appear to be able to resolve variations in crustal and upper mantle velocities and crustal thicknesses.

Discussion

The Pn and Pg velocities obtained herein generally indicate a thicker crust and lower velocity upper mantle than the results of the Magadan-Ust' Srednikan refraction line (Davydova et al., 1968; Ansimov et al., 1967; Belyaevsky, 1974). In comparison with the analysis of Suvorov and Kornilova (1986; Fig. 6), an interesting pattern develops. For individual stations, results are either in good agreement with Suvorov and Kornilova (1986), within 2 km, or not, being 6 km to 10 km greater. All stations where crustal thicknesses determined in this study are 6 km or greater than those of Suvorov and Kornilova (1986) fall along a north-west-north trend from Magadan. Results for stations to the northeast of this trend (Omsukchan, Seimchan, and Susuman) are in excellent agreement with Suvorov and Kornilova (1986). To the southwest, stations Yakutsk, Khandyga, and Nezhdaninskoe, are also in good agreement with values by Suvorov and Kornilova (1986). In general, the trend follows the region where the crust is thinnest in

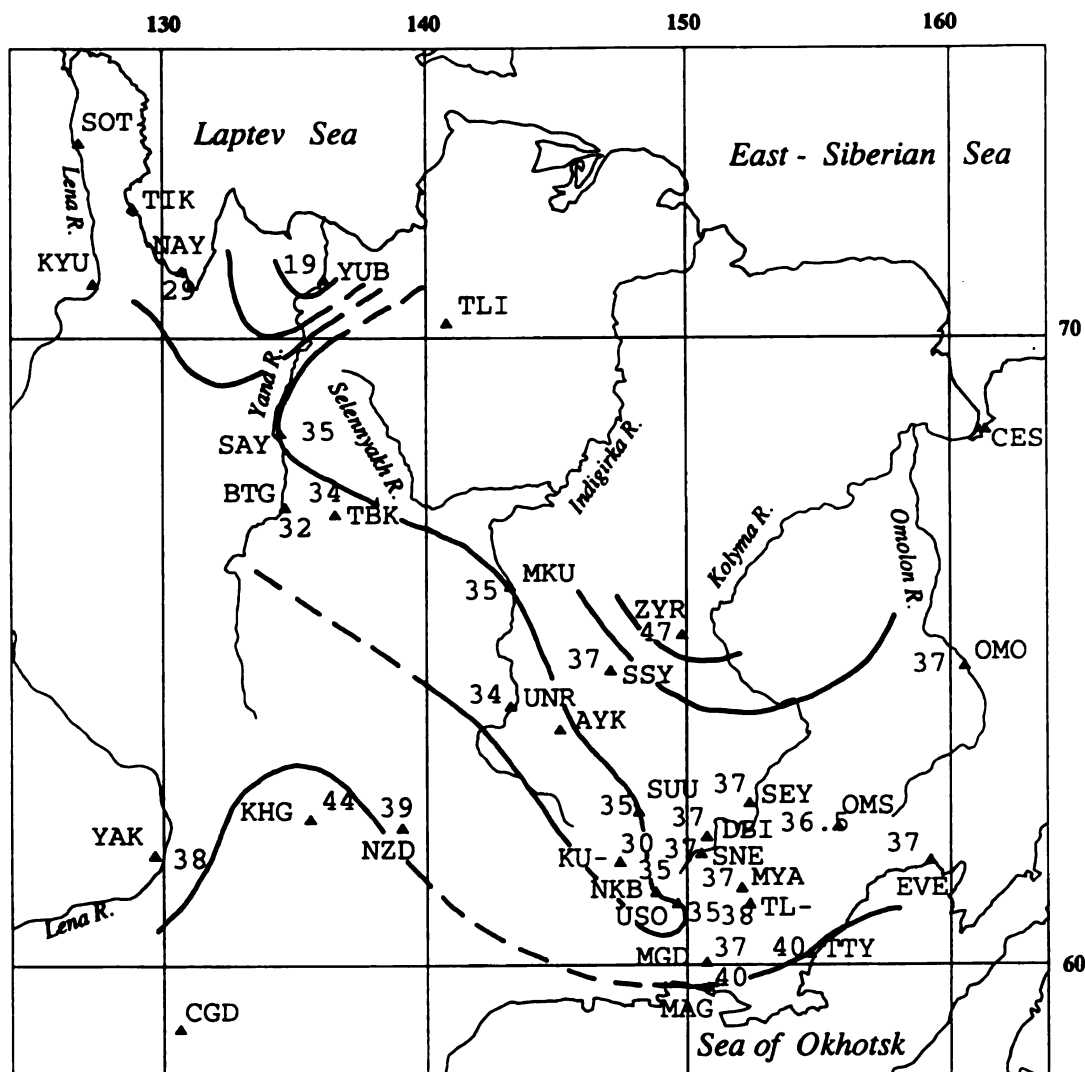


Figure 50. Summary of crustal thickness determinations for the study area. Contour interval = 5 km. Note the generally thinner crust extending northwest from station Ust' Omchug (USO). This region of thinner crust corresponds to the seismically active region and boundary between the North American and Eurasian plates. The thinned crust in this region may have resulted from a Cenozoic rifting episode. Station codes as in figure 7.

both studies. This trend is likely the result of the systematically mislocated epicenters used by Suvorov and Kornilova (1986). The associated errors appear to be about half that of Suvorov and Kornilova (1986). In addition, Suvorov and Kornilova (1986) assumed the thickness at Magadan using the refraction line, however as noted above, this result should be applied at Stekolnyi. Upper mantle velocities are generally slightly less, but are in agreement between this study and Suvorov and Kornilova (1986). Specifically, the highest Pn velocity determined in both studies study was at Khandyga (Table 1). The crustal thicknesses also agree fairly well with those reported by Belyaevsky and Borisov (1974) for Stekolnyi, Magadan, Omolon, and Omsukchan. Their value for Magadan lends some support for a thicker crust in the Okhotsk-Chukotka volcanic belt. Overall, Khandyga, Nezhdaninsk, Yakutsk, and perhaps Omolon show the most consistent agreement among multiple studies. Thus, the degree of confidence for stations in older platform regions is high.

The major differences between the various determinations are for Ust' Nera, Magadan, and Nelkoba. Nelkoba data indicates a thickness 4 km to 6 km thinner than that determined by P-Ps conversions (Mishin and Dareshkina, 1966; Belyaevsky and Borisov, 1974; Vaschilov, 1989). Nelkoba and Magadan both have a high degree of scatter in the Pn data, thus it is possible to vary the crustal structure model to conform with other studies and still maintain a reasonable fit to the data. The situation at Ust' Nera is more problematic. There is a great difference in the crustal thickness reported at Ust' Nera by Suvorov and Kornilova (1986), 24 km, and by Bulin (1989), 40 km. Our results fall somewhat in between at 34 km. Although there is some scatter in the Pn data,

a crust significantly thicker or thinner can not be supported. Thus, the author is inclined to disagree with the results of Suvorov and Kornilova (1986), and Bulin (1989). Gravity analysis by Norton et al. (1994) also suggest a crustal thickness near Ust' Nera of 35-36 km, supporting a slightly thinned crust relative to the regional average.

The overall general trend for crustal thicknesses determined in this study support a slightly thinner crust throughout the central Chersky seismic belt (Fig 50). Throughout most of the Chersky seismic belt, the crustal thickness variations are generally less than 4 km. This may imply that the effects of the Moma rift are less than envisioned by Parfenov et al. (1988) and Lander (1984). This study does indicate significant crustal thinning in the southern portions of the Laptev Sea rift. The basic trend is identical to that identified by Suvorov and Kornilova (1986), except lesser in degree. Converted wave studies are not clearly supportive of this trend.

Gravimetric data are available for the central and northern portion of the study area (Fig. 51; Parfenov et al., 1988; Crumley and Parfenov, 1994). The central portion of the study area shows some correlation with the gravity data. The region of thinned crust corresponds roughly with large negative anomalies, although crustal thickness contours here are constrained by only a few data points. Large negative anomalies do not correlate well with the thinned crust in the northern Laptev Sea rift portion on the study area. The lack of good correlation between gravity anomalies and crustal thickness attests to the difficulty of determining crustal thickness solely with gravity data as in studies by Vaschilov (1984), and Bobrobnikov and Izmailov (1989).

The locations of elevated heat flow levels (Fig. 52) are generally consistent with

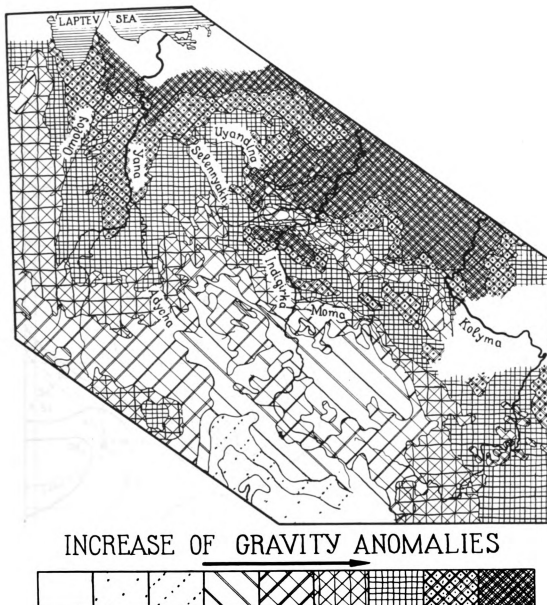


Figure 51. Map of relative gravity anomalies for the northern and central portion of the study area. From Parfenov et al.(1988).

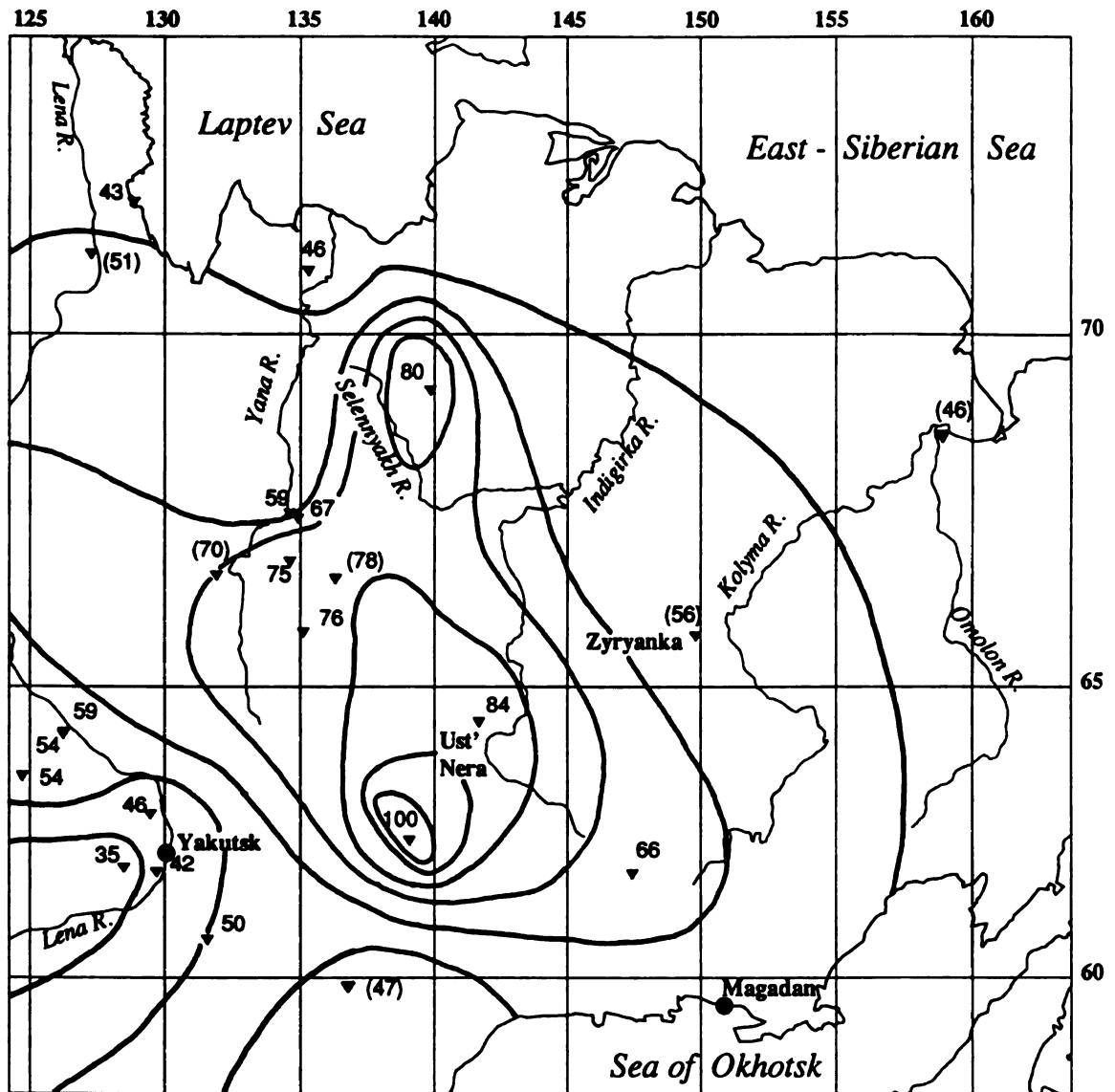


Figure 52. Map of heat flow levels in the study area. Triangles represent borehole locations with values in mW/m^2 . Values in brackets were interpolated from contours on other maps.

the region of thinned crust. Within the thinned crust region, heat flow reaches a maximum of 84 mW/m^2 at Ust' Nera (Melnikov et al., 1976). At Zyryanka, to the northeast of Ust'Nera, heat flow drops to 56 mW/m^2 (Duchkov et al., 1982; Duchkov and Sokolova, 1985). To the southwest, there is a slight increase in heat flow to 100 mW/m^2 at Nezhdaninskoe (Parfenov, 1988), and then a rapid decline to 42 mW/m^2 near Yakutsk and less than 30 mW/m^2 just beyond (Duchkov et al., 1982; Koz'min et al., 1994). The regions of elevated heat flow are likely remnants of the extensional episode which formed the Moma rift. However, it is puzzling that heat flow values in the Laptev Sea rift region, on an active rift, do not appear elevated as would be expected. Reported heat flow measurements may be affected by extremely thick permafrost layers ($>500\text{m}$), which in some cases is as deep as the boreholes used in the heat flow measurements penetrate (Melnikov et al., 1976). It should be noted that the actual boundaries of the elevated heat flow region are difficult to constrain with the available data.

Conclusions

The method of Ruff et al. (1994) allows one to obtain corrections in origin time and timing errors and allows rapid identification of spurious arrivals reported in the Russian bulletins. Combined with relocations of epicenters, this method has allowed the refining of the first-order crustal structure of northeast Russia using available phase data and the investigation of crustal thickness and upper mantle velocities at individual stations. This work confirms that a simple crustal model is a superior method of locating

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Conclusions

The method of Ruff et al. (1994) allows one to obtain corrections in origin time and timing errors and allows rapid identification of spurious arrivals reported in the Russian bulletins. Combined with relocations of epicenters, this method has allowed the refining of the first-order crustal structure of northeast Russia using available phase data and the investigation of crustal thickness and upper mantle velocities at individual stations. This work confirms that a simple crustal model is a superior method of locating

earthquakes in the region; new earthquake relocations show the original Russian locations contain systematic errors resulting from the use of a travel time curve with excessive velocities. This study has resolved a slightly thinner crust in portions of the Chersky Seismic Belt, which likely reflect the extensional episode associated with the Moma rift and present Laptev Sea rift systems. This study has also demonstrated the applicability of the 'SQUINT' program to a geographically large area with sparse station coverage. For future works, data from the Yakut network for Magadan region events (and vice versa) will improve the existing data set, and allow determinations of crustal thickness at additional stations, particularly in the northern Sakha Republic (Yakutia) and Chukotka. I also plan to combine data from Alaska and Magadan to study the Bering strait region and to research the possible existence of a Bering Sea block. The extension of this study will also provide additional constraints on the tectonics and evolution of this highly complex region.

APPENDICES

APPENDIX A

Earthquake data for events shown in Figure 7 and Figure 11. Events preceded by an asterisk were used in the determination of crustal structure. Bulletin data is from *Materialy Po Seismichnosti Sibiri*, except as noted. All events were relocated using only Pg arrivals and using only first arrivals (primarily Pn). Epicenters and new origin times were determined with high residual stations removed. Dashed lines indicate where insufficient data were available for relocation, or where the relocation was unstable.

[illegible]

Appendix A (continued)

79-04-28	08 55 59.0	59.2	152.20	08 56 05.1	59.476	151.609	-----	-----
79-05-02	22 10 32.0	64.1	149.30	22 10 28.8	64.201	149.217	-----	-----
79-05-15	23 52 34.0	63.4	145.40	23 52 32.8	63.365	145.131	-----	-----
79-06-05	13 18 09.	75.4	117.80	-----	-----	-----	-----	-----
79-06-05	14 38 17.	75.4	117.80	-----	-----	-----	-----	-----
79-06-16	20 41 52.	64.8	143.60	21 41 47.7	64.910	143.671	-----	-----
79-06-23	08 22 41.0	58.2	133.70	08 22 33.8	58.111	133.677	08 22 43.3	58.625 133.452
79-06-27	19 27 28.	61.3	137.00	-----	-----	-----	-----	-----
79-07-13	15 12 47.	62.4	130.00	-----	-----	-----	-----	-----
79-08-18	19 31 50.	60.6	131.80	19 31 41.4	60.242	131.734	-----	-----
79-08-19	07 10 08.0	61.6	156.80	07 09 15.7	60.941	164.754	07 09 18.0	60.786 166.109
79-08-27	02 55 03.	63.0	145.70	02 55 10.7	62.690	146.643	-----	-----
79-09-10	00 15 46.	60.6	153.00	00 15 43.8	60.466	153.153	-----	-----
79-10-03	01 47 12.8	65.87	144.72	-----	-----	-----	-----	-----
79-10-07	01 29 30.	64.8	144.20	01 29 25.9	65.064	144.072	01 29 26.0	65.065 144.078
79-10-09	09 42 56.0	64.8	144.10	09 42 51.8	65.015	144.059	-----	-----
79-10-26	00 26 26.0	62.3	153.90	00 26 25.9	62.190	153.841	00 26 26.9	62.326 153.945
79-10-30	08 04 05.	60.6	131.90	-----	-----	-----	-----	-----
79-11-03	03 28 56.	72.5	124.00	-----	-----	-----	-----	-----
79-11-11	19 27 38.	62.3	153.80	19 27 36.2	62.282	153.821	19 27 35.6	62.226 153.843
79-11-18	08 59 17.0	62.2	153.80	08 59 15.7	62.240	153.802	08 59 15.5	62.259 153.814
79-12-09	06 57 54.0	62.2	153.80	06 57 55.7	62.254	153.416	06 57 54.6	62.281 153.298
79-12-21	08 27 53.	70.3	132.80	-----	-----	-----	-----	-----
79-12-25	05 36 28.	60.2	154.40	05 36 26.8	60.267	154.318	-----	-----
79-12-29	04 22 21.0	61.5	142.60	04 22 16.0	61.374	142.694	04 22 20.7	61.742 143.264
80-01-10	20 57 34.	64.4	148.80	20 57 21.8	64.880	149.777	-----	-----
80-01-18	18 32 29.	72.3	124.20	-----	-----	-----	-----	-----
80-01-25	18 45 50.	64.0	145.90	18 45 39.5	64.307	145.250	-----	-----
80-01-27	18 55 41.0	63.4	150.60	18 55 39.7	63.395	150.571	18 55 40.0	63.443 150.502
80-01-28	05 11 57.0	63.5	150.60	05 11 56.8	63.506	150.656	05 11 56.7	63.465 150.676 k,1
80-02-01	17 37 27.	73.3	122.60	-----	-----	-----	17 30 16.9	73.226 119.769
80-02-01	19 51 51.	73.2	122.40	-----	-----	-----	-----	-----
80-02-01	21 32 32.	73.2	122.00	-----	-----	-----	-----	-----
80-02-01	21 39 02.	73.2	123.10	-----	-----	-----	-----	-----
80-02-02	03 55 18.	73.1	122.50	-----	-----	-----	-----	-----
80-02-02	04 58 20.	73.1	122.40	-----	-----	-----	-----	-----
80-02-02	18 28 37.	73.1	122.70	-----	-----	-----	-----	-----
80-02-03	05 54 11.	73.2	122.50	-----	-----	-----	-----	-----
80-02-03	07 43 16.	73.2	122.60	-----	-----	-----	-----	-----
80-02-03	09 21 42.	73.2	122.00	-----	-----	-----	-----	-----
80-02-05	11 10 35.	66.6	146.90	-----	-----	-----	-----	-----
80-02-10	12 08 46.	73.5	124.30	-----	-----	-----	-----	-----
80-02-12	14 03 03.	73.3	123.70	-----	-----	-----	-----	-----
80-02-14	03 49 34.	72.3	124.70	-----	-----	-----	-----	-----
80-02-17	06 15 00.	72.7	135.40	-----	-----	-----	-----	-----
80-03-11	18 11 23.2	57.13	127.65	18 11 19.3	57.010	127.670	18 11 22.1	56.959 127.694
80-03-12	08 20 25.	73.2	122.50	-----	-----	-----	-----	-----
80-03-17	08 24 05.	73.8	129.40	-----	-----	-----	-----	-----
80-03-20	19 08 42.	69.6	125.40	-----	-----	-----	-----	-----
80-04-03	19 15 13.	73.5	117.30	-----	-----	-----	-----	-----
80-04-22	19 07 48.	65.5	136.80	-----	-----	-----	-----	-----
80-05-07	05 04 36.	60.3	152.00	05 04 34.9	60.332	151.944	05 04 34.5	60.301 151.961
80-05-12	09 09 15.	63.16	147.68	09 09 13.2	63.146	147.648	09 09 13.5	62.997 147.439
80-05-12	19 30 15.	63.1	147.70	19 30 13.0	63.147	147.667	19 30 14.6	63.386 148.069
80-05-19	17 29 50.	60.0	144.60	-----	-----	-----	-----	-----
80-06-02	13 15 09.	62.8	145.90	13 15 05.9	62.828	145.765	13 15 07.8	62.973 146.034
80-06-07	02 04 52.9	64.33	145.47	02 04 52.5	64.066	145.100	02 04 52.0	64.244 145.148
80-06-22	00 07 53.	60.0	146.10	00 07 45.6	59.624	146.011	00 07 52.3	59.987 146.367
80-07-09	05 03 53.	73.3	122.80	-----	-----	-----	-----	-----
80-07-14	08 30 04.	72.8	131.80	-----	-----	-----	-----	-----
80-09-19	18 28 50.	63.3	148.30	18 28 48.6	63.250	148.172	18 28 50.4	63.125 148.160
80-09-24	06 06 57.	74.3	125.50	-----	-----	-----	-----	-----
80-09-26	10 29 08.	74.5	132.20	-----	-----	-----	-----	-----
80-10-16	12 34 54.	71.8	129.10	-----	-----	-----	-----	-----
80-11-08	15 45 30.	62.0	125.00	-----	-----	-----	-----	-----
80-12-03	17 58 17.5	63.58	152.15	17 58 12.6	63.809	152.133	17 58 15.6	63.674 152.402 b
80-12-17	08 59 54.3	66.88	130.80	-----	-----	-----	-----	-----
80-12-27	02 31 36.	60.1	143.3	-----	-----	-----	-----	-----
80-12-29	20 19 12.	69.6	138.1	20 19 04.3	69.754	139.814	20 19 10.2	69.663 138.490
80-12-31	05 00 21.0	64.0	140.70	-----	-----	-----	05 00 19.4	64.151 140.975
*81-02-02	19 15 18.	62.4	144.50	19 15 15.5	62.385	144.471	19 15 15.4	62.342 144.434
81-02-05	12 14 17.	58.7	132.30	12 13 52.2	58.139	134.501	-----	-----
81-02-22	23 06 21.	63.2	151.00	23 06 20.0	63.176	150.968	23 06 20.3	63.111 150.973
81-03-01	18 39 37.6	62.44	143.31	18 39 33.8	62.216	143.226	18 39 30.7	61.943 142.760
81-03-15	03 50 32.	69.8	138.00	-----	-----	-----	-----	-----
*81-05-10	18 08 28.	61.6	157.20	18 08 25.8	61.477	157.220	18 08 26.7	61.586 157.228
81-05-22	04 59 21.0	61.0	156.7	04 59 19.6	61.045	156.728	-----	-----
81-05-22	04 59 24.5	61.24	156.58	04 59 19.6	61.045	156.728	04 59 23.8	61.361 156.543 isc
81-05-27	05 16 49.	73.7	139.20	-----	-----	-----	-----	-----
81-06-19	02 27 28.	63.7	151.60	02 27 24.5	63.775	151.695	-----	-----
81-07-03	06 48 06.	75.0	137.00	-----	-----	-----	-----	-----
81-07-16	03 45 49.	61.8	144.80	03 45 54.1	61.931	145.968	-----	-----
81-07-27	22 31 33.	61.6	144.5	22 31 18.9	60.968	143.614	-----	-----
81-08-03	08 16 38.	70.7	132.20	08 16 35.9	70.209	129.172	-----	-----
81-08-09	19 13 41.	63.4	146.40	19 13 38.4	63.416	146.506	19 13 39.4	63.326 146.245
81-08-19	19 17 32.0	67.59	140.45	-----	-----	-----	-----	-----

Appendix A (continued)

81-08-26	10 45 12.	58.5	140.80	10 45 02.3	58.338	141.057	-----	-----	
81-08-29	22 23 52.	65.4	136.9	22 23 51.4	65.356	136.736	22 23 49.5	65.389	136.315
81-08-29	22 23 51.5	65.49	136.43	22 23 51.4	65.356	136.736	22 23 49.2	65.374	136.469
81-10-20	14 12 52.	73.4	127.10	-----	-----	-----	-----	-----	isc
81-10-20	21 23 46.	73.5	127.40	-----	-----	-----	-----	-----	
81-11-03	03 43 03.	70.4	140.60	-----	-----	-----	-----	-----	
*81-11-08	21 56 12.9	61.91	153.56	21 56 08.9	61.822	153.724	21 56 08.3	61.885	153.616
81-11-08	21 56 11.	61.8	153.60	21 56 08.9	61.822	153.724	21 56 08.2	61.857	153.615
81-11-08	22 04 59.	61.7	153.60	22 04 60.0	61.801	153.687	-----	-----	c
81-11-09	00 33 22.	61.8	153.70	00 33 20.1	61.840	153.722	00 33 21.9	61.918	153.737
81-11-10	10 07 52.7	63.99	148.75	10 07 46.5	64.327	148.978	10 07 50.6	64.018	148.711
81-11-10	10 07 52.	64.0	148.90	10 07 46.5	64.327	148.978	10 07 50.7	63.983	148.703
*81-11-10	10 54 18.	63.9	148.80	10 54 15.5	63.914	148.675	10 54 15.5	63.901	148.586
*81-11-11	14 22 21.	61.8	153.60	14 22 18.5	61.856	153.674	14 22 18.0	61.918	153.629
81-11-11	15 29 49.5	61.80	153.62	15 29 47.8	61.767	153.724	-----	-----	
81-11-28	05 14 40.5	62.14	154.14	05 14 37.6	62.201	154.270	-----	-----	
81-12-03	14 41 27.	64.0	148.70	14 41 24.9	63.871	148.372	14 41 26.8	63.867	148.820
*81-12-08	10 57 22.	61.8	153.70	10 57 20.6	61.798	153.662	10 57 21.4	61.833	153.548
82-03-12	23 23 20.	59.6	148.10	23 23 15.7	59.401	148.058	-----	-----	
82-04-05	09 41 16.4	61.94	153.60	-----	-----	-----	09 41 14.6	61.807	153.631
*82-04-06	14 41 13.9	61.79	153.61	14 41 13.3	61.791	153.669	14 41 14.3	61.818	153.515
82-06-23	08 04 37.	60.7	137.60	08 04 26.1	60.275	138.221	08 04 27.4	60.252	138.615
82-07-24	08 39 04.	63.6	146.20	08 39 01.8	63.563	146.219	08 39 04.3	63.563	146.537
*82-08-04	20 17 05.9	62.48	146.93	20 17 03.5	62.370	146.957	20 17 03.9	62.413	147.027
82-09-03	07 29 31.8	67.04	133.91	07 29 26.5	66.989	133.414	07 29 22.3	66.883	132.813
82-09-08	01 47 44.8	58.9	126.40	-----	-----	-----	-----	-----	
82-09-09	11 42 38.8	62.61	151.10	11 42 37.3	62.562	151.037	-----	-----	
82-09-19	12 51 06.	70.0	129.00	-----	-----	-----	-----	-----	
82-09-22	07 23 47.	59.5	152.00	07 23 46.1	59.425	152.022	-----	-----	
82-10-04	15 57 17.	59.9	141.50	15 57 08.8	59.684	141.313	-----	-----	
82-12-22	12 10 05.	64.1	156.90	12 10 04.6	63.885	156.648	12 10 00.8	64.135	156.929
*82-12-22	15 47 03.0	59.22	152.70	15 47 03.6	59.201	152.693	15 47 04.3	59.195	152.658
82-12-29	04 37 41.2	67.05	140.10	-----	-----	-----	-----	-----	f
83-01-04	07 17 16.4	62.19	143.72	07 17 13.6	62.155	143.655	07 17 15.6	62.250	143.772
83-03-04	18 03 02.	69.7	138.10	-----	-----	-----	-----	-----	
*83-03-12	11 55 14.	64.2	141.00	11 55 11.7	64.275	140.871	11 55 12.2	64.342	140.893
83-03-12	18 43 07.	64.3	140.80	18 43 05.2	64.216	141.027	-----	-----	
83-03-23	14 45 07.3	62.98	155.70	14 45 05.5	63.046	155.746	14 45 04.0	63.046	156.214
*83-03-25	10 36 57.	63.63	149.74	10 36 55.1	63.560	149.797	10 36 55.7	63.609	149.807
83-03-25	10 36 54.	63.6	149.80	10 36 55.1	63.560	149.797	10 36 56.8	63.543	149.933
83-04-04	14 37 36.	67.0	140.20	14 37 34.6	66.942	140.073	14 37 34.4	67.005	140.107
*83-05-09	16 48 05.	63.3	146.20	16 48 05.3	63.282	146.227	16 48 03.2	63.377	145.777
83-05-10	05 27 25.	64.2	150.80	05 27 24.4	64.193	150.838	-----	-----	d
83-05-28	01 10 26.	74.2	134.70	-----	-----	-----	-----	-----	
83-05-28	02 57 58.	62.1	150.20	02 57 57.0	61.991	150.358	02 57 57.6	61.006	150.352
83-06-08	18 29 46.	59.6	148.20	18 29 43.0	59.465	148.088	18 29 45.1	59.527	148.188
83-06-10	02 13 23.2	75.53	122.75	02 13 25.	75.035	134.995	02 13 24.5	73.439	122.138
83-06-10	02 13 25.	75.4	122.50	02 13 25.	75.035	134.995	02 13 58.0	73.429	128.102
83-06-26	05 44 02.	71.4	130.10	-----	-----	-----	-----	-----	isc
83-10-12	16 07 25.0	60.0	150.00	16 07 23.7	60.026	149.772	16 07 25.4	59.965	150.048
83-10-12	16 09 18.	60.0	150.00	16 09 17.9	60.001	149.904	-----	-----	
*83-10-25	19 44 58.	60.0	153.10	19 44 59.9	60.034	153.031	19 45 01.3	60.145	152.850
83-11-07	14 21 04.	65.6	136.50	14 20 59.9	65.537	136.343	14 20 58.3	65.385	136.508
84-04-01	22 43 51.4	59.58	146.80	22 43 41.5	59.142	146.190	-----	-----	
84-04-11	20 50 42.0	59.45	148.24	20 50 40.6	59.419	148.080	20 50 42.2	59.490	148.123
84-07-14	23 32 00.	72.4	136.90	-----	-----	-----	-----	-----	
84-07-19	01 52 36.3	68.94	132.39	-----	-----	-----	-----	-----	
84-08-02	21 25 44.	61.0	144.7	21 25 32.1	60.612	145.244	21 25 51.4	61.750	143.902
84-08-02	21 25 37.8	60.89	144.7	21 25 32.1	60.612	145.244	21 25 40.8	60.843	144.703
84-08-08	22 34 10.6	63.15	152.90	-----	-----	-----	-----	-----	isc
84-08-12	15 27 08.	74.8	136.60	-----	-----	-----	-----	-----	
84-08-12	15 28 03.	74.17	135.10	-----	-----	-----	15 28 03.1	74.094	134.579
84-08-12	18 34 32.	74.5	137.60	-----	-----	-----	-----	-----	isc
84-08-12	21 29 29.	74.8	137.70	-----	-----	-----	-----	-----	
*84-08-21	17 41 04.3	60.90	153.79	17 41 02.7	60.893	153.842	17 41 04.3	60.983	153.770
84-09-03	18 40 23.7	61.16	136.74	18 40 20.9	61.145	136.623	18 40 22.3	61.162	136.660
84-09-12	20 10 43.3	59.38	138.59	-----	-----	-----	-----	-----	
84-09-19	11 36 35.2	63.48	145.76	11 36 32.7	63.393	145.635	11 36 33.1	63.393	145.750
84-10-29	14 06 14.	62.1	163.50	14 06 11.9	61.876	163.794	14 06 14.7	62.408	163.551
84-11-21	08 08 17.0	61.33	156.52	08 08 14.4	61.230	156.433	-----	-----	
84-11-22	13 53 06.	68.6	140.50	13 52 55.8	68.320	141.169	13 52 56.1	68.492	140.875
84-11-27	09 05 19.	58.8	140.90	-----	-----	-----	-----	-----	
*84-12-02	08 35 47.	63.3	150.70	08 35 45.1	63.376	150.560	08 35 44.7	63.418	150.534
*84-12-02	18 17 53.6	63.37	150.51	18 17 54.9	63.321	150.579	18 17 54.1	63.339	150.366
85-01-13	07 31 04.0	60.06	153.05	07 31 03.3	60.025	153.184	07 31 04.2	59.997	153.156
85-01-15	02 08 32.4	65.01	141.81	02 08 32.7	65.007	141.723	-----	-----	
85-01-16	23 44 43.3	71.07	123.75	-----	-----	-----	-----	-----	
*85-01-21	18 03 51.0	60.80	155.20	18 03 50.4	60.782	155.319	18 03 51.0	60.759	155.302
*85-01-24	20 26 34.	66.9	133.30	20 26 33.2	66.900	132.840	20 26 33.0	66.871	132.799
85-01-29	00 36 05.6	64.16	145.82	00 36 06.2	64.116	145.801	00 36 07.6	64.205	145.852
*85-01-29	00 36 09.4	64.29	145.7	00 36 06.2	64.116	145.801	00 36 07.5	64.242	145.857
85-01-29	09 45 51.0	64.1	145.80	09 45 52.7	64.200	145.878	-----	-----	q,isc
85-02-01	08 31 55.	62.5	127.90	08 31 44.0	62.855	127.144	08 31 46.4	63.011	127.452
85-02-01	08 31 44.0	62.84	127.4	08 31 44.0	62.855	127.144	08 31 46.3	63.016	127.540
85-02-01	10 20 52.6	62.63	127.66	-----	-----	-----	-----	-----	isc
85-02-01	21 53 18.3	64.25	145.70	-----	-----	-----	-----	-----	

Appendix A (continued)

81-08-26	10 45 12.	58.5	140.80	10 45 02.3	58.338	141.057	-----	-----	
81-08-29	22 23 52.	65.4	136.9	22 23 51.4	65.356	136.736	22 23 49.5	65.389	136.315
81-08-29	22 23 51.5	65.49	136.43	22 23 51.4	65.356	136.736	22 23 49.2	65.374	136.469
81-10-20	14 12 52.	73.4	127.10	-----	-----	-----	-----	-----	isc
81-10-20	21 23 46.	73.5	127.40	-----	-----	-----	-----	-----	
81-11-03	03 43 03.	70.4	140.60	-----	-----	-----	-----	-----	
*81-11-08	21 56 12.9	61.91	153.56	21 56 08.9	61.822	153.724	21 56 06.3	61.885	153.616
81-11-08	21 56 11.	61.8	153.60	21 56 08.9	61.822	153.724	21 56 08.2	61.857	153.615
81-11-08	22 04 59.	61.7	153.60	22 04 60.0	61.801	153.687	-----	-----	c
81-11-09	00 33 22.	61.8	153.70	00 33 20.1	61.840	153.722	00 33 21.9	61.918	153.737
81-11-10	10 07 52.7	63.99	148.75	10 07 46.5	64.327	148.978	10 07 50.6	64.018	148.711
81-11-10	10 07 52.	64.0	148.90	10 07 46.5	64.327	148.978	10 07 50.7	63.983	148.703
*81-11-10	10 54 18.	63.9	148.80	10 54 15.5	63.914	148.675	10 54 15.5	63.901	148.588
*81-11-11	14 22 21.	61.8	153.60	14 22 18.5	61.856	153.674	14 22 18.0	61.918	153.629
81-11-11	15 29 49.5	61.80	153.62	15 29 47.8	61.767	153.724	-----	-----	
81-11-28	05 14 40.5	62.14	154.14	05 14 37.6	62.201	154.270	-----	-----	
81-12-03	14 41 27.	64.0	148.70	14 41 24.9	63.871	148.372	14 41 26.8	63.867	148.820
*81-12-08	10 57 22.	61.8	153.70	10 57 20.6	61.798	153.662	10 57 21.4	61.833	153.548
82-03-12	23 23 20.	59.6	148.10	23 23 15.7	59.401	148.058	-----	-----	
82-04-05	09 41 16.4	61.94	153.60	-----	-----	-----	09 41 14.6	61.807	153.631
*82-04-06	14 41 13.9	61.79	153.61	14 41 13.3	61.791	153.669	14 41 14.3	61.818	153.515
82-06-23	08 04 37.	60.7	137.60	08 04 26.1	60.275	138.221	08 04 27.4	60.252	138.615
82-07-24	08 39 04.	63.6	146.20	08 39 01.8	63.563	146.219	08 39 04.3	63.563	146.537
*82-08-04	20 17 05.9	62.48	146.93	20 17 03.5	62.370	146.957	20 17 03.9	62.413	147.017
82-09-03	07 29 31.8	67.04	133.91	07 29 26.5	66.989	133.414	07 29 22.3	66.883	132.813
82-09-08	01 47 44.8	58.9	126.40	-----	-----	-----	-----	-----	
82-09-09	11 42 38.8	62.61	151.10	11 42 37.3	62.562	151.037	-----	-----	
82-09-19	12 51 06.	70.0	129.00	-----	-----	-----	-----	-----	
82-09-22	07 23 47.	59.5	152.00	07 23 46.1	59.425	152.022	-----	-----	
82-10-04	15 57 17.	59.9	141.50	15 57 08.8	59.684	141.313	-----	-----	
82-12-22	12 10 05.	64.1	156.90	12 10 04.6	63.885	156.648	12 10 00.8	64.135	156.929
*82-12-22	15 47 03.0	59.22	152.70	15 47 03.6	59.201	152.693	15 47 04.3	59.195	152.658
82-12-29	04 37 41.2	67.05	140.10	-----	-----	-----	-----	-----	f
83-01-04	07 17 16.4	62.19	143.72	07 17 13.6	62.155	143.655	07 17 15.6	62.250	143.772
83-03-04	18 03 02.	69.7	138.10	-----	-----	-----	-----	-----	
*83-03-12	11 55 14.	64.2	141.00	11 55 11.7	64.275	140.871	11 55 12.2	64.342	140.893
83-03-12	18 43 07.	64.3	140.80	18 43 05.2	64.216	141.027	-----	-----	
83-03-23	14 45 07.3	62.98	155.70	14 45 05.5	63.046	155.746	14 45 04.0	63.046	156.214
*83-03-25	10 36 57.	63.63	149.74	10 36 55.1	63.560	149.797	10 36 55.7	63.609	149.807
83-03-25	10 36 54.	63.6	149.80	10 36 55.1	63.560	149.797	10 36 56.8	63.543	149.933
83-04-04	14 37 36.	67.0	140.20	14 37 34.6	66.942	140.073	14 37 34.4	67.005	140.107
*83-05-09	16 48 05.	63.3	146.20	16 48 05.3	63.282	146.227	16 48 03.2	63.377	145.777
83-05-10	05 27 25.	64.2	150.80	05 27 24.4	64.193	150.838	-----	-----	d
83-05-28	01 10 26.	74.2	134.70	-----	-----	-----	-----	-----	
83-05-28	02 57 58.	62.1	150.20	02 57 57.0	61.991	150.358	02 57 57.6	61.006	150.352
83-06-08	18 29 46.	59.6	148.20	18 29 43.0	59.465	148.088	18 29 45.1	59.527	148.188
83-06-10	02 13 23.2	75.53	122.75	02 13 25.	75.035	134.995	02 13 24.5	73.439	122.138
83-06-10	02 13 25.	75.4	122.50	02 13 25.	75.035	134.995	02 13 58.0	73.429	128.102
83-06-26	05 44 02.	71.4	130.10	-----	-----	-----	-----	-----	isc
83-10-12	16 07 25.0	60.0	150.00	16 07 23.7	60.026	149.772	16 07 25.4	59.965	150.048
83-10-12	16 09 18.	60.0	150.00	16 09 17.9	60.001	149.904	-----	-----	
*83-10-25	19 44 58.	60.0	153.10	19 44 59.9	60.034	153.031	19 45 01.3	60.145	152.850
83-11-07	14 21 04.	65.6	136.50	14 20 59.9	65.537	136.343	14 20 58.3	65.385	136.508
84-04-01	22 43 51.4	59.58	146.80	22 43 41.5	59.142	146.190	-----	-----	
84-04-11	20 50 42.0	59.45	148.24	20 50 40.6	59.419	148.080	20 50 42.2	59.490	148.123
84-07-14	23 32 00.	72.4	136.90	-----	-----	-----	-----	-----	
84-07-19	01 52 36.3	68.94	132.39	-----	-----	-----	-----	-----	
84-08-02	21 25 44.	61.0	144.7	21 25 32.1	60.612	145.244	21 25 51.4	61.750	143.902
84-08-02	21 25 37.8	60.89	144.7	21 25 32.1	60.612	145.244	21 25 40.8	60.843	144.703
84-08-08	22 34 10.6	63.15	152.90	-----	-----	-----	-----	-----	isc
84-08-12	15 27 08.	74.8	136.60	-----	-----	-----	-----	-----	
84-08-12	15 28 03.	74.17	135.10	-----	-----	-----	15 28 03.1	74.094	134.579
84-08-12	18 34 32.	74.5	137.60	-----	-----	-----	-----	-----	isc
84-08-12	21 29 29.	74.8	137.70	-----	-----	-----	-----	-----	
*84-08-21	17 41 04.3	60.90	153.79	17 41 02.7	60.893	153.842	17 41 04.3	60.983	153.770
84-09-03	18 40 23.7	61.16	136.74	18 40 20.9	61.145	136.623	18 40 22.3	61.162	136.660
84-09-12	20 10 43.3	59.38	138.59	-----	-----	-----	-----	-----	
84-09-19	11 36 35.2	63.48	145.76	11 36 32.7	63.393	145.635	11 36 33.1	63.393	145.750
84-10-29	14 06 14.	62.1	163.50	14 06 11.9	61.876	163.794	14 06 14.7	62.408	163.551
84-11-21	08 08 17.0	61.33	156.52	08 08 14.4	61.230	156.433	-----	-----	
84-11-22	13 53 06.	68.6	140.50	13 52 55.8	68.320	141.169	13 52 56.1	68.492	140.875
84-11-27	09 05 19.	58.8	140.90	-----	-----	-----	-----	-----	
*84-12-02	08 35 47.	63.3	150.70	08 35 45.1	63.376	150.560	08 35 44.7	63.418	150.534
*84-12-02	18 17 53.6	63.37	150.51	18 17 54.9	63.321	150.579	18 17 54.1	63.339	150.366
85-01-13	07 31 04.0	60.06	153.05	07 31 03.3	60.025	153.184	07 31 04.2	59.997	153.156
85-01-15	02 08 32.4	65.01	141.81	02 08 32.7	65.007	141.723	-----	-----	
85-01-16	23 44 43.3	71.07	123.75	-----	-----	-----	-----	-----	
*85-01-21	18 03 51.0	60.80	155.20	18 03 50.4	60.782	155.319	18 03 51.0	60.759	155.302
*85-01-24	20 26 34.	66.9	133.30	20 26 33.2	66.900	132.840	20 26 33.0	66.871	132.799
85-01-29	00 36 05.6	64.16	145.82	00 36 06.2	64.116	145.801	00 36 07.6	64.205	145.852
*85-01-29	00 36 09.4	64.29	145.7	00 36 06.2	64.116	145.801	00 36 07.5	64.242	145.857
85-01-29	09 45 51.0	64.1	145.80	09 45 52.7	64.200	145.878	-----	-----	q,isc
85-02-01	08 31 55.	62.5	127.90	08 31 44.0	62.855	127.144	08 31 46.4	63.011	127.452
85-02-01	08 31 44.0	62.84	127.4	08 31 44.0	62.855	127.144	08 31 46.3	63.016	127.540
85-02-01	10 20 52.6	62.63	127.66	-----	-----	-----	-----	-----	isc
85-02-01	21 53 18.3	64.25	145.70	-----	-----	-----	-----	-----	

Appendix A (continued)

85-02-02	11 28 45.3	65.85	137.05	11 28 44.9	65.834	136.990	-----	-----	
85-02-18	12 51 35.	65.6	136.50	12 51 31.3	65.557	136.457	12 51 32.7	65.662	136.653
*85-03-08	22 24 38.0	59.35	151.96	22 24 37.8	59.356	152.162	22 24 34.7	59.119	152.197
85-04-10	11 27 46.6	70.43	141.03	11 27 45.1	70.329	141.424	-----	-----	
85-04-12	09 22 16.	62.4	124.10	-----	-----	-----	-----	-----	
85-04-17	20 37 21.8	65.36	142.96	20 37 19.8	65.406	142.946	-----	-----	
85-04-20	22 29 19.6	59.28	141.72	-----	-----	-----	-----	-----	
85-05-22	18 28 48.6	61.02	157.88	18 28 47.3	60.952	157.850	-----	-----	
85-06-02	04 08 08.9	64.83	144.08	04 08 08.8	64.857	144.044	04 08 09.9	64.871	144.060
*85-06-02	04 08 12.8	64.8	144.0	04 08 08.8	64.857	144.044	04 08 09.0	64.898	144.249
85-06-24	03 54 35.	65.2	145.00	03 54 34.2	65.286	144.664	-----	-----	isc
85-06-24	03 54 32.4	65.25	144.49	03 54 34.2	65.286	144.664	03 54 34.6	65.205	144.346
85-08-20	03 41 37.7	62.14	145.64	03 41 37.9	62.237	145.488	-----	-----	t,isc
85-08-28	05 04 11.3	59.90	137.36	05 04 09.0	59.956	137.081	-----	-----	
85-09-10	10 53 03.3	62.46	142.98	-----	-----	-----	-----	-----	
85-10-05	22 32 36.8	59.44	150.23	22 32 36.0	59.465	150.201	22 32 35.8	59.430	150.179
85-10-05	22 37 04.5	59.41	150.26	22 37 00.7	59.299	149.987	-----	-----	
85-10-05	22 37 13.6	59.45	150.22	22 37 10.9	59.225	150.192	-----	-----	
*85-11-28	08 38 25.	64.9	144.30	08 38 20.5	64.863	144.133	08 38 22.1	64.850	144.422
86-01-05	00 35 23.	70.2	128.40	00 35 23.9	70.276	128.612	-----	-----	
*86-01-18	13 13 23.3	60.20	153.67	13 13 22.0	60.191	153.761	13 13 24.8	60.255	153.530
86-01-24	13 25 26.8	60.70	138.49	13 25 23.0	60.616	138.566	-----	-----	
86-01-25	21 02 08.7	64.59	147.47	-----	-----	-----	-----	-----	
*86-02-15	20 30 27.5	63.97	152.89	20 30 26.3	63.973	153.096	20 30 26.8	64.001	153.038
*86-03-07	23 28 10.0	63.99	153.50	23 28 08.2	64.104	153.511	23 28 07.5	64.106	153.469
86-03-15	04 02 02.	59.9	144.50	-----	-----	-----	-----	-----	
86-04-03	15 38 17.6	59.19	154.20	15 38 15.8	59.135	154.478	15 38 13.0	58.975	154.750
*86-04-06	01 27 20.6	70.76	130.31	01 27 20.5	70.755	130.200	01 27 20.1	70.748	130.241
86-04-23	04 29 51.	73.8	114.60	-----	-----	-----	-----	-----	
86-05-11	17 29 00.1	62.07	154.10	17 28 58.9	62.034	154.151	17 29 00.2	62.157	154.243
86-06-04	22 43 54.2	61.78	158.92	22 43 53.5	61.871	159.025	-----	-----	
86-06-15	06 55 36.8	72.94	126.53	06 55 36.8	72.883	126.515	06 55 34.7	72.946	125.867
86-06-15	06 55 35.8	72.73	126.3	06 55 36.8	72.883	126.515	06 55 33.4	72.630	123.975
86-06-15	06 57 45.3	72.94	126.62	-----	-----	-----	-----	-----	isc
86-07-23	23 28 58.	71.9	128.90	-----	-----	-----	-----	-----	
86-07-27	11 25 41.8	64.65	147.09	11 25 40.6	64.634	147.058	11 25 41.3	64.569	147.062
86-07-27	21 08 42.0	61.96	160.96	-----	-----	-----	-----	-----	
86-08-10	11 11 59.0	63.74	147.88	11 11 59.8	63.532	147.931	11 12 00.2	63.500	147.731
86-11-09	07 15 36.	75.0	139.40	-----	-----	-----	-----	-----	
86-12-05	15 50 12.	74.6	125.00	-----	-----	-----	-----	-----	
86-12-08	20 07 24.1	71.32	140.39	-----	-----	-----	-----	-----	
86-12-11	00 15 55.	74.0	119.60	-----	-----	-----	-----	-----	
86-12-11	01 47 09.	74.0	119.70	-----	-----	-----	-----	-----	
86-12-18	18 04 17.2	61.37	143.53	18 04 11.2	61.177	143.634	18 03 58.9	60.361	145.102
*86-12-18	18 04 10.2	61.31	143.7	18 04 11.2	61.177	143.634	18 04 09.3	61.135	143.533
86-12-22	02 18 09.4	73.80	119.77	-----	-----	-----	-----	-----	isc
*86-12-26	03 21 04.9	61.42	149.48	03 21 04.5	61.375	149.426	03 21 03.6	61.403	149.465
87-01-09	04 29 45.0	60.02	153.01	04 29 44.0	59.974	153.039	04 29 32.7	59.262	154.152
87-01-09	13 14 18.6	67.23	140.17	13 14 14.6	67.162	140.135	-----	-----	
87-01-16	23 53 20.0	58.59	125.09	23 53 15.1	58.644	125.067	23 53 18.3	58.618	124.947
87-01-19	09 50 36.	74.2	116.80	-----	-----	-----	-----	-----	
87-02-11	00 58 20.8	62.79	156.90	00 58 19.8	62.868	156.909	00 58 19.9	62.826	156.871
*87-02-11	00 58 24.	62.86	156.70	00 58 19.8	62.868	156.909	00 58 19.7	62.860	156.856
87-02-11	01 03 07.7	62.82	156.78	01 03 08.0	62.840	156.867	01 03 07.5	62.836	156.850
*87-02-11	01 09 51.1	62.84	156.76	01 09 50.8	62.859	156.804	01 09 51.5	62.741	156.777
*87-02-11	06 19 15.4	62.84	156.74	06 19 16.3	62.812	156.721	06 19 15.6	62.809	156.847
87-02-11	06 23 02.5	62.86	156.80	-----	-----	-----	-----	-----	
87-02-11	06 23 06.4	62.99	156.34	-----	-----	-----	-----	-----	
*87-02-11	07 28 17.5	62.77	156.78	07 28 17.5	62.851	156.849	07 28 18.6	62.823	156.856
87-02-11	07 29 00.8	62.74	156.64	07 29 06.5	62.656	156.060	07 29 11.9	62.595	155.096
*87-02-11	11 36 16.7	62.81	156.80	11 36 16.1	62.846	156.811	11 36 15.9	62.825	156.814
*87-03-04	00 09 28.2	61.21	148.50	00 09 28.0	61.116	148.472	00 09 28.3	61.128	148.374
87-03-08	06 47 31.4	62.17	143.62	-----	-----	-----	-----	-----	
87-03-16	20 58 53.	64.0	167.20	20 58 53.5	64.106	167.266	20 58 55.7	64.204	167.313
*87-04-13	21 20 11.3	66.12	143.11	21 20 12.8	66.207	143.085	-----	-----	
87-04-15	23 09 22.7	58.52	121.67	23 09 18.3	58.633	121.561	23 09 17.8	58.670	121.649
87-04-22	03 38 21.1	72.24	129.69	03 38 20.0	72.211	129.863	03 38 20.3	72.195	129.668
87-07-03	13 23 10.9	59.50	148.84	13 23 09.0	59.394	148.709	13 23 10.3	59.401	148.827
87-07-05	00 09 01.	61.3	144.60	00 08 55.8	61.316	144.483	00 09 00.3	61.680	144.692
87-07-17	03 43 43.	73.7	118.30	03 43 43.	73.653	118.581	03 43 43.	73.706	118.087
87-07-21	05 02 32.7	58.97	149.75	05 02 33.6	58.942	149.728	05 02 02.6	56.749	149.651
*87-09-09	04 43 23.2	60.15	150.28	04 43 22.8	60.149	150.386	04 43 22.8	60.121	150.454
87-09-27	13 16 36.8	61.20	160.82	13 16 32.0	61.061	161.183	13 16 34.6	61.039	161.273
87-10-06	07 08 43.	73.8	119.00	-----	-----	-----	-----	-----	
87-10-08	06 19 18.	73.9	119.30	-----	-----	-----	06 19 18.0	73.693	118.566
87-11-25	17 28 01.	73.8	118.90	-----	-----	-----	17 28 04.2	73.763	119.695
87-11-26	16 11 20.	73.9	119.20	16 11 35.3	73.202	121.342	16 11 20.0	73.788	118.661
87-11-29	06 15 42.	73.9	119.50	06 16 01.5	72.907	121.943	06 15 42.0	73.730	119.238
87-12-07	10 51 00.0	63.77	145.65	10 50 59.5	63.795	145.669	10 50 59.4	63.716	145.630
87-12-30	12 34 31.8	73.76	118.90	-----	-----	-----	-----	-----	r
88-01-01	14 36 13.	74.6	130.90	14 36 15.8	74.405	131.060	14 36 08.9	74.682	130.977
88-01-01	14 36 09.8	74.65	130.90	14 36 15.8	74.405	131.060	14 36 09.6	74.584	130.687
88-01-13	11 56 31.9	71.45	129.14	11 56 31.5	71.451	128.982	11 56 31.3	71.449	129.227
88-01-19	10 35 32.8	63.76	145.74	10 35 31.6	63.663	145.512	-----	-----	isc
88-01-30	14 19 22.	73.5	117.80	-----	-----	-----	-----	-----	
*88-02-19	00 04 04.8	64.34	148.60	00 04 04.0	64.318	148.521	00 04 04.9	64.335	148.554

Appendix A (continued)

85-02-02	11 28 45.3	65.85	137.05	11 28 44.9	65.834	136.990	-----	-----
85-02-18	12 51 35.	65.6	136.50	12 51 31.3	65.557	136.457	12 51 32.7	65.662 136.653
*85-03-08	22 24 38.0	59.35	151.96	22 24 37.8	59.356	152.162	22 24 34.7	59.119 152.197
85-04-10	11 27 46.6	70.43	141.03	11 27 45.1	70.329	141.424	-----	-----
85-04-12	09 22 16.	62.4	124.10	-----	-----	-----	-----	-----
85-04-17	20 37 21.8	65.36	142.96	20 37 19.8	65.406	142.946	-----	-----
85-04-20	22 29 19.6	59.28	141.72	-----	-----	-----	-----	-----
85-05-22	18 28 48.6	61.02	157.88	18 28 47.3	60.952	157.850	-----	-----
85-06-02	04 08 08.9	64.83	144.08	04 08 08.8	64.857	144.044	04 08 09.9	64.871 144.060
*85-06-02	04 08 12.8	64.8	144.0	04 08 08.8	64.857	144.044	04 08 09.0	64.898 144.249 isc
85-06-24	03 54 35.	65.2	145.00	03 54 34.2	65.286	144.664	-----	-----
85-06-24	03 54 32.4	65.25	144.49	03 54 34.2	65.286	144.664	03 54 34.6	65.205 144.346 t,isc
85-08-20	03 41 37.7	62.14	145.64	03 41 37.9	62.237	145.488	-----	-----
85-08-28	05 04 11.3	59.90	137.36	05 04 09.0	59.956	137.081	-----	-----
85-09-10	10 53 03.3	62.46	142.98	-----	-----	-----	-----	-----
85-10-05	22 32 36.8	59.44	150.23	22 32 36.0	59.465	150.201	22 32 35.8	59.430 150.179
85-10-05	22 37 04.5	59.41	150.26	22 37 00.7	59.299	149.987	-----	-----
85-10-05	22 37 13.6	59.45	150.22	22 37 10.9	59.225	150.192	-----	-----
*85-11-28	08 38 25.	64.9	144.30	08 38 20.5	64.863	144.133	08 38 22.1	64.850 144.422
86-01-05	00 35 23.	70.2	128.40	00 35 23.9	70.276	128.612	-----	-----
*86-01-18	13 13 23.3	60.20	153.67	13 13 22.0	60.191	153.761	13 13 24.8	60.255 153.530
86-01-24	13 25 26.8	60.70	138.49	13 25 23.0	60.616	138.566	-----	-----
86-01-25	21 02 08.7	64.59	147.47	-----	-----	-----	-----	-----
*86-02-15	20 30 27.5	63.97	152.89	20 30 26.3	63.973	153.096	20 30 26.8	64.001 153.038
*86-03-07	23 28 10.0	63.99	153.50	23 28 08.2	64.104	153.511	23 28 07.5	64.106 153.469
86-03-15	04 02 02.	59.9	144.50	-----	-----	-----	-----	-----
86-04-03	15 38 17.6	59.19	154.20	15 38 15.8	59.135	154.478	15 38 13.0	58.975 154.750
*86-04-06	01 27 20.6	70.76	130.31	01 27 20.5	70.755	130.200	01 27 20.1	70.748 130.241
86-04-23	04 29 51.	73.8	114.60	-----	-----	-----	-----	-----
86-05-11	17 29 00.1	62.07	154.10	17 28 58.9	62.034	154.151	17 29 00.2	62.157 154.243
86-06-04	22 43 54.2	61.78	158.92	22 43 53.5	61.871	159.025	-----	-----
86-06-15	06 55 36.8	72.94	126.53	06 55 36.8	72.883	126.515	06 55 34.7	72.946 125.867
86-06-15	06 55 35.8	72.73	126.3	06 55 36.8	72.883	126.515	06 55 33.4	72.630 123.975 isc
86-06-15	06 57 45.3	72.94	126.62	-----	-----	-----	-----	-----
86-07-23	23 28 58.	71.9	128.90	-----	-----	-----	-----	-----
86-07-27	11 25 41.8	64.65	147.09	11 25 40.6	64.634	147.058	11 25 41.3	64.569 147.062
86-07-27	21 08 42.0	61.96	160.96	-----	-----	-----	-----	-----
86-08-10	11 11 59.0	63.74	147.88	11 11 59.8	63.532	147.931	11 12 00.2	63.500 147.731
86-11-09	07 15 36.	75.0	139.40	-----	-----	-----	-----	-----
86-12-05	15 50 12.	74.6	125.00	-----	-----	-----	-----	-----
86-12-08	20 07 24.1	71.32	140.39	-----	-----	-----	-----	-----
86-12-11	00 15 55.	74.0	119.60	-----	-----	-----	-----	-----
86-12-11	01 47 09.	74.0	119.70	-----	-----	-----	-----	-----
86-12-18	18 04 17.2	61.37	143.53	18 04 11.2	61.177	143.634	18 03 58.9	60.361 145.102
*86-12-18	18 04 10.2	61.31	143.7	18 04 11.2	61.177	143.634	18 04 09.3	61.135 143.533 isc
86-12-22	02 18 09.4	73.80	119.77	-----	-----	-----	-----	-----
*86-12-26	03 21 04.9	61.42	149.48	03 21 04.5	61.375	149.426	03 21 03.6	61.403 149.465
87-01-09	04 29 45.0	60.02	153.01	04 29 44.0	59.974	153.039	04 29 32.7	59.262 154.152
87-01-09	13 14 18.6	67.23	140.17	13 14 14.6	67.162	140.135	-----	-----
87-01-16	23 53 20.0	58.59	125.09	23 53 15.1	58.644	125.067	23 53 18.3	58.618 124.947
87-01-19	09 50 36.	74.2	116.80	-----	-----	-----	-----	-----
87-02-11	00 58 20.8	62.79	156.90	00 58 19.8	62.868	156.909	00 58 19.9	62.826 156.871
*87-02-11	00 58 24.	62.88	156.70	00 58 19.8	62.868	156.909	00 58 19.7	62.860 156.856
*87-02-11	01 03 07.7	62.82	156.78	01 03 08.0	62.840	156.867	01 03 07.5	62.836 156.850
*87-02-11	01 09 51.1	62.84	156.76	01 09 50.8	62.859	156.804	01 09 51.5	62.741 156.777
*87-02-11	06 19 15.4	62.84	156.74	06 19 16.3	62.812	156.721	06 19 15.6	62.809 156.847
87-02-11	06 23 02.5	62.86	156.80	-----	-----	-----	-----	-----
87-02-11	06 23 06.4	62.99	156.34	-----	-----	-----	-----	-----
*87-02-11	07 28 17.5	62.77	156.78	07 28 17.5	62.851	156.849	07 28 18.6	62.823 156.856
87-02-11	07 29 00.8	62.74	156.64	07 29 06.5	62.656	156.060	07 29 11.9	62.595 155.096
*87-02-11	11 36 16.7	62.81	156.80	11 36 16.1	62.846	156.811	11 36 15.9	62.825 156.814
*87-03-04	00 09 28.2	61.21	148.50	00 09 28.0	61.116	148.472	00 09 28.3	61.128 148.374
87-03-08	06 47 31.4	62.17	143.62	-----	-----	-----	-----	-----
87-03-16	20 58 53.	64.0	167.20	20 58 53.5	64.106	167.266	20 58 55.7	64.204 167.313
*87-04-13	21 20 11.3	66.12	143.11	21 20 12.8	66.207	143.085	-----	-----
87-04-15	23 09 22.7	58.52	121.67	23 09 18.3	58.633	121.561	23 09 17.8	58.670 121.649
87-04-22	03 38 21.1	72.24	129.69	03 38 20.0	72.211	129.863	03 38 20.3	72.195 129.668
87-07-03	13 23 10.9	59.50	148.84	13 23 09.0	59.394	148.709	13 23 10.3	59.401 148.827
87-07-05	00 09 01.	61.3	144.60	00 08 55.8	61.316	144.483	00 09 00.3	61.680 144.692
87-07-17	03 43 43.	73.7	118.30	03 43 43.	73.653	118.581	03 43 43.	73.706 118.087
87-07-21	05 02 32.7	58.97	149.75	05 02 33.6	58.942	149.728	05 02 02.6	56.749 149.651
*87-09-09	04 43 23.2	60.15	150.28	04 43 22.8	60.149	150.386	04 43 22.8	60.121 150.454
87-09-27	13 16 36.8	61.20	160.82	13 16 32.0	61.061	161.183	13 16 34.6	61.039 161.273
87-10-06	07 08 43.	73.8	119.00	-----	-----	-----	-----	-----
87-10-08	06 19 18.	73.9	119.30	-----	-----	-----	06 19 18.0	73.693 118.566
87-11-25	17 28 01.	73.8	118.90	-----	-----	-----	17 28 04.2	73.763 119.695 o
87-11-26	16 11 20.	73.9	119.20	16 11 35.3	73.202	121.342	16 11 20.0	73.788 118.661
87-11-29	06 15 42.	73.9	119.50	06 16 01.5	72.907	121.943	06 15 42.0	73.730 119.238 p
87-12-07	10 51 00.0	63.77	145.65	10 50 59.5	63.795	145.669	10 50 59.4	63.716 145.630 r
87-12-30	12 34 31.8	73.76	118.90	-----	-----	-----	-----	-----
88-01-01	14 36 13.	74.6	130.90	14 36 15.8	74.405	131.060	14 36 08.9	74.682 130.977
88-01-01	14 36 09.8	74.65	130.90	14 36 15.8	74.405	131.060	14 36 09.6	74.584 130.687 isc
88-01-13	11 56 31.9	71.45	129.14	11 56 31.5	71.451	128.982	11 56 31.3	71.449 129.227
88-01-19	10 35 32.8	63.76	145.74	10 35 31.6	63.663	145.512	-----	-----
88-01-30	14 19 22.	73.5	117.80	-----	-----	-----	-----	-----
*88-02-19	00 04 04.8	64.34	148.60	00 04 04.0	64.318	148.521	00 04 04.9	64.335 148.554

Appendix A (continued)

85-02-02	11 28 45.3	65.85	137.05	11 28 44.9	65.834	136.990	-----	-----
85-02-18	12 51 35.	65.6	136.50	12 51 31.3	65.557	136.457	12 51 32.7	65.662 136.653
*85-03-08	22 24 38.0	59.35	151.96	22 24 37.8	59.356	152.162	22 24 34.7	59.119 152.197
85-04-10	11 27 46.6	70.43	141.03	11 27 45.1	70.329	141.424	-----	-----
85-04-12	09 22 16.	62.4	124.10	-----	-----	-----	-----	-----
85-04-17	20 37 21.8	65.36	142.96	20 37 19.8	65.406	142.946	-----	-----
85-04-20	22 29 19.6	59.28	141.72	-----	-----	-----	-----	-----
85-05-22	18 28 48.6	61.02	157.88	18 28 47.3	60.952	157.850	-----	-----
85-06-02	04 08 08.9	64.83	144.08	04 08 08.8	64.857	144.044	04 08 09.9	64.871 144.060
*85-06-02	04 08 12.8	64.8	144.0	04 08 08.8	64.857	144.044	04 08 09.0	64.898 144.249 isc
85-06-24	03 54 35.	65.2	145.00	03 54 34.2	65.286	144.664	-----	-----
85-06-24	03 54 32.4	65.25	144.49	03 54 34.2	65.286	144.664	03 54 34.6	65.205 144.346 t,isc
85-08-20	03 41 37.7	62.14	145.64	03 41 37.9	62.237	145.488	-----	-----
85-08-28	05 04 11.3	59.90	137.36	05 04 09.0	59.956	137.081	-----	-----
85-09-10	10 53 03.3	62.46	142.98	-----	-----	-----	-----	-----
85-10-05	22 32 36.8	59.44	150.23	22 32 36.0	59.465	150.201	22 32 35.8	59.430 150.179
85-10-05	22 37 04.5	59.41	150.26	22 37 00.7	59.299	149.987	-----	-----
85-10-05	22 37 13.6	59.45	150.22	22 37 10.9	59.225	150.192	-----	-----
*85-11-28	08 38 25.	64.9	144.30	08 38 20.5	64.863	144.133	08 38 22.1	64.850 144.422
86-01-05	00 35 23.	70.2	128.40	00 35 23.9	70.276	128.612	-----	-----
*86-01-18	13 13 23.3	60.20	153.67	13 13 22.0	60.191	153.761	13 13 24.8	60.255 153.530
86-01-24	13 25 26.8	60.70	138.49	13 25 23.0	60.616	138.566	-----	-----
86-01-25	21 02 08.7	64.59	147.47	-----	-----	-----	-----	-----
*86-02-15	20 30 27.5	63.97	152.89	20 30 26.3	63.973	153.096	20 30 26.8	64.001 153.038
*86-03-07	23 28 10.0	63.99	153.50	23 28 08.2	64.104	153.511	23 28 07.5	64.106 153.469
86-03-15	04 02 02.	59.9	144.50	-----	-----	-----	-----	-----
86-04-03	15 38 17.6	59.19	154.20	15 38 15.8	59.135	154.478	15 38 13.0	58.975 154.750
*86-04-06	01 27 20.6	70.76	130.31	01 27 20.5	70.755	130.200	01 27 20.1	70.748 130.241
86-04-23	04 29 51.	73.8	114.60	-----	-----	-----	-----	-----
86-05-11	17 29 00.1	62.07	154.10	17 28 58.9	62.034	154.151	17 29 00.2	62.157 154.243
86-06-04	22 43 54.2	61.78	158.92	22 43 53.5	61.871	159.025	-----	-----
86-06-15	06 55 36.8	72.94	126.53	06 55 36.8	72.883	126.515	06 55 34.7	72.946 125.867
86-06-15	06 55 35.8	72.73	126.3	06 55 36.8	72.883	126.515	06 55 33.4	72.630 123.975 isc
86-06-15	06 57 45.3	72.94	126.62	-----	-----	-----	-----	-----
86-07-23	23 28 58.	71.9	128.90	-----	-----	-----	-----	-----
86-07-27	11 25 41.8	64.65	147.09	11 25 40.6	64.634	147.058	11 25 41.3	64.569 147.062
86-07-27	21 08 42.0	61.96	160.96	-----	-----	-----	-----	-----
86-08-10	11 11 59.0	63.74	147.88	11 11 59.8	63.532	147.931	11 12 00.2	63.500 147.731
86-11-09	07 15 36.	75.0	139.40	-----	-----	-----	-----	-----
86-12-05	15 50 12.	74.6	125.00	-----	-----	-----	-----	-----
86-12-08	20 07 24.1	71.32	140.39	-----	-----	-----	-----	-----
86-12-11	00 15 55.	74.0	119.60	-----	-----	-----	-----	-----
86-12-11	01 47 09.	74.0	119.70	-----	-----	-----	-----	-----
86-12-18	18 04 17.2	61.37	143.53	18 04 11.2	61.177	143.634	18 03 58.9	60.361 145.102
*86-12-18	18 04 10.2	61.31	143.7	18 04 11.2	61.177	143.634	18 04 09.3	61.135 143.533 isc
86-12-22	02 18 09.4	73.80	119.77	-----	-----	-----	-----	-----
*86-12-26	03 21 04.9	61.42	149.48	03 21 04.5	61.375	149.426	03 21 03.6	61.403 149.465
87-01-09	04 29 45.0	60.02	153.01	04 29 44.0	59.974	153.039	04 29 32.7	59.262 154.152
87-01-09	13 14 18.6	67.23	140.17	13 14 14.6	67.162	140.135	-----	-----
87-01-16	23 53 20.0	58.59	125.09	23 53 15.1	58.644	125.067	23 53 18.3	58.618 124.947
87-01-19	09 50 36.	74.2	116.80	-----	-----	-----	-----	-----
87-02-11	00 58 20.8	62.79	156.90	00 58 19.8	62.868	156.909	00 58 19.9	62.826 156.871
*87-02-11	00 58 24.	62.88	156.70	00 58 19.8	62.868	156.909	00 58 19.7	62.860 156.856 isc
87-02-11	01 03 07.7	62.82	156.78	01 03 08.0	62.840	156.867	01 03 07.5	62.836 156.850
*87-02-11	01 09 51.1	62.84	156.76	01 09 50.8	62.859	156.804	01 09 51.5	62.741 156.777
*87-02-11	06 19 15.4	62.84	156.74	06 19 16.3	62.812	156.721	06 19 15.6	62.809 156.847
87-02-11	06 23 02.5	62.86	156.80	-----	-----	-----	-----	-----
87-02-11	06 23 06.4	62.99	156.34	-----	-----	-----	-----	-----
*87-02-11	07 28 17.5	62.77	156.78	07 28 17.5	62.851	156.849	07 28 18.6	62.823 156.856
87-02-11	07 29 00.8	62.74	156.64	07 29 06.5	62.656	156.060	07 29 11.9	62.595 155.096
*87-02-11	11 36 16.7	62.81	156.80	11 36 16.1	62.846	156.811	11 36 15.9	62.825 156.814
*87-03-04	00 09 28.2	61.21	148.50	00 09 28.0	61.116	148.472	00 09 28.3	61.128 148.374
87-03-08	06 47 31.4	62.17	143.62	-----	-----	-----	-----	-----
87-03-16	20 58 53.	64.0	167.20	20 58 53.5	64.106	167.266	20 58 55.7	64.204 167.313
*87-04-13	21 20 11.3	66.12	143.11	21 20 12.8	66.207	143.085	-----	-----
87-04-15	23 09 22.7	58.52	121.67	23 09 18.3	58.633	121.561	23 09 17.8	58.670 121.649
87-04-22	03 38 21.1	72.24	129.69	03 38 20.0	72.211	129.863	03 38 20.3	72.195 129.668
87-07-03	13 23 10.9	59.50	148.84	13 23 09.0	59.394	148.709	13 23 10.3	59.401 148.827
87-07-05	00 09 01.	61.3	144.60	00 08 55.8	61.316	144.483	00 09 00.3	61.680 144.692
87-07-17	03 43 43.	73.7	118.30	03 43 43.	73.653	118.581	03 43 43.	73.706 118.087
87-07-21	05 02 32.7	58.97	149.75	05 02 33.6	58.942	149.728	05 02 02.6	56.749 149.651
*87-09-09	04 43 23.2	60.15	150.28	04 43 22.8	60.149	150.386	04 43 22.8	60.121 150.454
87-09-27	13 16 36.8	61.20	160.82	13 16 32.0	61.061	161.183	13 16 34.6	61.039 161.273
87-10-06	07 08 43.	73.8	119.00	-----	-----	-----	-----	-----
87-10-08	06 19 18.	73.9	119.30	-----	-----	-----	06 19 18.0	73.693 118.566
87-11-25	17 28 01.	73.8	118.90	-----	-----	-----	17 28 04.2	73.763 119.695 o
87-11-26	16 11 20.	73.9	119.20	16 11 35.3	73.202	121.342	16 11 20.0	73.788 118.661
87-11-29	06 15 42.	73.9	119.50	06 16 01.5	72.907	121.943	06 15 42.0	73.730 119.238 p
87-12-07	10 51 00.0	63.77	145.65	10 50 59.5	63.795	145.669	10 50 59.4	63.716 145.630 r
87-12-30	12 34 31.8	73.76	118.90	-----	-----	-----	-----	-----
88-01-01	14 36 13.	74.6	130.90	14 36 15.8	74.405	131.060	14 36 08.9	74.682 130.977
88-01-01	14 36 09.8	74.65	130.90	14 36 15.8	74.405	131.060	14 36 09.6	74.584 130.687 isc
88-01-13	11 56 31.9	71.45	129.14	11 56 31.5	71.451	128.982	11 56 31.3	71.449 129.227
88-01-19	10 35 32.8	63.76	145.74	10 35 31.6	63.663	145.512	-----	-----
88-01-30	14 19 22.	73.5	117.80	-----	-----	-----	-----	-----
*88-02-19	00 04 04.8	64.34	148.60	00 04 04.0	64.318	148.521	00 04 04.9	64.335 148.554

88-02-19	23	50	25.8	64.20	145.79	23	50	24.9	64.171	145.827	23	50	25.5	64.187	145.853	
*88-04-03	02	01	29.8	69.47	138.79	02	01	28.6	69.428	138.694	02	01	27.7	69.477	138.476	
88-04-03	03	52	30.8	69.47	138.67	03	52	29.1	69.502	138.654						
88-04-05	18	25	57.	75.1	130.70											
88-04-05	18	25	41.9	76.7	129.6						18	25	36.5	76.567	127.948	isc
*88-05-25	16	55	45.3	64.19	150.96	16	55	43.7	64.209	150.934	16	55	44.4	64.161	151.000	j
88-06-01	08	29	54.4	61.96	161.14											
*88-06-09	13	37	32.2	63.29	157.54	13	37	32.9	63.266	157.627	13	37	33.5	63.309	157.545	
*88-06-14	14	44	43.6	63.33	149.55	14	44	44.1	63.356	149.579	14	44	44.0	63.393	149.380	
88-06-29	19	04	28.	75.0	132.50											
88-07-01	21	37	35.1	64.83	145.85	21	37	34.8	64.880	145.689						
88-09-22	23	58	14.8	61.83	160.00	22	58	14.5	61.934	160.047						
*88-10-17	00	27	59.3	62.82	148.84	00	27	59.2	62.824	148.904	00	27	59.2	62.869	148.799	
88-10-25	10	12	51.6	62.98	148.90	10	12	52.4	62.891	148.867	10	12	48.7	63.197	148.772	
88-12-24	02	43	22.3	63.90	149.04	02	43	23.1	64.006	148.913	02	43	22.2	64.064	148.900	
88-12-30	07	16	42.5	61.11	153.65	07	16	43.0	61.118	153.705	07	16	42.7	61.207	153.969	
89-01-05	17	52	13.	72.6	140.60	17	52	05.7	72.824	141.324						
89-01-14	04	53	41.	61.9	143.80	04	53	36.9	61.946	143.800	04	53	39.3	62.097	144.025	
89-01-15	17	17	32.1	58.90	151.27	17	17	18.0	57.964	150.965	17	17	30.0	58.591	151.226	
*89-01-29	23	23	03.8	62.91	144.88	23	23	01.6	62.825	144.936	23	23	02.0	62.872	144.862	
89-02-17	19	10	16.4	69.79	129.31	19	10	15.6	69.830	129.137	19	10	13.9	69.703	129.095	
89-02-25	04	56	16.1	61.72	157.66	04	56	16.6	61.715	157.701						
89-03-01	17	09	01.	73.8	117.00											
*89-03-21	10	53	07.0	65.15	145.13	10	53	05.1	64.920	145.199						
89-04-09	04	16	25.	59.9	145.30	04	16	23.	59.774	145.194	04	16	22.7	59.863	145.095	
*89-04-09	04	16	27.4	59.92	145.23	04	16	23.	59.774	145.194	04	16	22.7	59.879	145.041	isc
89-04-24	04	45	39.9	59.09	151.86	04	45	36.4	58.904	151.856	04	45	29.4	58.275	151.818	
89-05-19	19	29	22.8	62.30	155.20	19	29	23.7	62.411	155.229	19	29	24.5	62.483	155.234	
89-05-24	09	38	00.6	61.33	144.70	09	37	58.8	61.217	144.406	09	38	01.5	61.368	144.408	
*89-06-16	07	36	09.4	63.59	142.79	07	36	08.5	63.564	142.778	07	36	08.9	63.609	142.778	m,n
89-06-16	19	40	46.2	61.13	145.72	19	40	45.7	61.020	145.457						
89-06-30	19	59	59.5	59.25	152.60	20	00	01.3	59.350	152.686	20	00	01.5	59.302	152.657	r
89-07-02	23	58	50.1	59.65	150.14	23	58	48.6	59.578	150.119	22	58	48.6	59.587	149.929	
*89-07-07	10	51	46.3	64.97	141.78	10	51	43.1	64.991	141.596	10	51	42.8	64.999	141.623	
*89-07-09	18	11	48.9	59.96	152.62	18	11	49.0	59.924	152.716	18	11	49.0	59.859	152.780	
89-07-25	02	02	38.4	62.89	159.21	02	02	39.5	62.915	159.171						
89-08-05	06	56	07.	75.4	133.40	06	56	03.2	75.090	133.045	06	55	54.7	75.723	134.098	
89-08-05	06	55	50.	76.11	134.54	06	56	03.2	75.090	133.045	06	55	50.8	75.999	133.914	isc
89-08-05	10	49	34.	75.3	131.80	10	49	35.2	75.018	132.375	10	49	37.8	74.997	132.123	
89-08-05	10	49	23.1	76.16	134.4	10	49	35.2	75.018	132.375	10	49	22.2	76.171	133.374	isc
89-08-05	17	56	15.	75.9	130.10	17	56	20.8	75.315	130.353						
89-08-08	05	40	41.	74.8	117.10											
89-09-04	23	20	25.4	60.90	148.92	23	20	25.5	60.869	148.893	23	20	26.4	60.839	148.771	
89-09-26	00	18	51.	75.8	130.60											
89-09-26	00	18	50.1	76.17	134.4						00	18	48.8	76.137	132.907	isc
*89-10-04	20	56	49.5	64.79	146.86	20	56	47.2	64.709	146.818	20	56	47.3	64.696	146.926	
89-11-13	18	15	43.1	62.34	143.59	18	15	40.6	62.279	143.569	18	15	40.1	62.364	143.441	
89-12-14	19	16	12.	74.2	145.60	19	16	10.6	73.985	146.036						
89-12-18	21	00	40.	74.7	141.60	21	00	42.7	74.344	141.495						
89-12-22	12	46	37.2	65.48	136.74	12	46	34.3	65.499	136.828	12	46	34.9	65.504	136.845	
90-03-02	21	30	34.	73.8	115.90	21	30	23.1	73.934	113.609						
90-03-06	07	18	10.	67.0	125.40	07	18	01.7	66.916	124.749						
90-03-13	00	33	07.	73.2	133.90	00	33	05.5	73.173	134.461	00	33	00.0	73.277	134.528	
90-03-13	00	32	59.0	73.33	134.90	00	33	05.5	73.173	134.461	00	32	59.0	73.311	134.712	isc
90-03-14	01	12	24.	73.5	133.60	01	12	22.7	73.356	134.217	01	12	22.4	73.323	134.392	
90-03-21	04	31	28.	73.5	133.80	04	31	30.2	73.071	133.596	04	31	20.5	73.432	134.460	
*90-03-29	20	47	30.8	64.10	145.00	20	47	29.7	64.010	145.044	20	47	29.3	63.962	144.842	
90-04-02	15	32	47.1	62.01	138.12	15	32	44.3	61.969	137.944	15	32	46.2	62.139	138.066	
90-04-11	16	09	42.4	61.95	154.28	16	09	43.2	61.964	154.280						
90-05-05	02	44	16.3	61.30	153.99	02	44	17.4	61.321	153.953						
*90-05-30	11	56	46.5	62.93	144.90	11	56	45.1	62.915	144.806	11	56	47.0	62.953	144.919	
90-06-09	18	24	29.	75.5	113.40						18	24	10.7	75.981	108.939	
*90-06-25	07	33	57.	66.8	130.80	07	33	51.7	66.827	130.342	07	33	52.5	66.807	130.326	
90-06-28	22	04	00.	75.1	132.00	22	03	57.0	75.300	132.311	22	03	47.7	75.978	134.266	
90-06-28	22	03	47.8	76.2	134.10	22	03	57.0	75.299	132.311	22	03	46.8	76.007	134.266	isc
90-07-06	16	09	10.0	67.17	144.67	16	09	07.5	67.194	144.699	16	09	10.3	67.232	144.664	
90-07-11	09	44	31.	65.5	125.30											
*90-07-12	02	22	49.6	62.06	153.78	02	22	50.5	62.057	153.827	02	22	50.8	62.073	153.845	
90-07-24	15	17	22.0	60.2	142.80	15	17	20.3	60.332	142.664	15	17	16.4	59.888	142.081	
*90-08-24	01	04	43.9	63.01	151.20	01	04	44.6	63.032	151.219	01	04	44.7	62.993	151.201	
90-09-11	00	52	54.	74.4	116.50	00	52	50.8	74.465	115.860						
*90-11-01	13	42	05.5	61.28	156.79	13	42	06.1	61.309	156.763	13	42	06.2	61.321	156.935	
90-11-02	06	16	00.2	61.28	156.96	06	16	00.9	61.244	157.005						
*90-11-02	21	54	04.5	64.81	146.66	21	54	03.2	64.733	146.620	21	54	03.7	64.803	146.725	i
90-11-02	21	54	06.0	65.01	146.97	21	54	03.2	64.733	146.620	21	54	03.9	64.813	146.755	i,isc
90-11-21	01	12	19.7	59.84	153.44	01	12	19.5	59.929	153.414	01	12	18.8	59.764	153.604	
90-11-21	04	04	05.	61.6	142.90	04	04	05.7	61.836	142.953						
*90-11-22	19	36	24.8	62.73	156.72	19	36	25.1	62.767	156.743	19	36	25.7	62.773	156.835	
90-12-08	08	23	29.9	59.49	152.44	08	23	30.6	59.429	152.484						
*90-12-13	21	34	41.7	64.41	140.63	21	34	39.1	64.433	140.518	21	34	40.5	64.501	140.457	
*91-02-10	18	16	32.9	62.99	145.55	18	16	32.3	62.950	145.634	18	16	31.7	62.904	145.461	a
91-02-11	10	58	27.1	72.60	125.16	10	58	26.0	72.577	125.222	10	58	25.1	72.689	125.233	a
91-03-01	01	57	05.4	72.22	126.81	01	57	04.1	72.173	126.820	01	57	05.0	72.277	127.287	a,o
*91-03-01	01	57	06.	72.15	126.85	01	57	04.1	72.173	126.820	01	57	05.0	72.242	127.173	a,o
																isc
91-03-30	17	06	25.5	66.64	126.33	17	06	24.0	66.845	126.251						

Appendix A (continued)

91-04-01	07 21 57.9	71.38	130.00	07 21 57.2	71.401	130.094	-----	-----	a
91-05-02	07 18 07.7	73.02	121.43	-----	-----	-----	-----	-----	a
*91-07-02	13 43 48.7	65.18	139.84	13 43 45.0	65.174	139.816	-----	-----	a
91-07-24	02 26 04.7	62.23	143.68	-----	-----	-----	02 26 01.5	62.044	143.883 a
*91-07-31	01 44 02.5	72.06	127.56	01 44 02.7	71.980	127.221	01 44 02.6	72.132	127.810 a
91-08-04	19 08 08.3	65.47	143.32	19 08 05.9	65.495	143.127	19 08 06.7	65.460	143.199 a
*91-08-04	19 08 07.	65.5	142.9	10 08 05.9	65.495	143.127	19 08 07.1	65.449	143.120 a,isc
*91-08-04	19 14 41.6	65.47	143.33	19 14 40.6	65.498	143.220	19 14 39.7	65.516	142.890 a
91-08-25	13 51 02.3	70.73	140.90	-----	-----	-----	-----	-----	a
*91-08-26	09 35 48.9	63.18	146.00	09 35 49.0	63.390	146.359	09 35 50.0	63.464	146.522 a
91-10-13	00 36 37.3	61.09	144.93	00 36 33.4	61.112	144.907	00 36 26.5	60.746	145.318 a
91-10-28	21 41 31.4	65.18	131.64	-----	-----	-----	-----	-----	a
91-12-23	06 04 17.9	62.41	140.89	06 04 16.0	62.454	140.848	06 04 17.0	62.854	140.570 a
*92-01-22	06 29 19.4	65.86	143.38	06 29 16.1	65.852	143.180	06 29 17.0	65.870	143.087 a
92-01-22	06 29 17.1	65.8	143.0	06 29 16.1	65.852	143.180	06 29 16.5	65.863	143.124 a,isc
92-01-28	00 07 28.5	68.16	133.12	00 07 29.6	68.302	133.967	00 07 23.6	68.211	132.319 a
*92-02-12	17 14 57.	64.8	152.90	17 14 51.2	64.972	153.224	17 14 52.1	64.908	153.172 a
92-02-15	04 52 10.	75.9	124.20	04 52 36.7	74.227	124.354	04 51 59.5	76.142	124.780 a
92-02-15	04 52 05.1	75.95	125.1	04 52 36.7	74.227	124.354	04 52 04.2	75.800	125.159 a,isc
92-02-22	17 55 21.4	70.14	139.38	17 55 20.9	70.091	139.399	17 55 21.7	70.133	139.589 a
92-02-23	08 21 42.3	70.06	139.45	08 21 41.2	70.031	139.378	08 21 41.4	70.065	139.498 a
92-05-07	23 22 56.5	63.63	133.53	-----	-----	-----	23 22 54.9	63.848	133.988 a
*92-06-28	23 53 20.6	63.79	145.10	23 53 17.4	63.704	145.682	23 53 18.1	63.739	145.720 a
92-08-26	11 02 17.4	71.76	133.14	11 02 16.7	71.572	133.208	11 02 17.8	71.832	133.410 a
92-09-09	00 14 37.3	71.26	132.07	-----	-----	-----	-----	-----	a
92-09-13	21 43 00.4	62.00	154.13	-----	-----	-----	21 42 58.9	62.110	153.715 a,isc
92-10-30	14 20 31.3	72.72	123.83	-----	-----	-----	14 20 30.2	72.698	123.682 a
92-11-14	20 43 15.8	72.96	123.24	20 43 15.0	72.997	123.442	20 43 14.9	72.976	123.300 a
*92-11-17	07 55 18.	67.2	128.80	07 55 13.8	67.258	128.590	07 55 14.8	67.384	128.597 a
93-02-21	17 06 31.3	65.88	149.53	17 06 18.2	65.993	150.971	-----	-----	a
93-02-24	17 45 26.3	69.54	129.00	17 45 24.6	69.582	128.736	17 45 27.0	69.633	128.905 a
93-03-05	01 43 44.7	63.00	145.00	01 43 43.9	63.005	145.527	01 43 43.7	62.972	145.679 a
*93-03-05	04 21 05.2	63.78	145.67	04 21 05.1	63.793	145.408	04 21 04.8	63.747	145.452 a
93-03-13	03 26 30.5	63.74	142.47	03 26 28.3	63.791	142.337	-----	-----	a
*93-03-22	18 14 05.9	62.91	145.67	18 14 06.8	63.041	145.315	18 14 07.4	63.087	145.327 a
*93-03-24	16 19 08.5	65.34	142.69	16 18 05.9	65.341	142.609	16 19 06.5	65.492	142.633 a
93-03-24	22 43 32.4	71.58	129.76	22 43 30.3	71.541	130.109	22 43 28.5	71.820	130.369 a
93-04-29	12 21 32.5	69.30	139.68	12 21 30.7	69.161	140.013	12 21 30.9	69.160	139.878 a
93-05-04	20 49 03.8	75.71	132.73	20 49 14.8	74.832	132.134	20 48 50.0	76.999	131.502 a
93-05-19	08 32 12.5	58.14	140.77	-----	-----	-----	08 32 15.3	58.313	139.867 a
93-06-15	11 51 15.4	62.23	141.70	11 51 12.9	62.287	141.543	11 51 14.9	62.290	141.492 a
93-06-18	19 16 17.6	62.08	146.30	19 16 14.4	62.051	146.166	19 16 14.2	62.109	146.255 a
*93-08-30	07 56 37.9	64.16	145.80	07 56 34.9	64.006	145.881	07 56 34.5	64.020	145.905 a
93-09-26	10 58 27.7	59.81	144.95	-----	-----	-----	-----	-----	a
93-10-02	04 04 06.	73.1	116.50	-----	-----	-----	-----	-----	a

isc Earthquake parameters determined with supplemental information from *Bulletin of the international Seismological Center*. Bulletin origin time and epicenter also from *BIS*.

- a Phase data and parameters from B. Koz'min, Yakutsk Science Institute.
- b For stations Omsukchan and Seimchan, PG arrivals are misidentified in Bulletin as PN arrivals.
- c For stations Stekolnyi, Evensk, Ust' Nera, and Yakutsk, PN arrivals are misidentified in bulletin as PG. Station Seimchan PG arrival misidentified in bulletin as PN.
- d For station Omsukchan, PN arrival is misidentified in bulletin as PG.
- e For station Seimchan, PN arrival is misidentified in bulletin as PG.
- f For station Ust' Nera, PN arrival is misidentified in bulletin as PG.
- g For station Stekolnyi, PG arrival is misidentified in bulletin as PN.
- h For station Zyryanka, PG arrival is misidentified in bulletin as PN.
- i Station Tenkeli is misidentified in *Materialy* as station Tungurcha. This is likely due to nearly identical appearing russian codes.
- j For station Nezhdaninskoe, PN arrival is misidentified in bulletin as PG.
- k For station Magadan, PN arrival is misidentified in bulletin as PG.
- l For station Ust' Omchug, PN arrival is misidentified in bulletin as PG.
- m For station Moma, PN arrival is misidentified in bulletin as PG.
- n For station Khandyga, PN arrival is misidentified in bulletin as PG.
- o For station Yubileinaya, PN arrival is misidentified in bulletin as PG.
- p For station Naiba, PN arrival is misidentified in bulletin as PG.
- q For station Magadan, PG arrival is misidentified in bulletin as PN.
- r For station Nel' Koba, PN arrival is misidentified in bulletin as PG.

Appendix A (continued)

- s Station Ust' Nera misidentified in *Materialy* as station Ust'Nyukzha. This is likely due to nearly identical appearing russian codes.
- t For station Omolon, PN arrival is misidentified in bulletin as PG.

APPENDIX B

Seismic station coordinates from the Yakut and Magadan networks. Stations outside the study area but listed here were used in earthquake locations.

APPENDIX B

Station Name	Code	Elevation (m)	Latitude (N)	Longitude (+E,-W)	Region
Anadyr	ANY	55	64.734	177.496	Magadan
Artyk	AYK	700	64.181	145.133	Yakut
Batagai	BTG	120	67.650	134.625	Yakut
Bilibino	BIL	283	68.058	166.449	Magadan
Chagda	CGD	180	58.750	130.617	Yakut
Cherskii	CES	40	68.750	161.333	Yakut
Chul'man	CLN	600	56.867	124.900	Yakut
Debin	DBI	332	62.339	150.750	Magadan
Dunai	DUY	5	73.900	124.608	Yakut
Egvekinot	EGV	18	66.323	-179.127	Magadan
Evensk	EVE	21	61.921	159.231	Magadan
Iul'tin	ILT	245	67.875	-178.733	Magadan
Khandyga	KHG	125	62.650	135.557	Yakut
Khani	KHN	---	57.017	121.000	Yakut
Khatystyr	KHY	400	55.680	121.520	Yakut
Kulu	KU-	655	61.892	147.427	Magadan
Kyusyr	KYU	20	70.683	127.367	Yakut
Magadan	MAG	78	59.560	150.803	Magadan
Maiskii	MKI	261	68.975	173.700	Magadan
Markovo	MKN	25	64.684	170.412	Magadan
Moma (Khonu)	MKU	192	66.466	143.216	Yakut
Myakit	MYA	660	61.417	152.083	Magadan
Naiba	NAY	5	70.850	130.733	Yakut
Nelkoba	NKB	531	61.336	148.808	Magadan
Neryungri	NYG	700	56.675	124.650	Yakut
Nezhdaninskoe	NZD	603	62.497	139.058	Yakut
Omolon	OMO	260	65.232	160.535	Magadan
Omsukchan	OMS	527	62.515	155.774	Magadan
Provideniya	PVD	25	64.427	-173.225	Magadan
Saidy	SAY	88	68.700	134.450	Yakut
Sasyr	SSY	580	65.158	147.075	Yakut
Seimchan	SEY	206	62.933	152.382	Magadan
Sinegor'e	SNE	420	62.037	150.523	Magadan
Stekolnyi	MGD	221	60.046	150.730	Magadan
Stolb	SOT	50	72.400	126.825	Yakut
Susuman	SUU	640	62.781	148.149	Magadan
Tabalakh	TBK	200	67.539	136.522	Yakut

Appendix B (Continued)

Taimylyr	TML	60	72.610	121.917	Yakut
Takhtoyamsk	TTY	11	60.202	154.678	Magadan
Talaya	TLA	730	61.129	152.392	Magadan
Tenkeli	TLI	110	70.183	140.783	Yakut
Tiksi	TIK	30	71.632	128.872	Yakut
Tungurcha	TUG	300	57.317	121.500	Yakut
Ust'Nera	UNR	485	64.569	143.228	Yakut
Ust'Nyukzha	USZ	400	56.561	121.592	Yakut
Ust'Omchug	USO	550	61.133	149.631	Magadan
Ust'Urkima	UUR	600	55.300	123.267	Yakut
Yakutsk	YAK	94	62.015	129.678	Yakut
Zyryanka	ZYR	120	65.717	149.817	Yakut

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