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The effects of station coverage on the detection threshold existing throughout an area were quantitatively investigated. The calculations were applied to the NTS area to demonstrate the changes in the detection thresholds occurring in five year intervals since 1933. The results demonstrate the need for quantitative consideration of station placement to ensure maximum detection capability.

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Technical Report Summary

This is the fifth semiannual report dealing with an investigation of multiple seismic events and first zone discriminants. Reported here are the results obtained from an investigation of the detection capability of various seismic networks. Studies of this nature are necessary to quantitatively define the detection potential of a given network or to define the network necessary to achieve a required detection potential.

The detection surface was determined at individual points by determining the minimum magnitude event necessary to yield an 80% probability of detection by at least 3 stations of the assumed network. By iterating the minimum magnitude calculation over a series of grid points spaced at an interval of 0.25° within the area of interest, a detection surface appropriate to that area and for the assumed station coverage was obtained. An existing program was modified to perform the necessary calculations.

The program for calculation of the detection surface utilizes station distribution, number and noise level. It was, therefore, possible to investigate the effects, on the detection surface, of a change in one of these parameters while the others were held constant. The approach taken was to determine the detection capability within a 4° square for a single station located 50, 100, 250, 500 and 1000 km from the grid center. The station noise was assumed constant for each of these cases. In addition, the effect of station noise was investigated by utilizing several noise levels at the station 500 km from the grid center.

To provide a realistic example of the need for the calculation of minimum detection surfaces, the Nevada Test Site (NTS) was employed. It was assumed that the station coverage provided by continental United States

stations was constant during five year periods starting from 1933. A master list of all stations known to be operating during each of the five year periods from 1933 to 1972 was compiled. On the basis of this list the detection surface appropriate to NTS was calculated for each of the five year periods. The contoured results indicate the minimum event (m_b magnitude) which could be detected at any point within the NTS area during any of the five year periods.

To better demonstrate the changing detection capability occurring within the NTS area over the 40 year interval from 1933 to 1972, the 1933 to 1938 minimum detection surface was subtracted, point by point, from the surfaces appropriate to the other intervals. Thus, the minimum detection capability of the 1933 to 1938 period was employed as a base reference and the detection capabilities of the other periods considered in reference to this base period. The contoured results then indicate the change in a particular period with respect to the base period.

Introduction

The reliability of differentiating multiple underground explosions from natural earthquakes is clearly a function of the respective event sizes. It is obviously not possible to differentiate events which cannot be detected. While a minimum event size of any interest might be selected for various reasons, the selection of such a minimum event implies certain seismic station requirements. It does not appear that the relationships between a minimum event size for interest and the resulting seismic station requirements have received quantitative consideration.

The purpose of the research reported here is to initiate an investigation into the effects of station coverage on the minimum size event which may be detected at some point in space. The general methods of calculation will follow Booker (1964).

Theory

The theoretical considerations involved in this study are essentially due to Booker (1964) and are repeated here only for convenience.

Given an event i and a seismic station j, let A_{ij} be the ground motion occurring at station i as a result of the event j. A_{ij} may be determined from

$$\log A_{ij} = m_j + K_o + C_o \log \Delta_{ij} \qquad 1.$$

where m_j is the magnitude of event j, Δ_{ij} the distance from event to station and K_o and C_o are input constants. The station can be assigned to detect the event if $\frac{A_{ij}}{n_i} > q$ where q is a selected constant and n_i is the station noise. The probability that the station i will detect the event j, P_{ij}, is

$$P_{ij} = \text{Probability } [\frac{A}{n} > q]$$

If it is assumed that log n is a log normal distribution with mean log $\bar{n}$ and variance σ, then the variable

$$u = \frac{\log n - \log \bar{n}}{\sigma} \qquad 3.$$

is normally distributed with mean zero and variance 1. By substitution in equation 1,

$$P_{ij} = \text{Probability } [\frac{1}{\sigma} \log (\frac{A_{ij}}{q_{\bar{n}i}}) > j$$

Thus, P_{ij} may be determined from

$$P_{ij} = \int_{u}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-y^2/2\sigma^2} dy$$

or alternately found in one of the various tables for the above integral.

Using the above formulation, the probability of a particular station detecting a particular event may be calculated, or the magnitude may be incremently increased until the probability reaches a predefined level. This latter approach yields what is referred to here as the minimum detectable event. If the minimum detectable event is calculated over an area, the resulting magnitudes may be contoured to provide a minimum detection surface. This detection surface would be for events in the specified area and appropriate to one station. Other areas or stations would yield different detection surfaces.

The probability of N stations within a network of K stations detecting a particular event may be determined from the individual probabilities of each station within the network. In the same manner as previously described a minimum detection surface for detection by at least N stations of the network may be calculated.

<u>Results</u>

An area encompassing the Nuclear Test Site (NTS) facility in Nevada was selected for study. The specific area extended from 114.5 W to 119.5 W Longitude and from 34.5 N to 39.5 N Latitude. The area is outlined with respect to the Nevada state boundaries in Figure 1.

The effect of distance on the detection surface for a single station is shown in Figures 2 through 6. In all of these Figures a single station noise was employed and a detection probability of 80% was required. The structure of the detection surface within the area results from the effects of distances to the assumed station. As would be expected, Figure 6, the differential distances within the area are too small to greatly affect the detection capability of a station located at a distance of 1000 km. Figure 5 indicates the detection capability of a station located approximately 200 km to the north of the area boundary. It is evident in this Figure that the detection ability for this station varies by a whole magnitude unit, 3.75 - 4.75, over the region.

The effects of station noise on the detection capability is shown in Figures 7 and 8. Figure 5 is at the same distance and provides an intermediate noise level. The high noise level, Figure 7, is a level approximate to parts of the Pacific Coast while the low noise level, Figure 8, represents the quieter parts of the continent (Stepp, et. al., 1965). It is evident in these Figures that the different noise levels present within the continent can result in a change in the minimum detectable event of 2 magnitude units. This can also be interpreted to mean that an equivalent seasonal change and/or daily change due to meteorological variations or cultural activity in the noise level at any particular station could result in the same change in the minimum detectable event.

While the above results utilized an area surrounding the NTS site, the results are actually independent of the site, since only distance and noise levels were varied. The actual detection capability, with respect to the NTS site, was investigated by considering all stations known to exist during 5 year periods from 1938 to 1972. The stations existing during each period were taken from Cloud and Simila (1973), Hileman and others (1973), Bayer (1973) and Mackay School of Mines (1972). Stations beyond 2000 km were eliminated on the basis of having no significant effect on the results. The average noise level present at each station was taken from Frantti (1965). Since the variance in station noise was not available, a value of 0.13 was assumed.

The detection surfaces for the NTS area for each of the five year periods are shown in Figures 9 through 16. In all cases the surfaces are the minimum magnitude which would yield an 80% probability of detection by at least three stations. It is evident from Figures 9 through 12 that for the period from 1933 to 1947 m_b magnitudes of approximately 3.8 were required in the northeast portion of the area to ensure an 80% probability of detection. For the period from 1948 to 1962 this was lowered slightly to about 3.3. The southeast portion of the area was well covered from an early date by the extensive network of California stations. During the period from 1948 to 1952 a station was installed within the area and this accounts for the pronounced low evident in Figure 12.

The most rapid and significant change in the detection surface occurred between 1960 and 1965 as is evident from a comparison of Figures 14 and 15. This change of course reflects the increased instrumentation associated with the nuclear testing program. During the final period of 1968 to 1972 events as small as

m_b = 1 could theoretically be detected over the majority of the region.

In order to better demonstrate the effects of increasing station coverage, the 1933 to 1937 period was selected as a reference and the other periods compared to this base. The comparison was achieved by subtracting at each point in space the minimum m_b magnitude at the same point in space for the reference period. The result is a surface over the test area which represents the improvement in the detection capability of a given five year period as compared to the reference 1933 to 1937 period. The results are referred to by the center years of the five year periods.

The results of this comparison are shown in Figures 17 through 23. It is evident from Figures 17 and 18 that little improvement occurred between 1935 and 1945. On the basis of Figure 19, considerable improvement occurred in the northeast section of the region between 1935 and 1950. The eastern section, however, remained relatively unchanged during the same period. Between 1935 and 1955, Figure 20, improvement in the northeast section began to occur. By 1965, Figure 22, detection in the northeast section had greatly improved.

Conclusions

In general, the results presented in this report simply establish the obvious fact that detection capability is improved by locating numerous stations very near the event and in area of low noise; a statement which hardly requires varification. The significance of the results, however, are in their quantitative nature and not in the general trend. Thus, an improvement in detection capability is certainly expected to result from placement of an additional station but the quantitative change in the overall detection surface is the significant consideration.

The network capability program as developed by Booker (1964) and used in this report, provides a quantitative means for assessing the detection capability of any proposed network. The detection surface as defined here is a satisfying means of describing the detection capability existing within an area. An alternate method would be to contour the difference between actual detection ability and some predefined minimum acceptable level.

The significance of noise level on the detection capability is demonstrated by Figures 5, 7 and 8. It is evident from these Figures that the evaluation of any proposed network will require an accurate knowledge of noise levels existing at the proposed station site. To optimize the numbers of required stations would require a complete knowledge of noise levels throughout an area and the temporal variations associated with these levels.

A factor not discussed here but one that would have to be considered before applying this technique to other areas is any basic differences in the geological setting which would cause significant differences in the rate of the seismic waves.

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Hileman, J.A., C.R. Allen, and J.M. Nordquist, 1973, Seismicity of the Southern California Region - 1 January 1932 to 31 January 1972: Pasadena California Institute of Technology, 83p.

Mackay School of Mines, 1972, Bulletin of the Seismological Laboratory for the Period January 1 to March 31, 1971: Reno, University of Nevada, 36p.

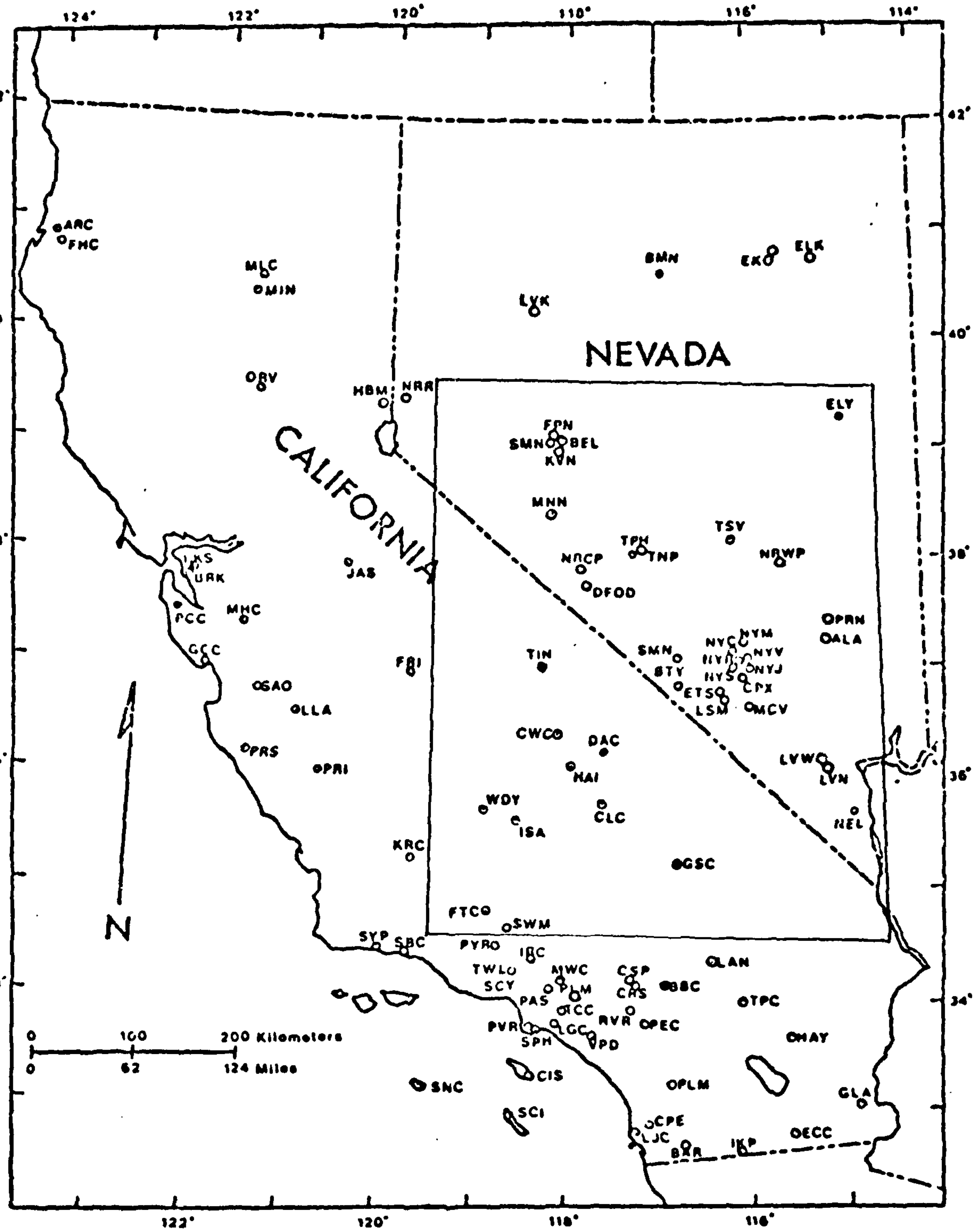


Figure 1 Seismograph stations in the California/Nevada area operated by the California Institute of Technology; University of California-Berkeley; University of Nevada; Lawrence Livermore Laboratories; USGS/NCER, Yucca Flats, Nevada; Sandia Laboratories; and USGS SRAB, Nevada. Station locations from Cloud and Simila (1973), Hileman and others (1973), Bayer (1973), and Mackay School of Mines (1972).

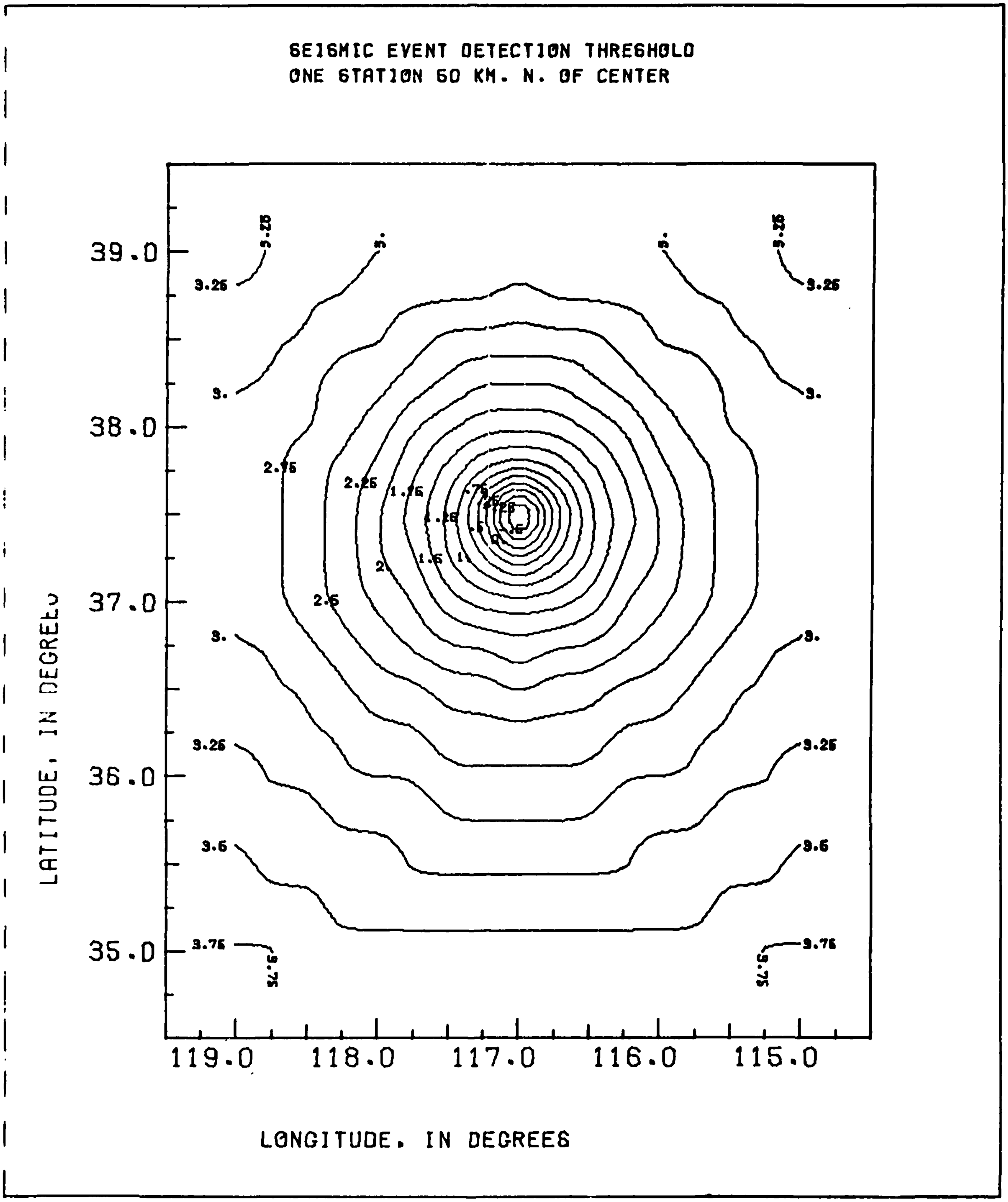


Figure 2 The detection surface for a single station located 50 km north of the area center.

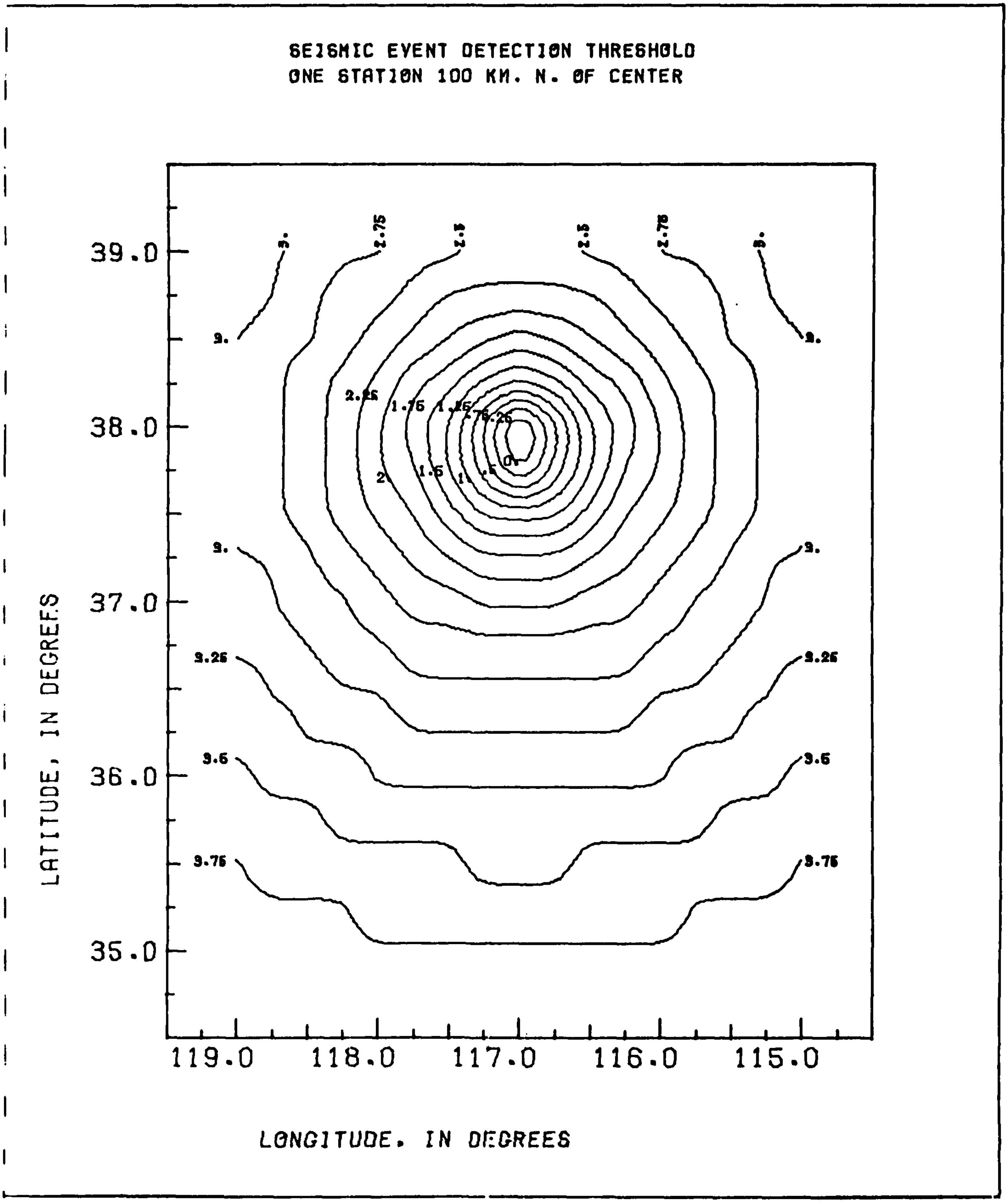


Figure 3 The detection surface for a single station located 100 km north of the area center.

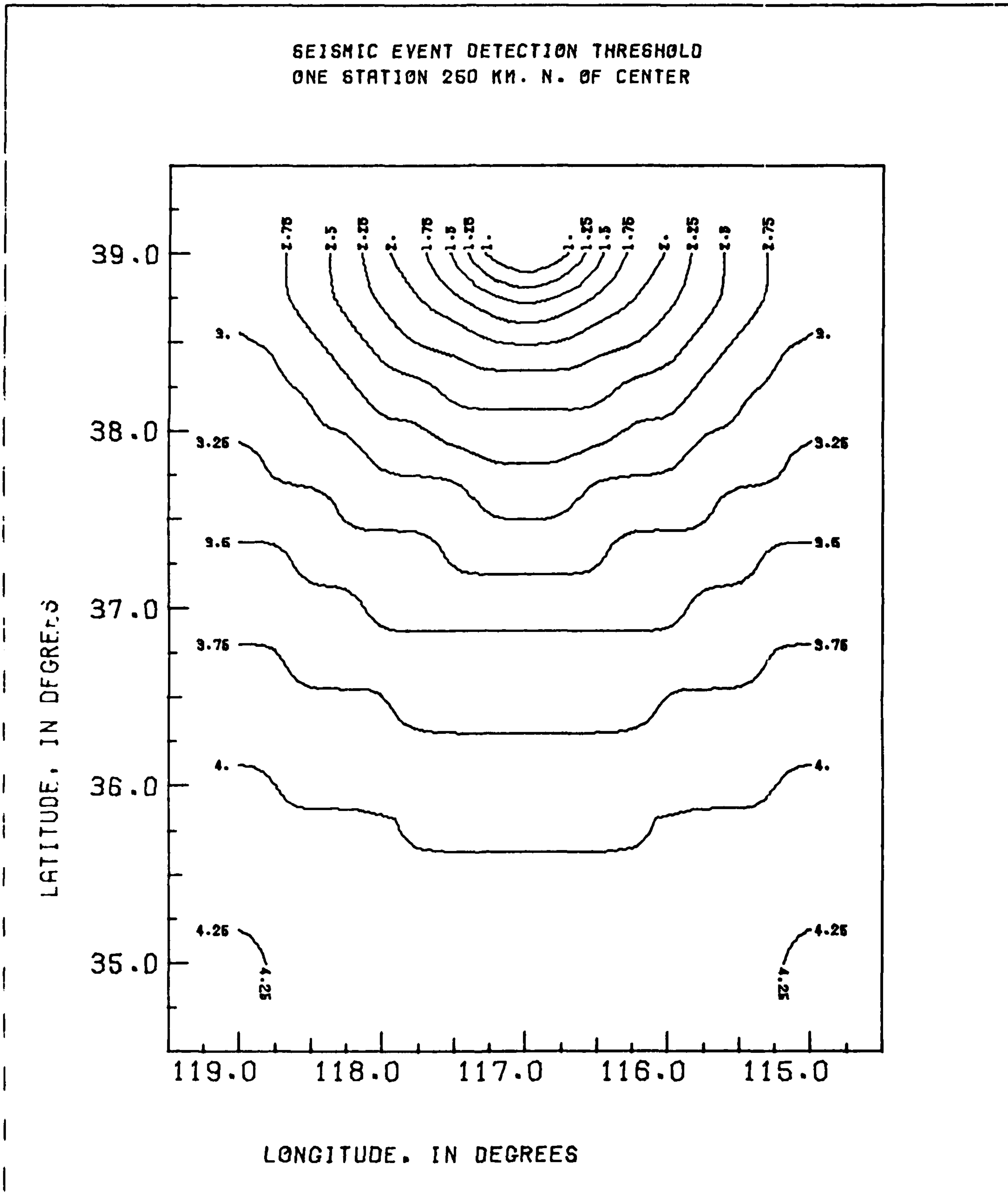


Figure 4 The detection surface for a single station located 250 km north of the area center.

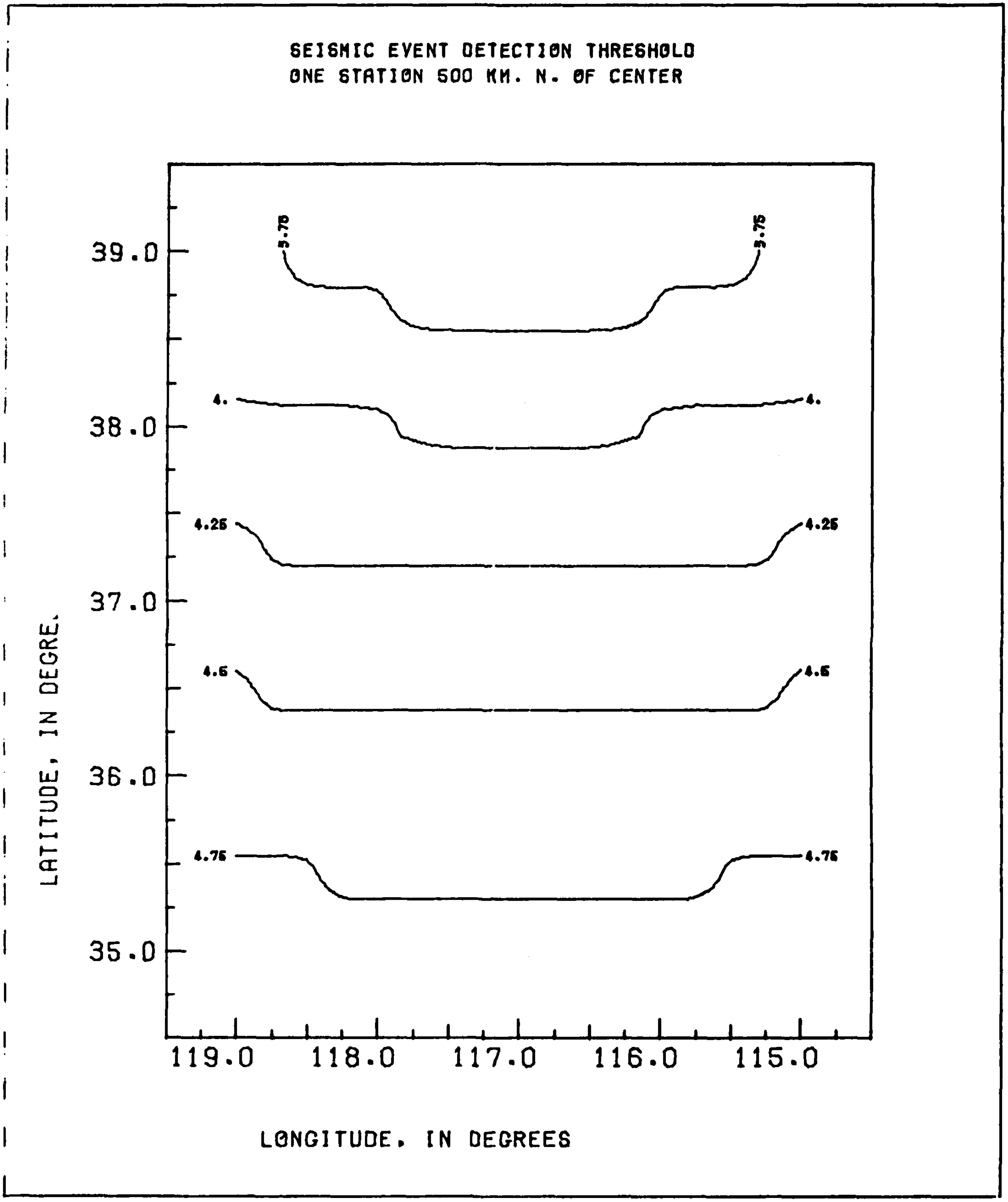


Figure 5 The detection surface for a single station located 500 km north of the area center.

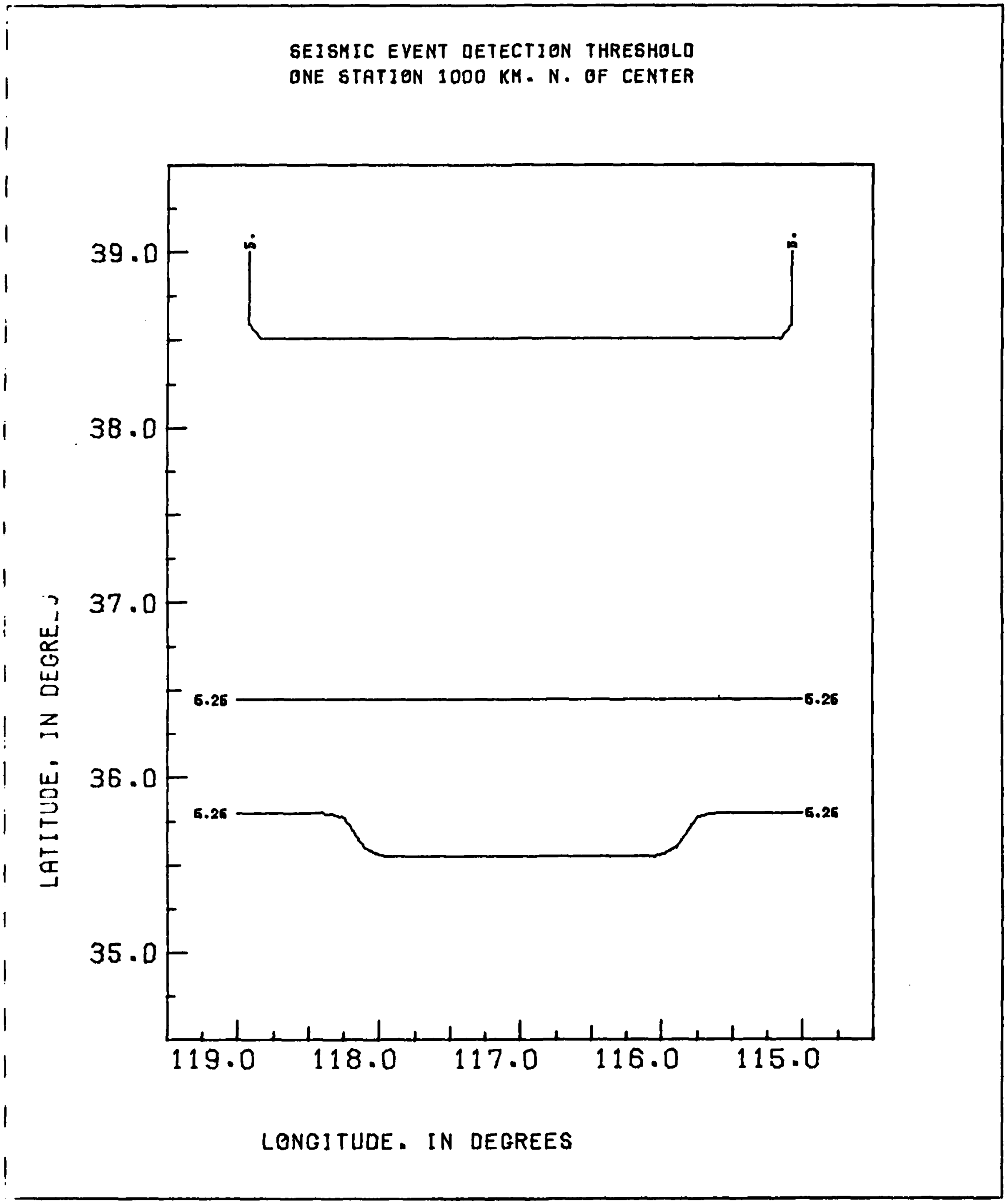


Figure 6 The detection surface for a single station located 1000 km north of the area center.

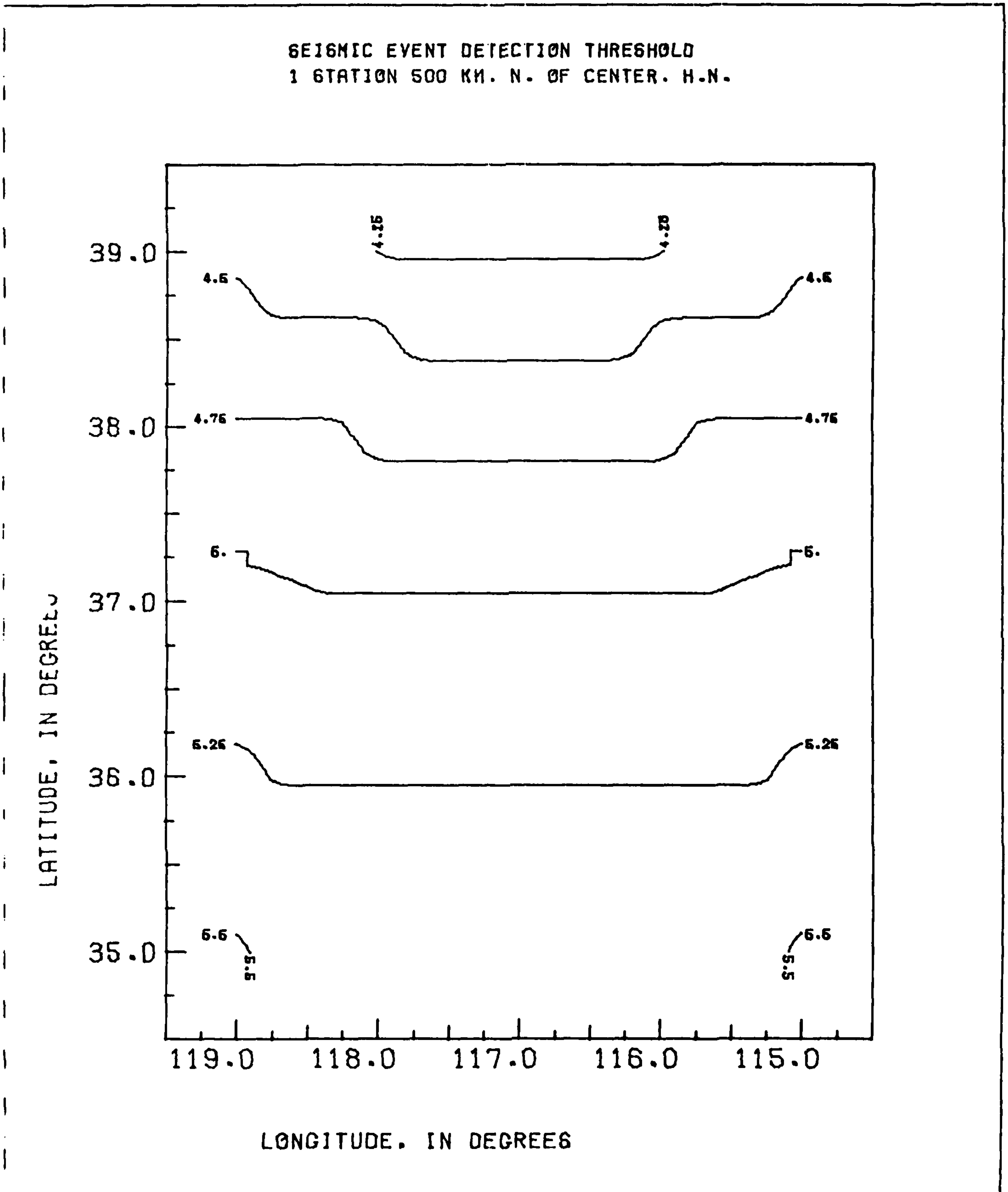


Figure 7 The detection surface fo: a noise level of 30 millicrons.

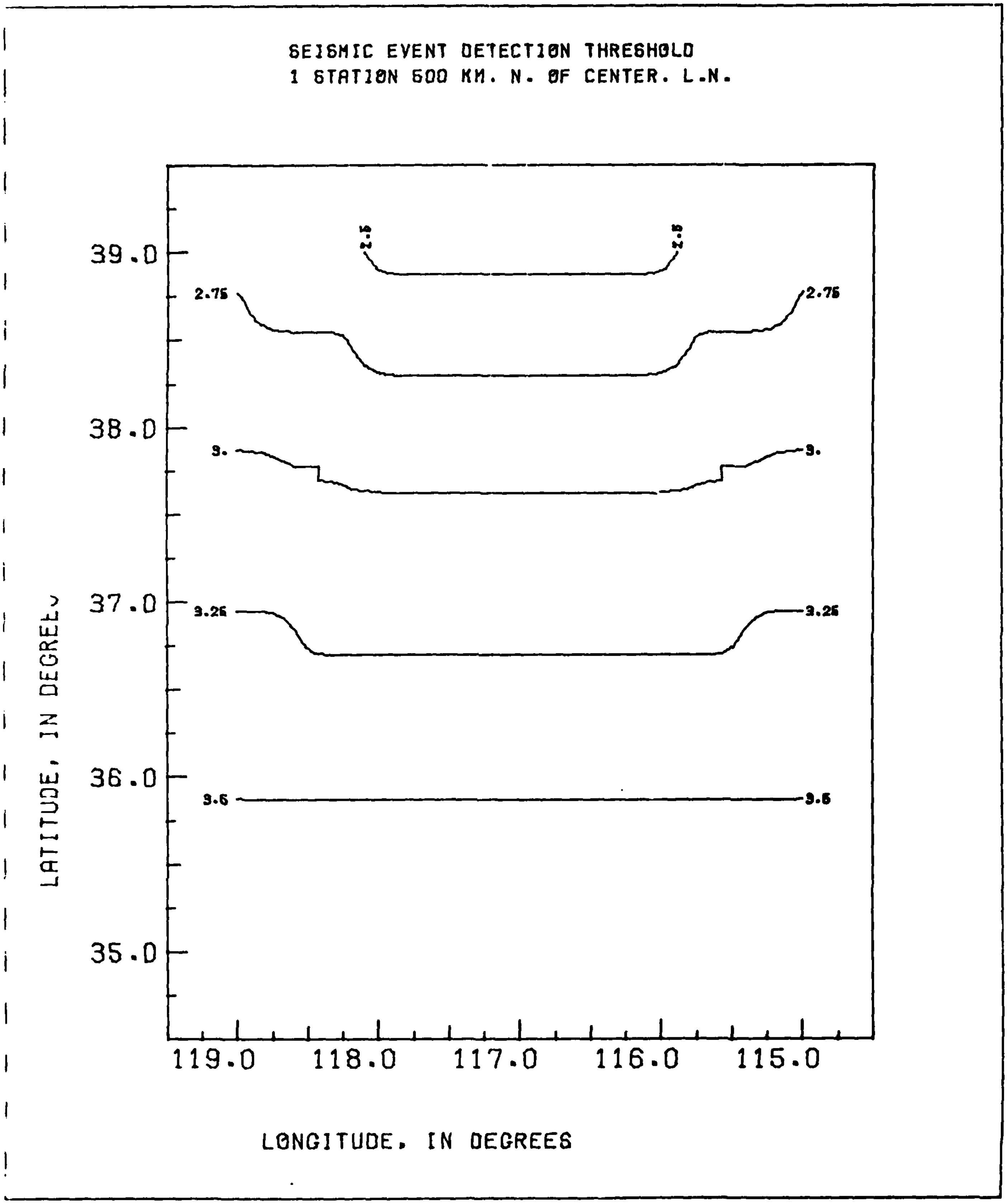
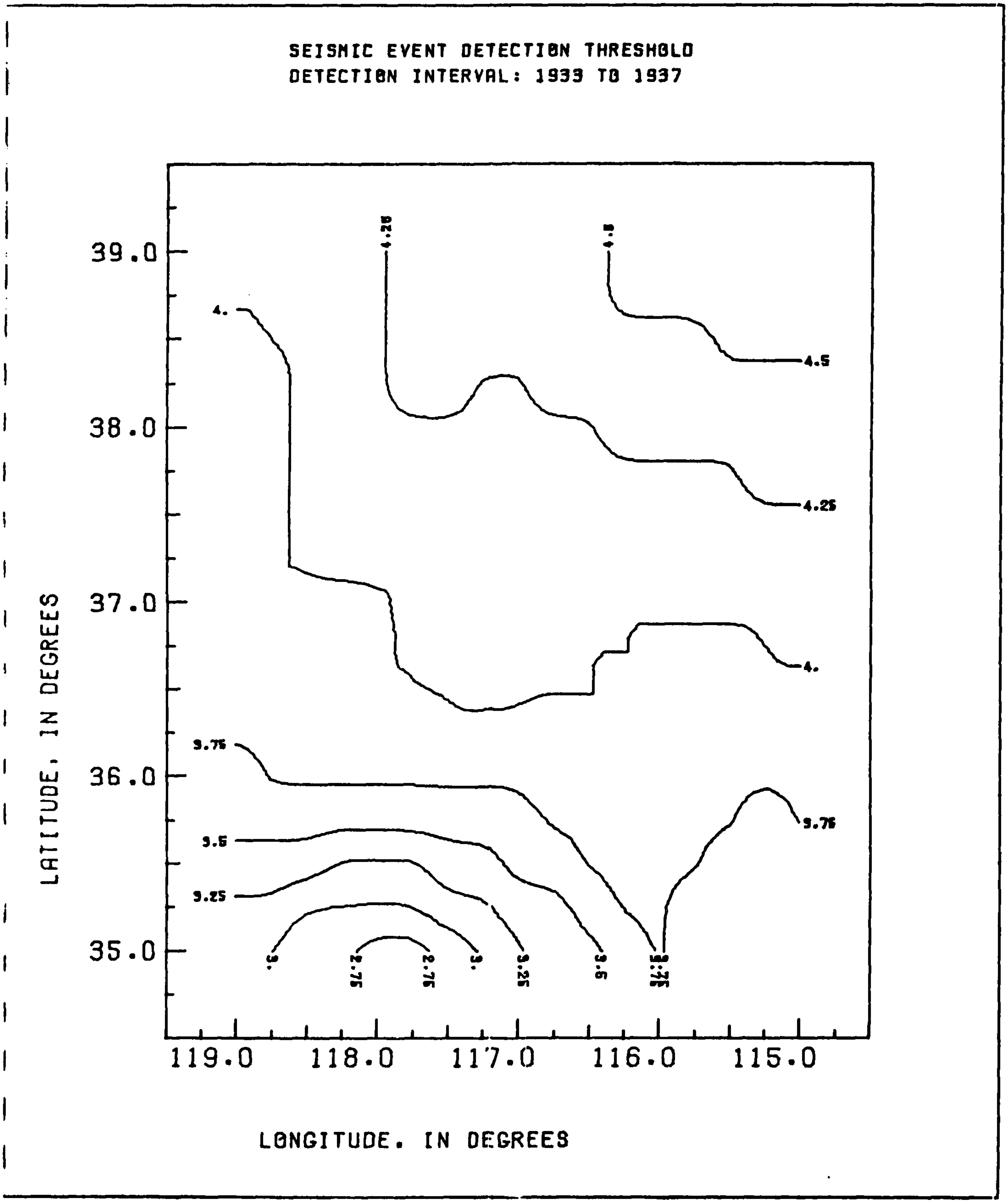


Figure 8 The detection surface for a noise level of 3 millicrons.



SEISMIC EVENT DETECTION THRESHOLD
DETECTION INTERVAL: 1933 TO 1937
39.0
38.0
37.0
36.0
35.0
119.0
118.0
117.0
116.0
115.0
LATITUDE, IN DEGREES
LONGITUDE, IN DEGREES
4.
4.25
4.5
3.75
3.5
3.25
3.
2.75

Figur 9

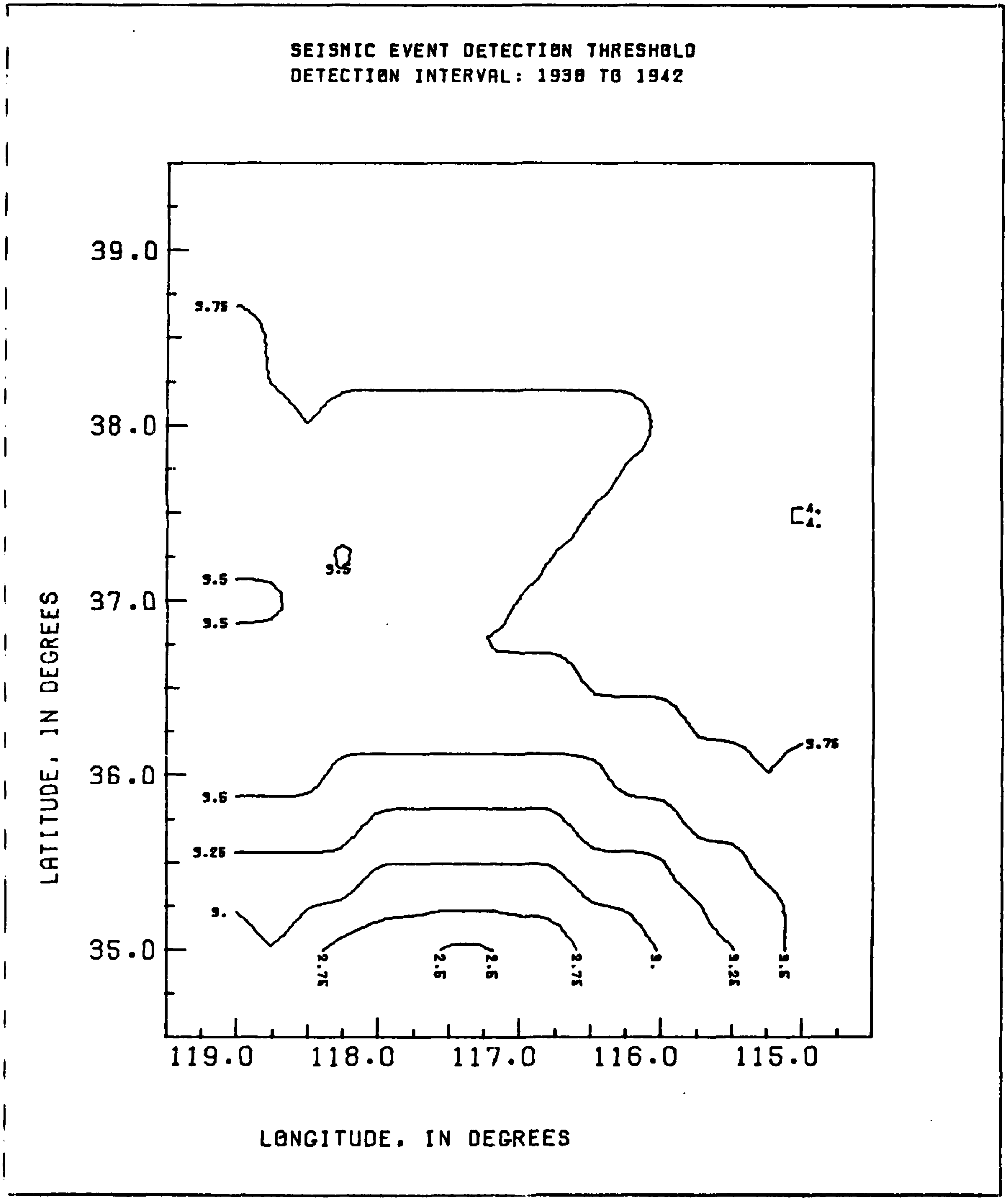

SEISMIC EVENT DETECTION THRESHOLD
DETECTION INTERVAL: 1938 TO 1942
39.0
38.0
37.0
36.0
35.0
LATITUDE, IN DEGREES
119.0
118.0
117.0
116.0
115.0
LONGITUDE, IN DEGREES
3.75
3.5
3.5
3.5
3.5
3.25
3.
2.75
2.5
2.5
2.75
3.
3.25
3.5
3.75
4.
4.

Figure 10

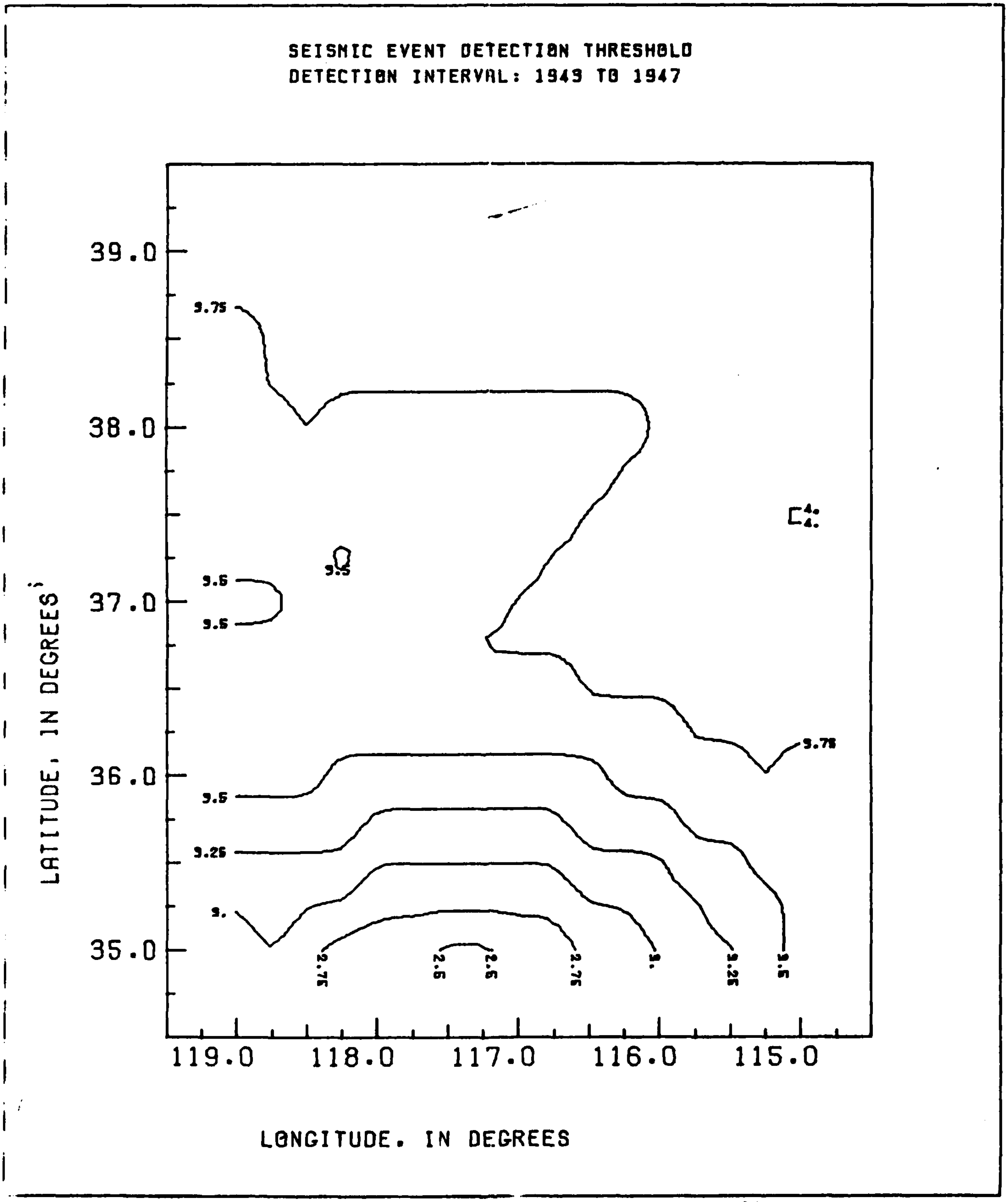


Figure 11 Detection surface, 1943 - 1947.

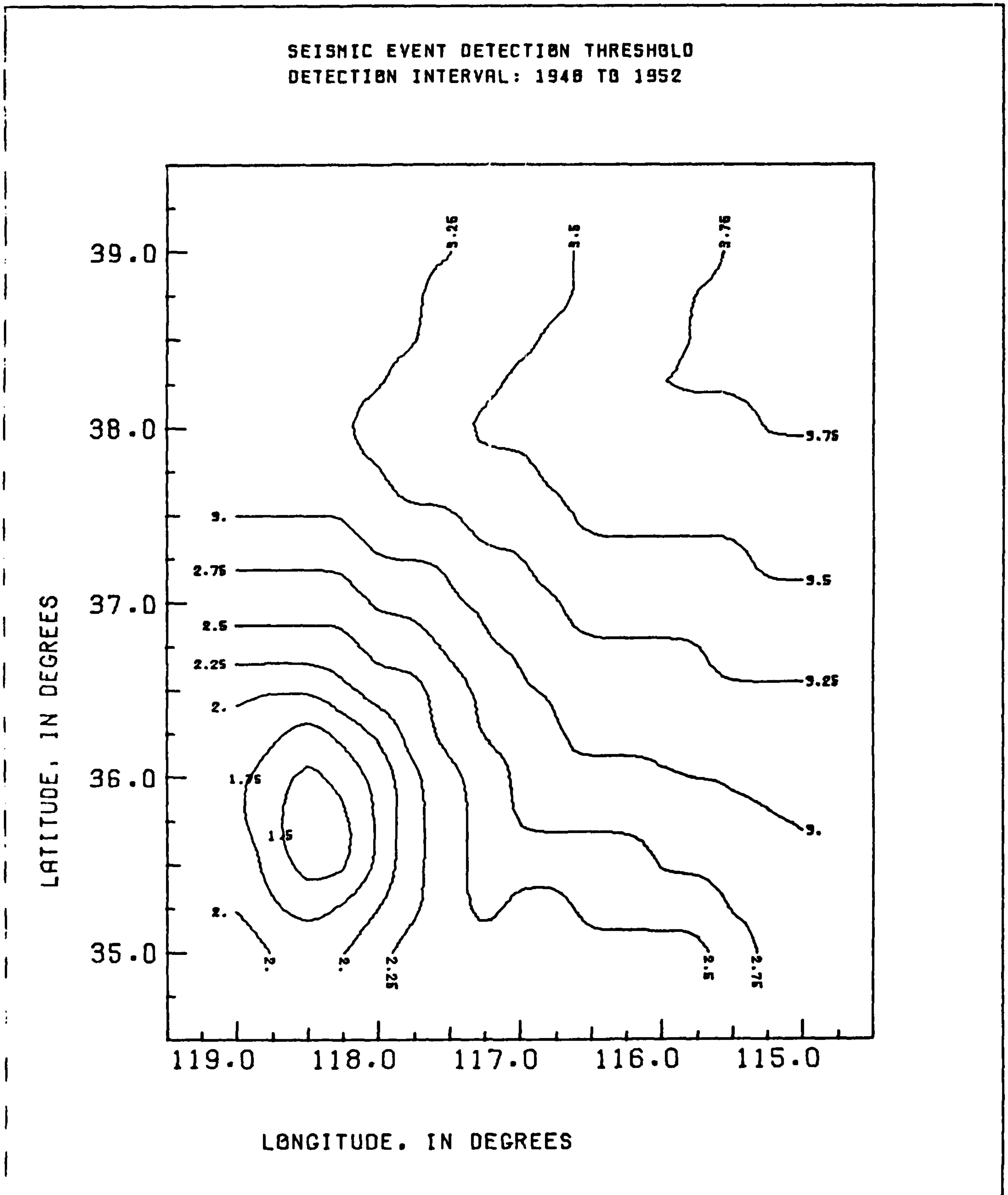


Figure 12 Detection surface, 1948 - 1952.

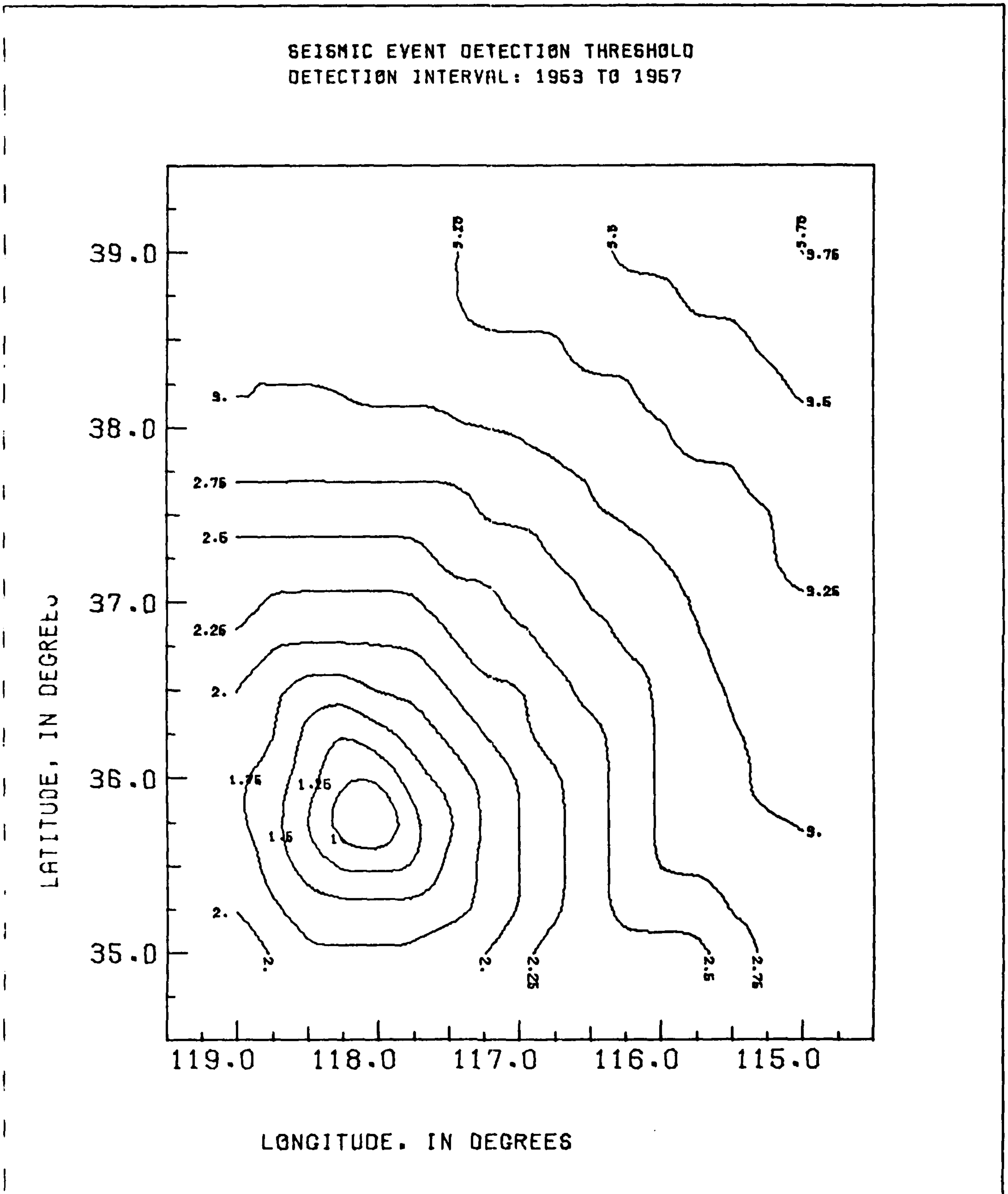


Figure 13 Detection surface, 1953 - 1957.

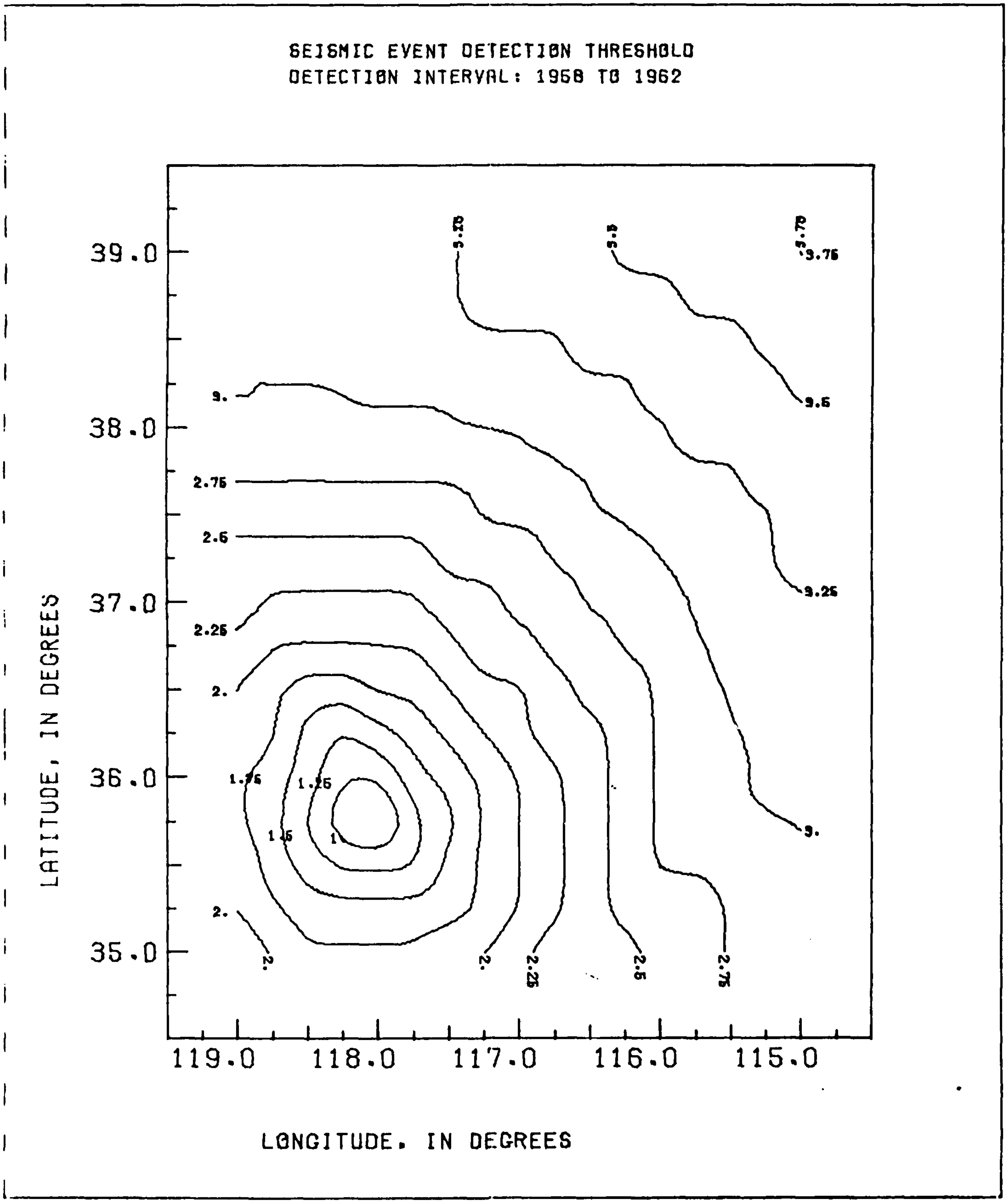


Figure 14 Detection surface, 1958 - 1962.

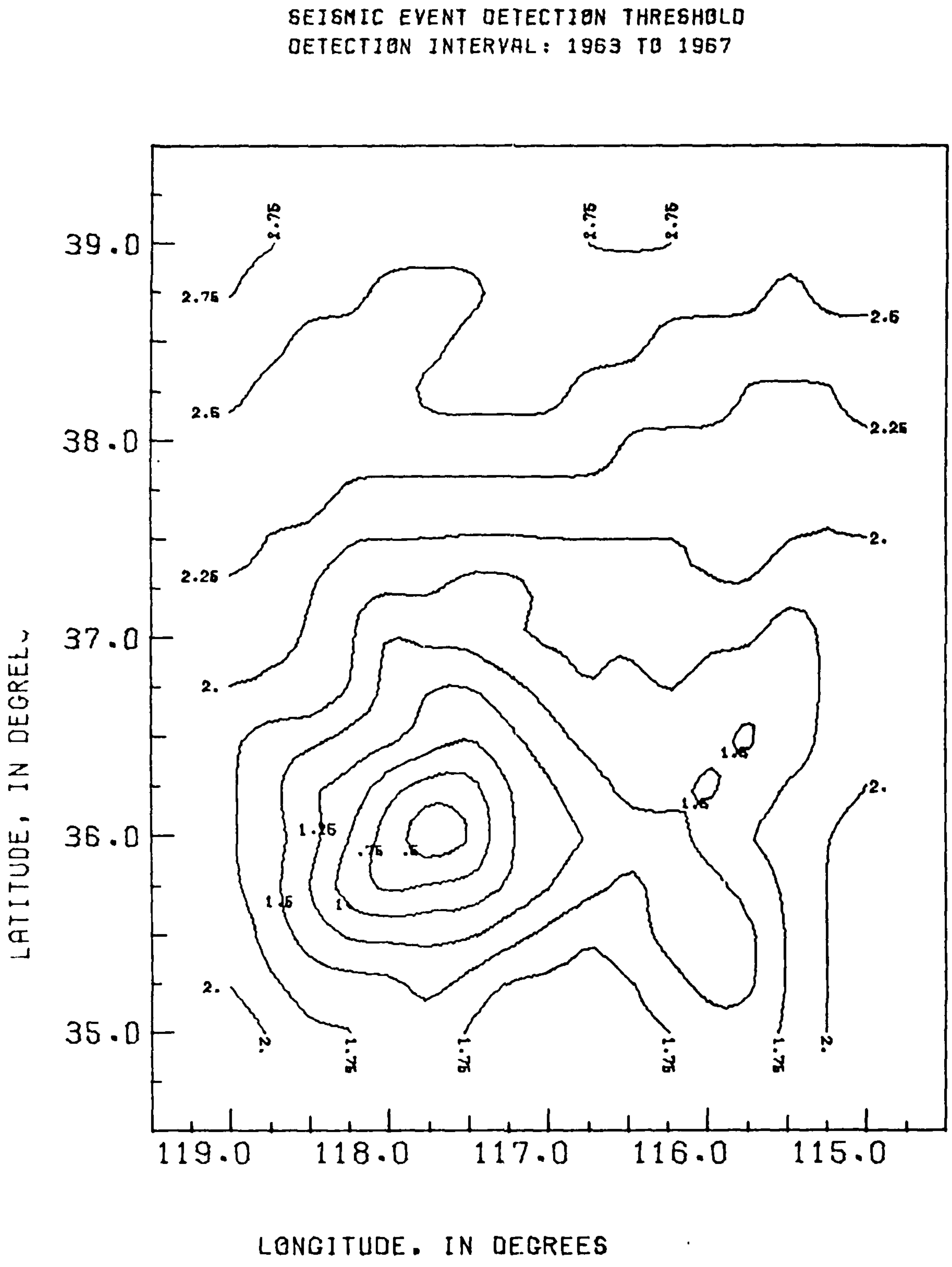


Figure 15 Detection surface, 1963 - 1967.

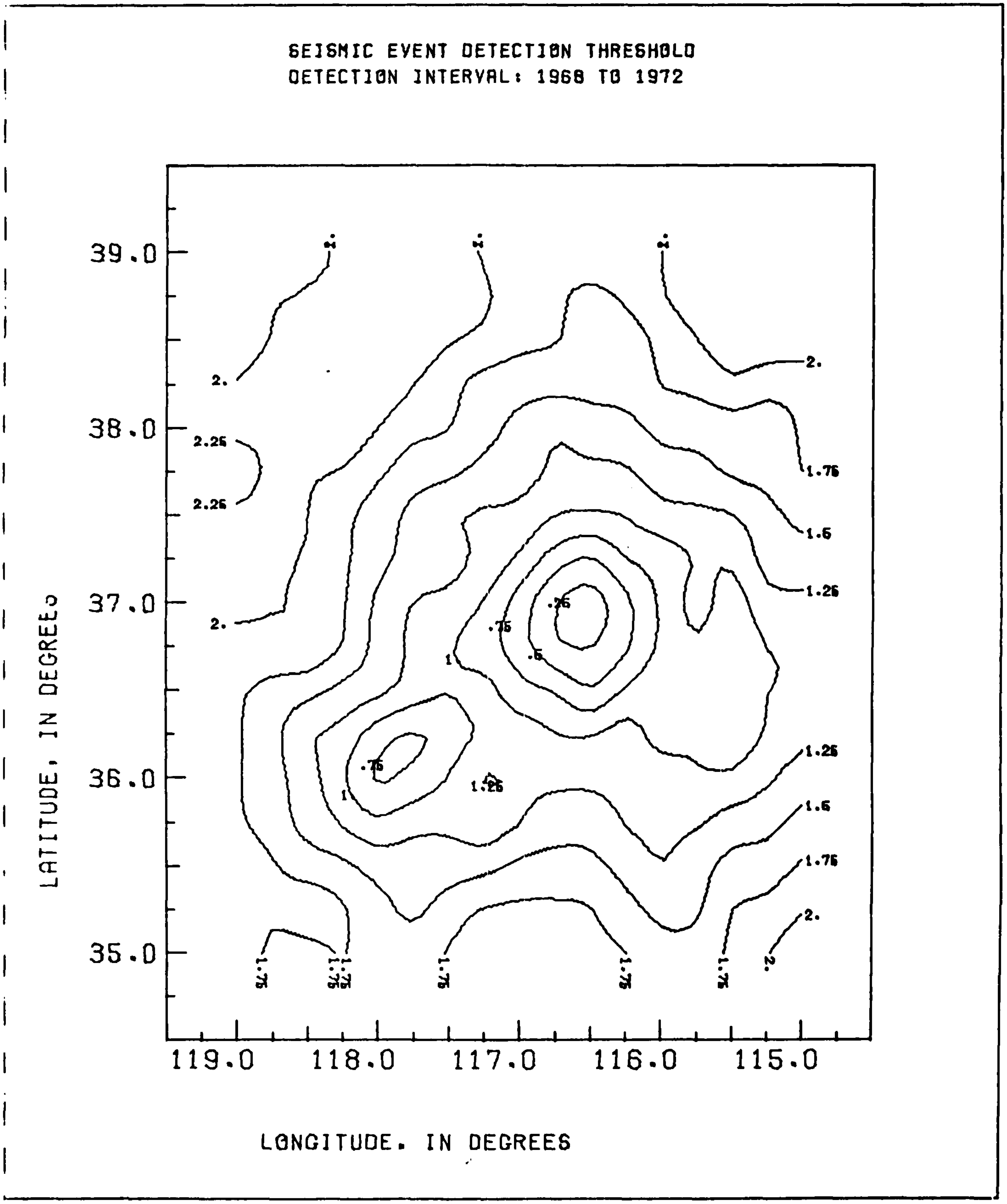


Figure 16 Detection surface, 1968 - 1972.

Figure 17 IMPROVEMENT IN DETECTION SURFACE
1935 TO 1940

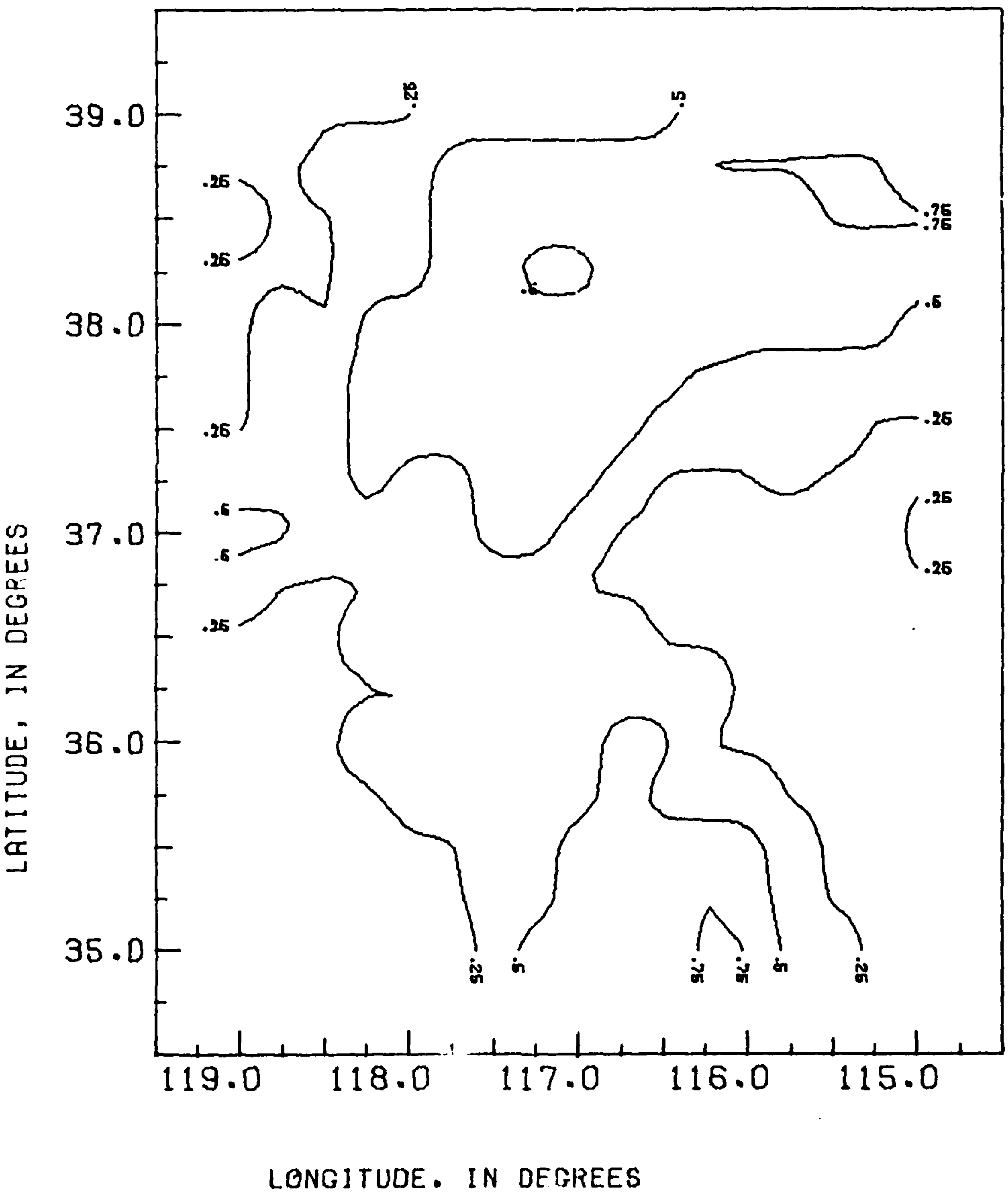


Figure 18 IMPROVEMENT IN DETECTION SURFACE 1936 TO 1945

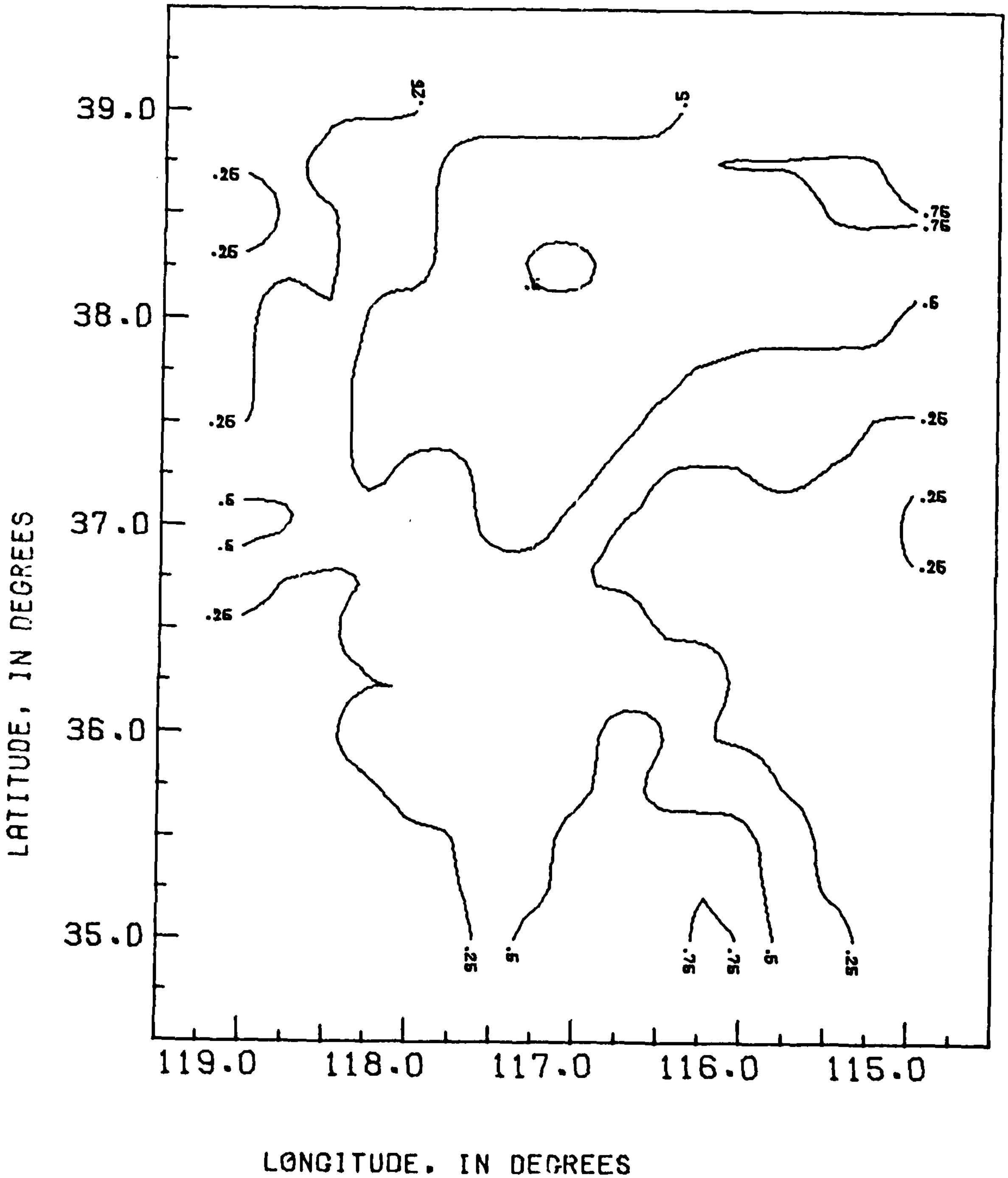


Figure 19 IMPROVEMENT IN DETECTION SURFACE 1935 TO 1960

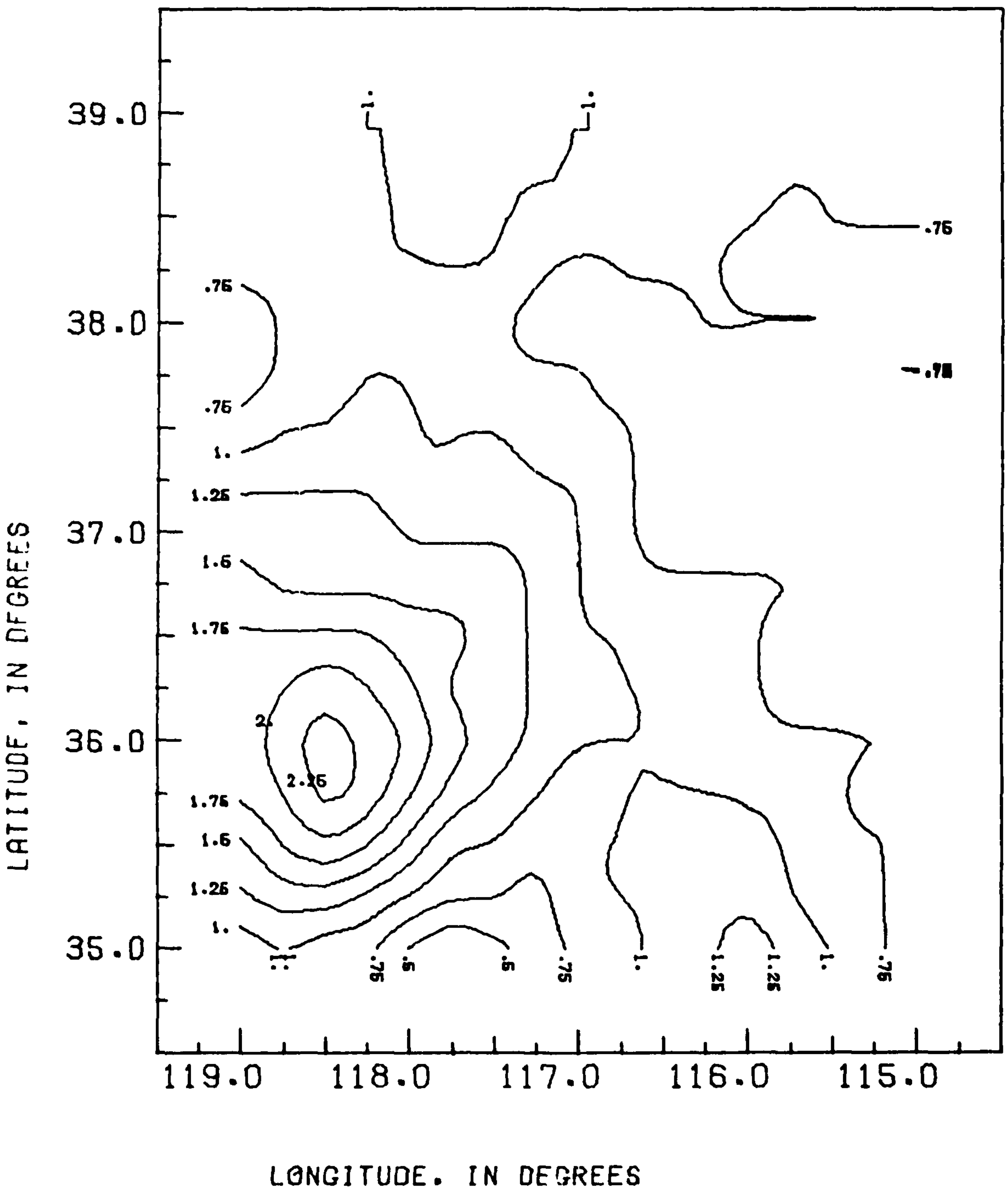


Figure 20 IMPROVEMENT IN DETECTION SURFACE 1936 TO 1966

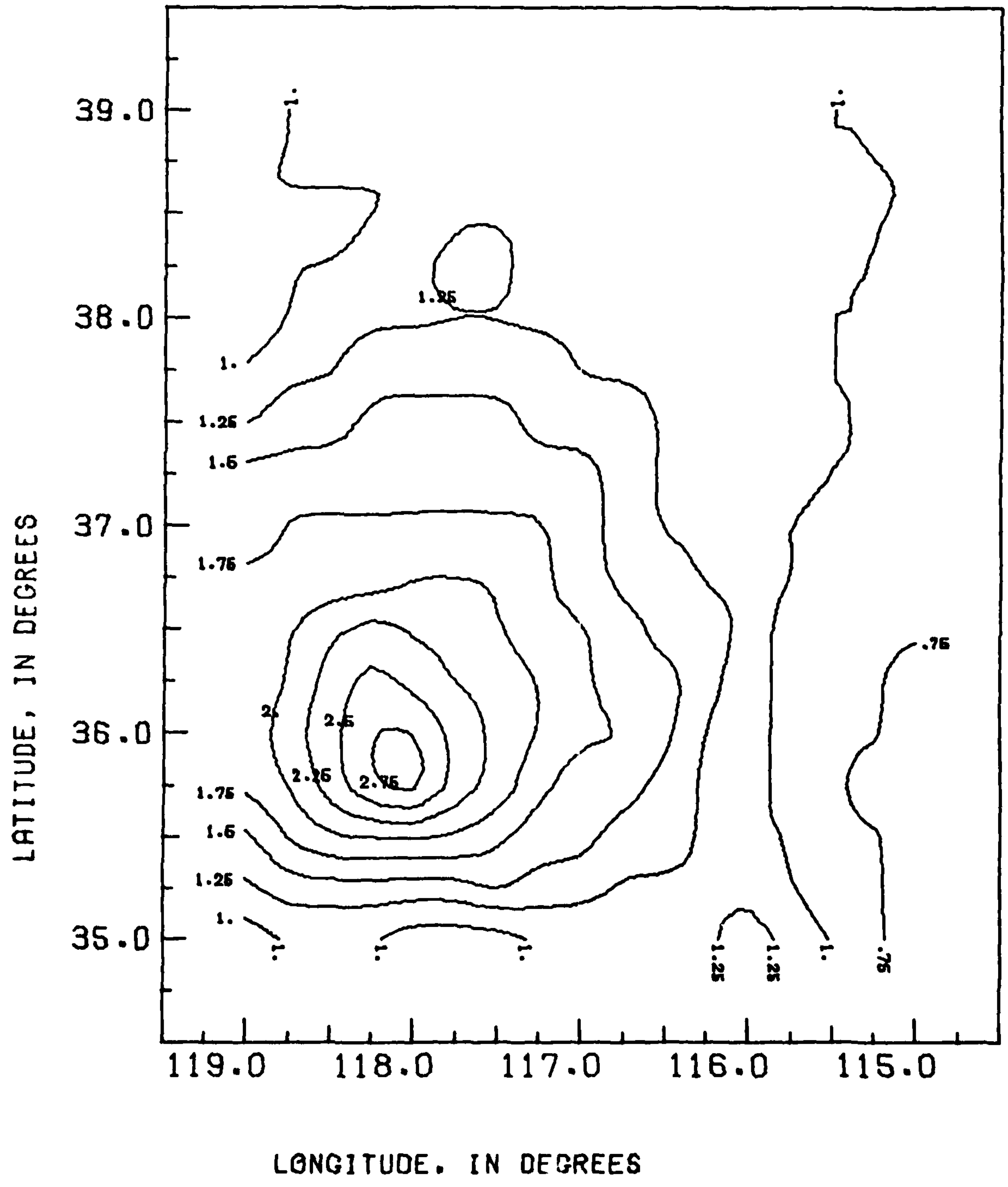


Figure 21 IMPROVEMENT IN DETECTION SURFACE 1936 TO 1960

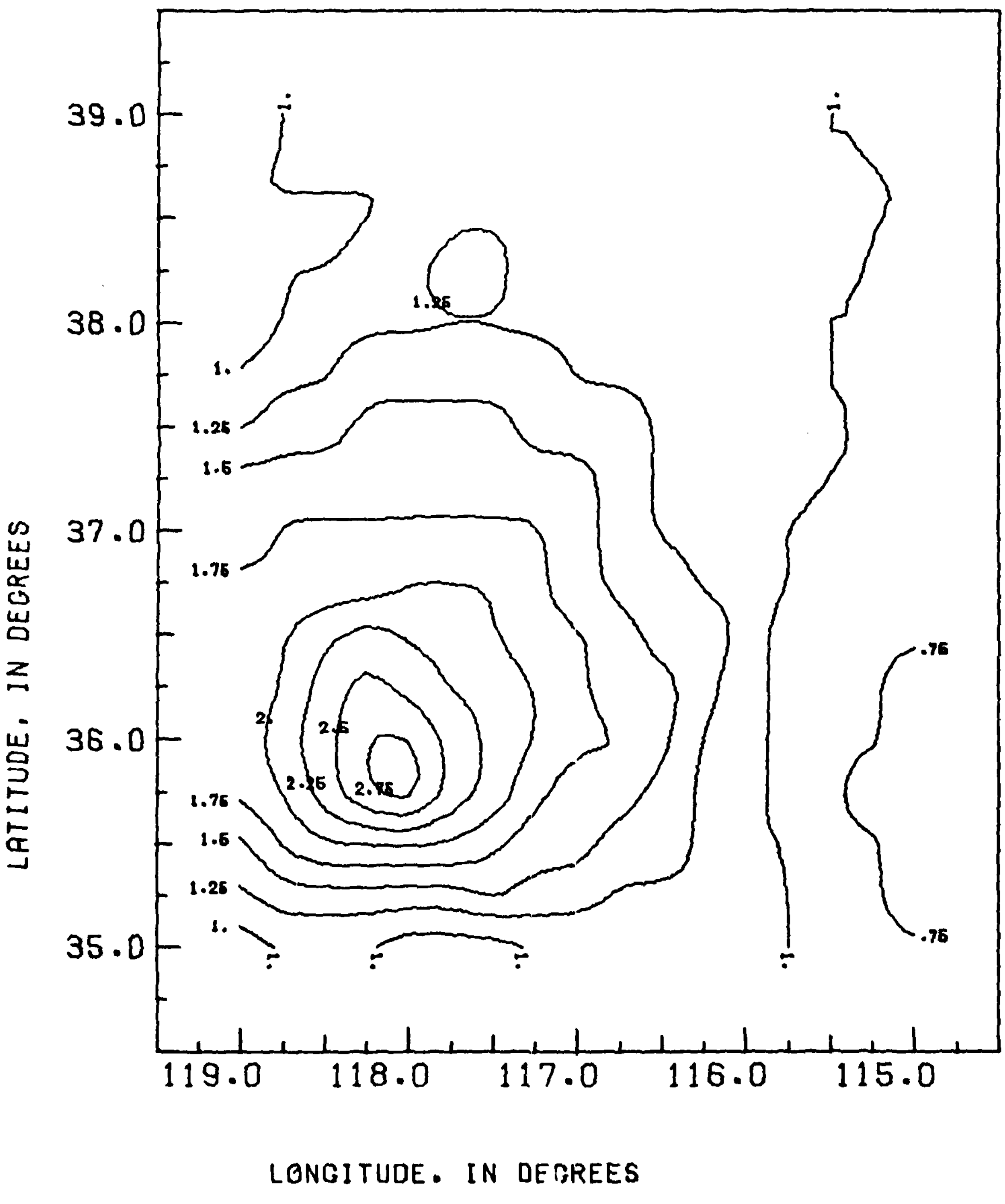


Figure 22 IMPROVEMENT IN DETECTION SURFACE 1936 TO 1965

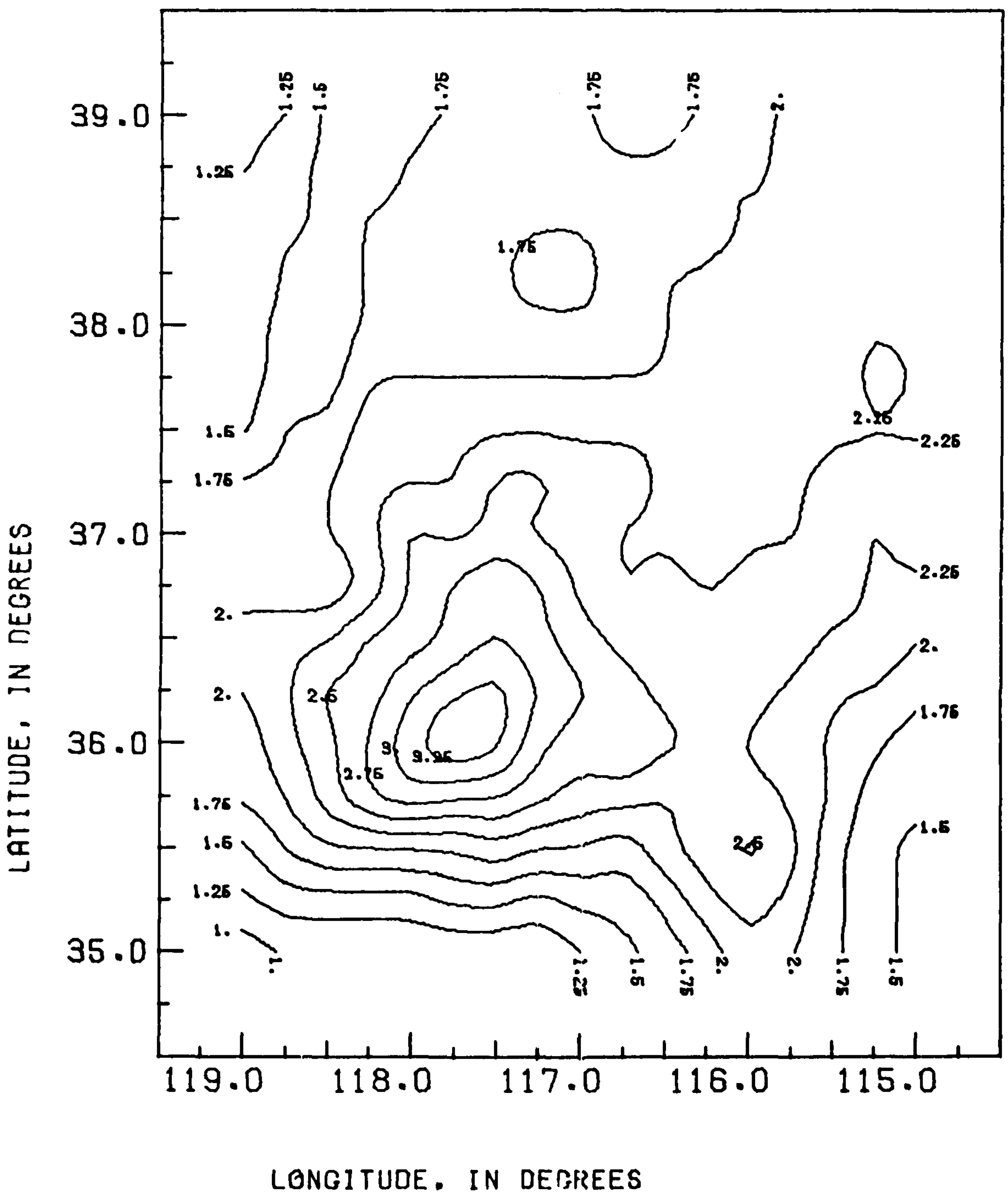
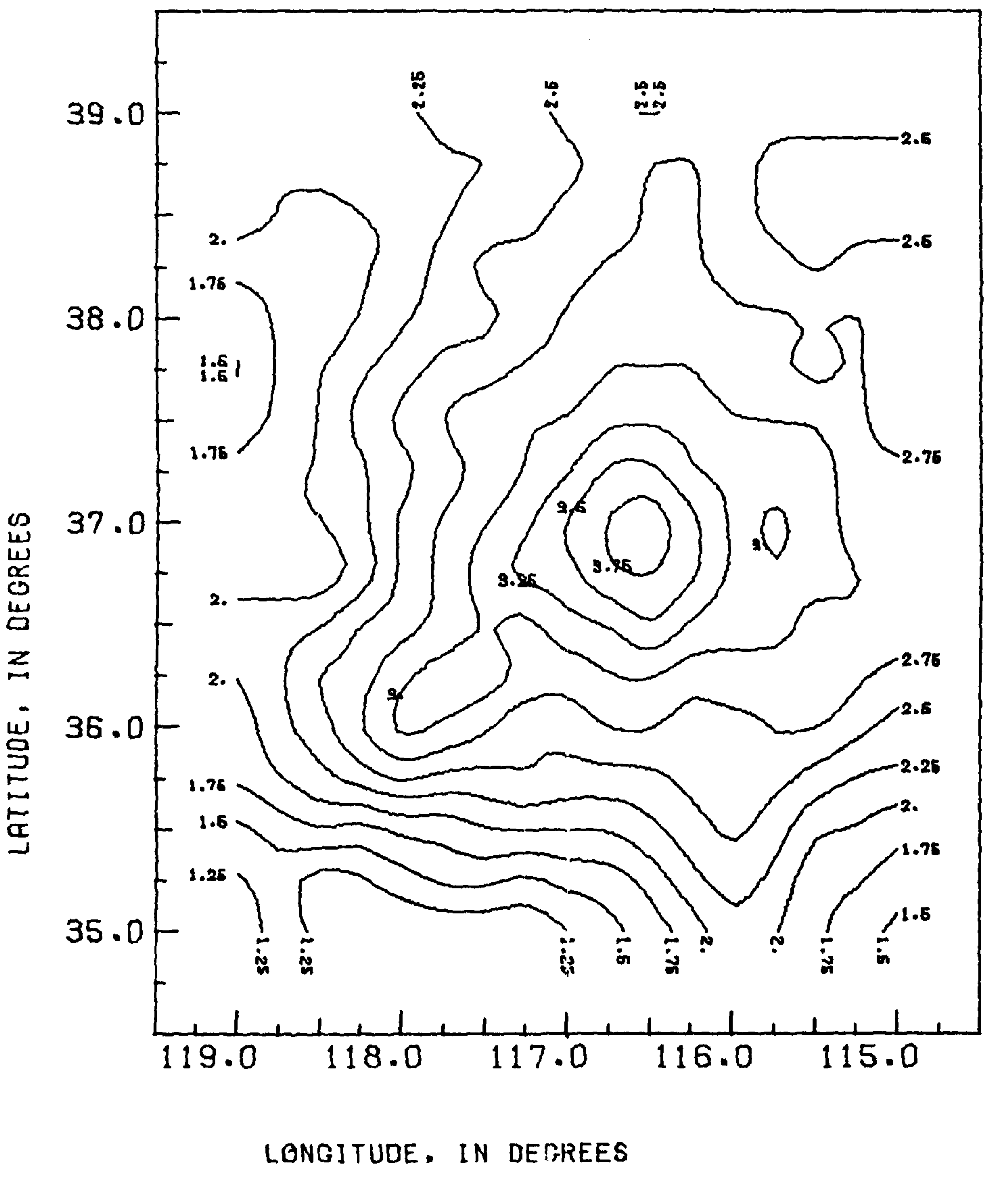


Figure 23 IMPROVEMENT IN DETECTION SURFACE
1936 TO 1970



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