UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TECHNICAL LETTER NUMBER 30

CALCULATION OF UPPER-MANTLE VELOCITY FROM PUBLISHED SOVIET EARTHQUAKE DATA*

by

Robert G. Rodriguez**

DENVER, COLORADO

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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Technical Letter
Crustal Studies-30
April 15, 1965

Mr. Donald Clements
VELA UNIFORM Branch
Advanced Research Projects Agency
Department of Defense
Pentagon
Washington 25, D. C.

Dear Mr. Clements:

Transmitted herewith are 10 copies of:

TECHNICAL LETTER NUMBER 30

CALCULATION OF UPPER-MANTLE VELOCITY FROM

PUBLISHED SOVIET EARTHQUAKE DATA*

by

Robert G. Rodriguez**

Sincerely,

John H Healy

J. H. Healy, Chief
Branch of Crustal Studies

* Work performed under ARPA Order No. 193-64.
** U. S. Geological Survey, Denver, Colorado.

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ABSTRACT

The lack of information on mantle velocities and crustal structure of the U.S.S.R. has led to a preliminary examination of published Soviet earthquake bulletins in the hope of deriving useful velocity and structure information from the data they contain. Mantle velocities deduced from earthquake data on several Russian earthquakes are in excellent agreement with results of Soviet deep seismic sounding.

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INTRODUCTION

The possibility of determining seismic-wave velocities and crustal structure in the Soviet Union by an analysis of published earthquake data is worthy of investigation because information concerning crustal structure and the velocity of seismic waves within the crust and upper mantle is not available for large areas of the U.S.S.R. A preliminary investigation using published Soviet earthquake bulletins as a data source has yielded interesting results.

The government of the Soviet Union maintains and operates a net of about 100 seismic observatories. The highest station density is along the southern border of Russia in the regions of greatest seismic activity; namely, in the mountainous areas of central Asia encompassing the Russian states north of and adjacent to Iran, Afghanistan, and western Sinkiang, and, to the west, in the region of the Caucasus between the Black Sea and the Caspian Sea. Much of the Soviet effort in probing the crust of the earth by deep seismic sounding has been expended in the central Asian region, permitting a comparison of the results derived from processing the published earthquake data with those deduced from deep seismic sounding (Fig. 1).

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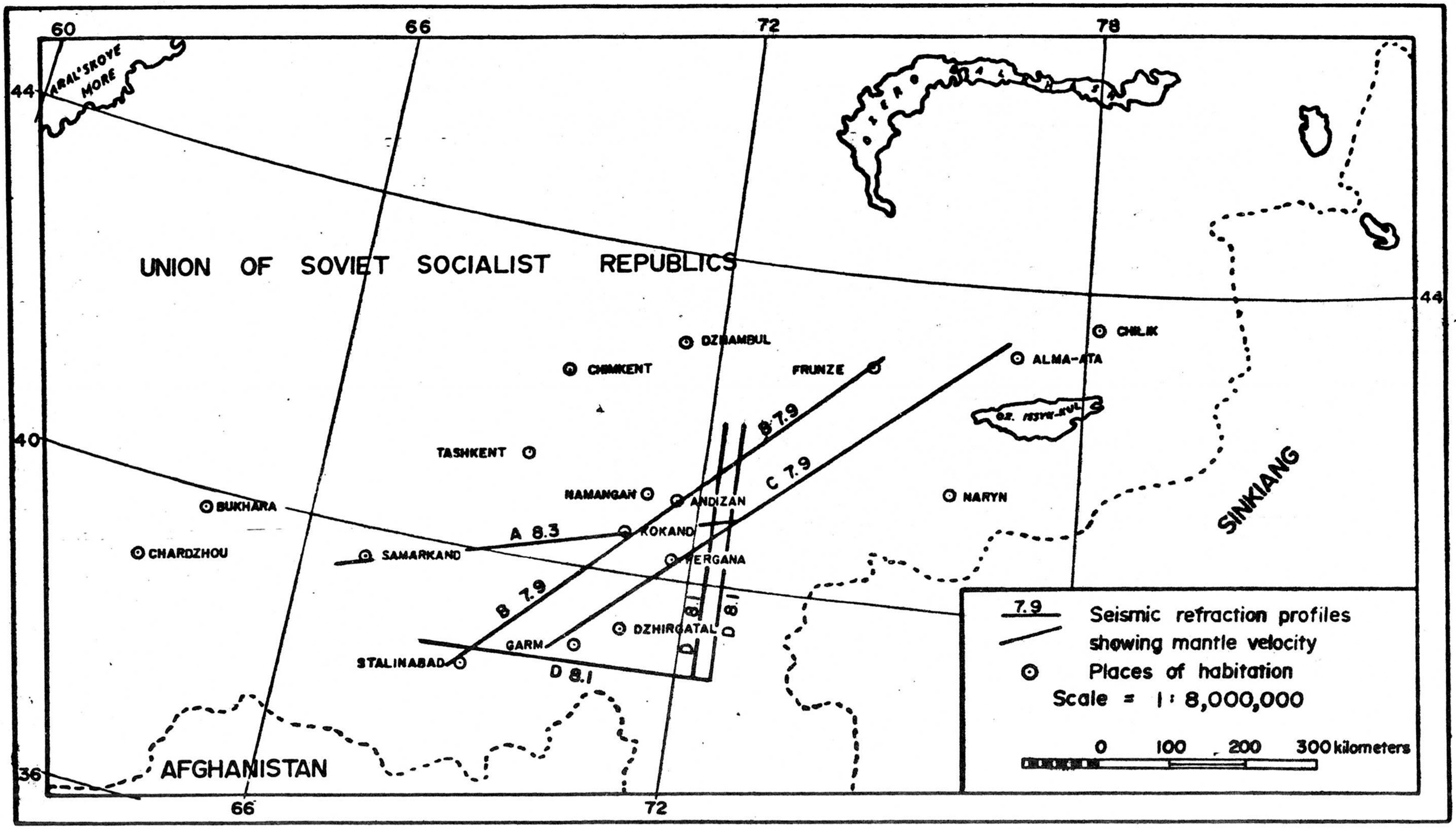

Figure 1.--Location of Soviet seismic-refraction profiles and mantle velocities.
(A - Godin, and others, 1960; B - Riznichenko, 1960; C - Ulomov, 1960; and D - Kosminskaya, and others, 1958).

SOURCE OF DATA FOR CENTRAL ASIAN EARTHQUAKES

The Academy of Sciences of the USSR regularly publishes data recorded by the Soviet seismic stations. Prior to 1962, the data were published by the Akademiya Nauk USSR Council on Seismology in quarterly bulletins entitled Bulletin of the Net of Seismic Stations of the USSR. This series seems to have been discontinued sometime during 1961 and replaced in 1962 by a new series of monthly bulletins, published by the Akademiya Nauk USSR Institute of Earth Physics, entitled Seismological Bulletin of the Net of Seismic Stations of the USSR. Information contained in the two bulletins is identical in format.

Data in the earlier bulletins is given in 3 tables. The first constitutes a list of all the earthquakes for which epicenters were determined. The second table presents detailed information concerning severe earthquakes. Its data are of primary interest for the determination of the velocity of propagation of seismic waves (Fig. 2). The third table lists all earthquakes recorded at each individual station.

ANALYSIS

The present analysis of Soviet earthquake data consisted primarily of reducing the data to basic travel-time curves of the P_n wave, and calculating the velocity by the method of least squares.

Initially, velocities were determined mathematically without actually plotting the data or considering the azimuthal location of recording stations. This procedure did not provide adequate information on the variations in mantle velocities and was abandoned. Later calculations made on travel-time plots of earthquake data recorded by seismograph stations situated along a linear profile seem to give superior results. (Riznichenko, 1960).

б) ПОДРОБНЫЕ ДАННЫЕ О ЗЕМЛЕТРЯСЕНИЯХ

Апрель I96I г.

Ст.	Δ		Продольные волны	Поперечные волны	Тр сек	A_N	A_E	A_Z	Примечания
	км	о	ч м с	ч м с		микрон			
I	2	3	4	5	6	7	8	9	I0
			№ 292. I апреля Южный Тянь-Шань φ = 39,8N ; λ = 77,6E ; O=I5ч I8м 23с M = 6½						
Нр	225	2,I	iP I5 I8 59						
Прж	305	2,8	P I9 09	S I5 I9 44					e(I9 36) α = I54°,6
Мг	350	3,2	P* I9 23	S̄ 20 I0					
Крм	365	3,3	iP I9 I5	eS (I9 5I)					
Ал₂	385	3,5	iP̄ I9 I9						
Ал	385	3,5	iP I9 20	iS 20 02	6	I473	3500		
Члк	425	3,9	iP I9 23						
Фр	425	3,9	iP̄ I9 25	eS* 20 22			>I000		e:I9 43
Ан	455	4,I	iP I9 30	S̄ 20 4I	5	I500			i:I9 33 I9 44 i:I9 48 α=99°
Фг	500	4,5	eP I9 36	eS* 20 40			I250		i:I9 38 e:20 24
Нмг	520	4,7	iP̄ I9 55						i:I9 4I i:20 37
Джг	550	5,0	P I9 44						

Figure 2.--Table taken from a Soviet seismological bulletin giving details of severe earthquakes.

Explanation:

1	Recording station
2	Epicentral distance in kilometers
3	Epicentral distance expressed in degrees of arc
4	Arrival time of indicated wave (compressional)
5	Arrival time of indicated wave (transverse)
6	Period of maximum displacement of the soil
7,8,9	Maximum amplitude of soil displacement (microns) 7 north-south 8 east-west 9 vertical
10	Other arrivals

Selection of data is an important part of the analysis. An estimated 15 percent of the 200 or more earthquakes of magnitude 4 and above that were examined in this study have given acceptable values for P_n velocity and reasonably linear travel-time plots. The percentage of useable data increases as the magnitude of the earthquake increases. However, as the magnitude increases, the number of earthquakes of that magnitude decreases and the analyst is again faced with the dilemma of quality versus quantity.

Much of the area of the Soviet Union from which earthquake data is available in sufficient quantity for analysis is structurally complex. The marked changes in structure cause considerable variation in the velocity of seismic waves, making it difficult to establish an absolute P_n velocity for a particular area (Godin, and others, 1961; Ulomov, 1960; Kosminskaya, and others, 1958). The following criteria, which establish a definite azimuth sensitivity to the resulting velocity values, have been observed in the selection of data for analysis:

1) Data must be derived from earthquakes of magnitude 4 or greater;
2) The epicenter of the earthquake must lie within 200 or 300 kilometers of an area of high station density;
3) The geographic distribution of the epicenter and recording stations must be such that they lie along a reasonably straight line;
4) Data must contain enough upper-mantle refractions to make a P_n velocity determination feasible.

After selecting a particular earthquake consistent with the above criteria, the data on the P_n phase contained in the bulletin were reduced to a travel-time curve. The epicentral distances reported in the Soviet bulletins are questionable and were disregarded in favor of computed distances from a computer program that computes surface distance by the central angle method, correcting for the ellipticity of the earth. A comparison between the reported epicentral distance and the calculated epicentral distance is shown in Table 1. In nearly every case the computed distance is greater than the distance reported in the bulletin. Use of the computed distances generally has the effect of raising the apparent velocity of the seismic waves. For earthquake 1365, from which the data of Table 1 have been taken, the calculated velocity of P_n based on bulletin values for epicentral distance is 8.0 km/sec. Computed epicentral distances raise this value to 8.2 km/sec. Although the velocity values derived from data on earthquake 1365 are themselves suspect, they do serve to point out the difference arising from the use of "measured" bulletin distances and "calculated" epicentral distances.

Several travel-time curves plotted from data on Soviet earthquakes are included in the Appendix. A brief statement explaining the significance of particular plots is also included where necessary. Plots and data are referred to by numbers that have been assigned by the Russian seismologists. The sequence begins with number 1 on January 1st and enumerates the events occurring in a particular "zone" for the duration of the year. Travel-time plots and subsequent calculations were usually made over the distance range 200-to-1000 kilometers from the epicenter. This range tends to cancel the major effects of focal depth on velocity near the epicenter, and the replacement of the P_n wave as the first arrival at distances greater than 10 degrees (1100 kilometers). The travel-time curves reproduced in this report represent data from profiles

Table 1.--Comparison of reported epicentral distance with calculated epicentral distance for earthquake 1365

Station	Reported epicentral distance, km	Calculated epicentral distance, km	Difference, km
Garm	30	34.5	+ 4.5
Obi-Garm	50	50.0	+ 0.0
Dzhirgatal	100	100.5	+ 0.5
Khorog	180	172.7	- 7.3
Fergana	225	225.2	+ 0.2
Namangan	270	280.6	+ 10.6
Andizan	285	289.9	+ 4.9
Tashkent	295	---	---
Samarkand	300	305.6	+ 5.6
Chimkent	400	406.9	+ 6.9
Naryn	565	573.2	+ 8.2
Frunze	580	587.5	+ 7.5
Rybach'ye	635	650.4	+ 15.4
Bairam-Ali	700	726.4	+ 26.4
Fabrichnii	700	714.7	+ 14.7
Alma-Ata	745	756.2	+ 11.2
Alma-Ata 2	765	783.6	+ 18.6
Przheralsk	795	805.0	+ 10.0
Ashkhabad	1030	1046.7	+ 16.7

parallel or coincident with profiles studied by the Soviet scientists with deep seismic sounding methods and from the records of earthquakes. The results of the Russian work place the P_n velocity at 7.9 km/sec. Velocities arising from the use of data contained in Soviet earthquake bulletins vary individually from 7.9 km/sec but when several are considered together, the predominant or "weighted" average velocity of the group is in excellent agreement with the Soviet value. In the case of earthquake 990 (Figs. 19 and 20), where the profile assumes a more northerly trend, the velocity increases toward the value of 8.1 km/sec shown in Figure 1. An increase in velocity was also noted for other earthquakes whose epicentral locations favored a north-trending profile.

CONCLUSIONS

Published earthquake bulletins are a reasonable source of crustal-structure information as long as the seismograms from the Russian stations remain generally unavailable. The accuracy of data for a single earthquake will not yield conclusive evidence regarding mantle velocities, but a system of processing selected quantities of Soviet data on an individual basis, followed by treatment of the individual results by statistical methods, will give relatively dependable values for seismic wave velocities.

APPENDIX

Earthquakes 526 and 804

(526) July 1, 1957 time: $11^h42^m10^s$ location: lat 37.5°N; long 69.0°E

magnitude = 4 3/4 depth of focus = normal

(804) October 5, 1957 time: $22^h40^m46{\pm}2^s$ location: lat 37.6°N; long 69.4°E

magnitude = ? depth of focus = 80 kilometers

The travel-time plots of earthquakes 526 (Figs. 3 and 4) and 804 (Figs. 5 and 6) show a definite change of P_n velocity over the Frunze-Ili section of the curves relative to the Dzhirgatal-Andizan section. Whether this change should be attributed to inaccuracies in the data or changes in crustal structure or other complications is uncertain. Soviet deep seismic sounding data support a marked thinning of the crust in the Frunze-Alma-Ata vicinity (Kosminskaya, and others, 1958; Ulomov, 1960) which would undoubtedly increase the apparent velocity of P_n waves in the area, but data from other earthquakes do not exhibit an increase in velocity over the same interval.

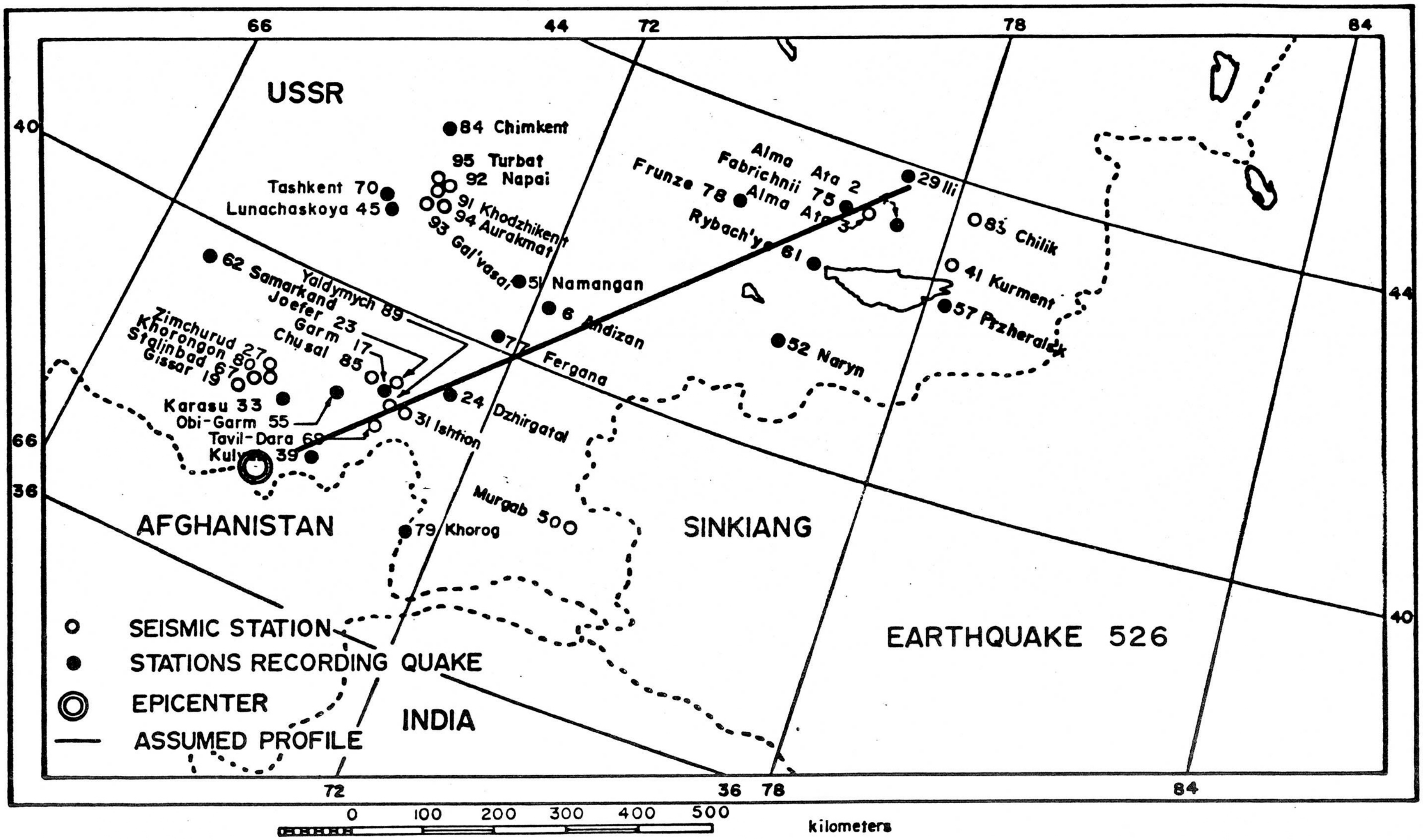

Figure 3.--Epicenter and profile location for earthquake 526.

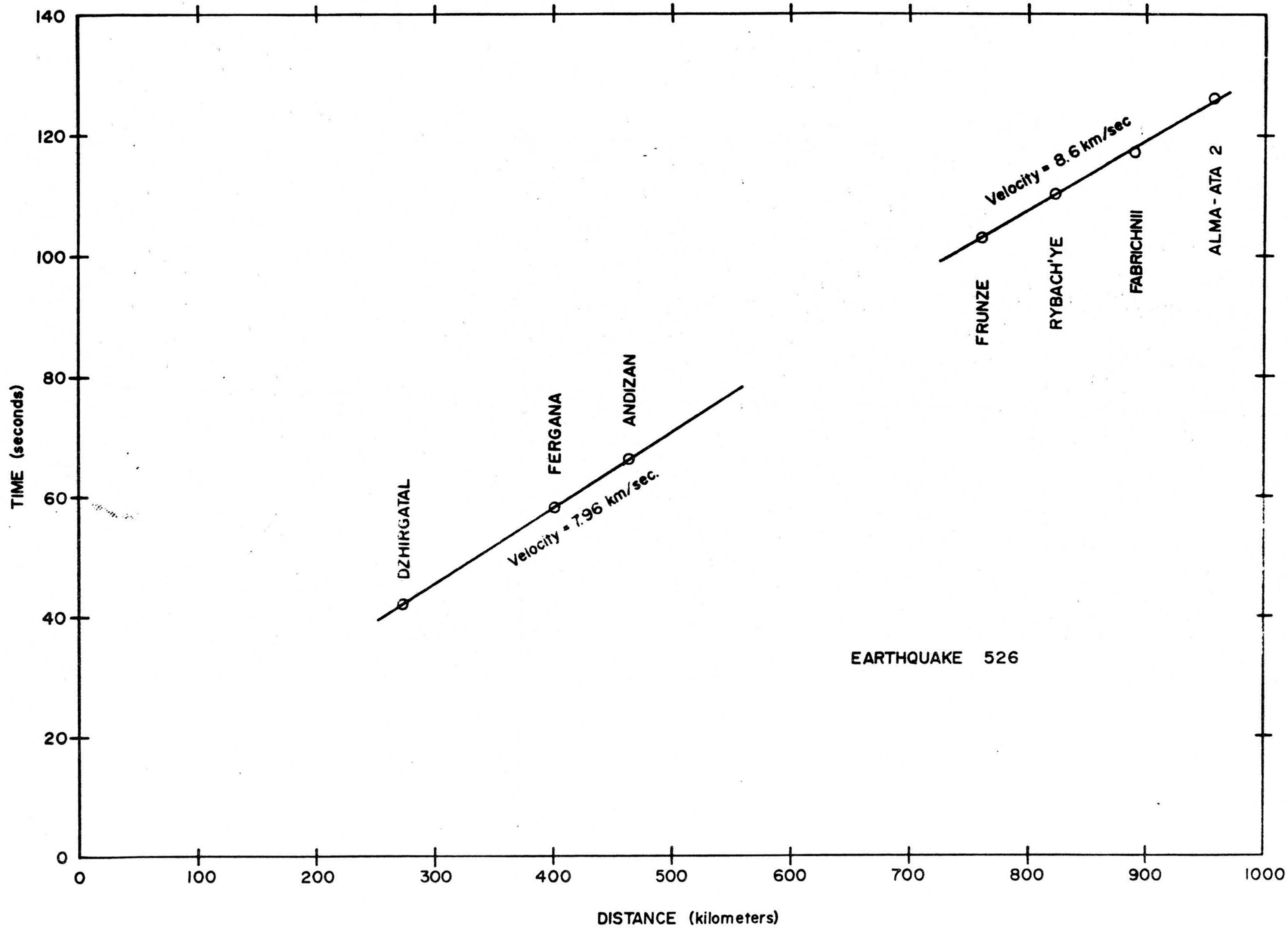

Figure 4.--Travel-time curve for earthquake 526 constructed from data in Soviet earthquake bulletins.

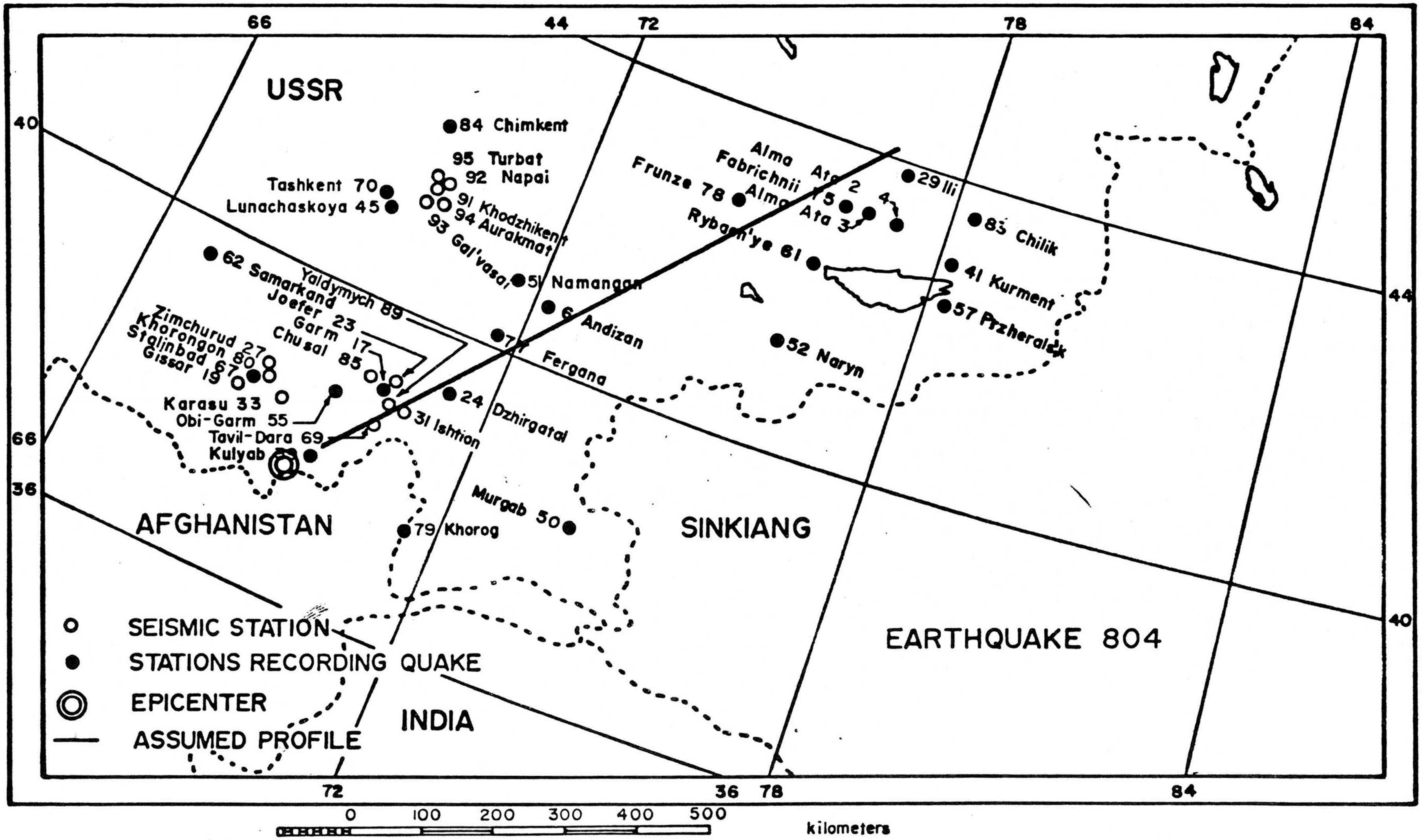

Figure 5.--Epicenter and profile location for earthquake 804.

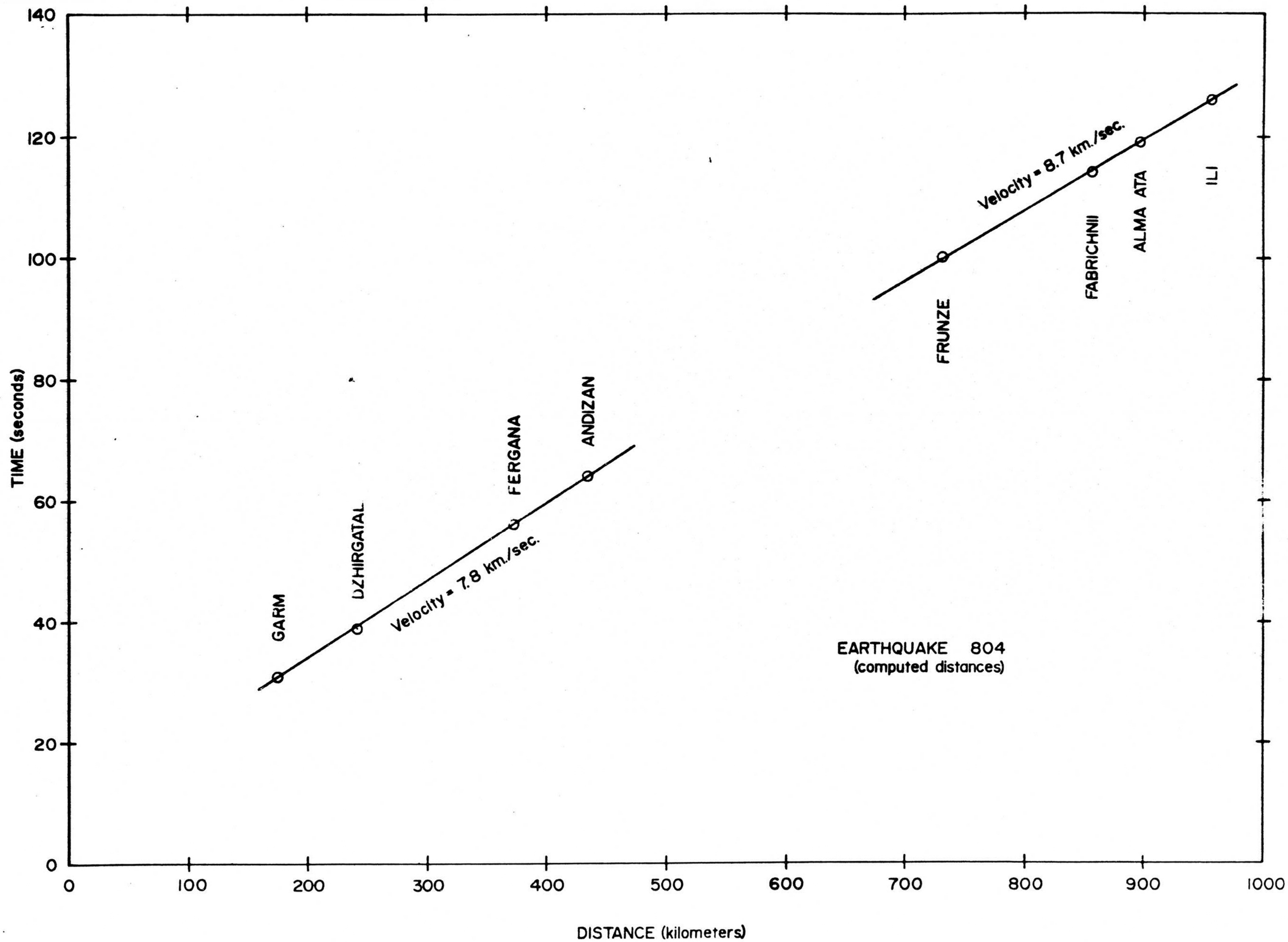

Figure 6.--Travel-time curve for earthquake 804 constructed from data in Soviet earthquake bulletins.

Earthquakes 361, 365, and 373

(361) Sept. 12, 1962 time: $20^h57^m00^s$ location: lat 36.4°N; long 68.7°E

magnitude = ? depth of focus = 50 kilometers

(365) Sept. 13, 1962 time: $12^h45^m58^s$ location: lat 36.4°N; long 68.7°E

magnitude = ? depth of focus = 50 kilometers

(373) Sept. 18, 1962 time: $05^h23^m05^s$ location: lat 36.4°N; long 68.7°E

magnitude = ? depth of focus = 50 kilometers

The travel-time plot of earthquakes 361, 365, and 373 (Figs. 7 and 8) is a composite of data from all three earthquakes. Travel times from the epicenter to the recording stations varied, according to bulletin data, from 0 to 3 seconds for the three different earthquakes. A weighted average of the travel times from each report was used to construct a travel-time curve which yields a P_n velocity of 8.1 km/sec. It is interesting to note that while the composite velocity is 8.1 km/sec, the individual velocities were (361) 8.3 km/sec, (365) 8.2 km/sec, and (373) 8.3 km/sec respectively. The composite velocity does not represent the average velocity value of the group and its significance is not clear at the present time.

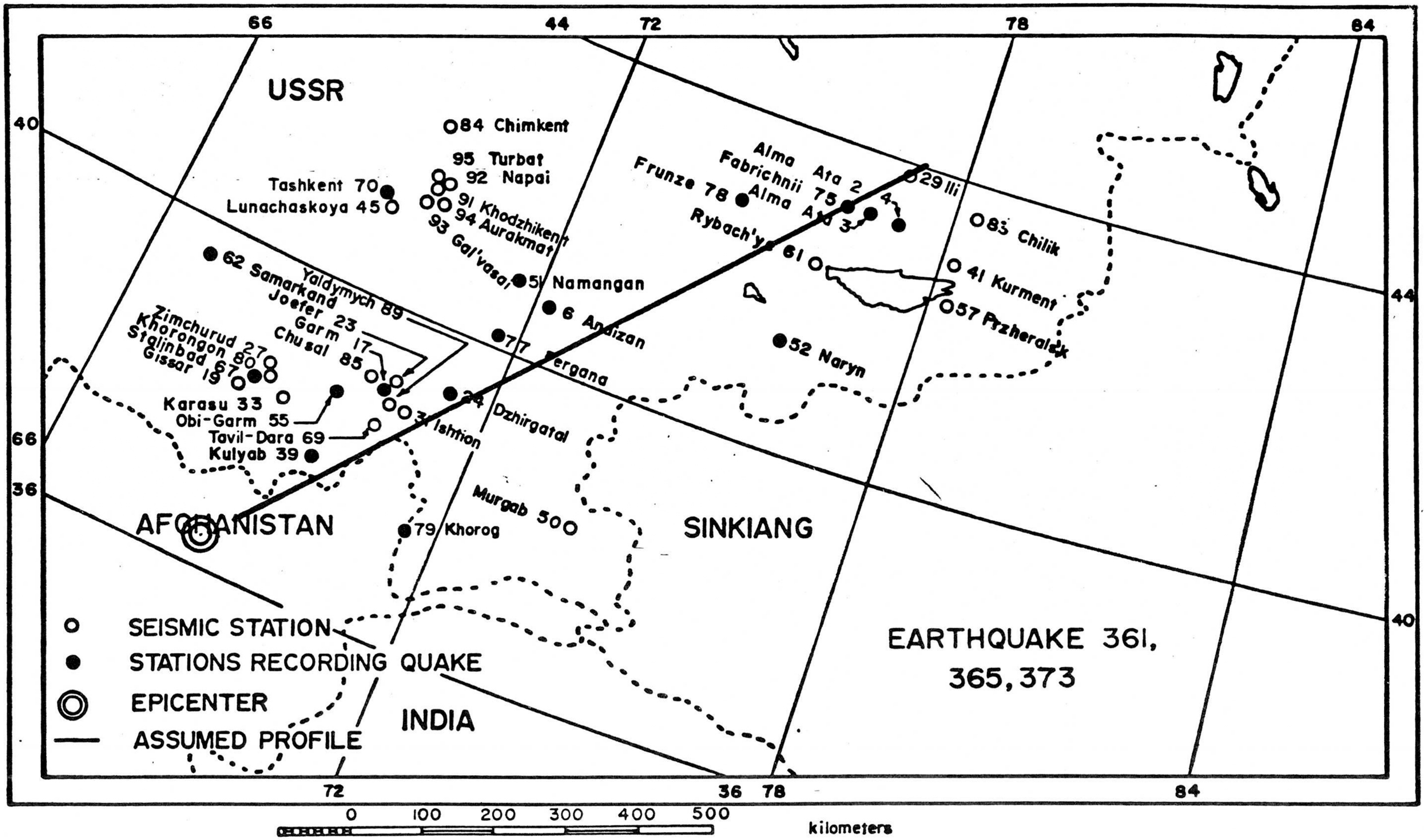

Figure 7.--Epicenters and profile location for earthquakes 361, 365, and 373.

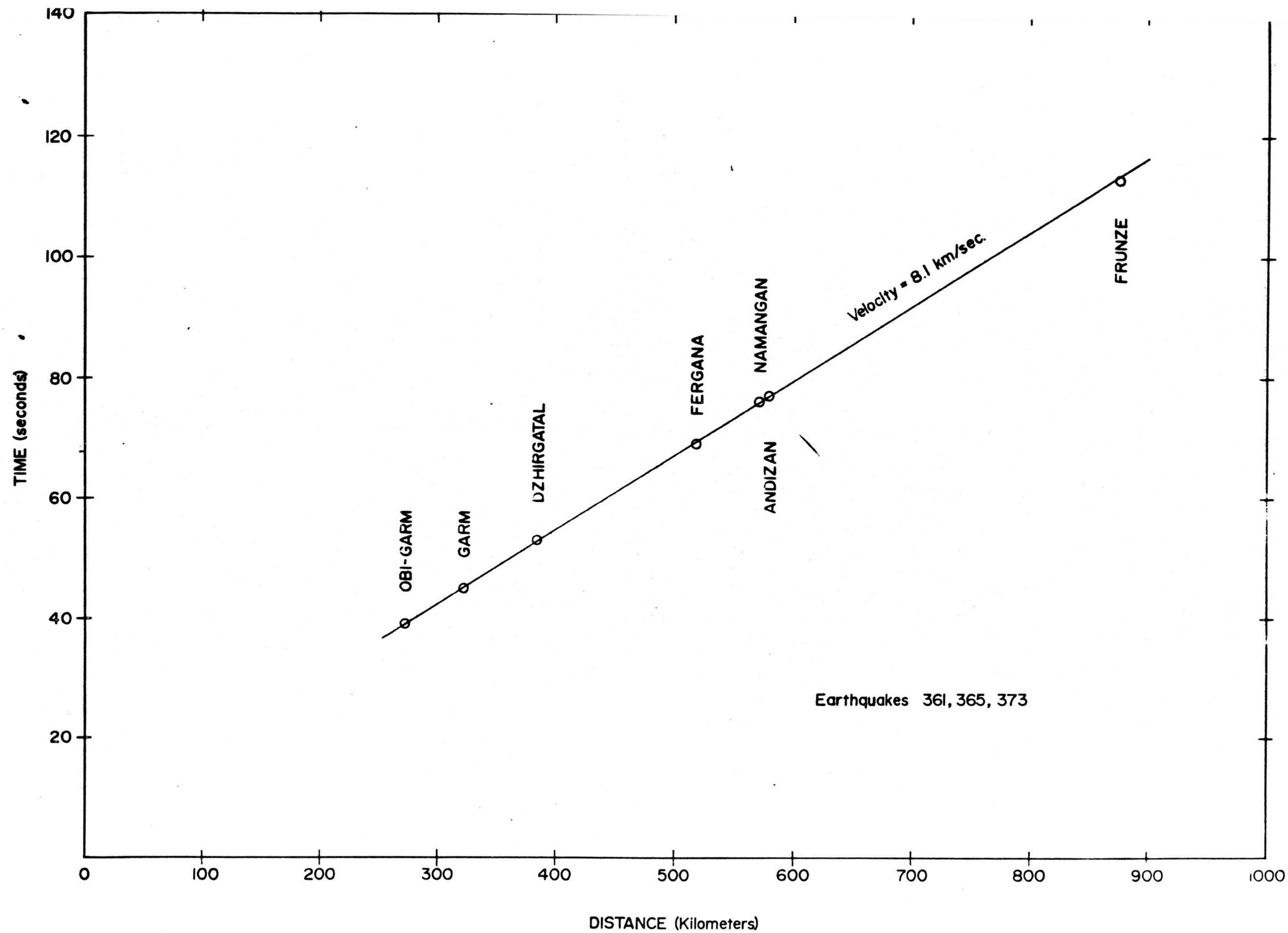

Figure 8.--Travel-time curve for earthquakes 361, 365, and 373 constructed from data in Soviet earthquake bulletins.

Earthquake 1365

(1365) December 20, 1960 time: $20^h43^m04^s$ location: lat 38.69°N; long 70.29°E

magnitude = $4\frac{1}{2}$ depth of focus = 10 kilometers

Earthquake 1365 demonstrates the difference in calculated P_n velocity (Figs. 9 and 10) arising from the use of epicentral distances published in the Soviet bulletins and epicentral distances calculated by the central-angle method.

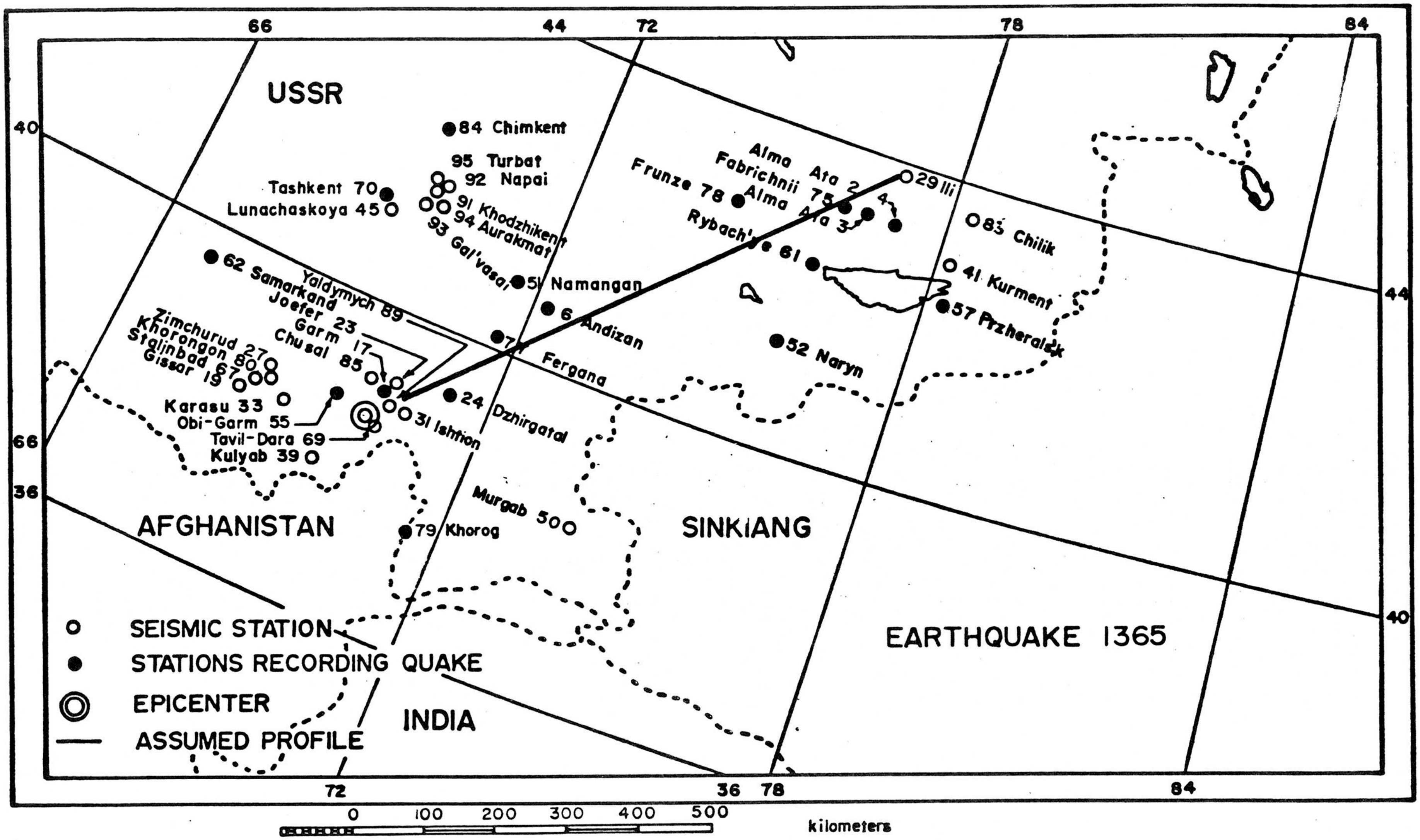

Figure 9.--Epicenter and profile location for earthquake 1365.

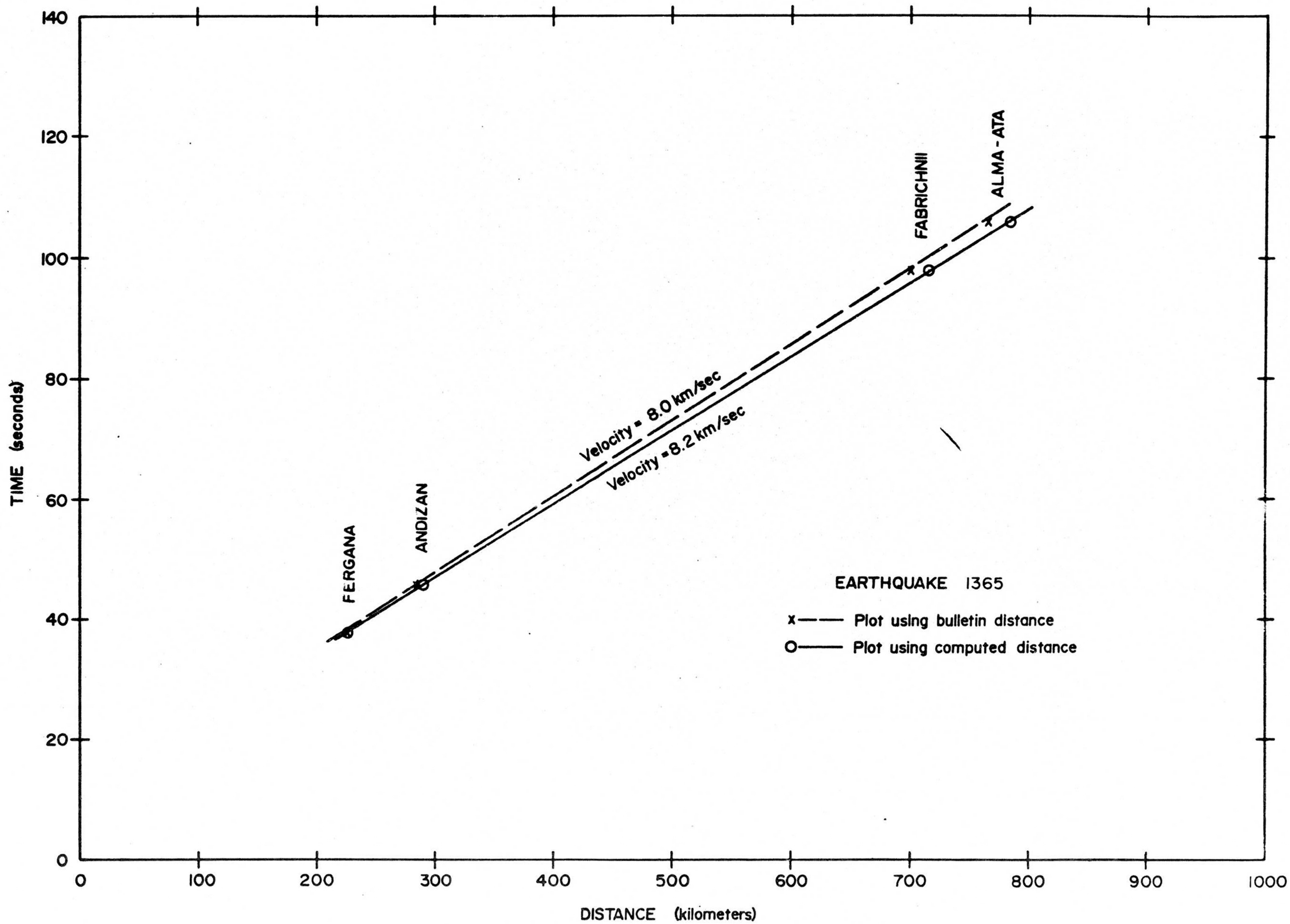

Figure 10.--Travel-time curve for earthquake 1365 constructed from data in Soviet earthquake bulletins.

Earthquakes 45 and 387

(45) January 13, 1957 time: $11^h38^m17^s$ location: lat 38.77°N; long 70.58°E

magnitude = 5 depth of focus = 10 kilometers

(387) May 9, 1957 time: $08^h44^m19^s$ location: lat 38.8°N; long 70.5°E

magnitude = $4\frac{1}{2}$ depth of focus = 10 kilometers

Data from earthquakes 45 and 387 (Figs. 11 and 12) have been plotted together to emphasize the difference in data from two earthquakes exhibiting the same P_n velocity. The greatest scatter is seen in the plot of earthquake 45 for which, according to the Soviet bulletin, the epicenter was determined to 0.01 degree. The less accurate epicenter determination for 387 provides a more-linear plot.

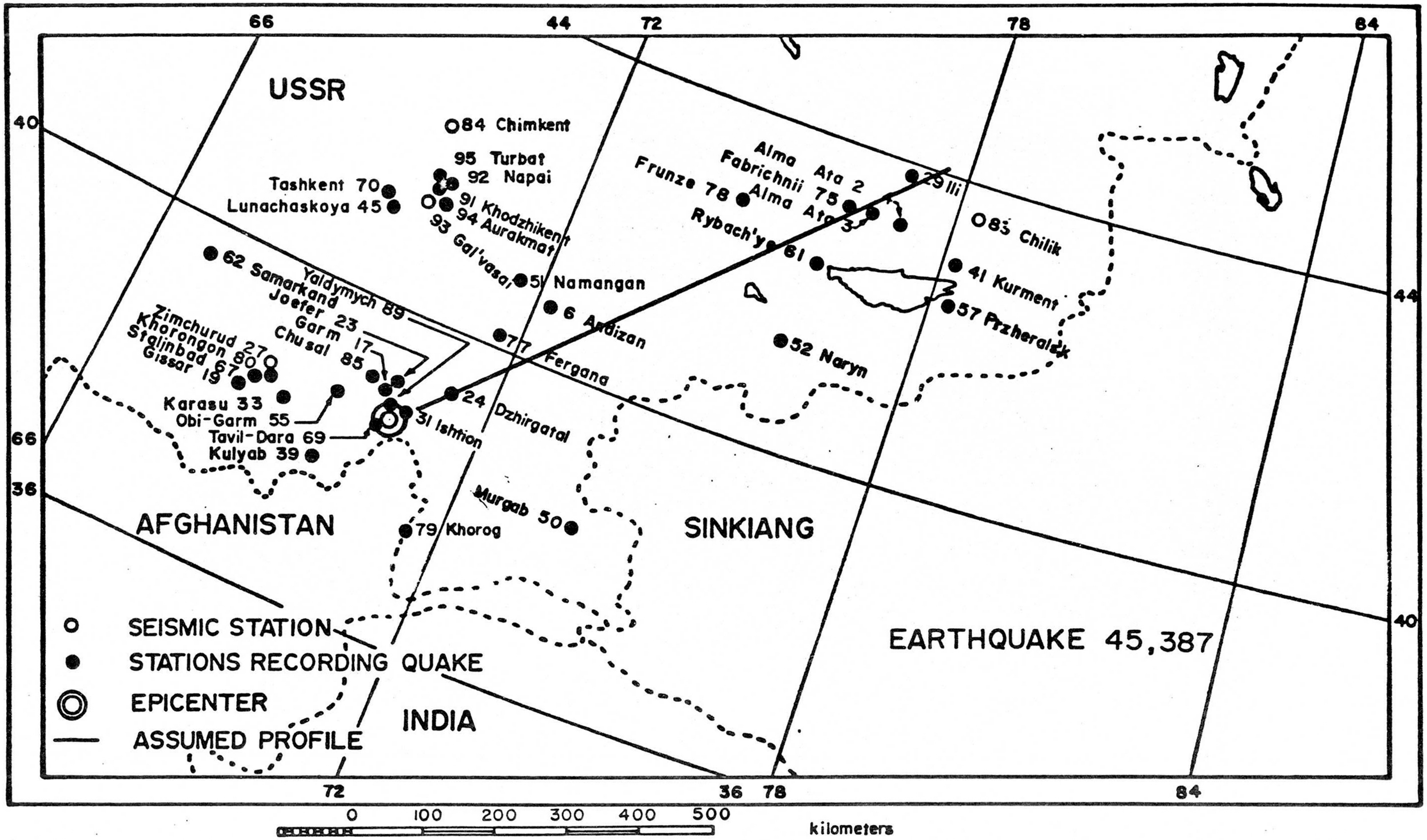

Figure 11.--Epicenter and profile location for earthquakes 45 and 387.

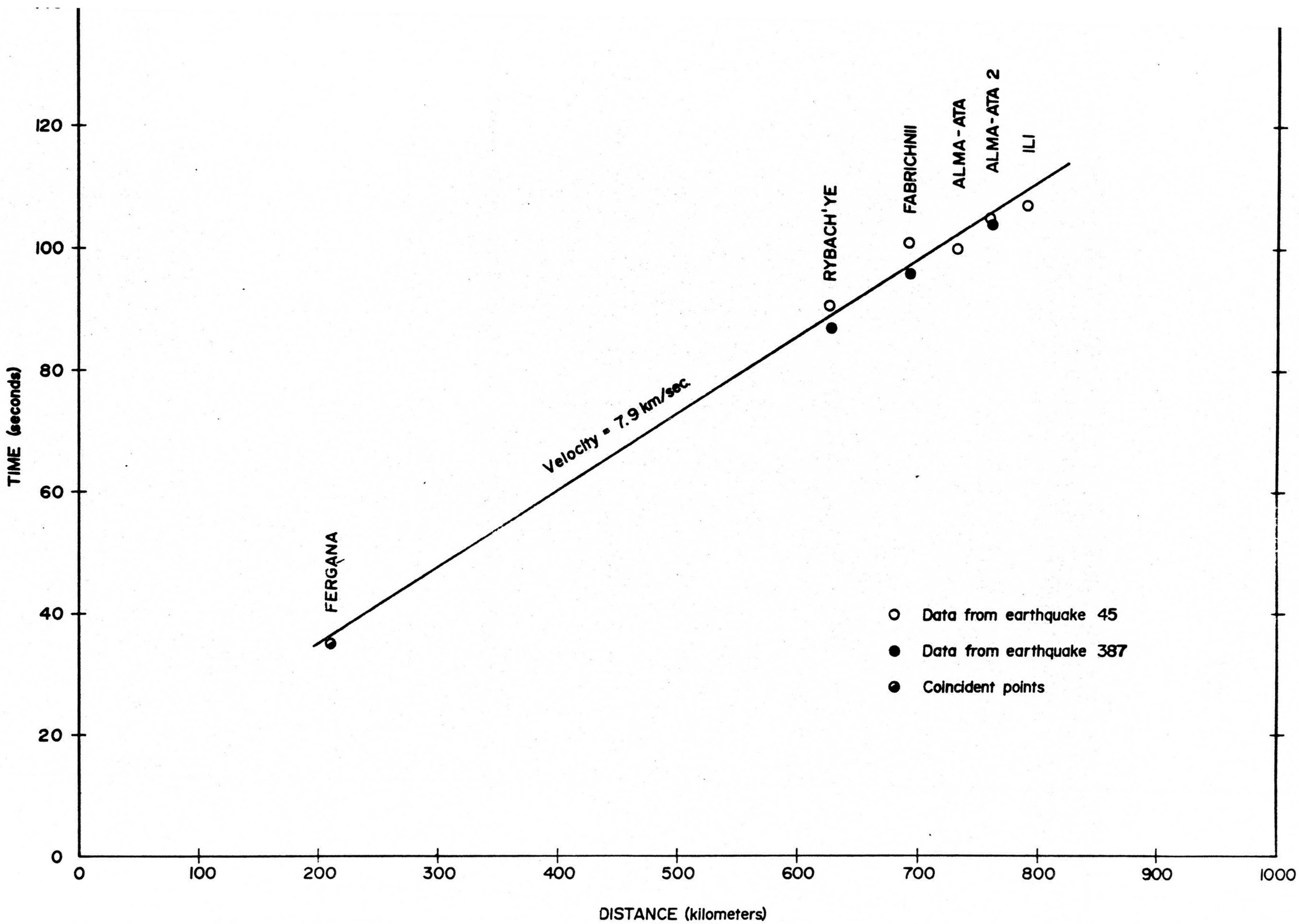

Figure 12.--Travel-time curve for earthquakes 45 and 387 constructed from data in Soviet earthquake bulletins.

Earthquakes 182, 285, 414, and 990

(182) June 19, 1962 time: $08^h13^m47^s$ location: lat 38.3°N; long 69.0°E

magnitude = 4 to 4-1/4 depth of focus = normal

(285) April 4, 1957 time: $11^h36^m22^s$ location: lat 36.1°N; long 69.9°E

magnitude = 5 depth of focus = ? (deep)

(414) November 1, 1962 time: $13^h46^m31^s$ location: lat 37.8°N; long 70.1°E

magnitude = 5 depth of focus = normal

(990) November 26, 1957 time: $00^h41^m33^s$ location: lat 37.1°N; long 72.5°E

magnitude = 4 depth of focus = normal

Travel-time plots and the location of recording stations for earthquake 182 are shown on Figures 13 and 14; for earthquake 285 are shown on Figures 15 and 16; for earthquake 414 are shown on Figures 17 and 18; and for earthquake 990 are shown on Figures 19 and 20.

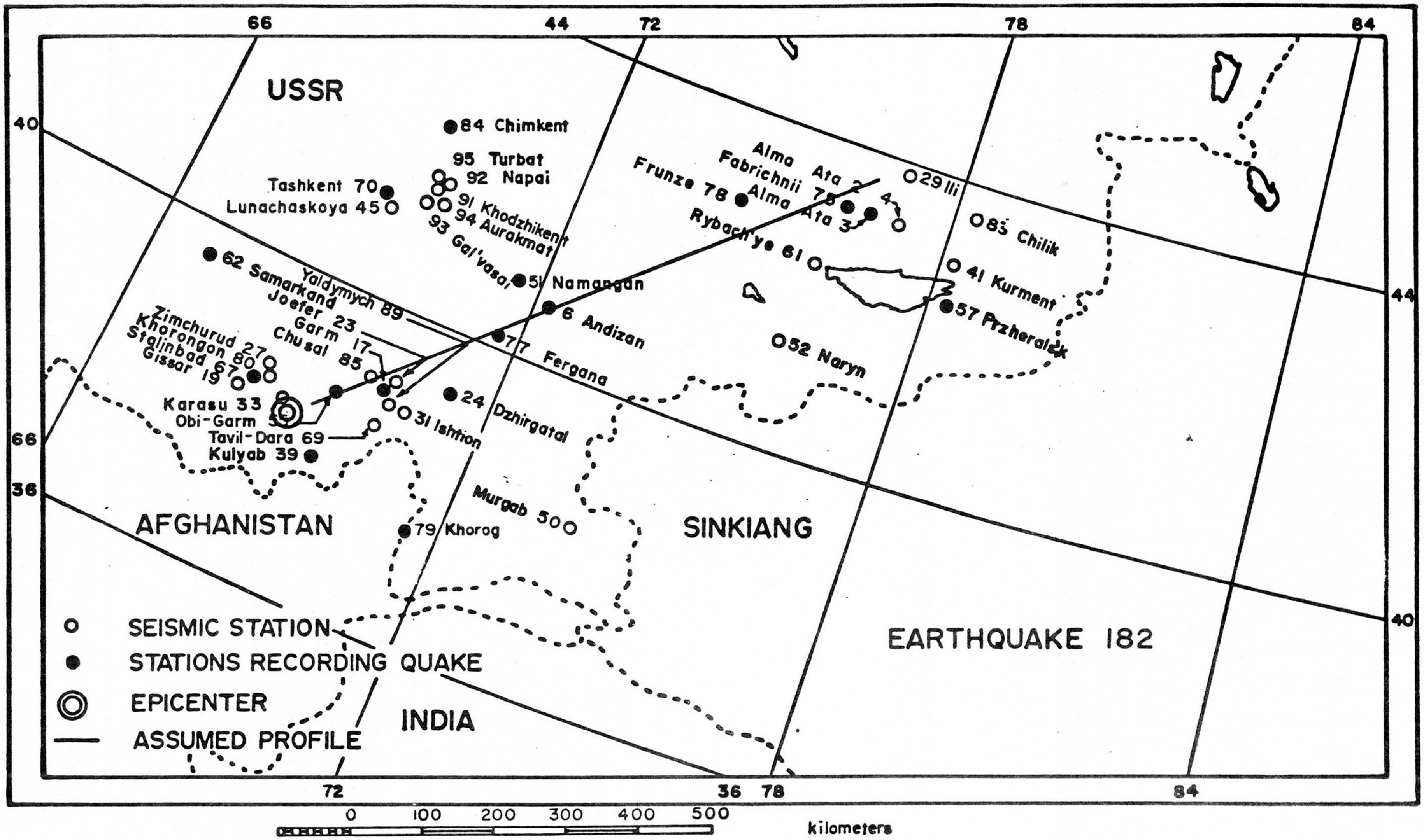

Figure 13.--Epicenter and profile location for earthquake 182.

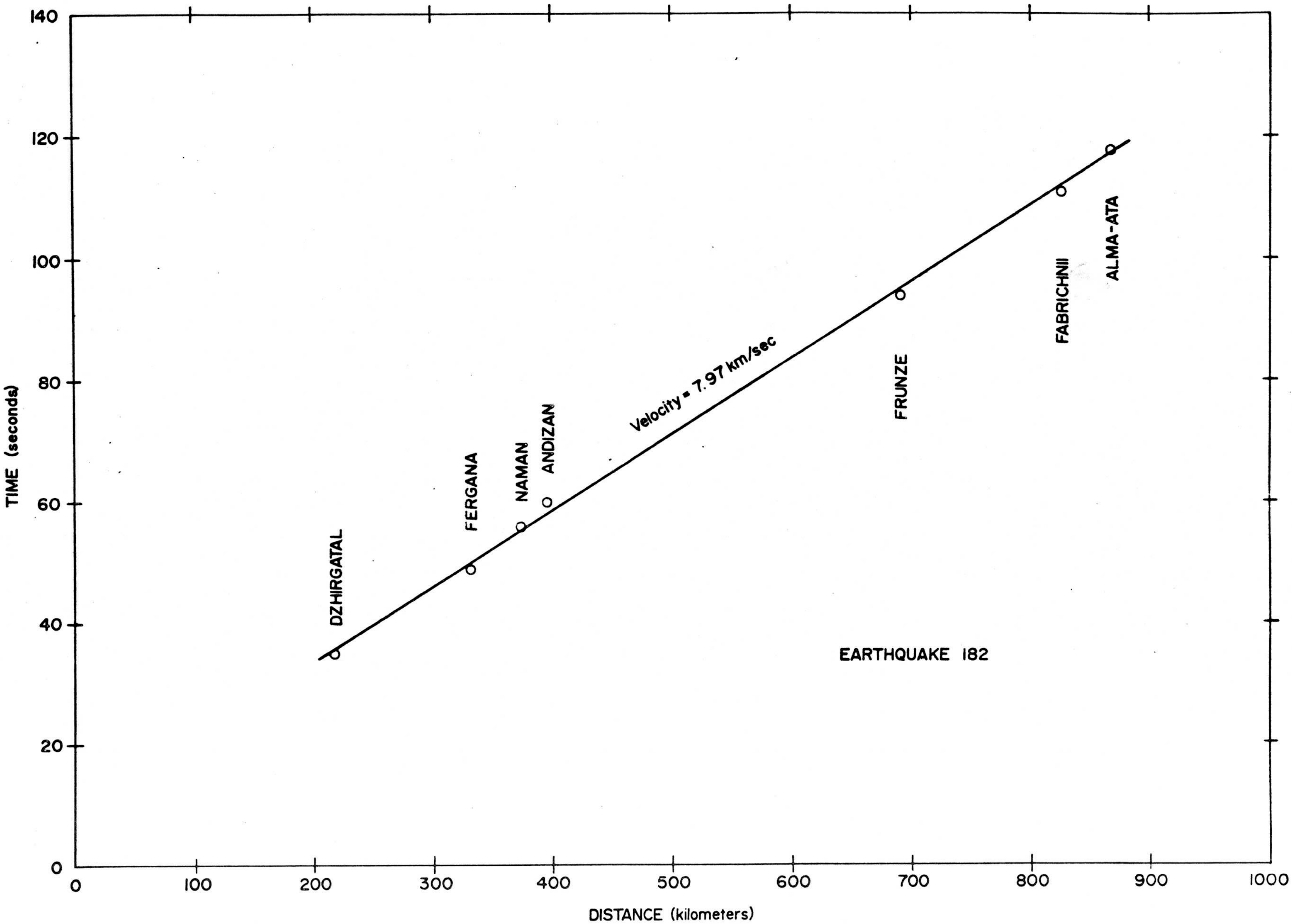

Figure 14.--Travel-time curve for earthquake 182 constructed from data in Soviet earthquake bulletins.

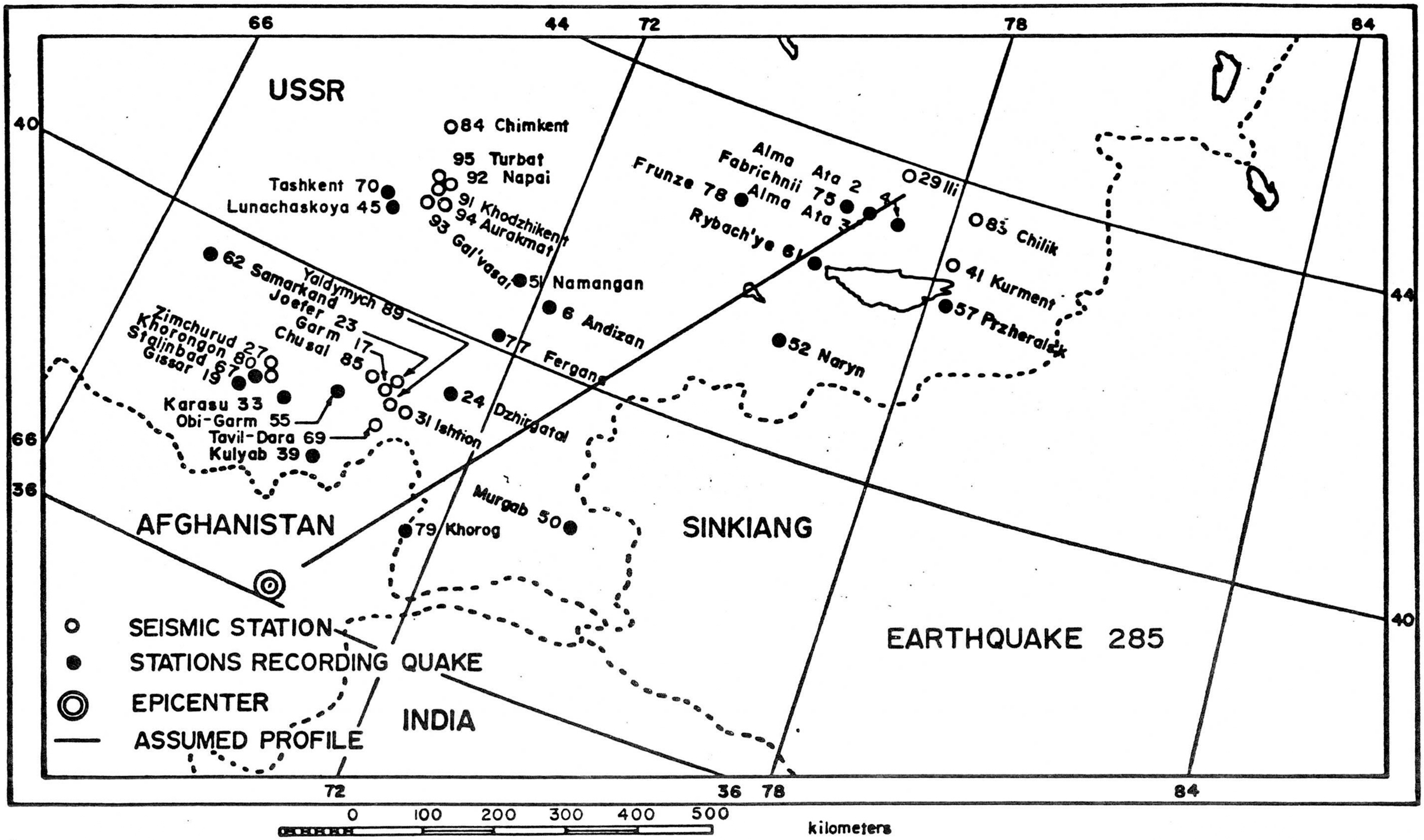

Figure 15.--Epicenter and profile location for earthquake 285.

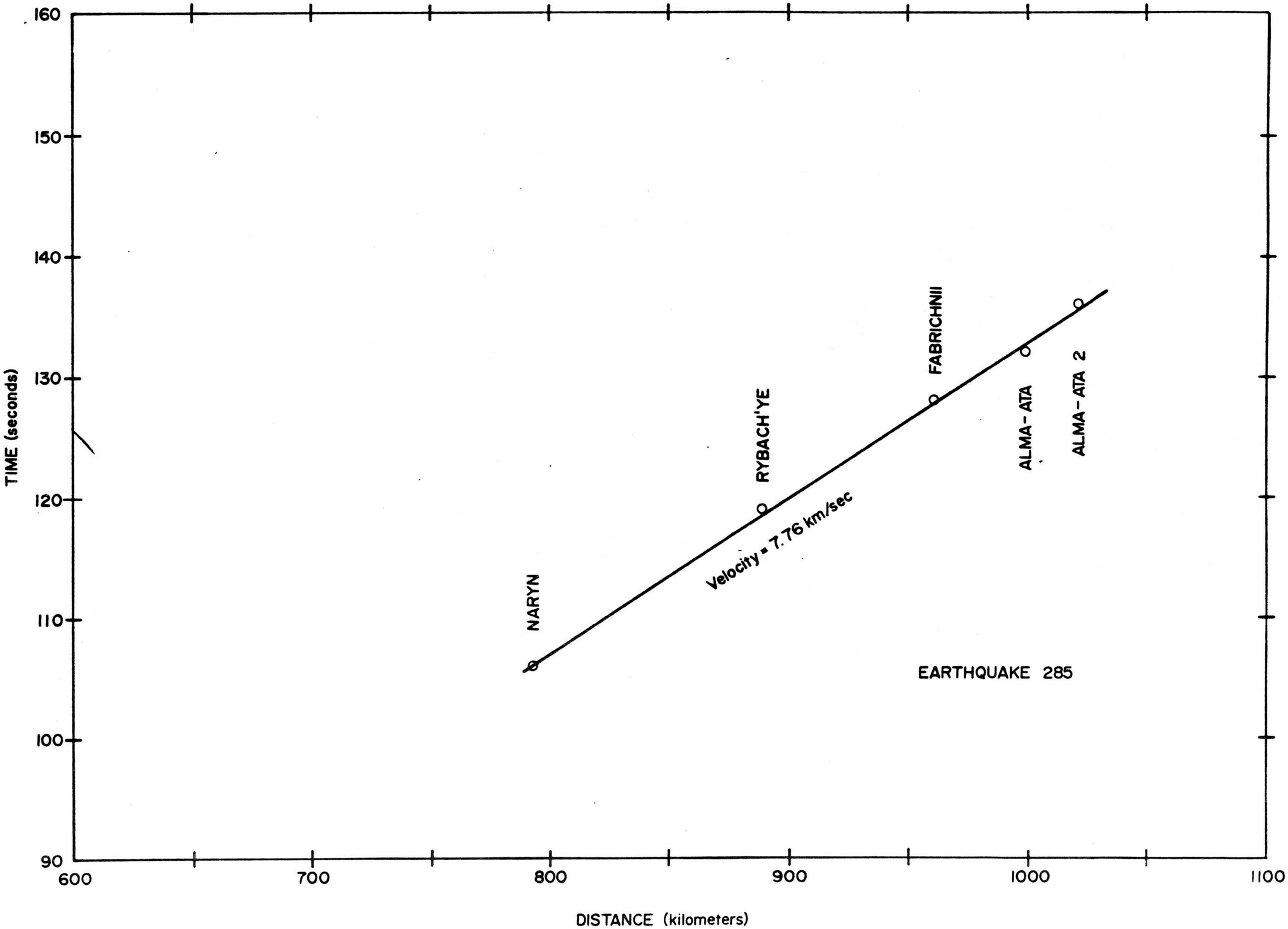

Figure 16.--Travel-time curve for earthquake 285 constructed from data in Soviet earthquake bulletins.

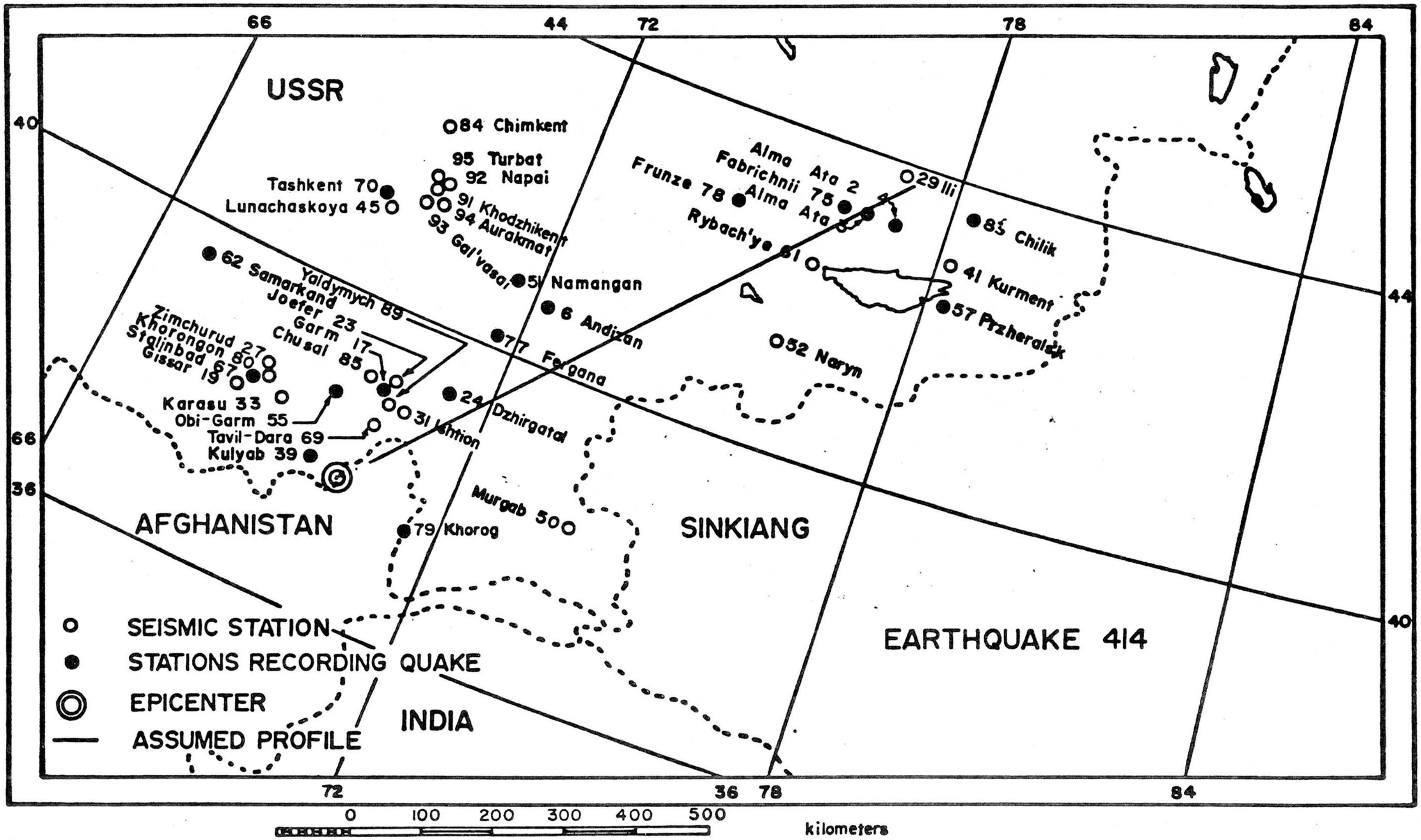

Figure 17.--Epicenter and profile location for earthquake 414.

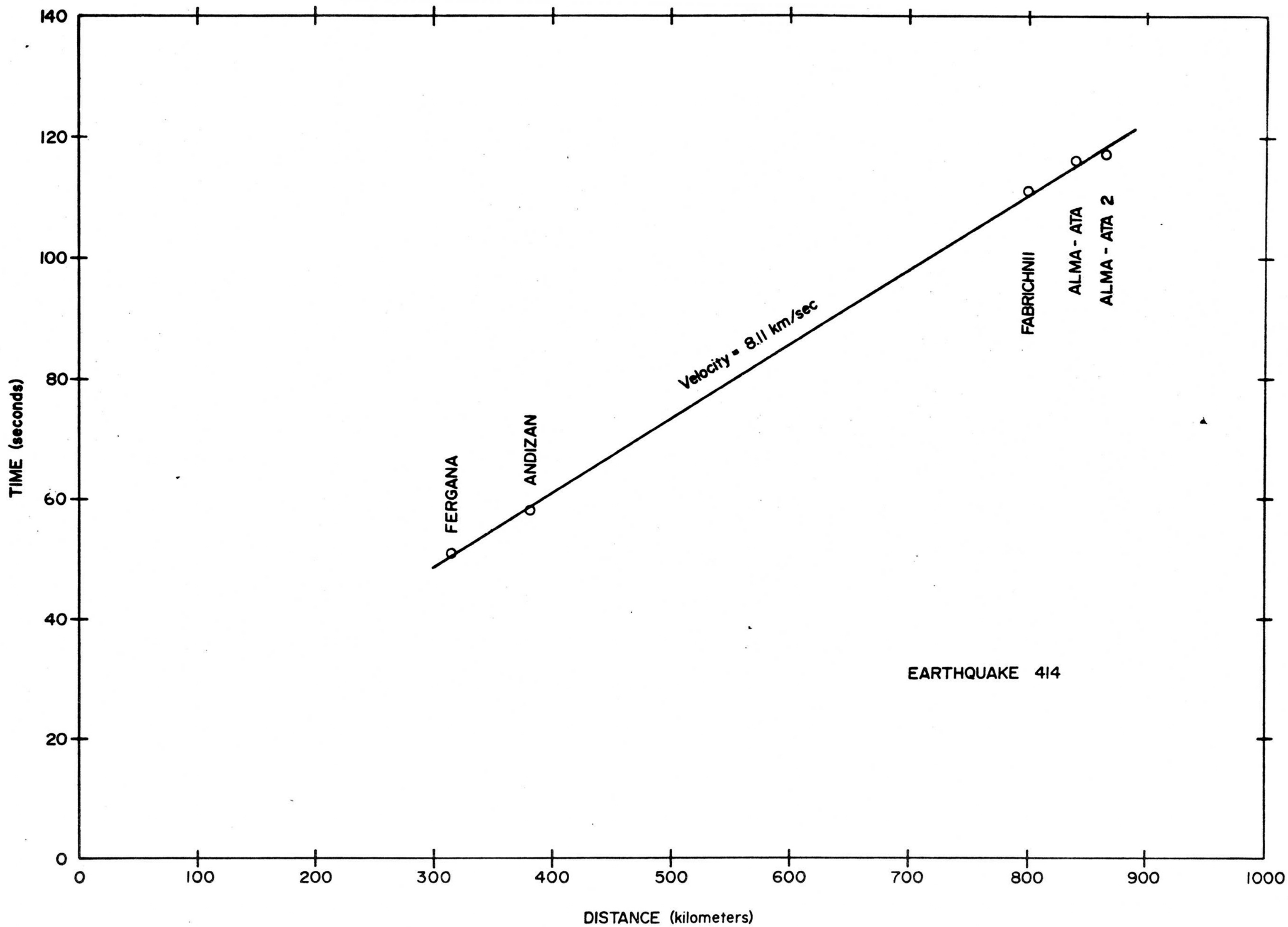

Figure 18.--Travel-time curve for earthquake 414 constructed from data in Soviet earthquake bulletins.

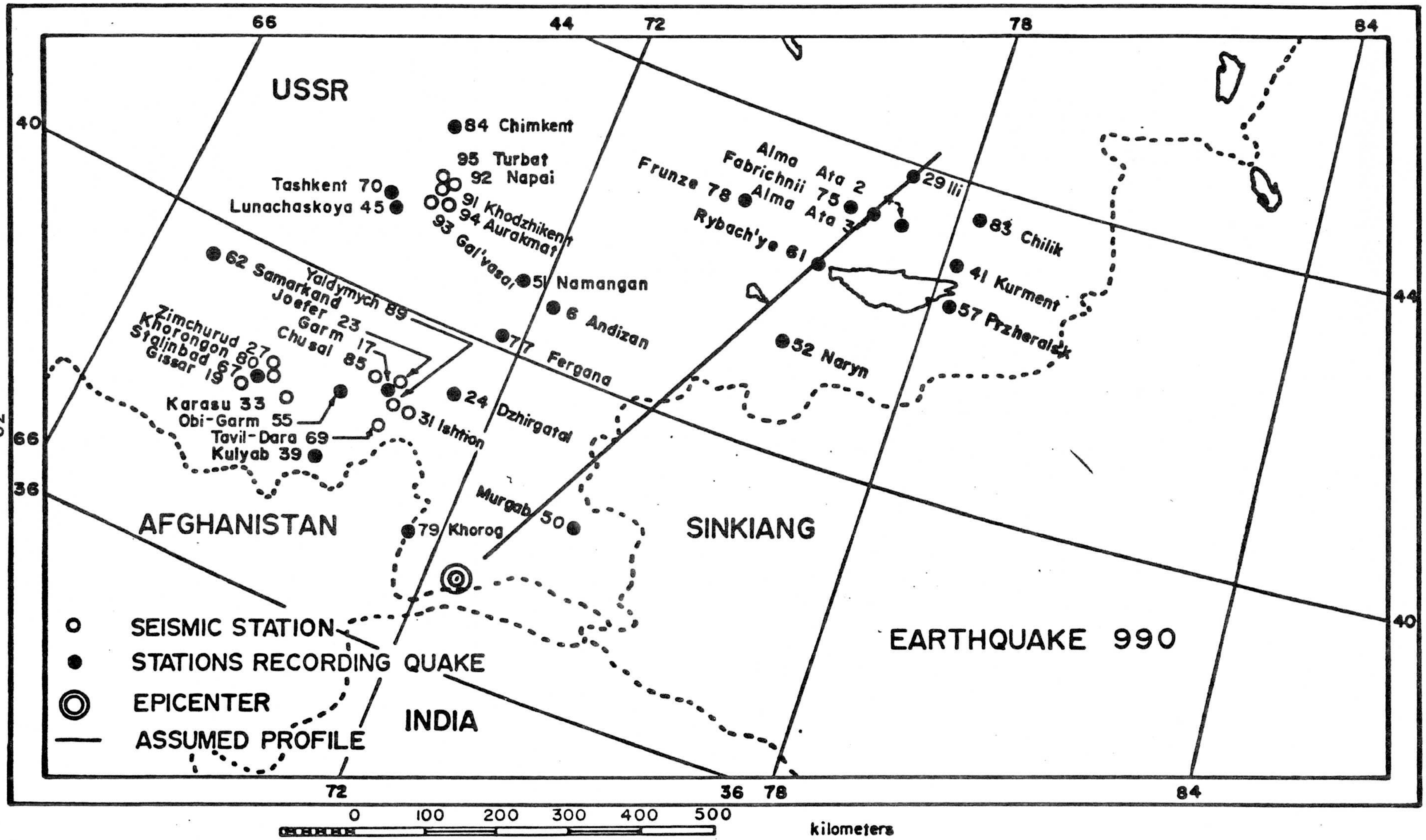

Figure 19.--Epicenter and profile location for earthquake 990.

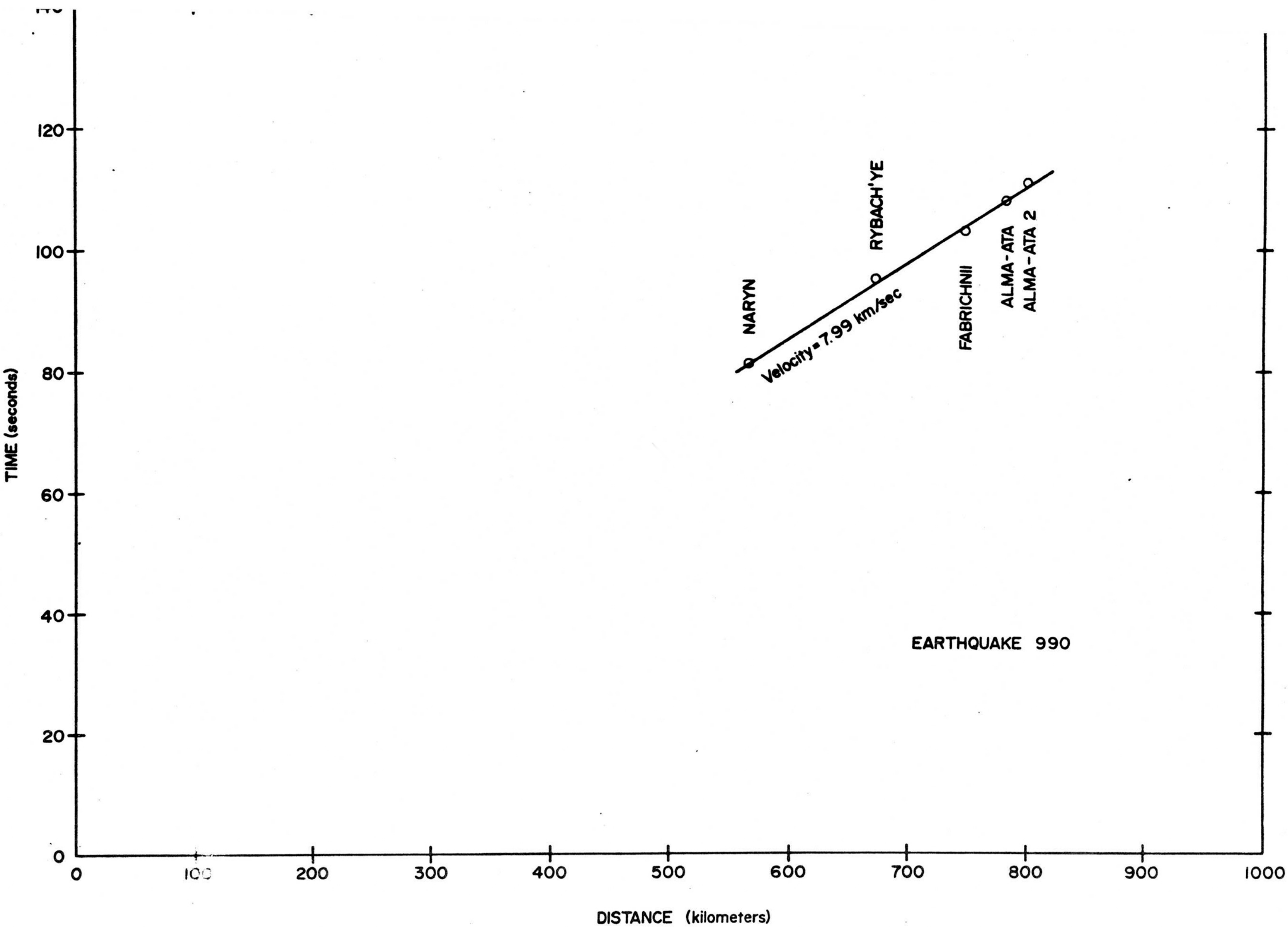

Figure 20.--Travel-time curve for earthquake 990 constructed from data in Soviet earthquake bulletins.

Earthquake 238

(238) August 19, 1962 time: $18^h 26^m 38^s$ location: lat 44.7°N; long 81.4°E

magnitude = 6 to 6-1/4 depth of focus = 25 kilometers

The location of the epicenter of earthquake 238 (Fig. 21) makes it possible to construct a travel-time curve representing a general reversal of direction over previous plots. Figure 22 is a travel-time plot constructed over the interval from Chilik to Tashkent. Calculations made in the direction Chilik-Obi Garm show a P_n velocity of 8.06 km/sec.

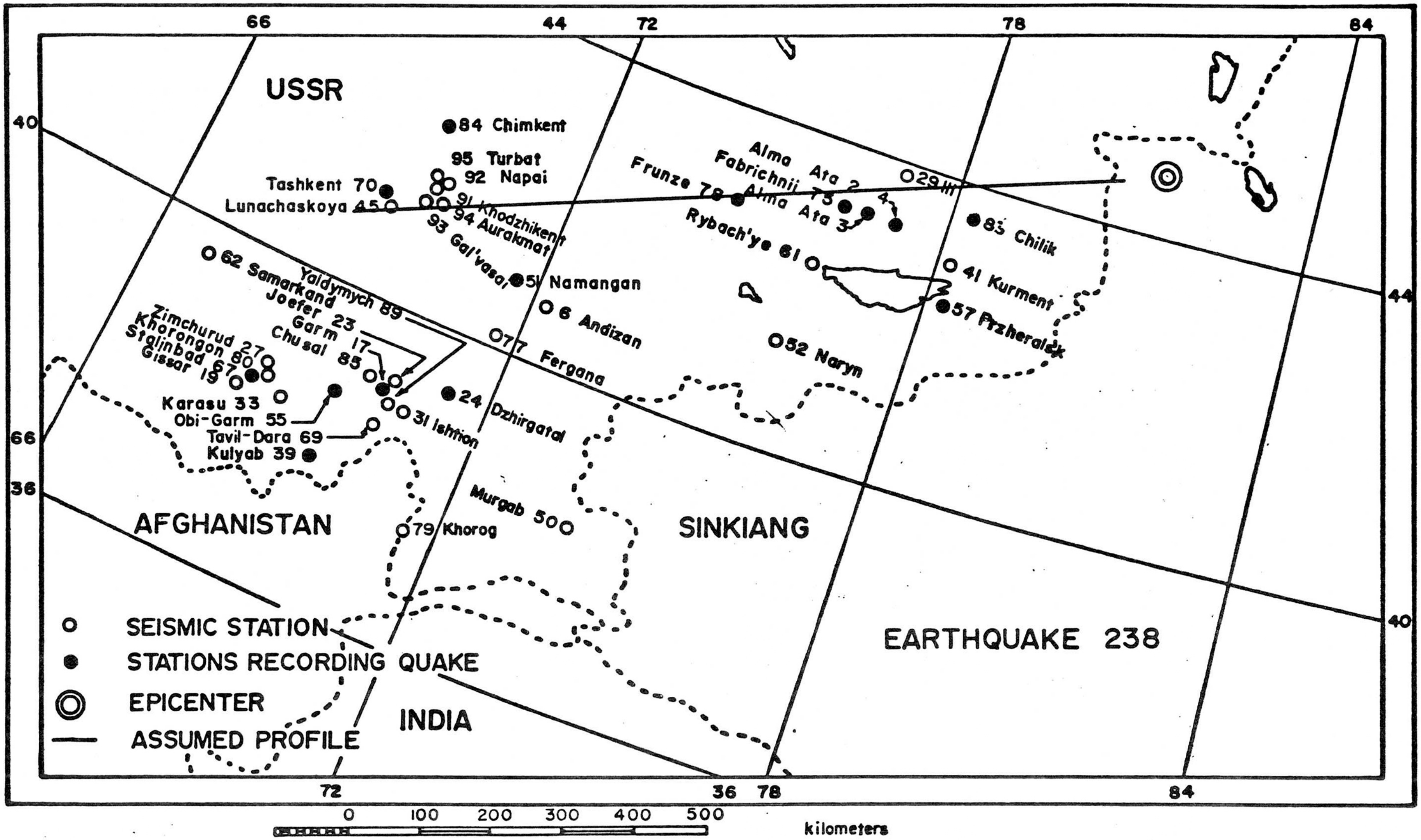

Figure 21.--Epicenter and profile location for earthquake 238.

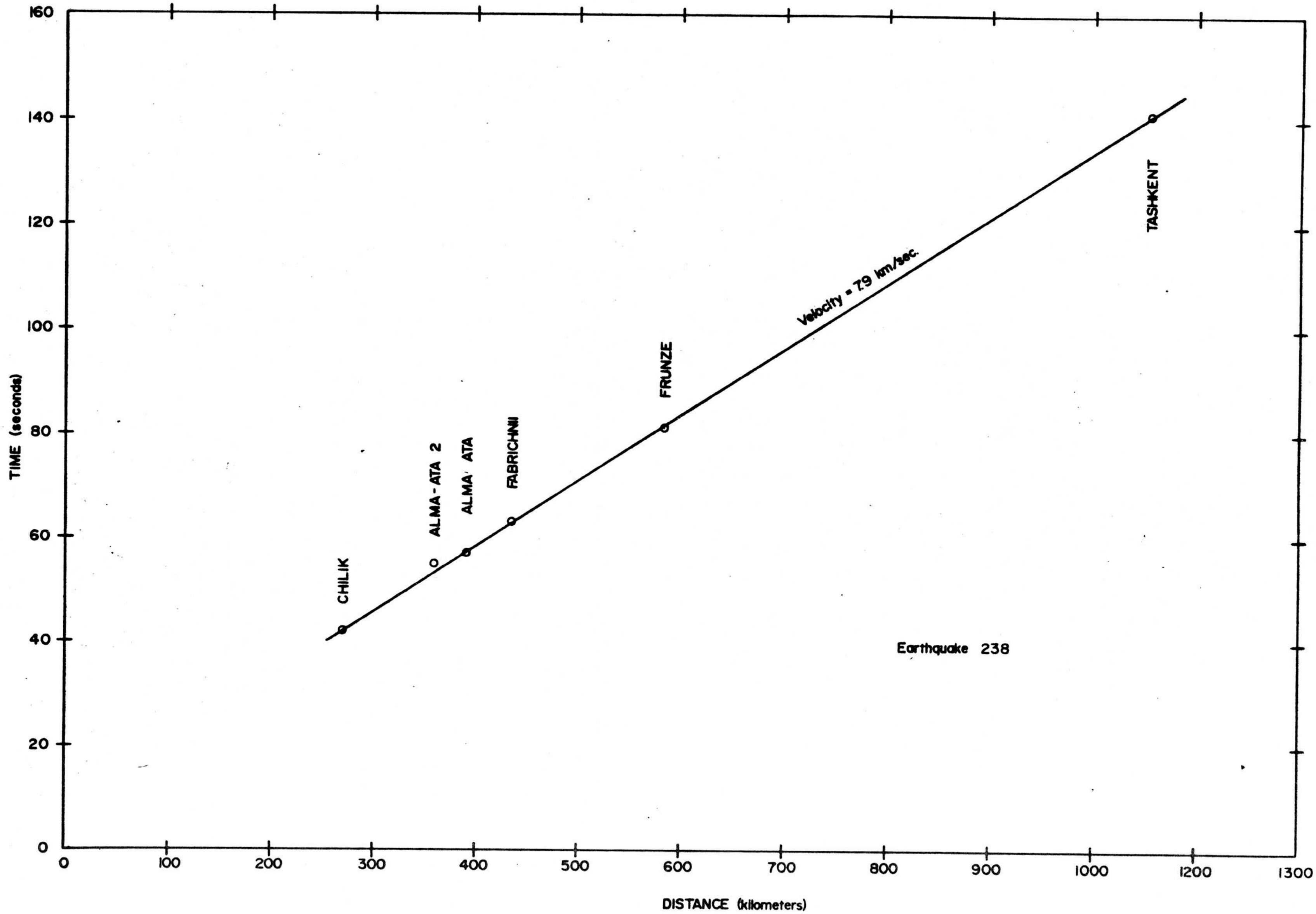

Figure 22.--Travel-time curve for earthquake 238 constructed from data in Soviet earthquake bulletins.

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