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A P P E N D I C E S

APPENDIX C - A

OTTO W. NUTTLI
PROFESSOR OF GEOPHYSICS
P.O. BOX 8099, LACLEDE STA.
ST. LOUIS, MISSOURI 63156
(314) ~~???-????~~ 658-3124

January 24, 1983

FEB 4 REC'D

Dr. Dae H. Chung, L-95
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550

Dear Dan;

I am writing to offer my suggestions as to how to handle the attenuation problem in LLNL's sensitivity study of strong ground motion.

My recommendation is to use three different models, to determine the sensitivity of the site ground motion to different attenuation relations. Model 1 would be the one used two or three years earlier in the LLNL-TERA study for specific eastern nuclear power plant sites. There are two reasons for including this model: first, it will show the sensitivity to different source models in the two studies, as the attenuation relation will be the same for both; second, it is based on intensity data, which make up the bulk of eastern United States data, and thus is the most empirical (relies least on theoretical modeling) kind of attenuation relation. The problem is that we have to use data bases from other parts of the world, primarily the western United States, that relate M.M. intensity to ground acceleration, velocity and displacement, and we have good reason to suspect that these data are not directly applicable to the eastern United States.

Model 2 would be Ken Campbell's attenuation curves for strong ground motion for the central United States. These curves assume that the source excitation is the same for eastern and western earthquakes of a given magnitude, but that the anelastic attenuation is different for the two regions. The idea is similar to that employed by Algermissen and Perkins in constructing their hazard maps for the United States, and to that used by me in the 1979 report to the Waterways Experiment Station of the Corps of Engineers. One potential problem with Campbell's curves is the way he defines magnitude, i.e., M_L for M_L less than 6.5 and M_S for M_S greater than 6.5. The relations which I obtain for the eastern United States (spectral scaling paper to appear in April 1983 issue of BSSA) are:

$$M_S = 1.0\ m_b - 1.15 \qquad \text{for } m_b \leq 4.5$$

$$M_S = 2.0\ m_b - 5.65 \qquad \text{for } 4.5 \leq m_b \leq 7.0.$$

For the eastern United States Bob Herrmann and I showed that $M_L = m_b$. In the East you seldom will have to deal with earthquakes of M_L greater than 6.5. Therefore my suggestion is to use M_L (or m_b) values with Campbell's curves.

Model 3 is one which has evolved from studies of Bob Herrmann and myself. The most recent published version is my paper in the Proceedings of the June 1982 Earthquake Microzonation Conference. The method uses empirical studies of mid-plate magnitudes and moments to establish spectral scaling relations, from which a scaling law for peak ground acceleration, velocity and displacement is derived. Frequency-dependent anelastic attenuation relations are obtained from measurements of eastern earthquakes by observatory-type instruments. The level of the attenuation curves is determined by existing central United States strong-motion data, as present in the Microzonation paper. Thus Method 3 is semi-empirical, semi-theoretical. Although I am not impartial and unbiased, I believe it represents the best existing set of strong motion relations for the East.

I don't believe it is advisable to attempt to distinguish between differences of anelastic attenuation in the craton region of the central and eastern United States and the accreted coastal-plain regions to the east and south of the Appalachian and Ouachita-Wichita Mountains. By attempting to consider this effect you would be introducing a refinement that has smaller consequences than those resulting from more basic uncertainties in the attenuation relations.

In the paper for the Microzonation meeting I presented my attenuation relations only in the form of sets of curves. In the past week I put them in equation form. Also, based upon material contained in my spectral scaling paper, I have more carefully considered the problem of minimum focal depth, which affects the ground motion at small epicentral distances. Included is a figure showing how the ground acceleration at near-source distances changes with focal depth for an m_b = 5.0 earthquake. Because we cannot possibly estimate focal depth for all the historical earthquakes, I suggest that in all cases you use the attenuation curves for minimum focal depth, as in the three figures included with this letter (for maximum acceleration, velocity and displacement). This is most conservative, in the sense that it will give the largest possible ground motions.

Please don't hesitate to call me if you have any questions, criticisms, suggestions, or such.

With best regards,

Sincerely,

Otto

Otto W. Nuttli

Enclosures

P.S. The equations and curves are an average for various rock and soil types. Probably they are most representative of a stiff or competent soil.

STRONG GROUND MOTION ATTENUATION RELATIONS FOR THE CENTRAL UNITED STATES

Minimum Focal Depth

$$\log_{10} h_{min}\ (\text{km}) = -0.949 + 0.284\ m_b \quad \text{for } m_b \leq 4.4$$

$$\log_{10} h_{min}\ (\text{km}) = -1.730 + 0.456\ m_b \quad \text{for } m_b > 4.4$$

Q_o (quality factor at 1 Hz) = 1000; $Q(f) = 1000f^{0.3}$ (f = frequency)

Max-Acc = arithmetic average of peaks on 2 horizontal components

assumed: a_{max} has a frequency of 5 Hz
v_{max} has a frequency of 1.5 Hz
d_{max} has a frequency of 0.5 Hz

$$\log_{10} a_{max}\ (\text{cm/sec}^2) = 1.69 + 0.25\ m_b - 0.833 \log_{10}\ r^2{+}h^2 - 0.00122\ (r-1) \quad \text{for } m_b \leq 4.4$$

$$\log_{10} a_{max} = 0.57 + 0.50\ m_b - 0.833 \log_{10}\ r^2{+}h^2 - 0.00122\ (r-1) \quad \text{for } 4.4 < m_b \leq 7.4$$

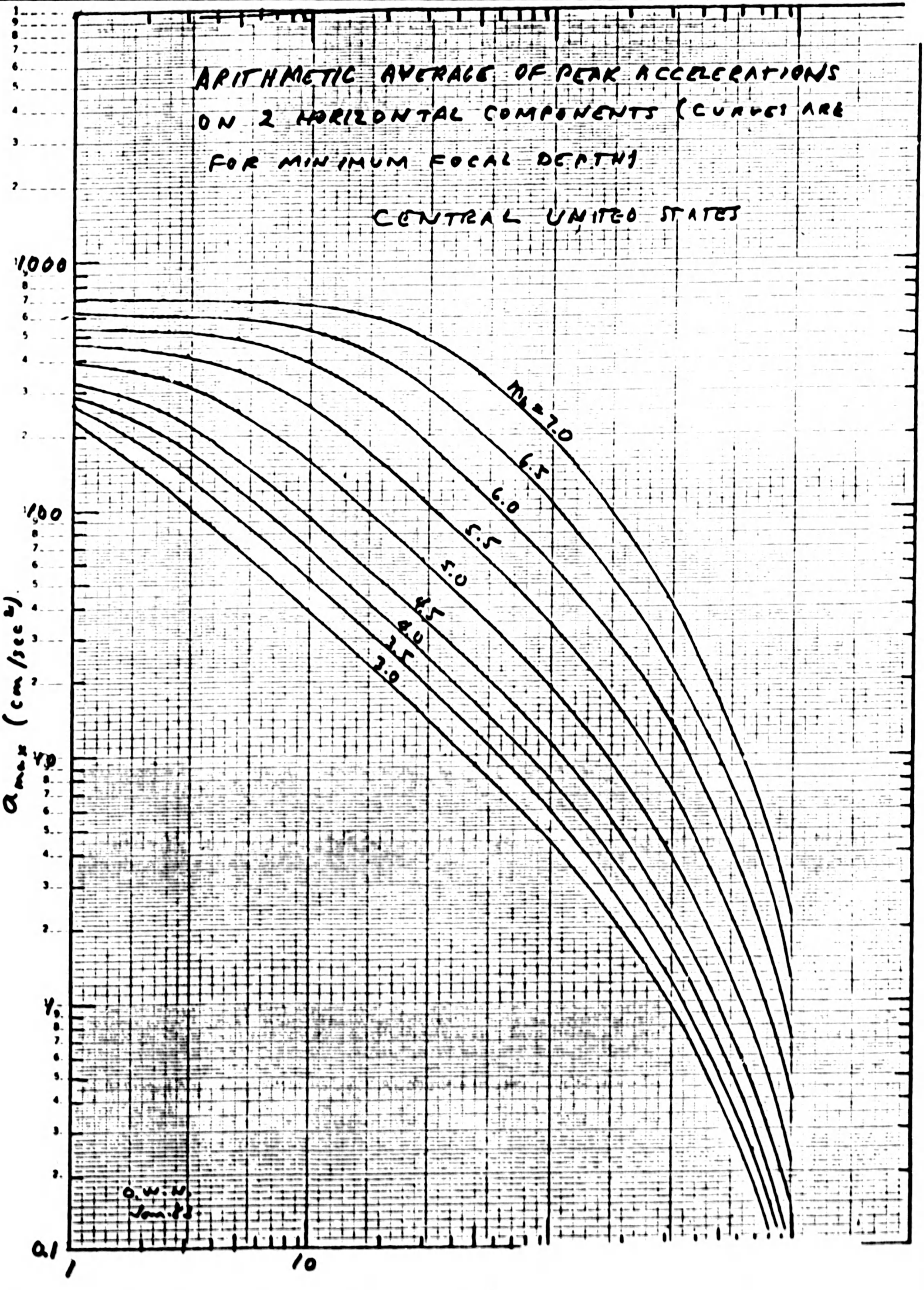
$$\log_{10} V_{max}\ (\text{cm/sec}) = -1.35 + 0.50\ m_b - 0.833 \log_{10}\ r^2{+}h^2 - 0.000532\ (r-1) \quad \text{for } m_b \leq 4.4$$

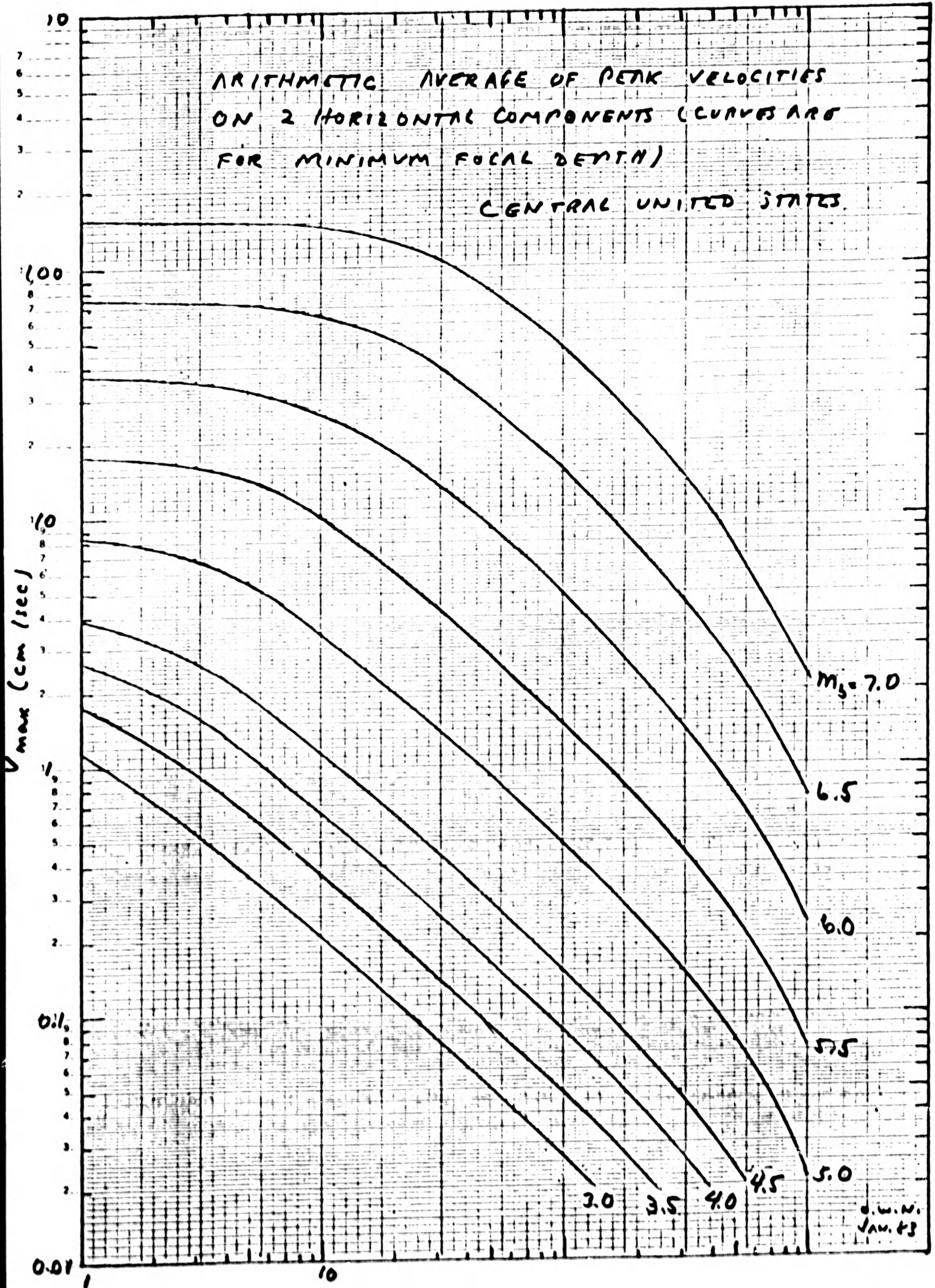
$$\log_{10} V_{max} = -3.60 + 1.00\ m_b - 0.833 \log_{10}\ r^2{+}h^2 - 0.000532\ (r-1) \quad \text{for } 4.4 < m_b \leq 7.4$$

$$\log_{10} d_{max}\ (\text{cm}) = -3.43 + 0.75\ m_b - 0.833 \log_{10}\ r^2{+}h^2 - 0.000244\ (r-1) \quad \text{for } m_b \leq 4.4$$

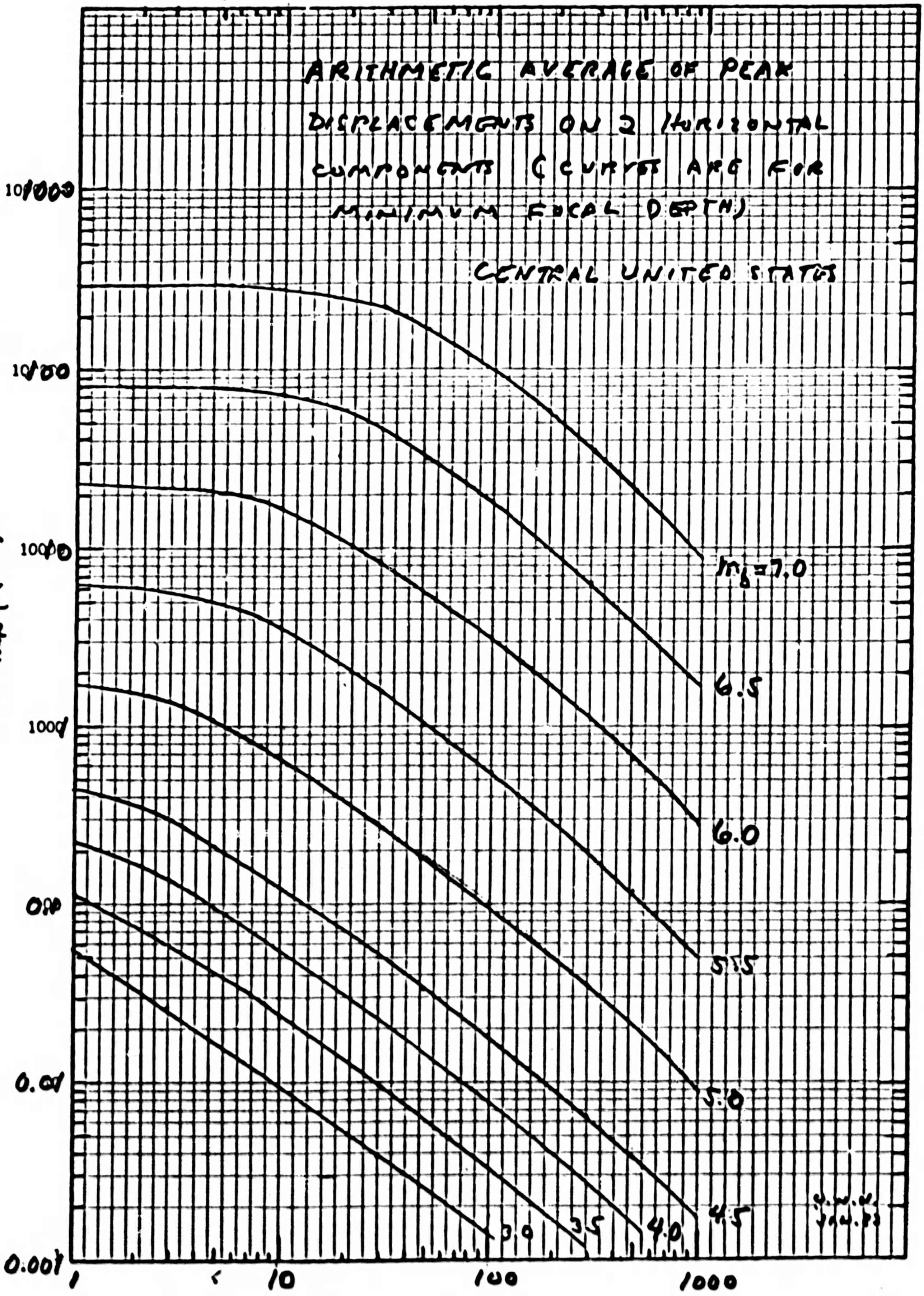
$$\log_{10} d_{max} = -6.81 + 1.50\ m_b - 0.833 \log_{10}\ r^2{+}h^2 - 0.000244\ (r-1) \quad \text{for } 4.4 < m_b \leq 7.4$$

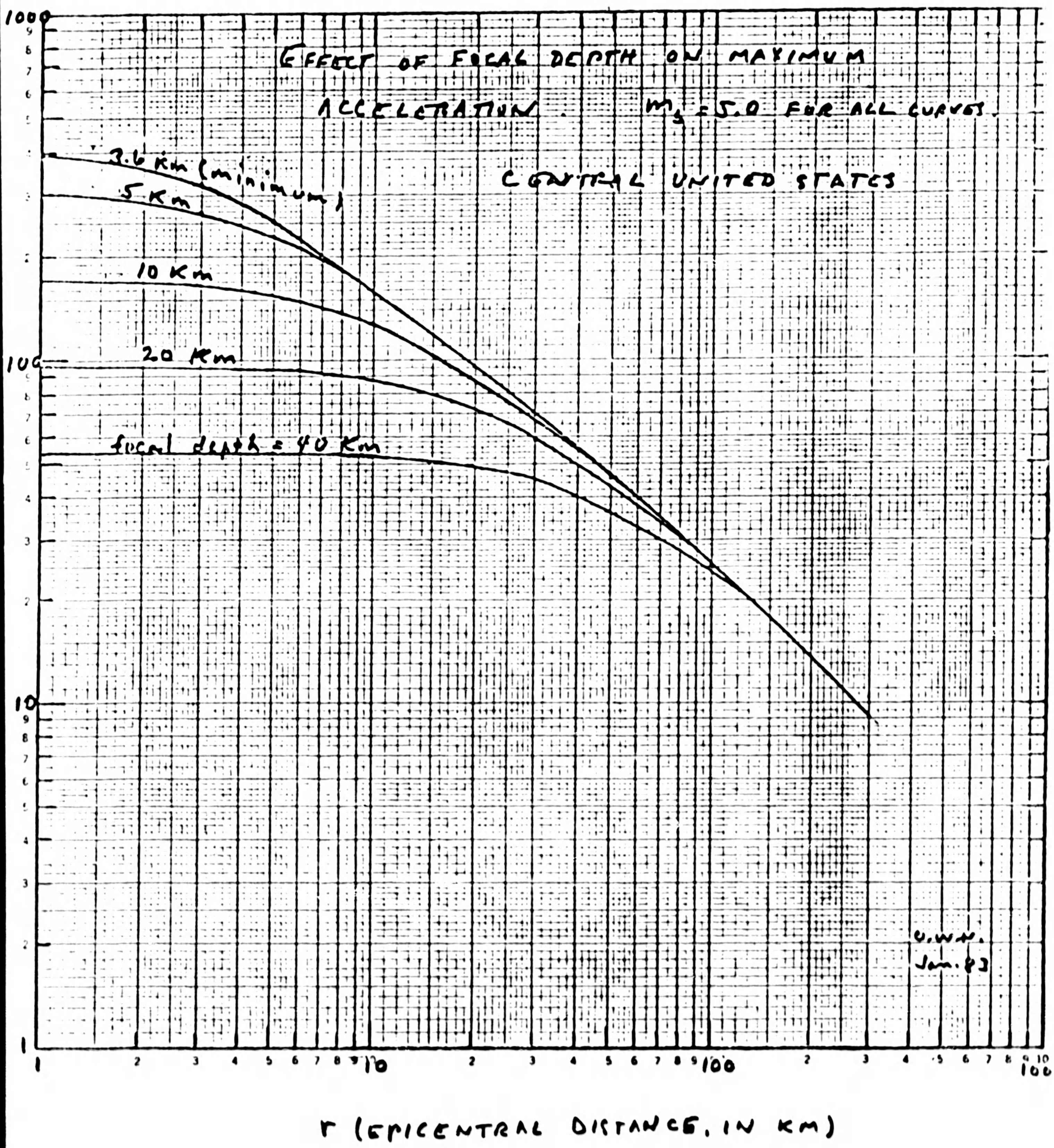
where h = focal depth (in km) and r = epicentral distance (in km).


ARITHMETIC AVERAGE OF PEAK ACCELERATIONS
ON 2 HORIZONTAL COMPONENTS (CURVES ARE
FOR MINIMUM FOCAL DEPTH)
CENTRAL UNITED STATES
M = 7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
a_{max} (cm/sec²)
1,000
100
10
1.0
0.1
1
10
O.W.N.
Jan 83


ARITHMETIC AVERAGE OF PEAK VELOCITIES
ON 2 HORIZONTAL COMPONENTS (CURVES ARE
FOR MINIMUM FOCAL DEPTH)
CENTRAL UNITED STATES
m_b = 7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
V_{max} (cm/sec)
10
1.00
10
1
0.1
0.01
1
10
D.W.N.
JAN. 83

MODEL DATE


ARITHMETIC AVERAGE OF PEAK
DISPLACEMENTS ON 2 HORIZONTAL
COMPONENTS (CURVES ARE FOR
MINIMUM FOCAL DEPTH)
CENTRAL UNITED STATES
10,000
1,000
100
10
1
0.1
0.01
0.001
m_b=7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
1
10
100
1000
d_{max} (cm)
r (EPICENTRAL DISTANCE, IN KM)


EFFECT OF FOCAL DEPTH ON MAXIMUM
ACCELERATION. m_b = 5.0 FOR ALL CURVES.
CENTRAL UNITED STATES
3.6 Km (minimum)
5 Km
10 Km
20 Km
focal depth = 40 Km
O.W.N.
Jan. 83
1000
100
10
1
10
100
1000
r (EPICENTRAL DISTANCE, IN KM)

APPENDIX C-B

UNIVERSITY OF SOUTHERN CALIFORNIA

UNIVERSITY PARK • LOS ANGELES, CALIFORNIA 90007

SCHOOL OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

FEB 4 REC'D

January 18, 1983

Dr. Dae H. Chung
Lawerence Livermore Laboratory
University of California
Livermore, California 94550

Dear Dae,

As you requested I am enclosing my brief comments on the use of 'distance' in the papers by Joiner and Boore (1981) and Campbell (1981). Those are:

1. Joiner and Boore (1981) employ a definition of distance which is equivalent to $(R_o^2 + h^{*2})^{1/2}$ in the enclosed Figure 1. In their work h* is a 'measure' of the source depth selected to minimize the sum of the squares of the residuals. This definition of distance would be appropriate if an argument could be made that the peak ground motion comes from the portion of the fault surface which is at 'depth' h* and beneath A in Figure 1.

2. Campbell (1981) uses distance R_2 (in Figure 1) and a magnitude dependent 'coefficient' C(M) which physically resembles h*. This is also fitted to the data to minimize the sum of the residuals squared.

Assume we have recorded three peak accelerations and we wish to plot those versus same distance R as in Figure 2. In a typical case (say Imperial Valley 1979 data) I interpret Campbell's work to plot these data points as crosses (+) in Figure 2. Joiner and Boore (1981) definition would lead to the peaks plotted as circles (o) in Figure 2 (assuming that somehow we know h*). Assuming on the other hand, that we wish to plot those peak accelerations versus distance R_1, which is a distance to a 'center' of the fault surface we would get the points shown by asterisks, (Figure 2). It is obvious from the geometry of Figure 2 that $R_o < R_1$, $R_2 < R_1$ and $(R_o^2 + h^{*2})^{1/2} < R_1$. Since we do not know a priori which part of the fault will contribute most to the peak ground motions, unless $L >> R_1$ it would seem reasonable to use some definition (in the mean) close to R_1. This effect is of course significant only for small R1 and as $R_1 \to \infty$ all definitions of distance become indistinguishable. Therefore I believe that Joiner and Boore (1981) as well as Campbell (1981) have a tendncy to underestimate peak amplitudes of ground motion for small R. This is seen from sketch in Figure 2.

I am taking the liberty of sending these comments to Boore and Campbell directly. I hope they can examine them and suggest wether I have erred in my interpretation of their results.

Please let me know if you feel that these comments are not clear and wether there are additional aspects of interest that I did not discuss.

Sincerely,

Mike

M. D. Trifunac

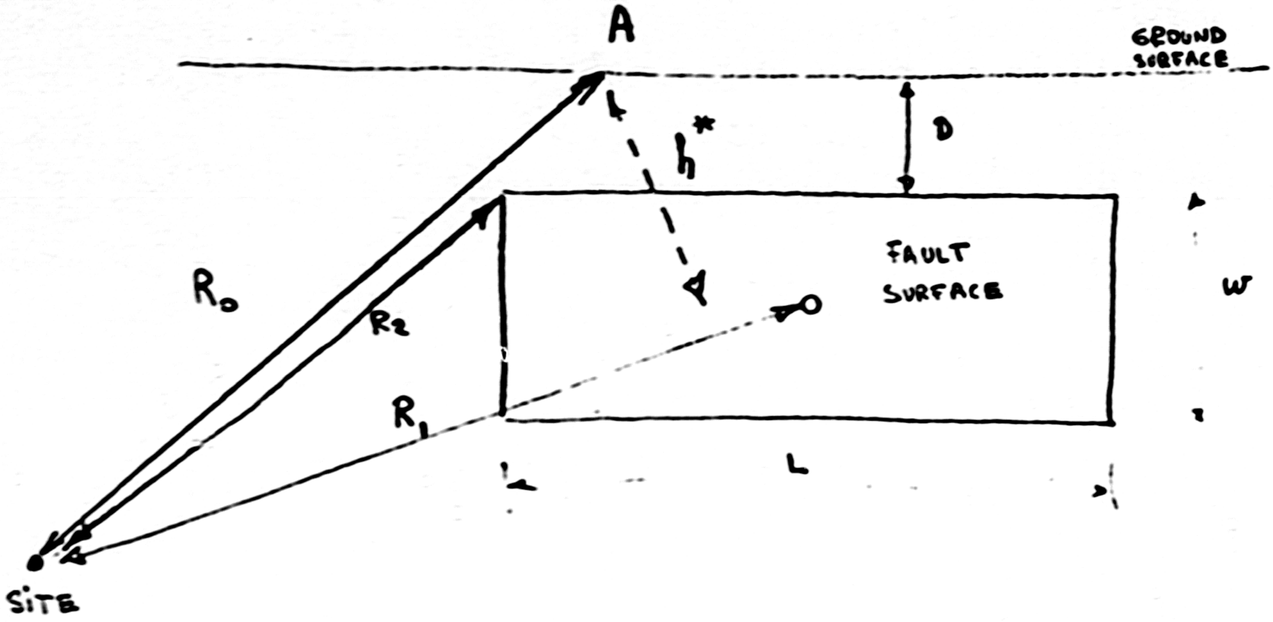


Figure 1

BOORE & JOINER (1981) use $r = (d^2 + h^2)^{1/2}$ where "d is the closest distance from the recording site to the surface projection of the fault rupture." This corresponds to R_0 in Figure 1

Campbell (1981) uses " shortest distance between the station and the fault rupture surface"... I interpret this to correspond to distance like R_2 in Figure 1

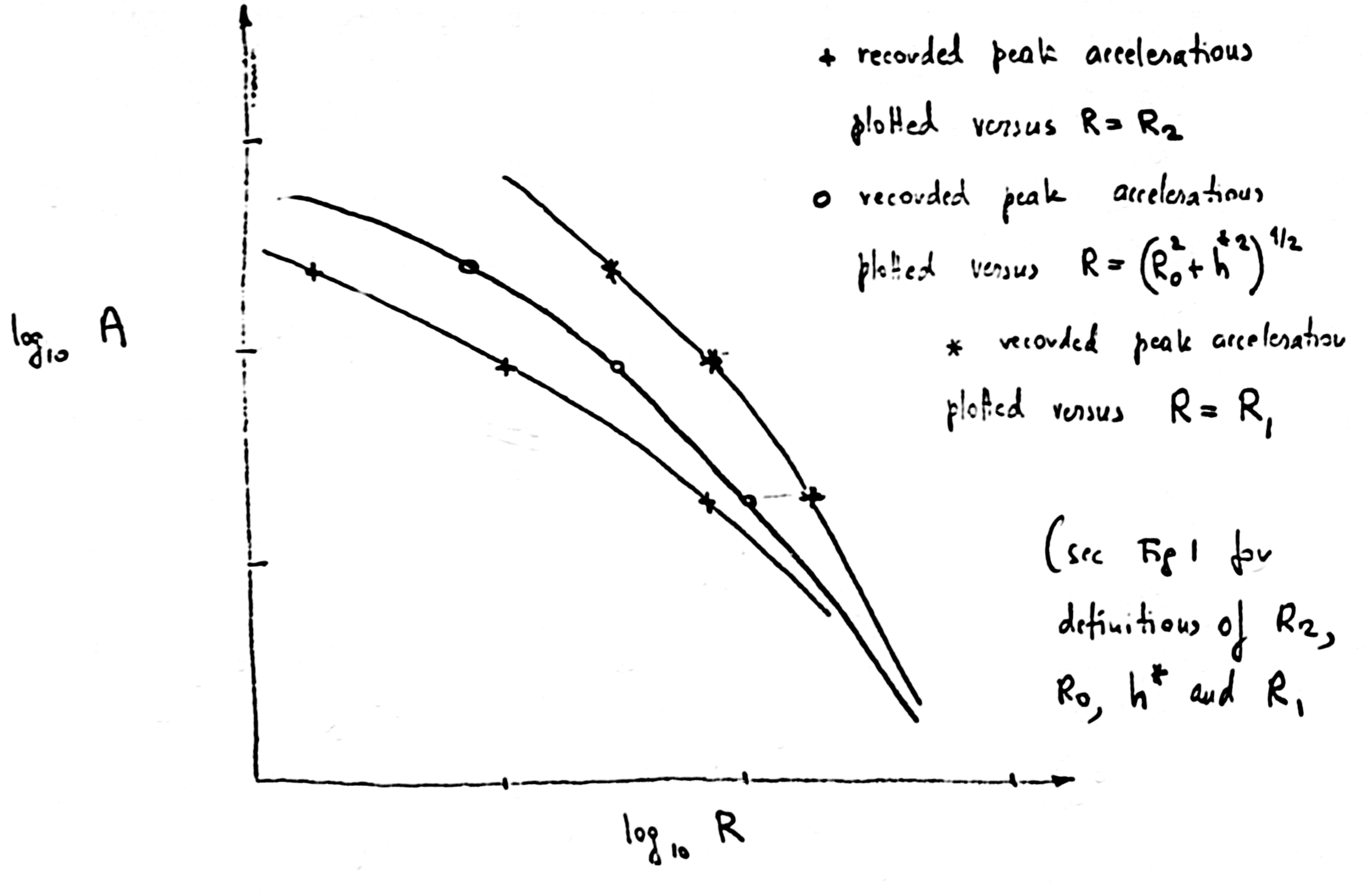

log10 A
log10 R
+ recorded peak accelerations plotted versus R = R2
o recorded peak accelerations plotted versus R = (R0^2 + h*^2)^1/2
* recorded peak acceleration plotted versus R = R1
(see Fig 1 for definitions of R2, R0, h* and R1

Figure 2

APPENDIX C-C

February 3, 1983

FEB 8 REC'D

Dr. Dae H. Chung, L-90
Lawrence Livermore National Laboratory
P. O. Box 808
Livermore, California 94550

Dear Danny:

I would like to take this opportunity to respond to Dr. Trifunac's letter of January 18 regarding the use of "distance" in strong-motion scaling relationships. He claims that the use of shortest distance between the recording site and the fault rupture surface (used by Campbell, 1981) has a tendency to underestimate peak amplitudes of strong ground motion for small distances. He infers from his Figure 2 that this could be avoided by defining distance as the distance from the recording site to the center of the fault surface. This latter definition is preferred by Dr. Trifunac, since it is not known in advance which part of the fault will contribute most to peak ground motions.

Although we may not know in advance where the peak motions will come from, there is considerable evidence to suggest that closest distance to the fault rupture (R_2) is a more appropriate measure than distance to the center of fault rupture (R_1) for characterizing and predicting the scaling properties of strong-motion parameters. In fact, scaling relationships based on R_1 as they are commonly used will lead to overestimation of peak parameters in some cases. Arguments in support of these statements are as follows:

(1) The use of closest distance to the fault rupture is consistent with the definition of distance in seismic design scenarios. For lack of more detailed information, design earthquakes are <u>always</u> hypothesized to rupture that portion of the causative fault closest to the site and distance is <u>always</u> measured from the closest point of this rupture. This is identical to the definition of distance used to develop the scaling relationship of Campbell (1981). The degree to which this distance is inappropriate in both past and future earthquakes is reflected adequately in the uncertainty associated with the prediction (the standard error of estimate) and may be properly accounted for by using a prediction based on a percentile greater than 50 percent (the median).

(2) With the realization that the portion of the fault responsible for the peak motion at a recording site is most likely closer than the center of rupture, taken with the way design earthquakes are hypothesized, the use of distance to the center of fault rupture will result in overestimation of strong-motion parameters in situations where the fault rupture is adjacent to the site. There are many fault rupture configurations where the fault can rupture adjacent to the site. For all but one of these configurations, the center of the fault rupture will not be associated with the

TERA CORPORATION
2150 SHATTUCK AVENUE BERKELEY, CALIFORNIA 94704 415·845·5200 TELEX: 338592

closest portion of the rupture. In fact, for very large events, the center of rupture could be tens of kilometers further away than the closest point. The inevitable assumption for design purposes that the closest approach of the fault zone represents the center of rupture characterizes only one extremely rare rupture configuration. Coupled with the realization that distances to the center of rupture used in the development of the scaling relationships would be based on a random selection of such rupture scenarios, this inevitably leads to the overestimation of predicted values for typical design scenarios. To properly account for this discrepancy, distance should more appropriately be taken as the average distance to the center of all possible rupture configurations that lead to rupture adjacent to the site.

(3) The analysis of peak acceleration has shown that distances measured to single fixed points on the fault rupture surface are statistically inferior to those measured to the closest point on the fault. In the case of the 1979 Imperial Valley earthquake, distance scaling relationships based on closest distance to the rupture were found to have substantially lower standard errors than those based on any single fixed point on the fault, including the center of rupture and the epicenter. Multiple regression analyses for the Campbell (1981) dataset have also demonstrated that substantially lower standard errors are obtained when closest distance is used rather than epicentral or hypocentral distance.

(4) Earthquake modeling studies of recent earthquakes indicate that there are multiple patches of rupture (i.e., asperities) on the fault that contribute to strong ground motion and that those patches nearest the recording station tend to dominate the motion at that station. This would tend to favor closest distance to the fault rupture over distance to the center of rupture as the appropriate distance measure to use for scaling purposes.

It must be emphasized that, in order for these arguments to hold, one must use the closest distance to the hypothesized fault rupture when using the relationship of Campbell (1981), or any other relationship based on closest distance, to predict ground motion for either deterministic or probabilistic analyses. The use of epicentral or hypocentral distance with such a relationship in probabilistic analyses will lead to the underestimation of peak amplitudes for a given return period. However, if the proper distance measure is used, then the use of such a relationship can appropriately lead to smaller probabilistic estimates because of the smaller standard error associated with the expression.

In conclusion, Dr. Trifunac's simple argument is not appropriate in light of the known characteristics of strong ground motion and the way in which seismic design scenarios are formulated. Closest distance to the fault rupture surface does represent a realistic and appropriate means of characterizing distance for the development of strong-motion scaling relationships. I hope this discussion clarifies the confusion that developed at the strong-motion panel meeting regarding the appropriate definition of distance. If there are any more questions, please feel free to give me a call.

Sincerely,

Kenneth W. Campbell

KWC:cas

cc: Dave Boore
Leon Reiter
M. D. Trifunac

APPENDIX D

Questionnaire 5

Feedback Questionnaire on Zonation and Seismicity

1. Introduction

This document constitutes the last step in LLNL elicitation process in finalizing the seismic zonation and the seismicity parameters of the Eastern United States (EUS). In the feedback meeting of December 13 and 14, 1983, held in Reston, Virginia, with representatives of the NRC, LLNL and the seismicity panel members, the details of the methodology were presented by LLNL. The Panel was given the opportunity to discuss the generic assumptions made by LLNL and to review the use of the experts' zonation and seismicity data. These discussions resulted in an improved understanding of the experts' data and of the methodology. As a result, several items have been identified as requiring clarification, modification, improvement or simply updating.

First, some minor errors in the interpretation of the experts' inputs and minor errors of interpretation of the questions in questionnaire Q1 (zonation questionnaire) and Q2 (seismicity questionnaire) were identified. For example, a change in the system of indexing regions by LLNL led to confusion and errors in the assignment of the regional self weights. This trivial error, which has little impact on the results, has been corrected. Another example is the way some experts interpreted the extent of the domain of validity of their recurrence relationships, in effect confusing the upper magnitude cutoff with the upper limit of the magnitude range within which their recurrence law is valid. This less trivial problem is discussed in Section 3.1 of this document.

Second, some more fundamental items were identified which require some modifications to improve the methodology. One item is the treatment of the recurrence relationship outside its domain of validity given by the experts. Another issue is the method used to simulate the recurrence models which does not account for correlation between the a's and b's in the linear (or bi-linear) models for the recurrence relationship.

And finally, some theoretical problems of more philosophical nature dealing with the meaning and the interpretation of self weights.

In Sections 2 to 5 of this document, each of these items is discussed with an emphasis on clarification and their consequences on the hazard calculation and uncertainty. These sections introduce the questions posed in Section 6, be it to clarify a point, update or modify a set of data or to elicit your opinion on items not discussed in the previous questionnaires.

2. Zonation Maps

In this part of the feedback elicitation process we are only concerned with the possible updating of the seismic source zone configurations. For this task, we would ask you to critically review your answers to the questionnaire on zonation (Q1) and modify your zonation maps as you see fit. The definition and assumptions necessary to perform this task are the same as the ones of Q1 and for more details you should refer to that document.

A variety of reasons may lead you to consider revising a zonation map, including:

- o You may have some new scientific information which may lead you to a different interpretation from the one derived at the time of answering Q1. This could include minor revisions to the original best estimate zonation map of Q1 as well as revised alternative maps or even entirely new best estimate maps and/or alternative maps.

- o The presentations and discussions which took place at the feedback meeting of December 13 and 14, 1983 may have modified your understanding of the seismicity zonation structure for a given part of the EUS.

- o Your responses to Q1, when interpreted by LLNL, lead to results which you do not consider plausible.

Please note that Tables A1 and A2 are an integral part of the zonation maps, since they are used to generate all the possible maps for the seismicity zonation of the EUS. You are therefore encouraged to critically review your responses in Tables A1 and A2 in Q1. As a reminder, Table A1 gives the level of confidence in the existence of each zone. Therefore, for a zone with level of confidence less than one, there is the possibility that the area of the EUS defined by that zone will be part of another zone. This replacement or "Host" zone is also specified in Table A1.

Table A2 includes your uncertainty in the boundary shape of a zone or a cluster of zones. It includes a list of the zones or cluster of zones which have an alternative boundary shape and your level of confidence associated with each shape.

3. Seismicity Parameters

3.1 Magnitude Recurrence Modeling

As a consequence of the constructive discussion at the feedback meeting, we are making some modifications in the magnitude recurrence modeling which, we believe, will improve the methodology. These modifications involve the treatment of the recurrence relationship at the lower and upper ends of the domain of validity of the linear (bi-linear) model you provided for each zone.

Originally, at the lower magnitudes, if the lower endpoint of validity M_{LB} was equal to M_0, the minimum magnitude, the value of the magnitude recurrence relation at M_0, i.e., the value of $\log_{10} N_{M0}$, was based on the average of

- $\log_{10} \lambda_0$
- $a + b\,M_0 \equiv a + b\,M_{LB}$

given the two separate inputs λ_0, the expected number of earthquakes with magnitudes greater than or equal to M_0, and the coefficients (a,b) of the linear model. If $\log_{10} \lambda_0 < a + b\,M_0$, then λ_0 was not used. In response to the discussion of the feedback meeting, we plan to modify this to use only the linear magnitude recurrence model. Thus, when $M_0 = M_{LB}$ we will not use your inputs about λ_0 but only the magnitude recurrence equation a + bm.

When $M_o < M_{LB}$, we will continue to model the recurrence relationship as we have previously, i.e, at M_o

$$\log_{10} N_{M_o} = \begin{cases} \log_{10} \lambda_o & \text{if } \log_{10} \lambda_o > a + b\, M_{LB} \\ a + b\, M_{LB} & \text{if } \log_{10} \lambda_o < a + b\, M_{LB} \end{cases}$$

and for $M_o < m < M_{LB}$ we model N_m as a quadratic polynomial function of m. The resulting magnitude recurrence models are shown in Figure 3.1.1

A point of possible concern arises when $M_o < M_{LB}$ and

$$\log_{10} \lambda_o < a + b\, M_{LB}.$$

This combination, as can be seen in Figure 3.1.1, suggests that no earthquakes with magnitudes between M_o and M_{LB} are expected to occur.

If this is an unacceptable description of the seismicity for a given zone, it is necessary for you to make some adjustments in your seismicity parameters. Specifically, two possible adjustments might be based on

- o reconsidering the estimates of λ_o
- o reconsidering the values of the coefficients (a,b) and domain (M_{LB}, M_{UB}) of validity of the linear model a + bm.

At the high magnitudes, our initial treatment of the recurrence model was based on the philosophy that your linear model a + bm would not be changed over the domain of validity (M_{LB}, M_{UB}). Thus, the only adjustments in the recurrence model were made for $m > M_{UB}$ when M_U, the upper magnitude cutoff, was greater than M_{UB}. If that occurred, then the model for N_m for $M_{UB} < m < M_U$ is

$$N_m = \alpha\, e^{\beta m}(M_U - m)^2 \tag{3.1}$$

which satisfies the condition that $N_{M_U} = 0$. This adjustment is illustrated in

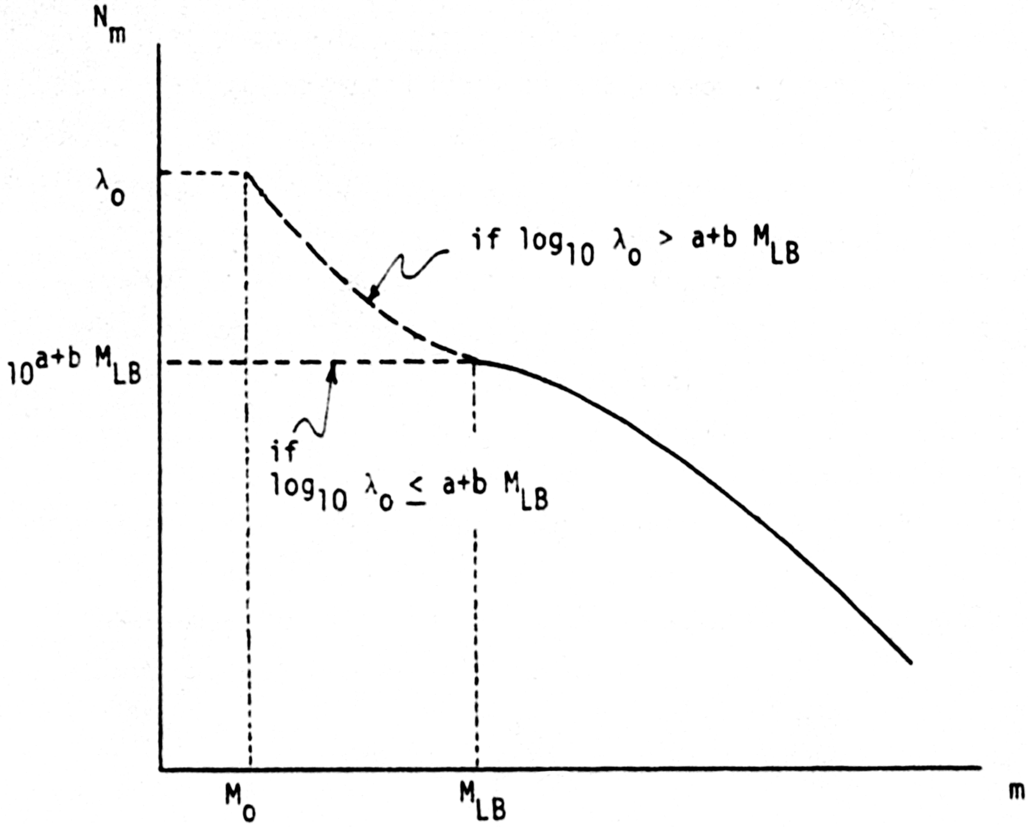


Figure 3.1.1 Magnitude Recurrence Models When $M_o < M_{LB}$

Figure 3.1.2. One consequence of modeling the recurrence relationship in this way is that the expected number of earthquakes in some magnitude interval $(m, m + \Delta)$ may be less than the expected number for a comparable interval at a higher interval $(m', m' + \Delta)$ where $m' > m$. This is illustrated in Table 3.1.1

In this illustration $M_{UB} = 7.5$. If $M_U = 7.75$, then, based on the LLNL method, the expected number of earthquakes with magnitudes between (7.5, 7.75) is 0.00069. On the other hand, the expected number with magnitudes (7.25, 7.5) is less, i.e., 0.00047. If $M_U = 7.5$, the expected number of earthquakes with magnitudes (7.25, 7.5) is .00116, again greater than the expected number .00079 in the preceding interval (7.0, 7.25). The same phenomena will occur if $M_U > M_{UB}$ and the adjustment in Equation (3.1) is used. Figure 3.1.3, although not to scale illustrates how the expected number increases in the last interval (7.25, 7.5) using the LLNL model.

An alternative model, suggested at the feedback meeting and described in [1] and [2], is based on modeling earthquake magnitudes as truncated exponential random variables with range (M_0, M_U). Without going into the mathematical details, the model for the logarithm of the expected number N_m of earthquakes with magnitude greater than or equal to m can be expressed as

$$\log_{10} N_m = \log_{10} N_o + \beta M_o \log_{10} e - \log_{10} \left(1-e^{-\beta(M_U-M_o)}\right) + \log_{10} \left(1-e^{-\beta(M_U-m)}\right)$$

$$-\beta m \log_{10} e \qquad (3.1.2)$$

where N_0 is the expected number of earthquakes with magnitudes greater than or equal to M_0 and β is the parameter of the exponential distribution. This

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[1] Weichert, D. H., Estimation of the Earthquake Recurrence Parameters for Unequal Observation Periods for Different Magnitudes, Bulletin of the Seismological Society of America, Vol. 70, No. 4, pp 1337-47, Aug. 1980.

[2] Cornell, C. A., Engineering Seismic Risk Analyses, Bulletin of the Seismological Society of America, Vol. 58, No. 5, pp 1583-1606, Oct. 1968.

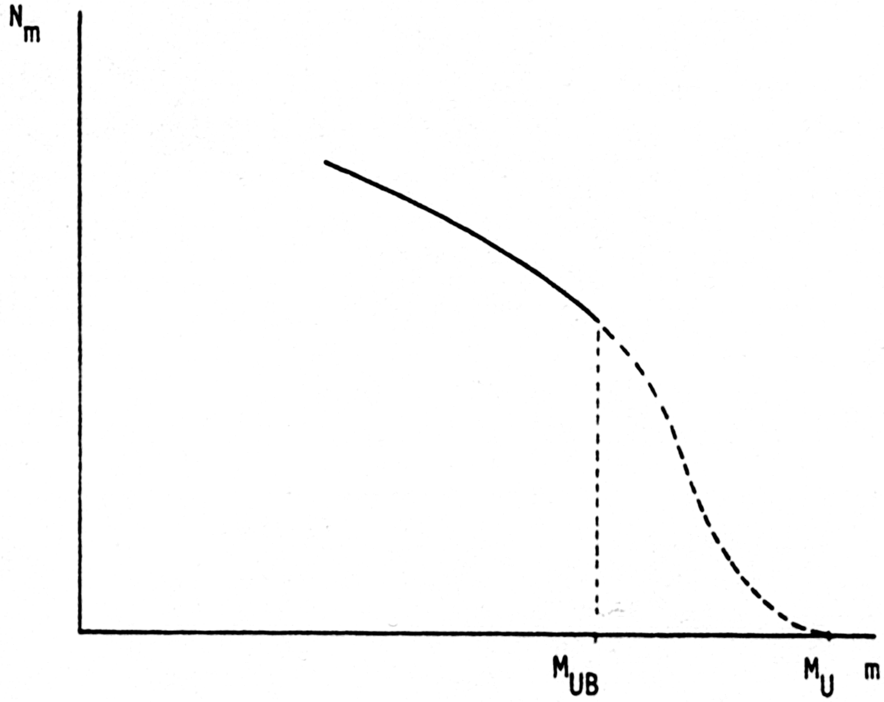


Figure 3.1.2 Adjustment in Recurrence Model When $M_U > M_{UB}$

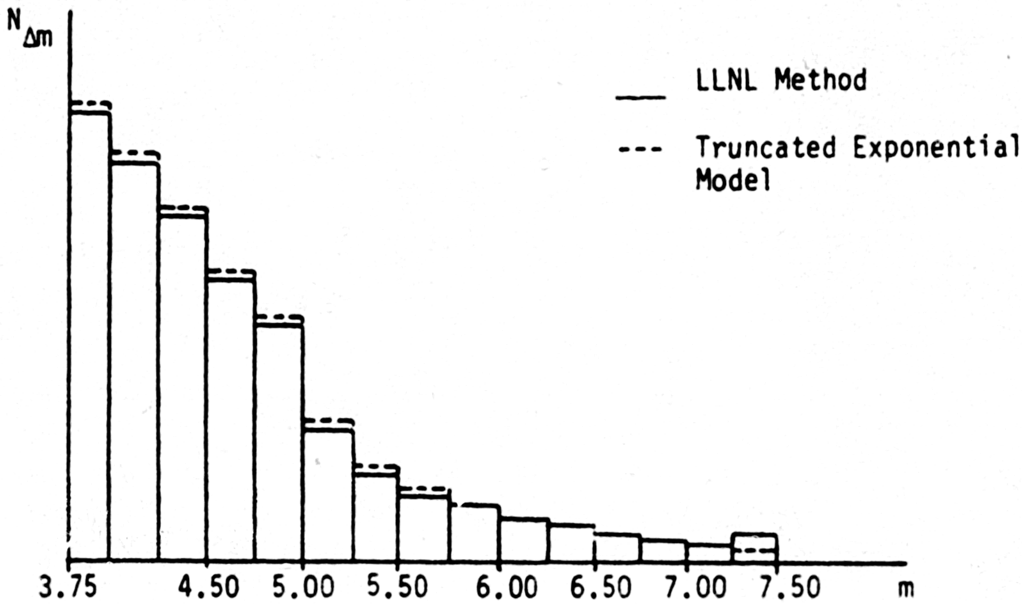


Figure 3.1.3 Estimates of the Expected Number of Earthquakes With Magnitudes in a Subinterval (Δm = .25) (Not to Scale)

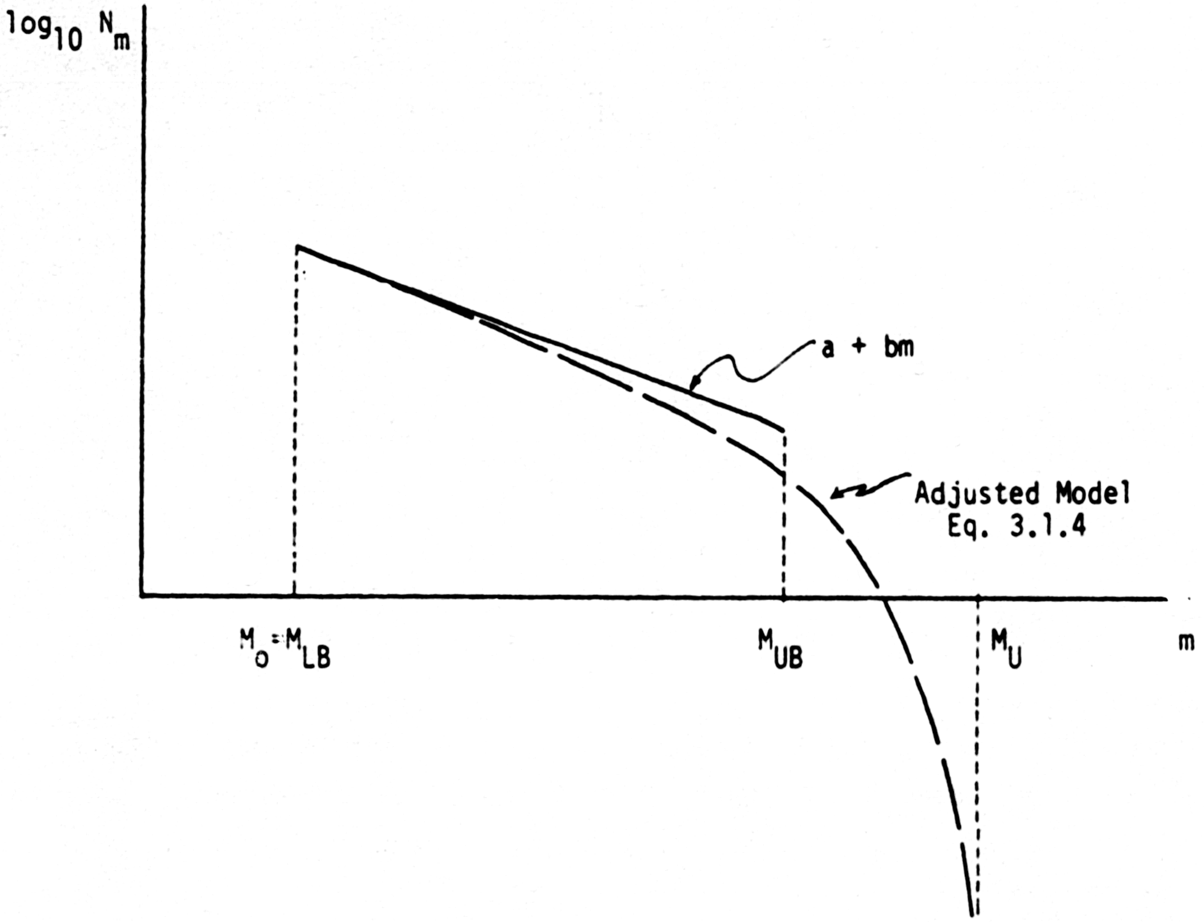


Figure 3.1.4 Truncated Exponential Model

relationship can be treated as an adjusted linear model by equating the linear model with Equation (3.1.2) at a point. Choosing that point to be $m = M_0$ gives

$$(3.1.3) \qquad a + b\,M_0 = \log_{10} N_0$$

Thus, Equation (3.1.2) can be rewritten in the form

$$\log_{10} N_M = a + b\,m + \log_{10}\left(1 - e^{-\beta(M_U - m)}\right) - \log_{10}\left(\left(1 - e^{-\beta(M_U - M_0)}\right)\right) \qquad (3.1.4)$$

where now $\beta = -b \log_{10}^{-1} e$. The adjusted model is shown in Figure 3.1.4.

One advantage of this model is that the expected number of earthquakes in a magnitude interval will be monotone decreasing, as illustrated in Table 3.1.1 and Figure 3.1.3. However, it does adjust, slightly, the linear model a + bm in the domain of validity M_{LB}, M_{UB}. As you can see for the example in Table 3.1.1, the expected number $N_{\Delta m}$ in an interval of low magnitudes increases slightly under this model. For example, for the magnitude interval (4.25, 4.50), based on the linear model (LLNL model), the expected number is .23536, whereas for the revised model (truncated exponential model) the expected number is .23547.

Although we have described this alternative assuming $M_0 = M_{LB}$, if you choose to have us use the truncated exponential model we will make an adjustment if $M_0 < M_{LB}$. In that case, because of the adjustment we make for $M_0 < m < M_{LB}$, we will use the truncated exponential model for $m > M_{LB}$.

In summary, we propose to have you select between these two alternative ways of modeling the magnitude recurrence relationships:

A. <u>LLNL Model</u>

<u>Case 1</u>: $M_0 = M_{LB}$ and $M_{UB} = M_{UU}$, i.e., the linear (piecewise linear) model is applicable for all m and upper magnitude cutoffs M_U. Use the linear model a + bm without adjustment.

TABLE 3.1.1

Estimates of the Expected Number of Earthquakes Based
on a Linear Model with a = 3.59, b = -0.9, M_{LB} = 3.75, M_{UB} = 7.5

	LLNL Model		Truncated Exponential Model	
M	N_m	$N_{\Delta m}$	N_m	$N_{\Delta m}$
3.75	1.64059		1.64059	
4.00	.97724	.66335	.97696	.66363
4.25	.58210	.39514	.51866	.39530
4.50	.34674	.23536	.34619	.23547
4.75	.20654	.14020	.20594	.14025
5.00	.12303	.08351	.12239	.08355
5.25	.07328	.04975	.07262	.04977
5.50	.04365	.02963	.04298	.02964
5.75	.02600	.01763	.02532	.01766
6.00	.01549	.01051	.01480	.01052
6.25	.00923	.00626	.00854	.00626
6.50	.00550	.00373	.00481	.00373
6.75	.00327	.00223	.00258	.00223
7.00	.00195	.00132	.00126	.00132
7.25	.00116	.00079	.00047	.00079
7.50	.00069	.00047		.00047
7.75		.00069		

Case 2: $M_o < M_{LB}$ or $M_{UB} < M_{UU}$, i.e., the linear model is applicable for $M_{LB} < m < M_{UB}$.

- o If $M_o < M_{LB}$, set $N_{M_o} = \lambda_o$ and model N_m as a quadratic polynomial in m for $M_o < m < M_{LB}^o$

- o For $M_{LB} < m < M_{LB}$, use the linear model a + bm

- o If $M_{UB} < M_{UU}$, for any $M_U > M_{UB}$, model N_m by

$$N_m = \alpha e^{\beta m}(m - M_U)^2$$

for $M_{UB} < m < M_U$.

B. Truncated Exponential Model

Case 1: $M_o = M_{LB}$
Use the adjusted model, Equation 3.1.4, for all $M_o < m < M_U$.

Case 2: $M_o < M_{LB}$

- o Set $N_{M_o} = \lambda_o$ and model N_M as a quadratic polynomial in m for $M_o < m < M_{LB}$.

- o Use the adjusted model, Equation 3.1.4, for all $M_{LB} < m < M_U$.

3.2 (a, b) Relationship and Uncertainty

Two issues, identified at the feedback meeting, relative to the estimates of the coefficients in the recurrence model which should be addressed in the final phase of the elicitation process are:

- o The ranges of uncertainty in (a, b) and their effects on the range of uncertainty in N_M, the expected number of earthquakes with magnitude greater than or equal to m.

o How LLNL treats your uncertainty in (a, b), specifically the fact that the estimates are treated as if they are independent.

With regard to the first issue, this may not be a problem. However, we feel it is appropriate to make you aware of the implications of uncertainties in a and b. Specifically, we want to make sure that you are cognizant of how changes in a and b translate into variations in N_M, the expected number of earthquakes. To illustrate the effect of uncertainty in (a, b) assume a linear recurrence model,

$$\log_{10} N_m = a + bm$$

and

$$N_m = 10^a \, 10^{bm}$$

For simplicity, assume further that the uncertainty bounds are symmetric, i.e., $(a_L, a_U) = \hat{a} \pm \Delta a$ and $(b_L, b_U) = \hat{b} \pm \Delta b$. The range of uncertainty in N_m at any m can be represented by $(\frac{1}{f} N_m^0, f N_m^0)$ where

$$N_m^0 = 10^{\hat{a} + \hat{b}m}$$

is the best estimate and

$$f = 10^{\Delta a + \Delta bm}$$

is the factor of uncertainty, which varies with m. For example, if Δa = 1.2 and Δb = 0.2,

$$f(m = 3.75) = 89$$
$$f(m = 6.25) = 282$$

That is, the uncertainty in N_m ranges from a factor of 89 to 282 over the range of magnitude (3.75, 6.25).

If you have not considered the effect of the uncertainty in (a, b) on uncertainty in N_m in your response to Q2 we would encourage you to consider it as you review your estimates of seismicity and your uncertainty in these estimates as represented by the bounds, (a_L, a_U) and (b_L, b_U).

With regard to the treatment of your best estimates of a, b and your uncertainty about these coefficients in the magnitude recurrence model, up to now we have treated your level of knowledge about these coefficients as independent. We would like to offer two additional approaches to handle the joint uncertainty in estimating a and b which introduce correlation between these estimates. To do this, consider the following interpretation of how the uncertainty analysis is handled when your estimates of a and b are treated as independent.

Given your best estimates $\hat{a}$, $\hat{b}$ and bounds (a_L, a_U) and (b_L, b_U) the uncertainty analysis is based on treating the coefficients a, b as random variables with probability distributions based on the best estimates and bounds. Treating a, b as well as other inputs, e.g. M_U, maps, as random produces a probability distribution on the hazard which describes the corresponding uncertainty in the hazard due to your uncertainty in the zonation and seismicity. Let $F(a; \hat{a}, a_L, a_U)$ and $G(b; \hat{b}, b_L, b_U)$ denote the probability distributions for the intercept and slope respectively. Another distribution we can consider is the distribution of b given a value, say a_0, for a. Let $G(b|a_0)$ denote this distribution. This distribution would represent your level of knowledge about b corresponding to an intercept a_0. Since your estimate of the most likely value of b or uncertainty about b could change for each a_0, this conditional distribution could change with a_0. However, treating a and b as independent means that $G(b|a_0)$ is the same for all a_0 and

$$G(b|a_0) = G(b; \hat{b}, b_L, b_U)$$

Stated yet another way, independence of a and b is saying that your best estimate of b and uncertainty in b is the same for all values of the intercept. Graphically the relationship between a and b when, they are treated independently, is described by the set of possible magnitude recurrence models for different intercepts, as shown in Figure 3.2.1 for two values of a, a_U and a_0. Notice that the upper bound (best estimate, lower bound) models are parallel for all values of a.

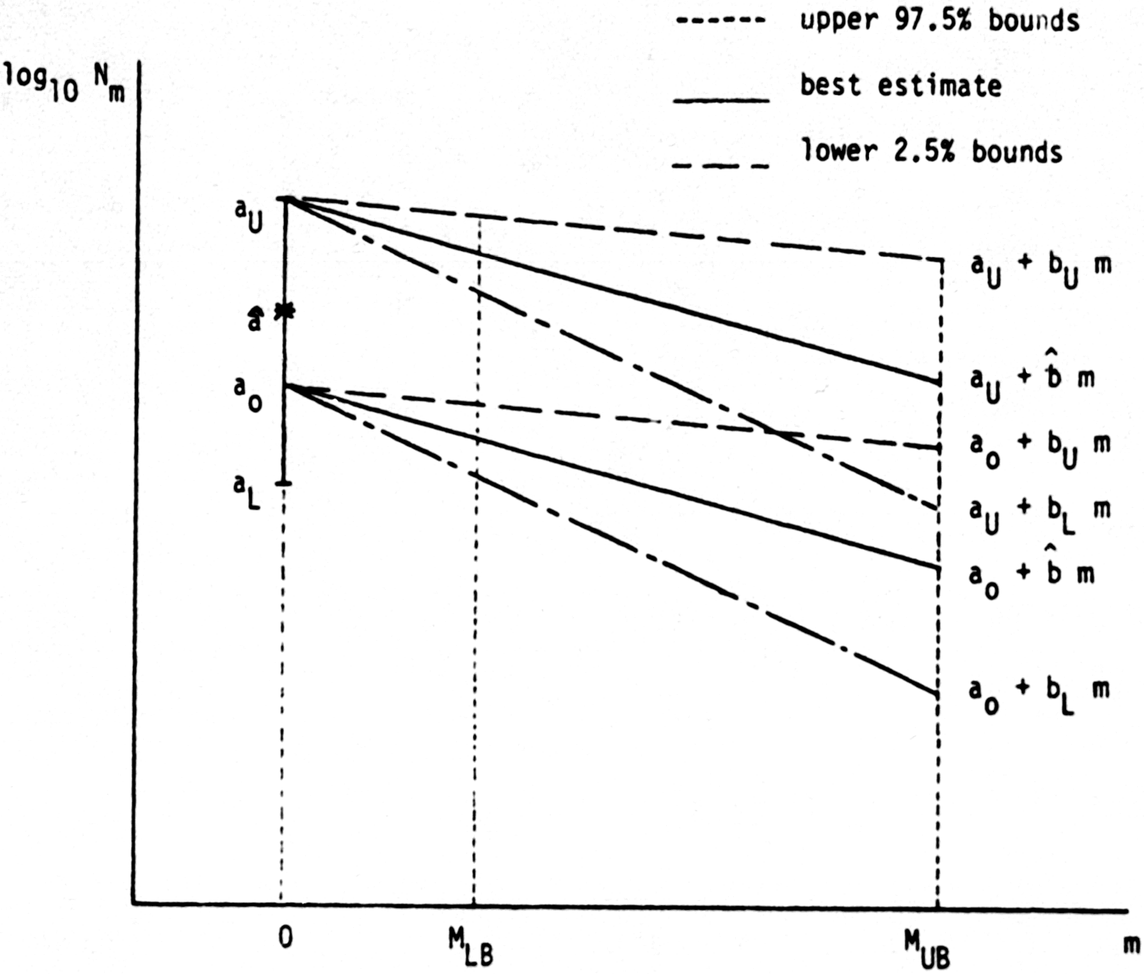


Figure 3.2.1 Range of Recurrence Models, Given a_U and a_o, When Estimates of a and b are Treated as Independent.

Some of you felt that independence of a and b is not the best model, however, it is difficult to assess the relationship (correlation) between these coefficients. Thus, we would like to offer two alternatives which impose some correlation but which use only the best estimates and bounds you already provided. Neither alternative requires additional inputs. We recognize that none of the alternatives are ideal. Also, the last alternative is very special and will only be an alternative for some of you. However, we will ask you to choose one of the approaches as the method for handling your estimates of the coefficients a, b. Note that in the two alternatives presented below (alternatives 2 and 3), the variation in the recurrence law is less than when a and b are independent (alternative 1), since the range of equations used in alternatives 2 and 3 is a subset of the range used in alternative 1.

Three ways of handling the relationship between your estimates of the coefficients a, b are:

1. <u>(a, b) are independent</u>

This method has been described in the introductory paragraphs. It assumes that the uncertainty distribution for b, <u>given a,</u> is the same for all a. Thus, the correlation between a and b is zero.

2. <u>(a, b) are "partially" negatively correlated</u>

This method is based on interpreting the model

$$\log_{10} N_m = \hat{a} + \hat{b}m$$

derived from your best estimates $\hat{a}$, $\hat{b}$ as representing your best estimate of $\log_{10} N_{M_{UB}}$ at the upper bound of the domain of validity of the model.

With this "interpretation" of your inputs, consider the following models for your estimates of a and b. As for the independence case, $F(a;\ \hat{a},\ a_L,\ a_U)$ is the uncertainty distribution for the intercept. However, instead of using the same distribution of b for all a, we use a conditional distribution

$$G(b|a_0;\ \hat{b}_{a_0},\ b_L,\ b_U)$$

which is based on the most likely value of b, denoted $\hat{b}_{a_o}$, as that value of the slope of the straight line which connects the points a_o and $\hat{a} + \hat{b}\, M_{UB}$, i.e.

$$\hat{b}_{a_o} = \frac{\hat{a} + \hat{b}\, M_{UB} - a_o}{M_{UB}}$$

Bounds for b, given a_o, continue to be the bounds you provide. Thus, we assume the most likely value of b changes for different values of a but your level of knowledge, as described by the uncertainty bounds (b_L, b_U) remain the same for all a. Graphically, the relationship between a and b is shown in Figure 3.2.2a. The equation used for a given a_o is represented by the intermittent long-small dashed line (—— – ——) in Fig. 3.2.2a. The change here from the previous case, i.e. a, b independent, is that the most likely recurrence model changes for each value of a. It should be noted that, dependency on $\hat{a}$, $\hat{b}$, (b_L, b_U,) and (a_L, a_U), occassionally produces

$$\hat{b}_{a_o} < b_L \quad \text{or} \quad \hat{b}_{a_o} > b_U$$

as shown in Fig. 3.2.2b and c. In this case, we impose the restrictions $b_{a_o} = b_L$ or $\hat{b}_{a_o} = b_U$ respectively.

An obvious question is "how much correlation does this procedure impose on a, b?". It will depend on the inputs, however, we have estimated the correlation using your response to Questionnaire 2. We find the correlation to range from close to -0.5 to close to -0.02. On the average, the correlation was about -0.22. Some specific illustrations are given in Table 3.2.1.

To summarize, the difference between treating a, b as independent and this case is, whereas in the former the most likely value of b is $\hat{b}$ your best estimate, the same for all a_o, in this case, the most likely value of b is $\hat{b}_{a_o}$ which changes with a_o. The bounds (b_L, b_U) remain the same in both cases. Thus with respect to your uncertainty in b, given a_o, this method implies that the range (b_L, b_U) remains the same for all a_o but the "peak"

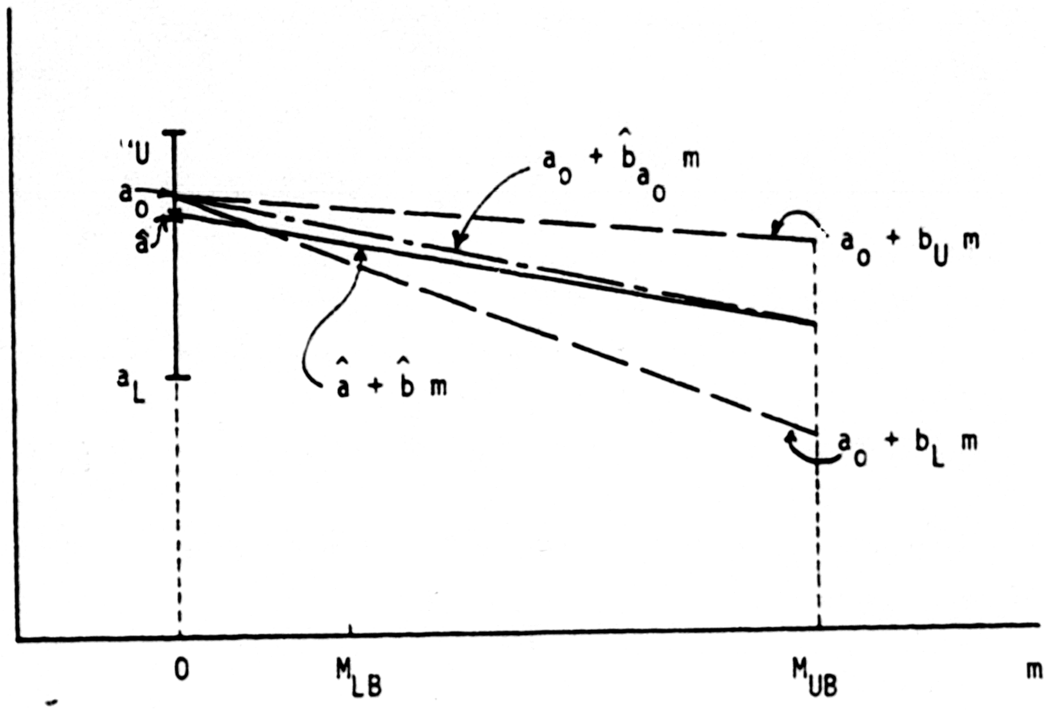


Figure 3.2.2a Bounding and Most Likely Recurrence Models When a and b are Treated as "Partially" Correlated

Fig. 3.2.2b

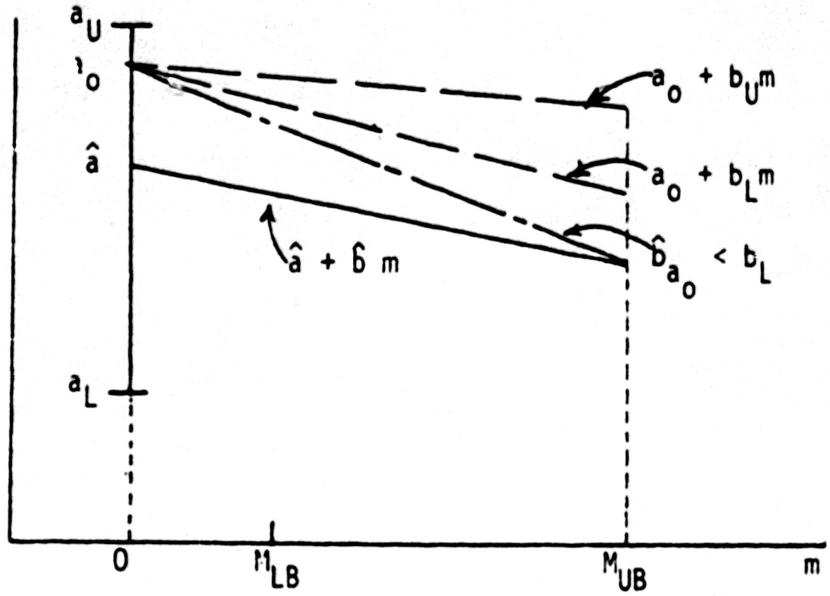


Fig. 3.2.2c

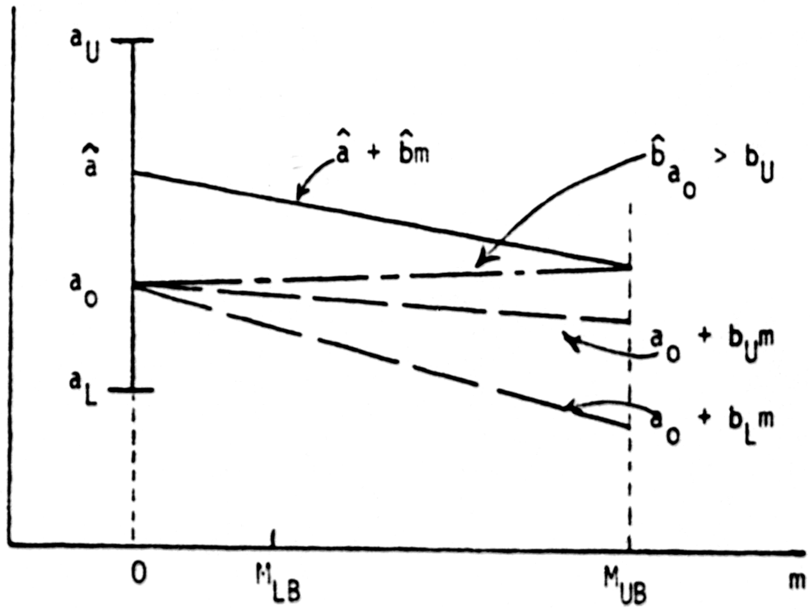


Figure 3.2.2 (Continued)

TABLE 3.2.1

Some Illustrations of Correlations Imposed by Treating a, b as "Partially" Correlated

$(\hat{a}, \hat{b})$	(a_L, a_U)	(b_L, b_U)	M_{UB}	Correlation
2.434, -.906	2.344, 2.584	-1.170, -.906	4.5	-.037
1.5, -.59	1.4, 2.5	-.85, -.50	6.75	-.186
3.00, -.69	2.71, 3.26	-.74, -.64	8.7	-.245
4.167, -1.06	2.947, 5.387	-1.226, -.901	6.0	-.375
5.786, -1.40	4.786, 6.786	-1.50 -1.35	6.0	-.499

(region of the most probable value of the slope) of the uncertainty distribution changes with a_0.

3. <u>(a, b) are "highly" negatively correlated</u>

Alternative 2 introduced correlation in the estimates of (a, b) by making the most likely value of b depend on a but keeping the variation (b_L, b_U) the same for all a. Ideally, it seems like the most appropriate method would vary the range of b as well as the most likely value. This does not seem to be feasible given the information we derived from your response to Q2. To provide an alternative which introduces more correlation than alternative 2, we propose an alternative which reduces the variation in b, given a_0, to zero. That is, for each a_0 there is a unique value of b. The implication of this procedure is that the estimates of (a, b) are "highly" negatively correlated, in fact, the correlation is -1.0.

For this alternative the unique value of b, given a_0 is derived as follows:

- o Given $\hat{a}$, (a_L, a_U), $\hat{b}$, (b_L, b_U) , there exists some $m^* > 0$ such that

$$a_U + b_L m^* = a_L + b_U m^*$$

which is,

$$m^* = \frac{a_U - a_L}{b_U - b_L}$$

- o Given any a_0, the value of b_{a_0} is the slope of the line which connects a_0 to the point of intersection at m^*, i.e.

$$b_{a_0} = - \frac{(a_0 - a_L) - b_U m^*}{m^*}$$

It should be recognized that this procedure is only applicable if the best estimate model $\hat{a} + \hat{b}m$ also passes through the point of intersection at m^*. This will be guaranteed if the bounds (a_L, a_U) and (b_L, b_U) are symmetric about $\hat{a}$ and $\hat{b}$ respectively.

The basic concept of this alternative is that there is a unique slope for each intercept. Stated differently, the implication is that the uncertainty in the conditional value of b, given the intercept, is zero. Viewing this alternative from the standpoint of knowledge about log N_m, it suggests that one is most knowledgeable at certain values of magnitude. For example, consider the three cases illustrated in Figures 3.2.3a, b, c. In Figure 3.2.3a, clearly the implication is that the uncertainty in $\log_{10} N_m$ is less at M_{UB} than it is for M_{LB}. In Figure 3.2.3c the opposite is true. If m* lies between M_{LB} and M_{UB}, the implication is that the uncertainty is minimum for magnitudes between M_{LB} and M_{UB}.

3.3 Complementary Zone (CZ)

The purpose of this section is to help you in evaluating the parameters of the CZ. No action is requested from you. The seismicity parameters of the CZ determined from your answers to Questionnaire 2 exhibit a large amount of variation in the a and b values, as well as in the upper magnitude cutoffs. The following is an enumeration of some possible reasons for this fact:

- The surface areas of the CZ can be very different from one expert to the other.

- One expert may have constrained every seismogenic area to be part of a specific zone other than the CZ. In this case, the CZ clearly could have a low seismicity.

- Another expert may not have constrained all seismogenic areas to be part of a specific zone other than the CZ. This could be the case when the uncertainty on the location and seismicity parameters of some seismogenic areas is too large to warrant defining a specific seismic zone. In this case, some seismicity is allowed to "float" within the CZ, thereby leading to higher seismicity parameters for the CZ.

- There may have been some misunderstandings on the part of the experts as to the exact size, shape and location of the CZ.

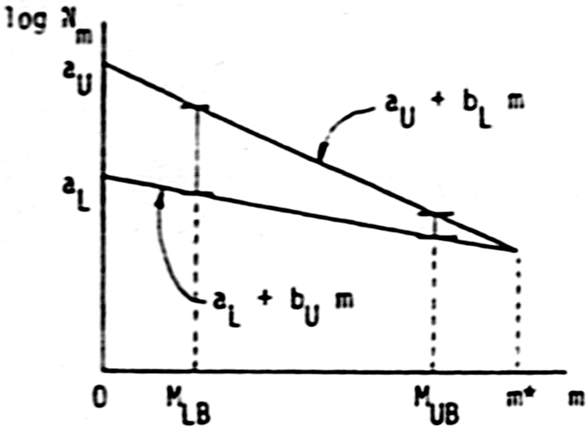


Figure 3.2.3a

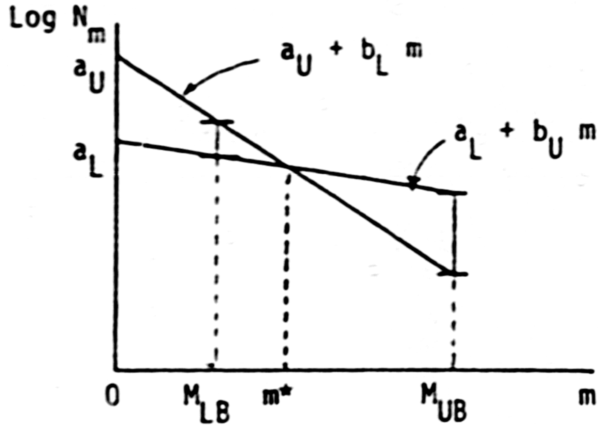


Figure 3.2.3b

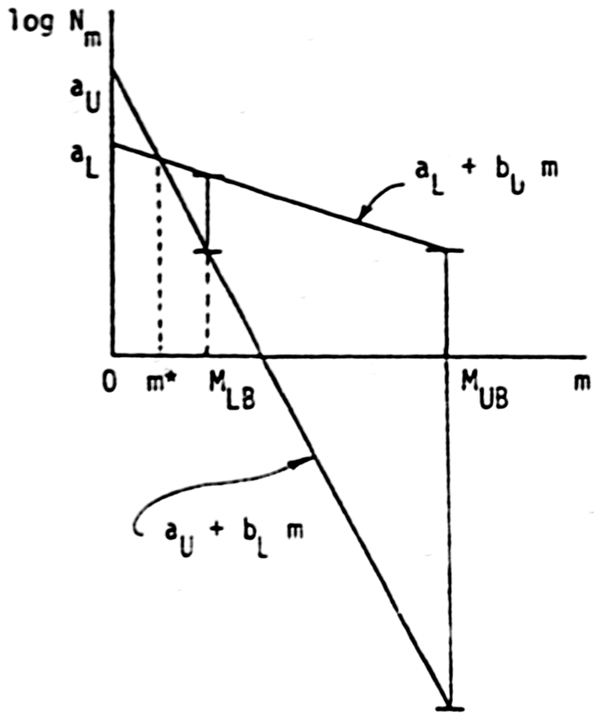


Figure 3.2.3c

Figure 3.2.3 Uncertainty Bounds for $\log_{10} N_m$ at M_{LB} and M_{UB} for Various m*

- o The experts may have lacked some knowledge as to the consequences of the choice of parameters of the CZ on the final hazard at the site.

- o And finally, as is the case for Expert 4 (see Table 3.3.1), the expert did not provide the seismicity parameters for the CZ, but only for a portion of it. In this case, LLNL extended these properties to the overall CZ.

In order to help you in defining the geographical boundaries of the CZ, a set of maps is provided in Figs. 3.3.1 through 3.3.11. In these maps the CZ is represented by the shaded area. In the case of Expert 4, zone 13 is shaded in one way and the zone identified as the CZ is shaded in a different way, but the actual CZ is the union of both these zones.

The seismicity parameters of the CZ's are presented for comparison in Table 3.3.1. One has to be careful in interpreting the values in Table 3.3.1 and translating them directly into a comparison in hazard values, as the characteristics of the CZ can be very different for the reasons mentioned above. Table 3.3.1 shows the map index of the CZ, the surface area as well as the a and b values, the upper magnitude cutoff, the number of earthquakes greater than magnitude 3.75 per year and unit of area for each expert.

The best estimate recurrence relationships are plotted in Fig. 3.3.12 from $m = 3.75$ to the upper magnitude cutoff M_U. These curves are expressed per unit area (10^6 km^2) and for 1 year. They can be used directly to make inferences on the relative hazard at sites located inside the CZ. For example, the CZ of Expert 10 has the highest density of earthquakes per unit area but has a relatively low magnitude cutoff (M_U), therefore one can infer that the hazard at low PGA will be the highest (for a site inside the CZ), but the hazard will decrease faster than for zones with higher magnitude cutoffs. On the other hand, a CZ with relatively low a and high M_U, such as in the case of Expert 2, will lead to relatively low hazard at low PGA values and relatively high values of the hazard at high PGA, thereby increasing the positive concavity of the hazard curve.

TABLE 3.3.1
AREA OF THE COMPLEMENTARY ZONE FOR EACH EXPERT

Expert Number	I.D. of Zone on maps	Area ($10^6 km^2$)	a	a per $10^6 km^2$	b Value	$N(M_o)/10^6 km^2$ for $m=m_o=3.75$	M_U
1	15	1.656	5.614	5.395	-1.48	.700	5.8
2	CZ	7.661	3.500	2.616	-1.00	.074	7.3
3	1	7.406	4.549	3.679	-1.10	.360	6.5
4(*)	CZ+13	5.785	2.590 & 2.150	1.962	-.90	.039	5.5
5	CZ	6.503	4.170	3.357	-.92	.810	(+)5.75
6	1	7.840	4.196	3.302	-1.04	.250	6.0
7	2	5.380	4.000	3.269	-.90	.780	6.7
10	19	7.904	4.890	3.992	-1.00	1.750	5.5
11	0/CZ	6.513	4.250	3.436	-.90	1.150	5.8
12	1	2.913	5.311	4.847	-1.28	1.110	5.0
13	CZ	9.310	4.600	3.631	-1.09	.350	6.3

Notes: (*) The entire complementary zone for Expert 4 is made of zone #13 and the zone named CZ on the map of Fig. 3.3.4. The areas are: 1.532 for zone 13 and 4.253 for the zone called CZ. The total is 5.785 as shown in this table for Expert 4. These two zones have the same seismicity parameters per unit of area.

(+) Expert 5 gave an upper MMI cutoff of 8 which is used in the relation MMI = 2m - 3.5 specified by the expert to obtain M_U = 5.75

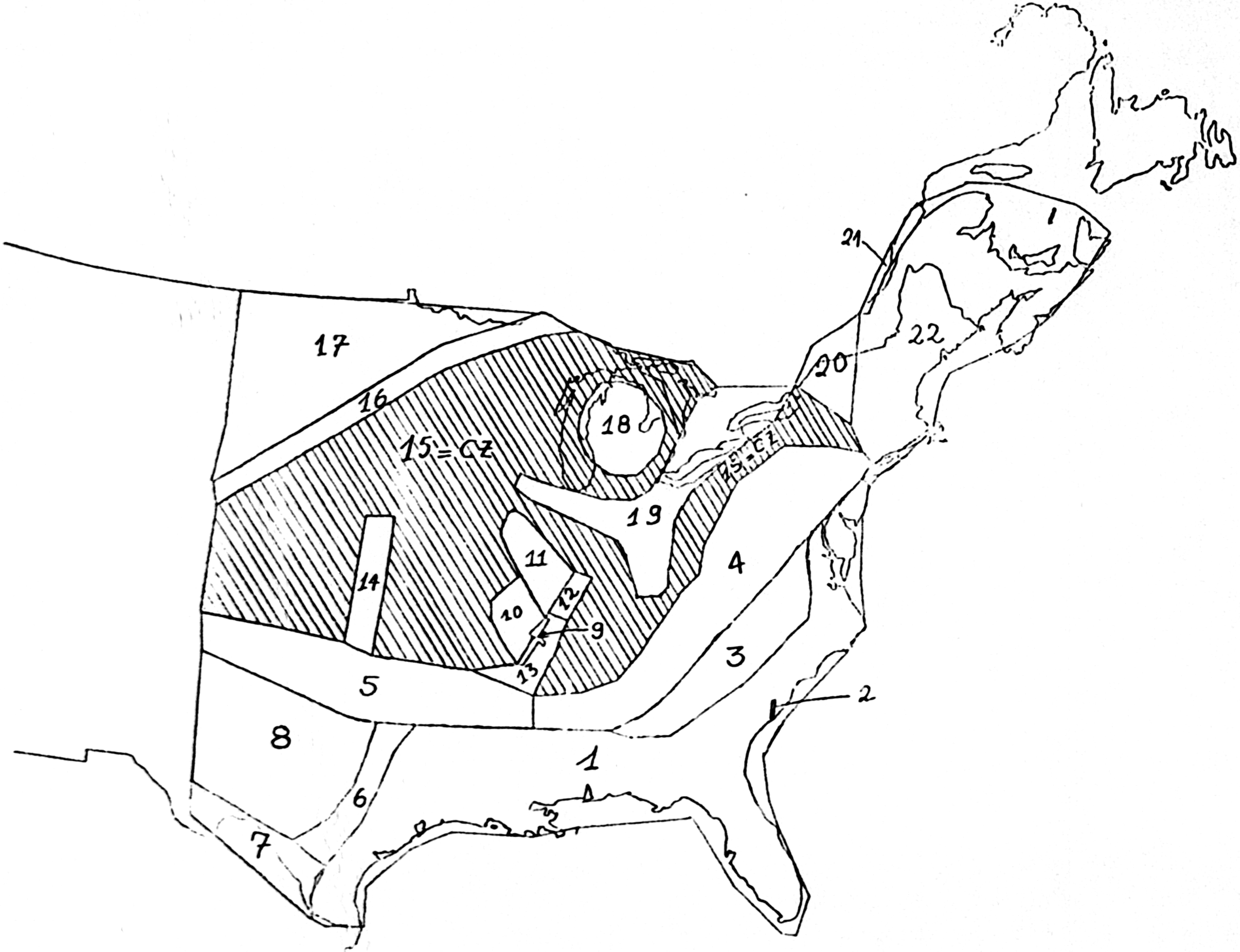


Figure 3.3.1 Seismic Zonation Base Map for Expert 1

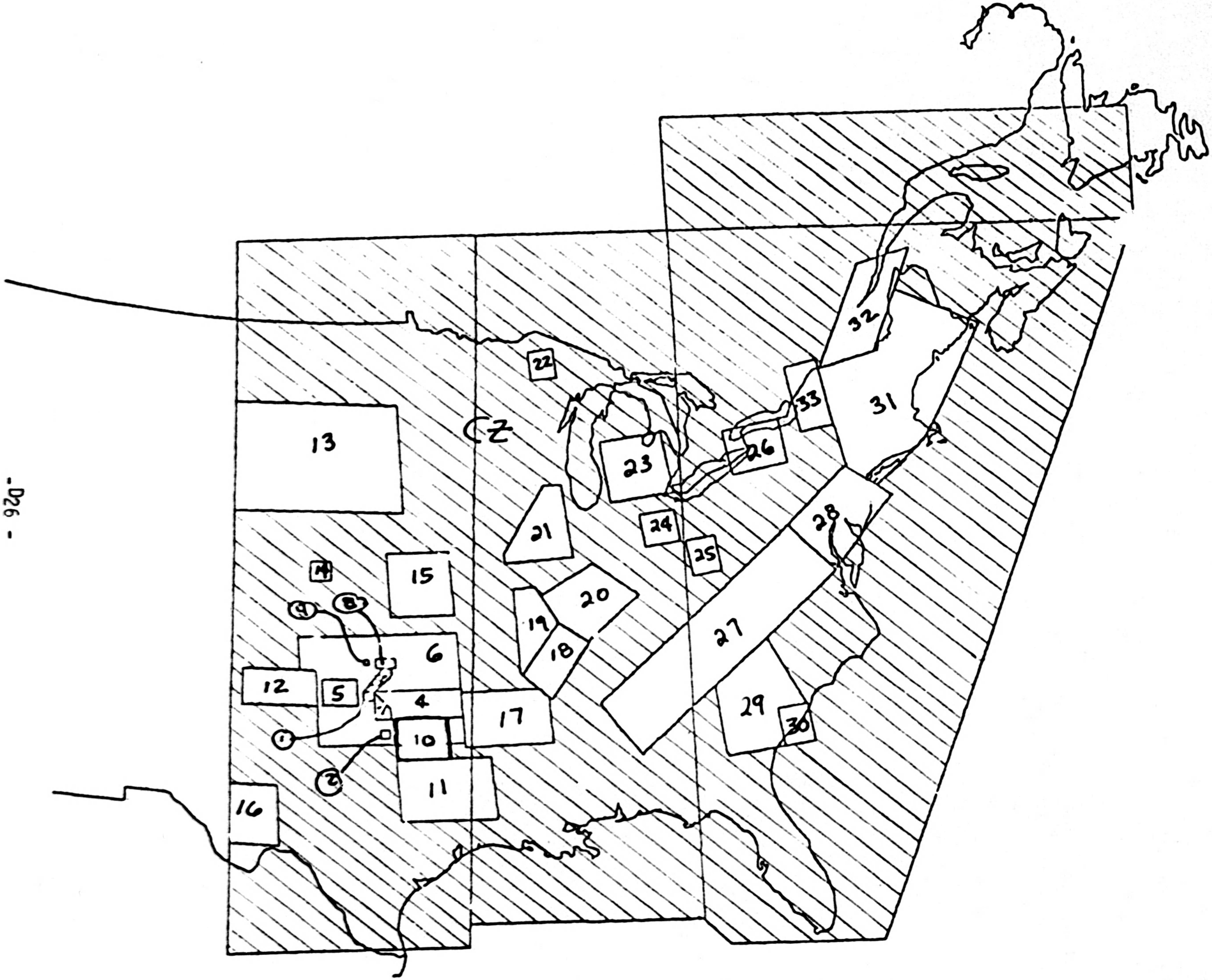


Figure 3.3.2 Seismic Zonation Base Map for Expert 2

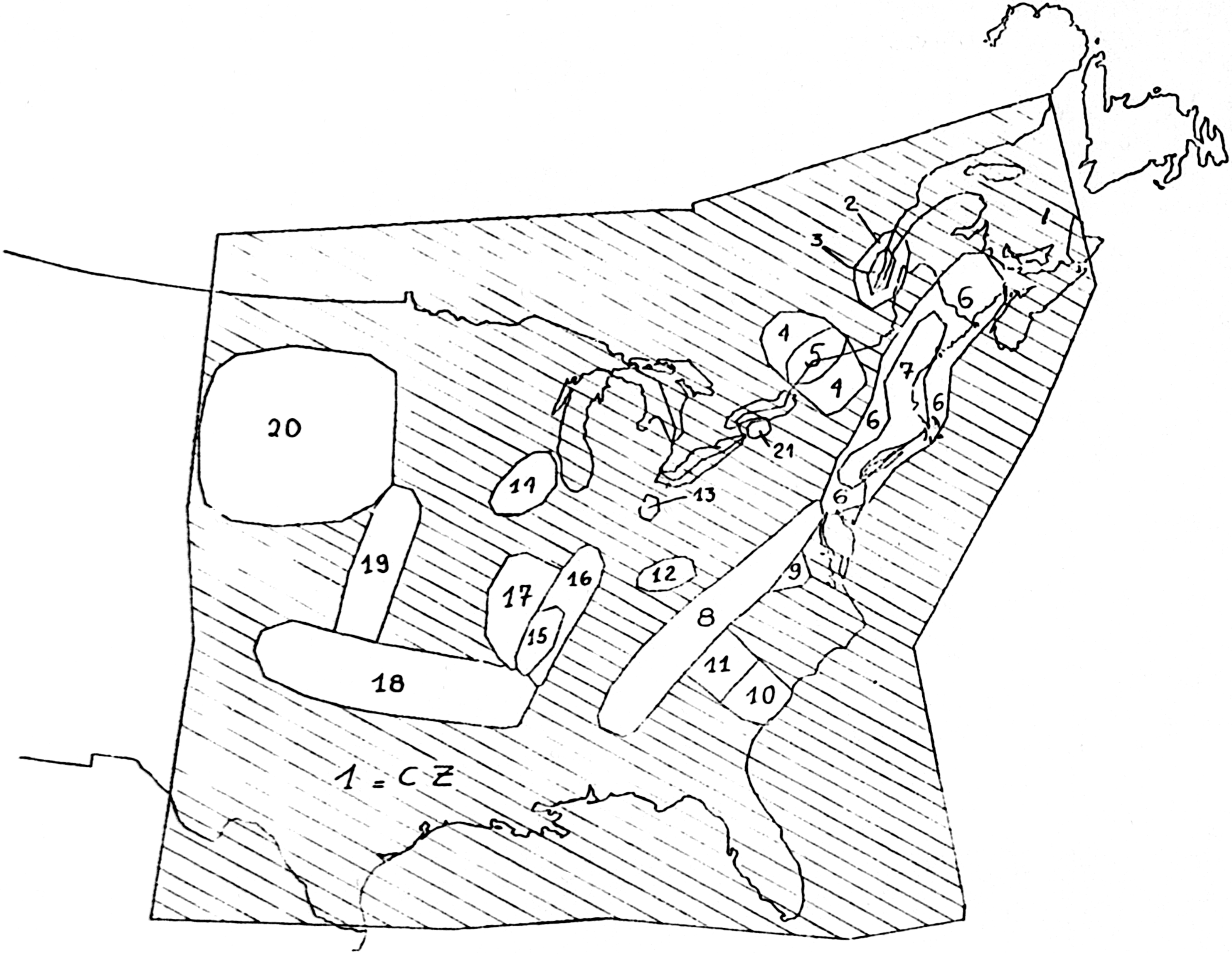


Figure 3.3.3 Seismic Zonation Base Map for Expert 3

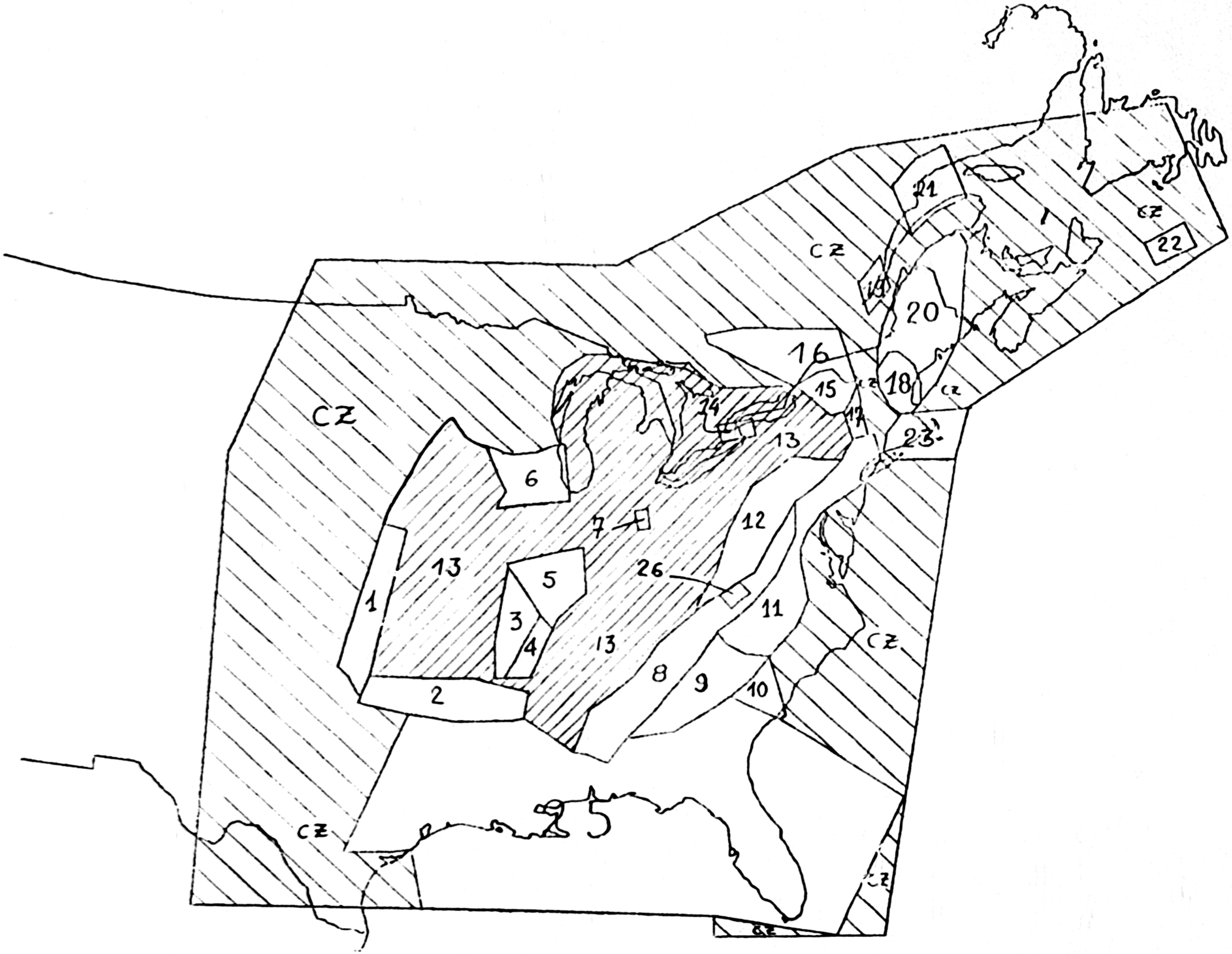


Figure 3.3.4 Seismic Zonation Base Map for Expert 4

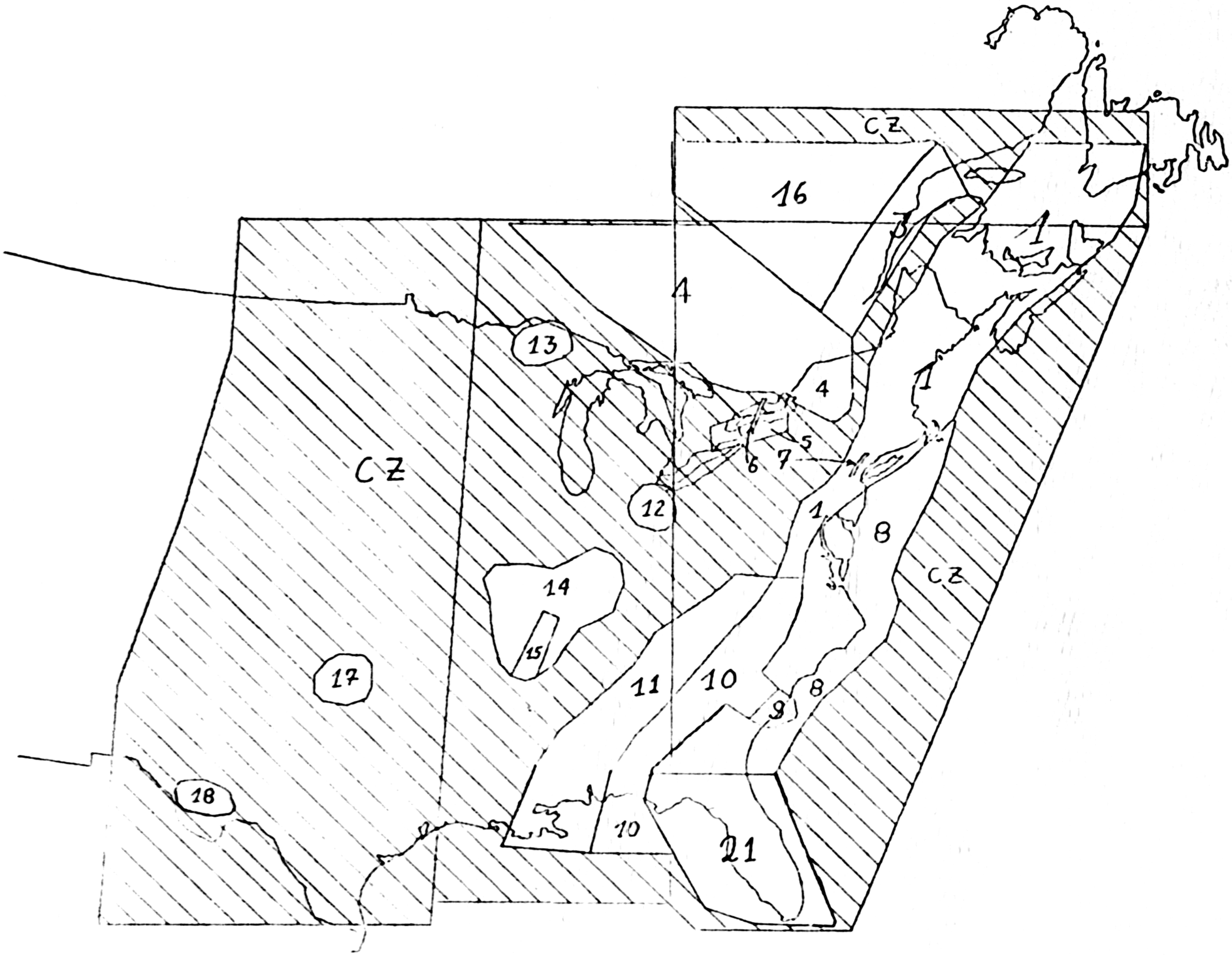


Figure 3.3.5 Seismic Zonation Base Map for Expert 5

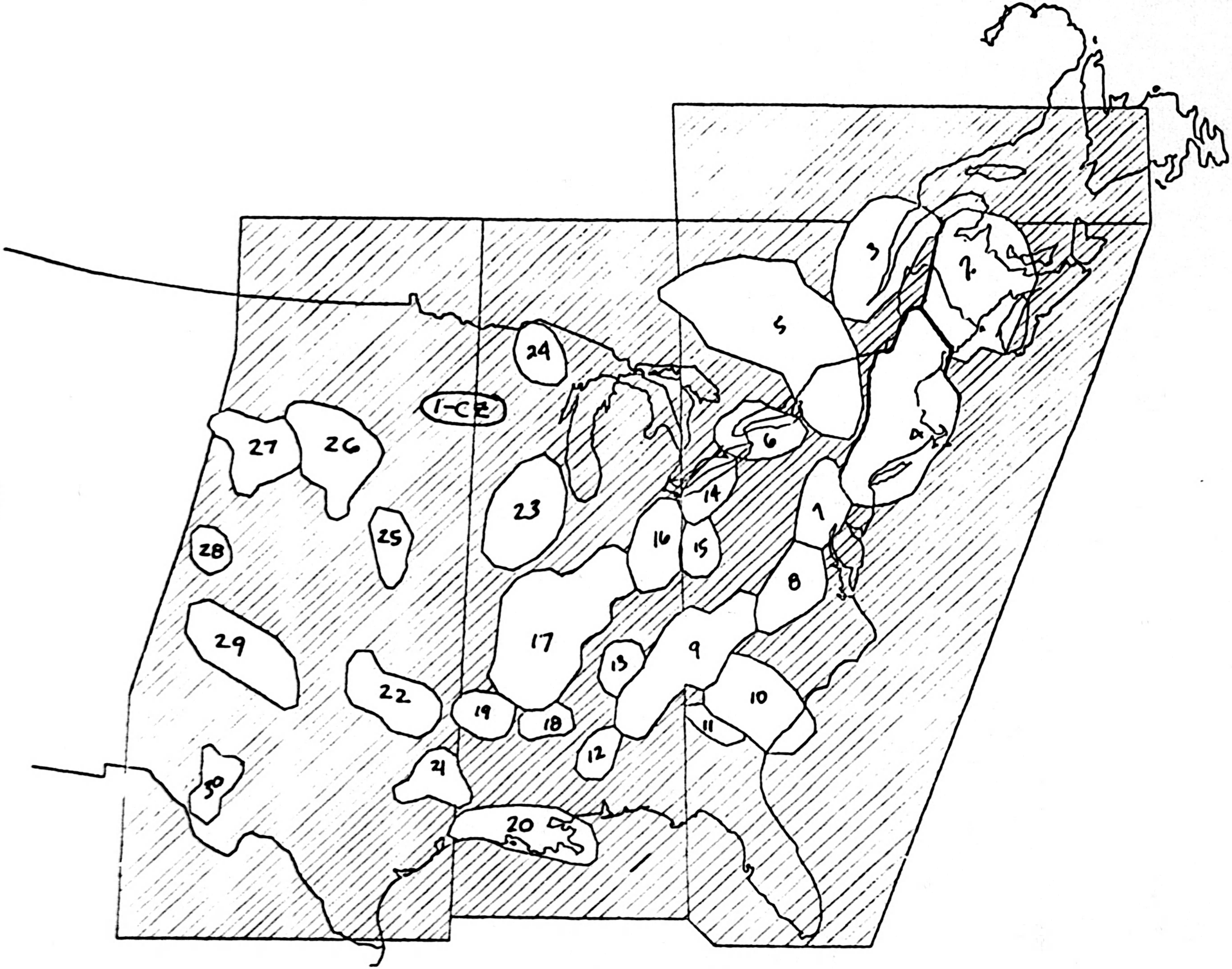


Figure 3.3.6 Seismic Zonation Base Map for Expert 6

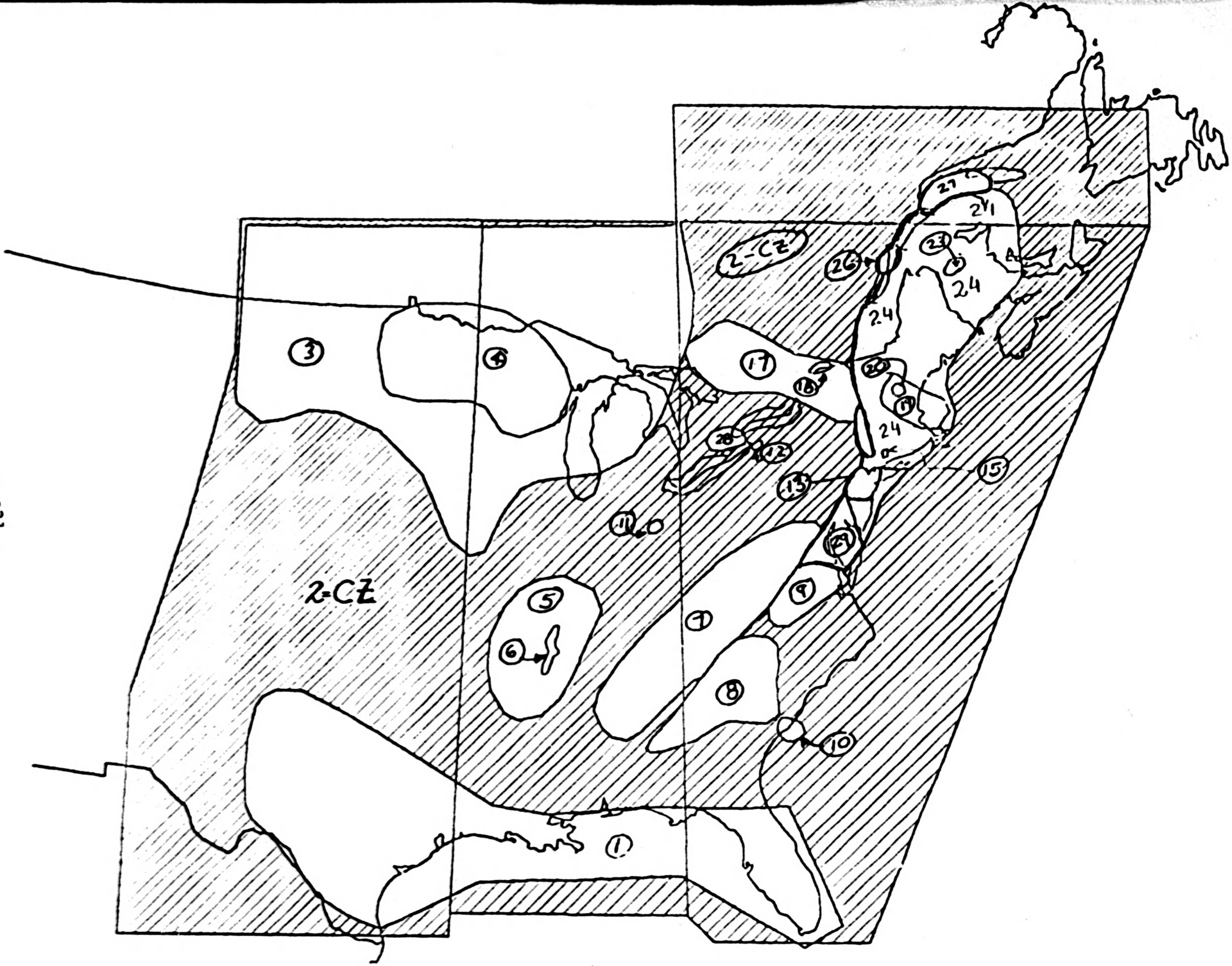
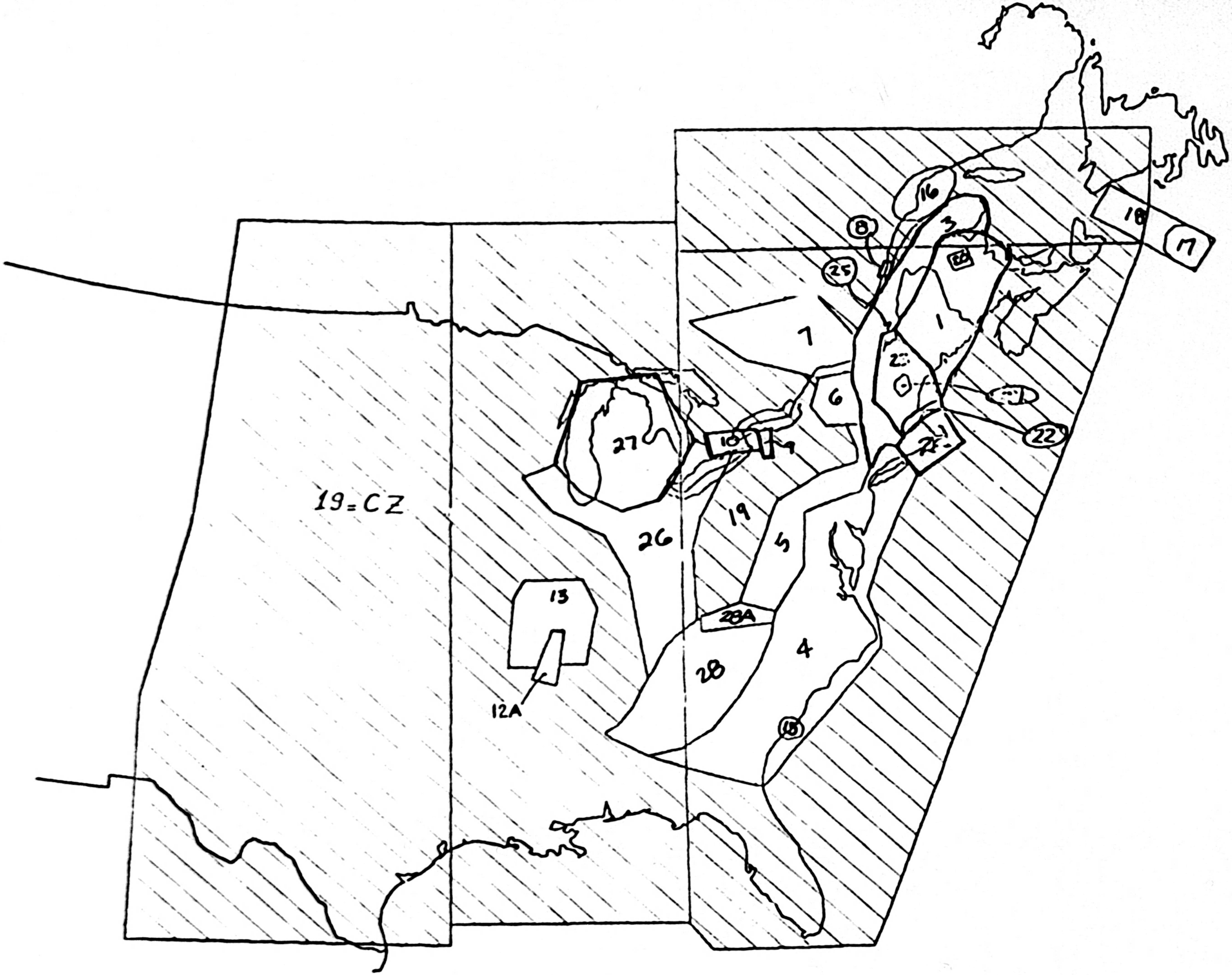
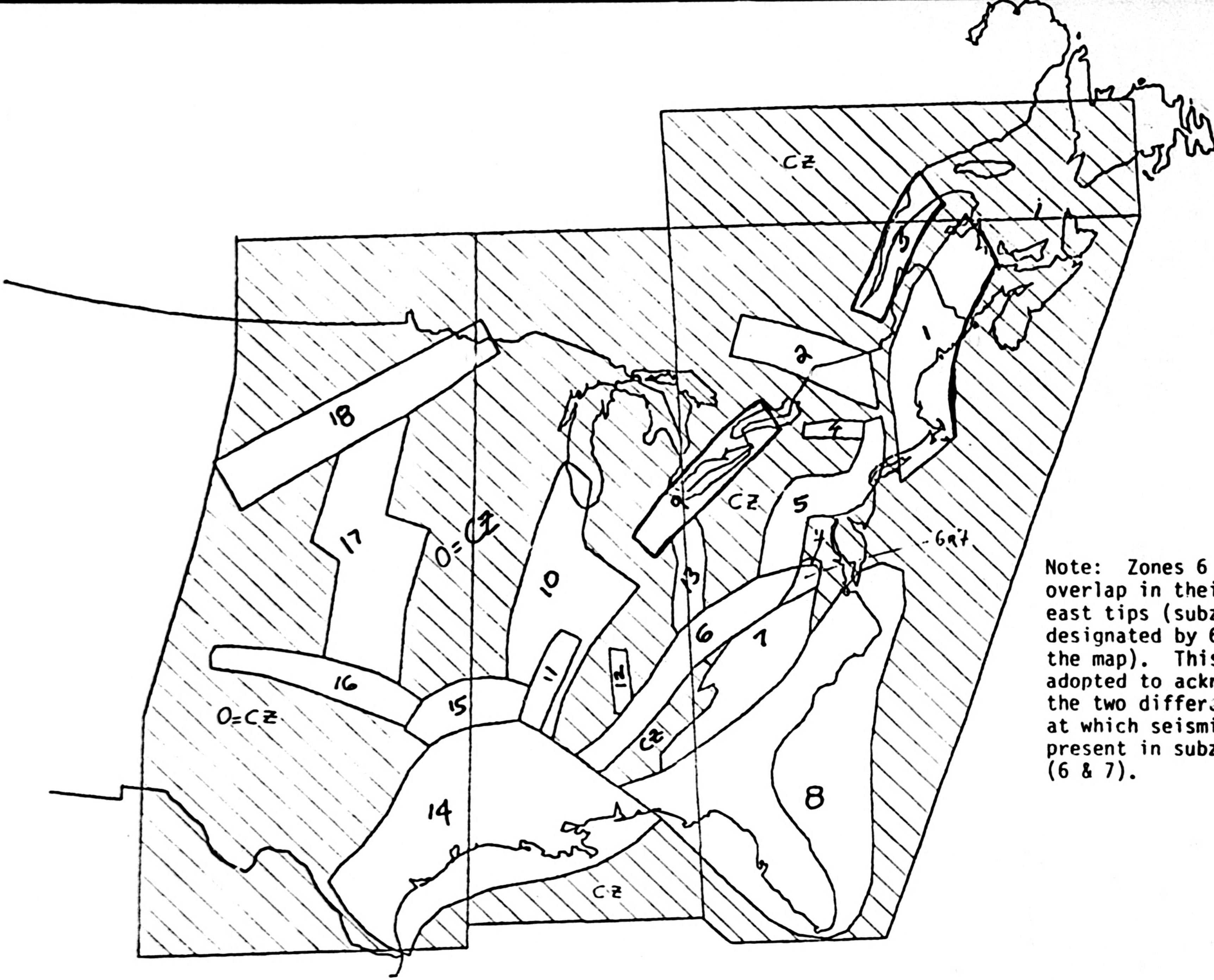


Figure 3.3.7 Seismic Zonation Base Map for Expert 7



Fiqure 3.3.8 Seismic Zonation Base Map for Expert 10



Note: Zones 6 and 7 overlap in their northeast tips (subzone designated by 6 & 7 on the map). This model is adopted to acknowledge the two different depths at which seismicity is present in subzone (6 & 7).

Figure 3.3.9 Seismic Zonation Base Map for Expert 11

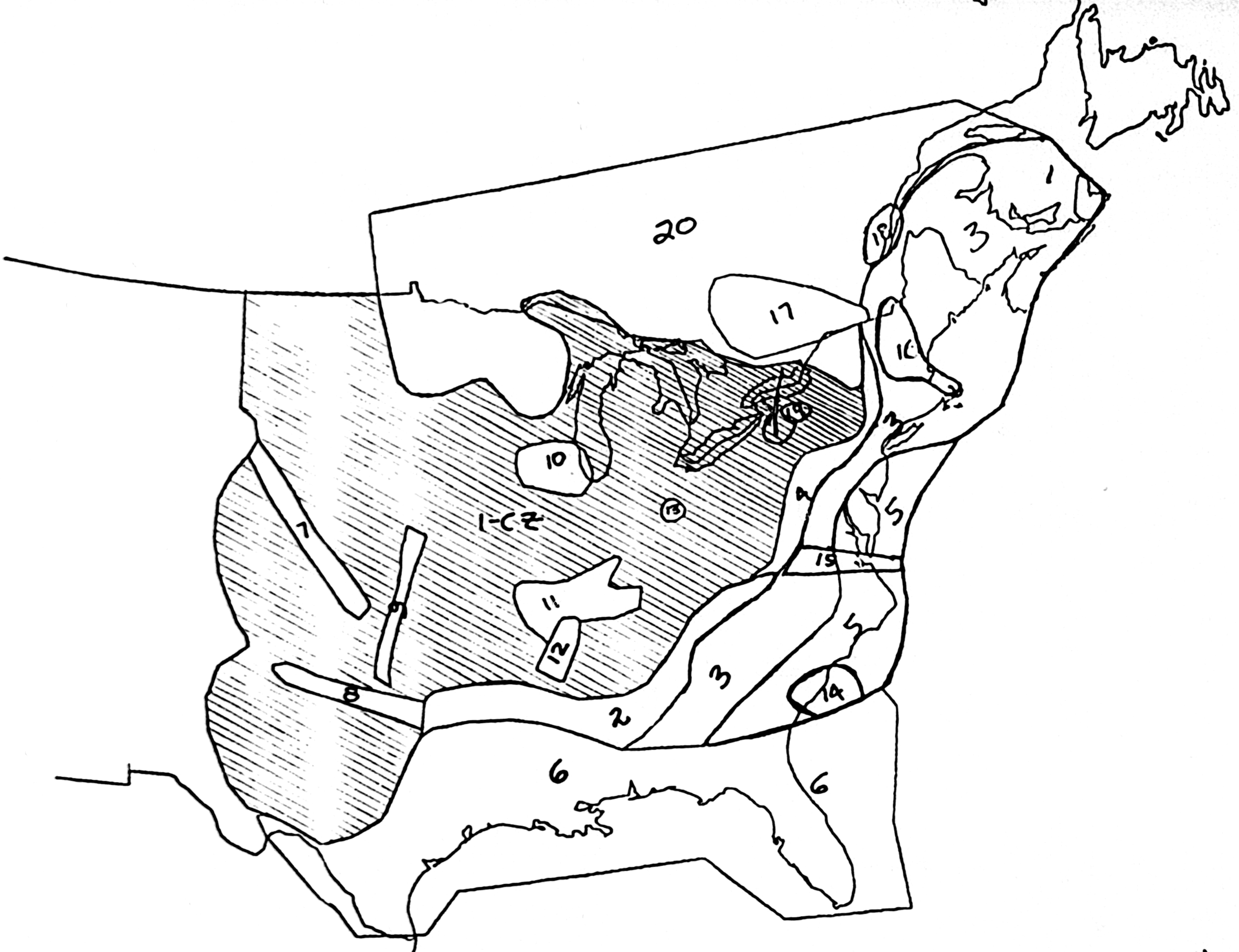


Figure 3.3.10 Seismic Zonation Base Map for Expert 12

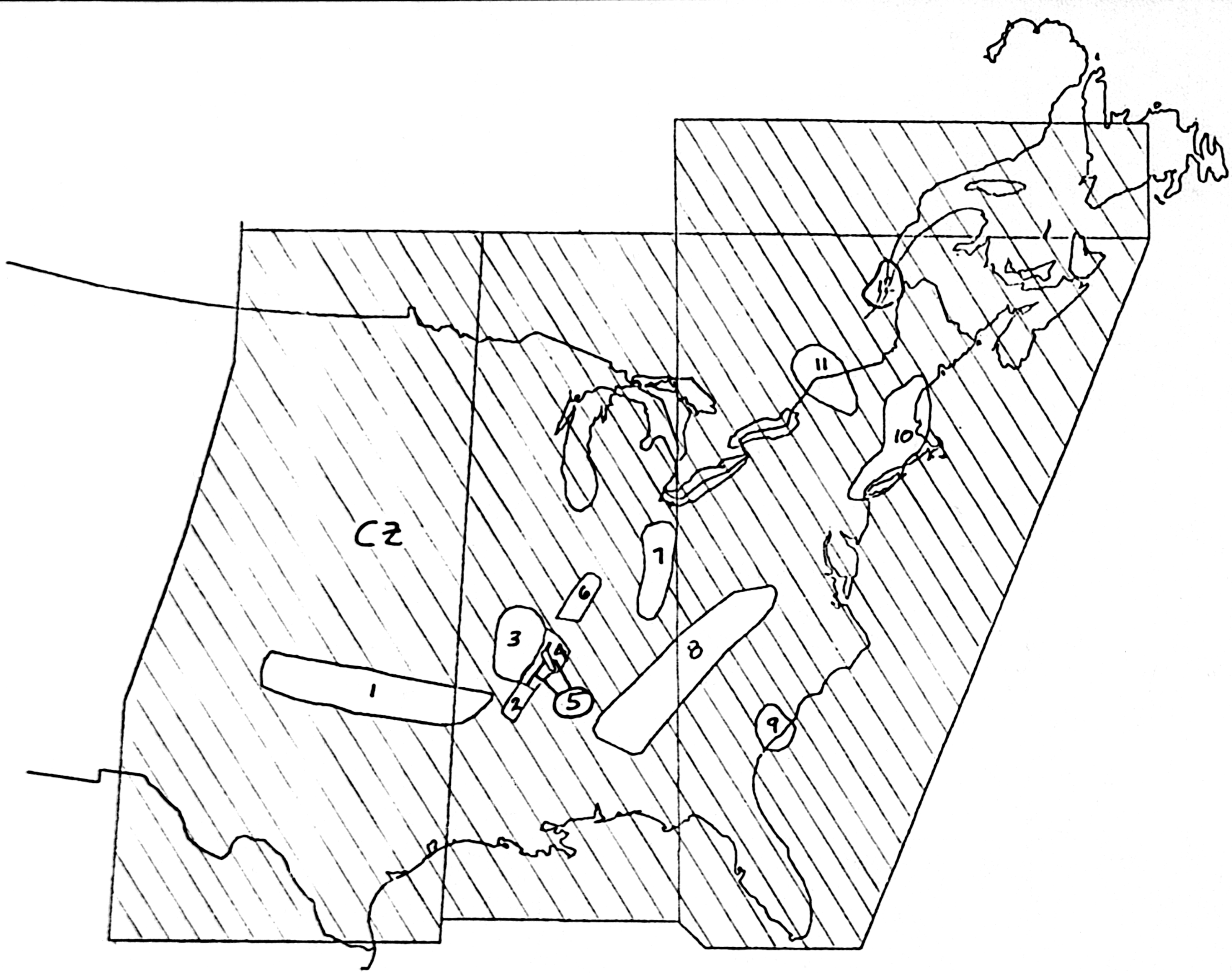


Figure 3.3.11 Seismic Zonation Base Map for Expert 13

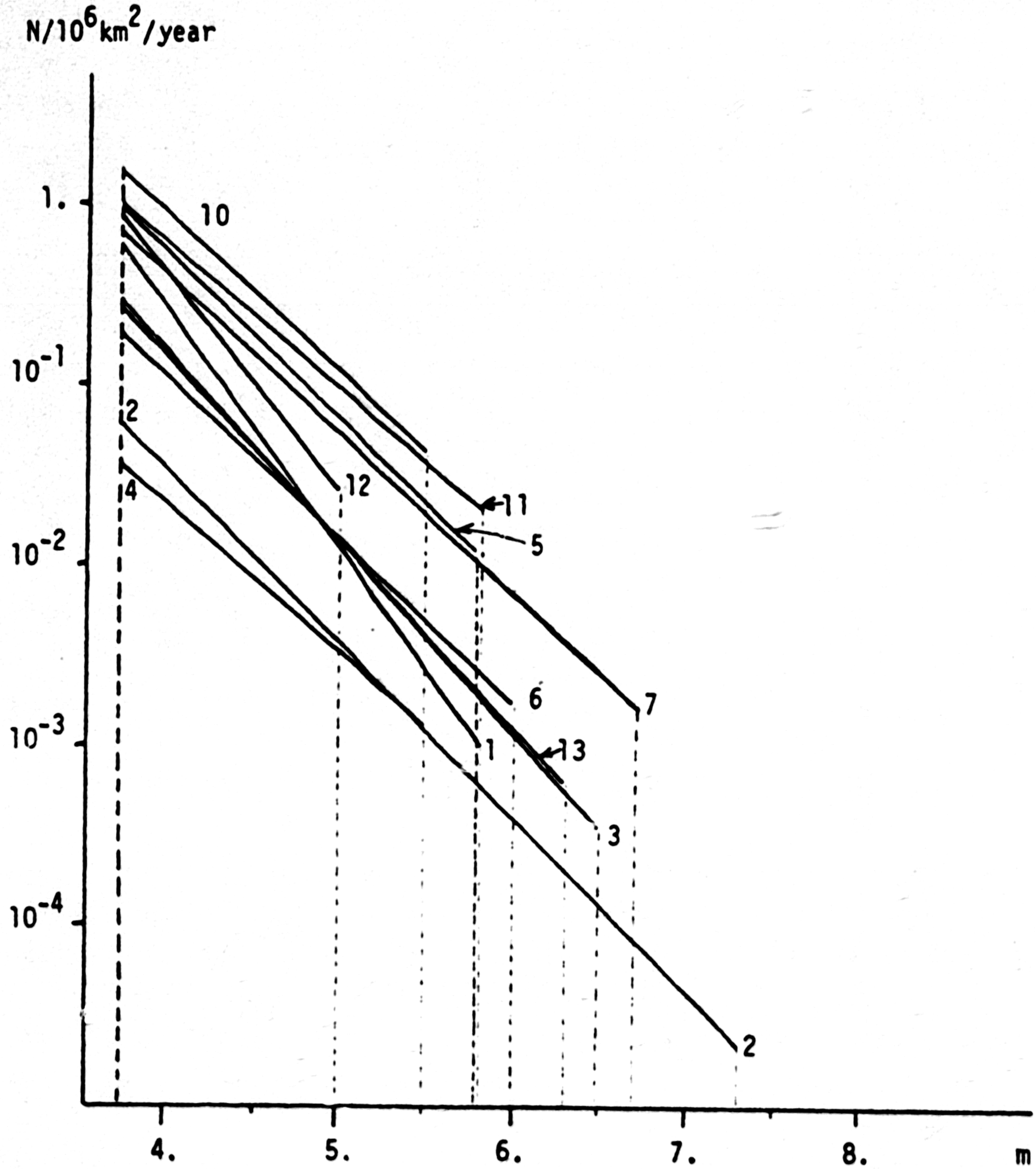


Figure 3.3.12 Number of earthquakes in the complementary zone (CZ), per year and normalized to a unit area of $10^6 km^2$, as a function of magnitude. Comparison between all the seismicity experts. The numbers refer to the experts' index used in the analysis. The interval of magnitude for which each of the lines is drawn is from the lowest magnitude used in the analysis ($m=m_0=3.75$) to the best estimate upper magnitude cutoff $\hat{M}_U$. For the purpose of this figure, the upper end of the curves (near $\hat{M}_U$) is not drawn exactly as they are actually used in the analysis. (See Section 3.1 for more details.)

Finally, you are invited to analyze the set of results presented to you at the December 1983 meeting to complete your understanding of the effect of the CZ on the hazard. In studying these results, you have to realize that a site which may be in the CZ for one expert may not be in the CZ for another expert.

4. Completeness of the Catalogues of Earthquake and Aftershock Sequences

The assessment of the parameters of the recurrence model is strongly dependent on the degree of completeness of the earthquake data available for a given zone. Furthermore, some catalogues of earthquakes contain aftershock sequences. A catalogue of earthquakes may be defined as complete over a time period of T years and for a range of magnitude $[m_1, m_2]$ or intensity $[I_1, I_2]$ if all the events with magnitude or intensity falling in these intervals form a sample representative of the long range seismicity of the area investigated. This implies that the necessary period of complete recording for frequent events (small events) is smaller than for less frequent and a fortiori for rare (large) events. On the other hand, as we consider events smaller and smaller in size, the likelihood of having them recorded in the catalogue decreases, whereas large and very large earthquakes are almost certain to have been recorded. This likelihood of recording depends principally on our ability to detect and properly assess a "size" (magnitude or source intensity) to the event.

As a consequence, the available catalogues for the EUS which include events as far back as the 17th century may be considered complete for rare events with return periods in the order of the time of recording, but they may not be considered complete for smaller events. The practical consequence of using an incomplete data set in the context of this analysis is the generation of an erroneous set of recurrence models. This analysis uses the form $\text{Log}_{10}N_m = a + bm$ (or $\text{Log}_{10}N_I$ = a-bI alternatively), where N is the number of earthquakes greater than m (or I) and a, b are parameters to be determined for each zone. Thus, using an incomplete data set would lead to low a values and low b values in comparison with the ones which would be obtained from a complete data set. There are several published methods to account for incompleteness, ranging from the ad hoc to more sophisticated statistical types.

An aftershock sequence in a data set may also lead to erroneous estimates of the recurrence laws and some analyst choose to remove the aftershock sequences from the catalogues of events.

In responding to Q2, the panel members were invited to use a catalogue of earthquakes of their choice. We have provided LLNL's catalogue to the experts who requested it. This catalogue has not been adjusted for completeness nor for aftershock sequences. Testing for completeness and removing aftershock sequences requires a high level of experience and judgment, thus it was left to each expert's discretion.

It is not appropriate for us to evaluate the methods you used to account for incompleteness and aftershocks. However, in order to formulate a generic evaluation of our analysis, we feel it necessary to survey your level of effort in handling incompleteness and aftershocks.

Thus, in Questions 4.1 to 4.3 you are requested to indicate what was your level of effort in dealing with the problem of completeness (Question 4.1) of the catalogue you used and the problem of aftershock sequences (Question 4.2) either generically for all EUS or specifically zone by zone. Question 4.3 gives you an opportunity to elaborate on the methods used.

5. Self Weights

During the feedback meeting it became clear that your self-ratings (Responses to Q3) were not all on the same basis. Your comments suggested that some of you rated yourself relative to the other panel members whereas others rated yourselves relative to some overall knowledge of zonation and seismicity for the EUS. Therefore, it is appropriate that we establish a basis for you to rate yourself and then give you the opportunity to reconsider your self-ratings.

Although there are several bases that one might consider for forming self ratings, three that we consider appropriate are:

o Your level of expertise relative to the other panel members.

- o Your level of expertise relative to the scientific community at large.

- o Your level of expertise relative to an "absolute level" of overall knowledge.

There is no general agreement on which is the preferred basis to use, however, two points influence our consideration.

- o The ratings are used to establish weights to use in combining hazard results and uncertainties. The combinations are based on a relative weighted averaging process.

- o Development of the weights was based on treating your self ratings as a measure of your "utility" of your estimates of the hazard.

The former point suggests that the "level" or basis is not important, thus, it is not important what basis one uses to measure ones level of expertise. However, the latter point suggests that the ratings should reflect some measure of overall worth of ones estimates.

After some consideration we have decided to ask you to use the scientific community at large as the basis for self rating your level of expertise. Although this request may not be as easy as rating yourself relative to the other panel members, we believe the overall study will benefit from your assessment of your level of expertise relative to the overall scientific community. In particular, the overall ratings of all panel members will give us some indication of how you rate yourself (as a panel) relative to other groups of experts who might have been assembled.

6. <u>Questions</u>

<u>Section 2: Zonation Maps</u>

<u>Question 2.1</u>

Please review the zonation maps that you provided in answer to Q1 and generate updated versions of these maps if you think it is necessary.

You will find the original maps that you designed in response to Q1 which you can use to respond to this question if your modifications are not extensive. Please indicate your modifications by altering these same maps clearly (using different colors and a clear key, for example). Feel free, however, to use a new blank map sheet if your modifications are extensive or if you have new alternatives. In any case, please return the original maps together with your responses to this questionnaire.

Question 2.2

Please update Table A1 as necessary.

Question 2.3

Please update Table A2 as necessary.

Section 3: Seismicity

Question 3.1

Please indicate the magnitude recurrence model we should use to develop hazard curves based on your opinions about seismicity.

_____ LLNL Model

_____ Truncated Exponential Model

Question 3.2

Please indicate the most appropriate way for us to handle correlation between your estimate of the intercept, a, and slope, b, of the magnitude recurrence equation.

_____ (a, b) should be treated "independently"

_____ (a, b) should be treated as "partially" negatively correlated

_____ (a, b) should be treated as "highly" negatively correlated

Question 3.3

Please review the seismicity estimates you provided in response to Q2 and make any modifications you deem appropriate. In doing this, please keep in mind any changes that are necessary due to changes in zonation (i.e. responses to Questions 2.1-2.3) and your responses to how we should treat the magnitude recurrence modeling (Question 3.1) and correlation between (a, b) (Question 3.2).

Tables, as provided in Q2, are included. You need not recopy any information which is the same as before. Only fill in the appropriate modifications.

Section 4: Completeness of the Catalogue and Aftershock Sequences

Question 4.1

What level of consideration would you say you gave to the problem of completeness of the catalogue you used in your final answers about seismicity in Section 3 of this Questionnaire? Please respond by filling Table 4.1 with check marks ( ) in columns 2 to 5. You may chose to answer specifically for each zone or have a single generic answer. In Table 4.1, the zone index nmbers refer to the zone numbers on your final zonation maps, which you might have updated in response to question 2.1 of this Questionnaire.

Question 4.2

What level of consideration would you say gave to the problem of aftershock sequences in the catalogue you used in your response about your final answers on seismicity in Q2 and Section 3 of this Questionnaire?

Please respond by filling Table 4.1 with check marks ( ) in columns 6 to 9.

Question 4.3 (Response to this question is optional.)

If you deem it appropriate, please elaborate on the method you used to account for incompleteness in the catalogue you used and/or to account for aftershock sequences.

Section 5: Self Rating

Question 5.1

For each of the four regions identified below, please indicate your level of expertise (on a scale of 1-10, with 1 indicating a low level of expertise) with regard to the geologic, tectonic, and seismic characteristics within the region.

	REGION	SELF-RATING
I	Northeast	________
II	Northcentral	________
III	Southeast	________
IV	Southcentral	________

Table A1
Level of Confidence in Existence of Zones

Zone Index on Final Updated Maps	Level of Confidence in Existence	If Zone does not Exist, it Becomes Part of Zone Number	Additional Comments
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			

Table A1 (Continued)
Level of Confidence in Existence of Zones

Zone Index on Final Updated Maps	Level of Confidence in Existence	If Zone does not Exist, it Becomes Part of Zone Number	Additional Comments
24			
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
38			
39			
40			
41			
42			
43			
44			

Table A1 (Continued)
Level of Confidence in Existence of Zones

Zone Index on Final Updated Maps	Level of Confidence in Existence	If Zone does not Exist, it Becomes Part of Zone Number	Additional Comments
45			
46			
47			
48			
49			
50			

Table A2
Level of Confidence in Boundary Shapes of
Zones or Cluster of Zones and Alternative Shapes

Zone Number(s) of the Zones or (Cluster of Zones) in Final Updated Map	Level of Confidence in Boundary Shape	Zone Index of Alternative Zone (or Cluster of Zones) Boundary Shape	Additional Comments

MAGNITUDE DISTRIBUTION

Question	Q3-8	Q3-9	Q3-10	Q3-11	Q3-12	Q3-13		Q3-14		Q3-15	Q3-16	Q3-17	Q3-18	Q3-19		
	MAGNITUDE-RECURRENCE RELATION											PROBABILITY DISTRIBUTION (5)				
			Magnitude-Recurrence Curve					Model Range		Extrapolation				Parameters of Distribution		
Zone (1)	Mag. Scale	Sat. Value (2)	Model	Coef. Best Estimate	Time Length	Coef. Conf. Bounds Lower	Upper	Lower M_{LB}	Upper M_{UB}	Between M_c, M_{LB}	Between M_{UB}, M_{UU}	Magnitude Scale	Probability Distribution	Best Estimate	Confidence Bds. Lower	Upper

(1) Please use the index numbers identifying the zones on your maps of the zonation of the EUS.
(2) Indicate a saturation value only if constrained by that value in your responses.
(5) Respond to Questions 3-17 through 3-19 only if you did not respond to Questions 3-8 through 3-16.

Update of Seismicity Parameters Response to Question 3.3

Table 4.1
Level of Consideration on Completeness and Aftershock Sequences

Zone Number on Updated Map	Completeness				Aftershock Sequences				Additional Comments
	None	Low	Medium	Full Analysis	None	Low	Medium	Full Analysis	
1	2	3	4	5	6	7	8	9	10
For All Zones If you answer Generically									
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
12									

GROUND MOTION FEEDBACK MEETING

Questionnaire Number 6 (Q6)

1.INTRODUCTION

The purpose of the feedback meeting is to give the members of the Ground Motion Panel (GMP), a chance to update their input of the ground motion models, and to express their opinion on the methodology to be used in accounting for local site effects. Hence, as a member of the GMP, this meeting was intended to give you:

1) An understanding of how we interpreted and used your input.

2) A chance to review the implications of your input, i.e., the combination of ground motion models with the seismicity models provided by the Seismicity Panel.

3) A chance to either correct any misinterpretations we (LLNL) might have made or alter your responses in light of the results and or responses from other panel members.

4) A chance to evaluate the proposed methods to correct for local site soil conditions by assigning a level of confidence to each one of them, and possibly propose modifications or different methods.

5) A chance to revise your weights relative to other responses.

To assist you in reviewing and updating your input, we have sent each of you a copy of our Interim Report. At the June 27, 1984 meeting, we briefly reviewed our methodology (which is discussed in detail in Section 2, and Appendix D of the Interim Report) and gave you an opportunity to ask questions. Section 3.4 of the Interim Report gives our interpretation of the input you provided in response to the Ground Motion Questionnaire given in Appendix C.

In addition, this document provides you with additional information. In particular, Section 2 of this document provides a more complete listing of the models and the weights for each model than given in the Interim Report and includes the responses from Expert 2 which were not available at the time the Interim Report was published. Section 3 of this document expands upon the results presented in Sections 4.1 and 4.2 of the Interim Report with emphasis on ground motion models and their contribution to the uncertainty of the estimate of the seismic hazard at selected sites. The results presented in Section 3 of this document have been updated to include the input from Ground Motion Expert 2.

In Section 4 of this document we briefly revisit ground motion saturation and other topics. In Section 5 we address the approach we propose using to correct for the local soil conditions. In keeping with our Monte Carlo approach, several alternative schemes are proposed which you will be asked to evaluate by providing a level of confidence for each one of them. Section 6 contains the ground motion feedback questionnaire.

2. REVIEW OF THE GROUND MOTION MODELS SELECTED BY THE PANEL EXPERTS

2.1 Background

The ground motion models presented in this section are the ones selected by the GMP experts in response to questionnaire Q4. In Q4, we (LLNL) organized all possible availale models into several classes, described their origins, characteristics and limitations. You were then requested to choose one model in each class and to assign a level of confidence to each of the classes.

However, the enumeration of models provided in this section contains some models not mentioned in the questionnaire Q4, and is also more complete than the list provided in Table 3.4.3 of the Interim Report. The reasons for this are as follows:

1. The list of possible models provided in the questionnaire Q4 was not as complete as possible and two models have been added by one expert, prior to making the computations reported in the Interim Report. These two models include the acceleration model number 27 and the spectra model number 119 of Table 3.4.3 in the Interim Report, which are both labeled "Trifunac-Anderson."

2. One expert who had not been able to provide his answers to Q4 in time for performing the analyses reported in the Interim Report, returned his answer recently permitting us to include it in this section. However, the effect of this new input requires some more analysis to determine the impact of these new models on the hazard. This is treated in Section 3.

For the large part, all the models (except for 3 models) presented in this section were described in detail in the questionnaire Q4, which you al. have, (it is also the Appendix C of the Interim Report), and this will not be repeated here. In this section, we present the models by classes and give a short description and reference for the models not present in Q4. We also present the method of simulation used in the calculations for the random selection of ground motion models and give, for each expert, the levels of confidence assigned to each class of models.

2.2 The Ground Motion Models

2.2.1 Acceleration models.

There are seven classes of acceleration models. Five of them are intensity based, and two are direct. Table 2.1 gives the list of PGA attenuation models arranged by classes. It also gives for each model a file index number which cross references it with Appendix A. The Appendix A is a listing of the actual coefficients of each model as used in the analysis. The index number is not the same as the index of Table 3.4.3 of the Interim Report for velocity and spectra models as a result of addition of new models. Table 2.1 also contains an indicator which tells us if the models distinguish between soil or rock. In the last four columns, Table 2.1 provides the index of the expert who chose the model as a best estimate model for each region. The geographical definition of the regions is given in Fig. 2.1.The model number 27, labeled "Trifunac-Anderson," was obtained by using the Gupta-Nuttli (Central U.S.) intensity attenuation relationship with the Trifunac (1976) (G16) acceleration versus Site intensity relationship. The equation A3 of questionnaire Q4 is different from the Gupta-Nuttli relationship, only in its leading coefficient of 3.2 instead of 3.7. This "modified Gupta-Nuttli" equation was developed in the S.E.P. study in an arbitrary fashion by decreasing the intensity of a half unit to account for the fact that the relationship was based on isoseismal data rather than individual intensity reports. If we were to call A6 the Gupta-Nuttli equation, the Trifunac-Anderson relationship used for the interim report would be labeled A6-G16. This relation was updated as a result of the feedback meeting of June 27. The final equation will use "Modified Gupta-Nuttli" equation A3. (thus, it becomes A3-G16.), and to make it consistent with the other models it uses the coefficients for soil (S=0) instead of rock (S=2). This last update applies also to spectral model #125.

The value of γ used in the Campbell's (1982) equation (e.g. D13) is 0.002, and the Nuttli equation (D21) was obtained by using the h_{min} value given in Nuttli's letter of January 24, 1983 (see Appendix C of Interim Report). Furthermore, it has to be stressed that the hazard calculation assumed all distances to be epicentral distances. Because of this limitation the experts have been requested to factor this in their evaluation of the models, and it is reflected in the attribution of levels of confidence provided to us (LLNL) as responses to questionnaire Q4. These models are plotted for each class, for magnitude m_b = 5 and 7, in Figure 2.2 through 2.7. Note that model number 27 has been updated and actually becomes model number 12. Furthermore, a new model has been proposed for your consideration, at the June 27 meeting.

This model developed by G. Atkinson, is described in detail in Section 7 of this document, which is a copy of the paper submitted by the author for publication in BSSA; and appended here with her permission. This model has been added in the list of models to choose from in Section 6. Because of the way it was developed, it falls in the category of direct models and is labelled D22 in Table 6.1.

2.2.2 Velocity Models

As for acceleration, there are seven classes of peak ground velocity models, which are given in Table 2.2. The same general remarks made for acceleration applies to velocity. In addition, note that expert number 5 did not provide a velocity model, and expert number 2 provided a model not described in questionnaire Q4. This is the model GV53 developed by Klimkiewicz G, G and Pulli, JP 1983, which can be found in Earthquake notes, V54, N.1, p. 10. These models are plotted for each class, for magnitude m_b = 5 and 7, in Figure 2.8 through 2.12.

2.2.3 Spectra Models

The spectra models were separated into six classes. The first three classes consist of scaling spectra shapes, namely the Reg. Guide 1.60, the NBS, 1978-ATC and the Newmark-Hall spectral shapes. Reg. 1.60 and ATC shapes are anchored with one acceleration equation and Newmark-Hall are anchored with both acceleration and a velocity equation. The next three models are intensity based and were obtained by using distance weighting, magnitude weighting and no weighting. The no-weighting intensity based model was taken from Trifunac and Anderson's report "Preliminary Empirical Models for Scaling Absolute Acceleration Spectra," Report No. CE 77-03, USC, 1977. In all cases, the spectra used in the analysis assume a 5% damping.

Table 2.3 lists the spectra models, and Figure 2.13 through 2.16 shows these spectra plotted for the rock site conditions and for m_b magnitudes 5 and 7 for distances of 10 and 100 km.

2.2.4 Best Estimate Models

Figure 2.17 shows the best estimate (BE) acceleration ground motion models, Fig. 2.18 through BE velocity models and Figs. 2.19a and b shows the BE spectra models selected by the GMP members for magnitudes 5 and 7 and for distances 10 and 100 km. Tables 2.1 - 2.3 indicate which expert selected the various models and for which regions the models are assumed to be BE models.

2.3 Random Uncertainty

The values of the standard deviation on the logarithm of the ground motion parameter used in the analysis are presented in Table 2.A. In most cases these values are identical to the ones provided by the experts as answers to questionnaire Q4. However, it was necessary to make some interpretation in some cases. For instance, one expert provided a different standard deviation for each frequency. We need only one value obtained by averaging the g values given by the expert, after discussing the problem with him.

2.4 Model Uncertainty

The hazard analysis accounts for the model uncertainty by assuming a given distribution of ground motion models. The actual calculations are performed by using a Monte Carlo simulation technique where the hazard is calculated for each sample ground motion model. The models are drawn from the discrete probability distribution of models constructed with the input from questionnaire Q4. The probability of each model being the right one, for a given expert, is assumed proportional to his level of confidence in the class to which that model belongs. The Table 2.5 gives the cumulative levels of confidence assigned to each ground motion model by each expert to the models they selected. The actual discrete probability distribution of the ground motion models used in the analysis is simply a scaled version of the cumulative values presented in Table 2.5 a, b and c. The scaling value is 1/5 = .2. In addition, however, the hazard analysis accounts for the self rates you provided in questionnaire Q4.