UCRL-CR-103612
PREPRINT

ANALYSIS OF SOVIET SEISMICITY CATALOGS

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This paper was prepared for Lawrence Livermore National Laboratory.

February 1990

Lawrence Livermore National Laboratory

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Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

UCRL-CR--103612

DE90 011462

RDA-TR-003501-001

Analysis of Soviet Seismicity Catalogs

BY:
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FEBRUARY 1990

Final Report

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SECTION 1
BACKGROUND

In any negotiations between the United States and the U.S.S.R. regarding possible new test ban treaties, the utility of in-country seismic monitoring stations for treaty verification will be a topic of considerable interest. Under either a LYTTBT or a CTBT it would likely be in the U.S. interest to deploy seismic stations in U.S.S.R. Considerable work has already been done to define station distribution, station types, and sensitivity required for in-country monitoring. Considerably less work has been done to define the overall monitoring system, processing load, and throughput requirements under various possible treaty regimes. Indeed, current evaluations of the numbers and types of events to be processed by such a system are on the order of a decade old and are based on the assumption of monitoring a CTBT. Furthermore, proposed algorithms for discrimination between earthquakes and underground nuclear explosions have yet to be fully tested against a realistic data set which accurately reflects what the in-country monitoring conditions would be like in the Soviet Union. A full design of any proposed monitoring system should be based on the best available evaluation of processing throughput requirements and the adequacy of current processing algorithms.

At the request of the Treaty Monitoring Program at Lawrence Livermore National Laboratory (LLNL) RDA has conducted a new evaluation to determine as accurately as possible the seismic activity rates and distributions of seismicity, magnitude, and depth for various geographic and geologic regions in the Soviet Union. With this information in hand, LLNL personnel can examine ability to meet the verification goals of a given treaty regime by testing proposed processing systems using a valid synthetic data set constructed on the basis of this new best estimate of seismicity characteristics in the Soviet Union.

This report describes the means used to develop this best estimate and the results of the analyses.

SECTION 2
INTRODUCTION

In our determination of seismicity rates, we have made use of the best available seismicity catalogs. The seismic source zones to be used in the later seismicity analyses were then outlined, based on the locations of the Soviet regional networks and then compared with geologic and tectonic maps. In this report we will describe, in detail, the derivation of seismicity rates for each of these zones from seismicity catalogs using methods based on the empirical relation between earthquake magnitude and recurrence derived by Gutenberg and Richter (1954). This relationship is given by

$$\log n(M) = a - b\,M, \qquad (1)$$

When this equation is applied to a set of earthquakes in a magnitude range from M to $M+dM$ then; $n(M)dM$ is the number of earthquakes in that magnitude range, the constant a is related to the rate of earthquake occurrence, and the constant b is related to the relative distribution of small versus large earthquakes. Given a catalog of n earthquakes, the constant b (known as the b-value) can be estimated by a number of methods. Gutenberg and Richter (1954) used the least-squares technique to fit a straight line in magnitude-log number space to the function $\log n(M)$. Utsu (1965) proposed a new method of estimating b, which was shown by Aki (1965) to be the maximum-likelihood estimate. Aki (1965) also showed how to calculate confidence limits on the estimate for a given sample. Utsu (1966) then derived an exact form for the probability density function for the value of b and derived a method to test the statistical significance of the difference between two different populations of earthquakes.

SECTION 3
METHODOLOGY

3.1 MAXIMUM LIKELIHOOD METHOD (MLM).

Utsu (1965) derived an estimator for the b-value given by

$$b = \frac{\log_{10}(e)}{\bar{M} - M_{min}}, \tag{2}$$

where $\bar{M}$ is the mean of the sample population and M_{min} is the minimum magnitude in that population. Aki (1965) showed that this estimator was the maximum-likelihood estimate for b and that the 95% confidence limits of this estimate could be derived from

$$\frac{(1 - d_\epsilon/\sqrt{n})}{\sum^{n_1} M_i/n - M_0} \le b' \le \frac{(1 + d_\epsilon/\sqrt{n})}{\sum^{n_1} M_i/n - M_0}, \tag{3}$$

where b' = b/log(ε) and d_ε = 1.96 for ε = 95%. This result was derived using the central limit theorem, assuming large numbers of earthquakes in the sample. Utsu (1966) then expanded upon this work and derived an exact representation for the probability density function for b for any size population. Utsu's results agreed with Aki's for sample populations greater that 50, but were extended down to sample sizes as small as 7. Using Utsu's results, one can estimate the significance of any difference in b-value between two samples by comparing the ratio of the two b-values to the F-value (at a given confidence level) which has degrees of freedom equal to those for each b-value estimate. Values of a were determined, once the MLM estimate of the b-value was made, using a least- square fit with the slope fixed to the derived b-value. In this case, b was fixed at the MLM value, and the best fitting a was solved for, given the slope b.

SECTION 4
DATA SETS

Any effort to accurately determine seismicity rates for a given area is highly dependent on the quality of available seismicity catalogs. In order to estimate a- and b-values for a given tectonic region, a geographic area must be defined that contains all reported earthquakes generated by faults (or other seismogenic zones) associated with that tectonic regime, and the limiting magnitude above which each catalog is believed to be complete (i.e. the magnitude above which no earthquakes are believed to have been excluded) must be established.

For the Soviet Union, the compilation of a catalog that is nominally complete for the entire country may prove to be impossible. However, RDA has utilized a number of sources to compile the most complete catalog available in the U.S. A number of catalogs, including the annual report of Earthquakes in the U.S.S.R. for 1973-1979 (Helterbran, 1985) are commonly available. These data sets, unfortunately, are not very complete. The RDA catalog consists of these and, in addition, a copy of a composite catalog obtained from researchers at the O. Yu. Schmidt Institute of Physics of the Earth (UPE) in Moscow. This composite catalog covers from 1900 through 1984 and is based (among other regional catalogs) on the following sources:

BCI	Bureau International de Seismologie, Strasbourg
EDF	Earthquake Data File of NGDC/NOAA
EMC	Catalog of the EMSC, Strasbourg
FFF	Fixed Format File of ISC
IPE	New Catalogue of Strong Earthquakes in U.S.S.R.,
ISC	Regional Catalogue of the International Seismological Centre
ISS	International Seismological Summary
JMA	Bulletin of Japan Meteorological Agency
K-A	Various Publications by H. Kanamori, K. Abe, R. Geller
LEE	W.K.H. Lee, 2 Catalogues of Earthquakes in China
MOS	Annual Bulletin "Earthquakes in the U.S.S.R."
SJD	S.J. Duda and M.Bath
SYK	Various Catalogues by R.L. Sykes
USM	R. Usami "Major Destructive Earthquakes In and Around Japan"
VKR	V. Karnik "Seismicity of the European Area"

The data from IPE were obtained on five 9-track magnetic tapes with about 50-60 Megabytes of data on each. Because the data were written to tape on an IBM-PC compatible computer, there were some difficulties in reading and decoding. RDA developed computer codes to read all of the tapes and unblock them so as to be readable on a Unix based computer. The resulting catalog comprises the best source of seismicity data about the Soviet Union that we know of. The entire data set for a large region around the Soviet Union is shown in Figure 1. The data were broken down into multi-year files starting with historical seismicity from 0 AD up to 1900 AD. Figures 2 through 7 show the data for each time period. For the historical seismicity and, indeed, the first half of the twentieth century, the catalog is only complete at moderately high magnitudes. In 1962, however, it appears that the Institute of Physics of the Earth began a program to document seismicity throughout the Soviet Union in a much more complete fashion. This is evident in figure 8 which shows the reported magnitudes as a function of time for the composite catalog for the last thirty years. The overall distribution of these events as a function of depth is shown in figure 9.

A question that arose early in the examination of this data set was how much of the data were new. In order to evaluate this, we extracted all epicenters that were attributed to the ISC or PDE. These epicenters are shown in figure 10. Of the approximately 98000 events in the composite catalog, about 12000 are attributable to the ISC or PDE and over 36000 are small events from the internal regional networks.

SECTION 5
TECHNICAL APPROACH

The first step in analyzing the seismic activity rates in the Soviet Union was to compile this composite catalog based on our best sources. The next step was to extract the data for events located in the U.S.S.R. and to plot seismicity maps. These maps show the overall pattern of seismicity in the Soviet Union based on internal and external stations. We then further subdivided the seismicity based on the Soviets' own regionalization scheme:

REGION CODE:	
CRP	Carpathians
CRM	Crimea and Lower Kuban
CAU	Caucasus
TRM	Turkmenia (Kopetdag)
MAK	Middle Asia and Kazakhstan
NTS	Northern Tien-Shan
ALT	Altai and Sayany
BK	Baikal
N-E	Northeast of the U.S.S.R.
YAK	Yakutia
PRM	Primorie Amur
SKH	Sakhalin
KRL	Kuril Islands (Far East)
KMC	Kamchatka and Komandor Islands
ARC	Arctic and Chukotka

5.1 CALCULATIONAL METHOD.

The maximum-likelihood estimator derived by Aki for b-values was used in deriving b-values for all zones. In an earlier study, (Scheimer and Mills, 1984) it was found that for cases in which many earthquakes were in a set of data for a zone the results from either the least-squares or maximum-likelihood approaches were quite comparable. When the distribution became a slightly abnormal or only a few earthquakes were included, the maximum-likelihood estimator for b-value seemed to be much more robust. For this reason, we have used the maximum-likelihood estimator for b-value calculations and have used the least-squares estimator for determining the a-value in :

$$\log n(M) = a - b\,M, \qquad (1)$$

When we have our best estimate of b, we can use this slope to project to low magnitudes (e.g. 2.0 and below) what the value of n(M) will be. Furthermore, with the ability to calculate confidence limits on the estimate, the range over which n(M) varies at low magnitudes can be identified. the fact that the b value can vary from tectonic region to region is well known and this may be extremely important in estimating data processing loads for various treaty regimes.

5.2 SELECTION OF DATA SETS.

The original intent of this project was to compile all of the seismicity data into a single catalog and then to select from this catalog events in a given geographic region which could be associated with known tectonic regimes in the Soviet Union. When this was done, however, the b-value estimates were extremely unstable, depending a great deal on the lower magnitude threshold chosen and the size of the magnitude bins (dM). A close examination of the dataset revealed a very high degree of variability in seismic detection thresholds over the Soviet Union. Further examination revealed that the detection threshold for a given region (as identified in the IPE catalog) was much more stable. From these observations we inferred that the identification of a given source region in the IPE cataloge was more likely to refer to the regional network that supplied the data than a geologically defined region. This inference was further borne out by the fact that a number of events were found which had been reported to be from more than one region. Examination of such events showed that one set of reported hypocentral parameters was chosen to be the master event in the catalog, and the others were identified as duplicates. We, therefore, redirected our analysis effort and based our examination of seismicity rates on each regional network which contributed to the overall IPE catalog.

5.3 DATA PROCESSING.

In most cases, the bulk of information about seismicity in a given area comes from the regional network data. The only regions of the USSR which had significant numbers of events contributed by the ISC catalog were the Caucasus, Kamchatka, Kuril, and Turkmenia. In contrast, the data for the Northeast of the USSR, Lake Baikal, Siberia, and Middle Asia are based solely on the IPE regional network catalogs. Data for each regional network were extracted from the master catalog and scanned for any duplicate records. We based our choice of which set of hypocentral parameters to use on flags in the data records which were provided by IPE, indicating their choice of the best solution to use. Epicentral maps, depth distribution histograms and plots of reported magnitudes versus time were then produced for each catalog. b-values were calculated using the Maximum-Likelihood method as implemented in an algorithm originally developed by Willie Lee of the USGS.

A range of dM's were tried in calculating the b-values. Using a dM smaller than .2 magnitude units does not appear to be a good choice. This is apparently due to the magnitude derivation methodology used by the IPE. The internal networks report an estimate of the "K" value, an estimate of the energy in released by the earthquake. A standard formula is used to convert from K to Ml for events from all of the internal networks, but the precision of the resulting magnitude distribution varies. For example, if the Middle Asia network estimates K to the nearest 1/10th, then the resulting M's may be calculated to the nearest .1 magnitude units. However, if another network only calculates K to the nearest whole number, the resulting magnitudes might only be calculated to the nearest 1/2 or whole magnitude unit. A dM of .25 was found to be most stable for all of the regions except Kuril, Northeast, and Siberia, for which a value of .2 was used.

Because of the differing detection thresholds for each network, a range of magnitudes were used as the lower cut-off in calculating the b-values. For magnitudes below the level where the catalog is complete, b-values will vary widely as the cut-off value is slowly increased. Above the level where the catalog is complete, the b-value will vary more slowly and the b-value estimates will cluster around the best-fit line that the human analyst would pick by eye. The actual b-value estimate for each region was based on visual analysis of the cumulative magnitude distribution plot, the behavior of the b-value estimates as a function of lower magnitude cut-off, the estimated uncertainty in the b-value estimate, and evaluation of the completeness of the catalog at each cut-off level.

SECTION 6
ANALYSIS RESULTS

6.1 SUMMARY OF b-VALUES FOR ALL REGIONS.

Table 1 summarizes the results of our analyses for all of the regions.

TABLE 1

Region	b-value	95% Conf. Limit	Number of Events Used	Overall	a-value
Altai and Sayany	0.975	0.068	787	2,215	6.105
Arctic and Chukota	0.795	0.218	51	88	4.204
Baikal	1.484	0.069	1,763	6,277	8.262
Carpathians	0.815	0.154	107	273	5.012
Caucasus	0.779	0.032	2,274	6,254	5.597
Crimea	0.812	0.205	60	60	3.748
Kamchatka	0.848	0.021	6,370	12,106	6.452
Kola Peninsula	0.766	0.262	33	35	4.202
Kuril	1.077	0.047	2,063	11,957	9.104
Middle Asia	0.857	0.013	30,118	32,047	7.688
North Tien Shan	1.251	0.181	184	3,568	5.061
Northeast USSR	1.017	0.180	123	1,426	6.595
Russian Platform	0.912	0.264	46	116	5.813
Primorie and Amur	1.091	0.122	308	533	5.485
Sakhalin	1.146	0.237	90	470	6.825
Siberian Plateau	1.492	0.345	33	85	8.430
Turkmenia	1.298	0.046	2,949	3,140	7.059
Yakutia	1.442	0.189	223	224	6.329
Mean Value:	1.044	0.147			6.221
		Total:	47,575	80,865	

6.2 ANALYSIS RESULTS BY TECTONIC PROVINCE.

There are eleven tectonic provinces in the U.S.S.R. (See Figure 11 from Samowitz and Hadley, 1980.) The provinces are:

Ukrainian Shield
Russian Platform
Urals
West Siberian Platform
Siberian Platform
Pacific Transitional Zone
Crimea-Caucasus
Kazakh
Baikal Rift Zone
Central Asia
Baltic Shield

Due to the differences in reporting standards by the various regional networks, we were not able to extract uniform catalogs for each region. However, all regions are addressed by various combinations of data from the various regional catalogs. In the following sections we will discuss the results for these combinations.

6.3 SIBERIAN PLATFORM AND BAIKAL RIFT ZONE TECTONIC PROVINCES. We will consider the Siberian Platform and the Baikal Rift Zone together since the seismicity catalogs for these regions overlap substantially. Data for the Siberian Platform are provided by the Northeast, Baikal, Primorie, Yakutia, Arctic and ISC catalogs. Data for the Baikal Rift Zone is provided by the Baikal catalog alone.

Results for the Baikal Rift Zone are summarized in Figures 12a, 12b, 12c, and 12d. The reported epicenters at the western end of the region overlap with data from the Altai and Sayany network which is considered part of the Central Asia tectonic province (see Figure 12a.). The Baikal Rift Zone exhibits the second highest b-value of any region in the composite catalog, $b = 1.48 \pm .07$ (see Figure 12b.). The lower magnitude cut-off was set at 3.25 even though there are portions of the catalog with lower reported magnitudes (see Figure 12c.). Virtually all of the seismicity is shallower than 100 km. The depth distribution is dominated by events fixed at a depth of 33 km from teleseismic locations (see Figure 12d.).

Results for the entire northeast of the U.S.S.R. which are all part of the Siberian Platform Tectonic Province are summarized in Figures 13a-d through 17a-d. The northeast catalog overlaps the Yakutia catalog completely. The Yakutia catalog was apparently produced by a network that operated only from 1962 through 1972. Both the Yakutia catalog and data extracted for the Siberian Plateau exhibit a very coarse quantization of reported magnitudes, e.g. whole magnitude units between reported levels. Both of these regions show high b-values on the order of 1.4 to 1.5 with large uncertainties. Due to the peculiarities of the catalogs (high cut of values of 4.7 and coarse magnitude quantization) and the small numbers of events, these b-values should be considered to be somewhat suspect. On the other hand, the b-values for the Altai and Sayany, Northeast, and Primorie and Amur catalogs appear to be much more reliable, with a common value of essentially b = 1.0. These values are essentially indistinguishable from the b = .8 ± .22 value for the Arctic catalog which is very sparse. Depths for all catalogs are shallower than 100 km with the exception of one event reported at 150 km in the Siberian Plateau.

6.4 PACIFIC TRANSITIONAL ZONE TECTONIC PROVINCE.

The Kamchatka, Kuril, and Sakhalin catalogs provide the data for this tectonic province. Results for Kuril and Sakhalin are summarized in Figures 17a-d and 18a-d. b-values for the Kuril and Sakhalin catalogs are essentially the same. The Kuril b-value is 1.08 ± .05 based on over 2000 earthquakes. The b-value for Sakhlin Island is 1.15 ± .24 based on only 90 earthquakes. Both of these regions are dominated by shallow seismicity, but events are reported as deep as 500 km (See Figures 17c and 18c.).

The seismicity rate for the Kamchatka Peninsula appears to be significantly different than for the Kuril and Sakhalin Islands. The Kamchatka value is b = .85 ± .02. The Kamchatka catalog appears to be quite complete since 1968 (See Figure 19c.) with significant activity down to a depth of about 200 km (See Figure 19d.).

6.5 KAZAKH AND CENTRAL ASIA TECTONIC PROVINCES.

The eastern end of the Central Asia Province is covered by the Altai and Sayany catalog. The Middle Asia and North Tien Shan catalogs cover both the central portion of the Central Asia Province and the southern end of the Kazakh Province. The western end of the Central Asia Province is covered by the Turkmenia catalog.

The Altai catalog shows seismicity characteristics much like those in the Siberian Platform. The b-value is .98 ± .07 with most of the seismicity occurring shallower than 100 km. The Northern Tien Shan catalog covers an area embedded within the larger Middle Asia catalog region. We speculate that this data is from the USGS installed network in the vicinity of Garm, Tadjikistan. The USGS network covers a rather limited area around Garm, using only vertical component stations and is intended for microearthquake monitoring. Figure 21c. shows that this network has not reported any events above magnitude 3.5 since 1979. For these reasons, we believe that the results from the Middle Asia catalog are more indicative of the actual seismicity in the central part of the Middle Asia Tectonic Province. For that province, the b-value estimate is .86 ± .01 based on over 30000 earthquakes. The seismicity is well distributed in depth, with most events occurring below 50 km (See Figure 22d.).

The western edge of the Middle Asia Province, abutting the Caspian Sea, is well covered by the Turkmenia catalog. The b-value for this catalog is estimated to be 1.30 ± .05 based on nearly 3000 events. Considering the quality of the Turkmenia and Middle Asia catalogs, the differences in b-values should be considered significant. Furthermore, the earthquakes in Turkmenia are all confined to depths less than 50 km, indicating that there is a real difference from the central portion of the Middle Asia Province.

6.6 CRIMEA-CAUCASUS TECTONIC PROVINCE.

The Crimea and Caucasus catalogs cover this tectonic province. The b-value estimates for these two catalogs are very close, though the number of events in the Crimea with reported magnitudes is very small. As with the Turkmenia events, all seismicity appears to be less than 50 km in depth.

6.7 UKRANIAN SHIELD.

Only the Carpathian catalog covers a portion of the Ukranian Shield Province, and this catalog has only 273 events. The estimated b-value is .82 ± .15. The depth of seismicity, however, is substantially deeper than from the adjacent Crimea catalog, with most events occurring deeper than 100 km.

6.8 URALS AND RUSSIAN AND WESTERN SIBERIAN PLATFORM TECTONIC. PROVINCES.

Due to the low seismicity in these regions, data for the central portion of the U.S.S.R. were extracted to cover all of these provinces. This portion of the catalog contains the only historical seismicity. The figures showing catalog completeness are based on 1900 being the zero year, so Figure 27c. shows an earthquake at about -400, or about 1500 AD. Based on only 46 events, the b-value for these provinces is estimated to be .91 ±.26, with all seismicity occurring shallower than 50 km.

6.9 BALTIC SHIELD.

Data for the Kola peninsula region were extracted to cover the Baltic Shield Province. These data overlap with that used for calculating the b-value for the Urals and Russian and Western Siberian Platform Provinces. More than 1/2 of the events used for these provinces occur on the Kola Peninsula. Removing the Kola events and processing them by themselves results in a b-value estimate of .77 ± .26, which can not be distinguished from the .91 ± .26 value derived for the central USSR provinces.

SECTION 7
CONCLUSIONS

Over the broad range of the central USSR through Siberia, the b-value is approximately 1.0. For these regions the seismicity is generally shallow, so depth may not be a reliable discriminant between earthquakes and explosions. While the b-values for these regions do not vary much, the a-values vary considerably, reflecting differences in the overall numbers of earthquakes occurring. The b-values for other regions show variations which are significant at the 95% confidence limit, such a Middle Asia, the Crimea and Caucasus, and Turkmenia, and Kamchatka. All along the southern border of the USSR, earthquakes appear to occur at greater depths than in the interior, allowing one to exclude many events from further analysis if one is only interested in possible clandestine explosions. A table of depths is provided in the Appendix.

SECTION 8
SUMMARY

Determining seismicity for the U.S.S.R. as a whole and in distinct tectonic regions in the U.S.S.R. will be critical not only to the design and positioning of internal stations, but to the development of a system to treat the data streams and provide the final seismic monitoring product. An accurate description of the characteristics of seismicity in the U.S.S.R. can be used to construct a test data set of synthetic seismograms with realistic magnitude, location and depth distributions for testing current and projected monitoring systems will be overwhelmed, and to identify required improvements to monitoring and processing system that would be needed to accommodate a lower threshold.

SECTION 9
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SECTION 10
FIGURES

IPE Composite Catalog

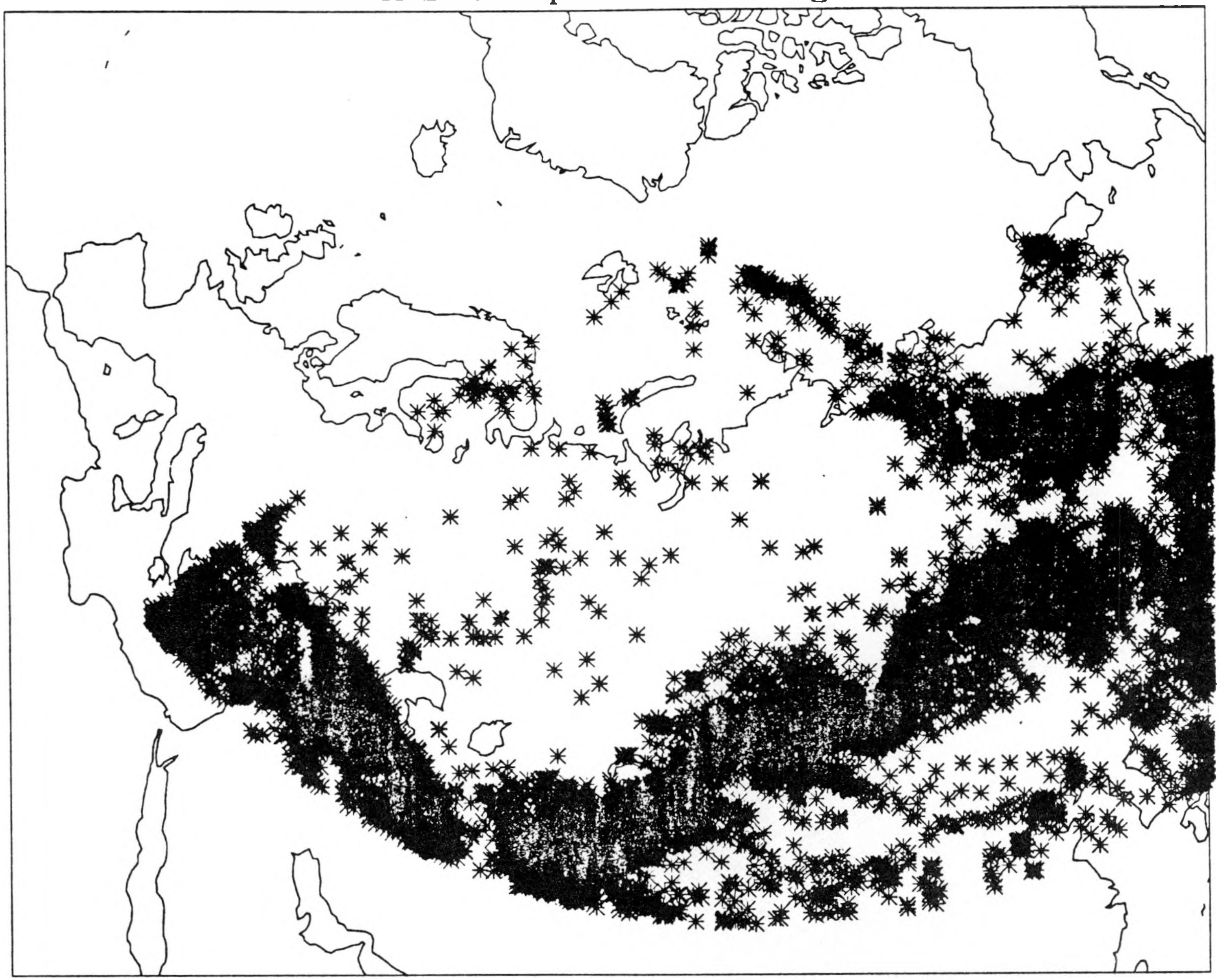

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Figure 1

0-1900

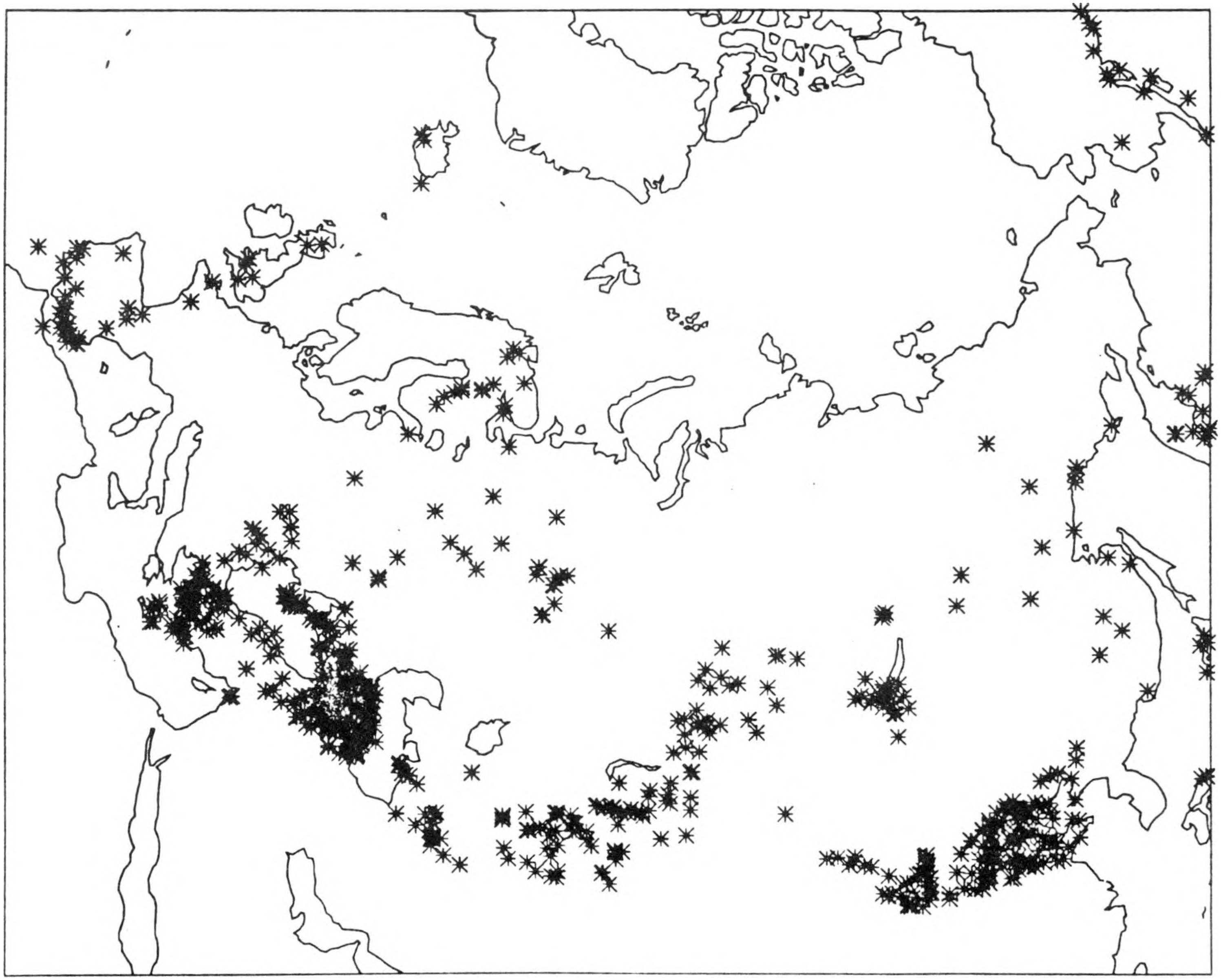

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Figure 2

1901–27

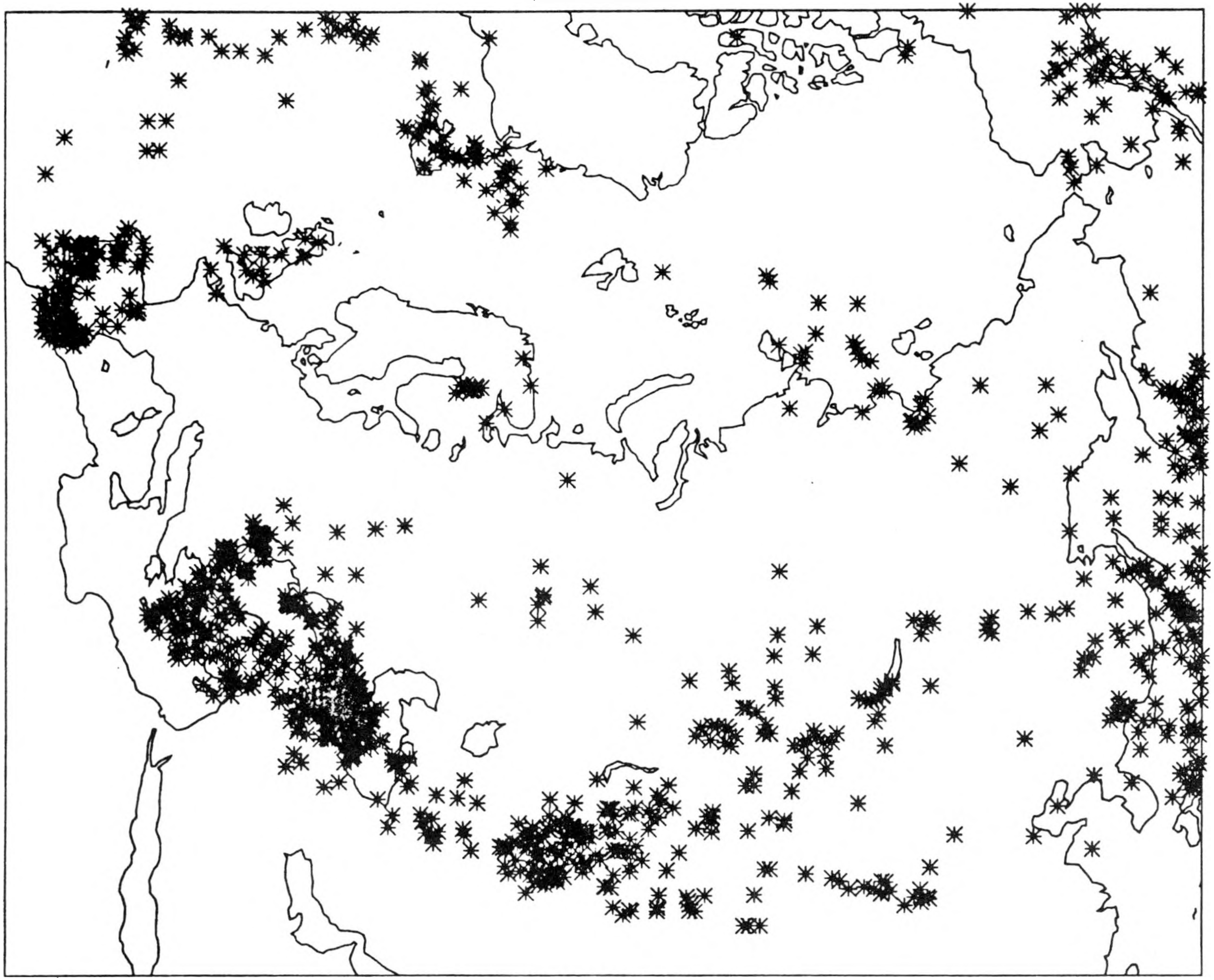

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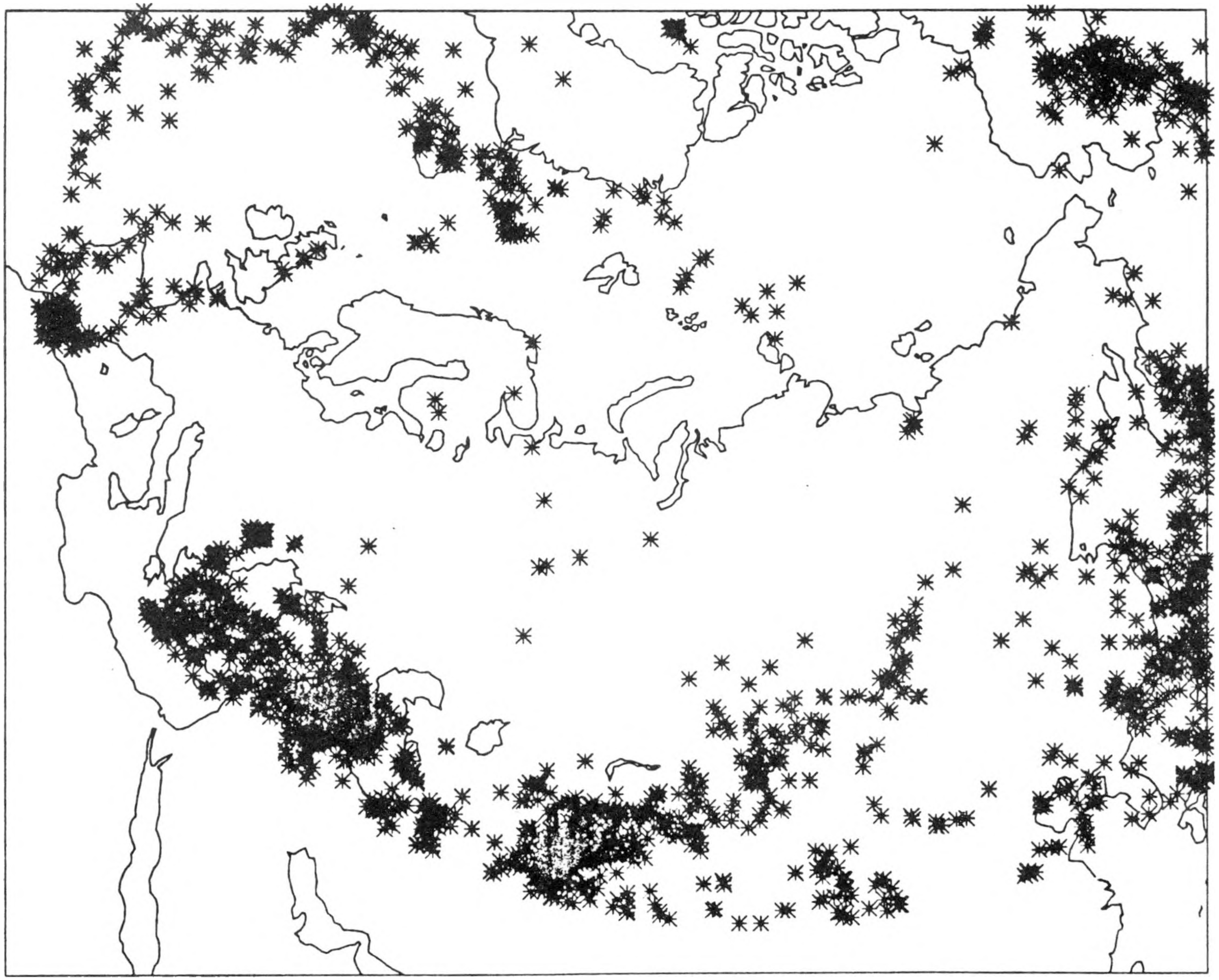
Figure 3

1928-49



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Fiqure 4

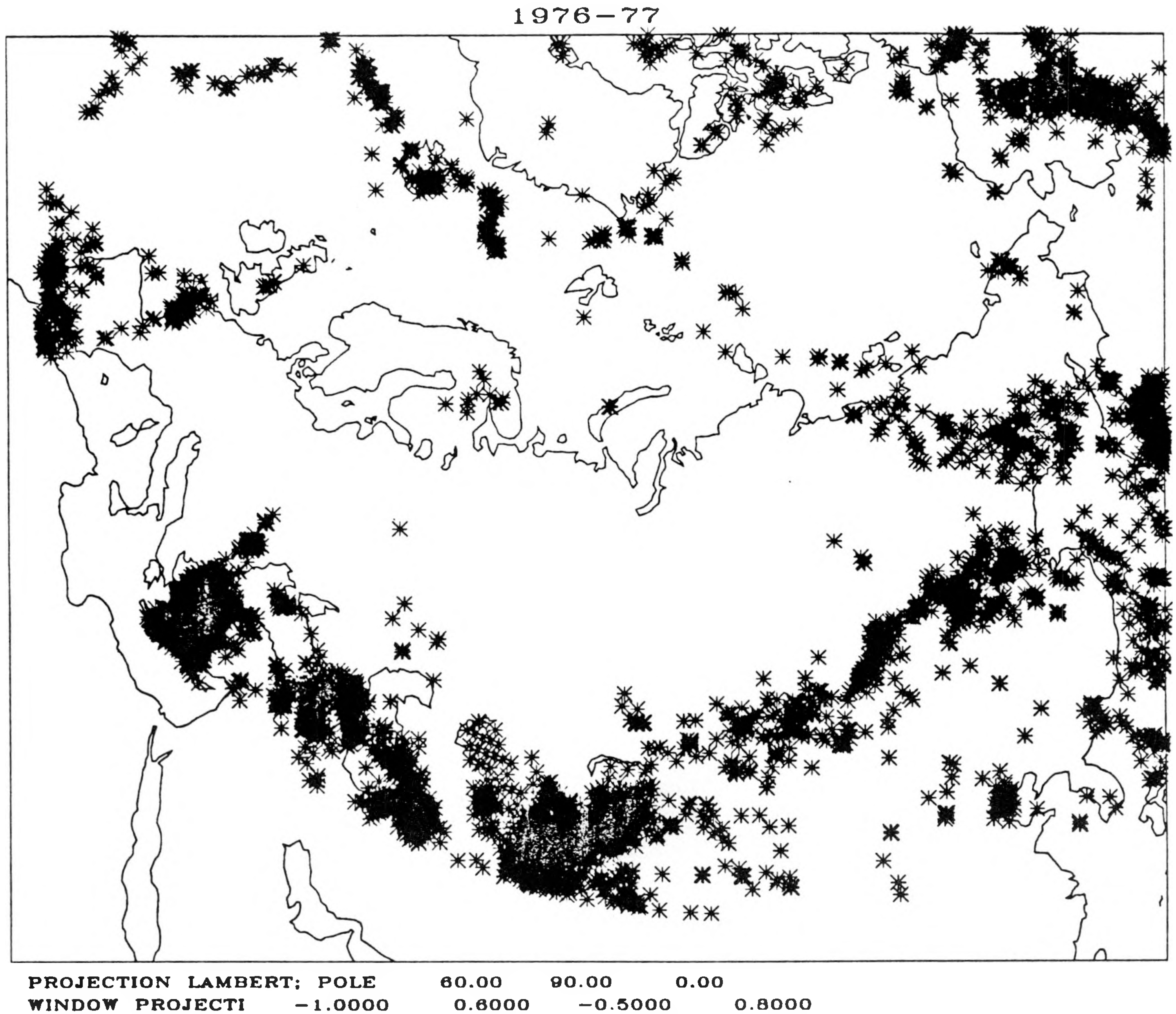
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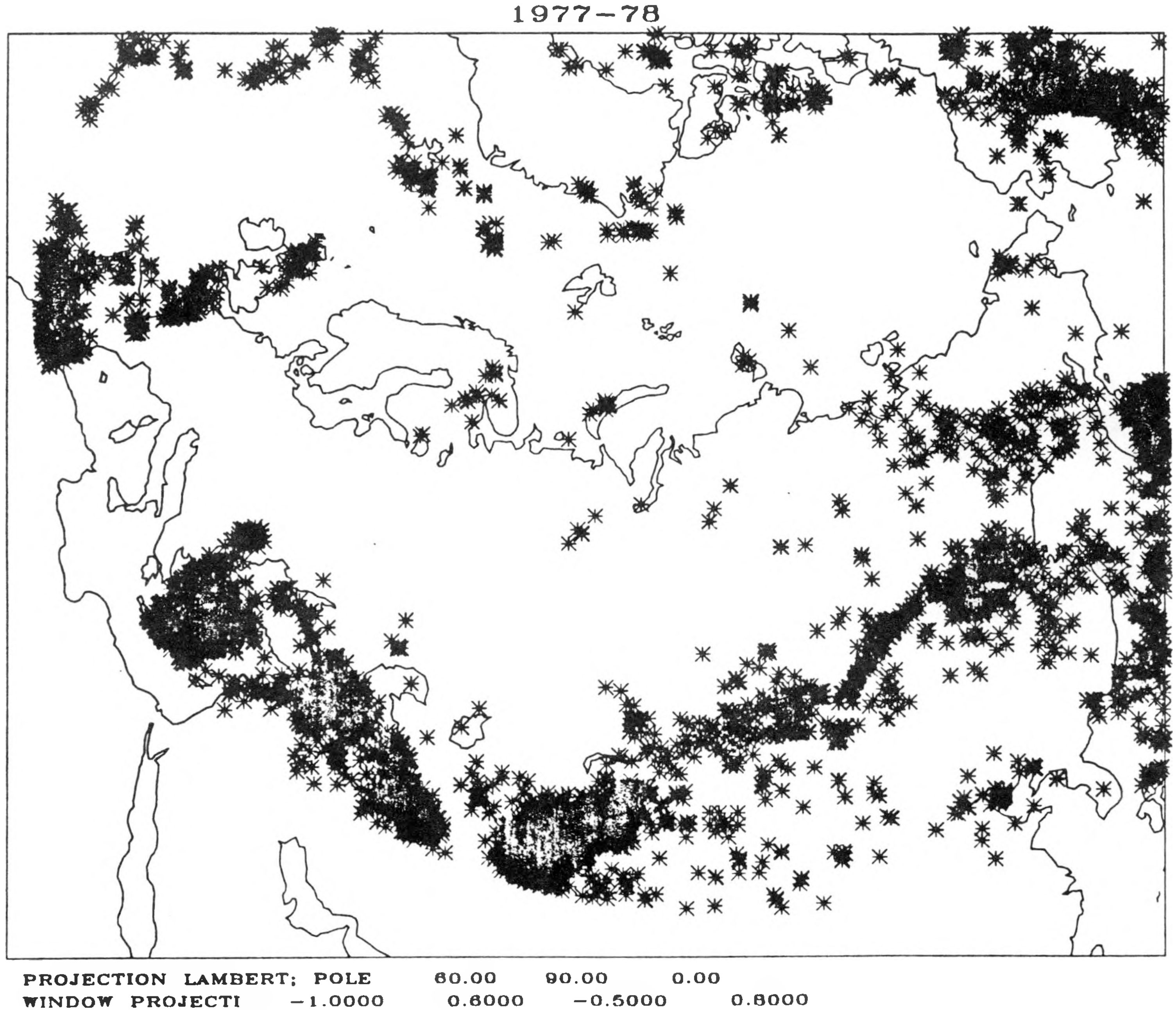
Figure 5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Fiɑure 6

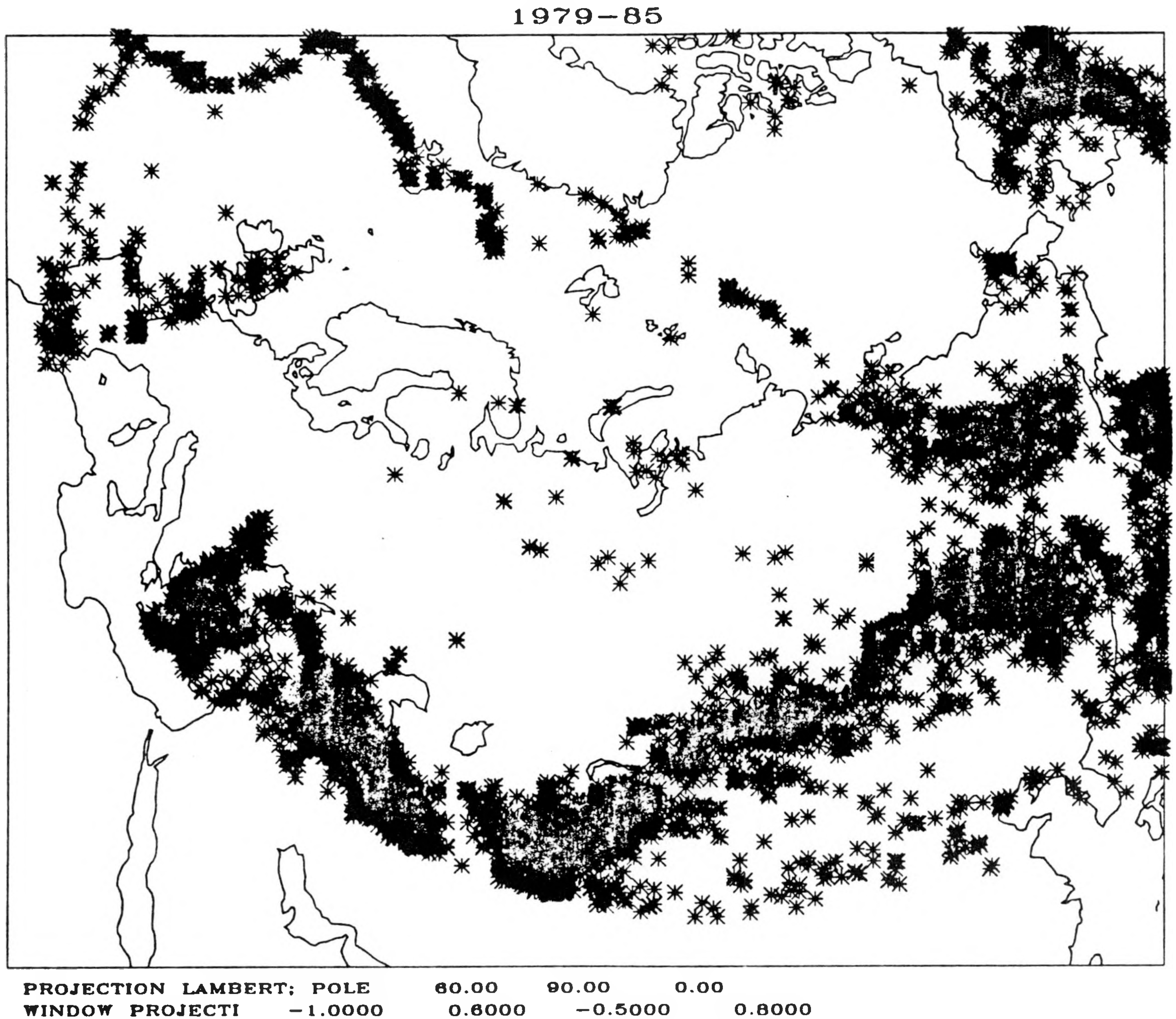
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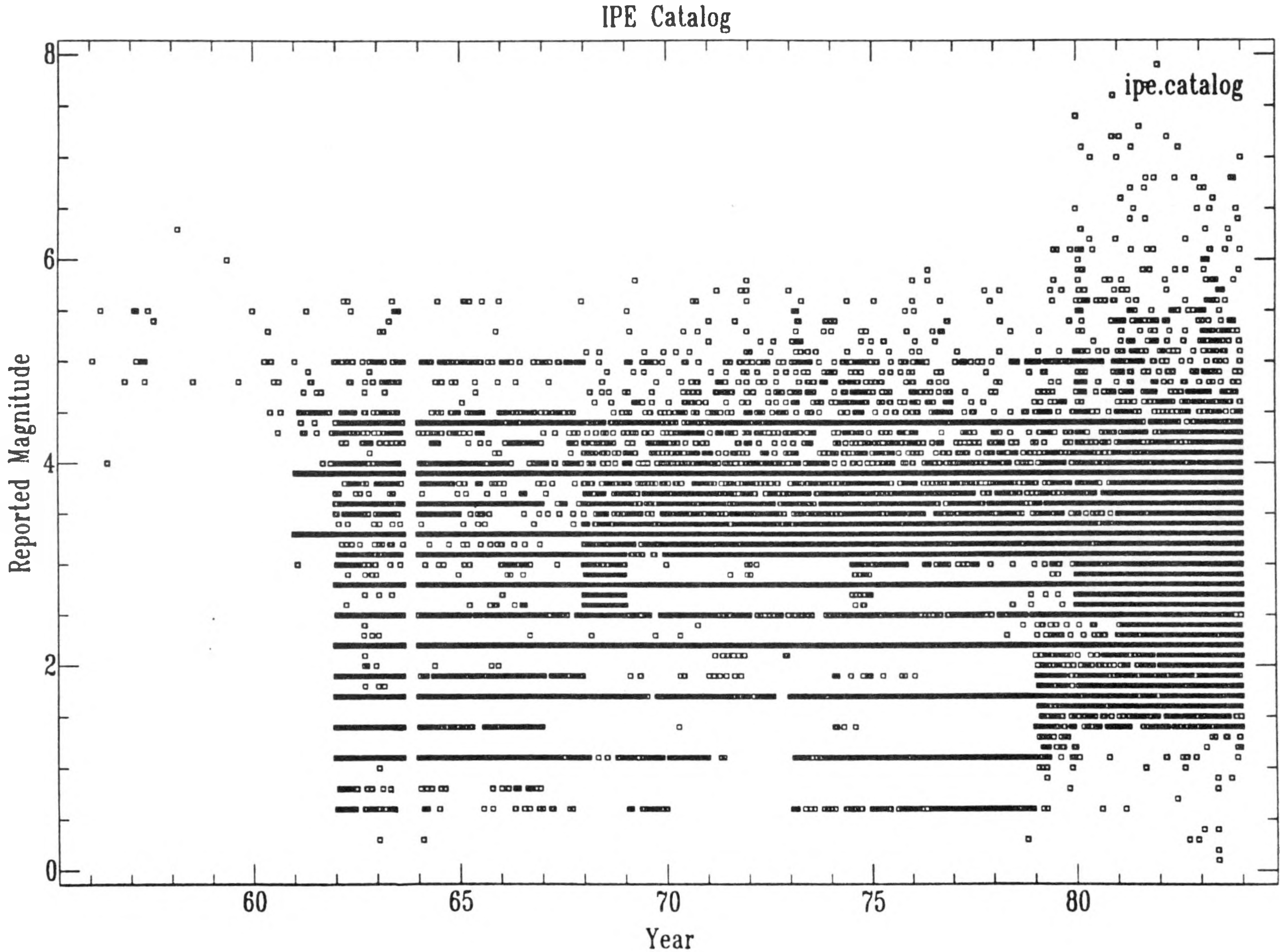
Figure 7



IPE Catalog
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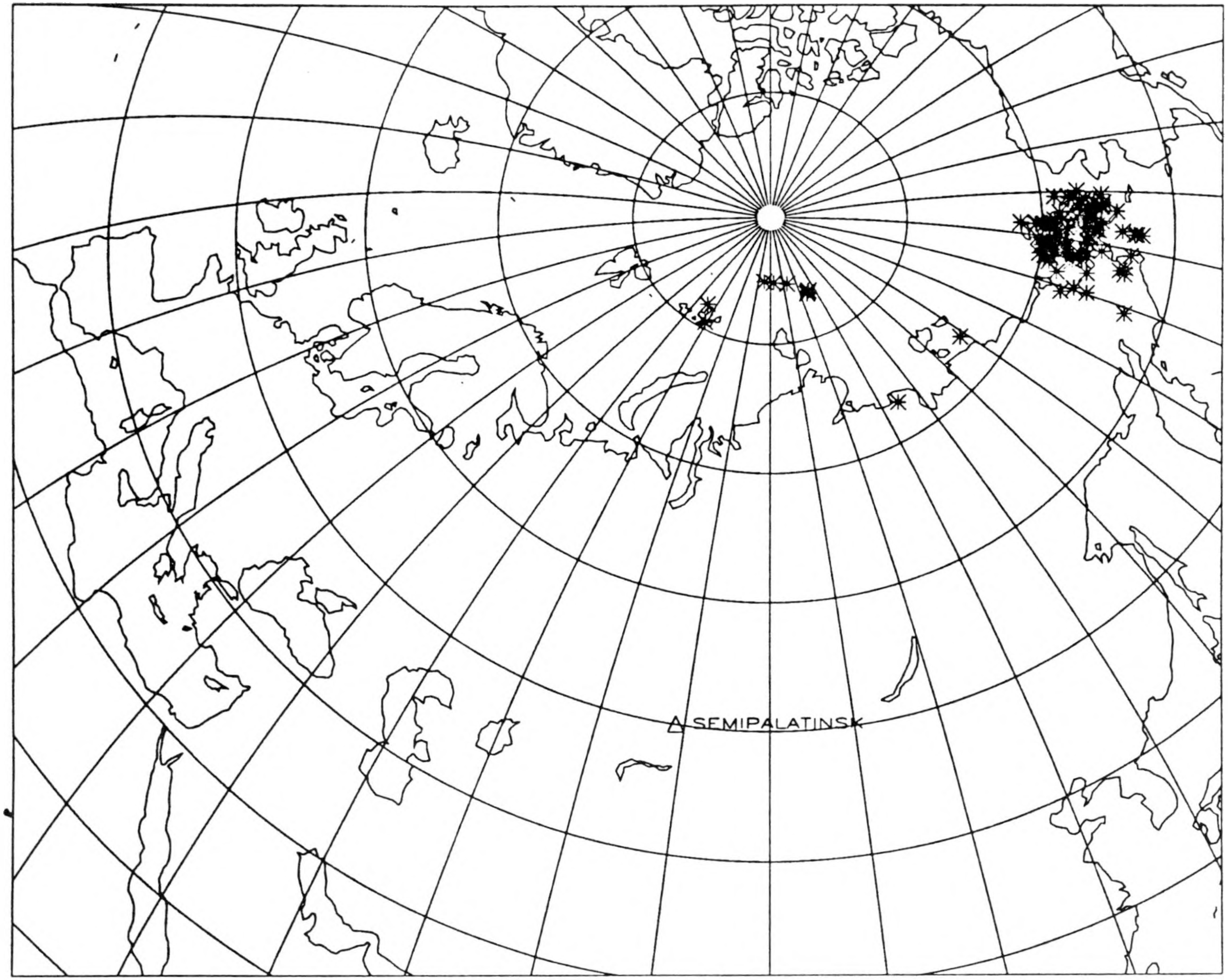
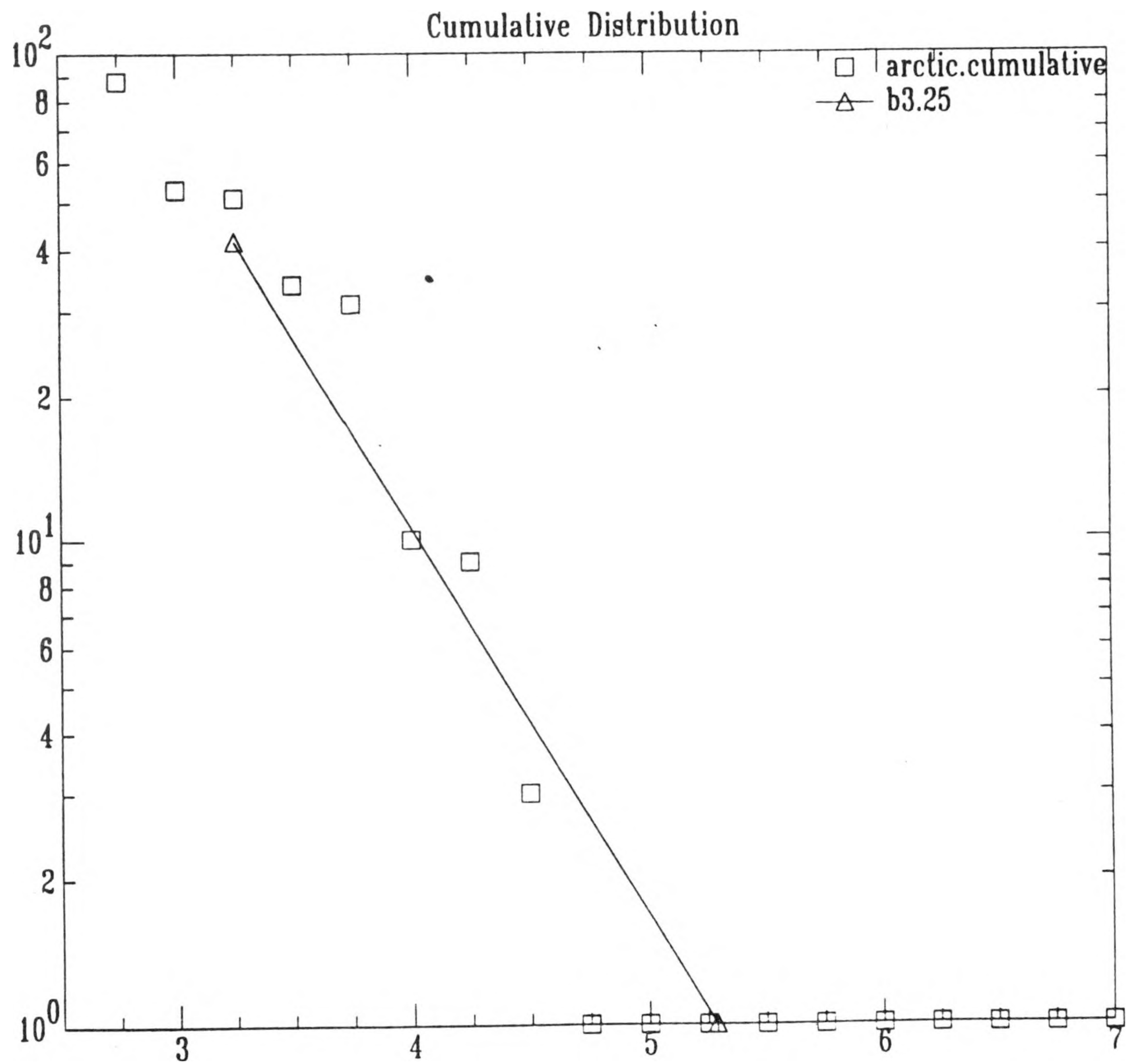
0
2
4
6
8
60
65
70
75
80
Year

Figure 8

Arctic and Chukota



PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000



Cumulative Distribution
arctic.cumulative
b3.25
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6
7

Figure 17b

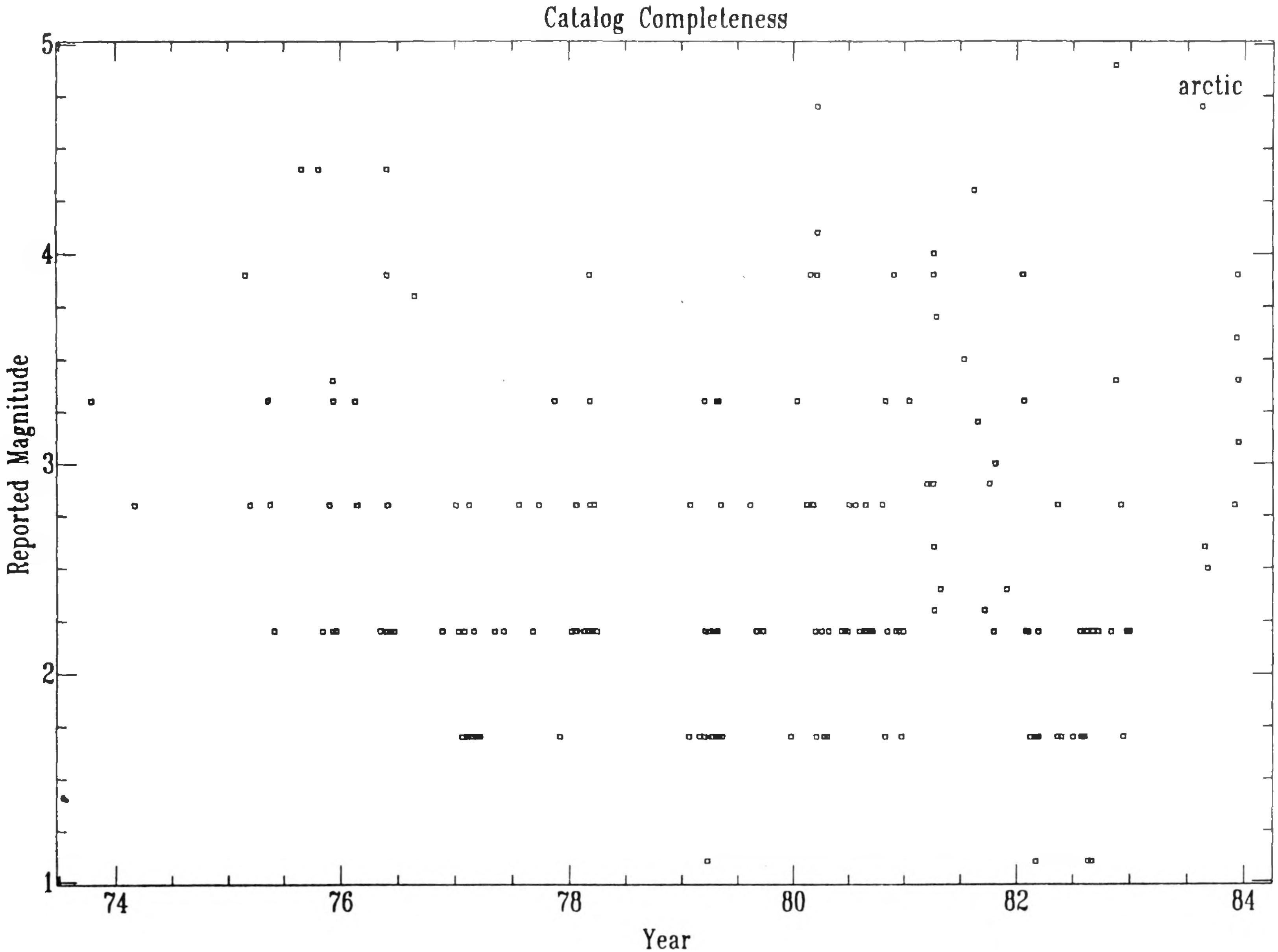

Catalog Completeness
arctic
Reported Magnitude
1
2
3
4
5
74
76
78
80
82
84
Year

Figure 17c

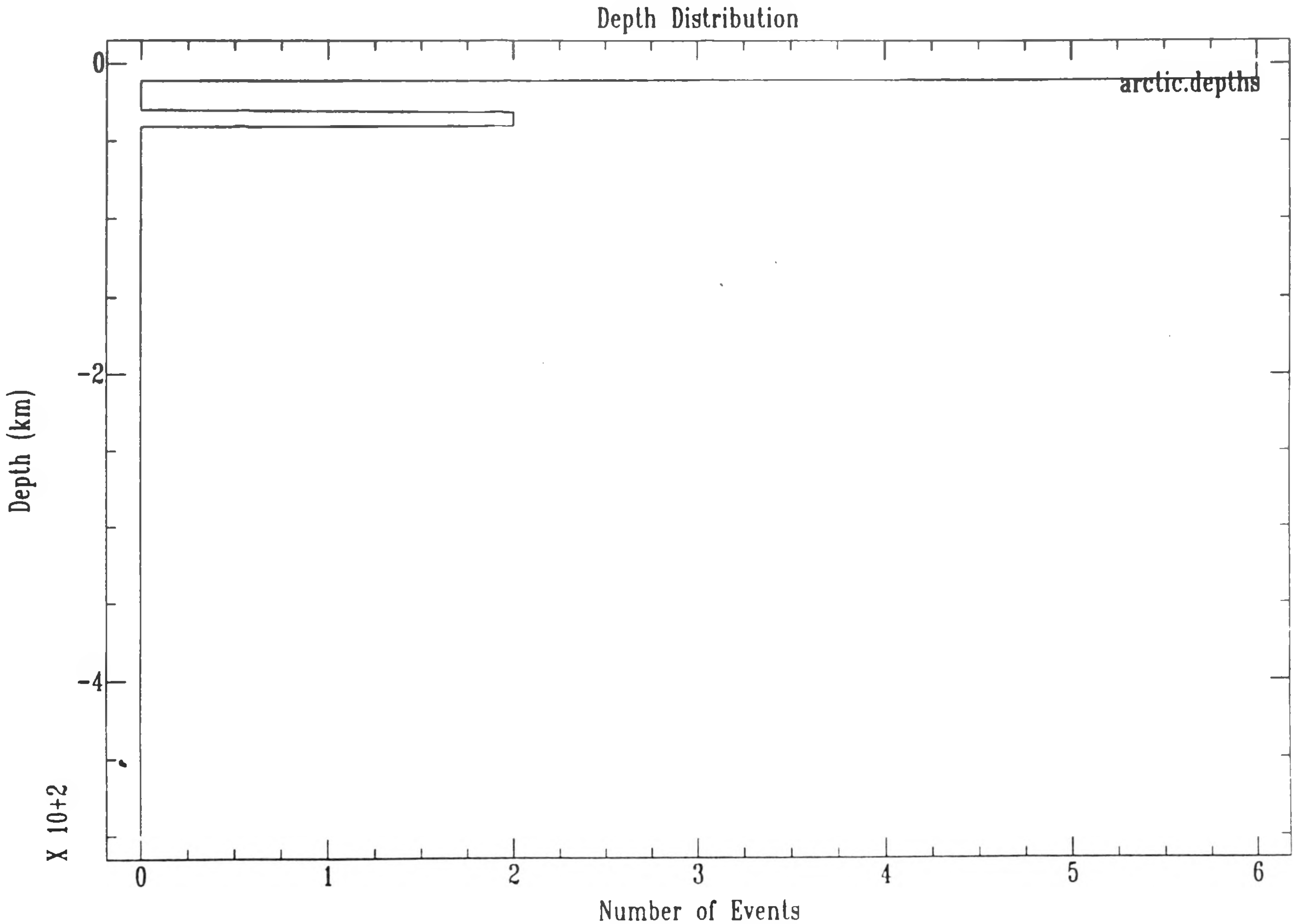
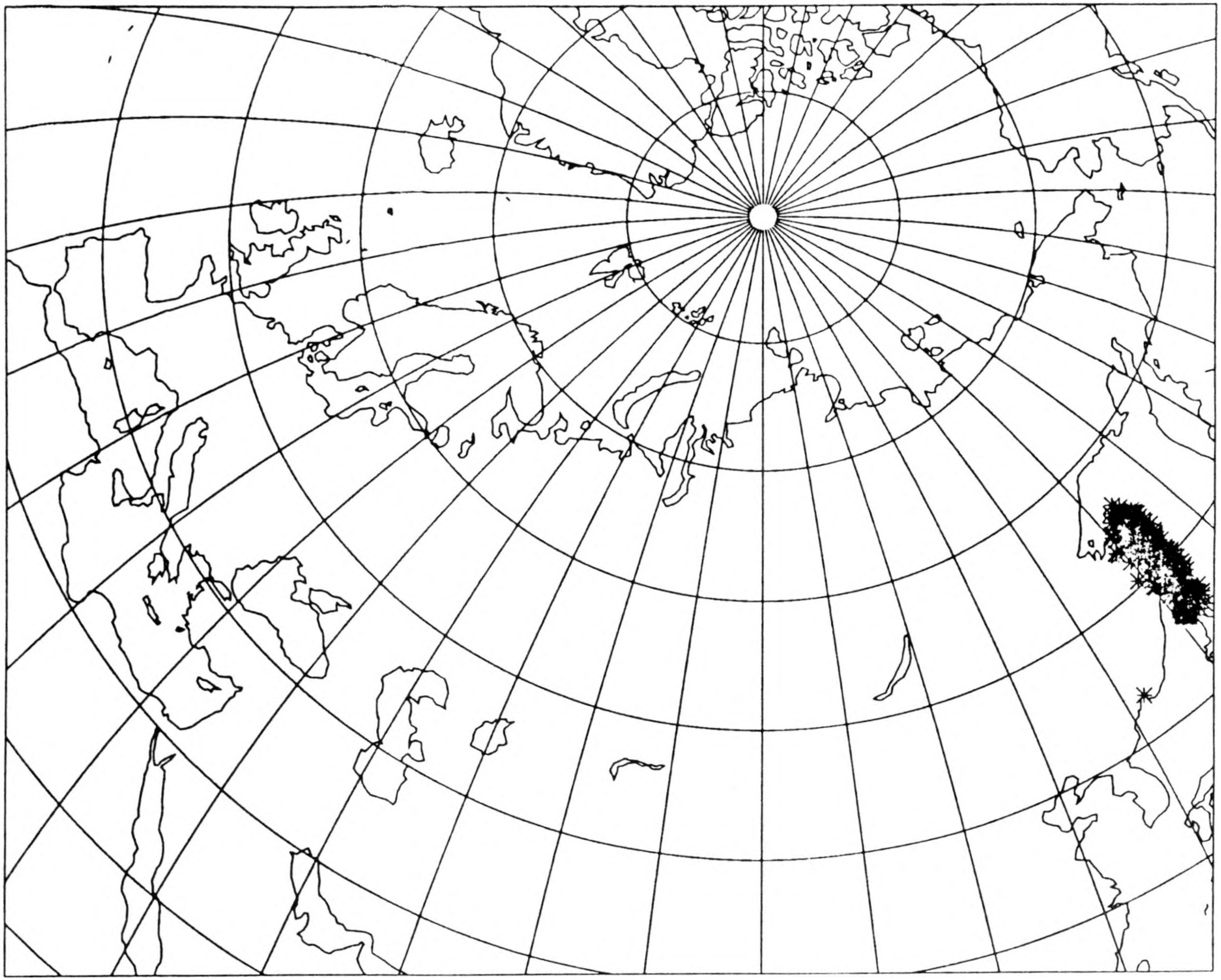

Depth Distribution
arctic.depths
0
-2
-4
X 10+2
Depth (km)
0
1
2
3
4
5
6
Number of Events

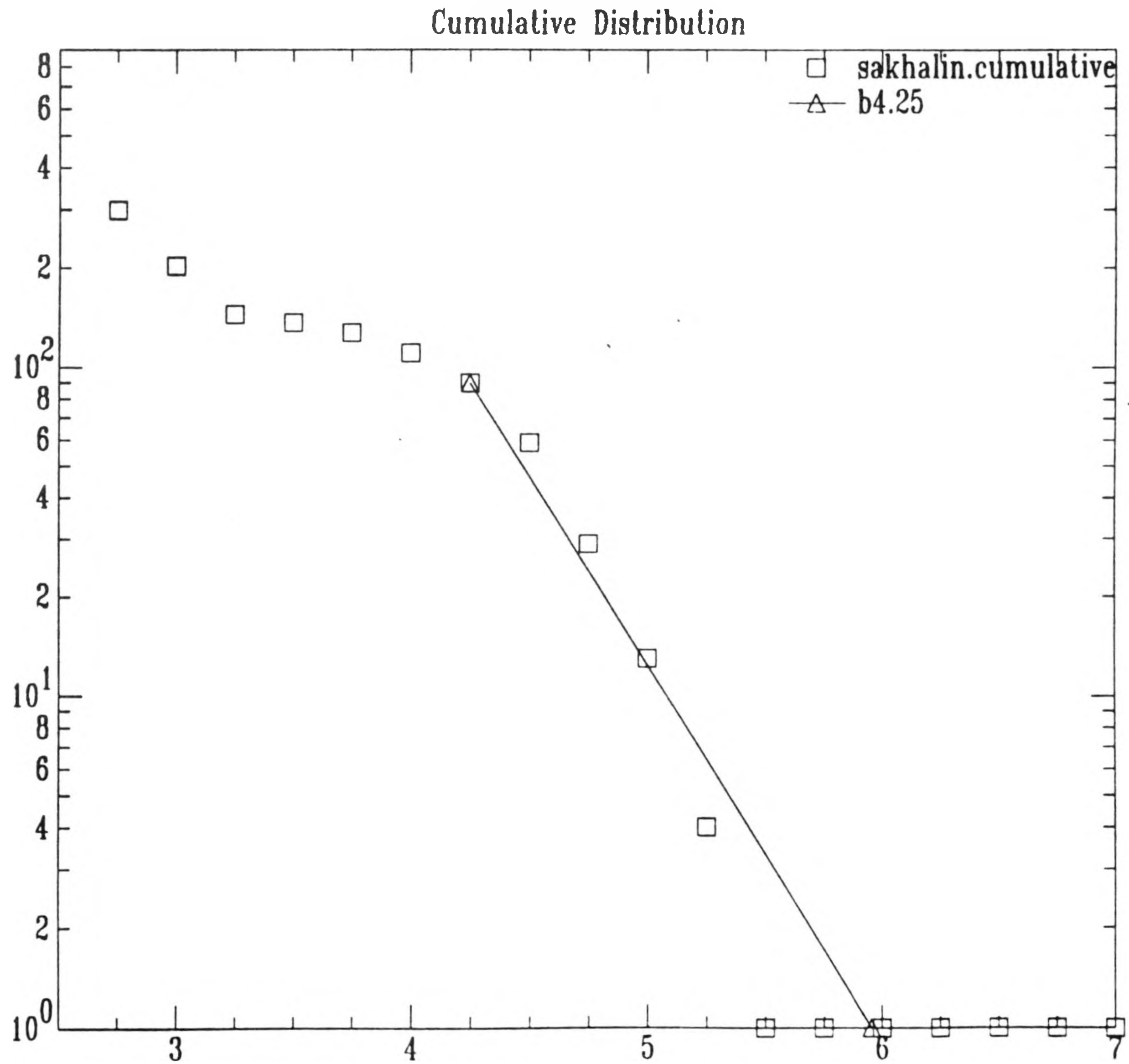
Figure 17d

Sakhalin



PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 18a



Cumulative Distribution
sakhalin.cumulative
b4.25
8
6
4
2
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6
7

Figure 18b

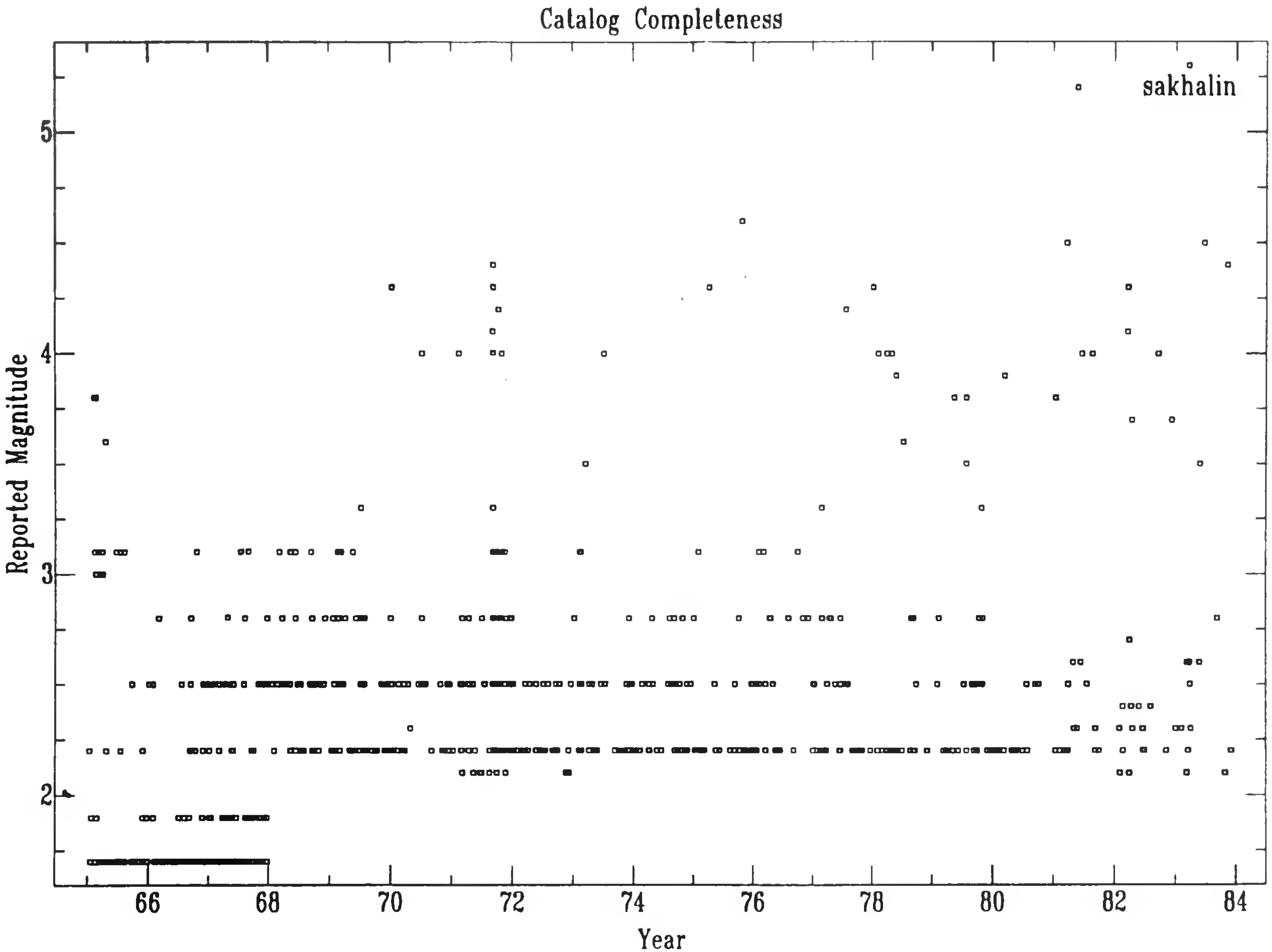

Catalog Completeness
sakhalin
Reported Magnitude
2
3
4
5
66
68
70
72
74
76
78
80
82
84
Year

Figure 18c

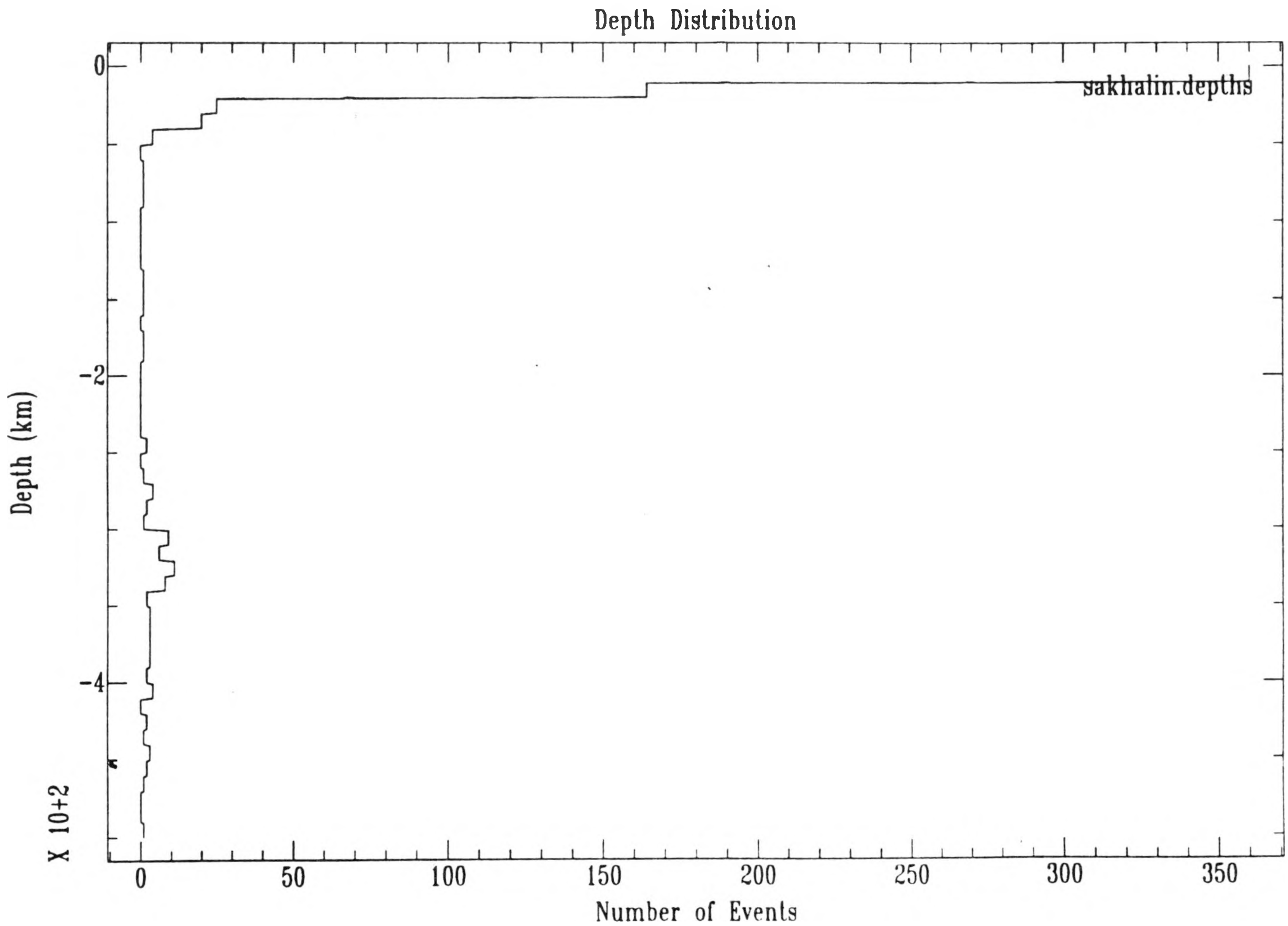
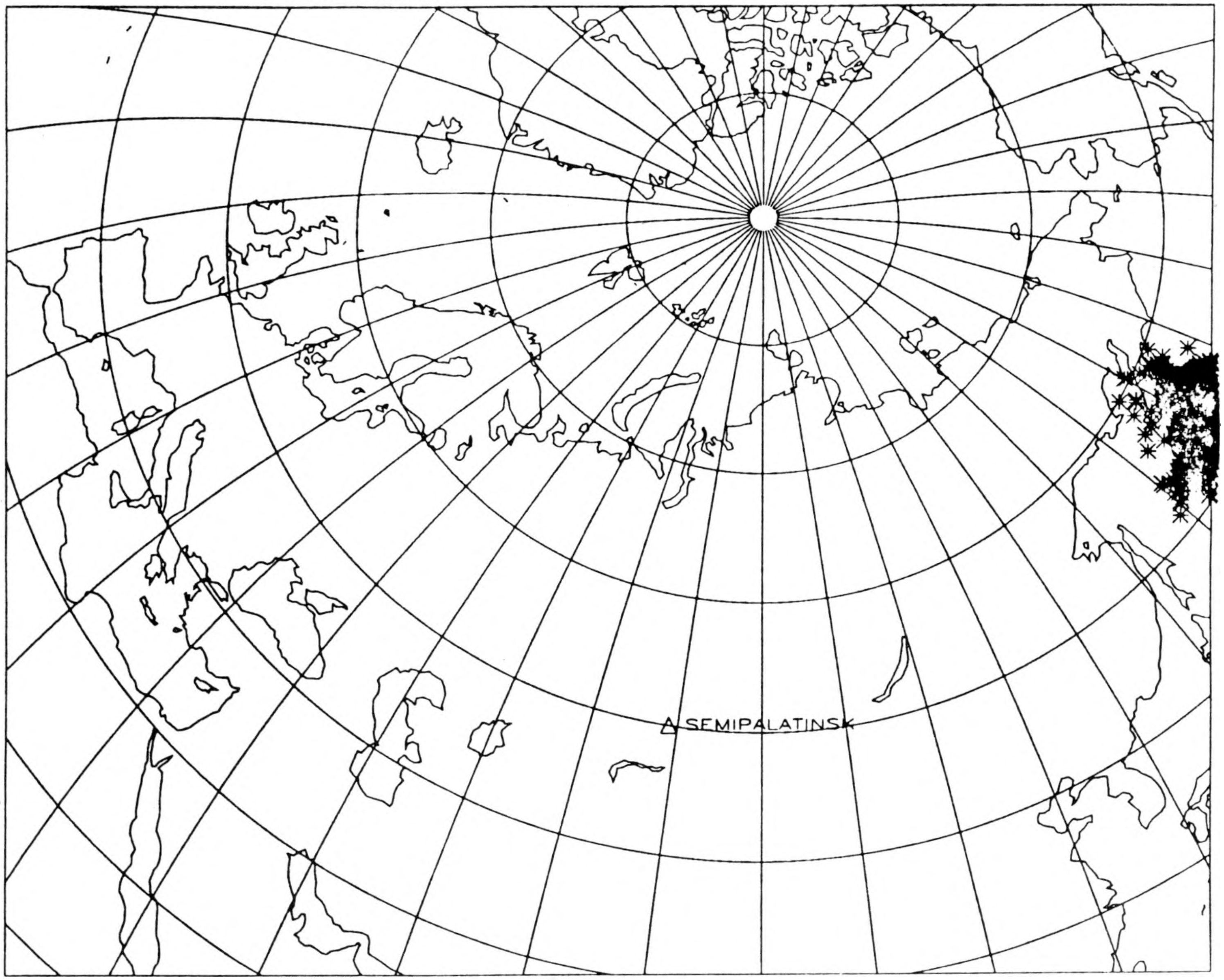

Depth Distribution
sakhalin.depths
Depth (km)
X 10+2
0
-2
-4
0
50
100
150
200
250
300
350
Number of Events

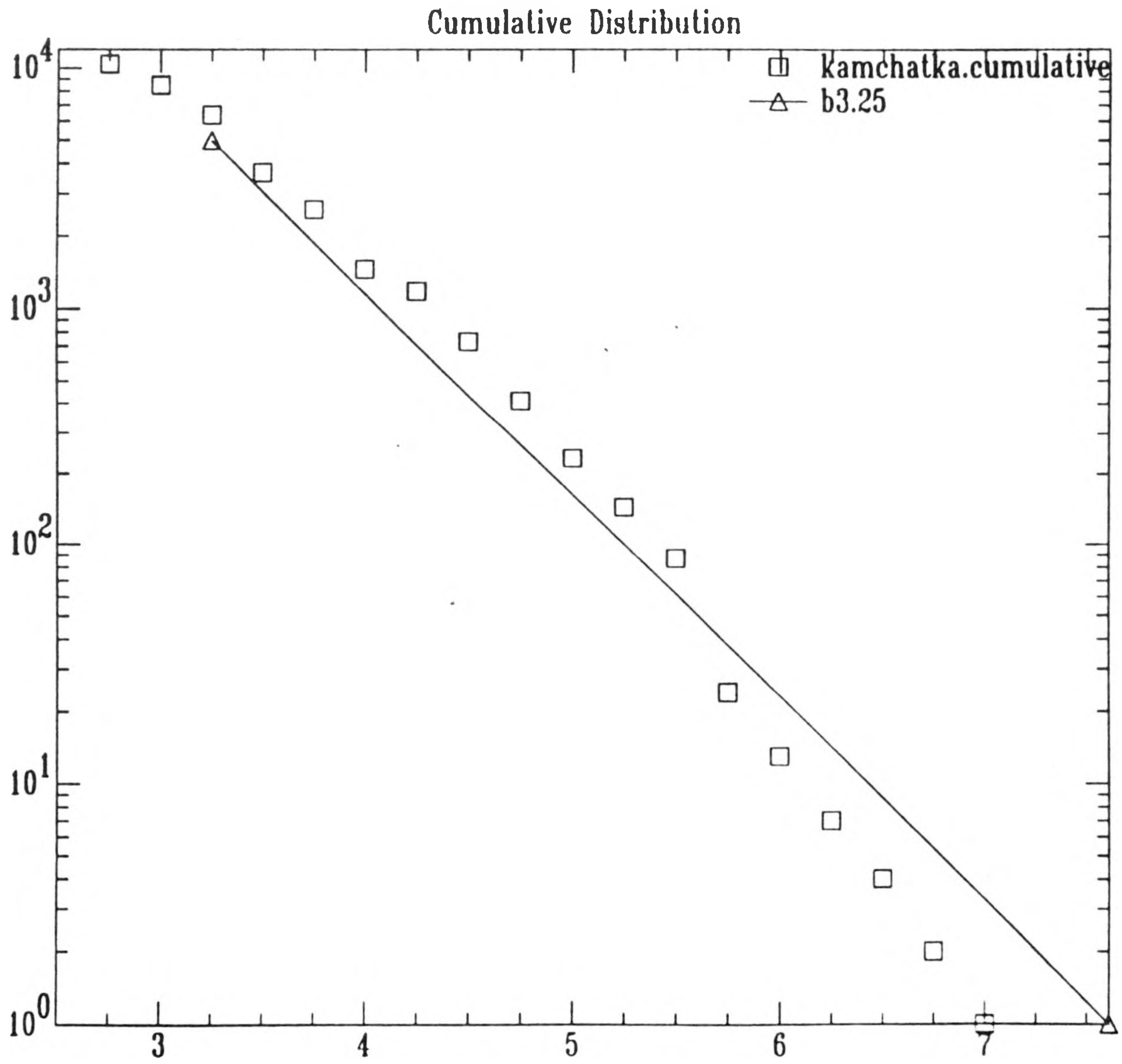
Figure 18d

Kamchatka and Komandor Islands



PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 19a



Cumulative Distribution
kamchatka.cumulative
b3.25
10^4
10^3
10^2
10^1
10^0
3
4
5
6
7

Figure 19b

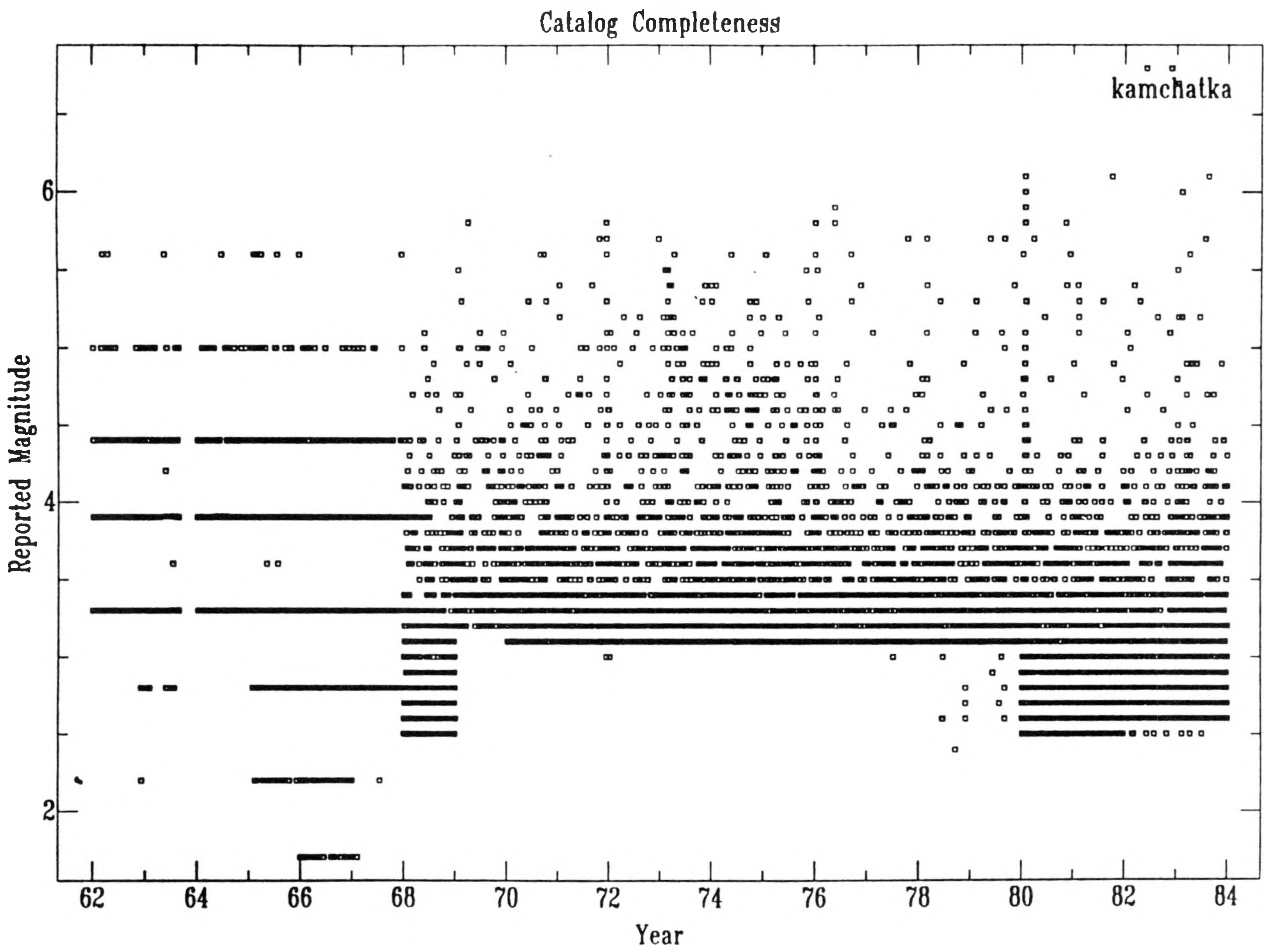
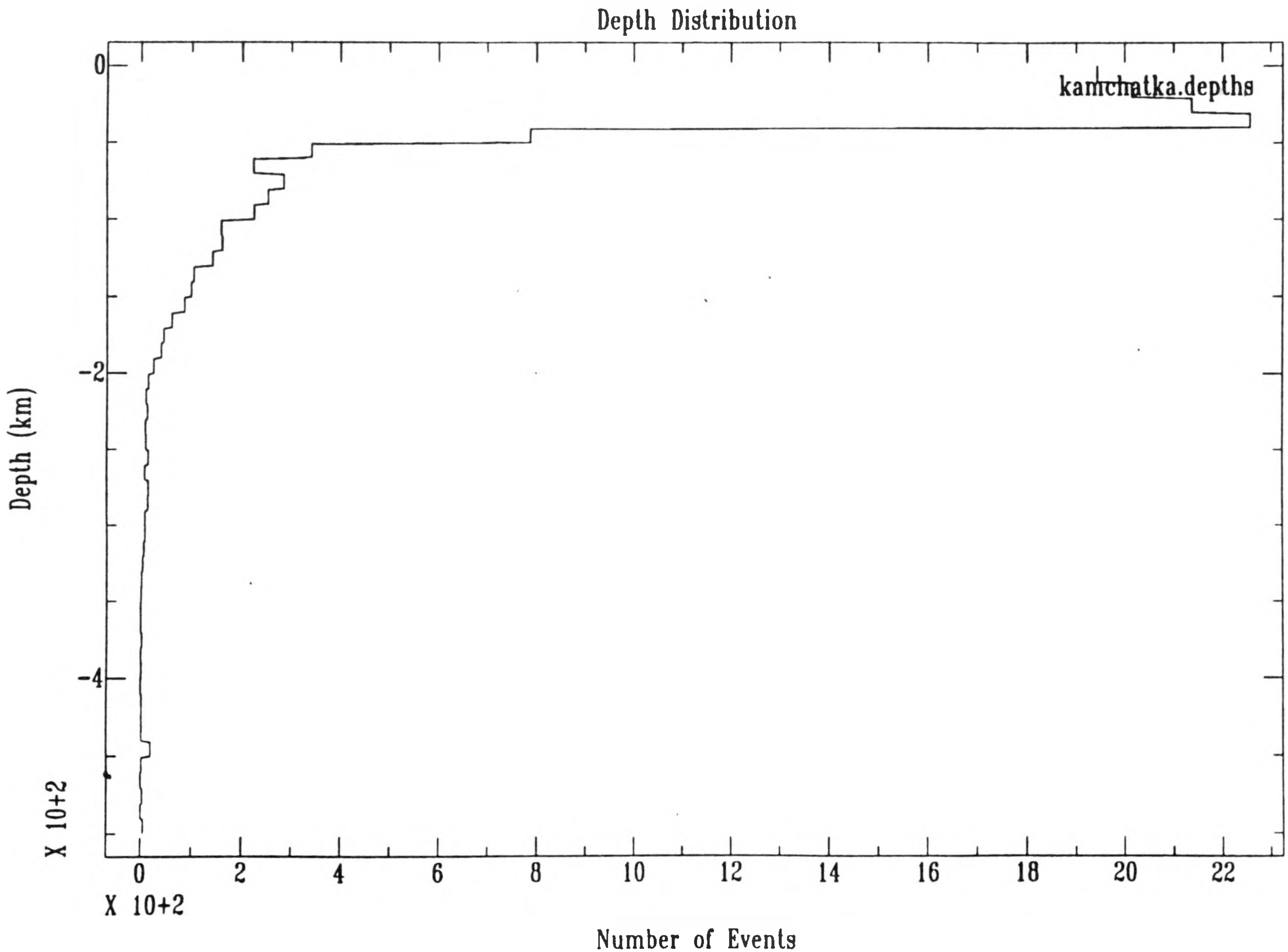

Catalog Completeness
kamchatka
Reported Magnitude
2
4
6
62
64
66
68
70
72
74
76
78
80
82
84
Year

Figure 19c



Depth Distribution
kamchatka.depths
0
-2
-4
X 10+2
Depth (km)
0
2
4
6
8
10
12
14
16
18
20
22
X 10+2
Number of Events

Figure 19d

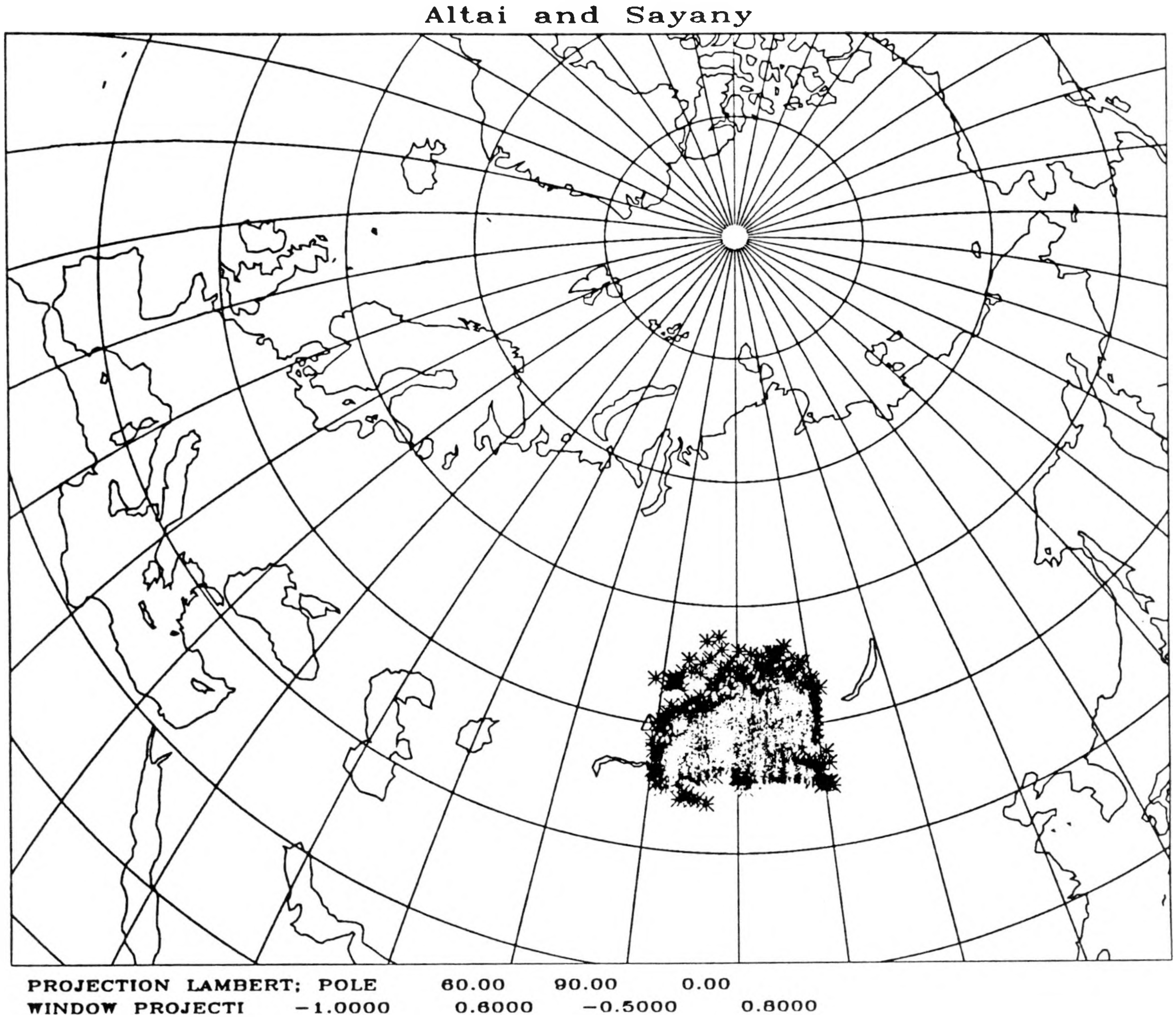
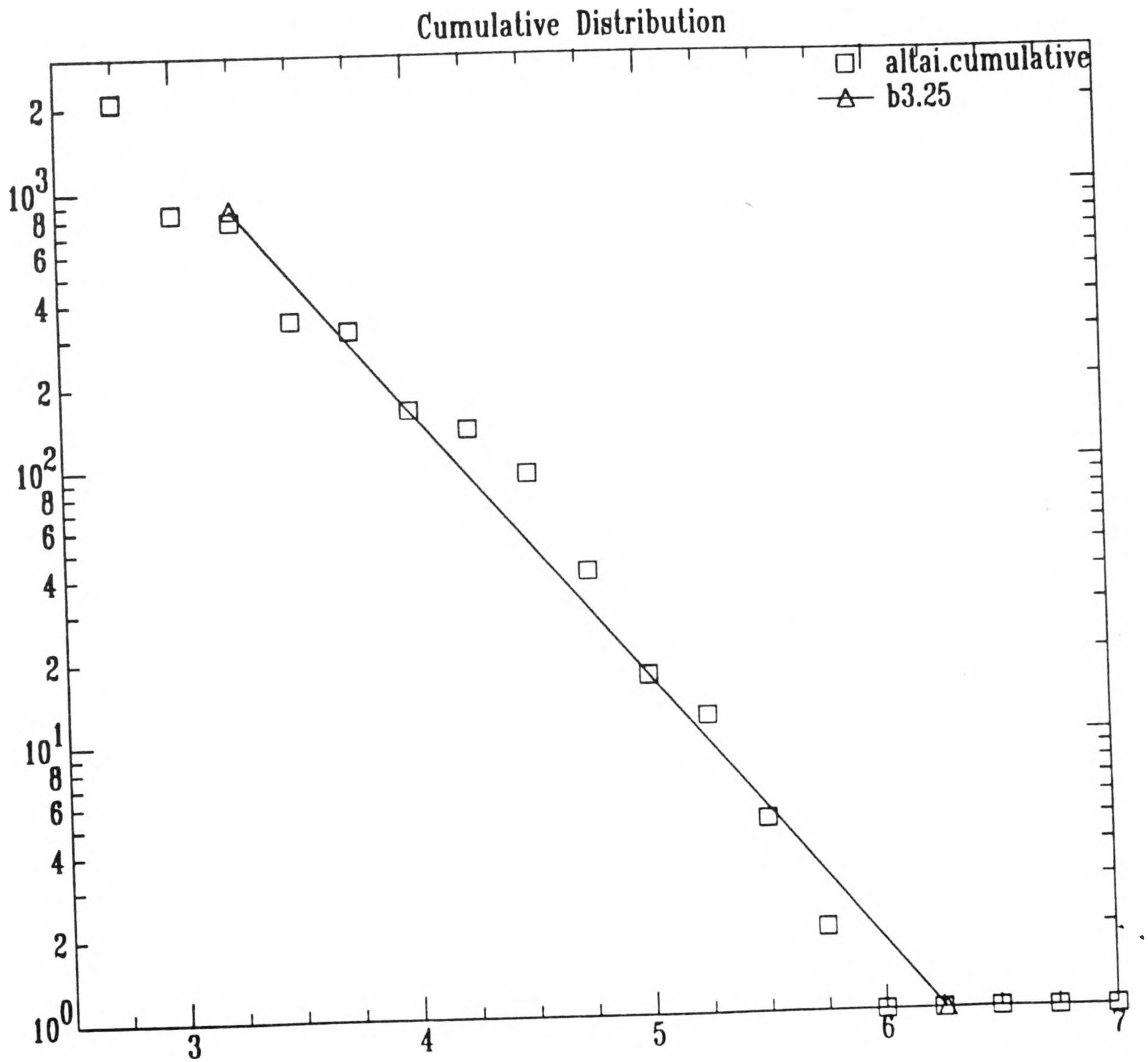
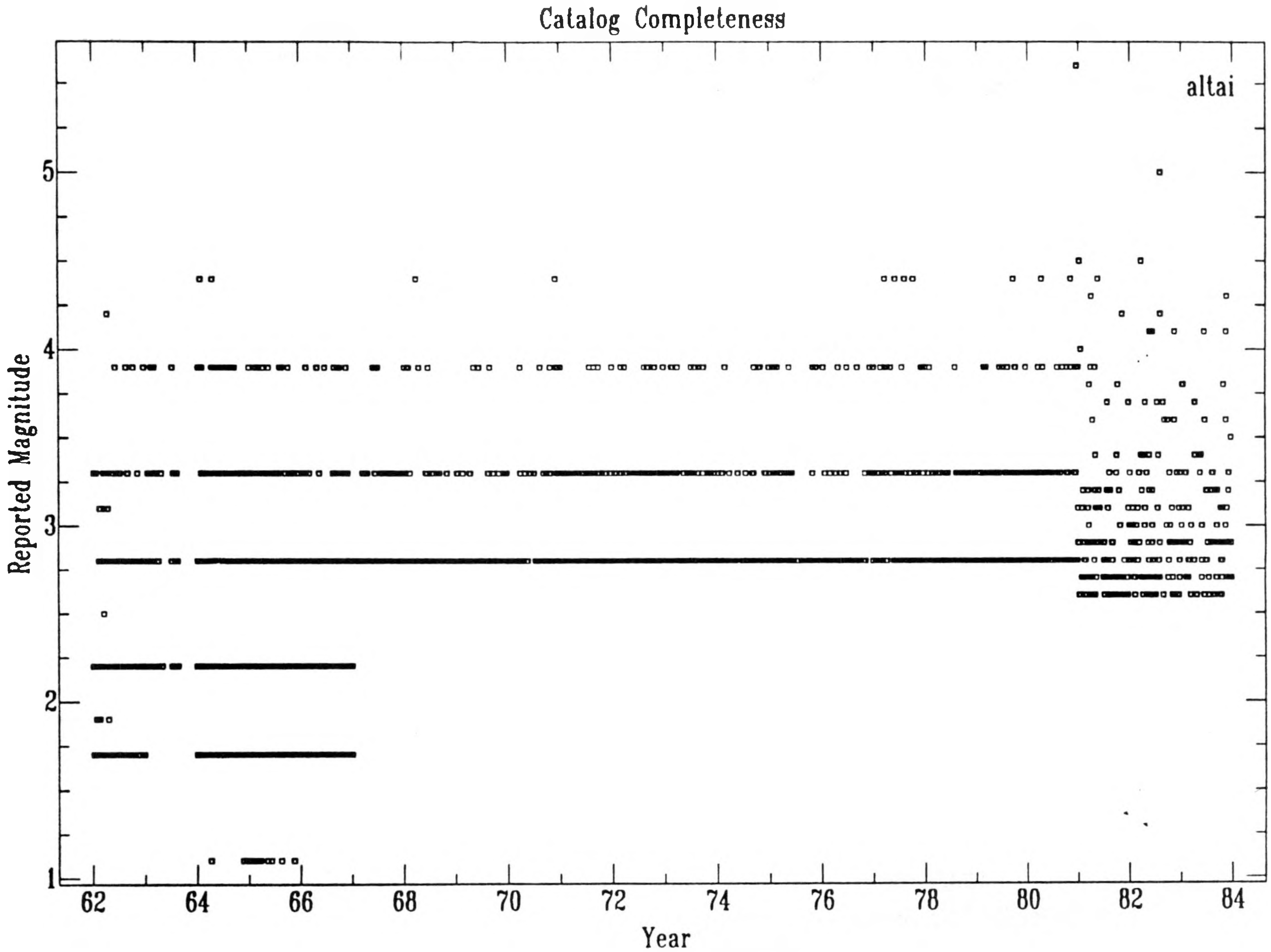

Altai and Sayany
PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 20a



Cumulative Distribution
altai.cumulative
b3.25
2
10^3
8
6
4
2
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6
7

Figure 20b



Catalog Completeness
altai
Reported Magnitude
1
2
3
4
5
62
64
66
68
70
72
74
76
78
80
82
84
Year

Figure 20c

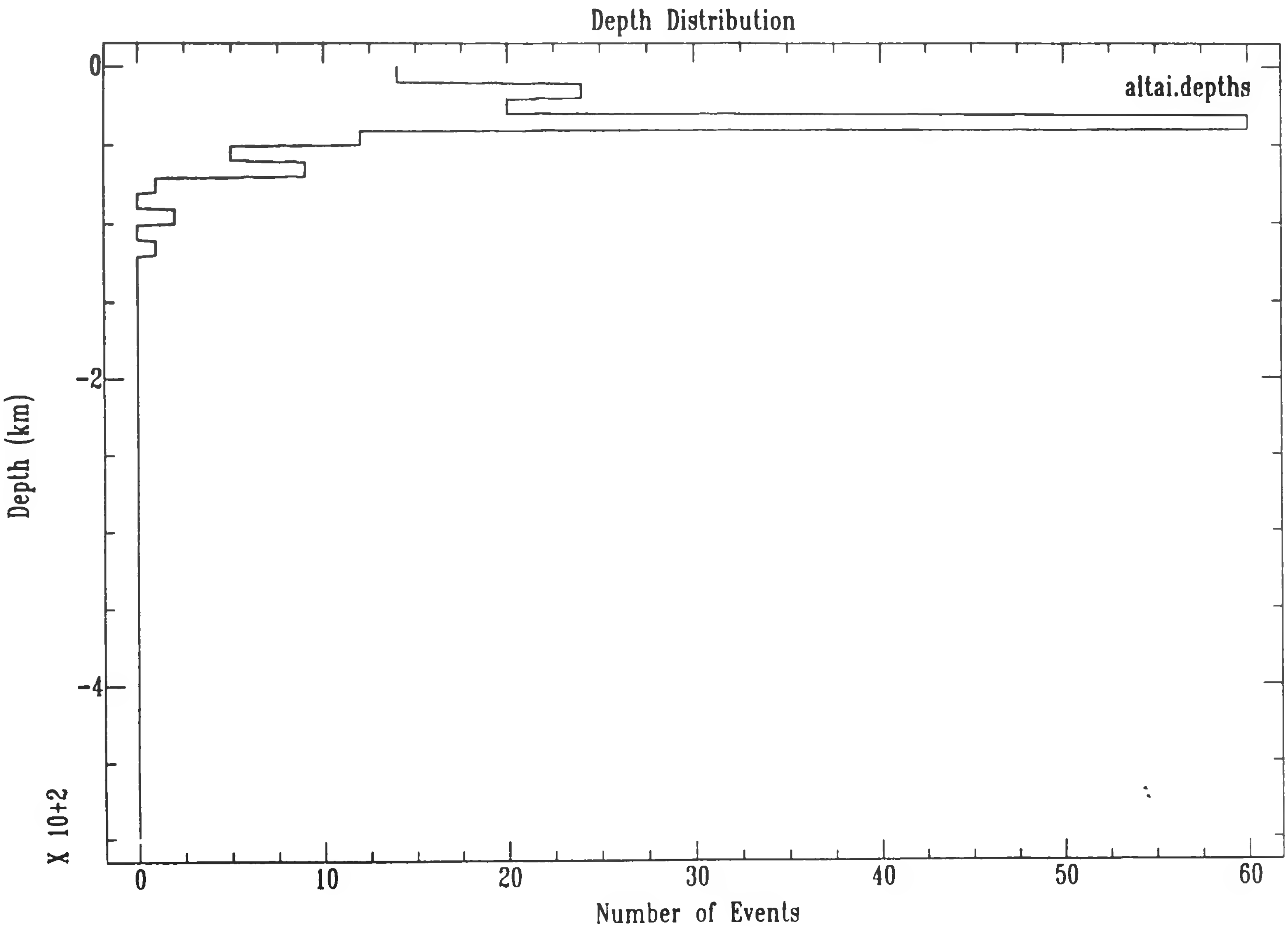

Depth Distribution
altai.depths
Depth (km)
X 10+2
0
-2
-4
0
10
20
30
40
50
60
Number of Events

Figure 20d

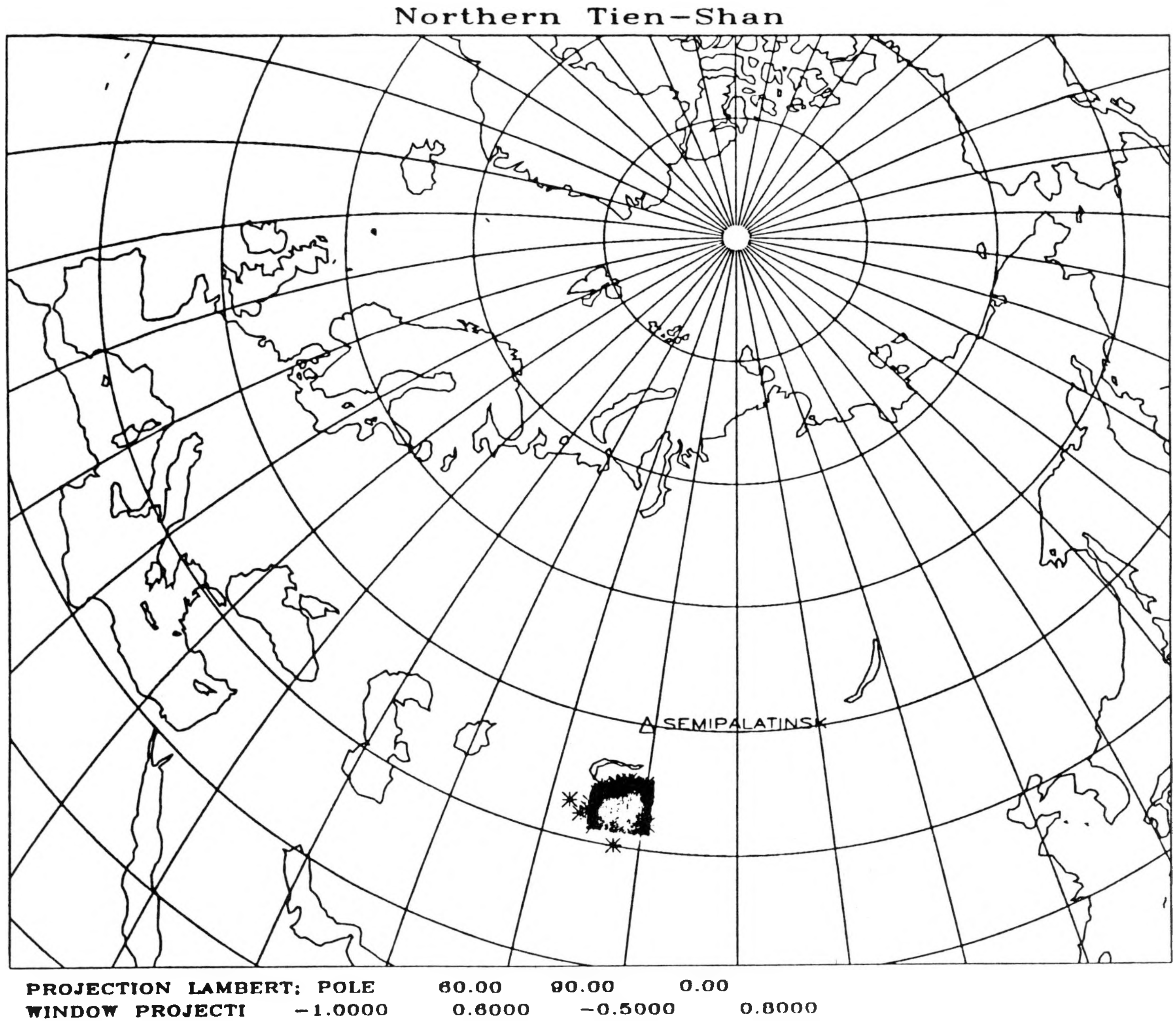

Northern Tien-Shan
SEMIPALATINSK
PROJECTION LAMBERT: POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 21a

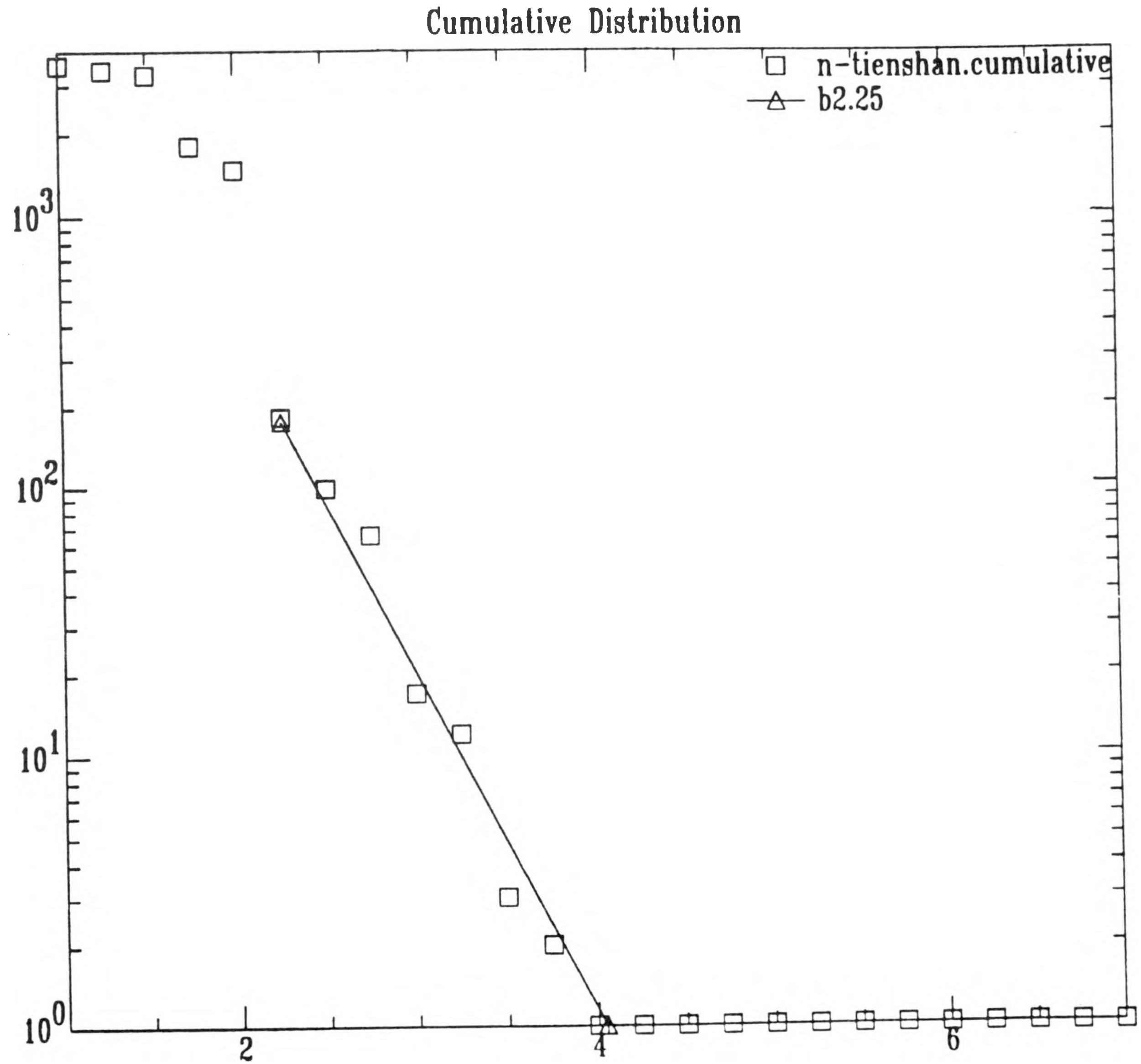

Cumulative Distribution
n-tienshan.cumulative
b2.25
10^3
10^2
10^1
10^0
2
4
6

Figure 21b

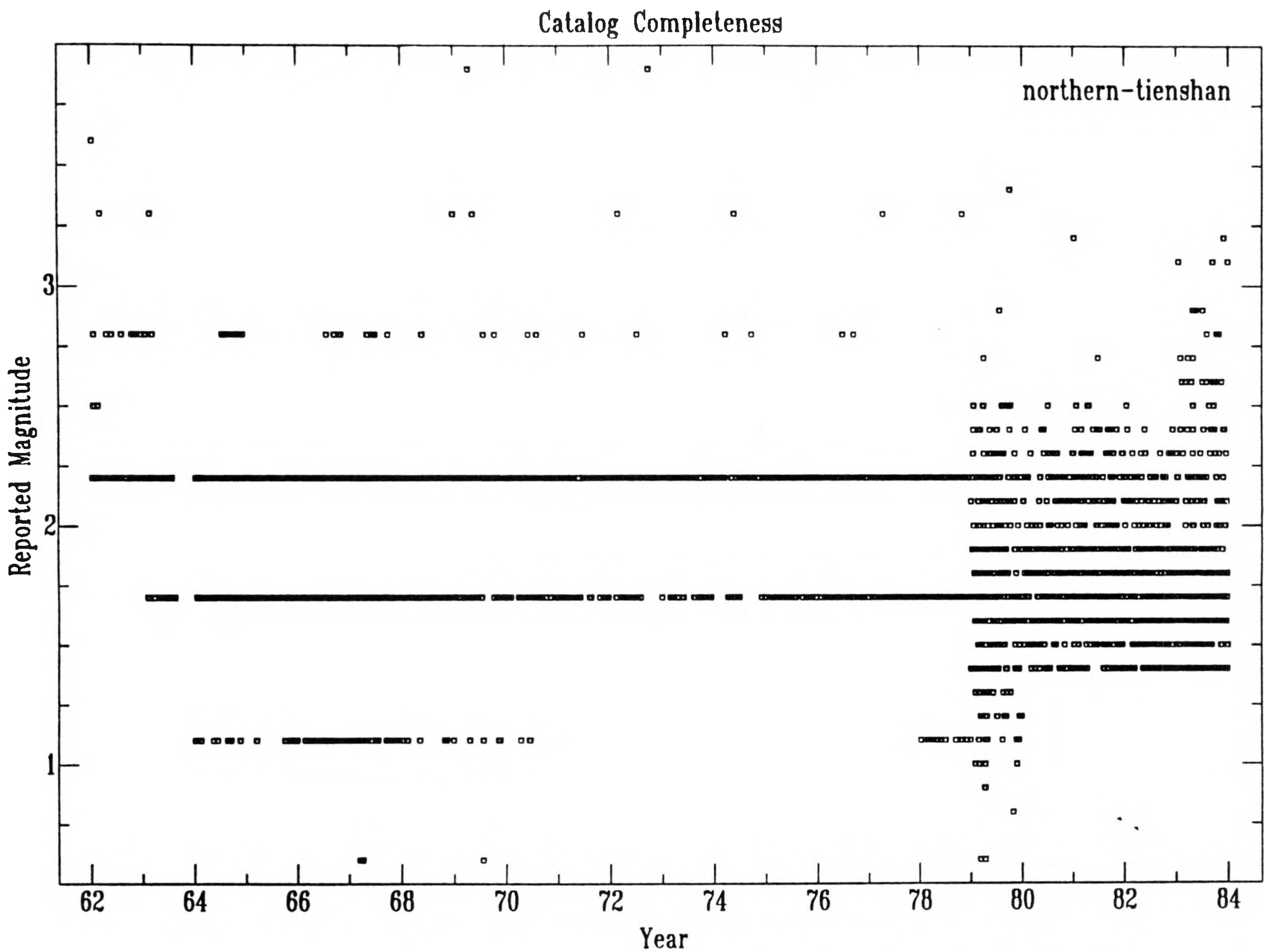

Catalog Completeness
northern-tienshan
Reported Magnitude
3
2
1
62
64
66
68
70
72
74
76
78
80
82
84
Year

Figure 21c

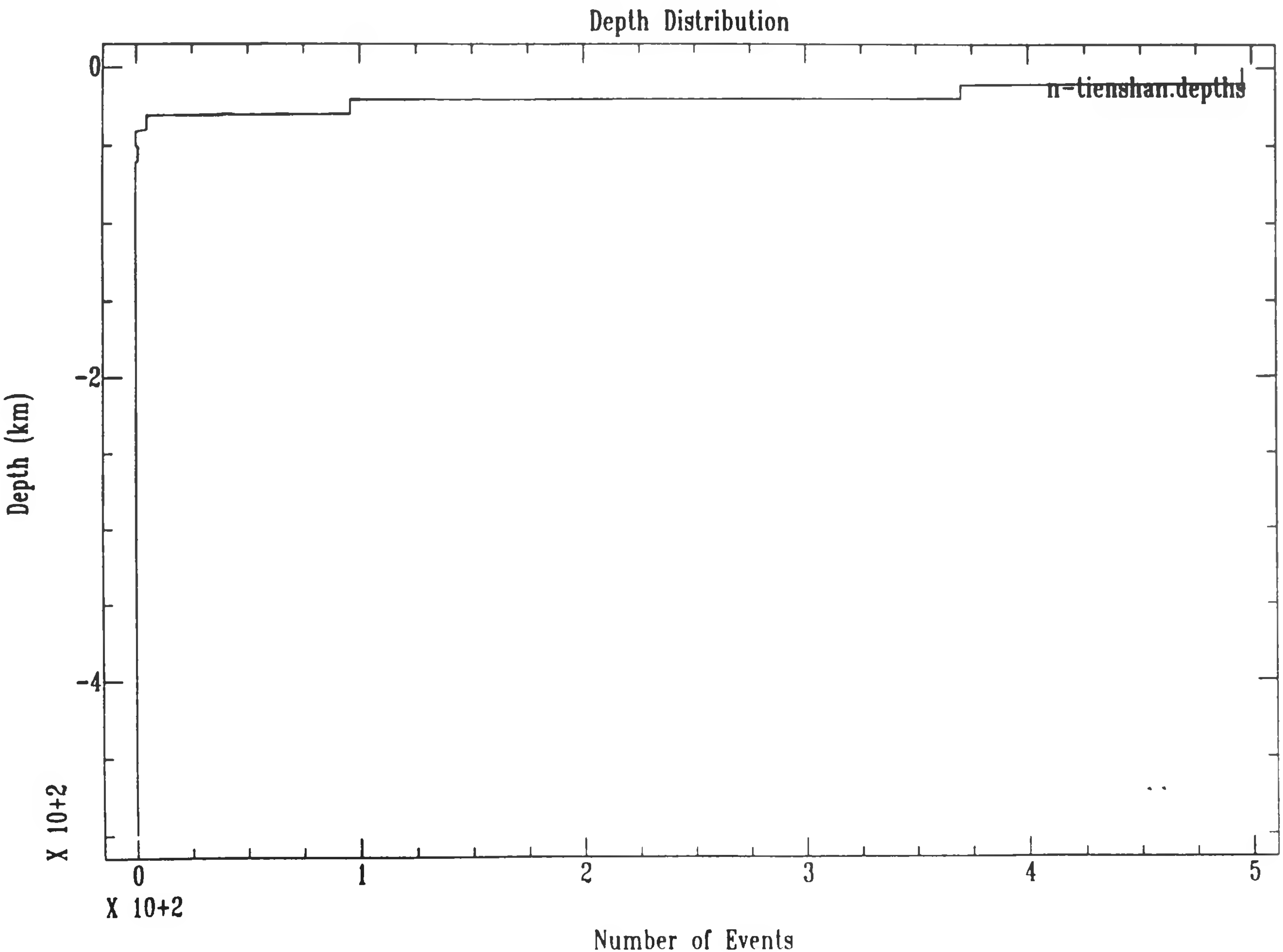

Depth Distribution
n-tienshan.depths
0
-2
-4
X 10+2
Depth (km)
0
1
2
3
4
5
X 10+2
Number of Events

Figure 21d

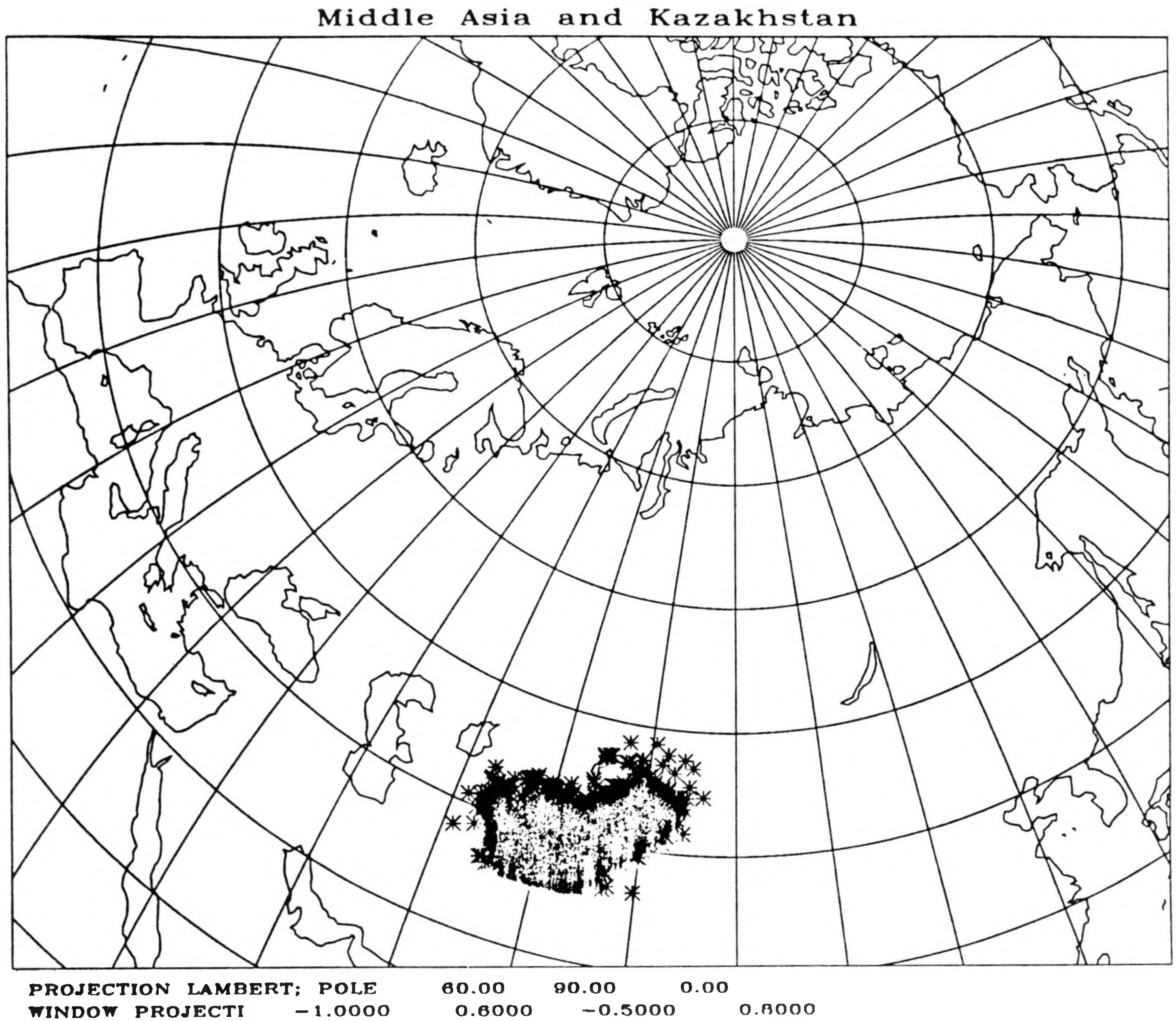
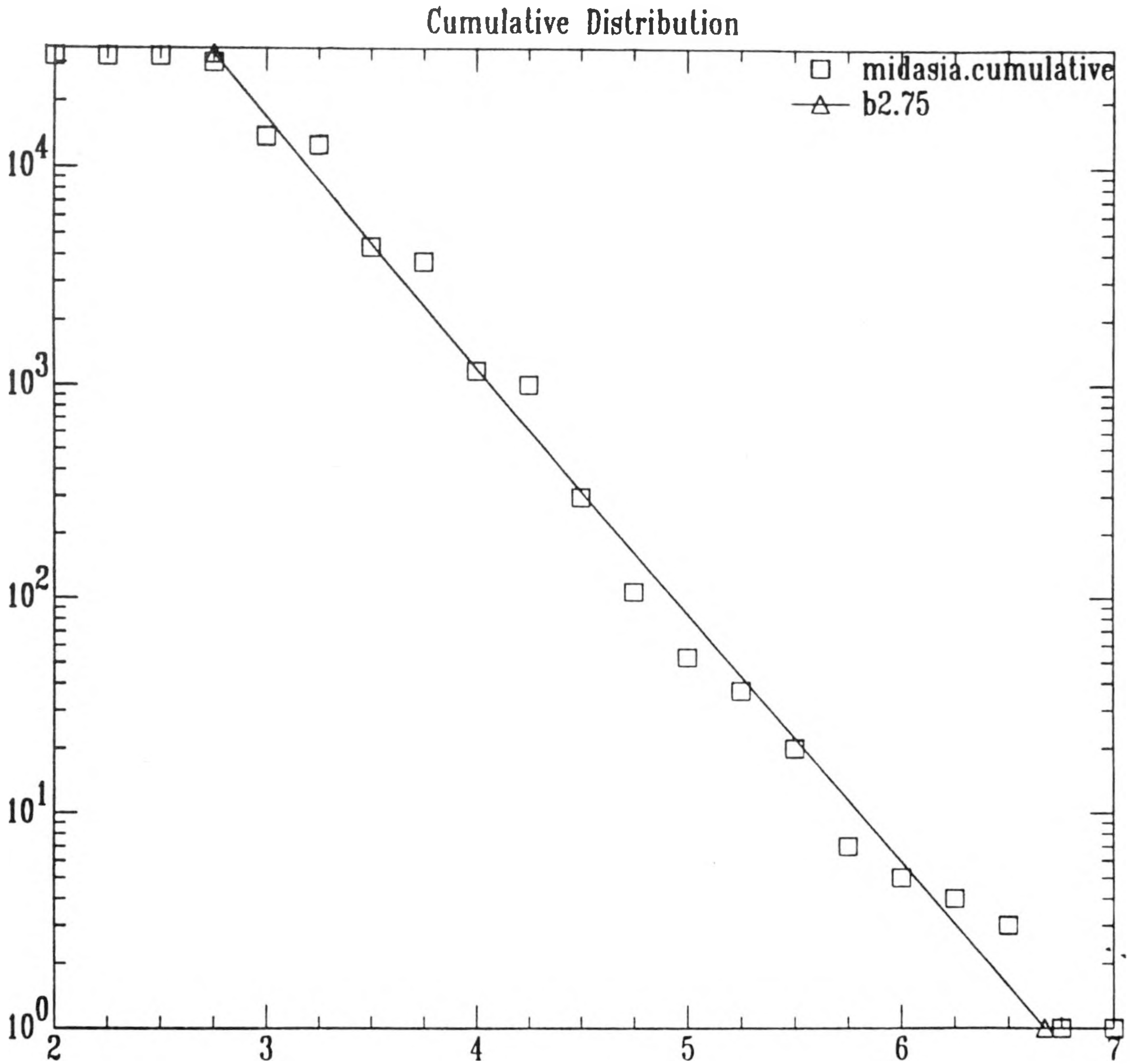

Middle Asia and Kazakhstan
PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 22a



Cumulative Distribution
midasia.cumulative
b2.75
10^4
10^3
10^2
10^1
10^0
2
3
4
5
6
7

Figure 22b

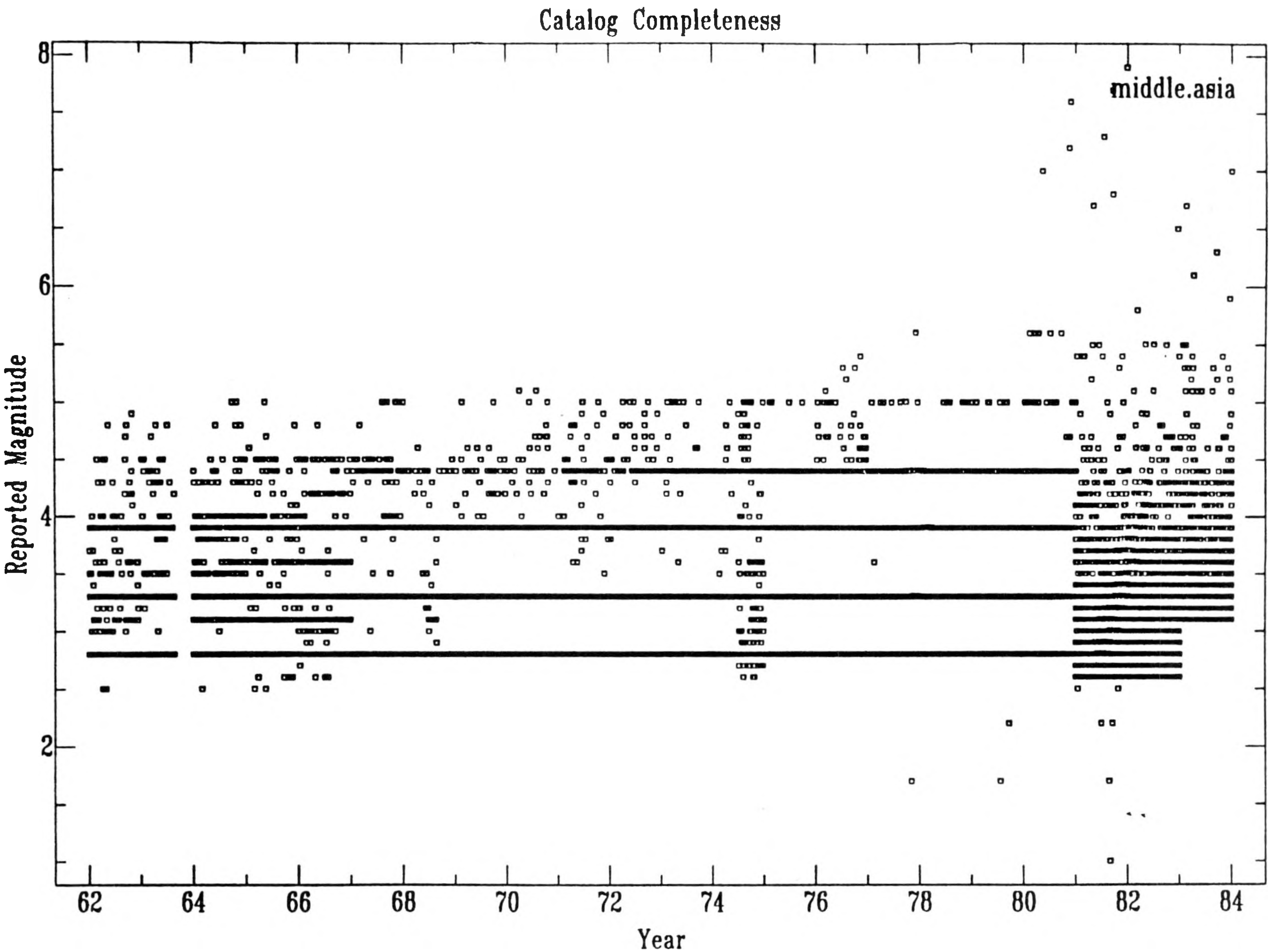
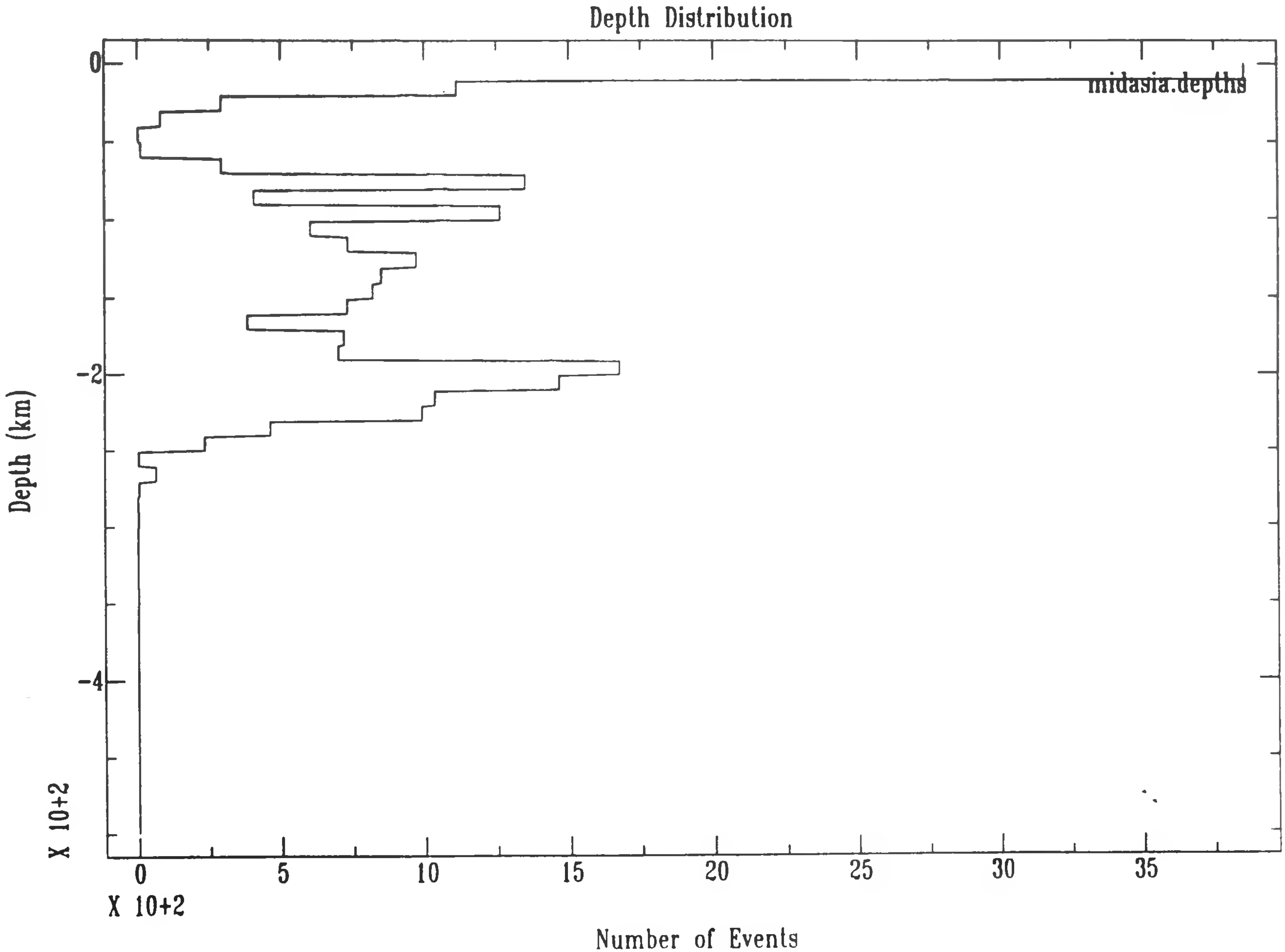

Catalog Completeness
middle.asia
Reported Magnitude
Year
8
6
4
2
62
64
66
68
70
72
74
76
78
80
82
84

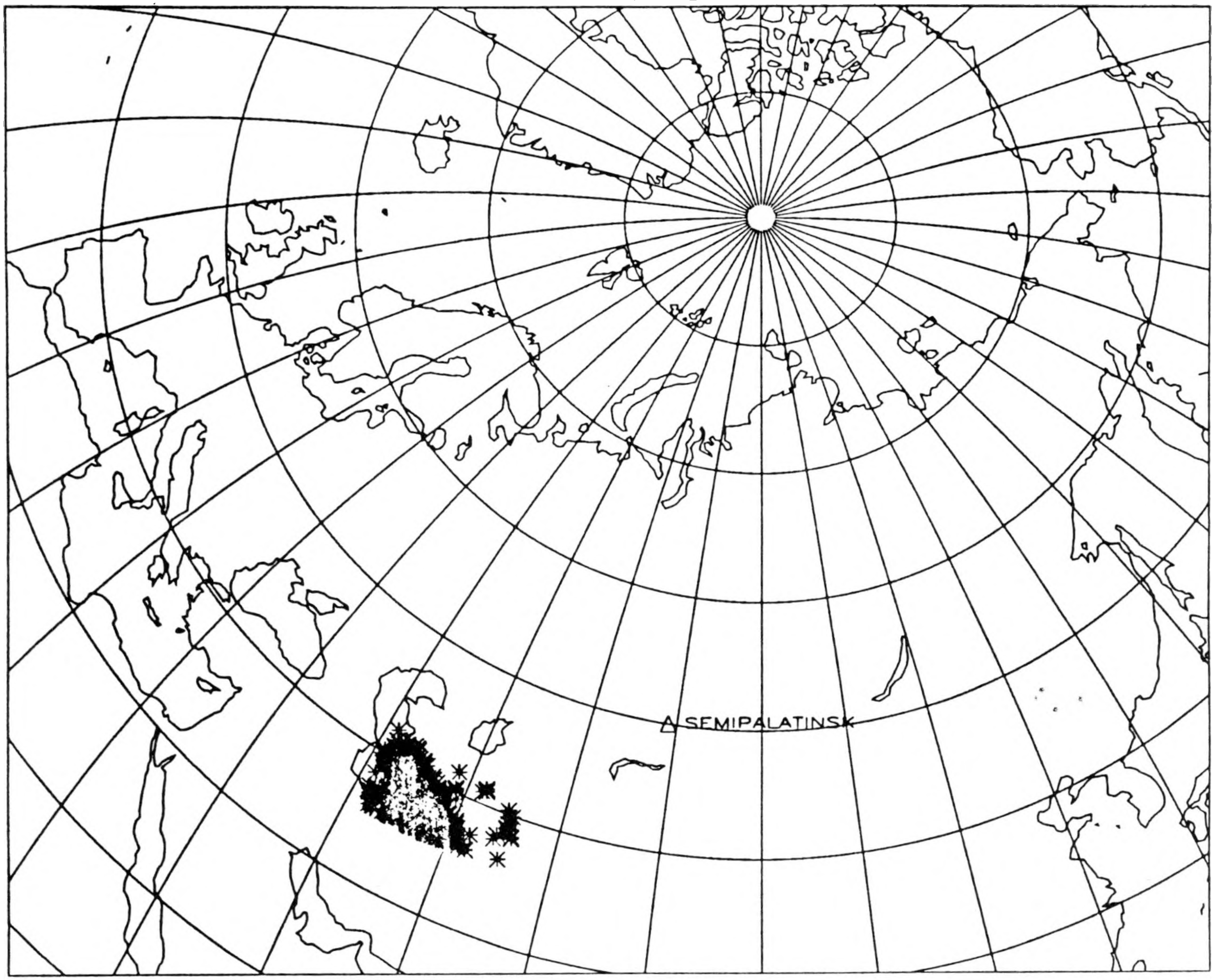
Figure 22c



Depth Distribution
midasia.depths
0
-2
-4
X 10+2
Depth (km)
0
5
10
15
20
25
30
35
X 10+2
Number of Events

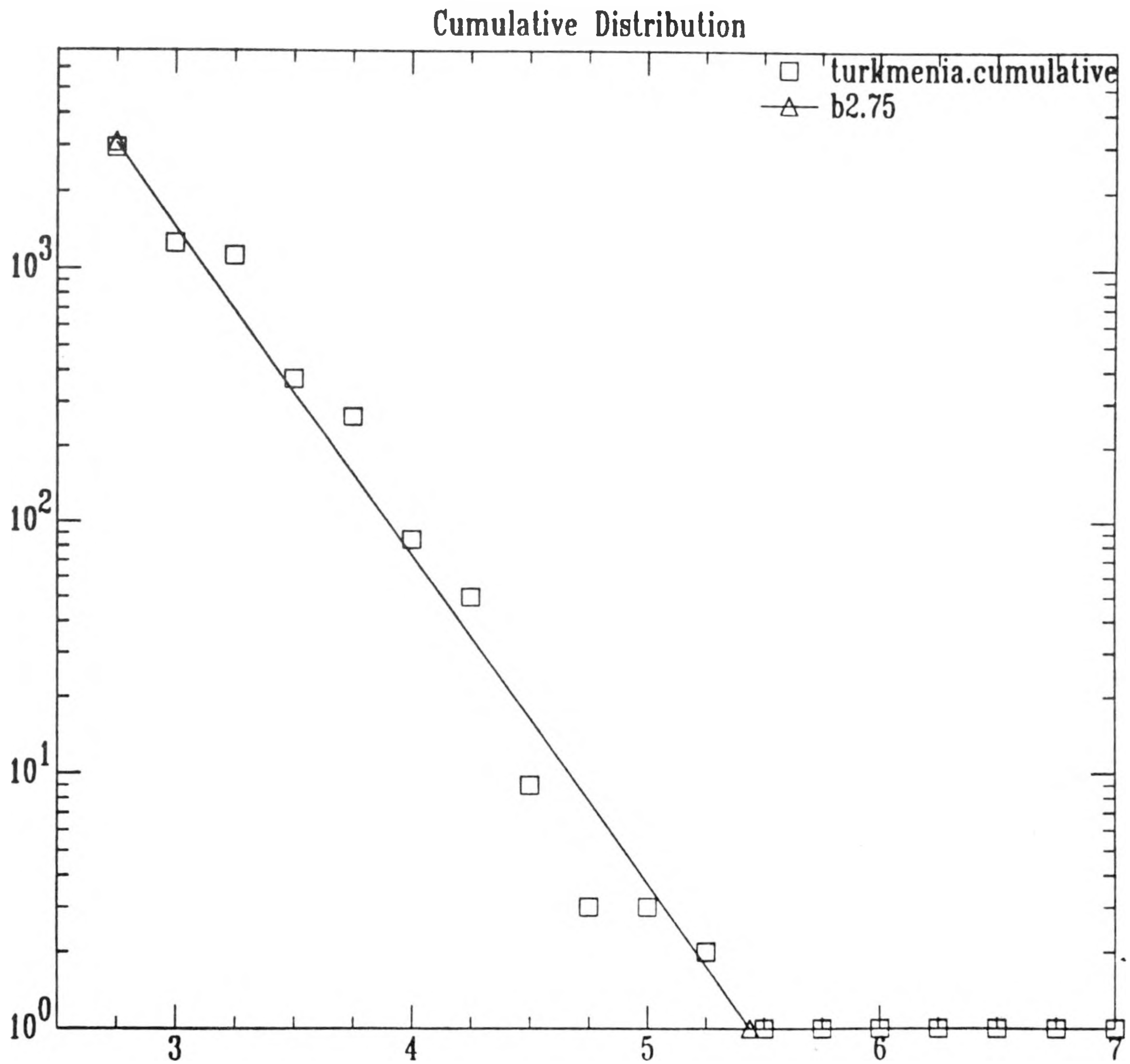
Figure 22d

Turkmenia (Kopetdag)



PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI −1.0000 0.6000 −0.5000 0.8000

Figure 33a



Cumulative Distribution
turkmenia.cumulative
b2.75
10^3
10^2
10^1
10^0
3
4
5
6
7

Figure 23b

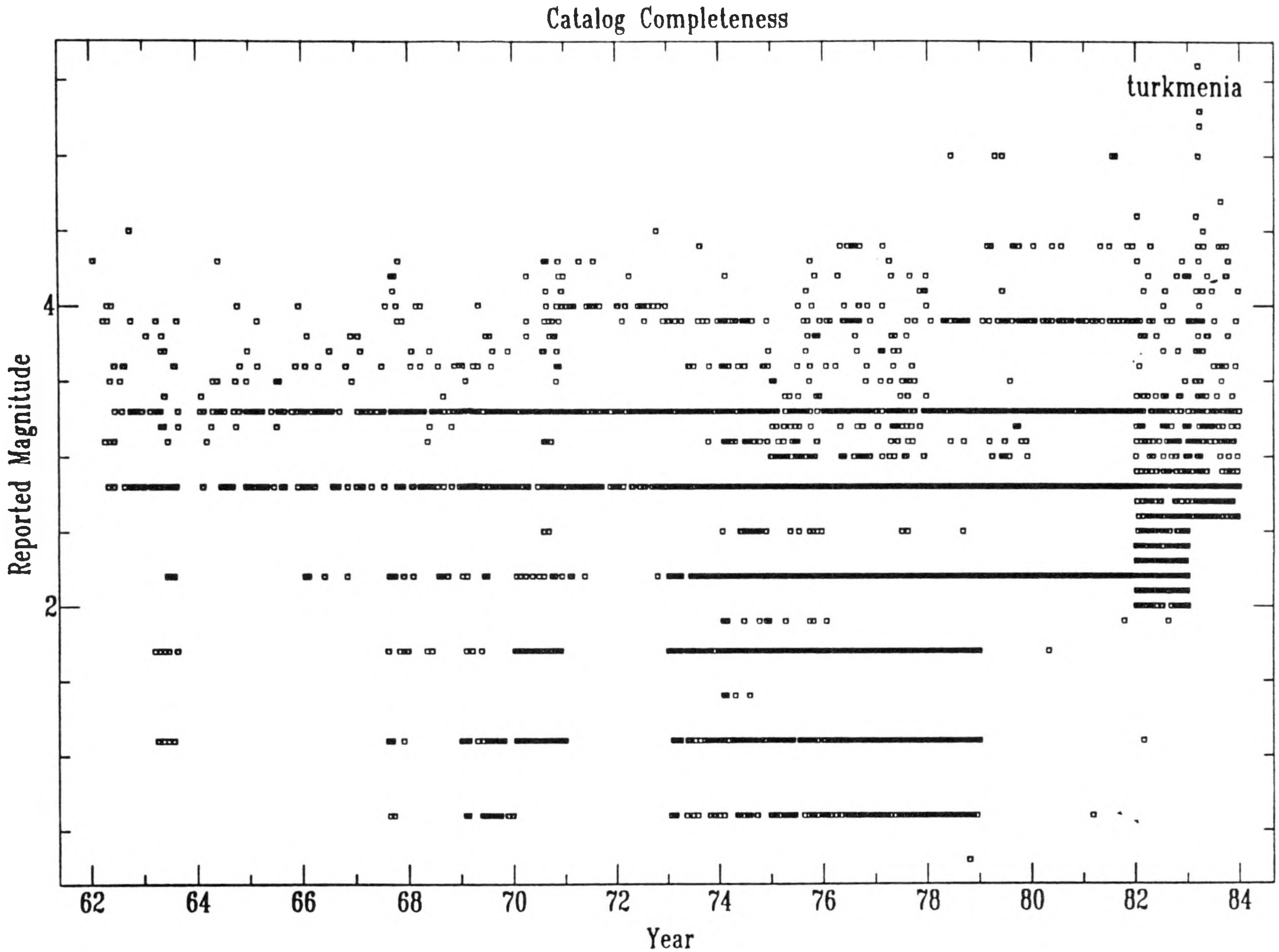

Catalog Completeness
turkmenia
Reported Magnitude
4
2
62
64
66
68
70
72
74
76
78
80
82
84
Year

Figure 23c

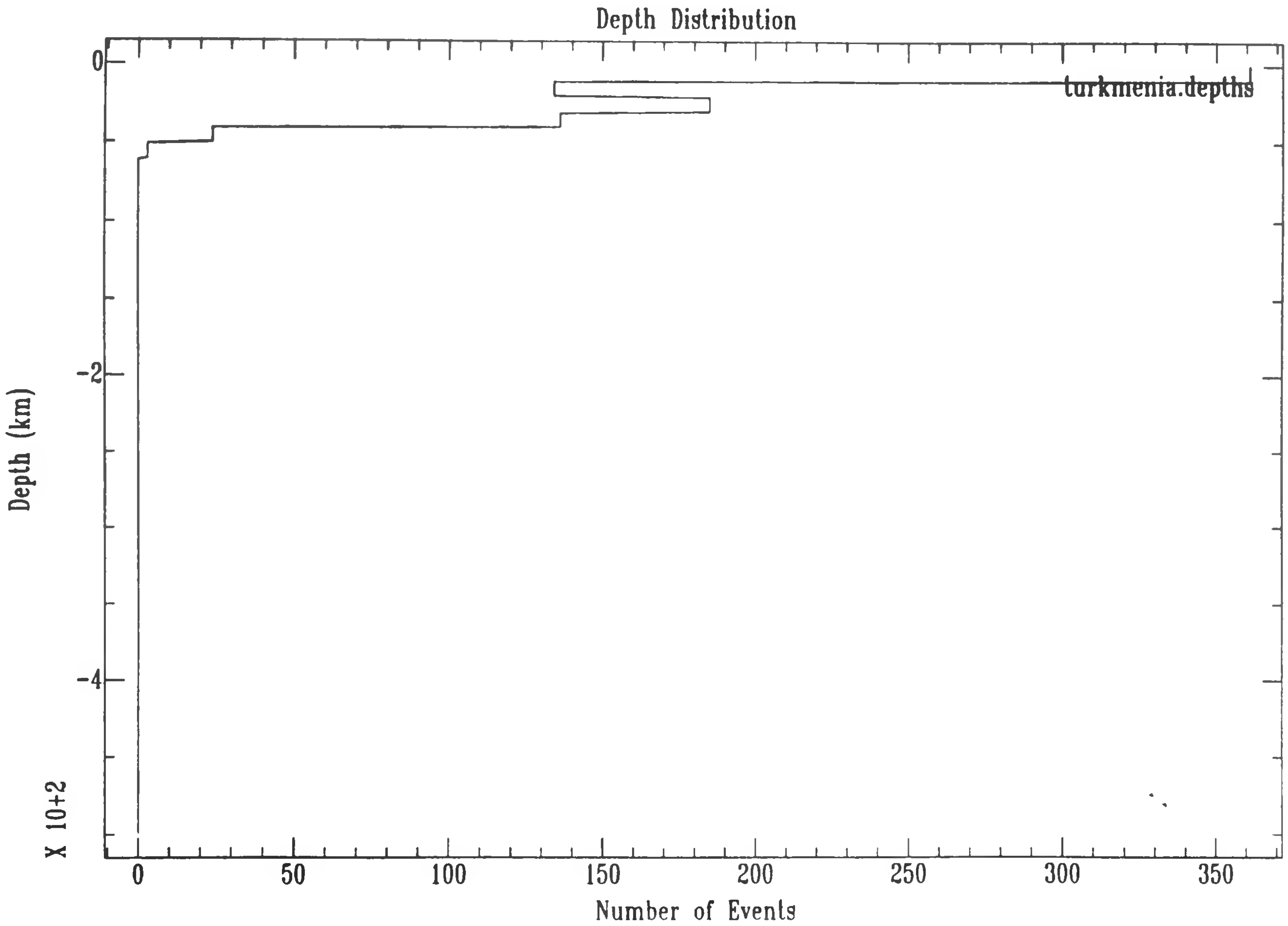
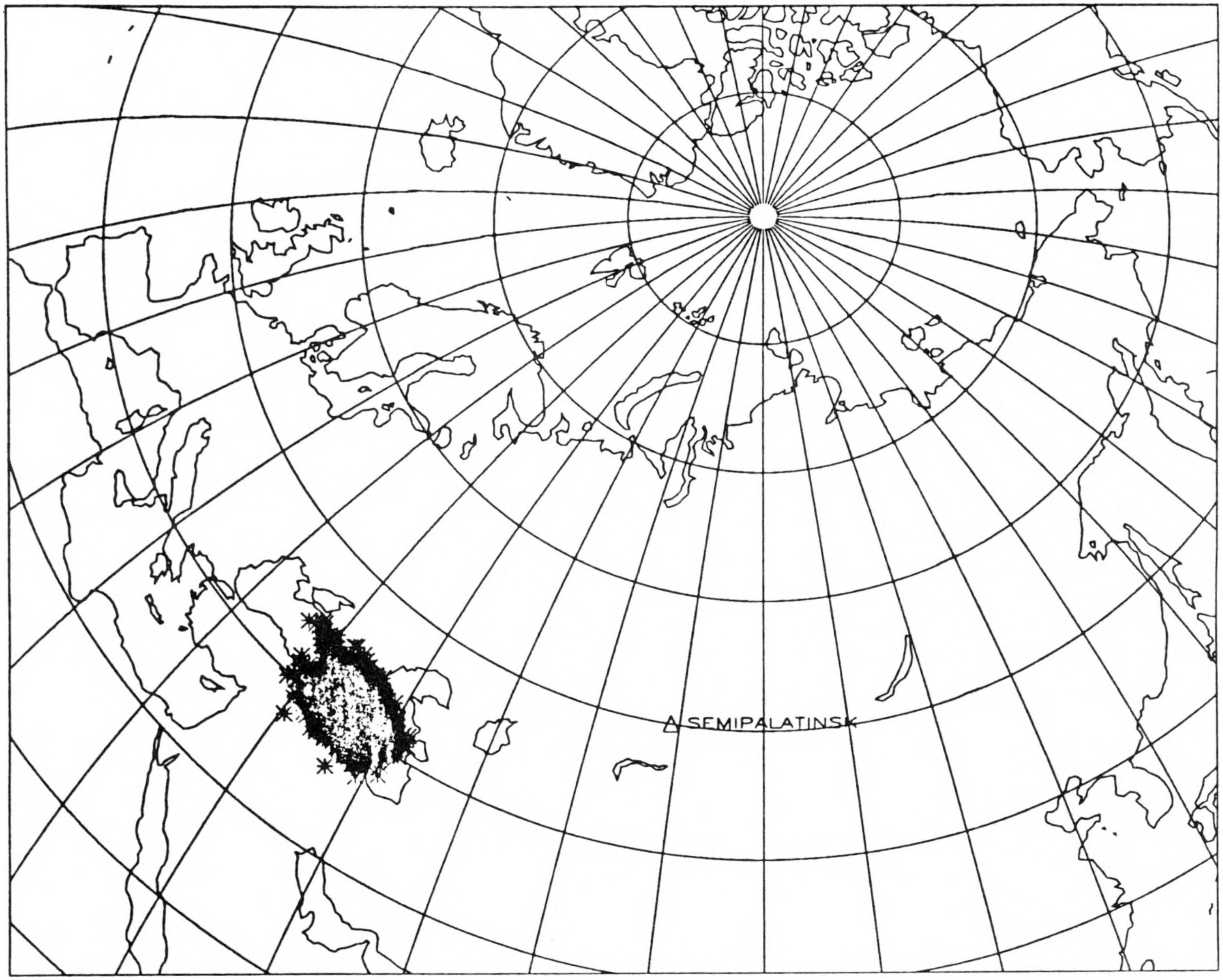

Depth Distribution
turkmenia.depths
Depth (km)
X 10+2
0
-2
-4
0
50
100
150
200
250
300
350
Number of Events

Figure 23d

Caucasus



PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 24a

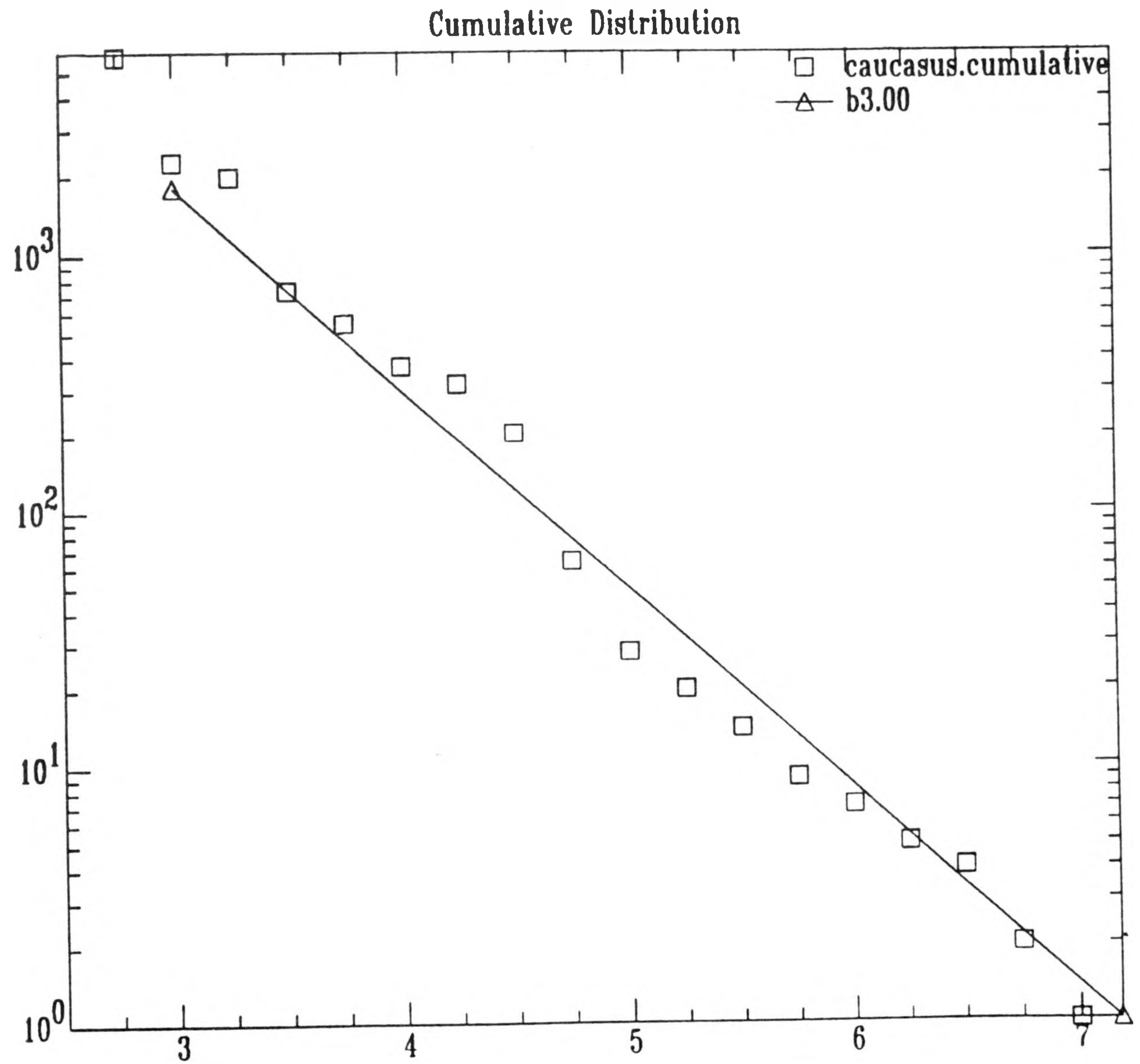

Cumulative Distribution
caucasus.cumulative
b3.00
10^3
10^2
10^1
10^0
3
4
5
6
7

Figure 24b

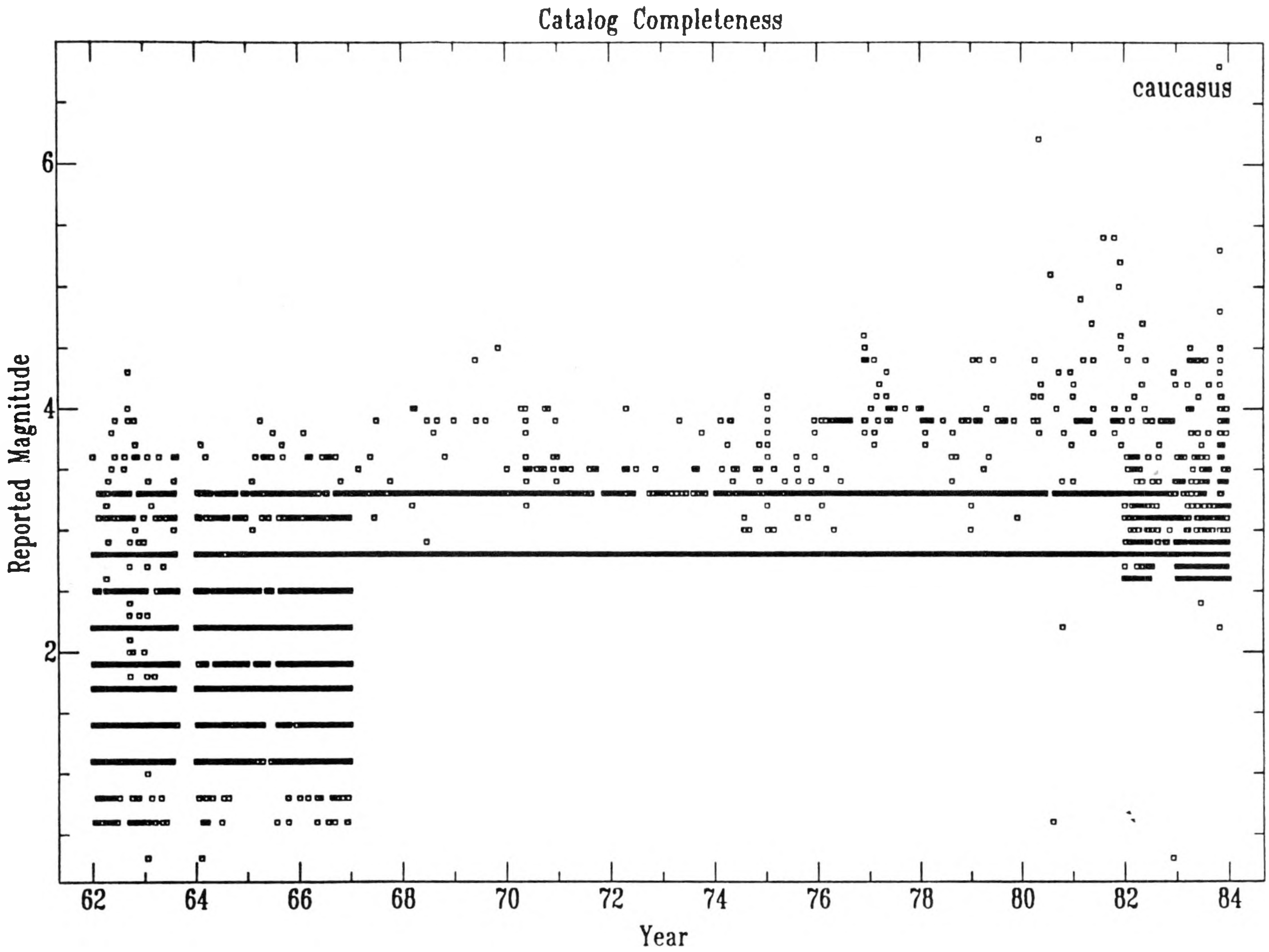
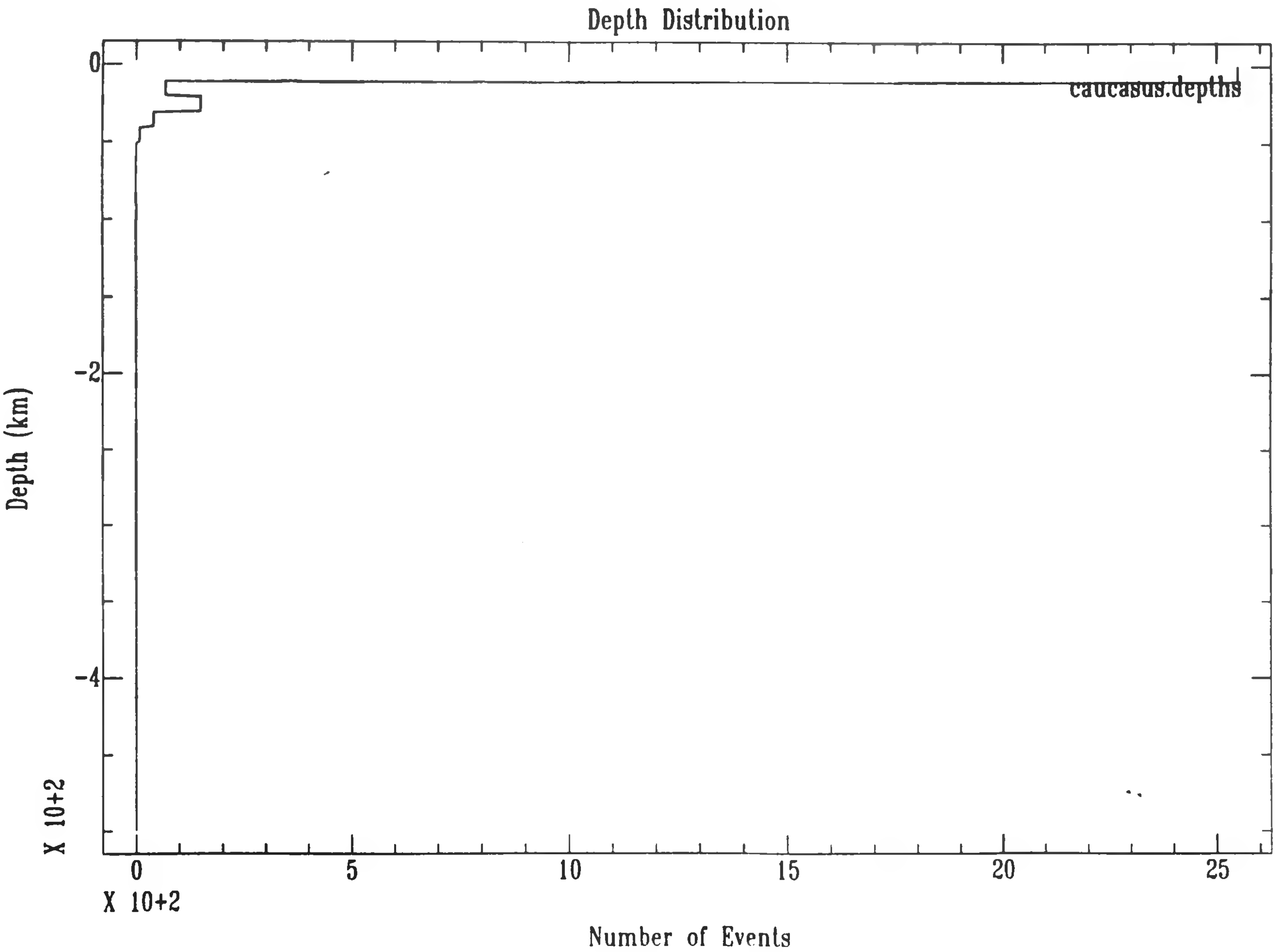

Catalog Completeness
caucasus
Reported Magnitude
Year
6
4
2
62
64
66
68
70
72
74
76
78
80
82
84

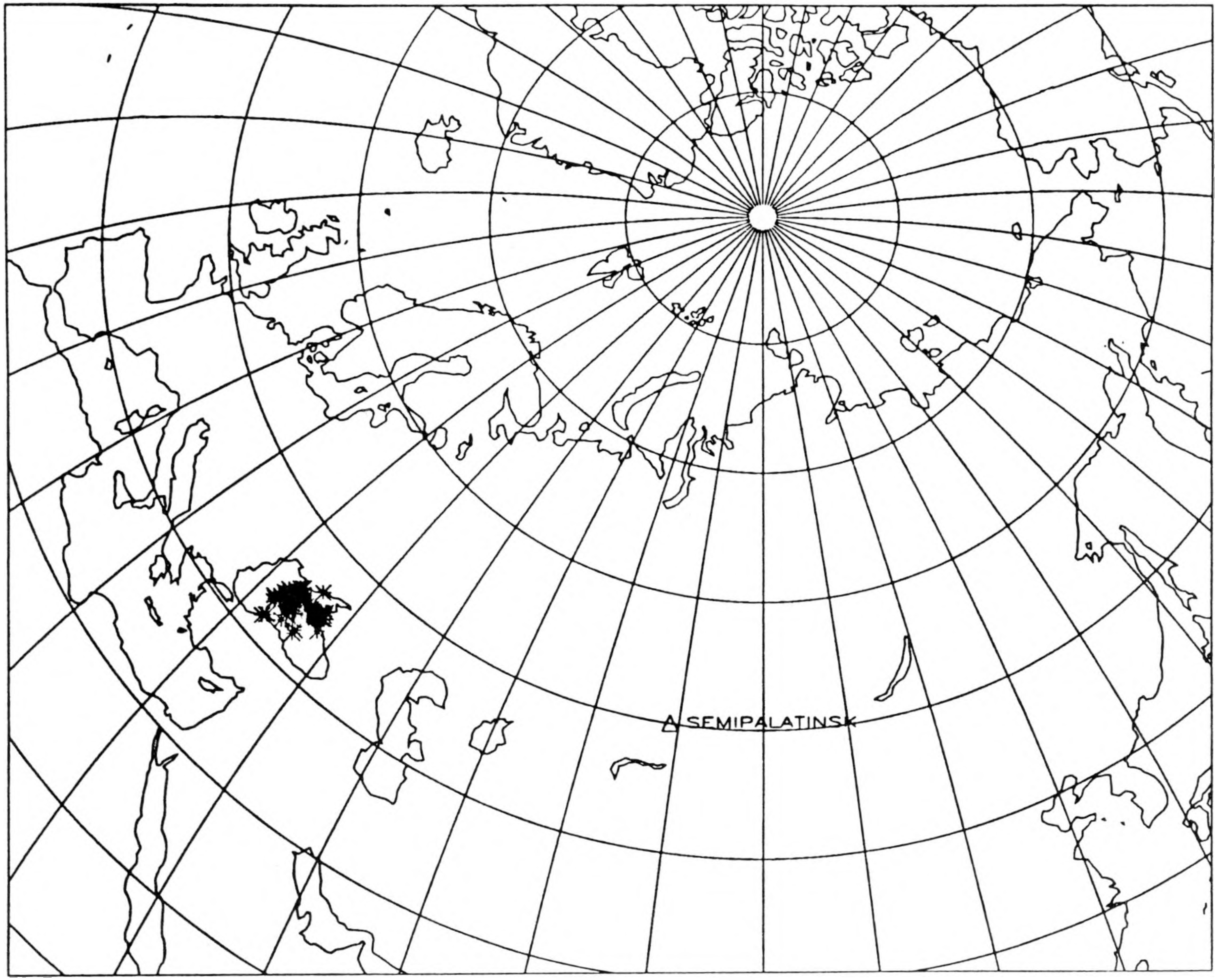
Figure 24c



Depth Distribution
caucasus.depths
0
-2
-4
X 10+2
Depth (km)
0
5
10
15
20
25
X 10+2
Number of Events

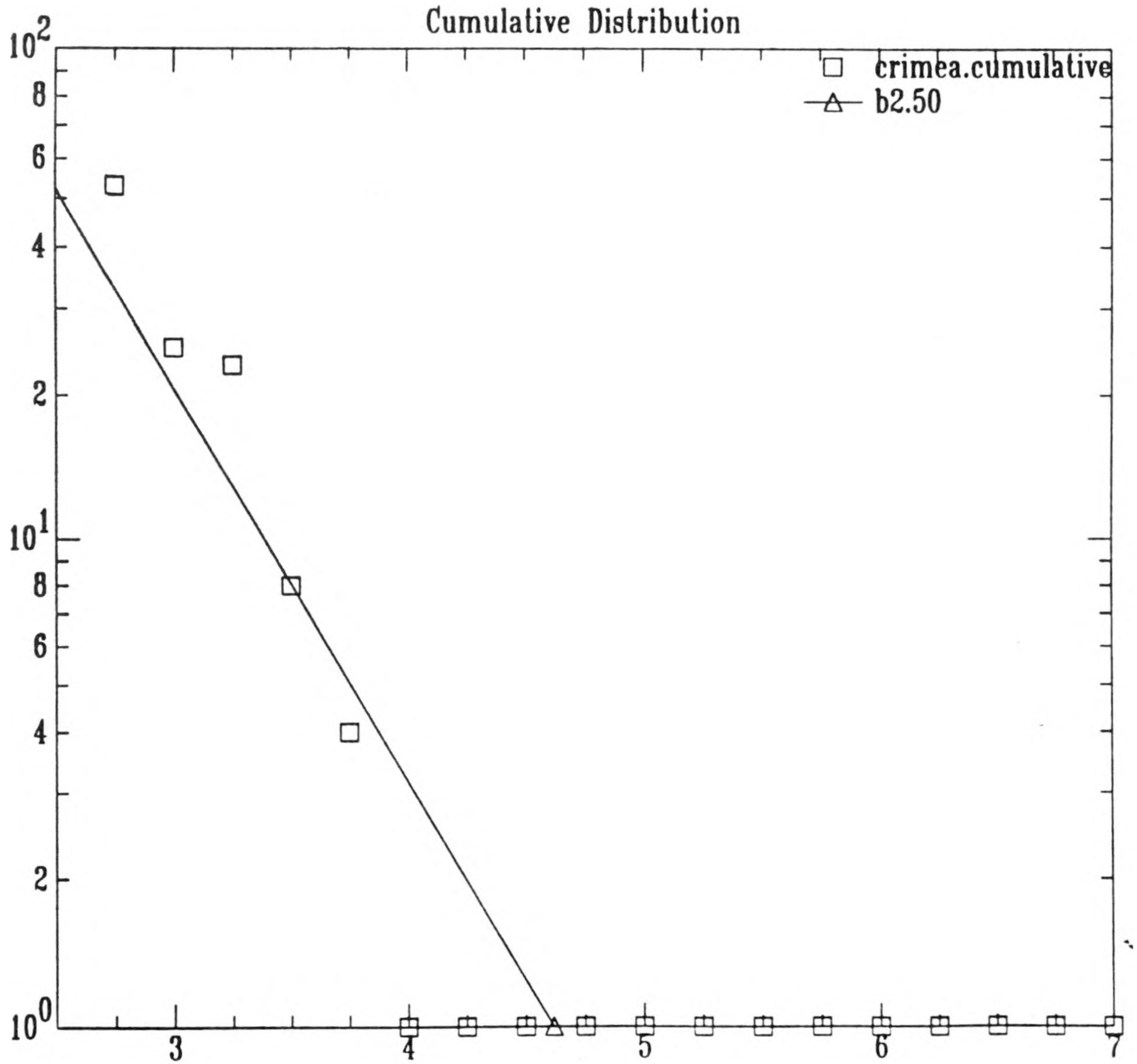
Figure 24d

Crimea and Lower Kuban



PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 25a



Cumulative Distribution
crimea.cumulative
b2.50
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6
7

Figure 25b

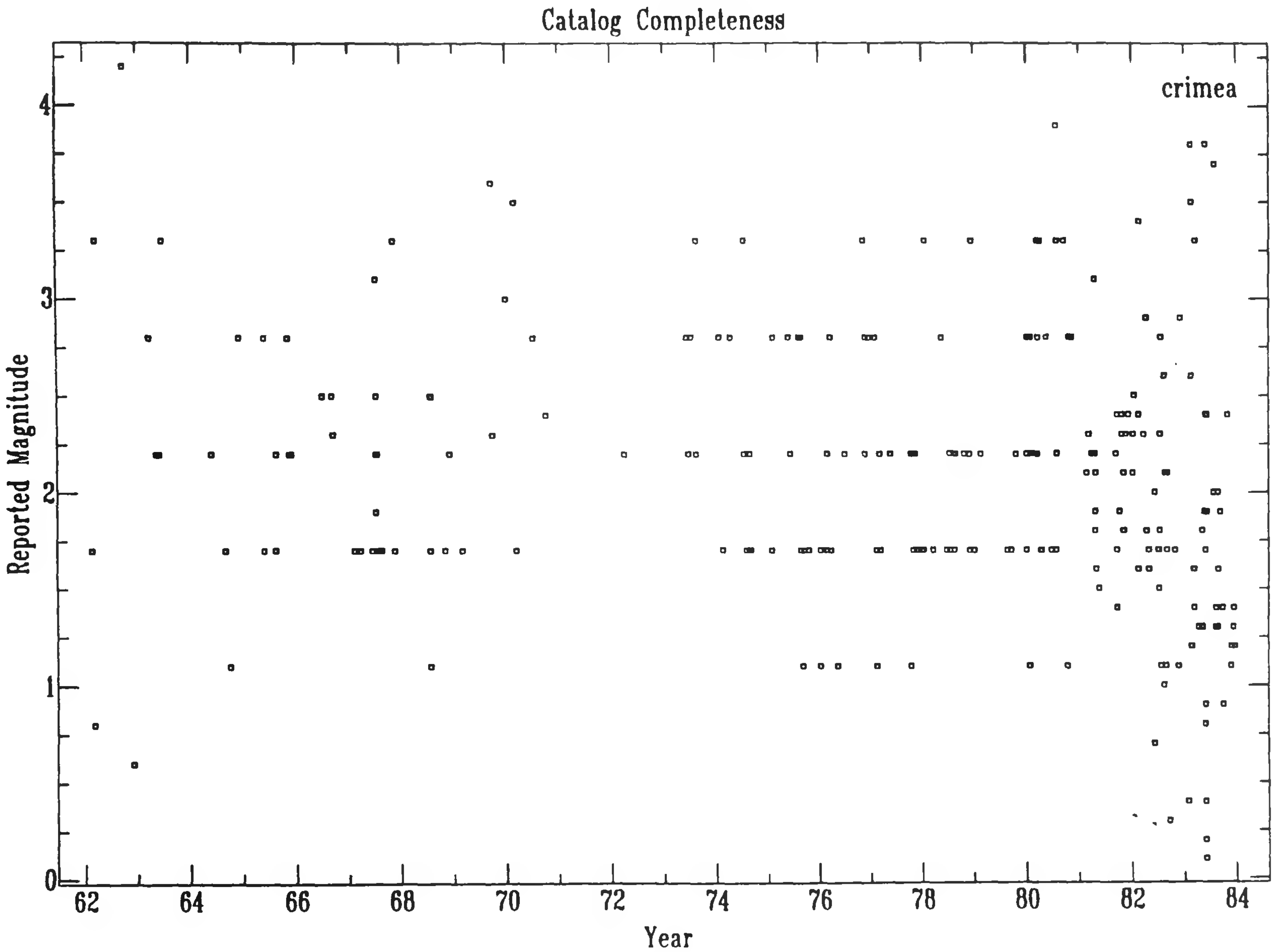

Catalog Completeness
crimea
Reported Magnitude
0
1
2
3
4
62
64
66
68
70
72
74
76
78
80
82
84
Year

Figure 25c

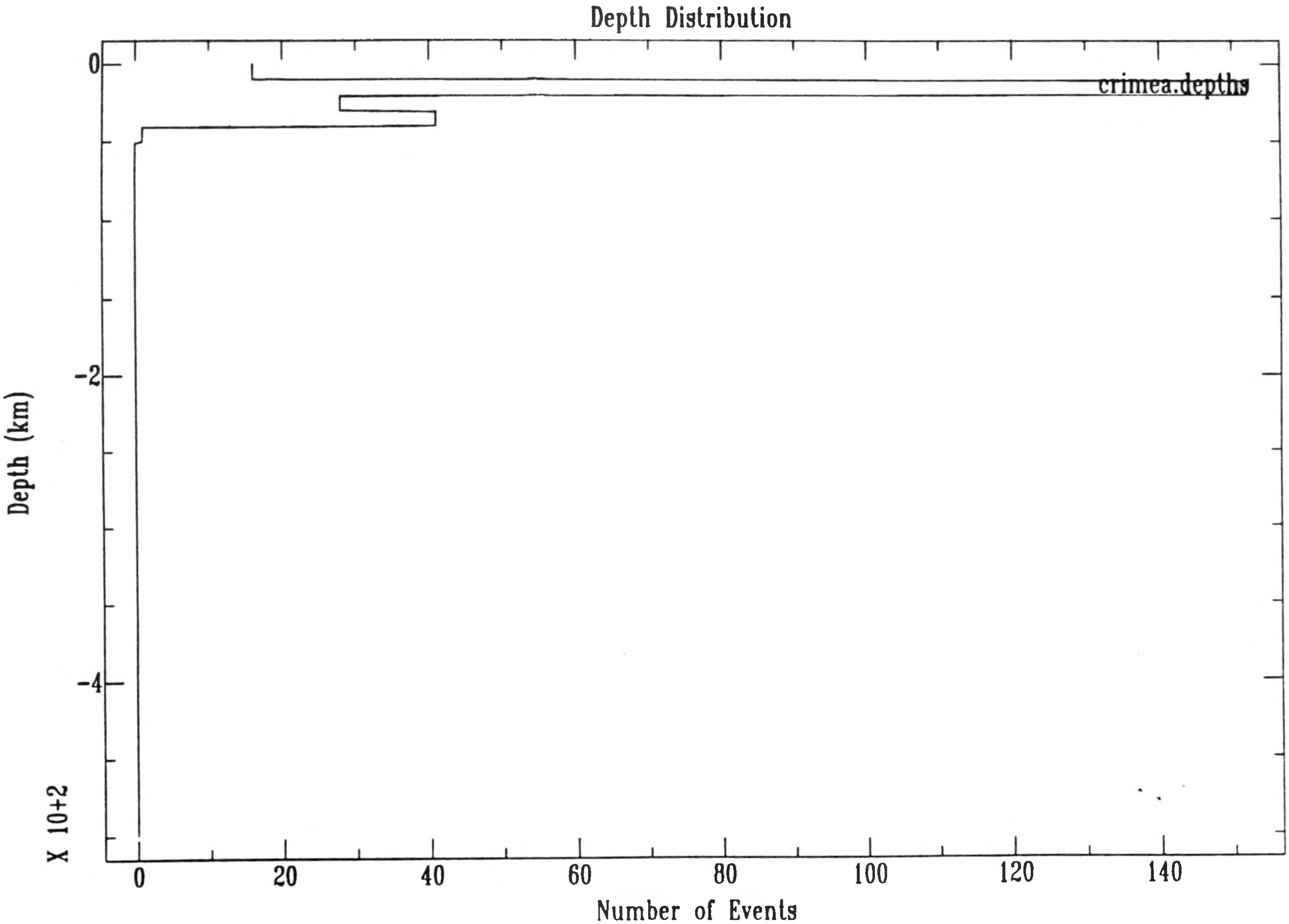
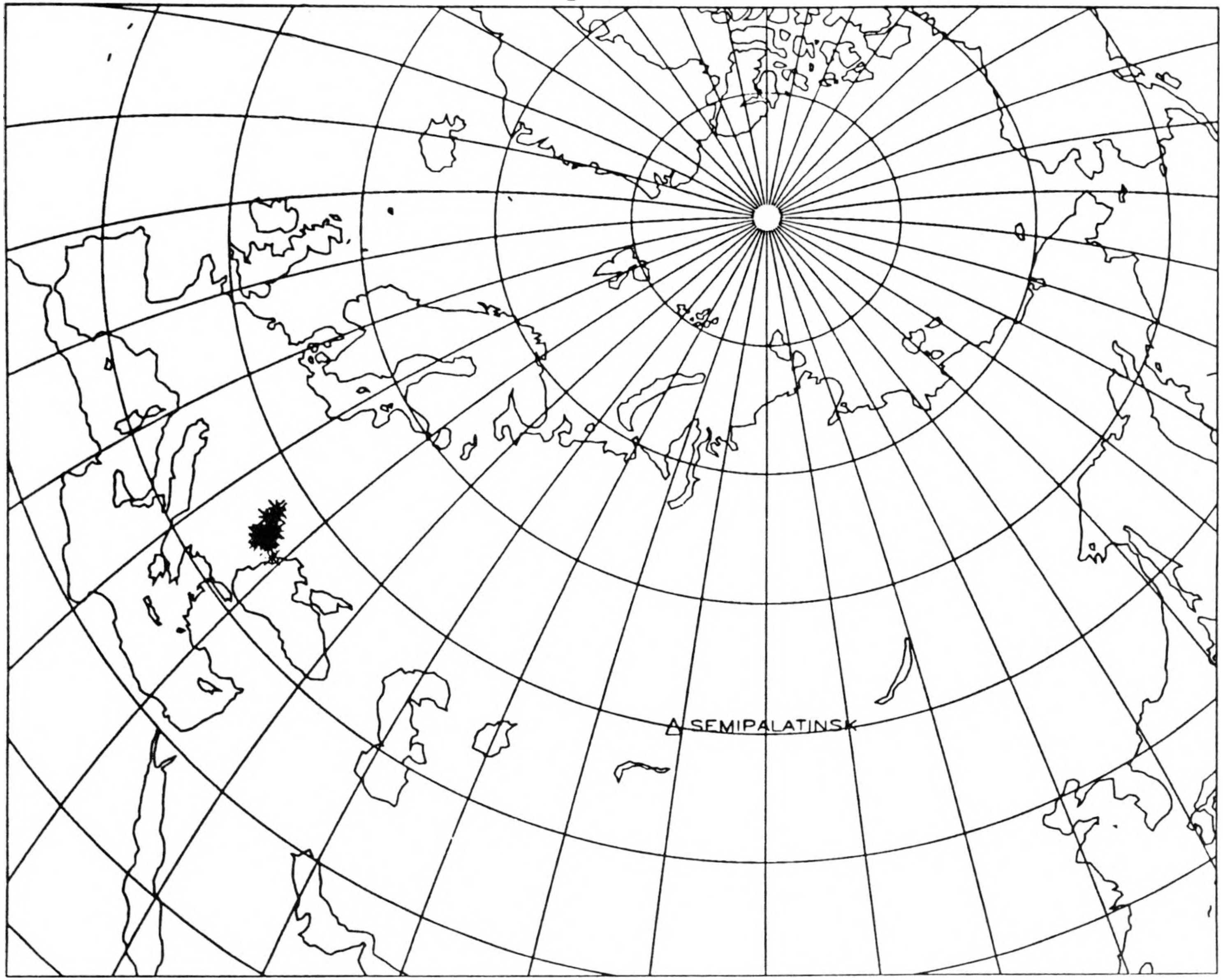
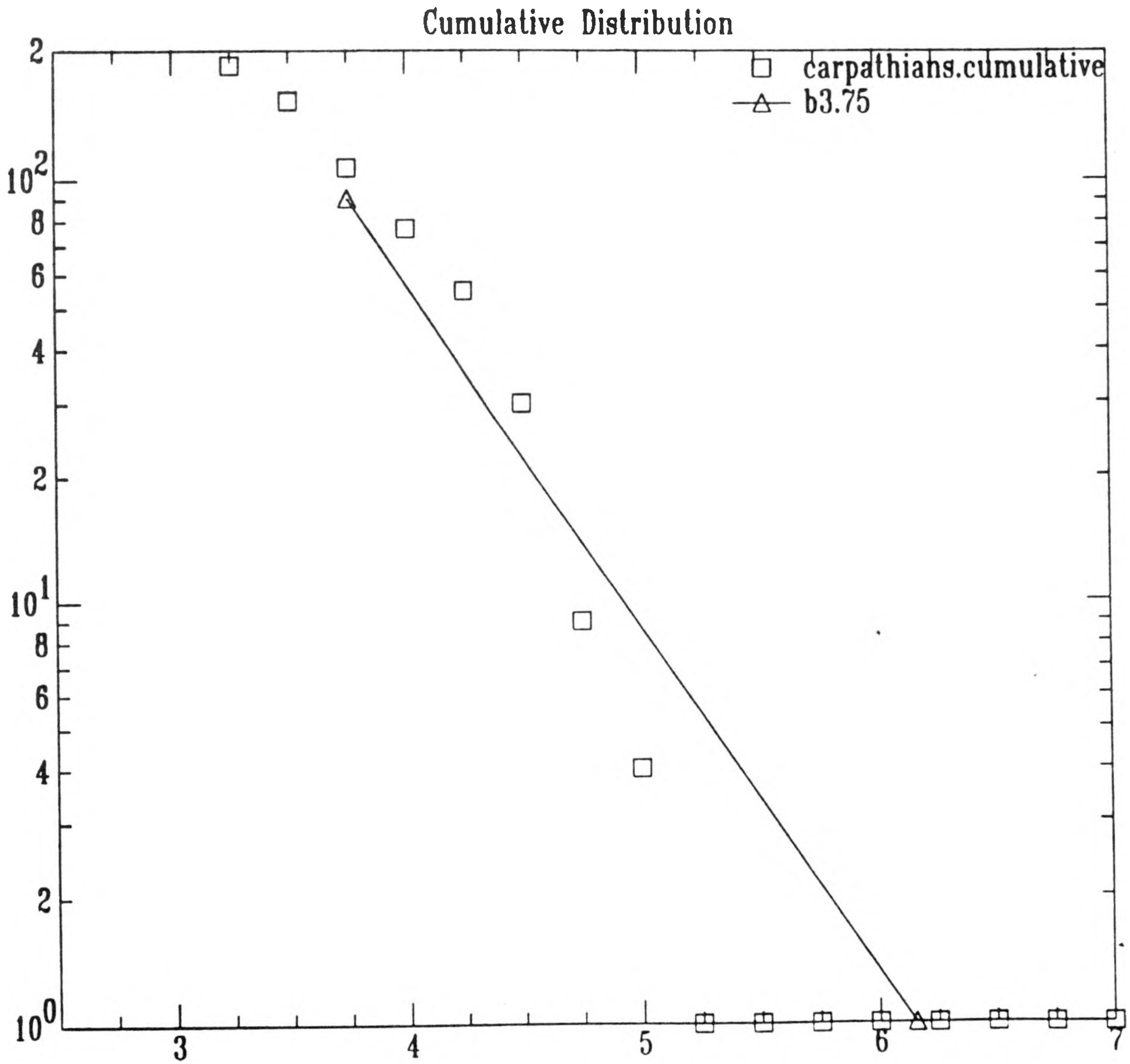

Depth Distribution
crimea.depths
0
-2
-4
X 10+2
Depth (km)
0
20
40
60
80
100
120
140
Number of Events

Figure 25d

Carpathians

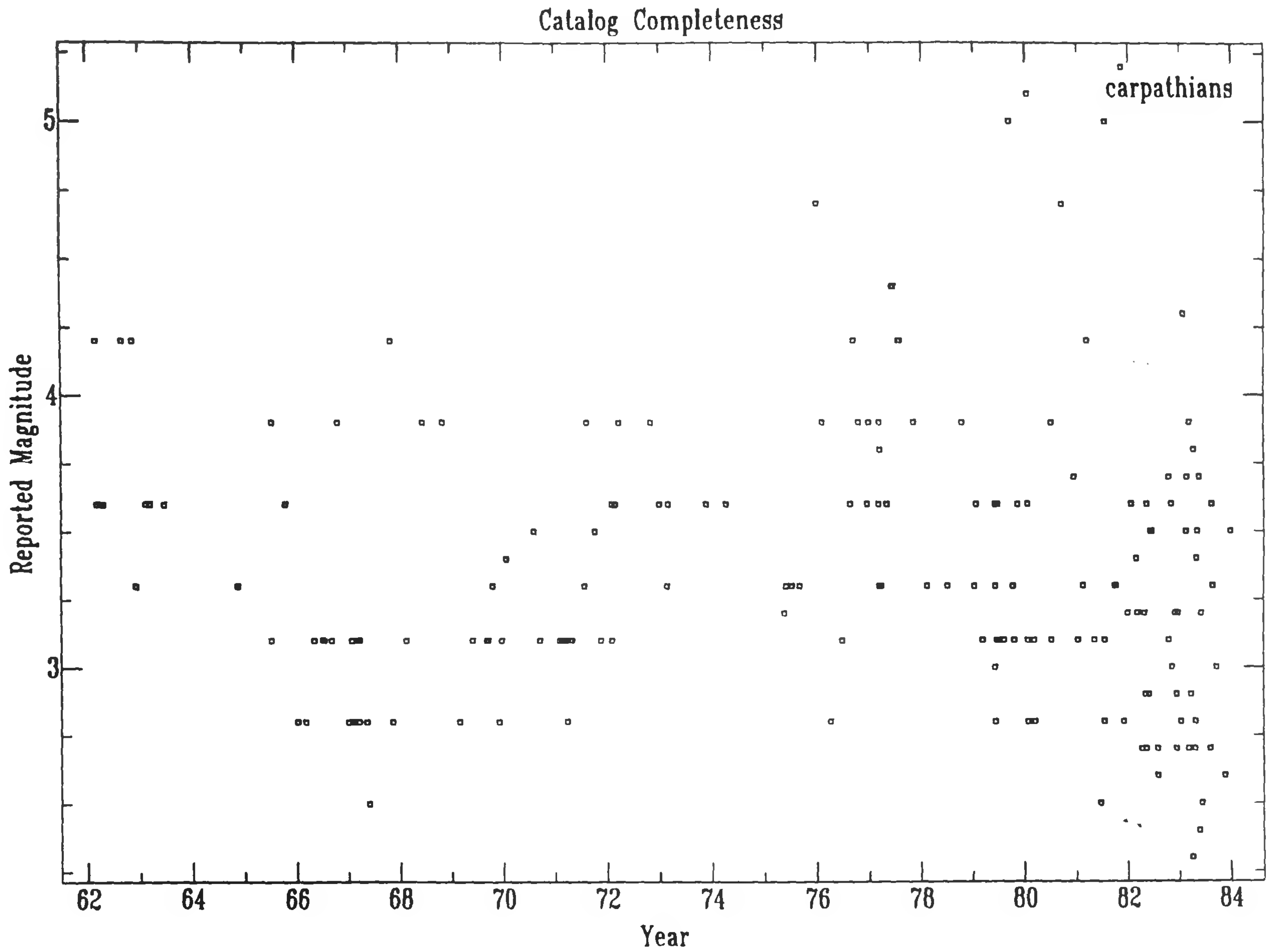


PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI −1.0000 0.6000 −0.5000 0.6000



Cumulative Distribution
carpathians.cumulative
b3.75
2
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6
7

Figure 26b



Catalog Completeness
carpathians
Reported Magnitude
3
4
5
Year
62
64
66
68
70
72
74
76
78
80
82
84

Figure 26c

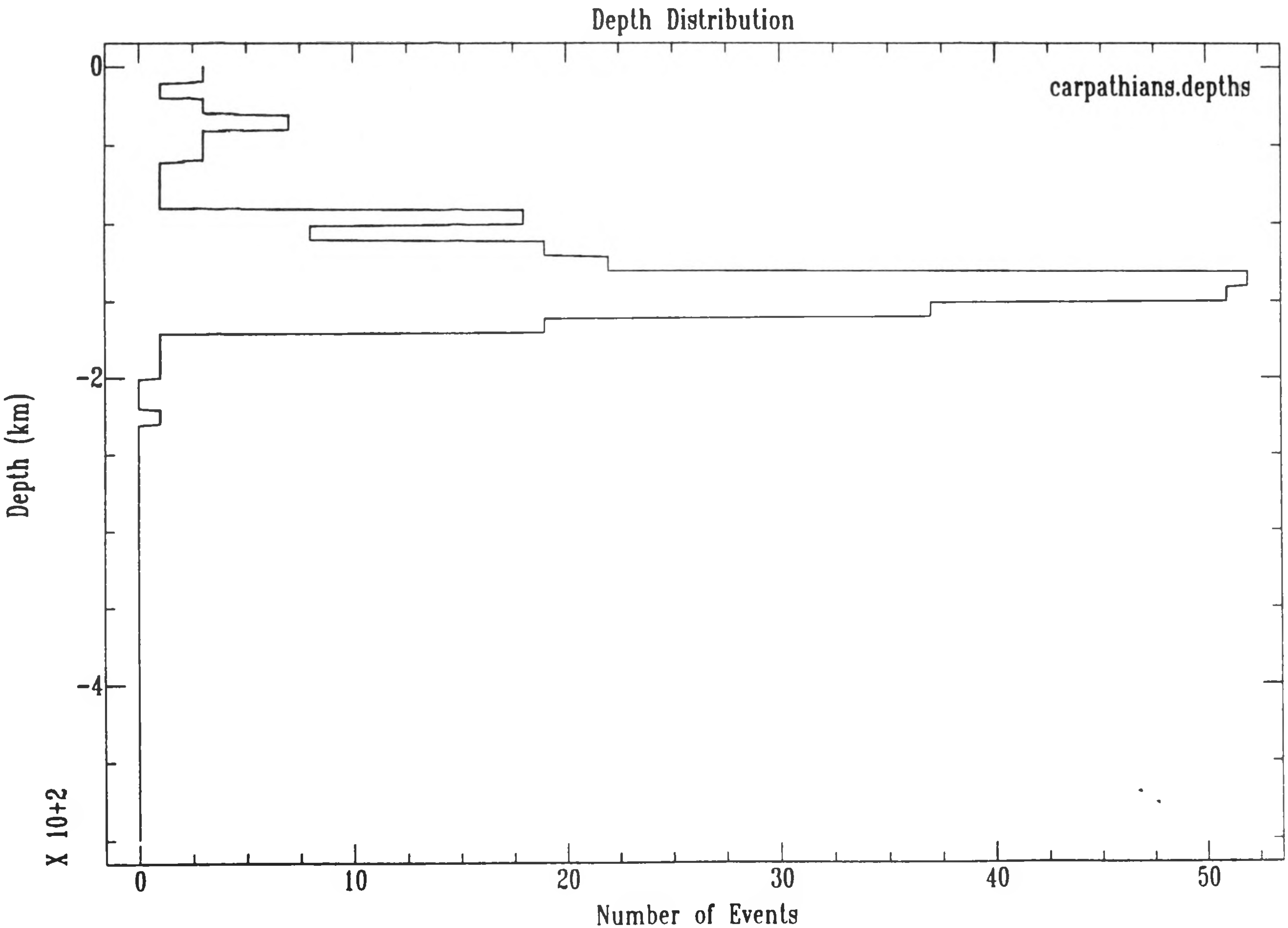
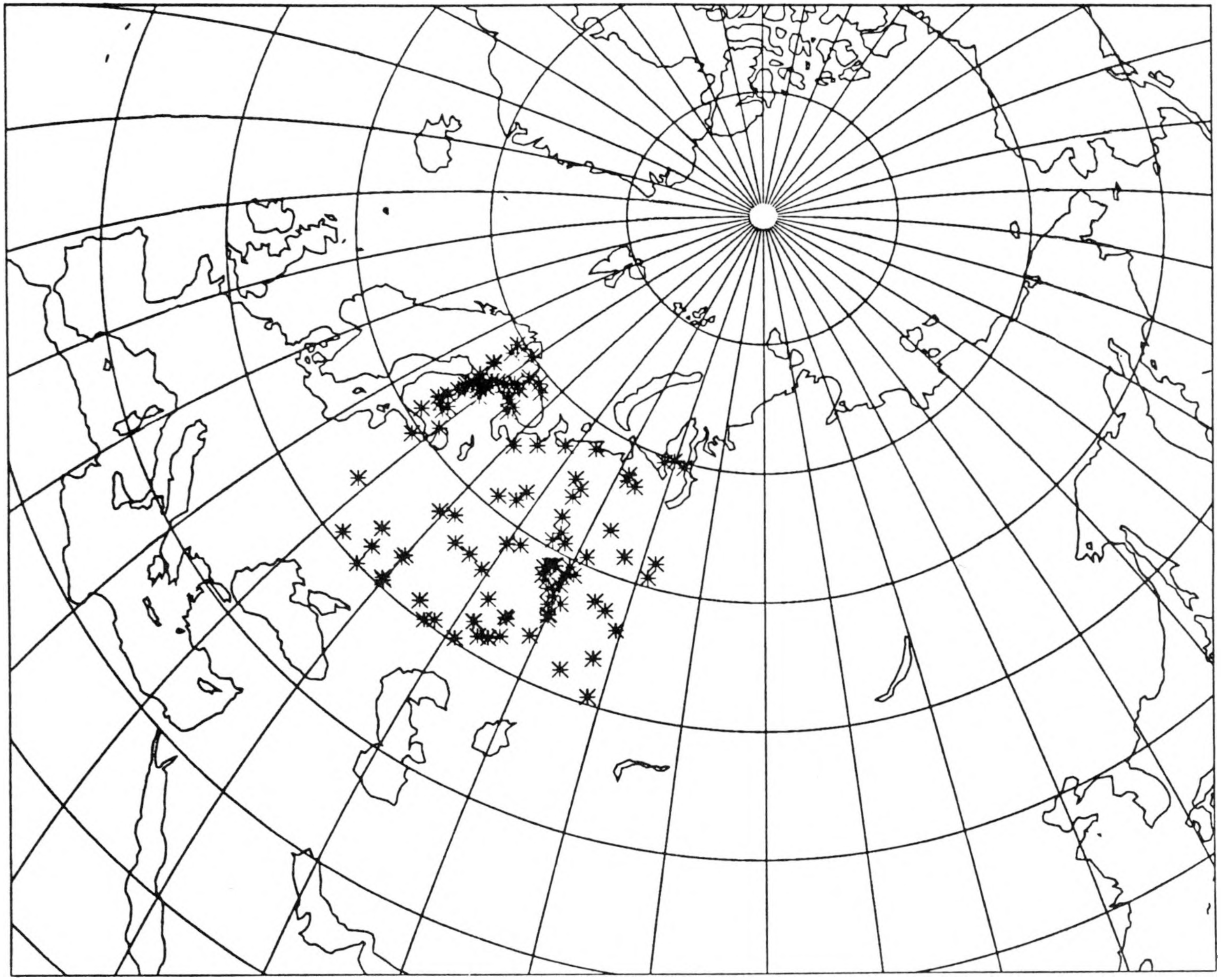

Depth Distribution
carpathians.depths
Depth (km)
X 10+2
0
-2
-4
0
10
20
30
40
50
Number of Events

Figure 26d

Russian Platform and Ural Mountains



PROJECTION LAMBERT: POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 27a

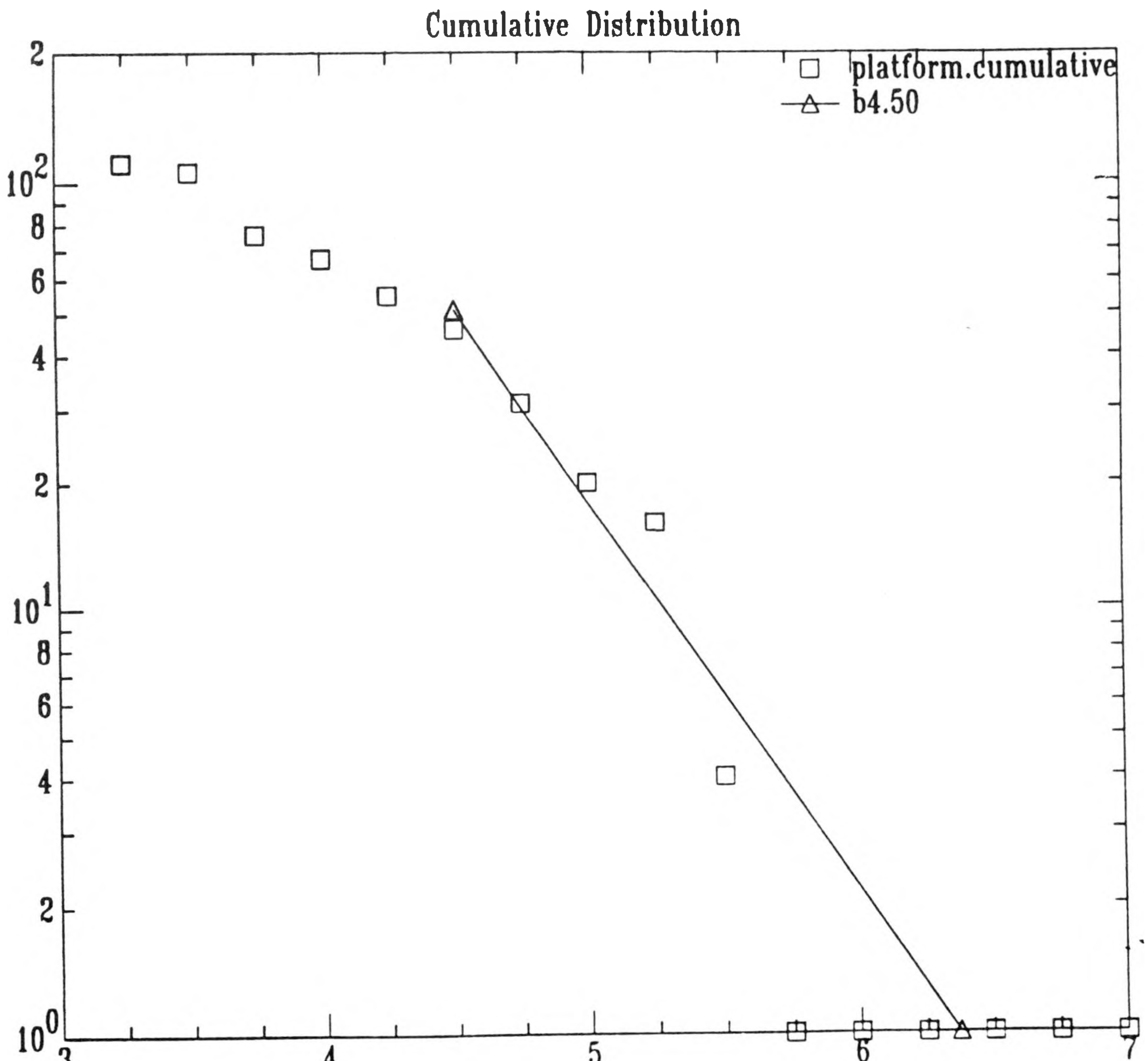

Cumulative Distribution
platform.cumulative
b4.50
2
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6
7

Figure 27b

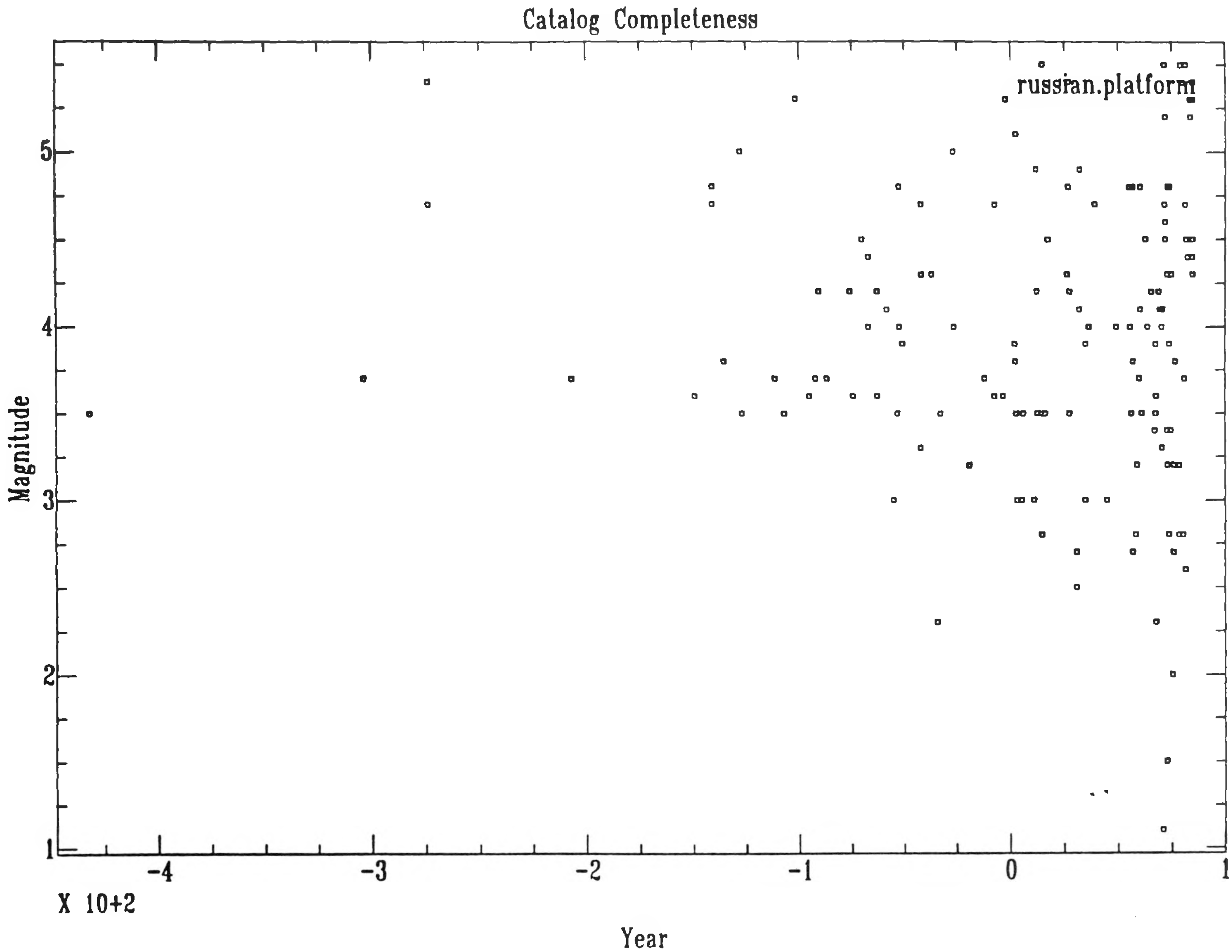
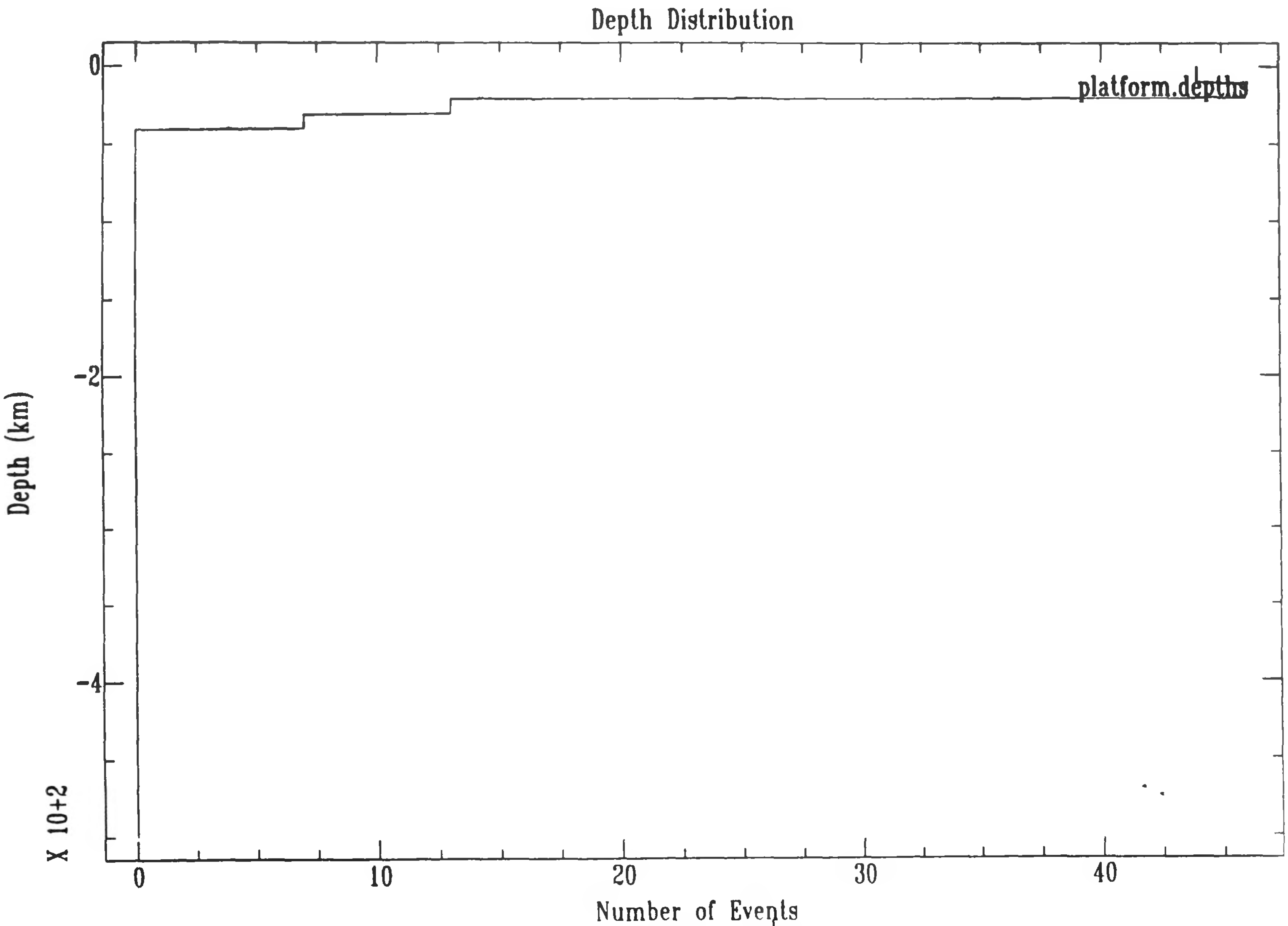
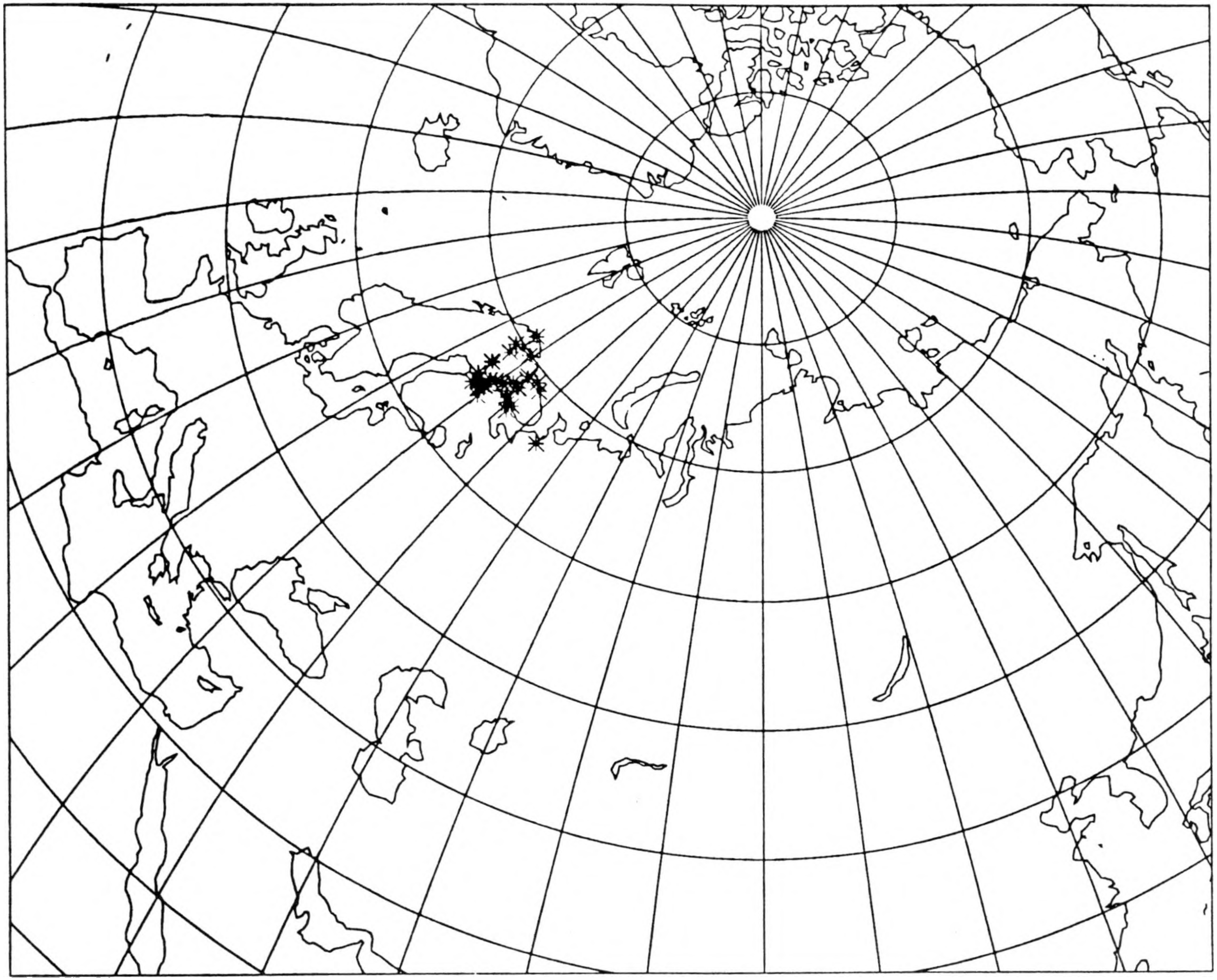

Catalog Completeness
russian.platform
Magnitude
5
4
3
2
1
-4
-3
-2
-1
0
1
X 10+2
Year

Figure 27c


Depth Distribution
platform.depths
0
-2
-4
X 10+2
Depth (km)
0
10
20
30
40
Number of Events
Figure 27d

Kola Peninsula



PROJECTION LAMBERT: POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 28a

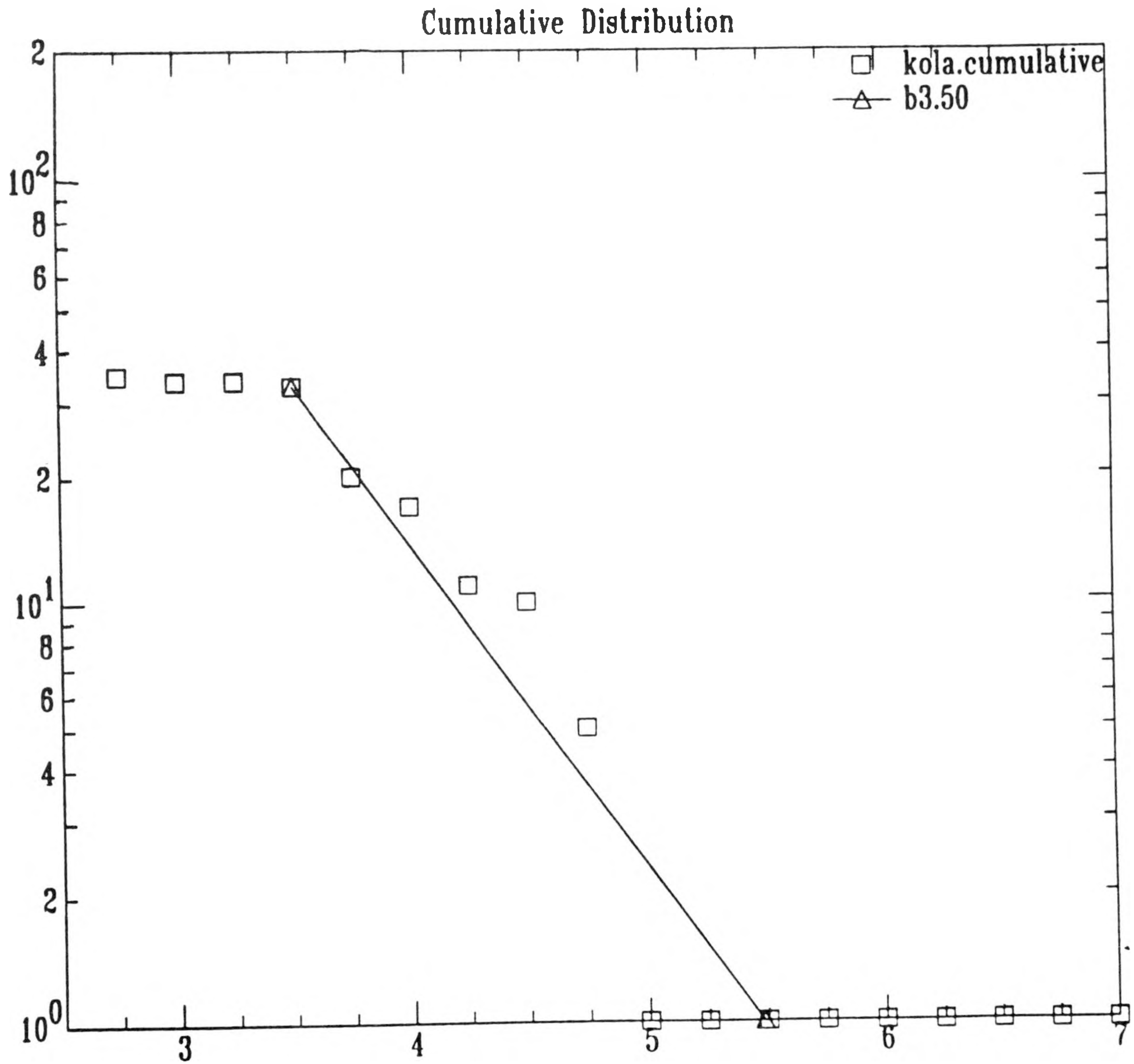
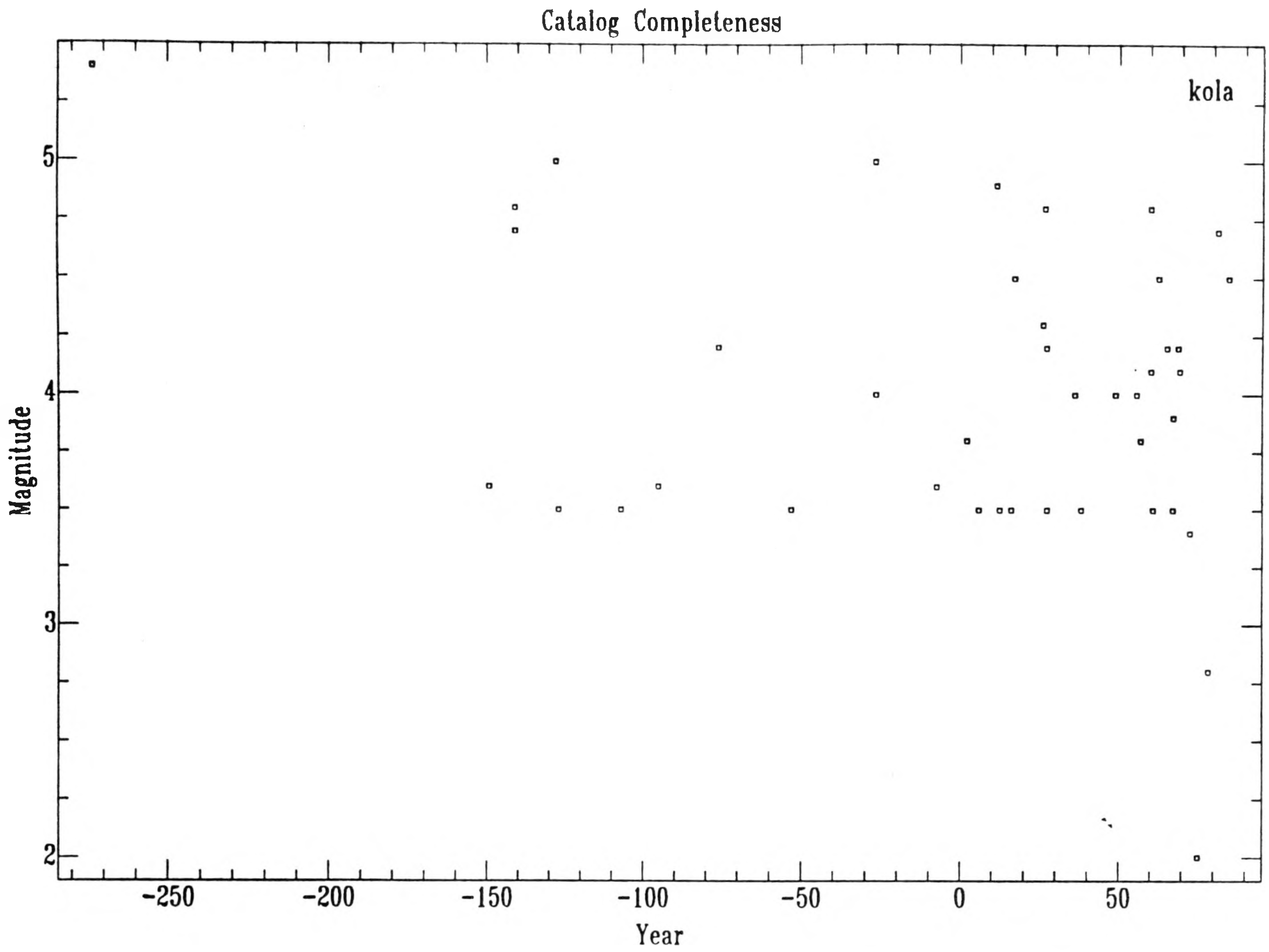

Cumulative Distribution
kola.cumulative
b3.50
2
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6
7

Figure 28b



Catalog Completeness
kola
Magnitude
Year
5
4
3
2
-250
-200
-150
-100
-50
0
50

Figure 28c

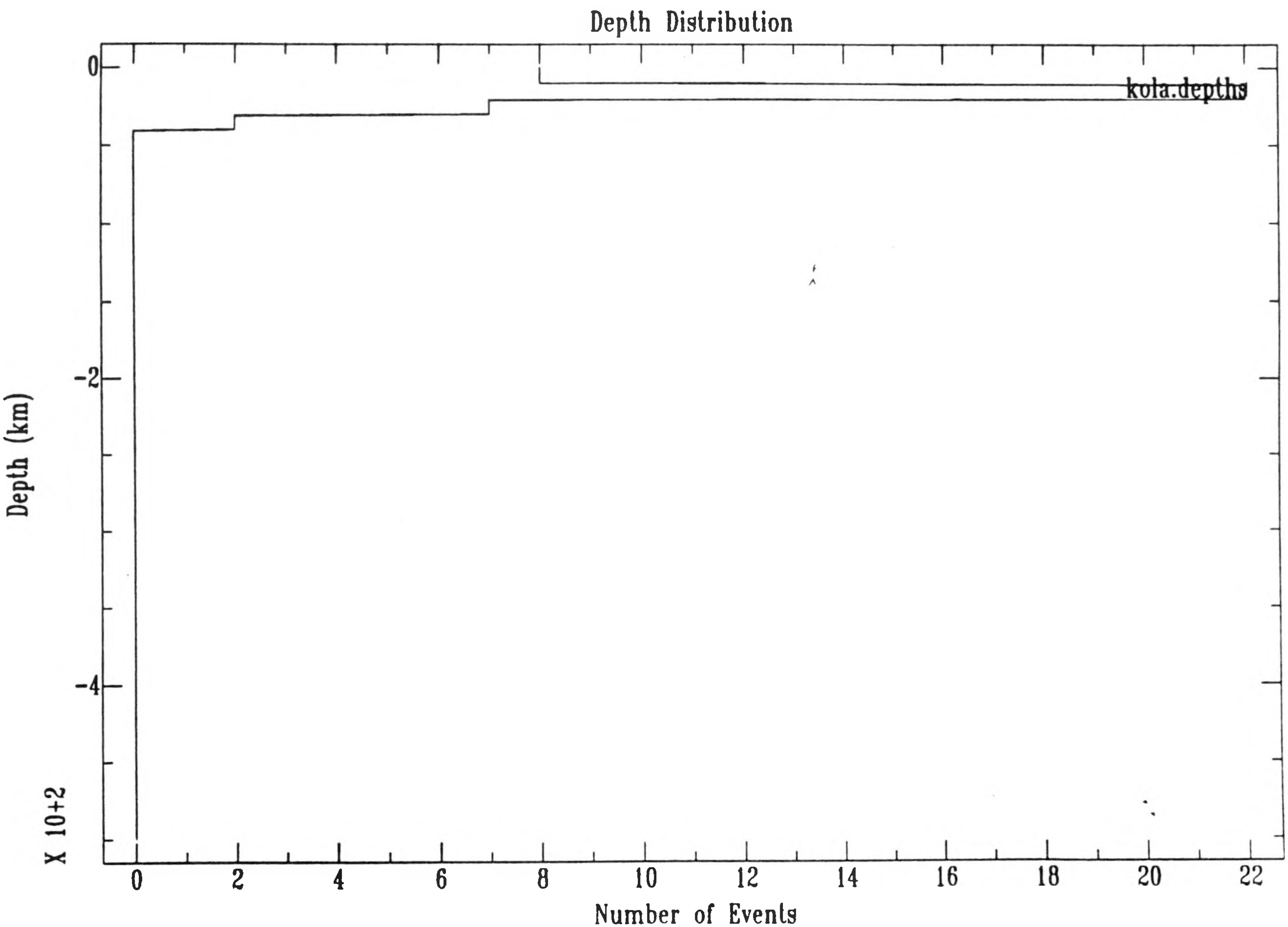

Depth Distribution
kola.depths
0
-2
-4
X 10+2
Depth (km)
0
2
4
6
8
10
12
14
16
18
20
22
Number of Events

Figure 28d

APPENDIX A

PRIMORIE	SAKHALIN	SIBERIA	TURKMENIA	YAKUTIA	USSR	Depth Range (km)
824	360	4	361	7	13923	0-10
169	164	4	134	28	8988	11-20
134	25	1	185	9	7794	21-30
14	20	7	136		11285	31-40
1	4	3	24		3856	41-50
0	0	0	3		2921	51-60
0	1	0			1793	61-70
0	1	0			2732	71-80
0	1	0			1118	81-90
0	0	0			2027	91-100
1	0	0			1042	101-110
	0	1			1231	111-120
	0				1341	121-130
	1				1186	131-140
	1				1199	141-150
	1				1025	151-160
	0				545	161-170
	1				859	171-180
	1				814	181-190
	0				1850	191 200
	0				1550	201-210
	0				1131	211-220
	0				1045	221-230
	0				524	231-240
	2				275	241-250
	0				46	251-260
	1				97	261-270
	4				56	271-280
	2				37	281-290
	1				29	291-300
	9				28	301-310
	6				23	311-320
	11				28	321-330
	8				24	331-340
	2				24	341-350
	3				51	351-360
	3				38	361-370
	3				27	371-380
	3				20	381-390
	2				32	391 400
	4				10	401-410
	0				22	411-420
	2				17	421-430
	1				13	431-440
	3				49	441-450
	2				12	451-460
	1				19	461-470
	0				14	471-480
	0				14	481-490
	1				29	491-500

NORTHEAST	NORTH TIEN SHAN	MIDASIA	KURIL	KOLA	Depth Range (km)
29	496	3855	395	8	0-10
75	370	1114	727	22	11-20
22	96	293	2378	7	21-30
2	5	82	4437	2	31-40
0	0	4	1127		41-50
1	1	12	606		51-60
		294	393		61-70
		1350	277		71-80
		409	206		81-90
		1264	162		91-100
		606	133		101-110
		736	123		111-120
		974	137		121-130
		852	103		131-140
		823	137		141-150
		734	61		151-160
		384	59		161-170
		721	47		171-180
		701	26		181-190
		1676	45		191 200
		1465	17		201-210
		1036	13		211-220
		991	5		221-230
		463	12		231-240
		234	9		241-250
		3	6		251-260
		63	9		261-270
		5	5		271-280
		0	10		281-290
		3	19		291-300
		0	13		301-310
		0	8		311-320
		0	17		321-330
		0	6		331-340
		2	21		341-350
			15		351-360
			11		361-370
			11		371-380
			9		381-390
			22		391 400
			7		401-410
			9		411-420
			11		421-430
			7		431-440
			17		441-450
			5		451-460
			9		461-470
			5		471-480
			11		481-490
			12		491-500

KAMCHATKA	CRIMEA	CAUCASUS	CARPATHIANS	Depth Range (km)
1943	16	2549	3	0-10
2014	152	68	1	11-20
2137	28	149	3	21-30
2257	41	41	7	31-40
787	1	9	3	41-50
341		1	3	51-60
223		0	1	61-70
284		0	1	71-80
252		0	1	81-90
224		1	18	91-100
158			8	101-110
160			19	111-120
141			22	121-130
104			52	131-140
99			51	141-150
86			37	151-160
61			19	161-170
45			1	171-180
40			1	181-190
25			1	191 200
15			0	201-210
10			0	211-220
13			1	221-230
9				231-240
10				241-250
15				251-260
8				261-270
15				271-280
14				281-290
8				291-300
8				301-310
6				311-320
4				321-330
2				331-340
1				341-350
0				351-360
0				361-370
2				371-380
0				381-390
1				391 400
0				401-410
2				411-420
2				421-430
2				431-440
20				441-450
2				451-460
0				461-470
3				471-480
0				481-490
5				491-500

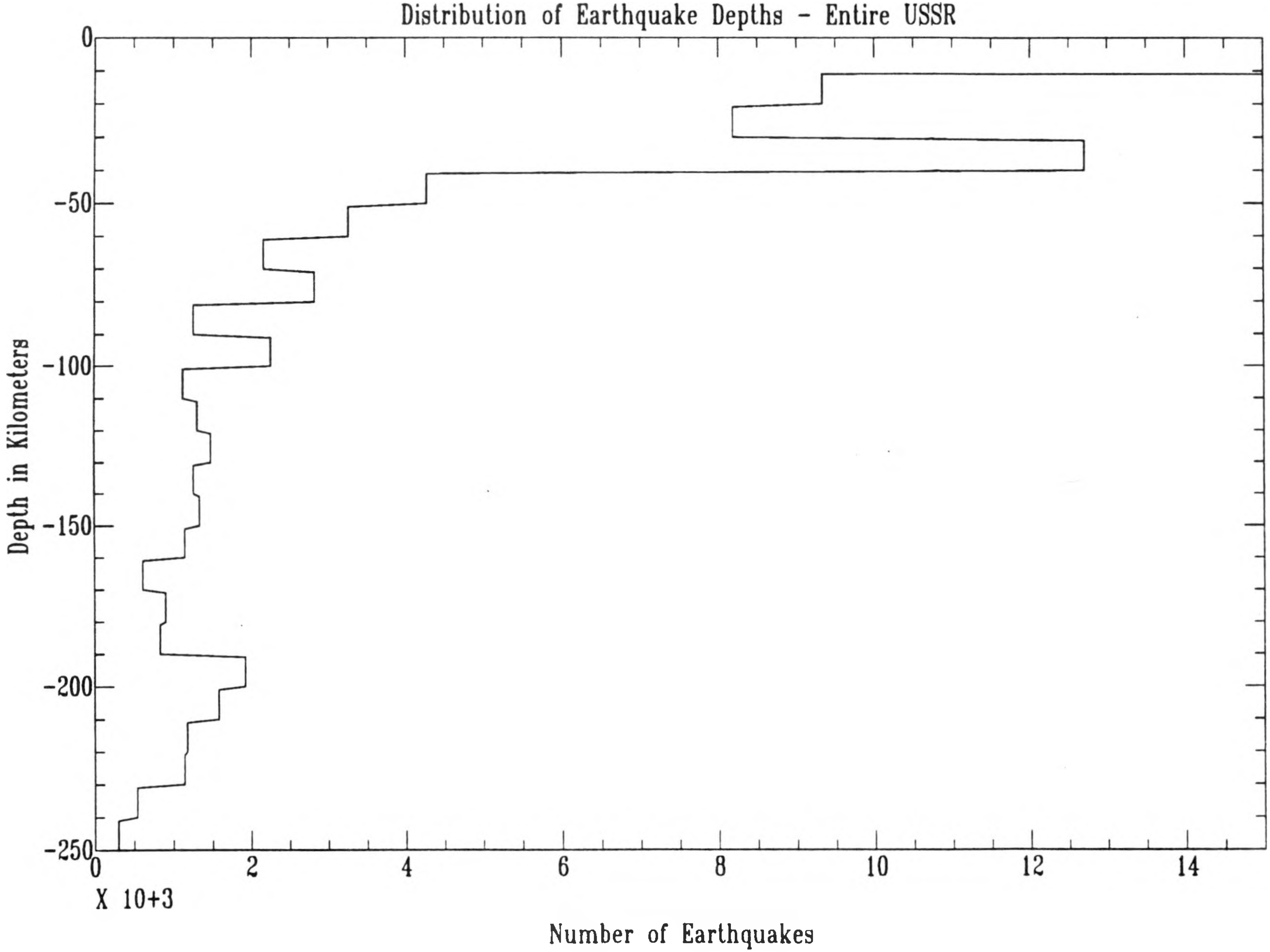
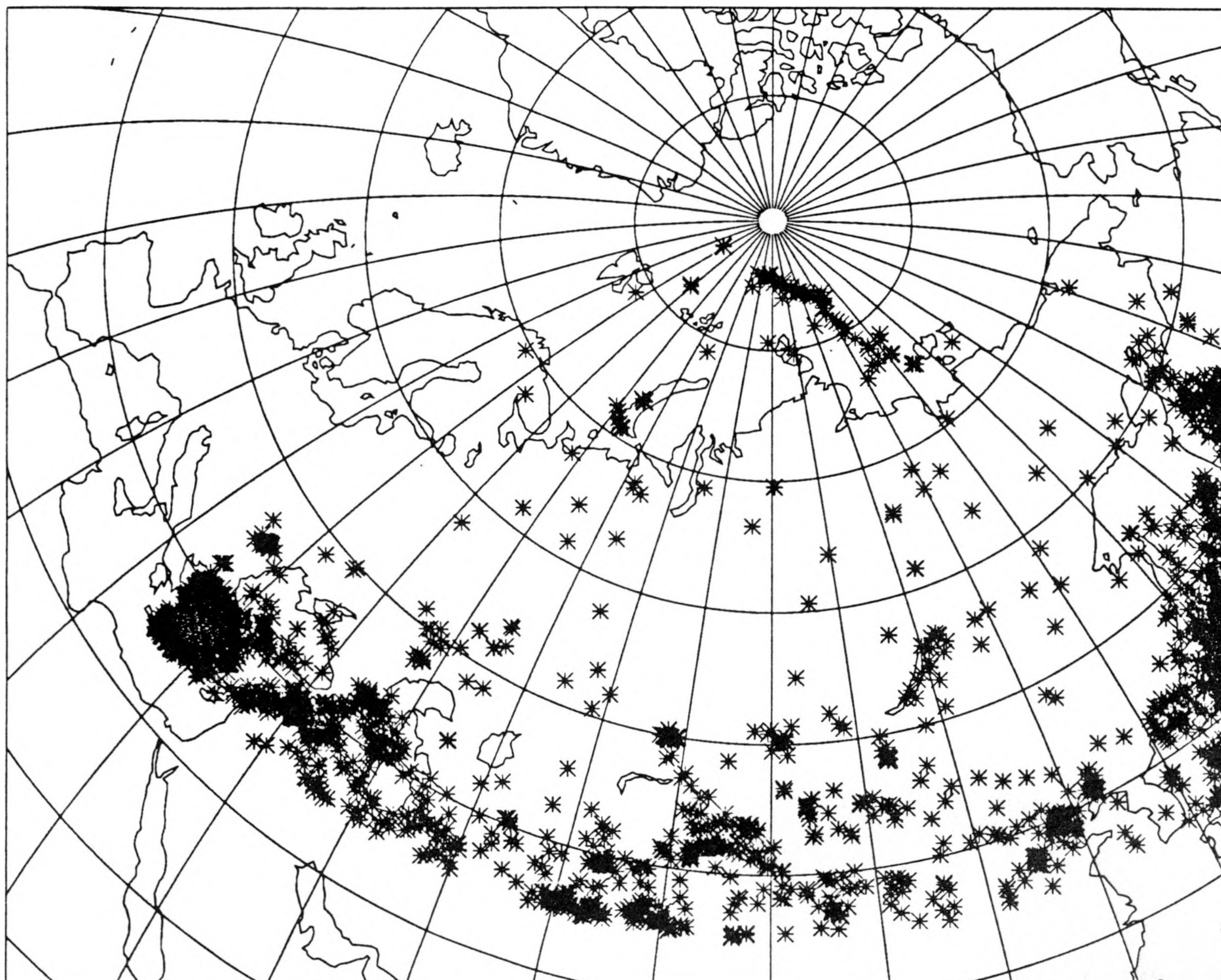
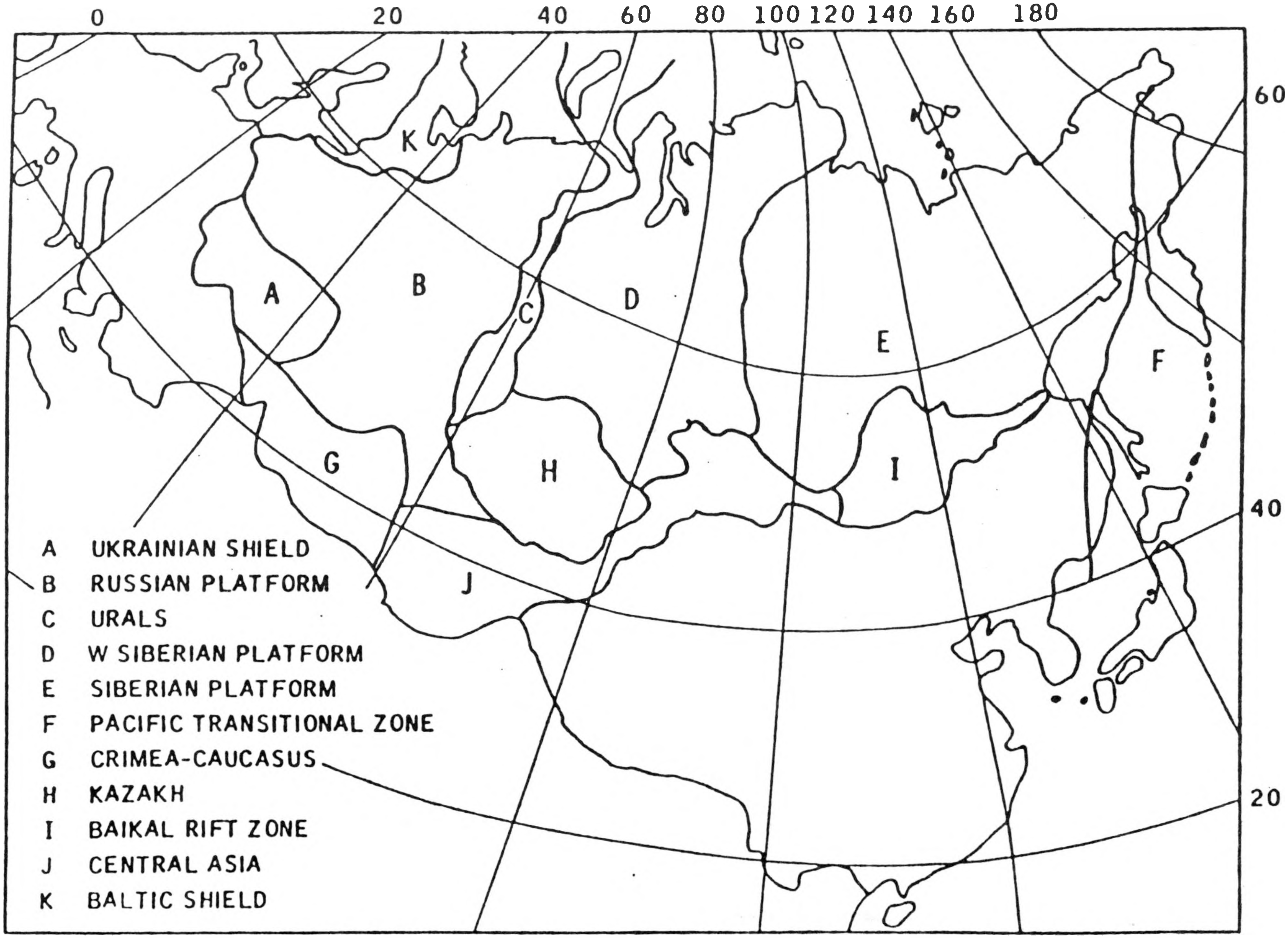

Distribution of Earthquake Depths - Entire USSR
0
-50
-100
-150
-200
-250
Depth in Kilometers
0
2
4
6
8
10
12
14
X 10+3
Number of Earthquakes

Figure 9

ISC Events



PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8



The eleven tectonic provinces of the U.S.S.R. (from Saimowitz and Hadley, 1980)
Figure 11

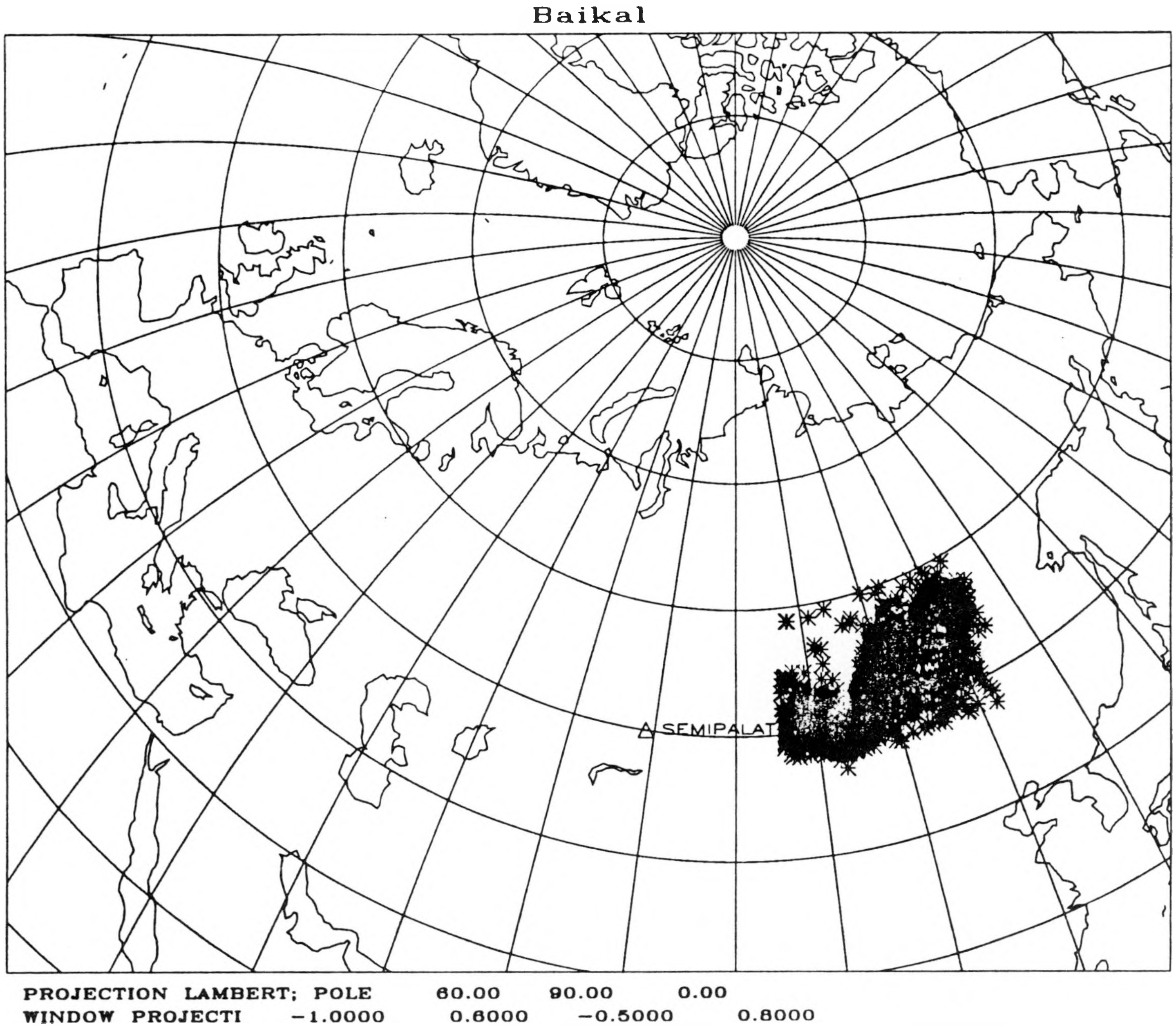
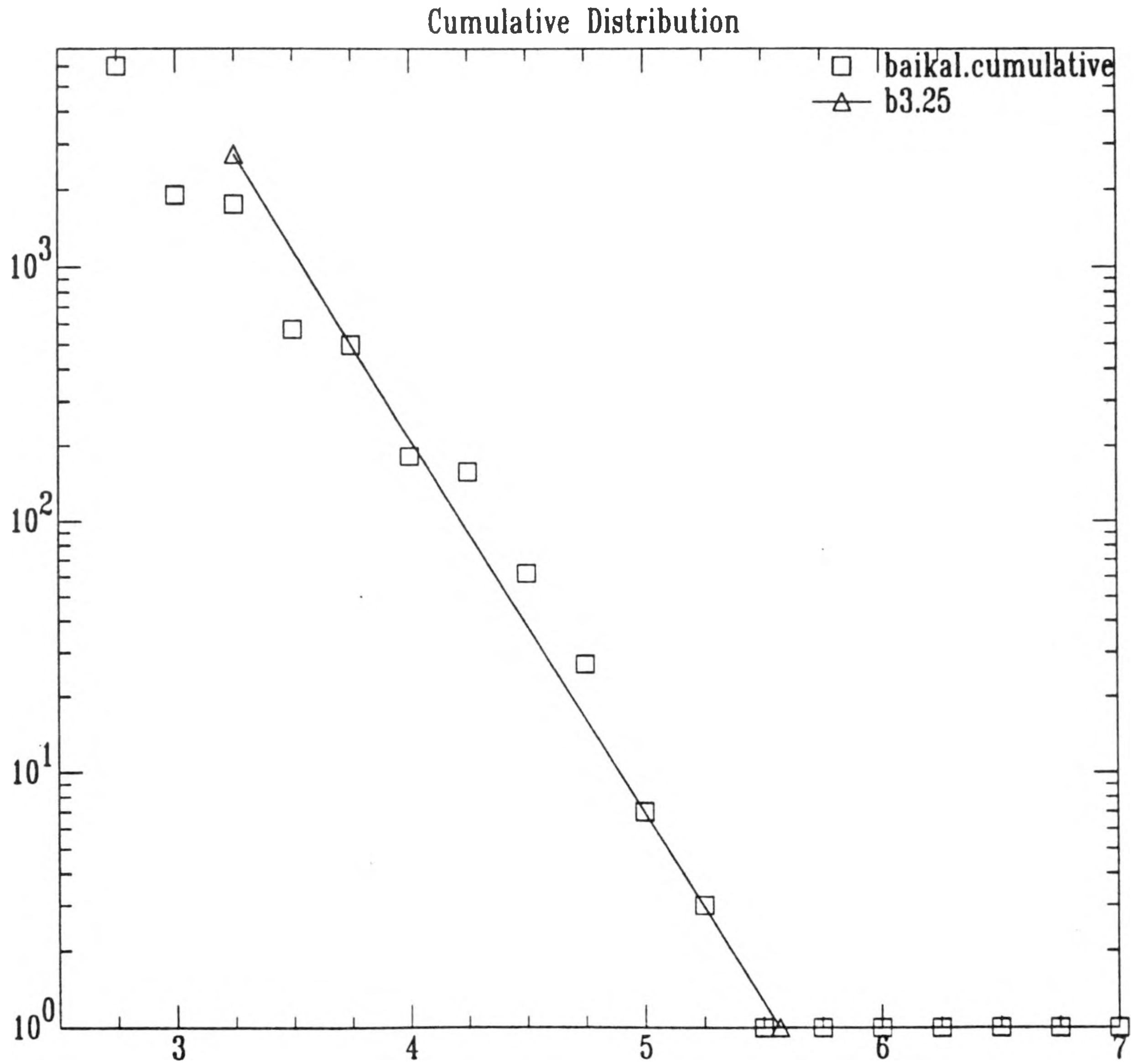

Baikal
SEMIPALAT
PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 12a



Cumulative Distribution
baikal.cumulative
b3.25
10^3
10^2
10^1
10^0
3
4
5
6
7

Figure 12b

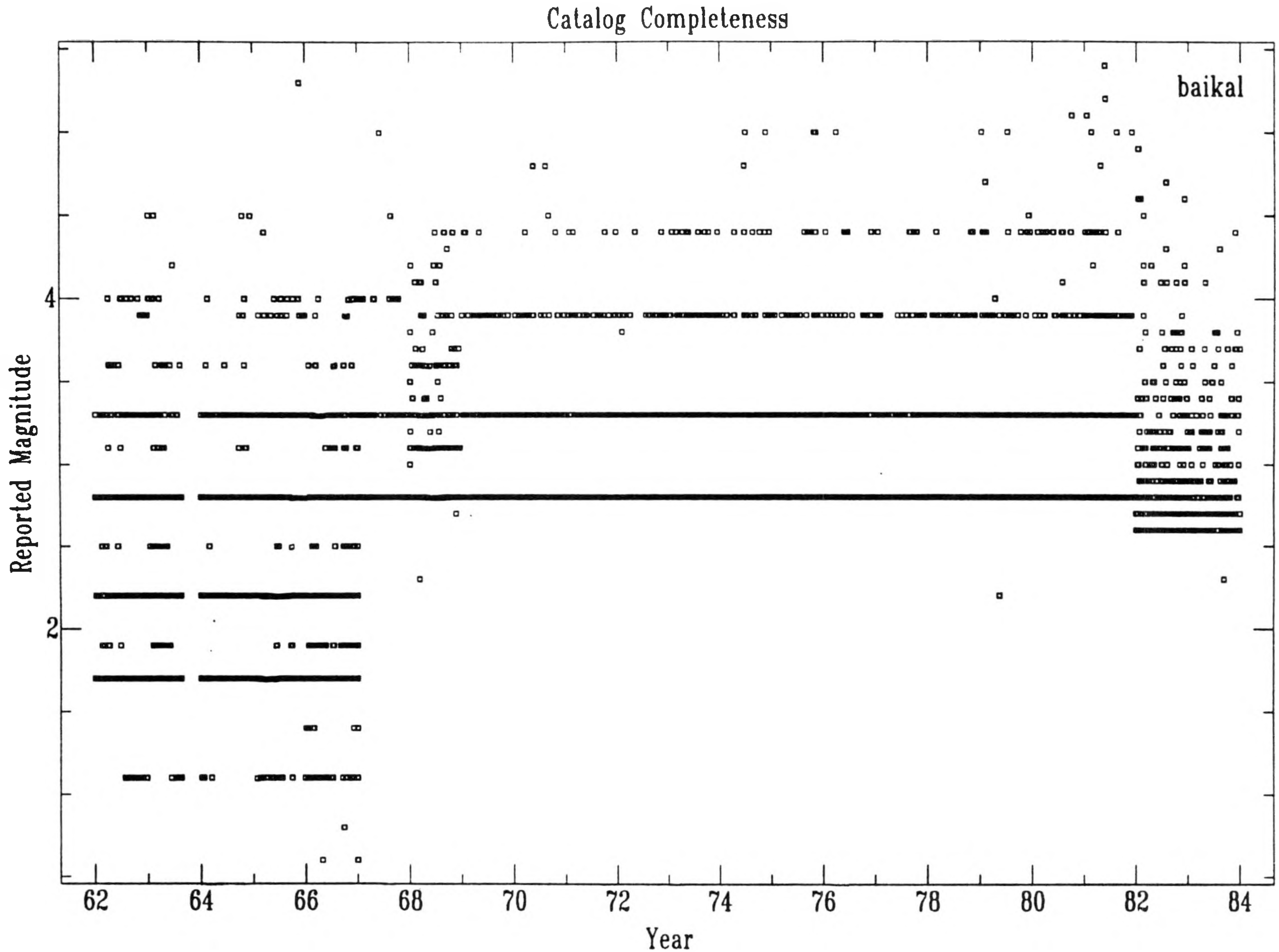
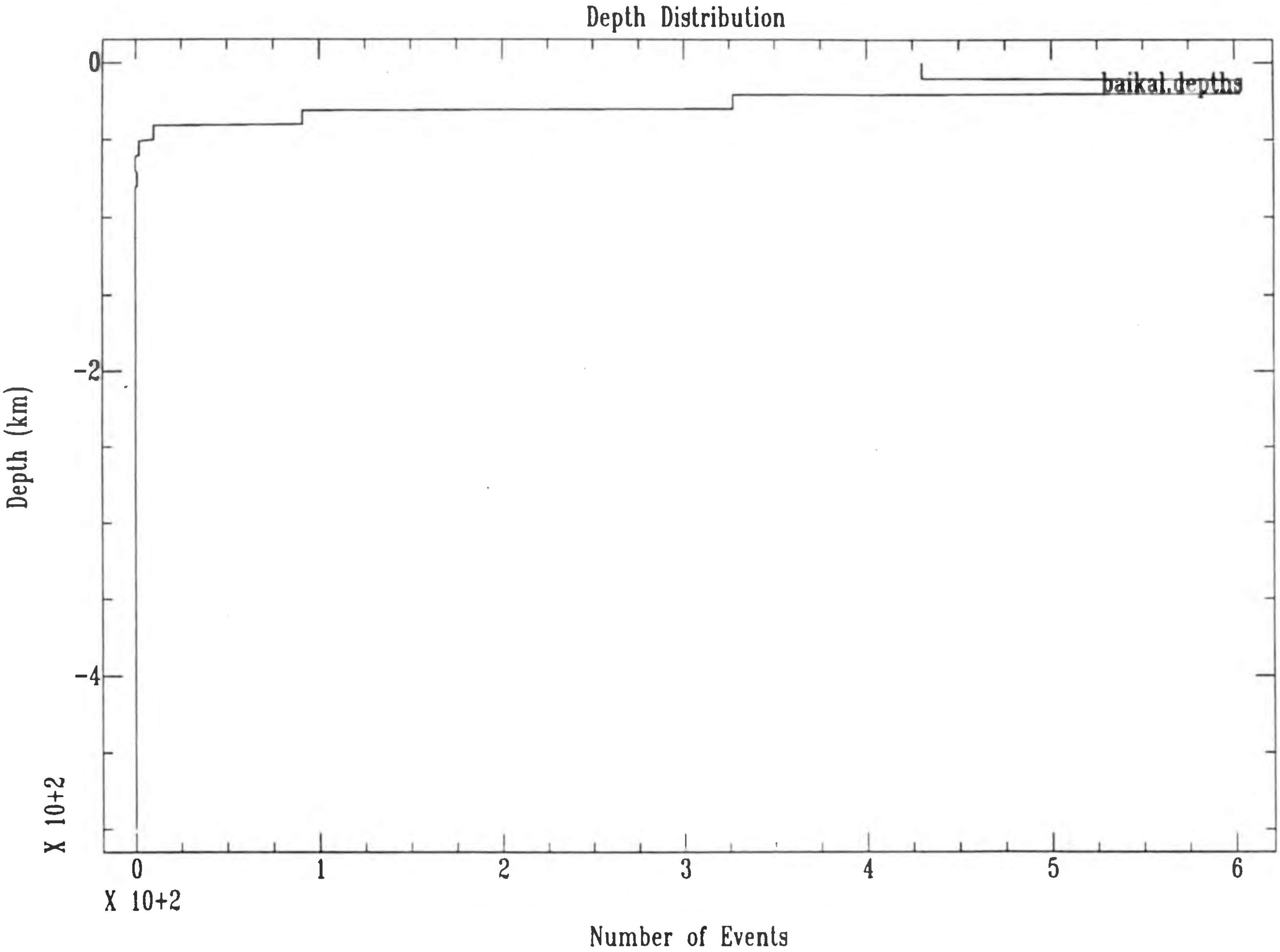
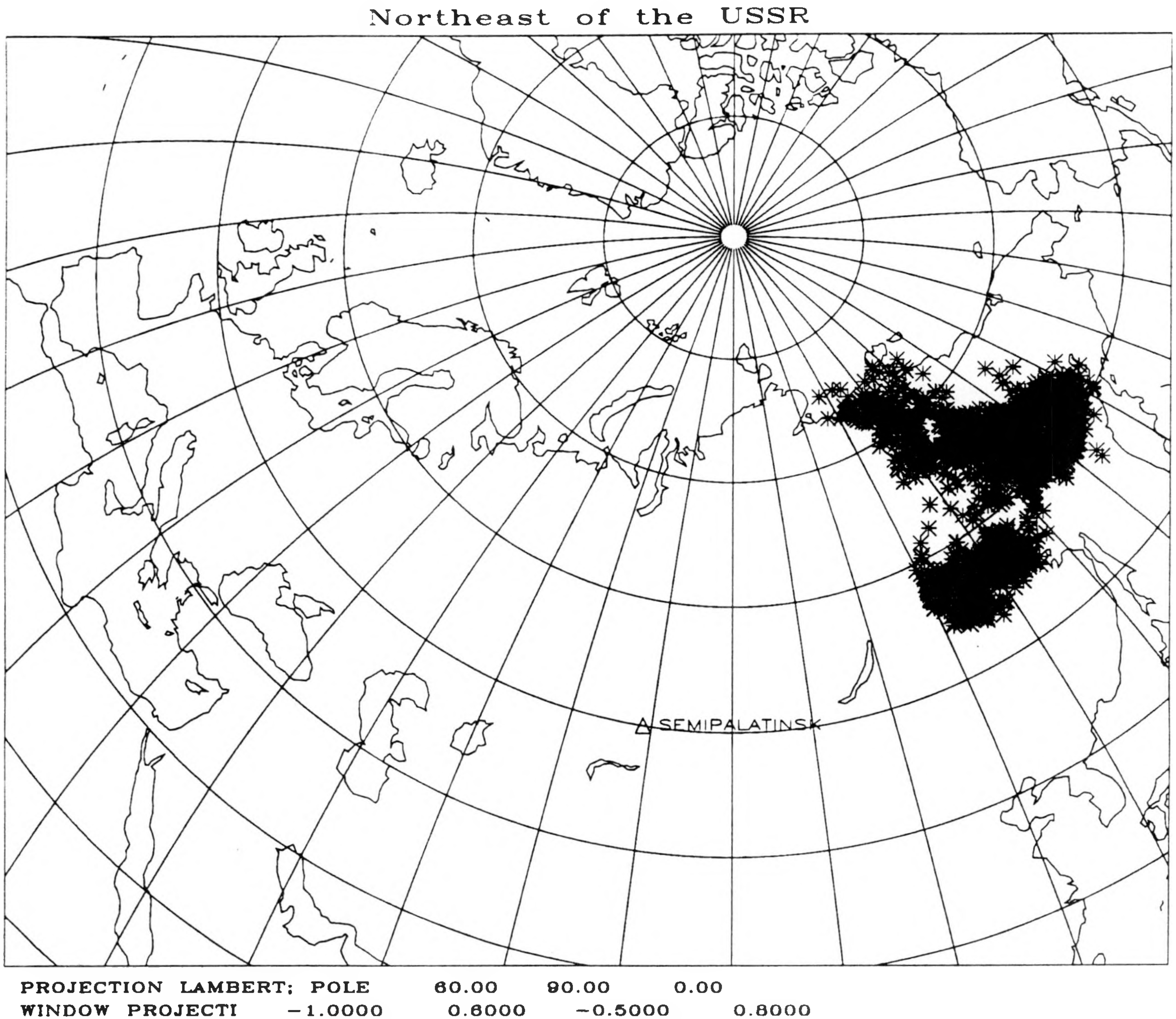

Catalog Completeness
baikal
Reported Magnitude
4
2
62
64
66
68
70
72
74
76
78
80
82
84
Year

Figure 12c



Depth Distribution
baikal.depths
0
-2
-4
Depth (km)
X 10+2
0
1
2
3
4
5
6
X 10+2
Number of Events

Figure 12d



Northeast of the USSR
SEMIPALATINSK
PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 13a

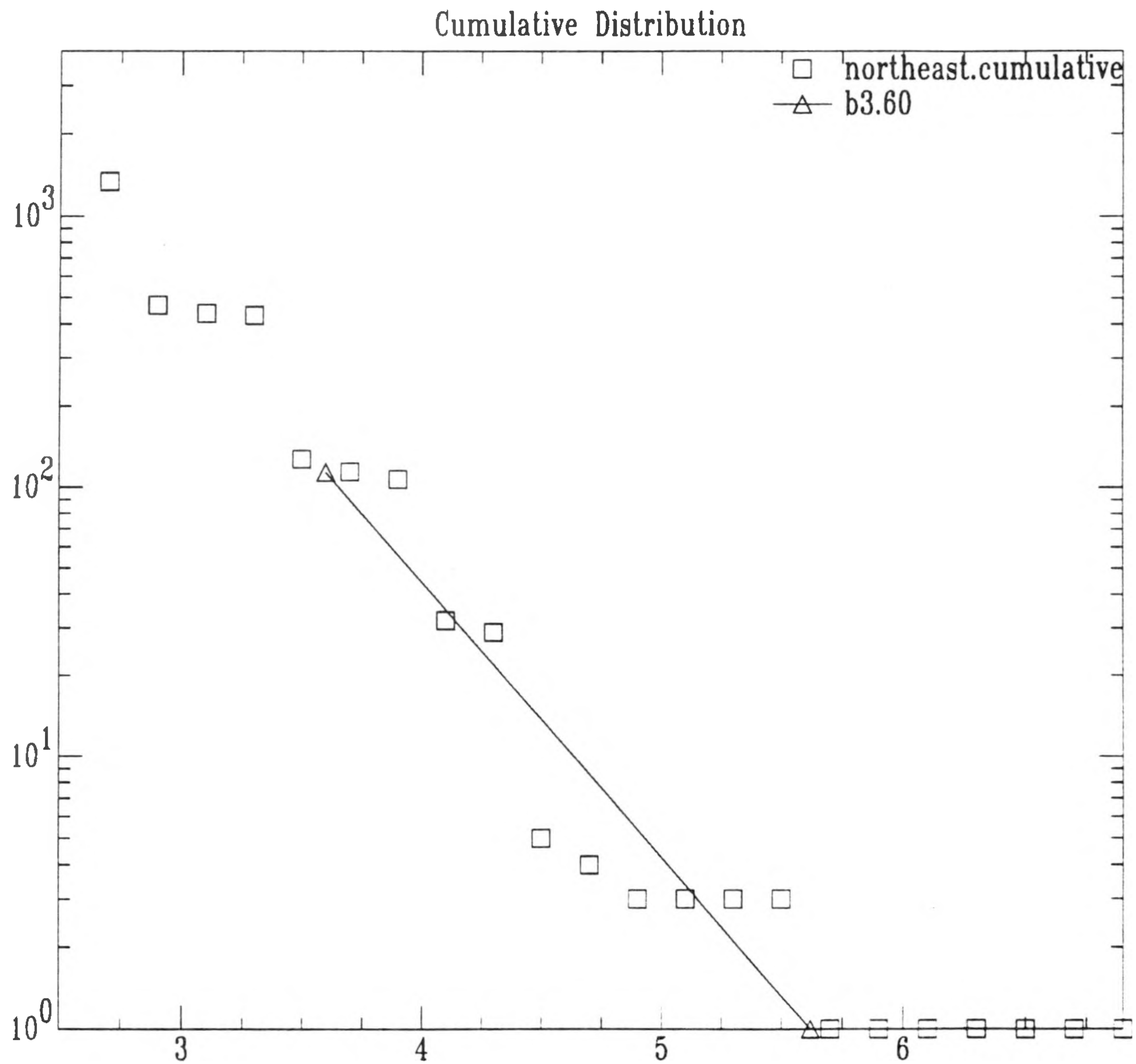
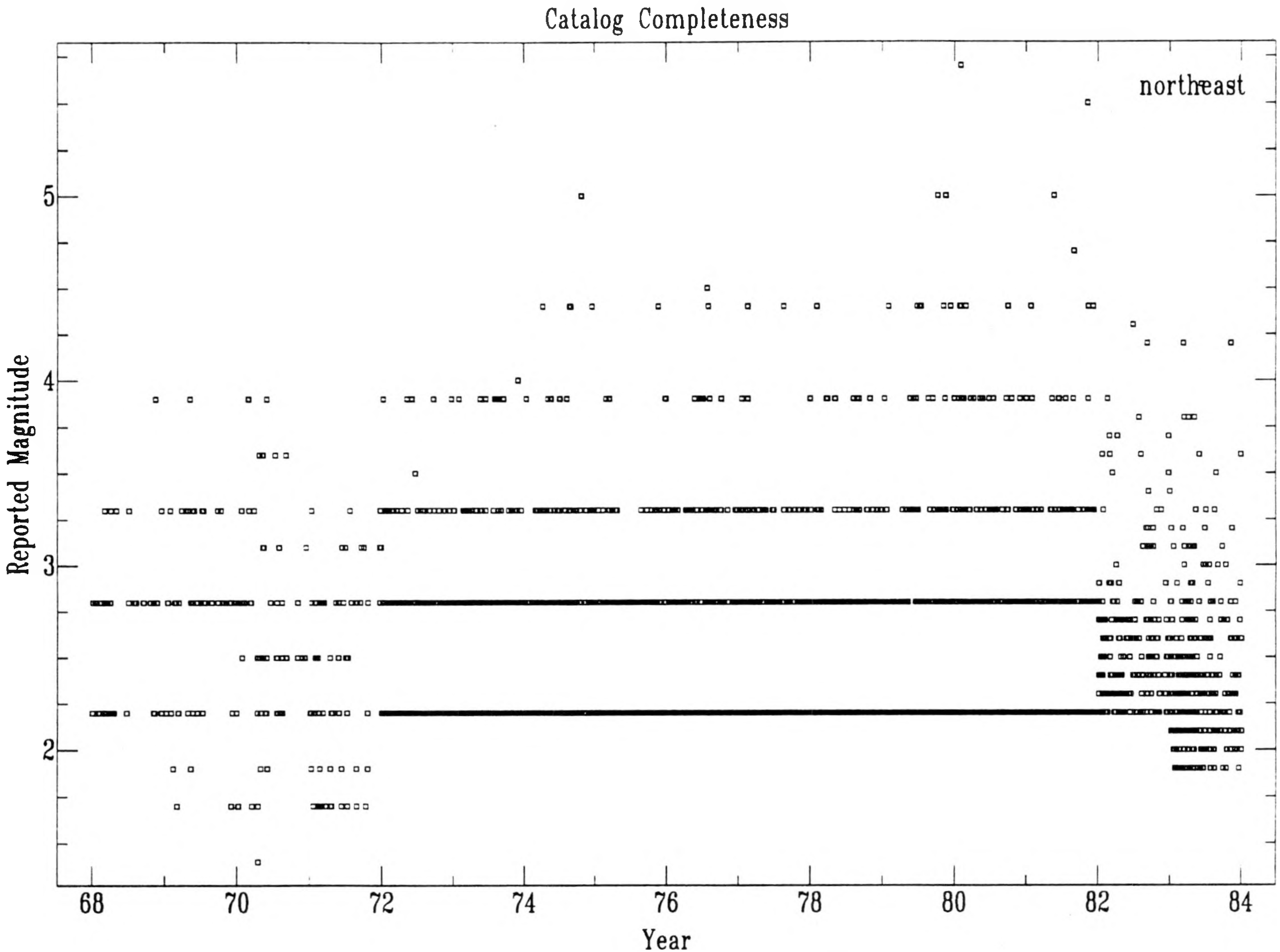
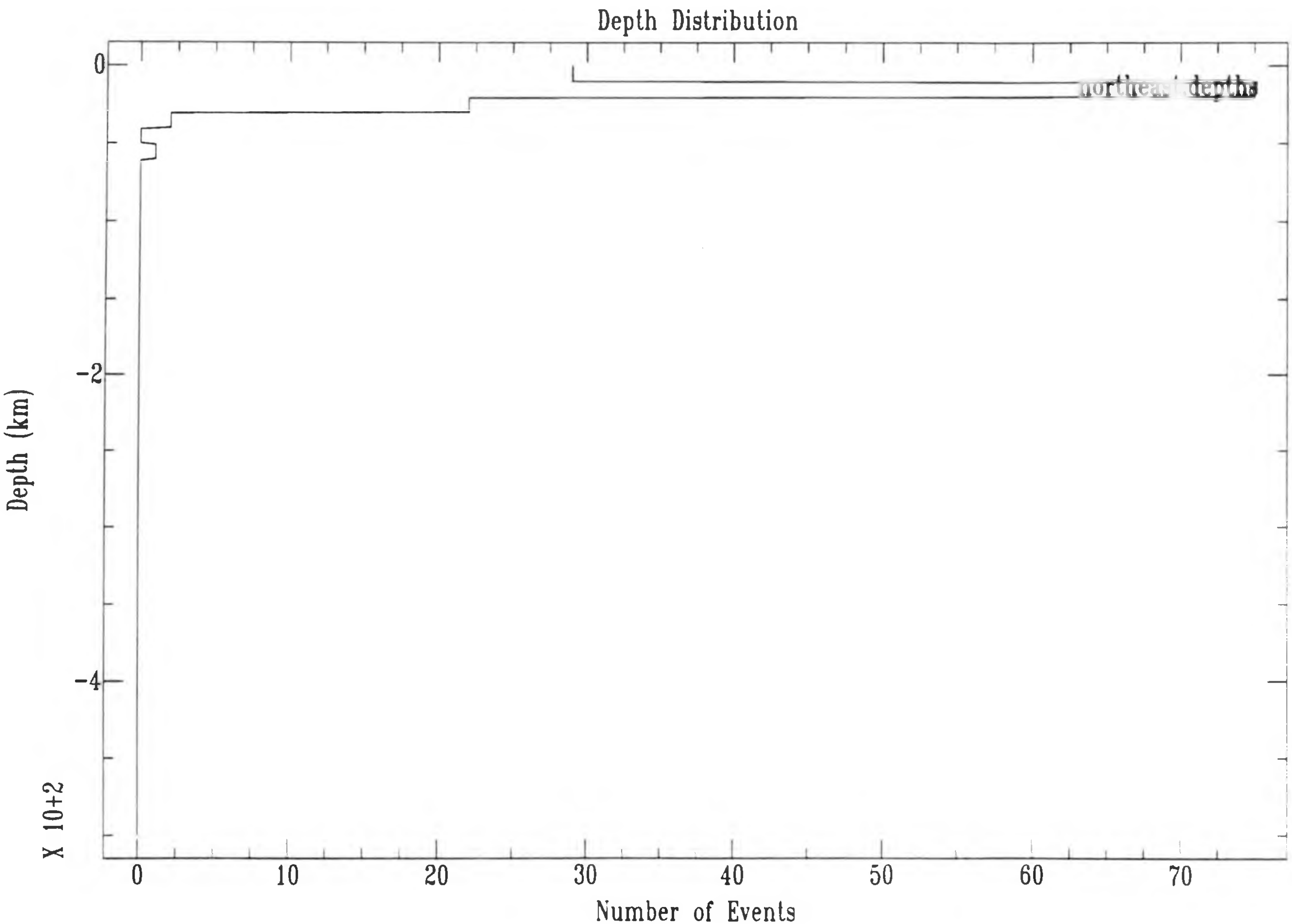

Cumulative Distribution
northeast.cumulative
b3.60
10^3
10^2
10^1
10^0
3
4
5
6

Figure 13b



Catalog Completeness
northeast
Reported Magnitude
Year
68
70
72
74
76
78
80
82
84
2
3
4
5

Figure 13c



Depth Distribution
northeast depths
0
-2
-4
X 10+2
Depth (km)
0
10
20
30
40
50
60
70
Number of Events

Figure 13d

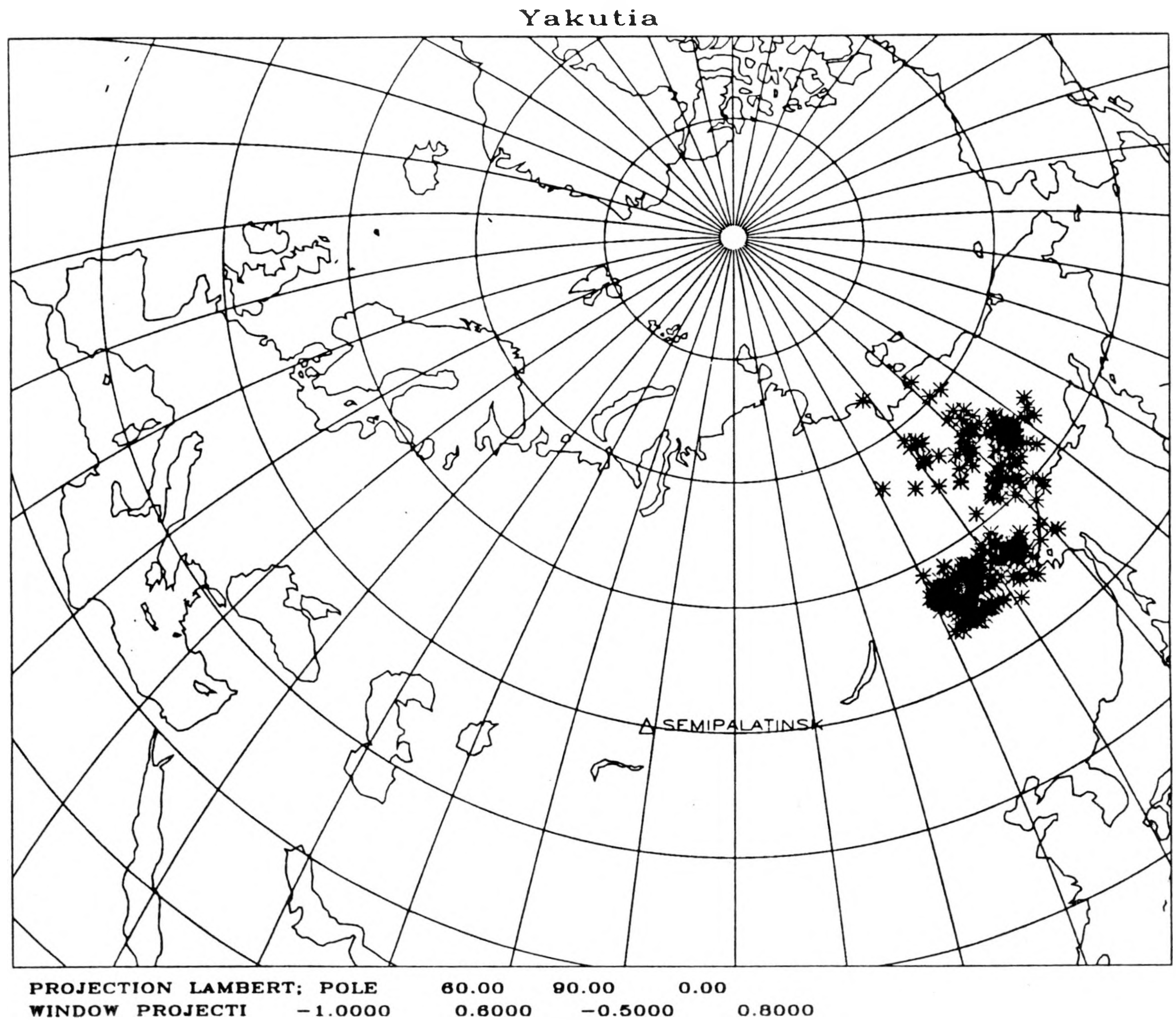
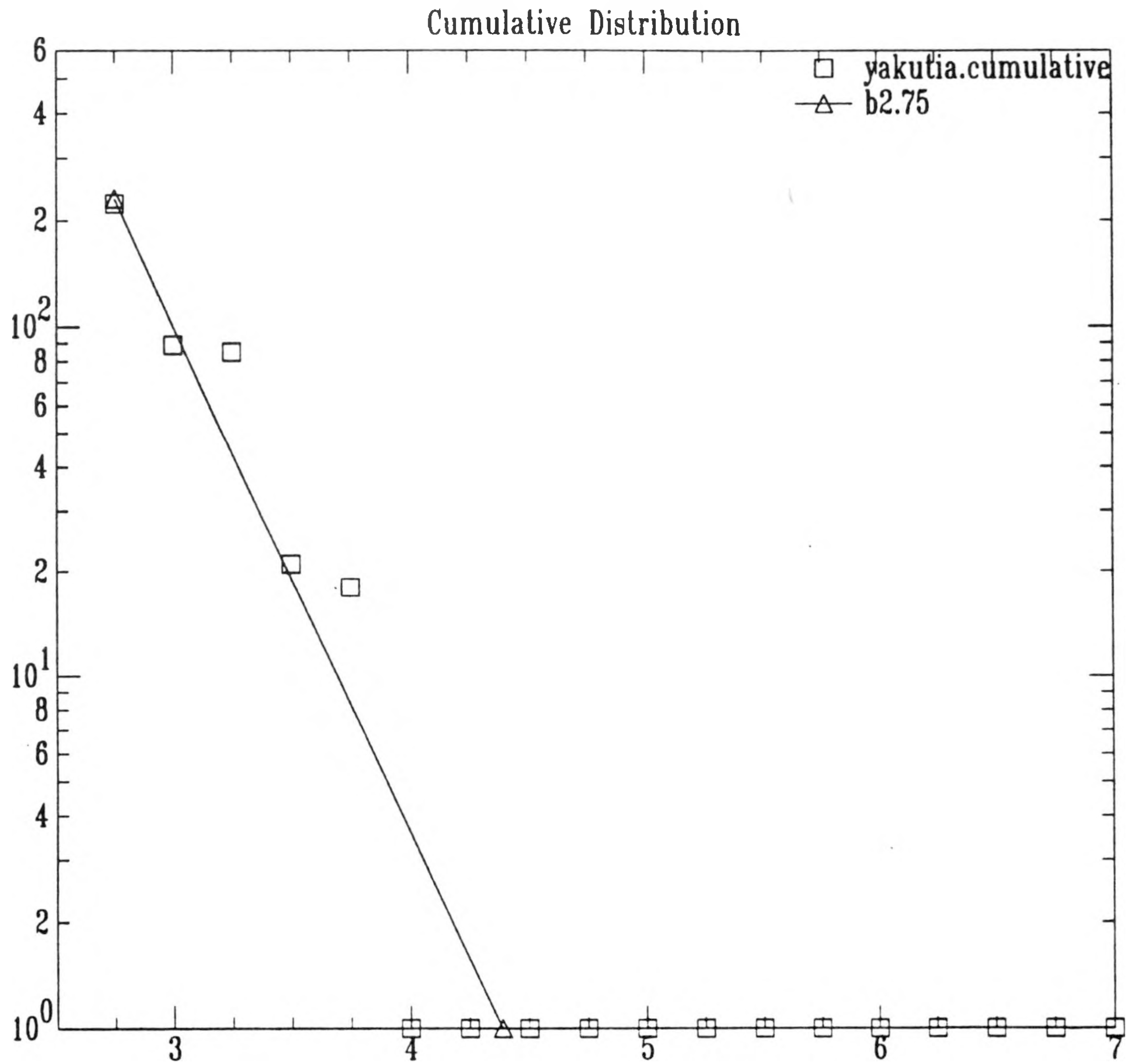

Yakutia
SEMIPALATINSK
PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 14a



Cumulative Distribution
yakutia.cumulative
b2.75
6
4
2
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6
7

Figure 14b

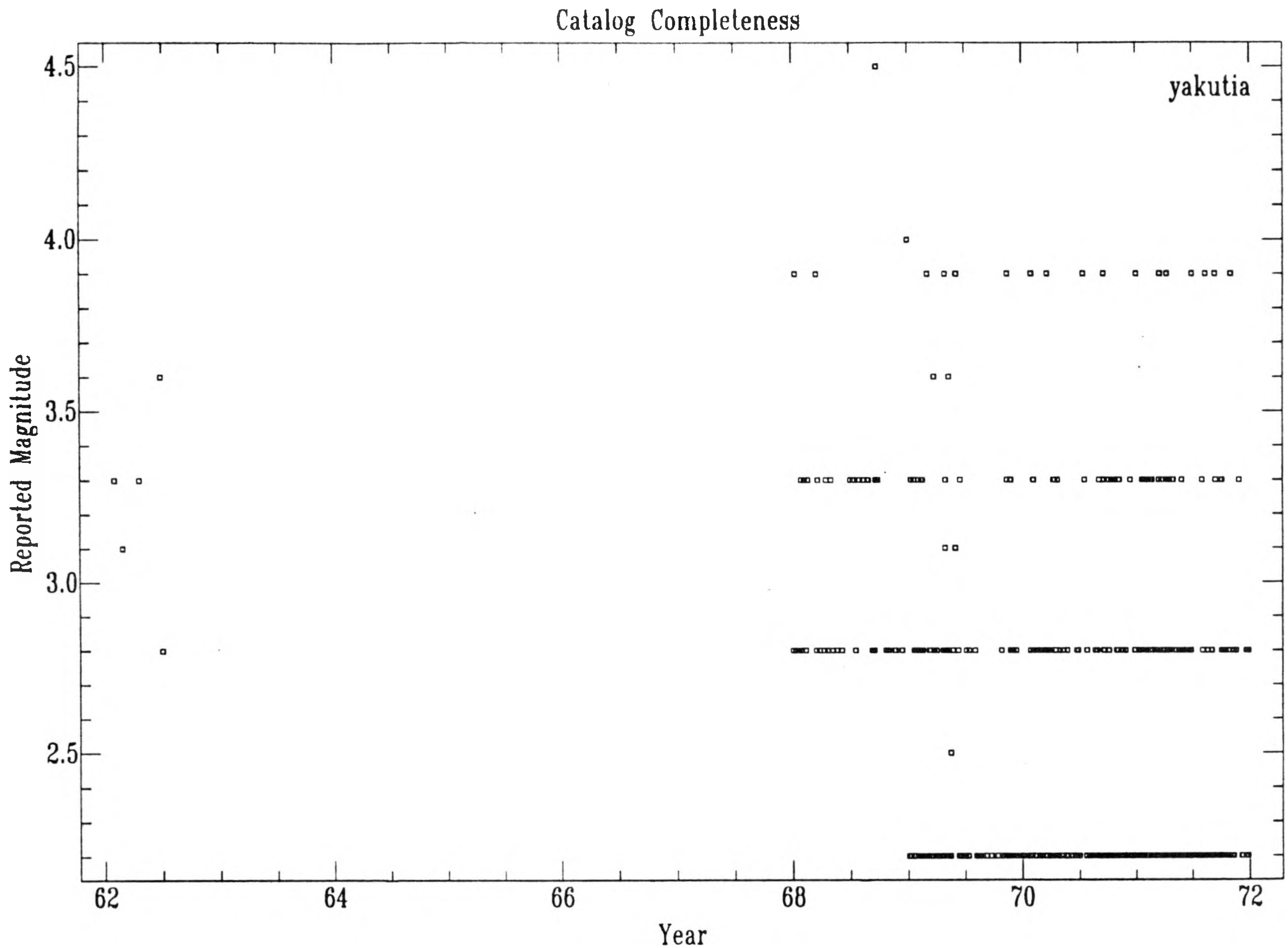
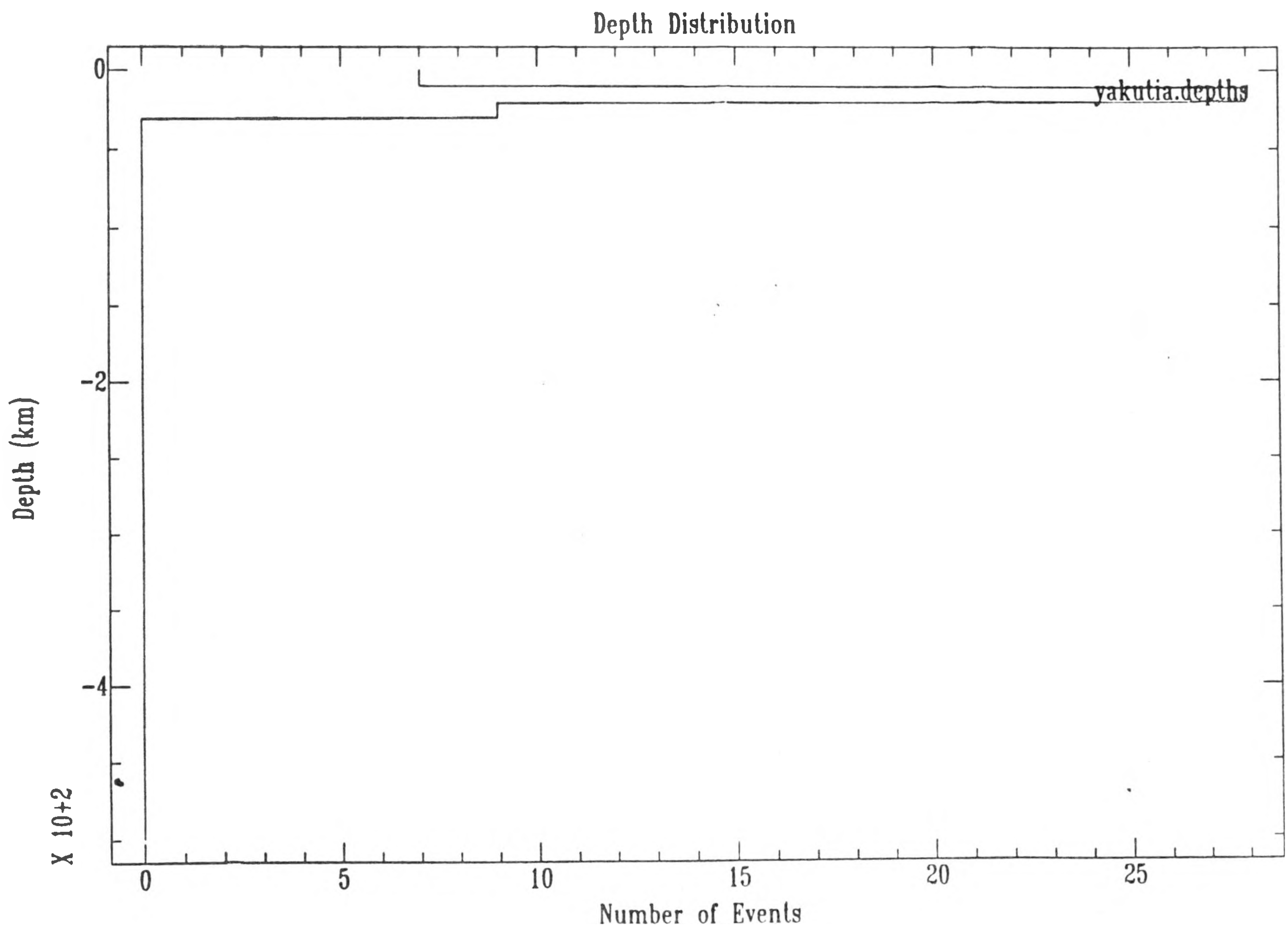

Catalog Completeness
yakutia
Reported Magnitude
4.5
4.0
3.5
3.0
2.5
62
64
66
68
70
72
Year

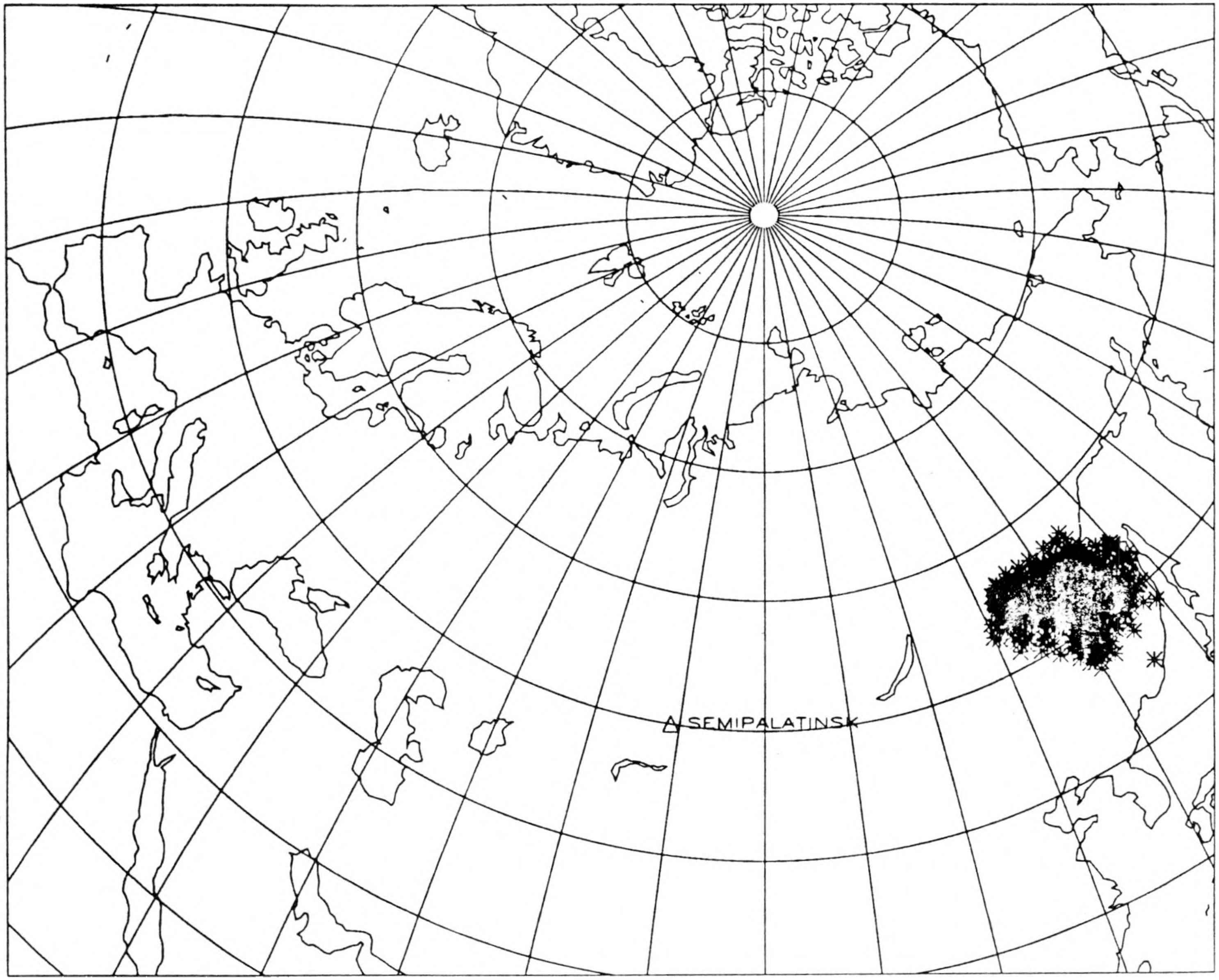
Figure 14c



Depth Distribution
Depth (km)
X 10+2
0
-2
-4
yakutia.depths
0
5
10
15
20
25
Number of Events

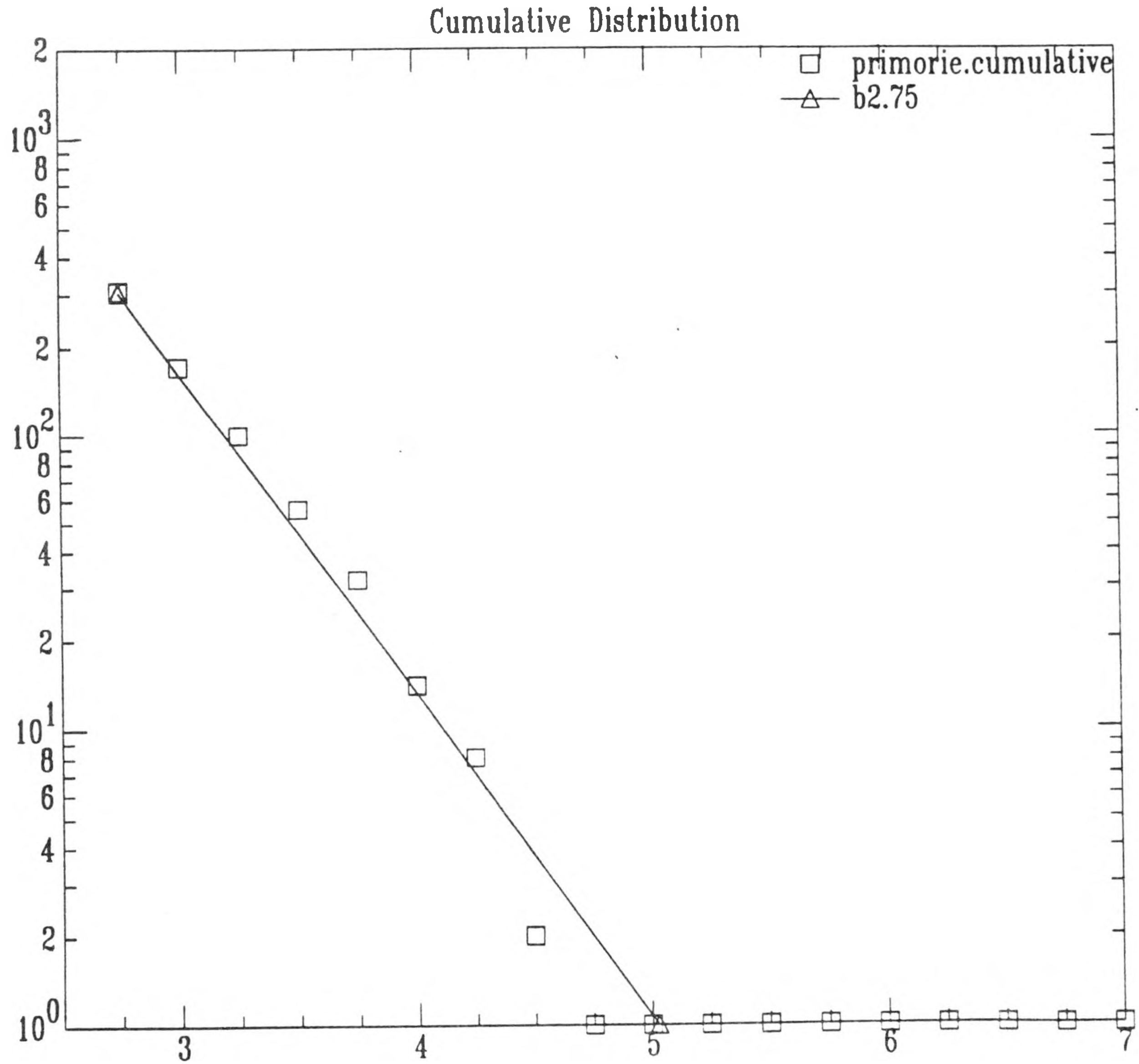
Figure 14d

Primorie and Amur



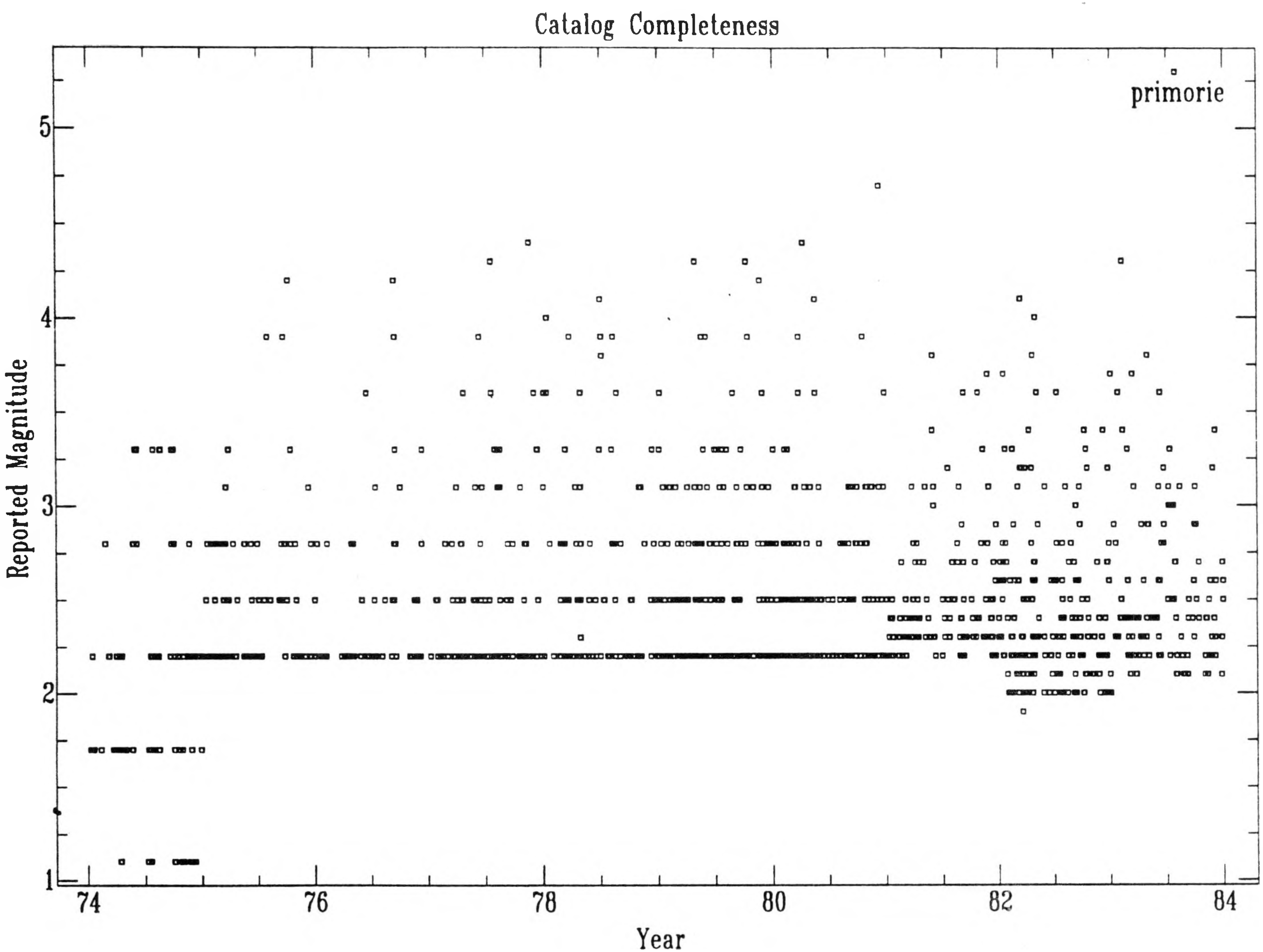
PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI −1.0000 0.6000 −0.5000 0.8000

Figure 15a



Cumulative Distribution
primorie.cumulative
b2.75
2
10^3
8
6
4
2
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6
7

Figure 15b



Catalog Completeness
primorie
Reported Magnitude
Year
1
2
3
4
5
74
76
78
80
82
84

Figure 15c

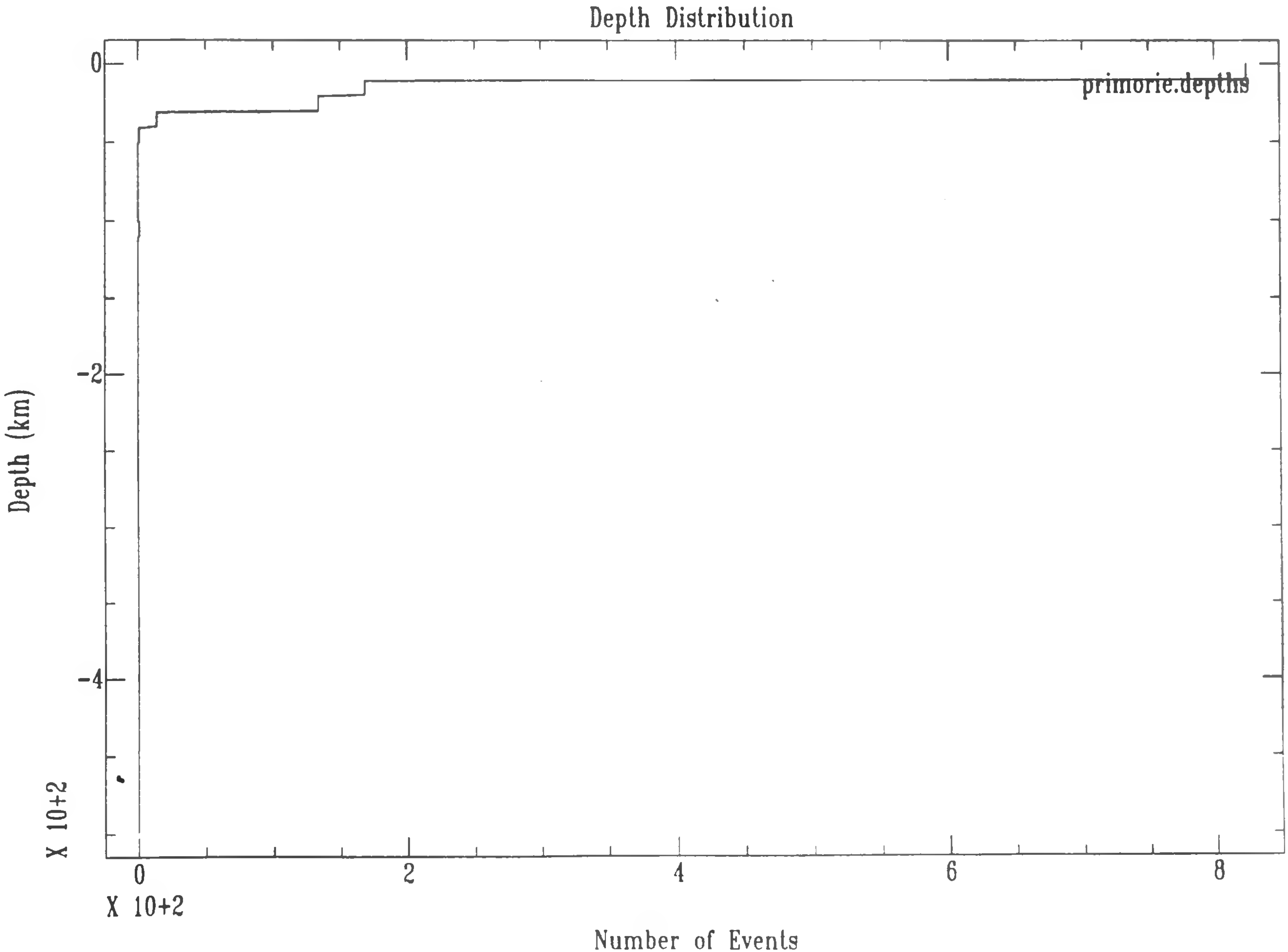

Depth Distribution
0
-2
-4
X 10+2
Depth (km)
primorie.depths
0
2
4
6
8
X 10+2
Number of Events

Figure 15d

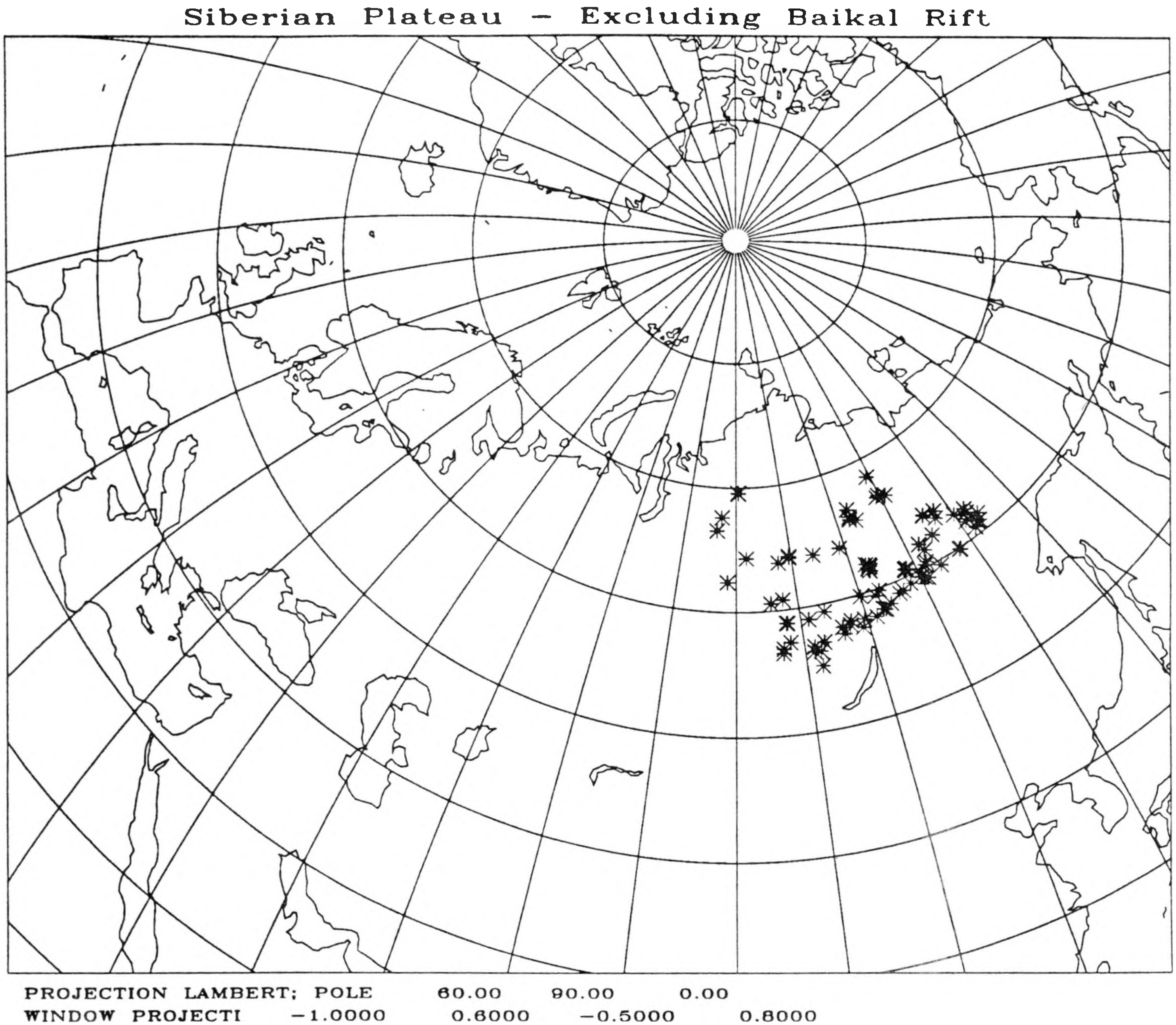
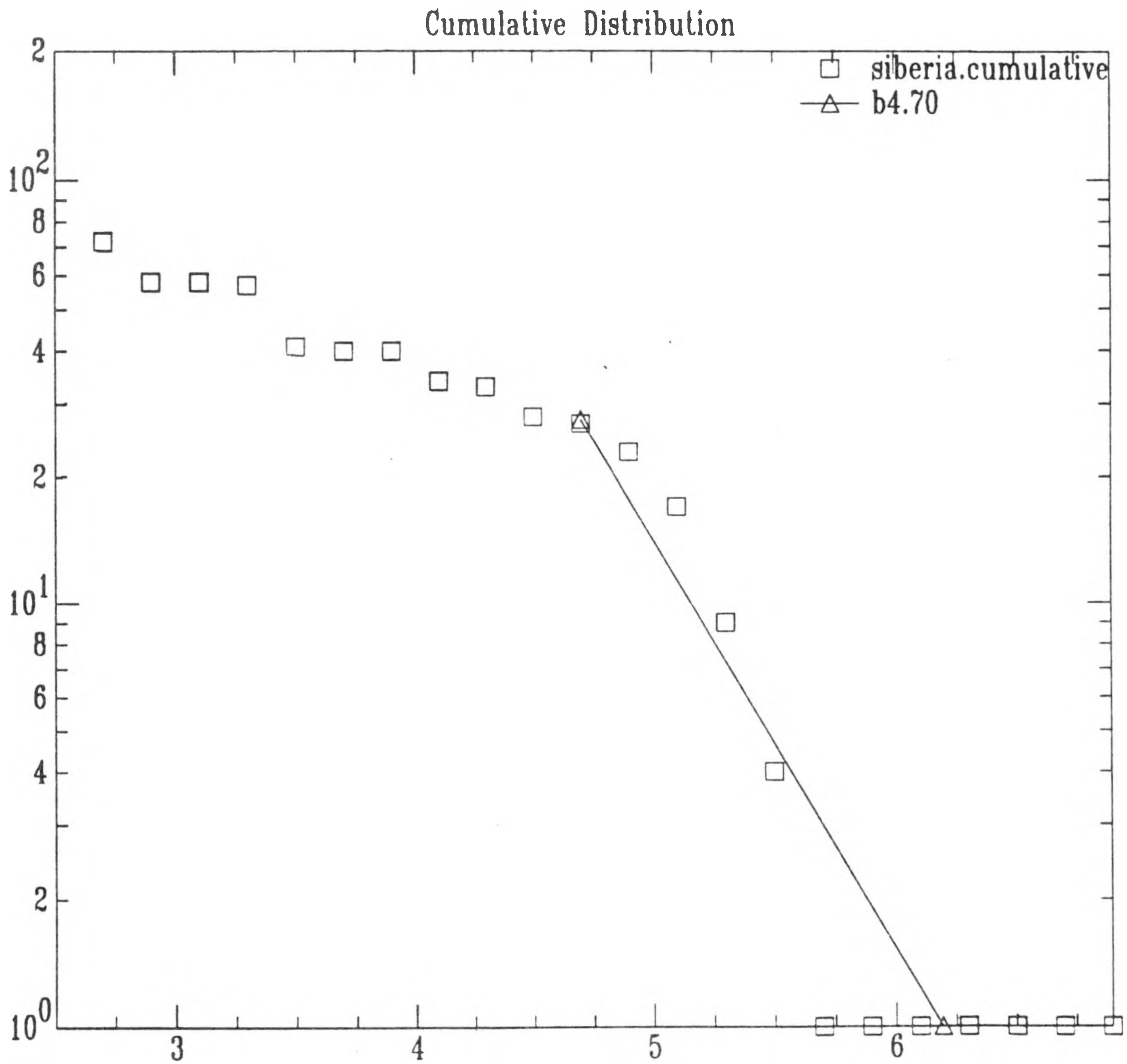

Siberian Plateau - Excluding Baikal Rift
PROJECTION LAMBERT; POLE 60.00 90.00 0.00
WINDOW PROJECTI -1.0000 0.6000 -0.5000 0.8000

Figure 16a



Cumulative Distribution
siberia.cumulative
b4.70
2
10^2
8
6
4
2
10^1
8
6
4
2
10^0
3
4
5
6

Figure 16b

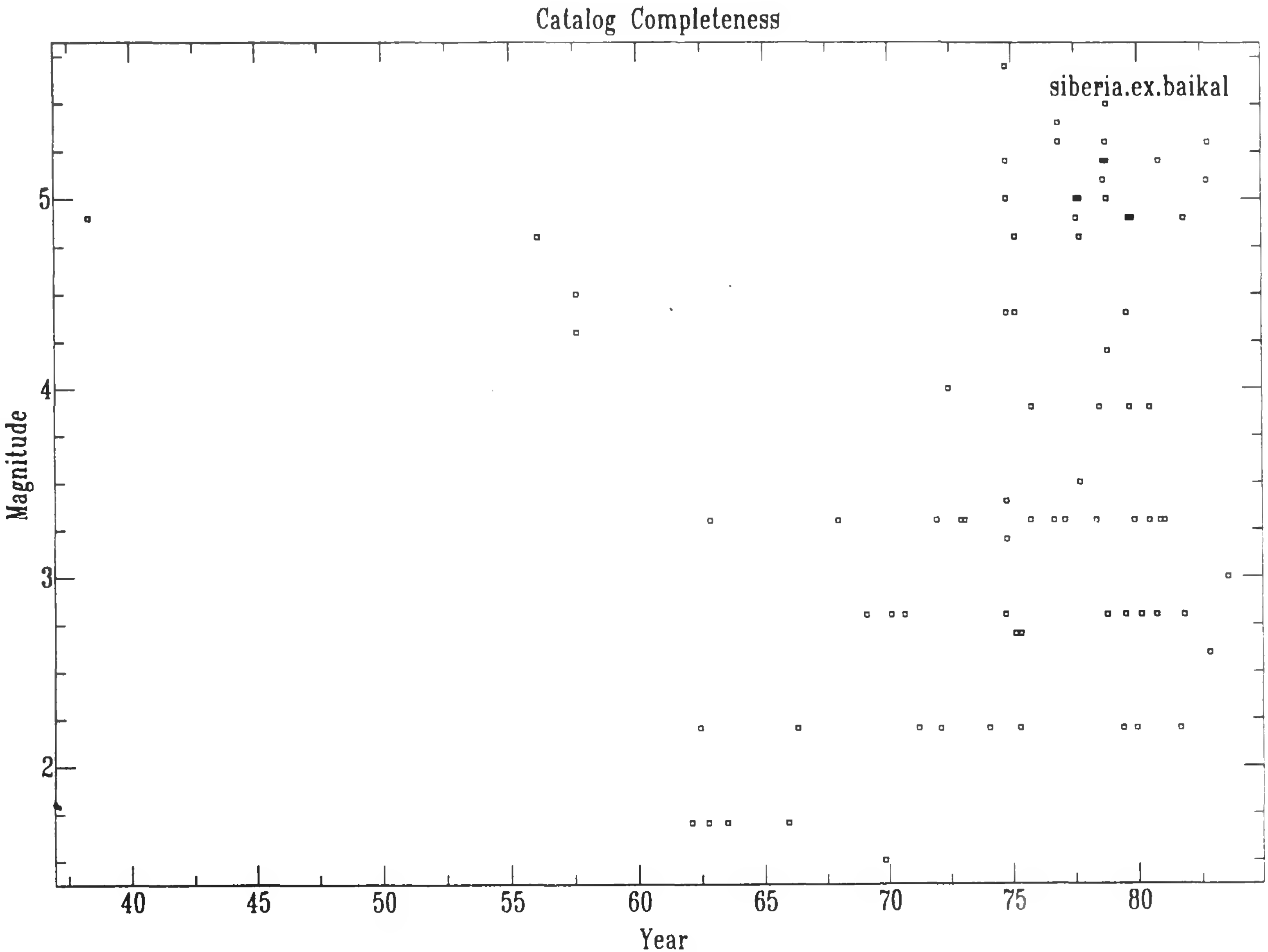

Catalog Completeness
siberia.ex.baikal
Magnitude
2
3
4
5
40
45
50
55
60
65
70
75
80
Year

Figure 16c

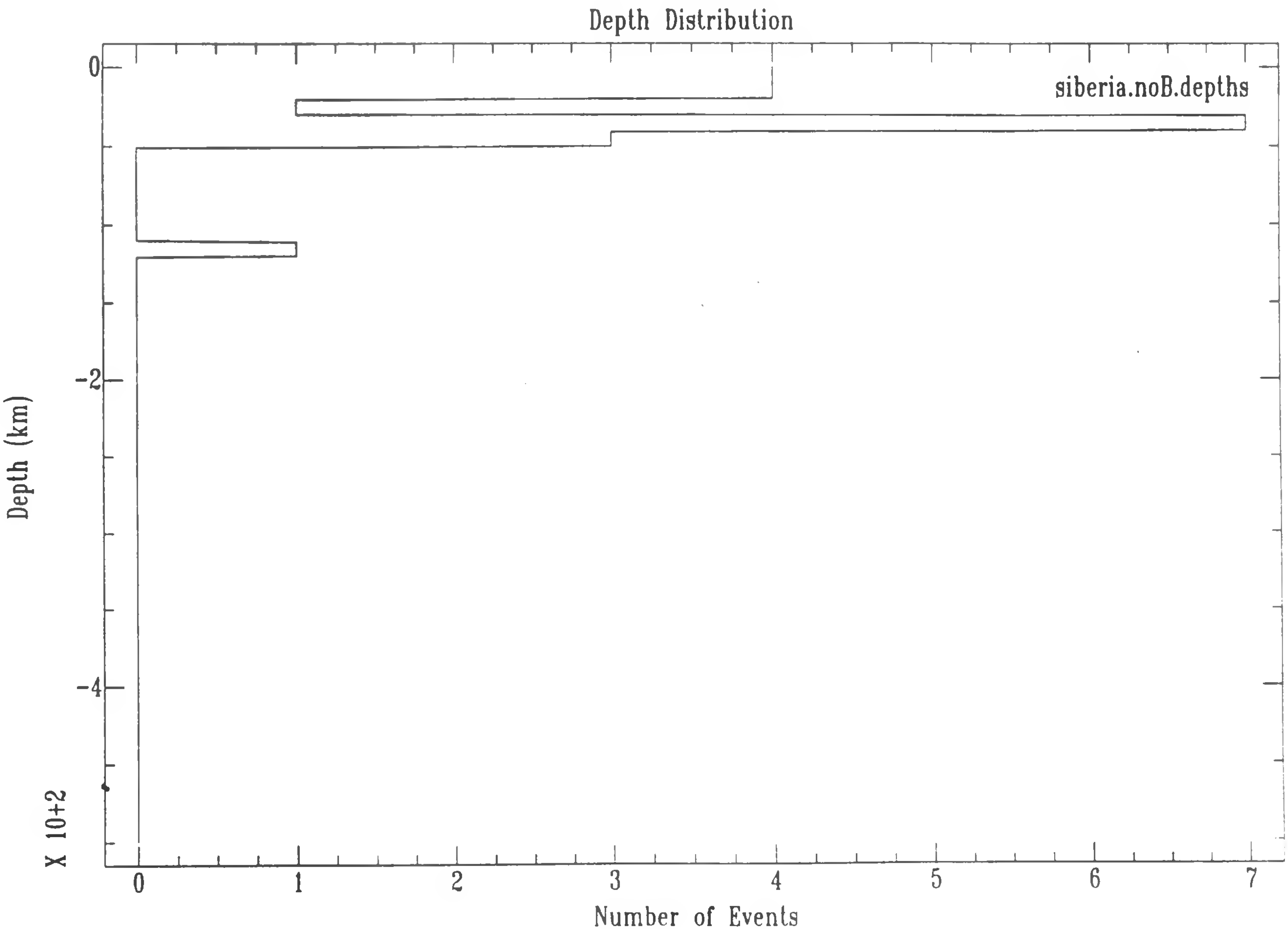

Depth Distribution
siberia.noB.depths
0
-2
-4
Depth (km)
X 10+2
0
1
2
3
4
5
6
7
Number of Events

Figure 16d