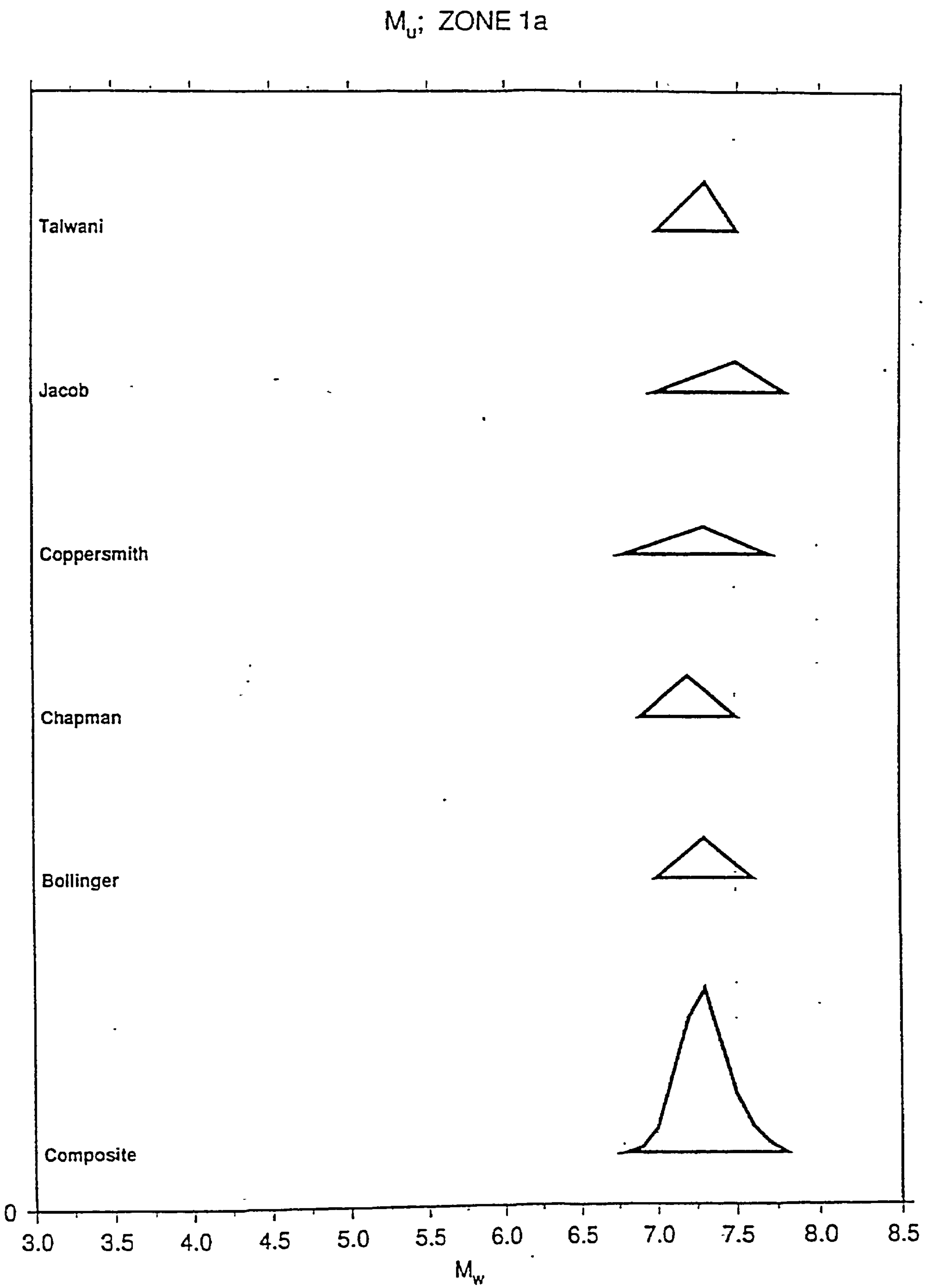
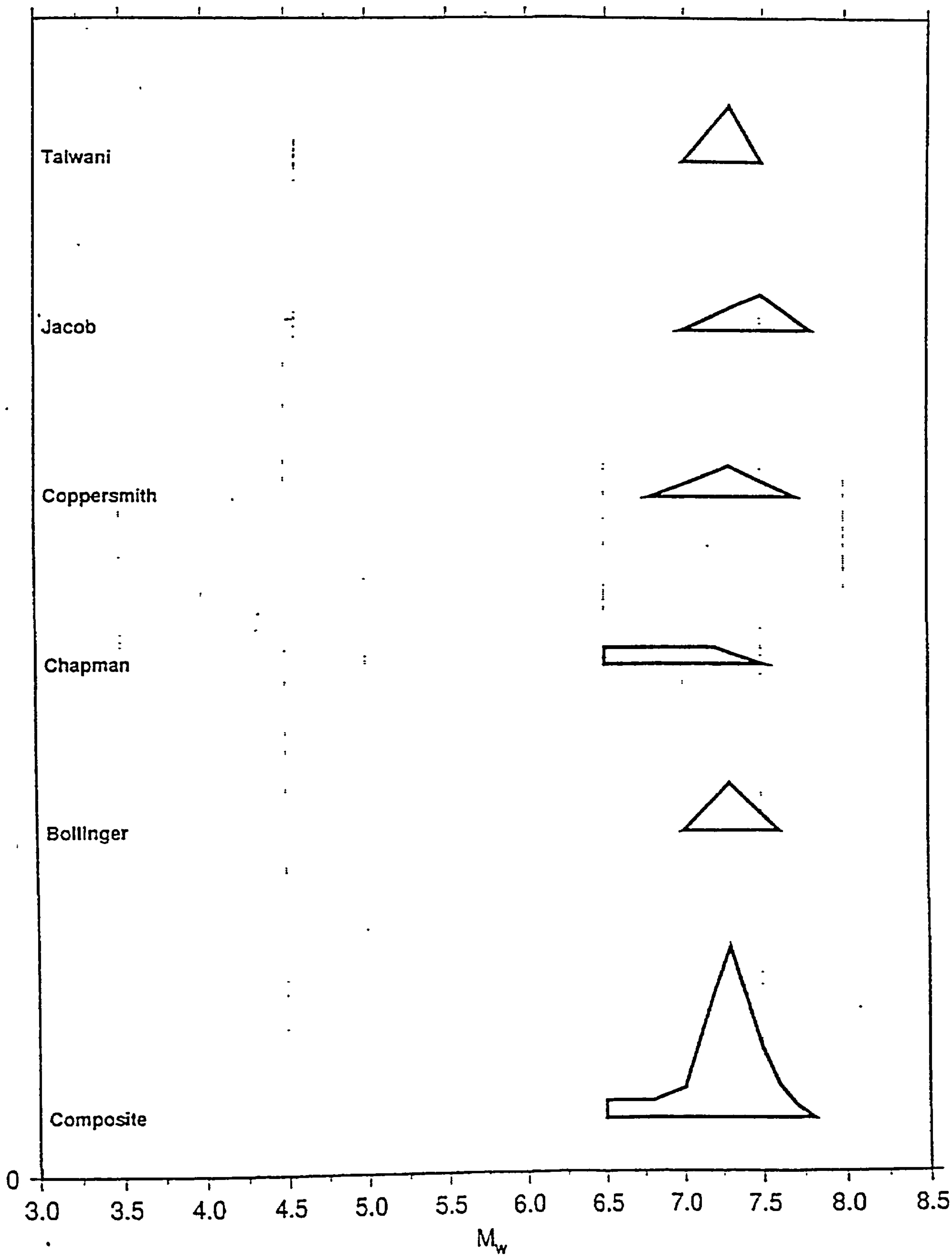
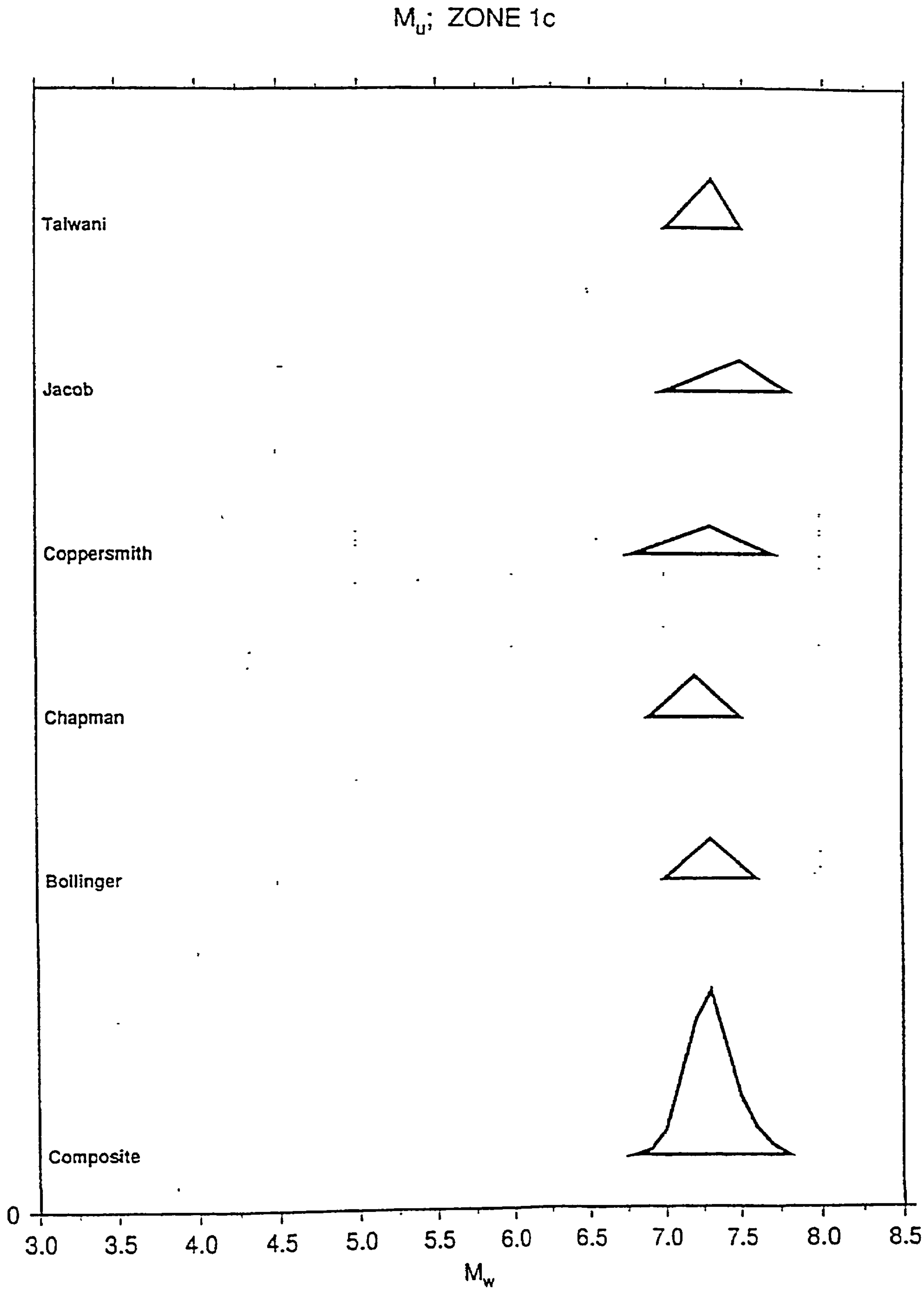
APPENDIX F: TRIAL IMPLEMENTATION PROJECT—PLOTS OF MAXIMUM MAGNITUDE AND RECURRENCE RATE ESTIMATES FOR EACH EXPERT, AND COMPOSITE PROBABILITY DISTRIBUTION FUNCTION

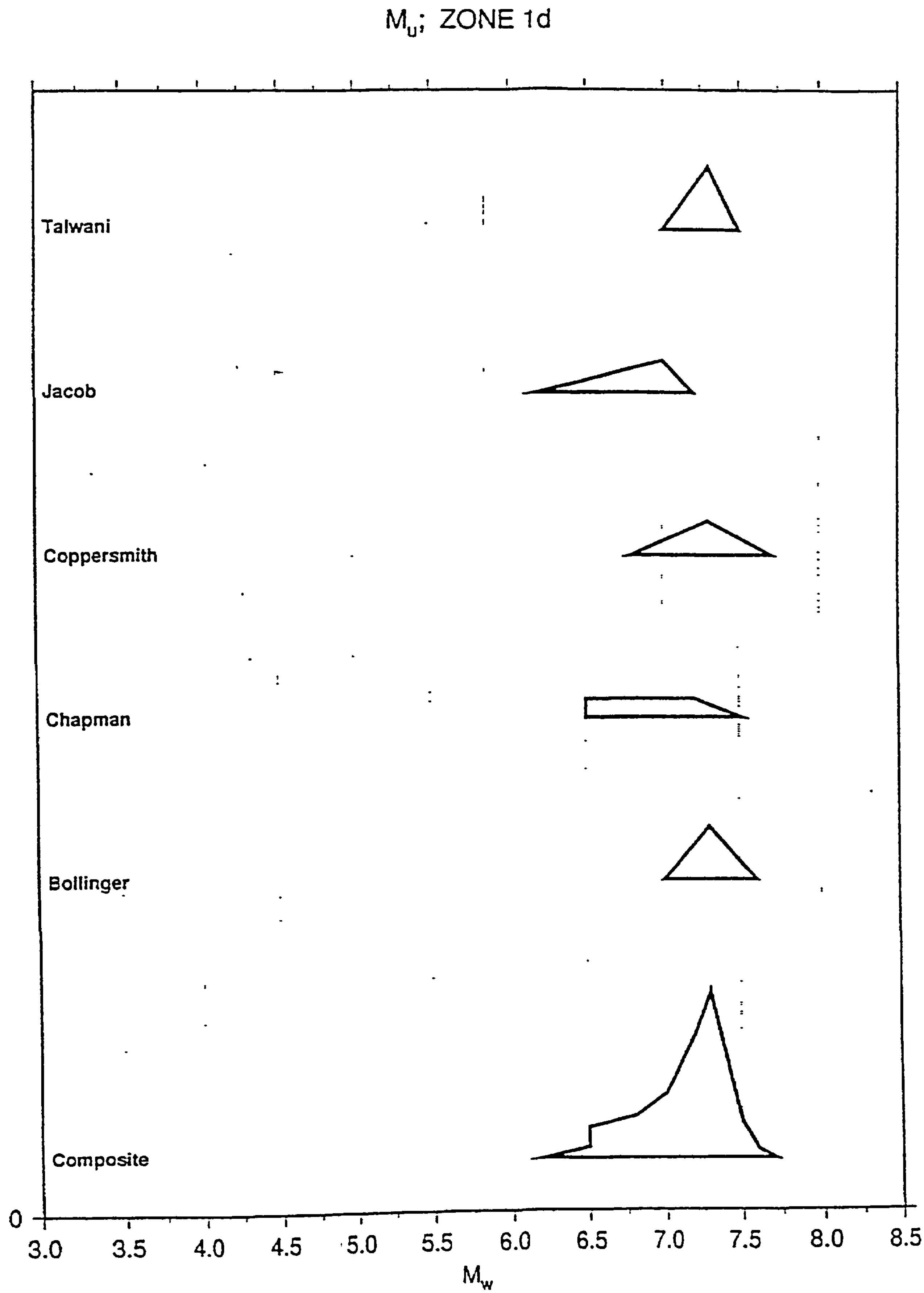

M_u; ZONE 1a
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w

M_u; ZONE 1b



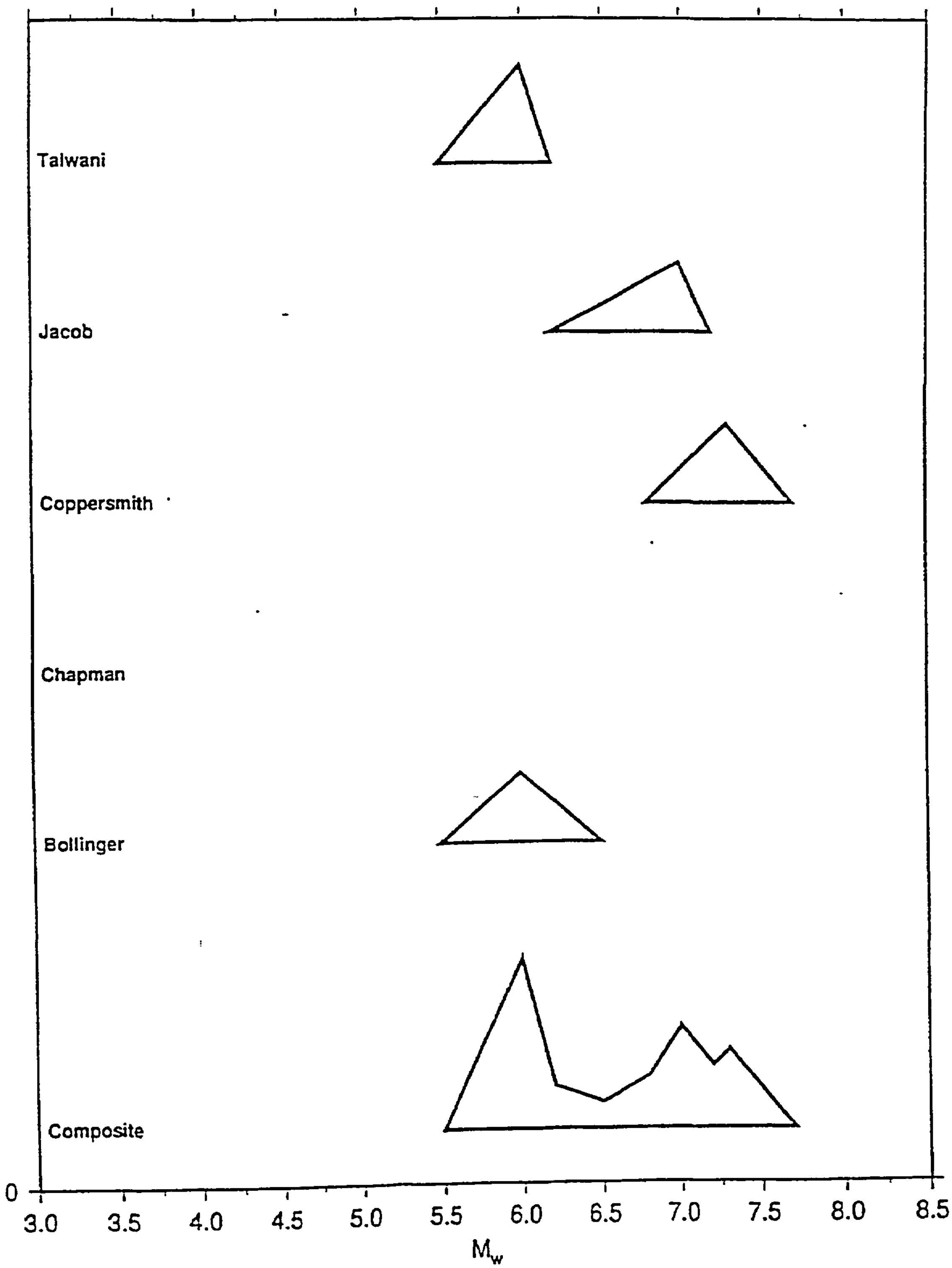
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w


Mu; ZONE 1c
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Mw



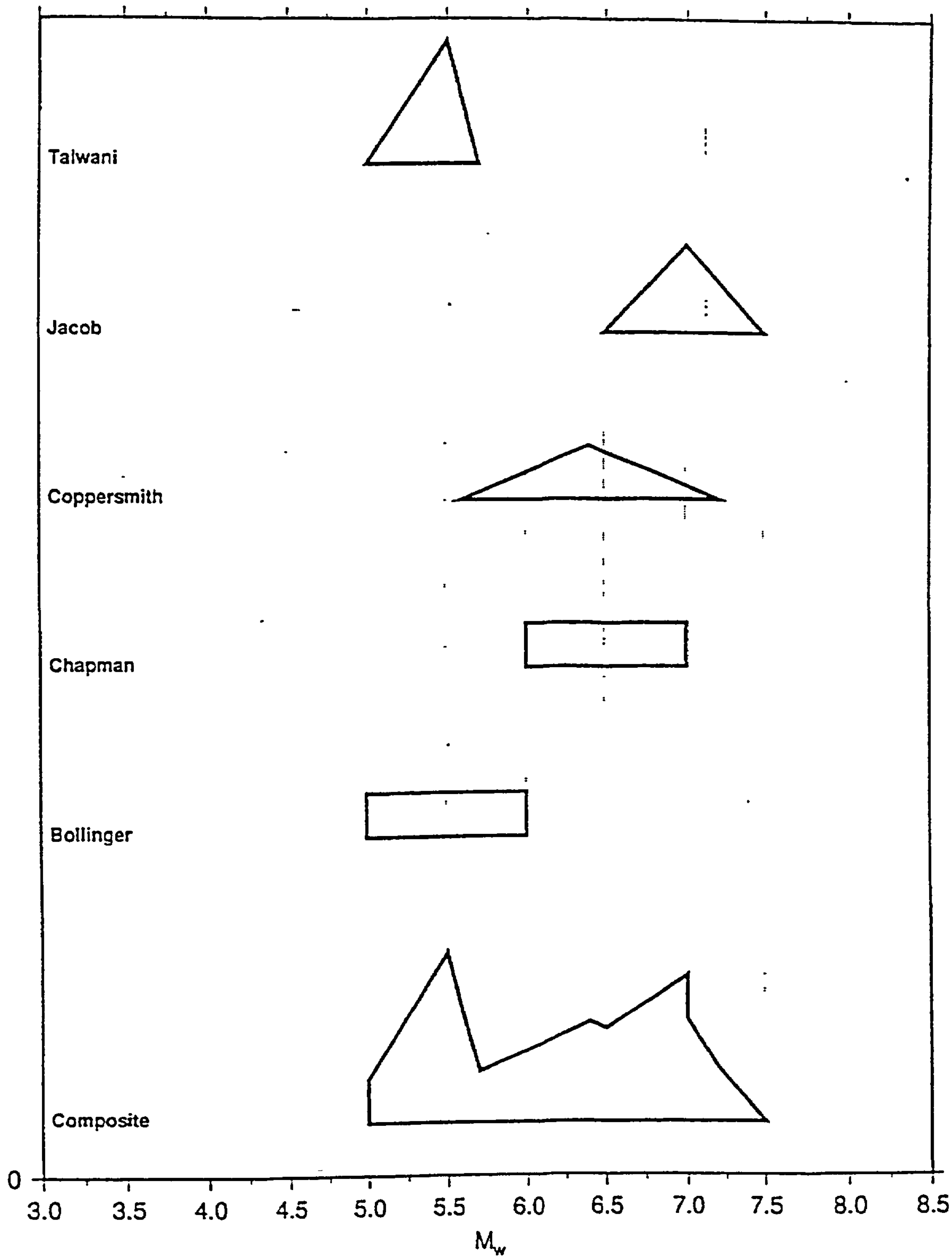
Mu; ZONE 1d
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Mw

M_u; ZONE 1e

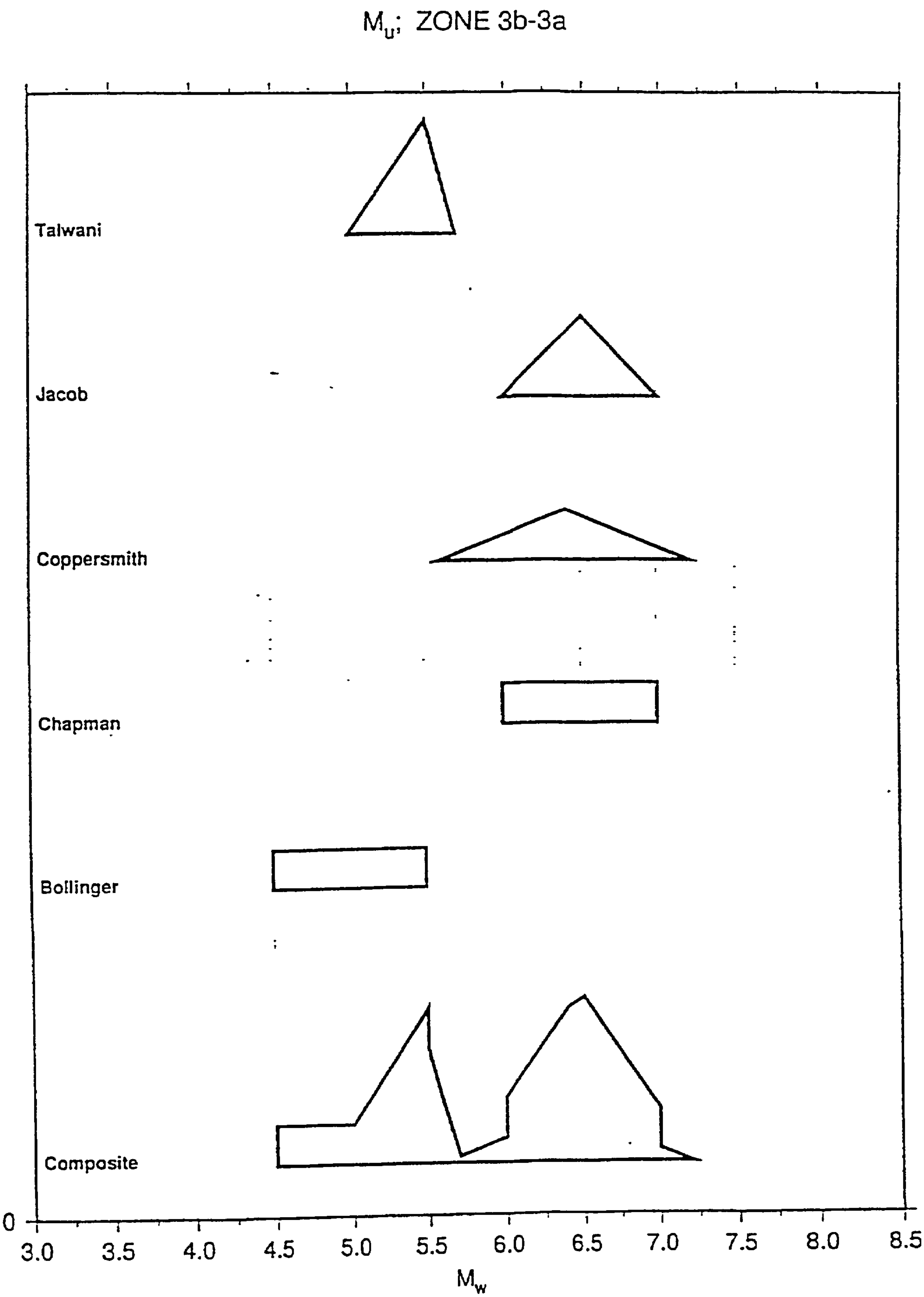


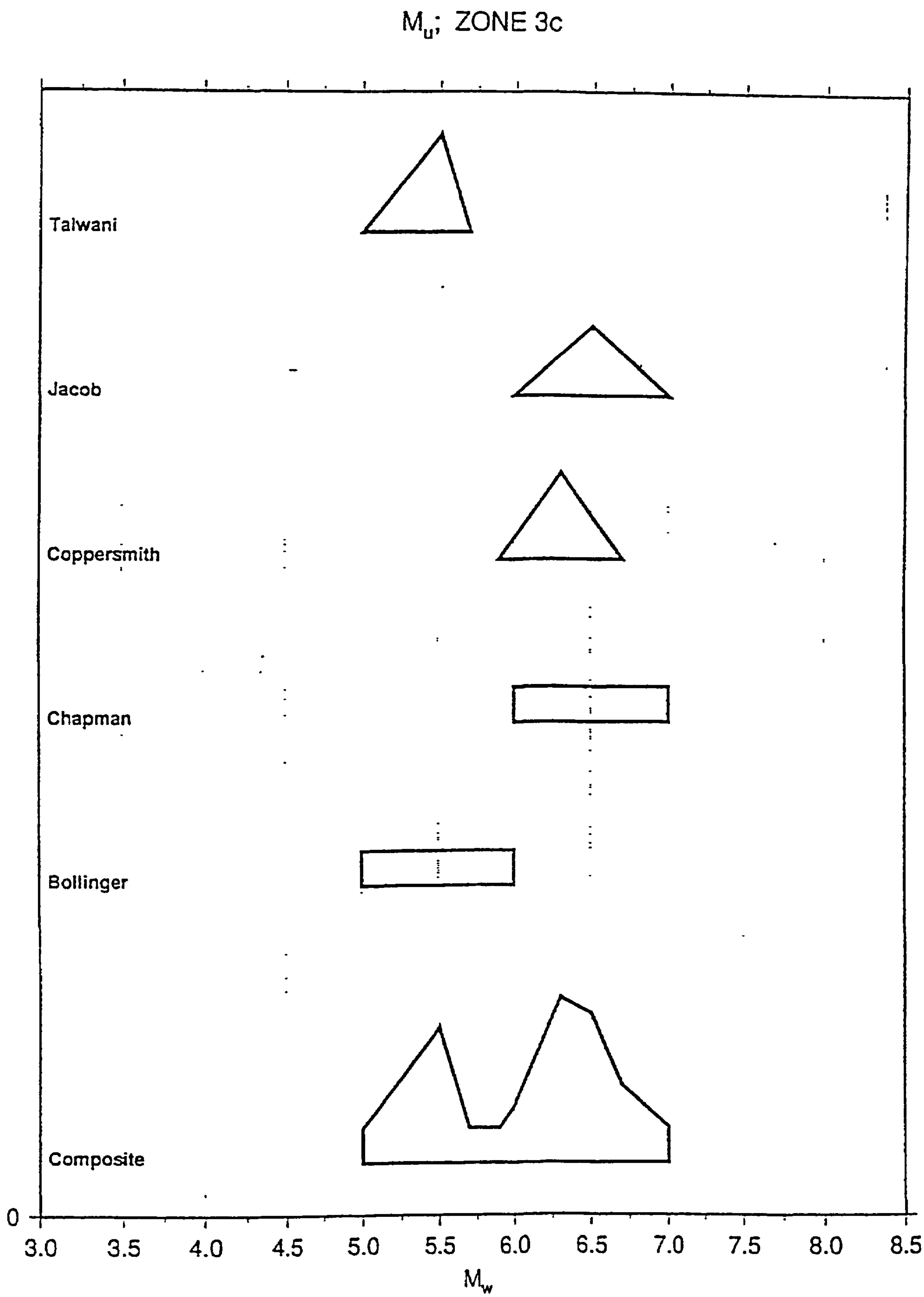
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Mw

M_u; ZONE 3a

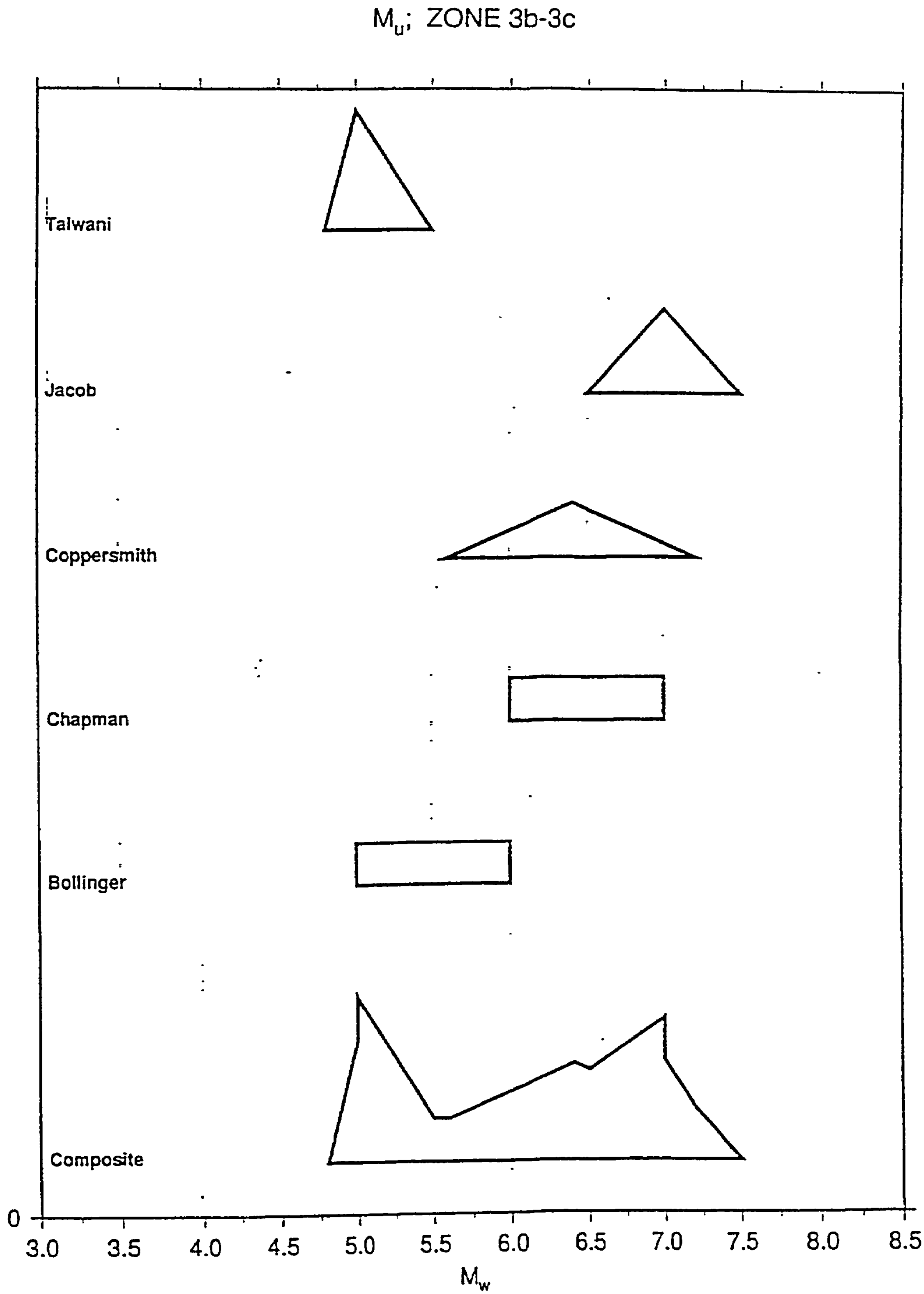


Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M
w

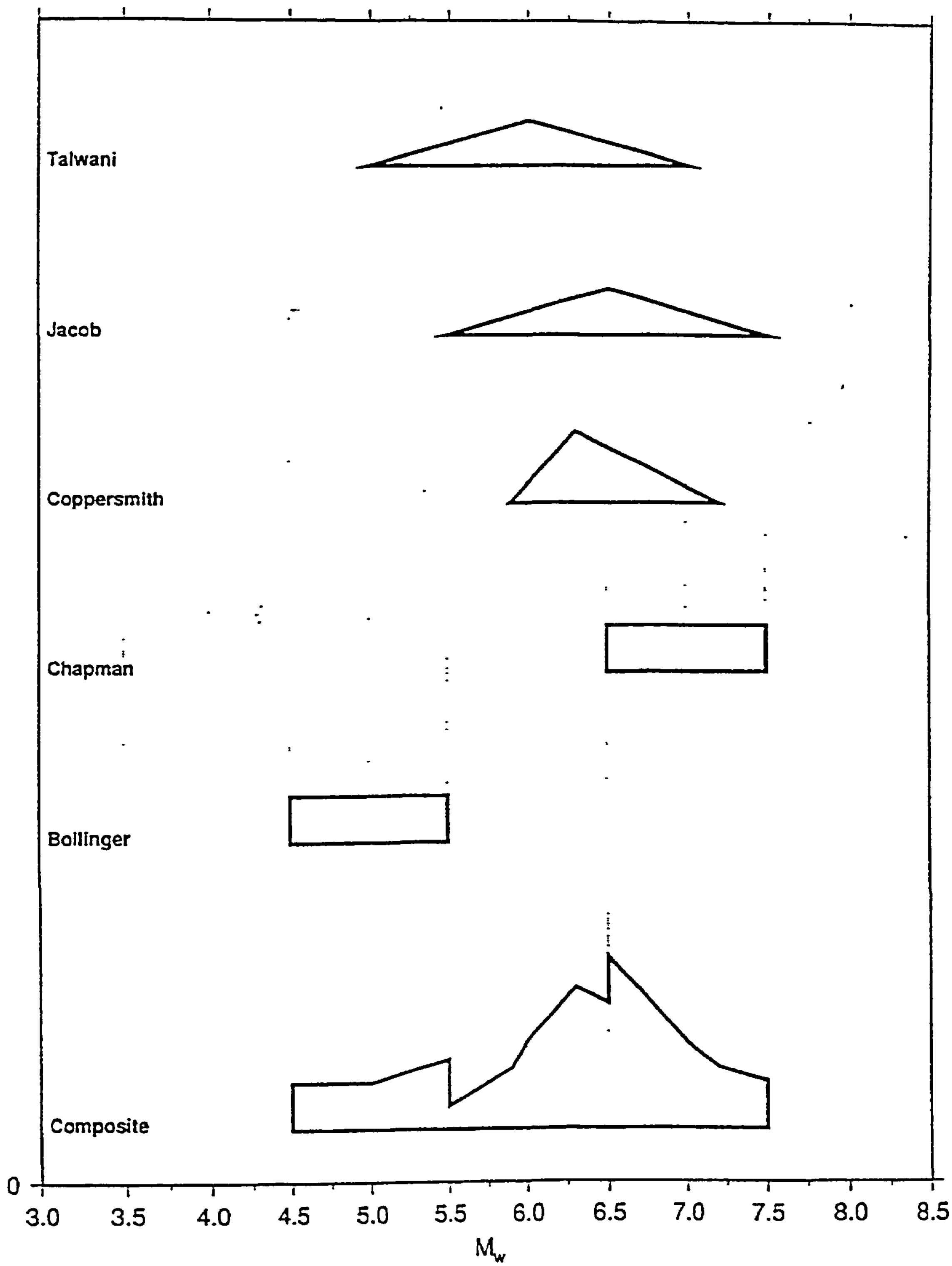

M_u; ZONE 3b-3a
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w



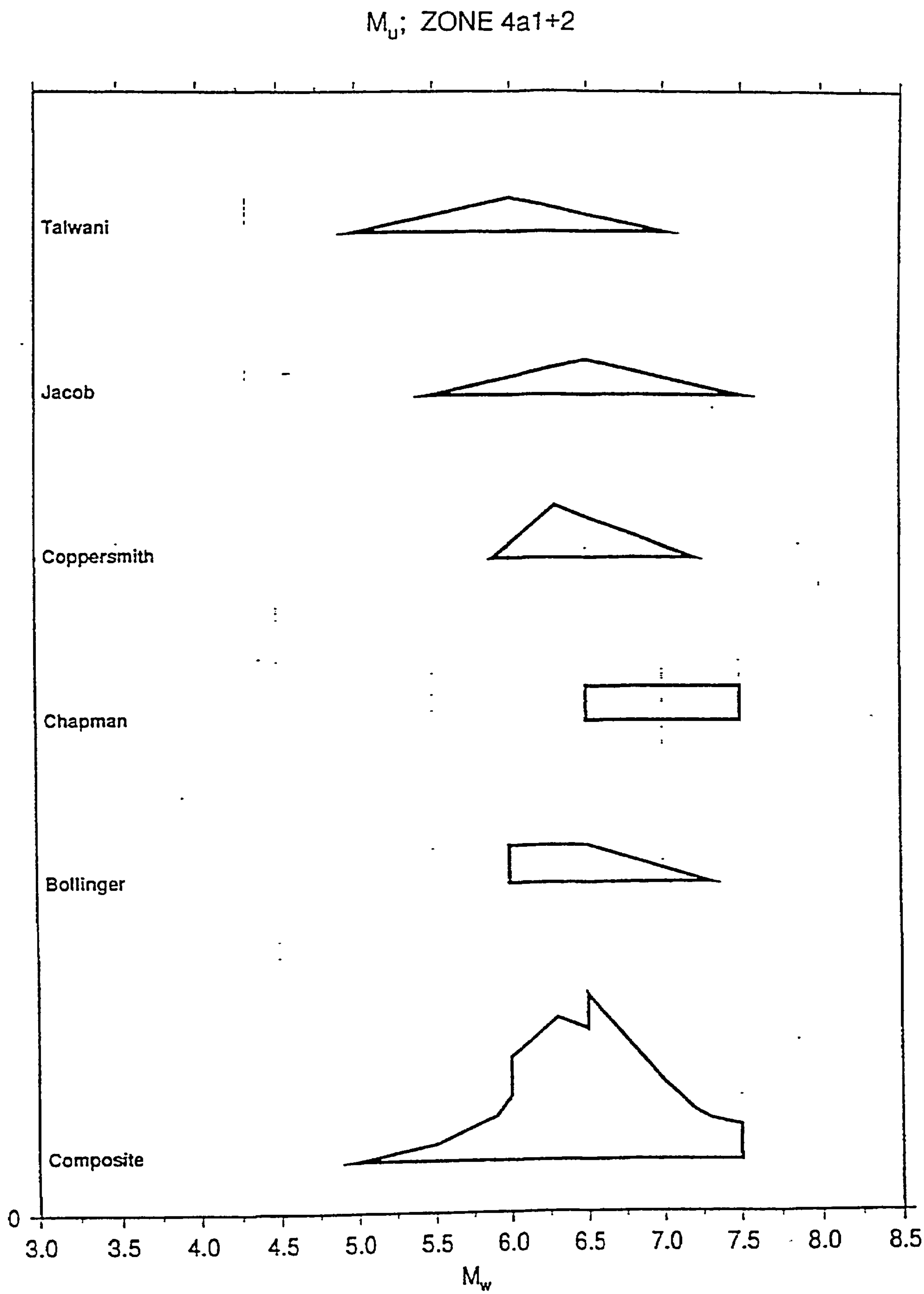
M_u; ZONE 3c
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w


Mu; ZONE 3b-3c
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Mw

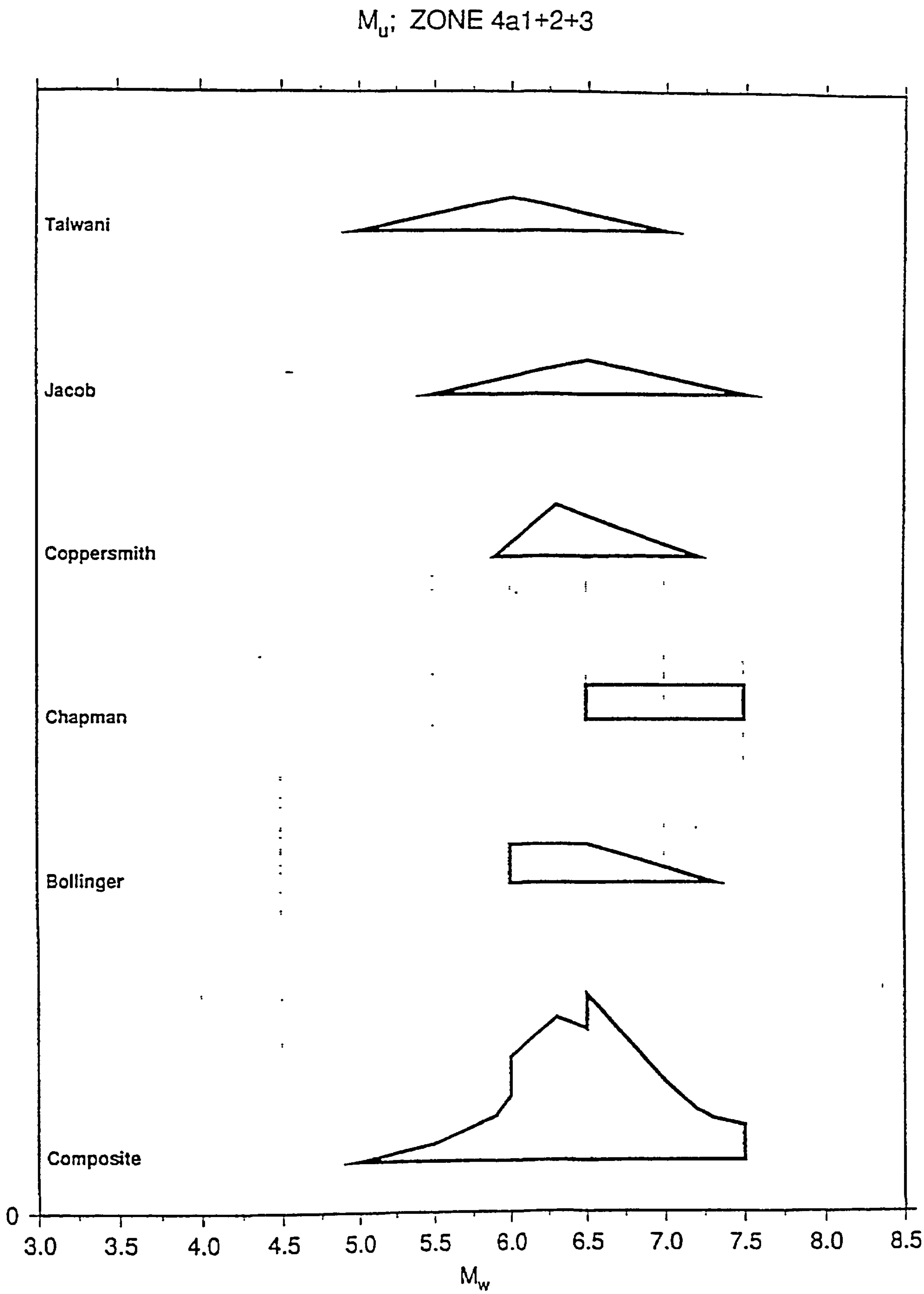
M_u; ZONE 4a1



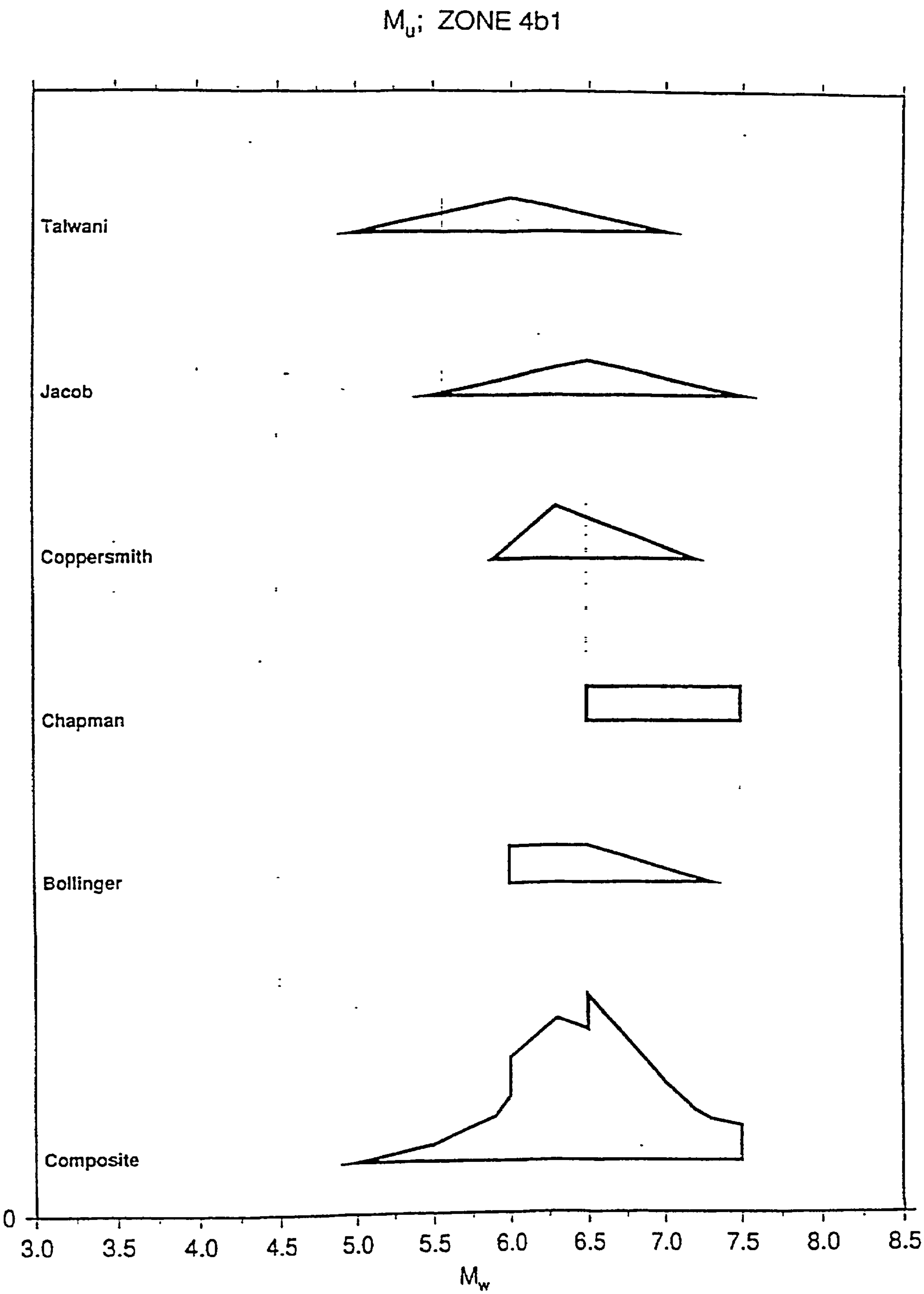
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w



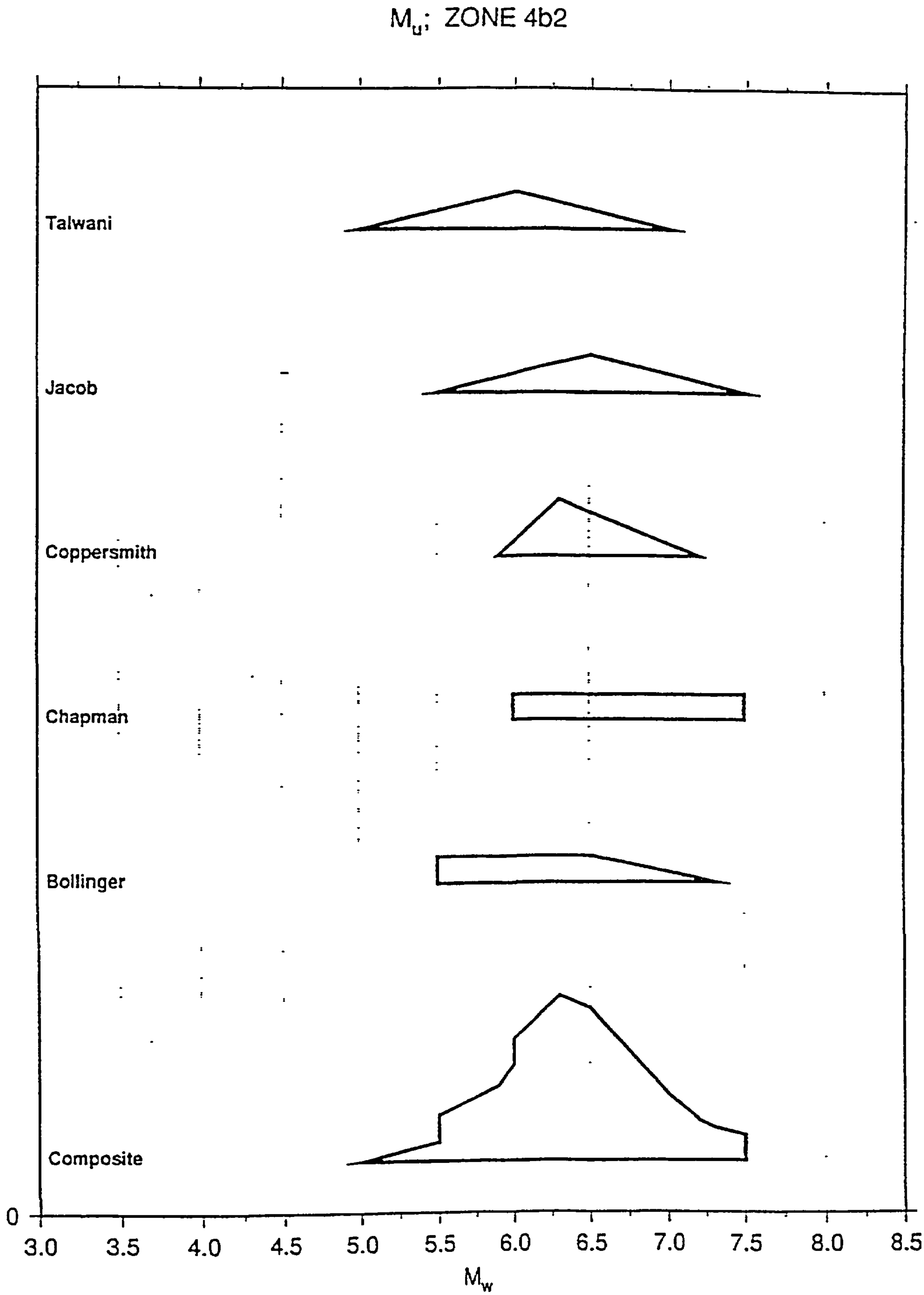
M_u; ZONE 4a1+2
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w



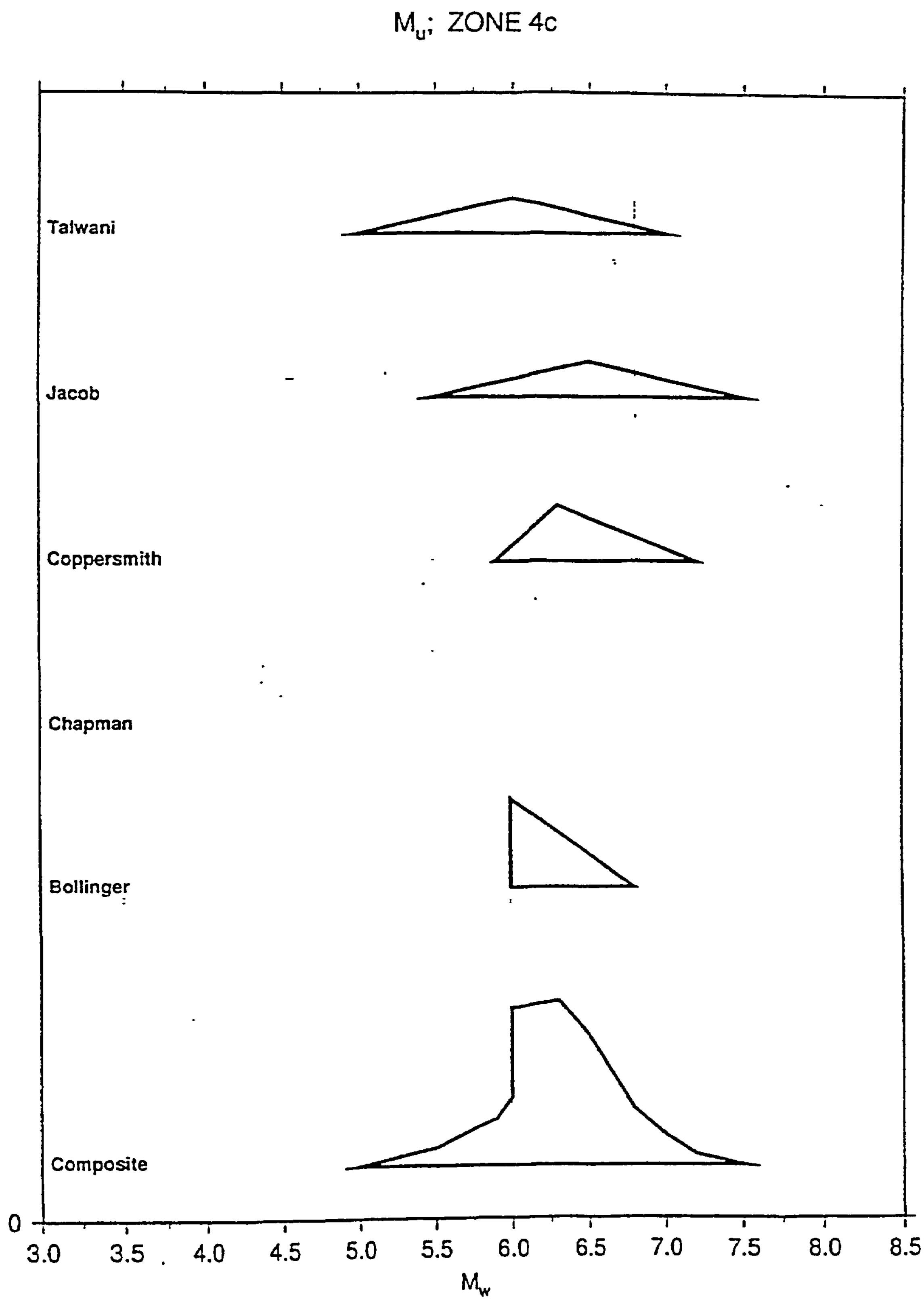
Mu; ZONE 4a1+2+3
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Mw



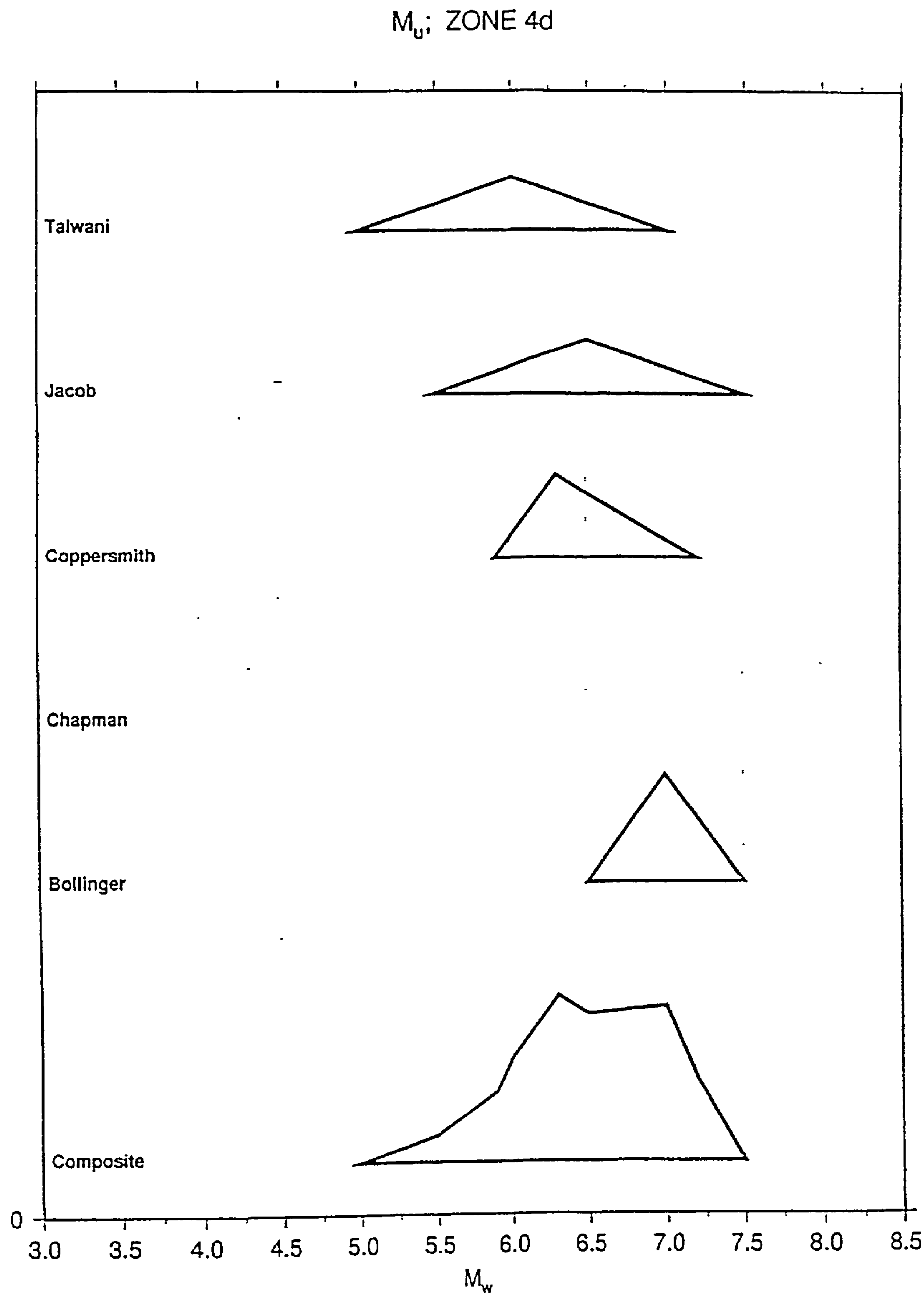
M_u; ZONE 4b1
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w



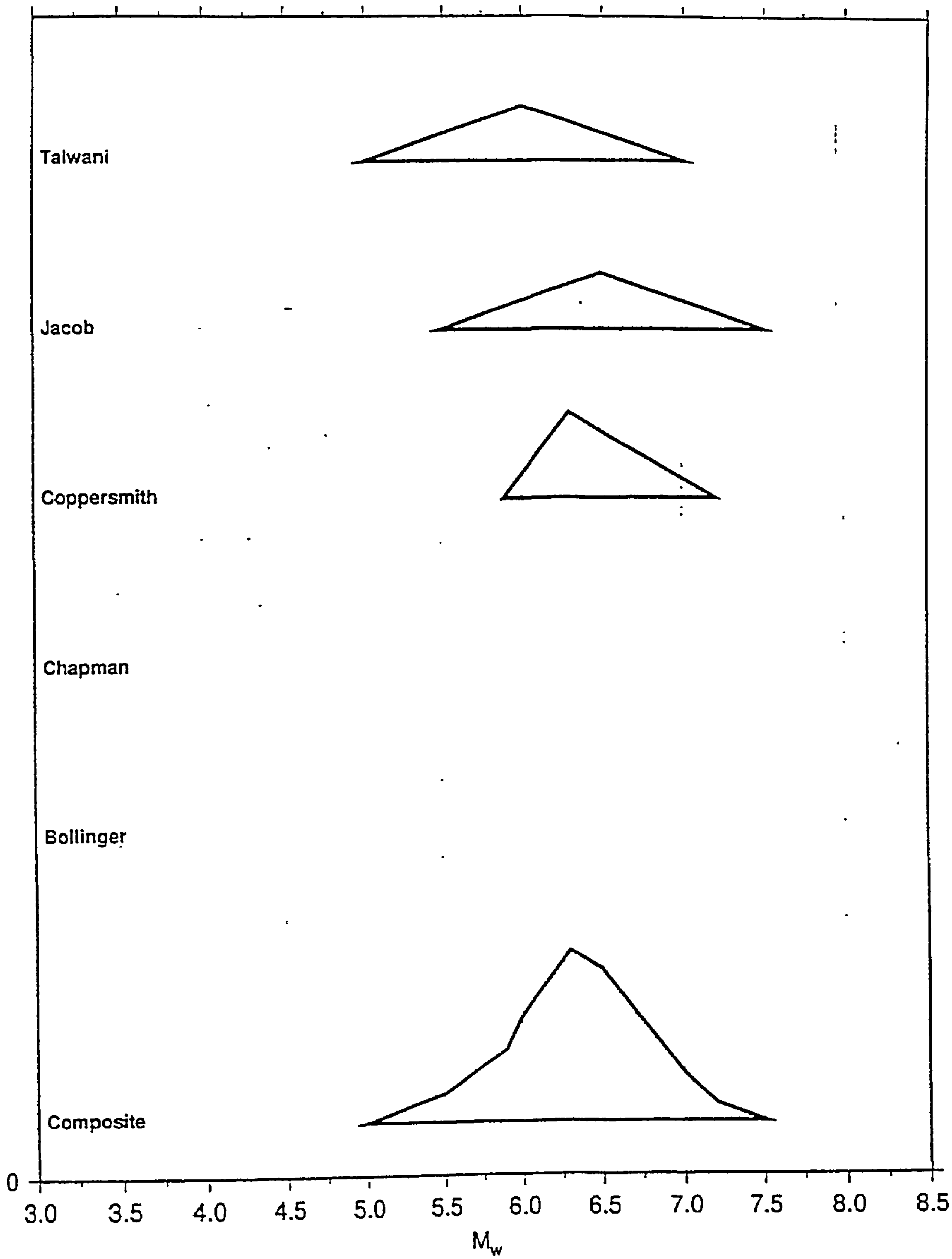
M_u; ZONE 4b2
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w



M_u; ZONE 4c
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w

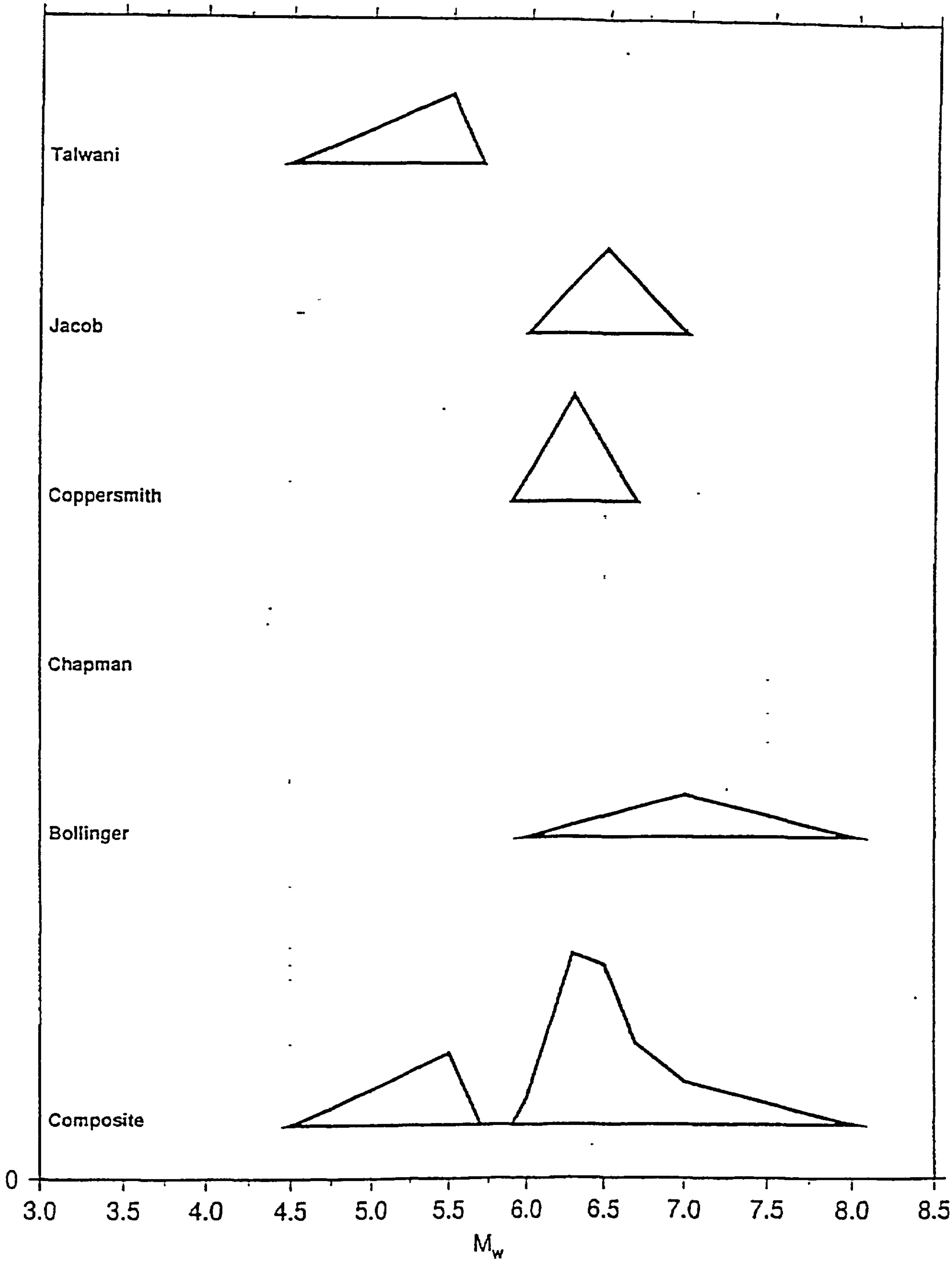

Mu; ZONE 4d
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Mw

M_u; ZONE 4e



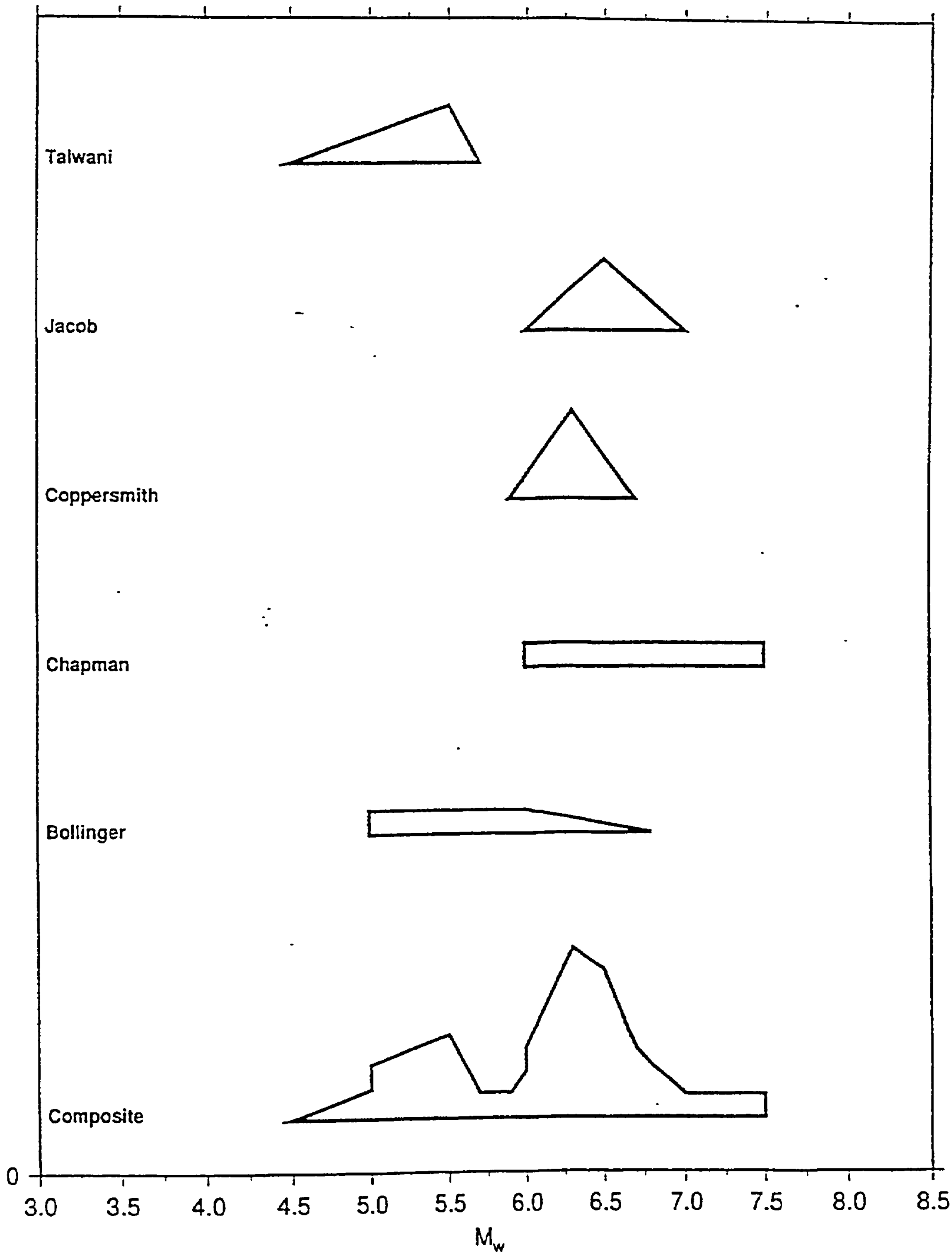
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Mw

M_u; ZONE 5-1



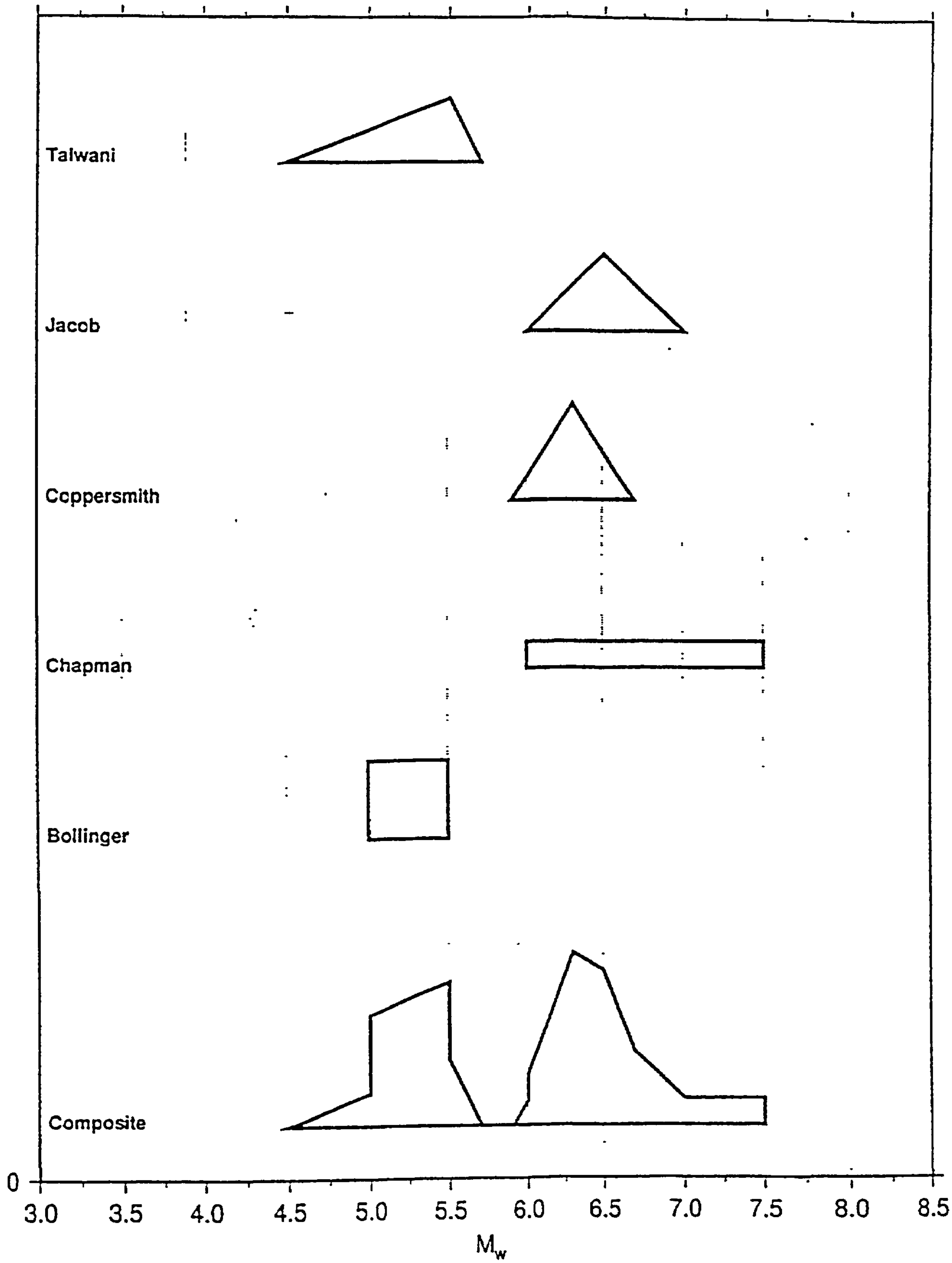
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M
w

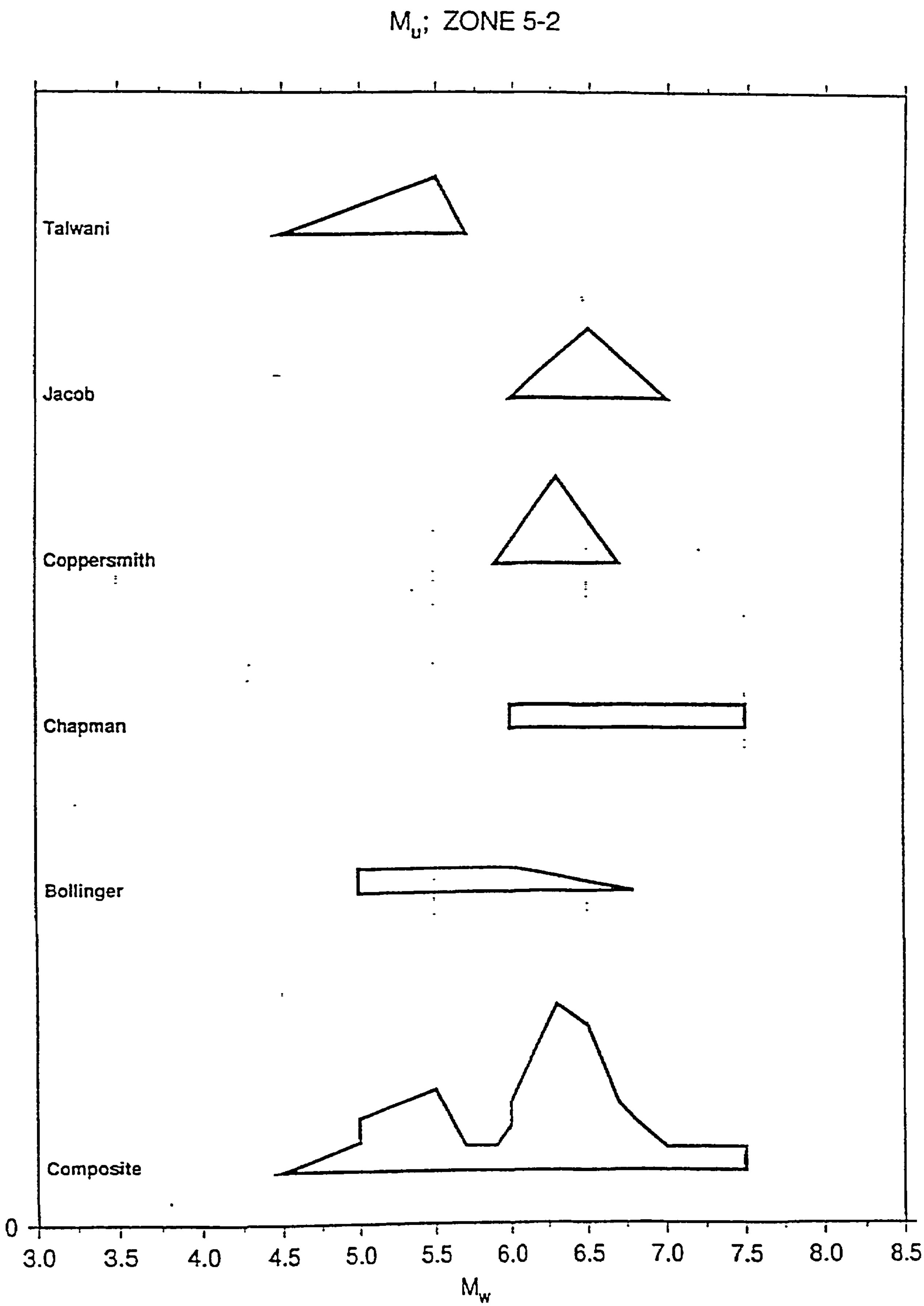
M_u; ZONE 5-1+2

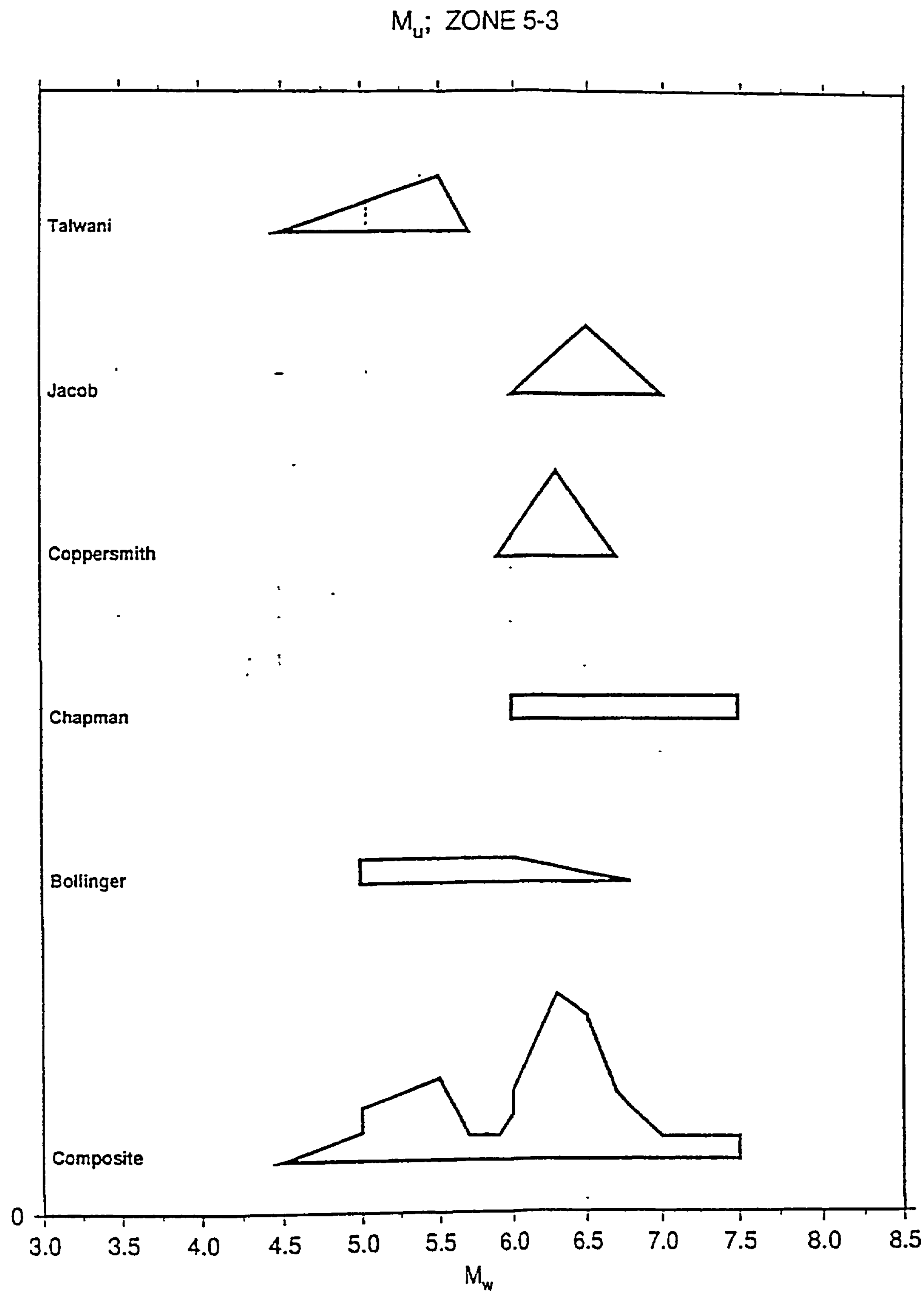


Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w

M_u; ZONE 5-1+2+3

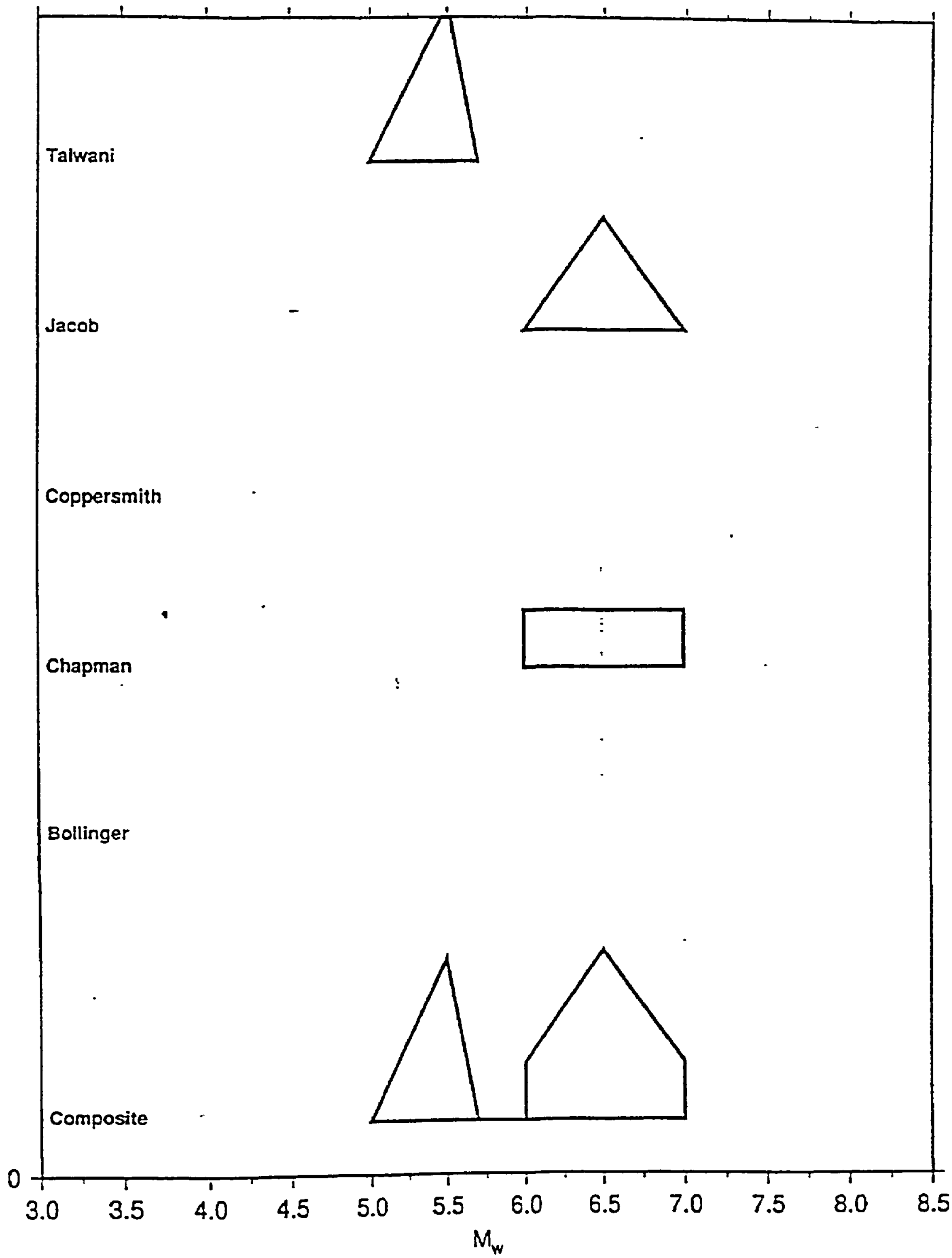

Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Mw


M_u; ZONE 5-2
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w

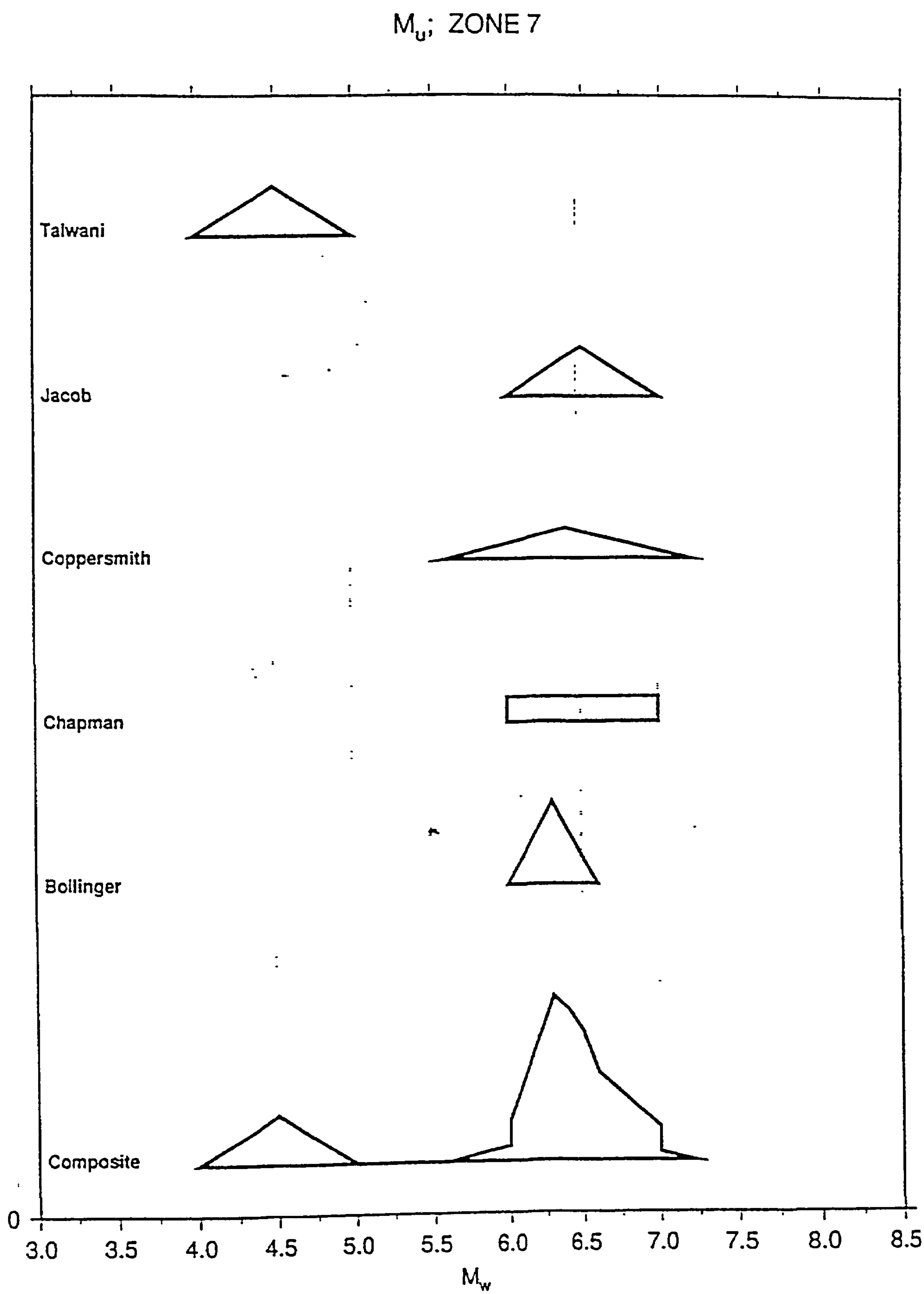


M_u; ZONE 5-3
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w

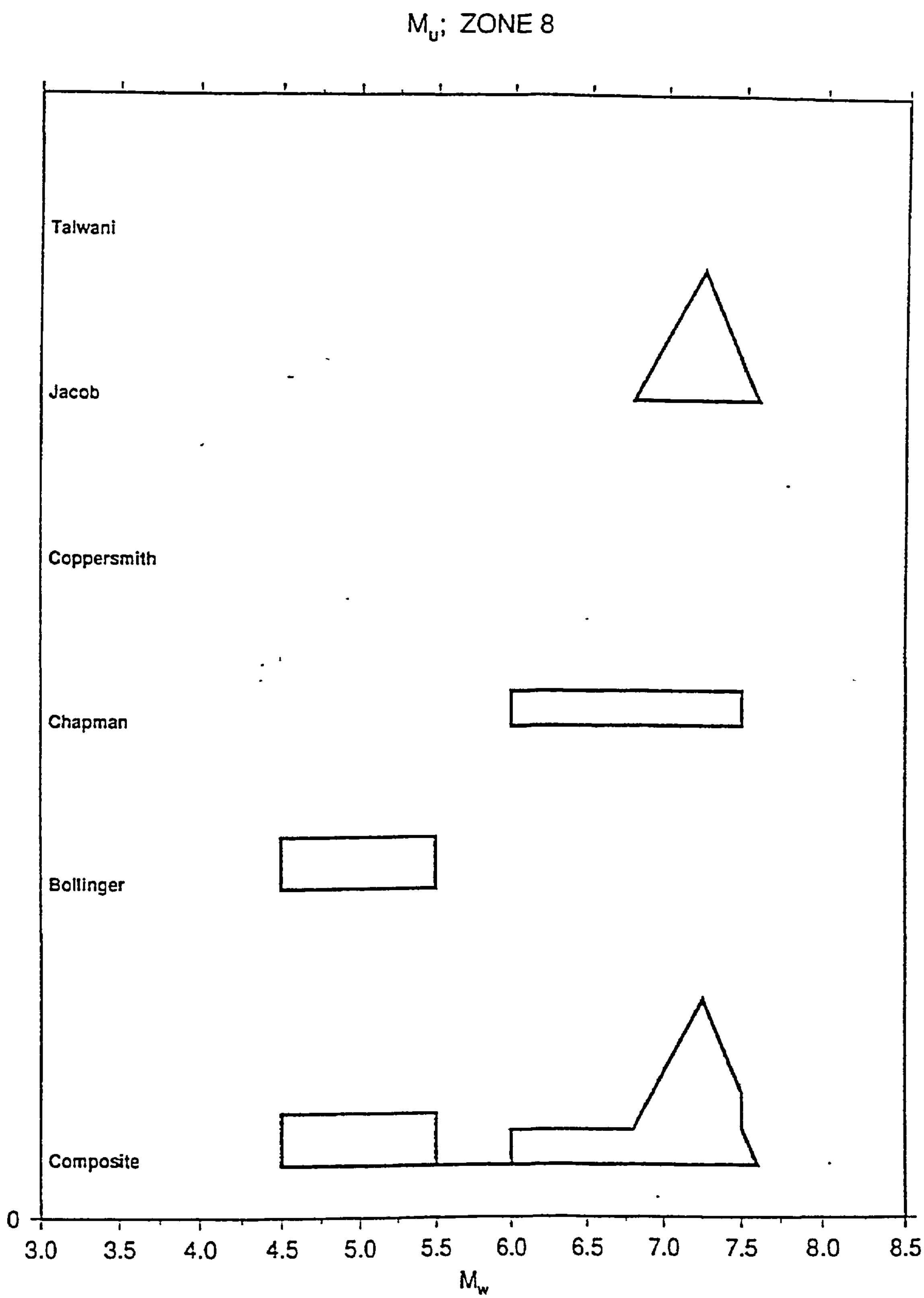
M_u; ZONE 6



Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w

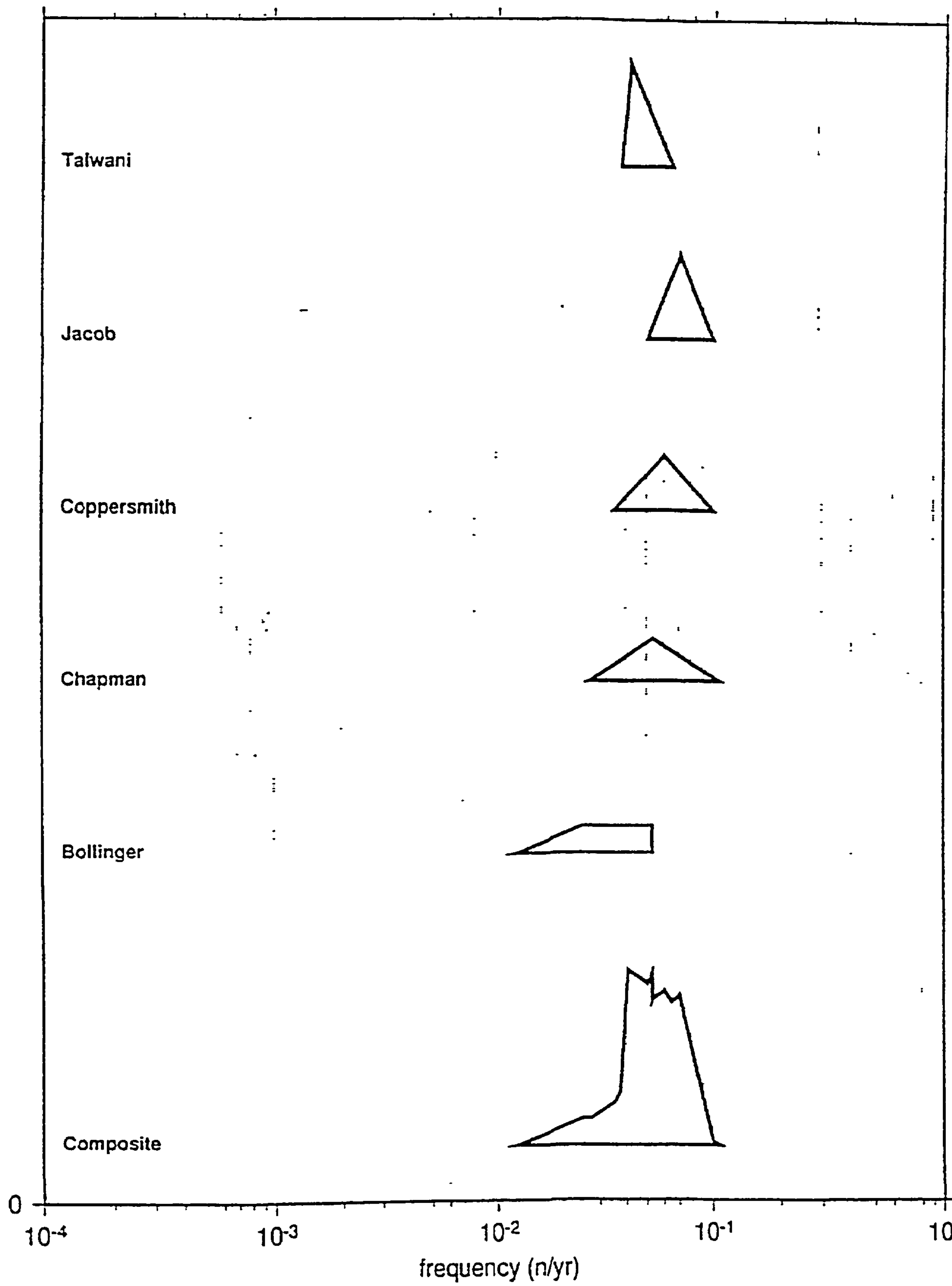


M_u; ZONE 7
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
M_w

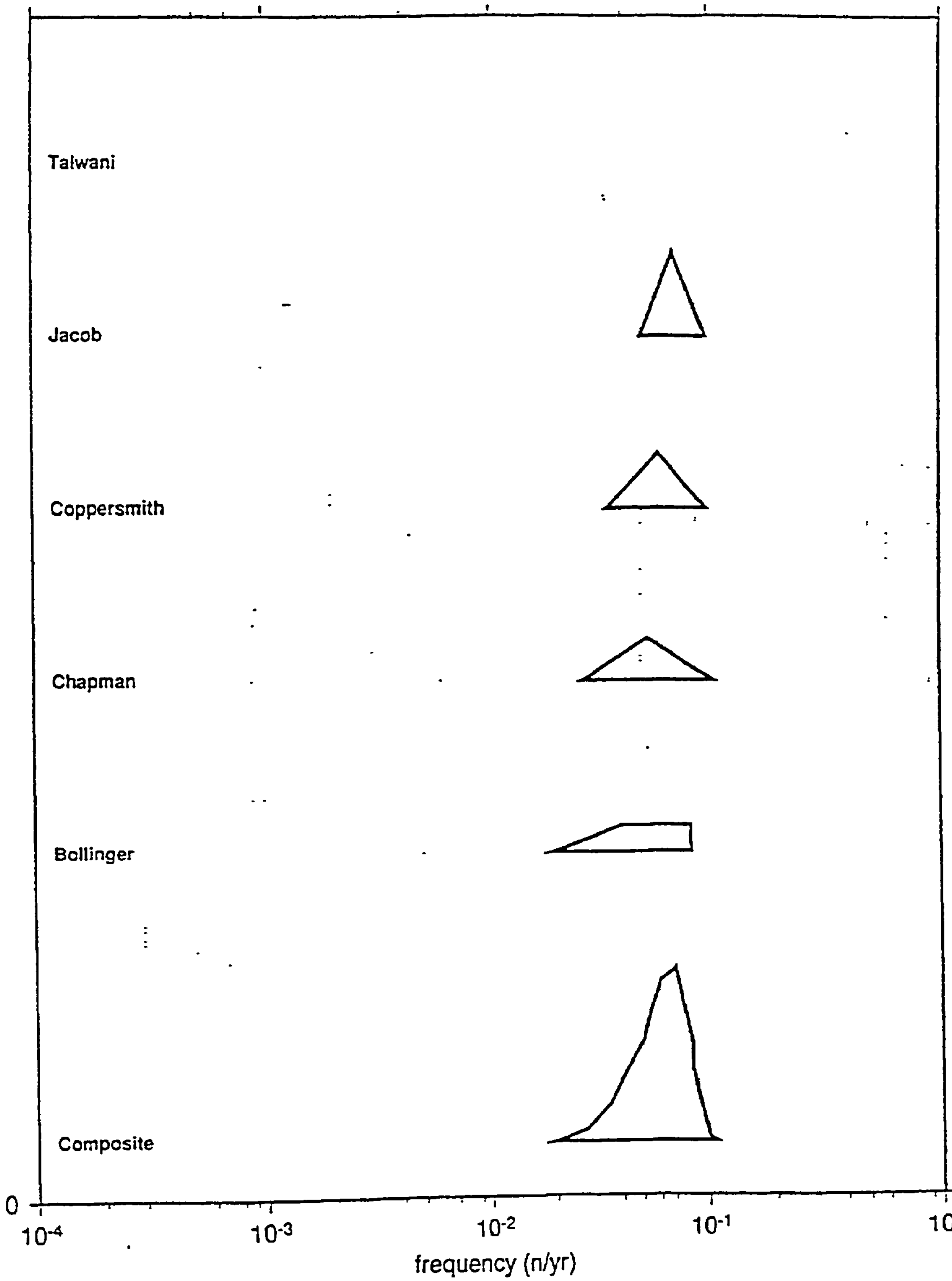


Mu; ZONE 8
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Mw

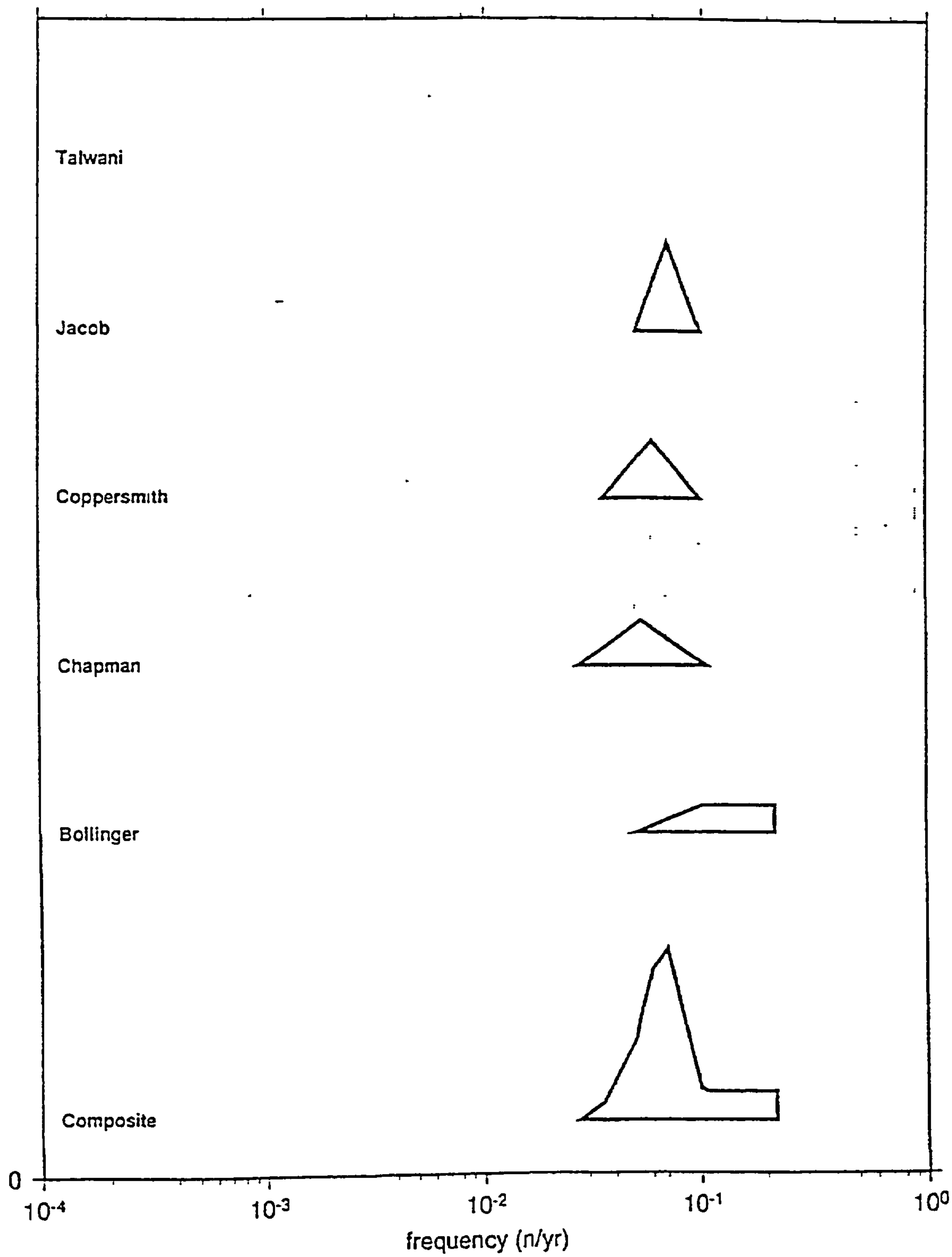
FREQUENCY at M4 ; ZONE 1a



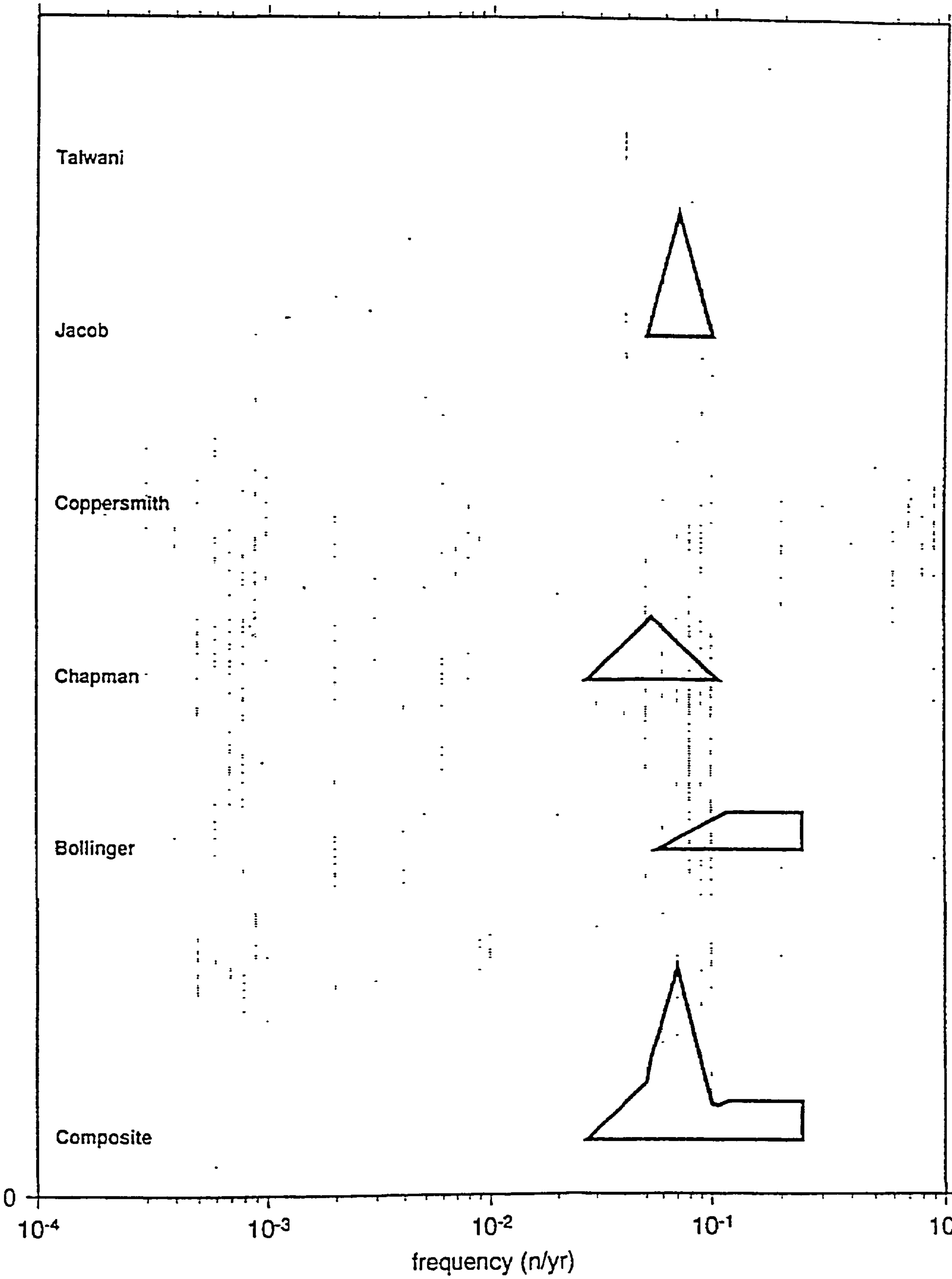
FREQUENCY at M4 ; ZONE 1b



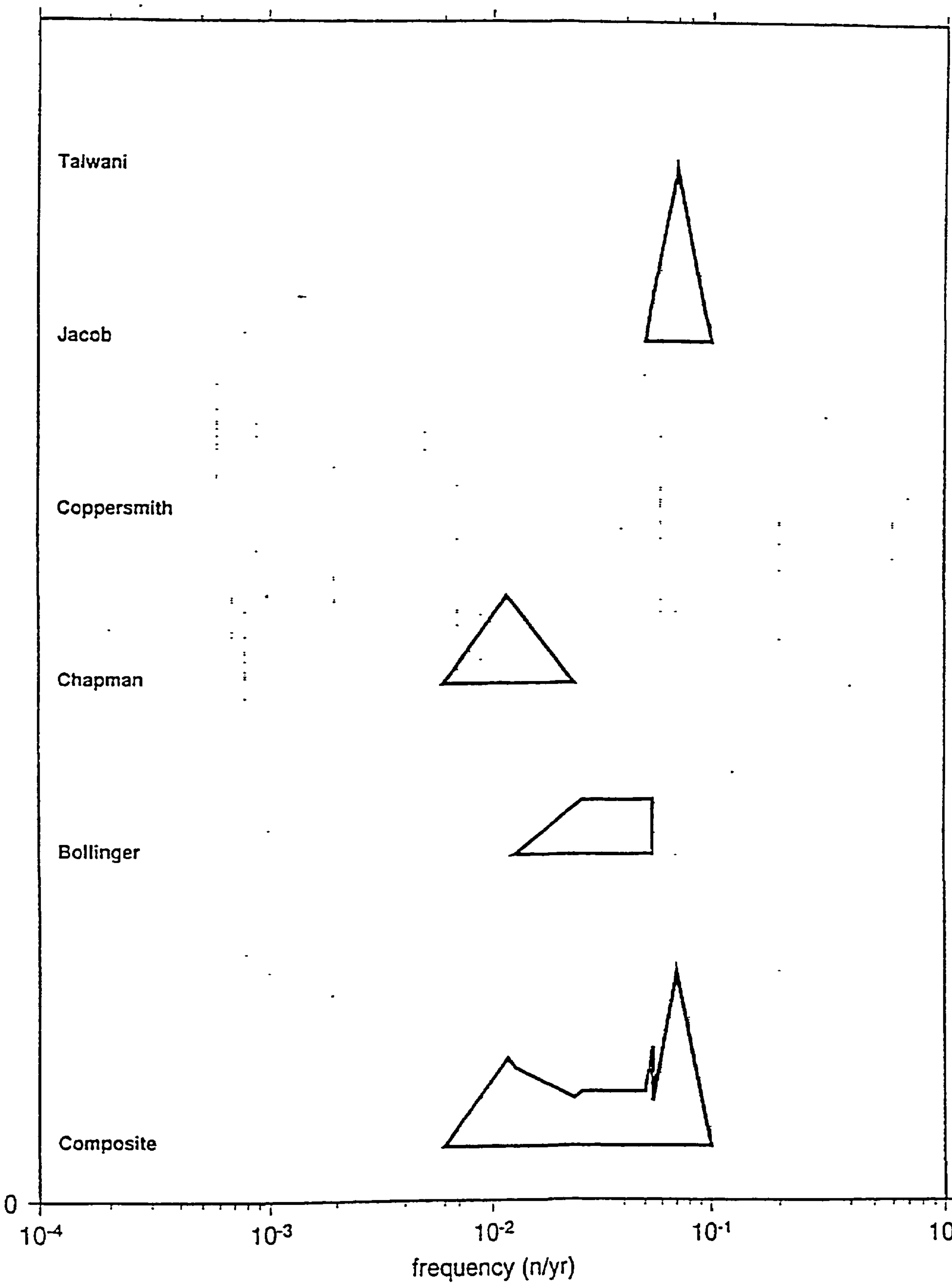
FREQUENCY at M4 ; ZONE 1c



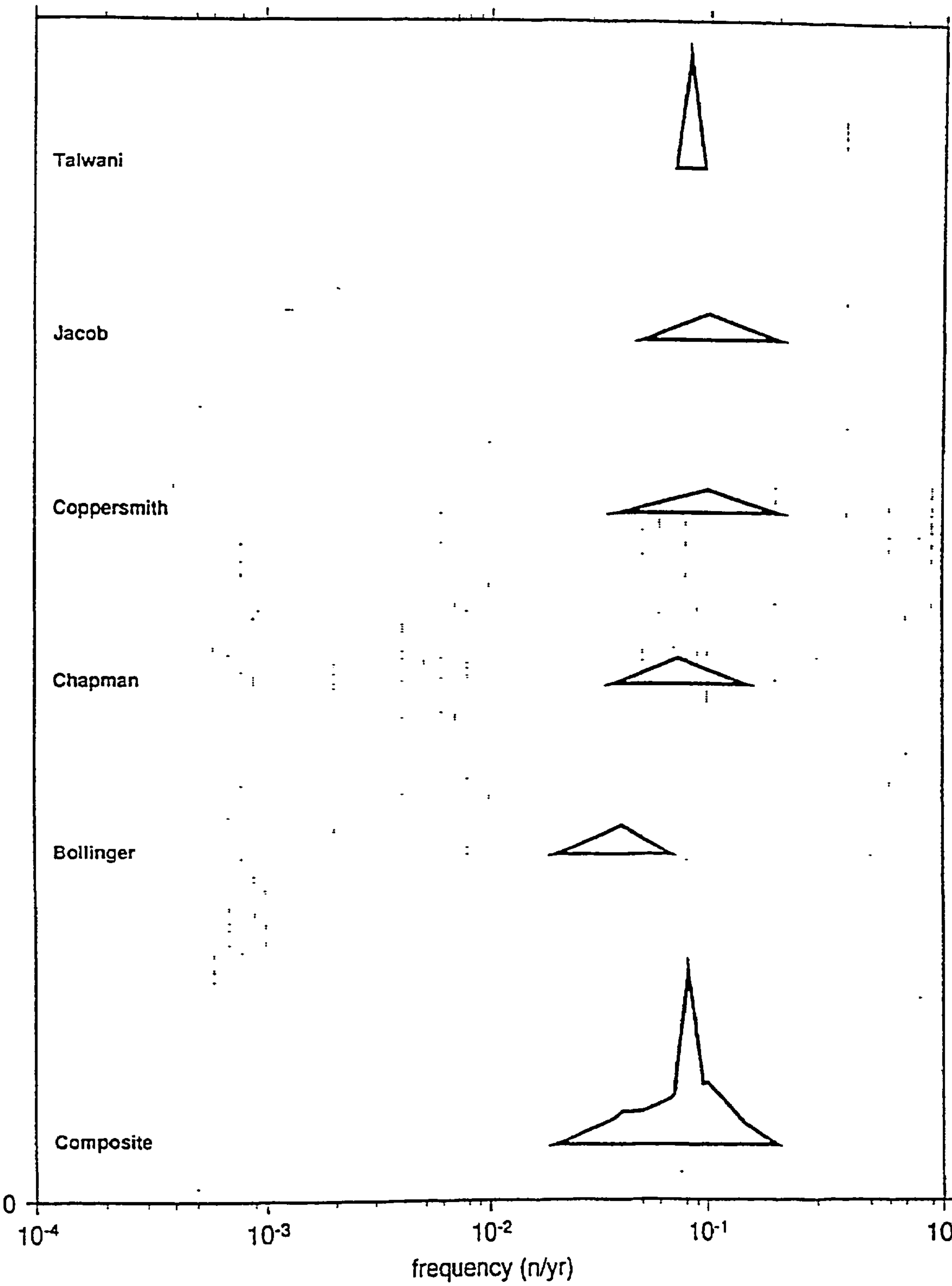
FREQUENCY at M4 ; ZONE 1d



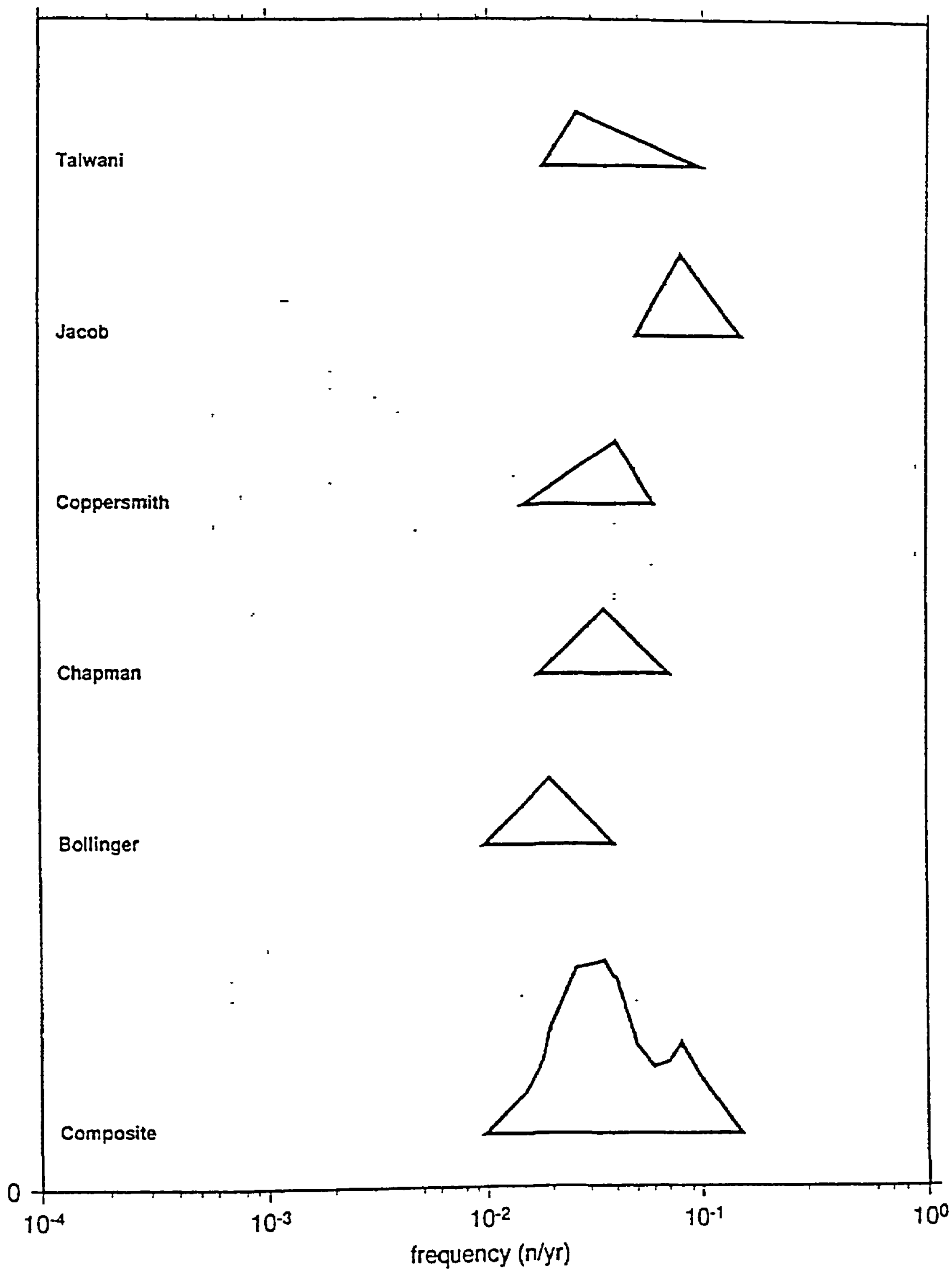
FREQUENCY at M4 ; ZONE 1e



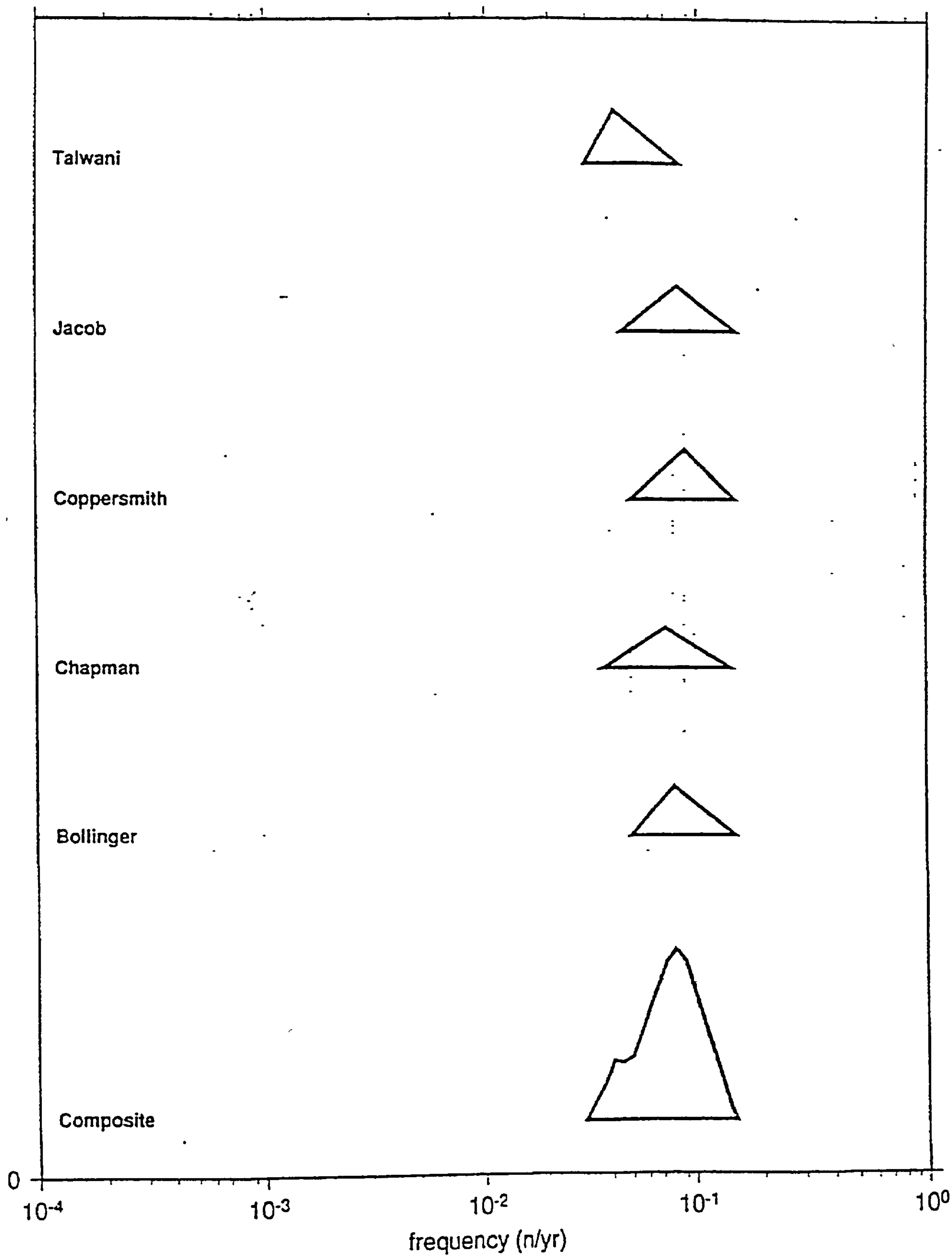
FREQUENCY at M4 ; ZONE 3a



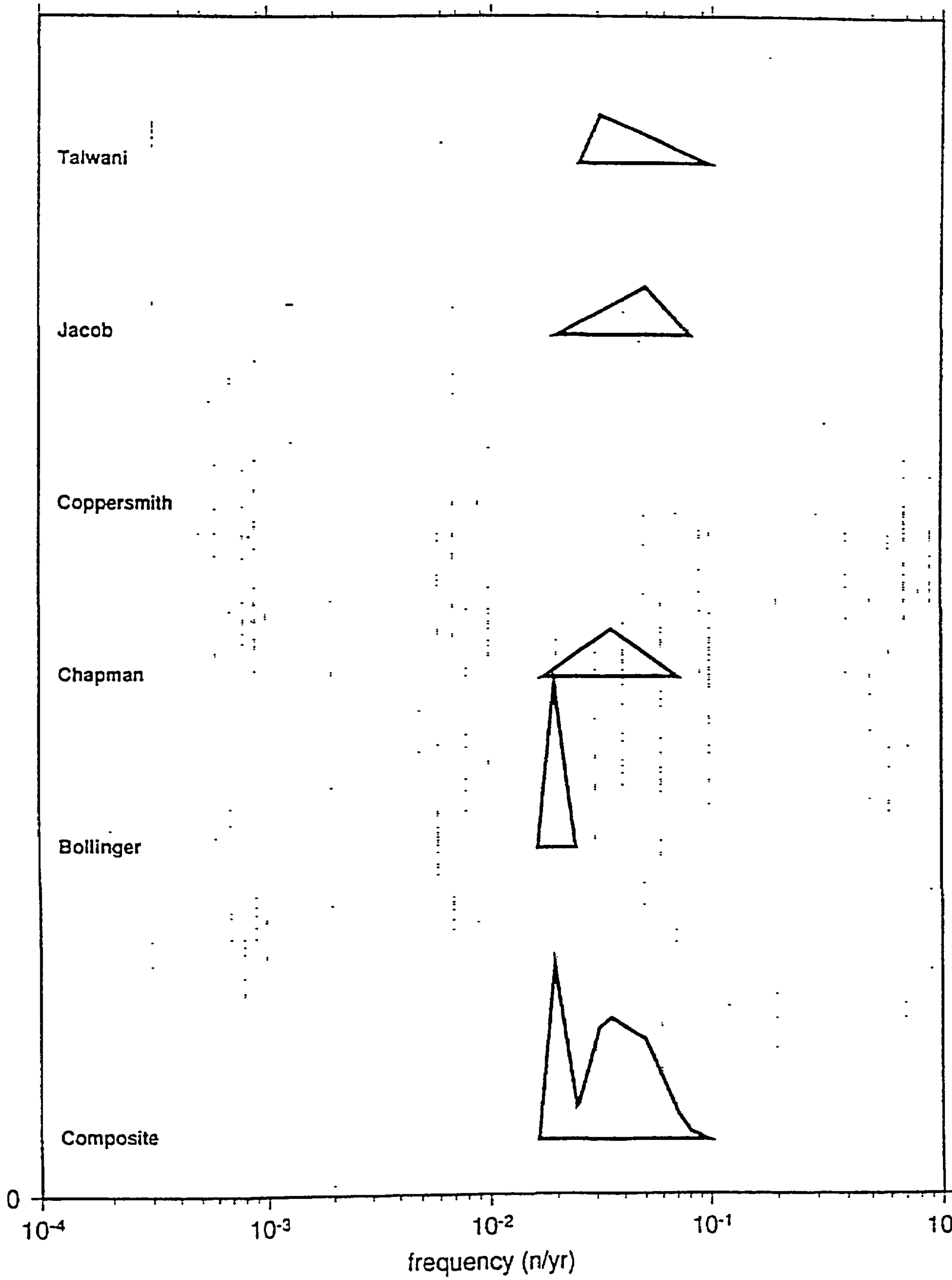
FREQUENCY at M4 ; ZONE 3b-3a

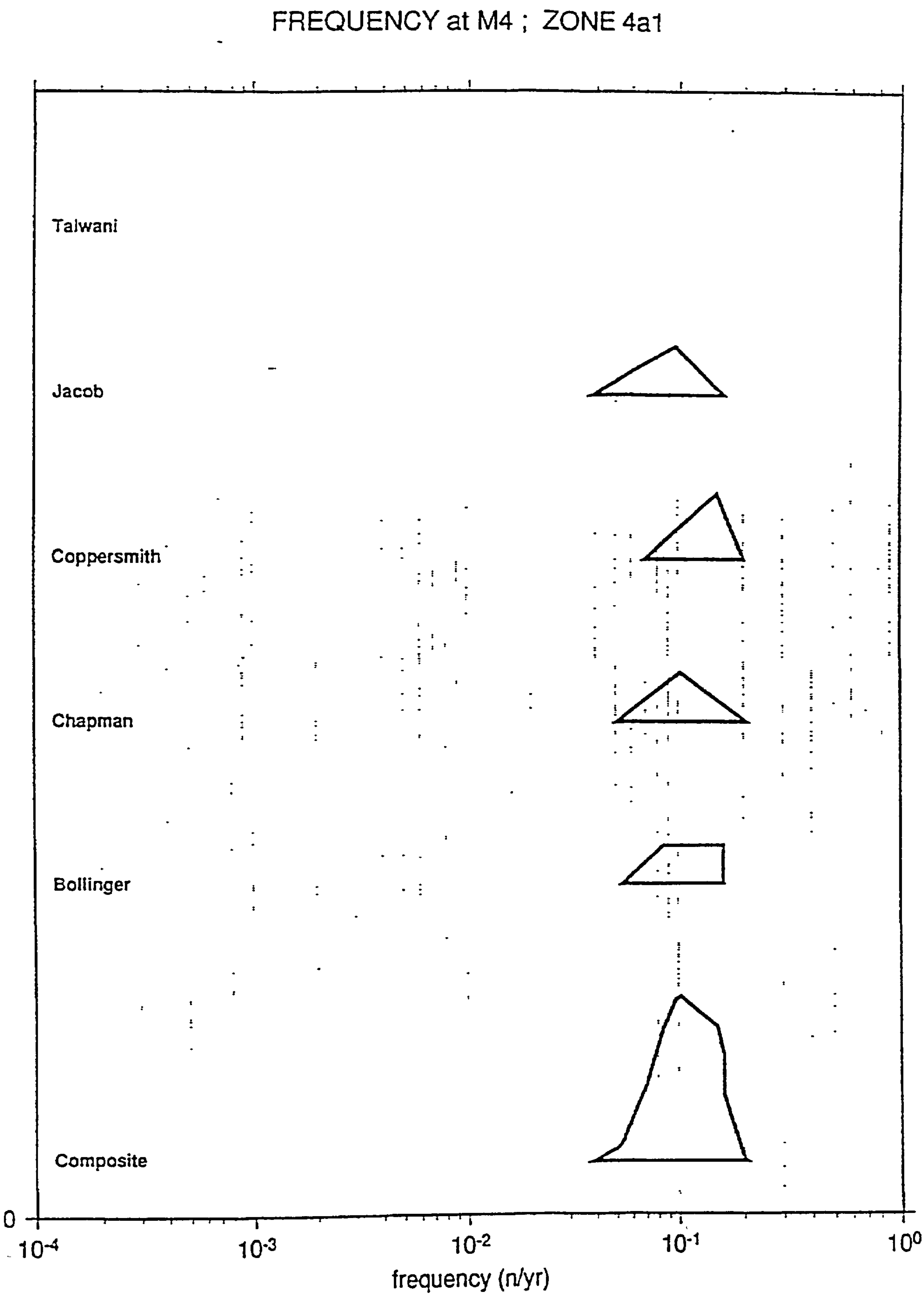


FREQUENCY at M4 ; ZONE 3c



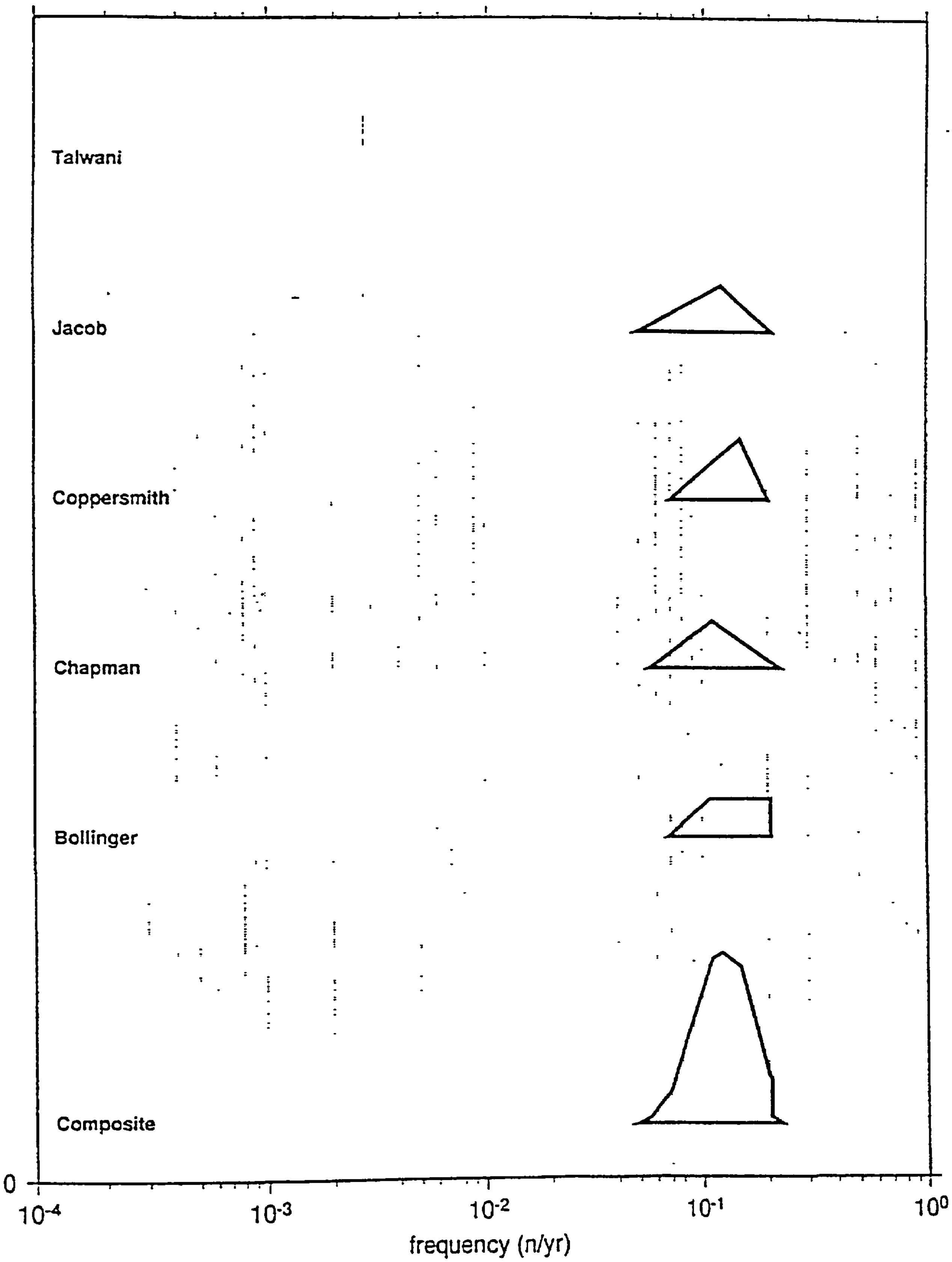
FREQUENCY at M4 ; ZONE 3b-3c

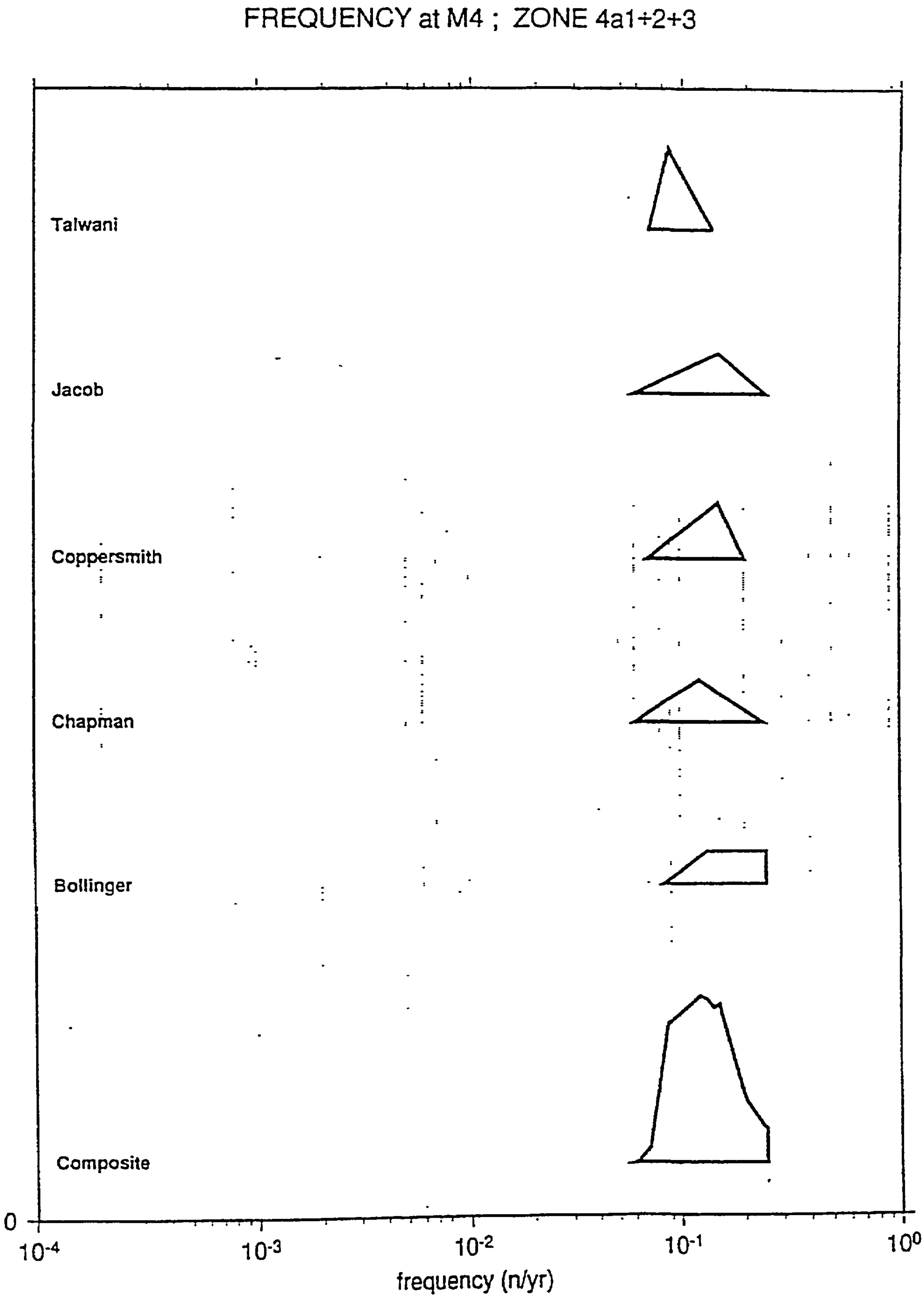




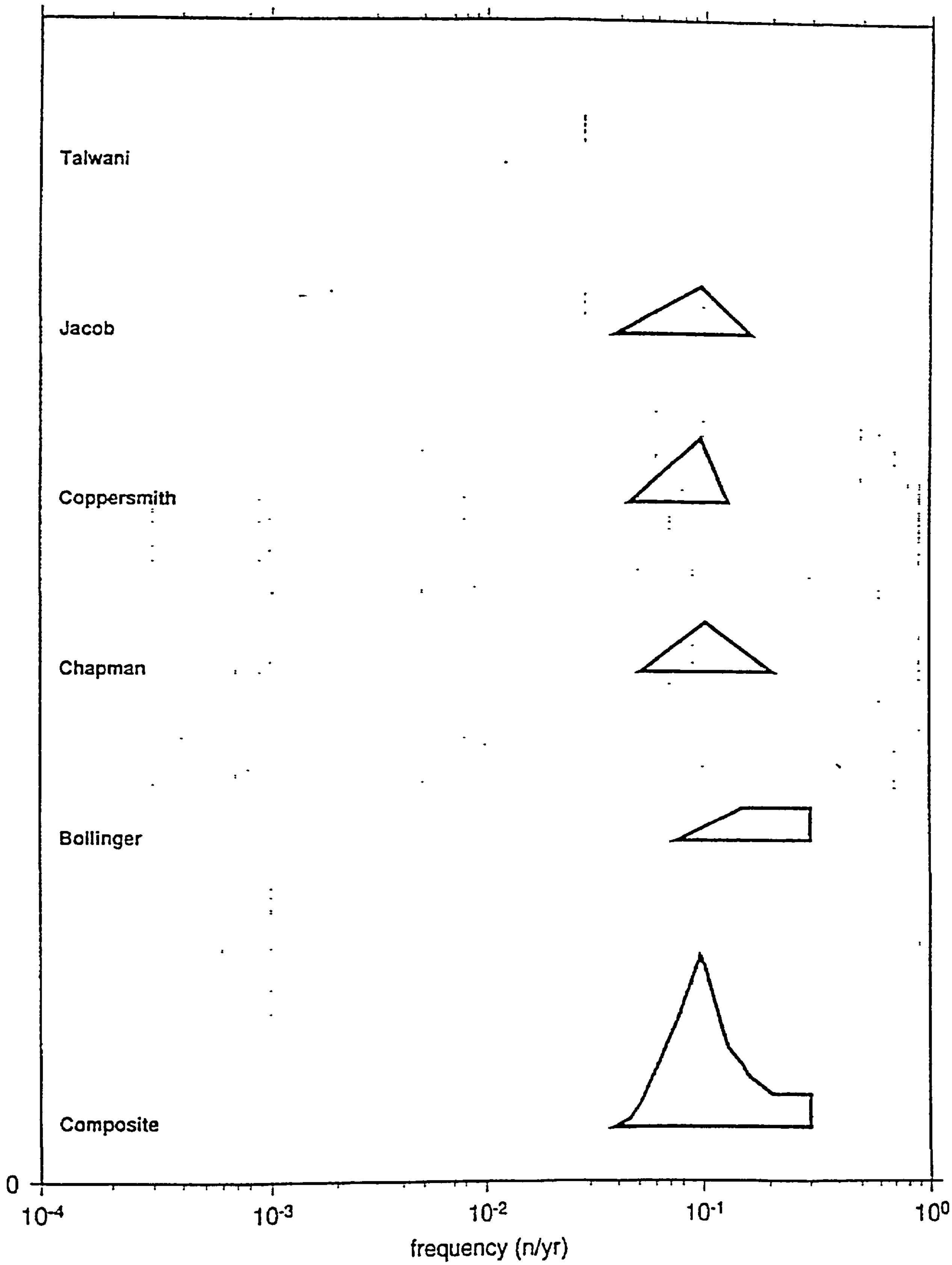
FREQUENCY at M4 ; ZONE 4a1
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
10-4
10-3
10-2
10-1
100
frequency (n/yr)

FREQUENCY at M4 ; ZONE 4a1+2

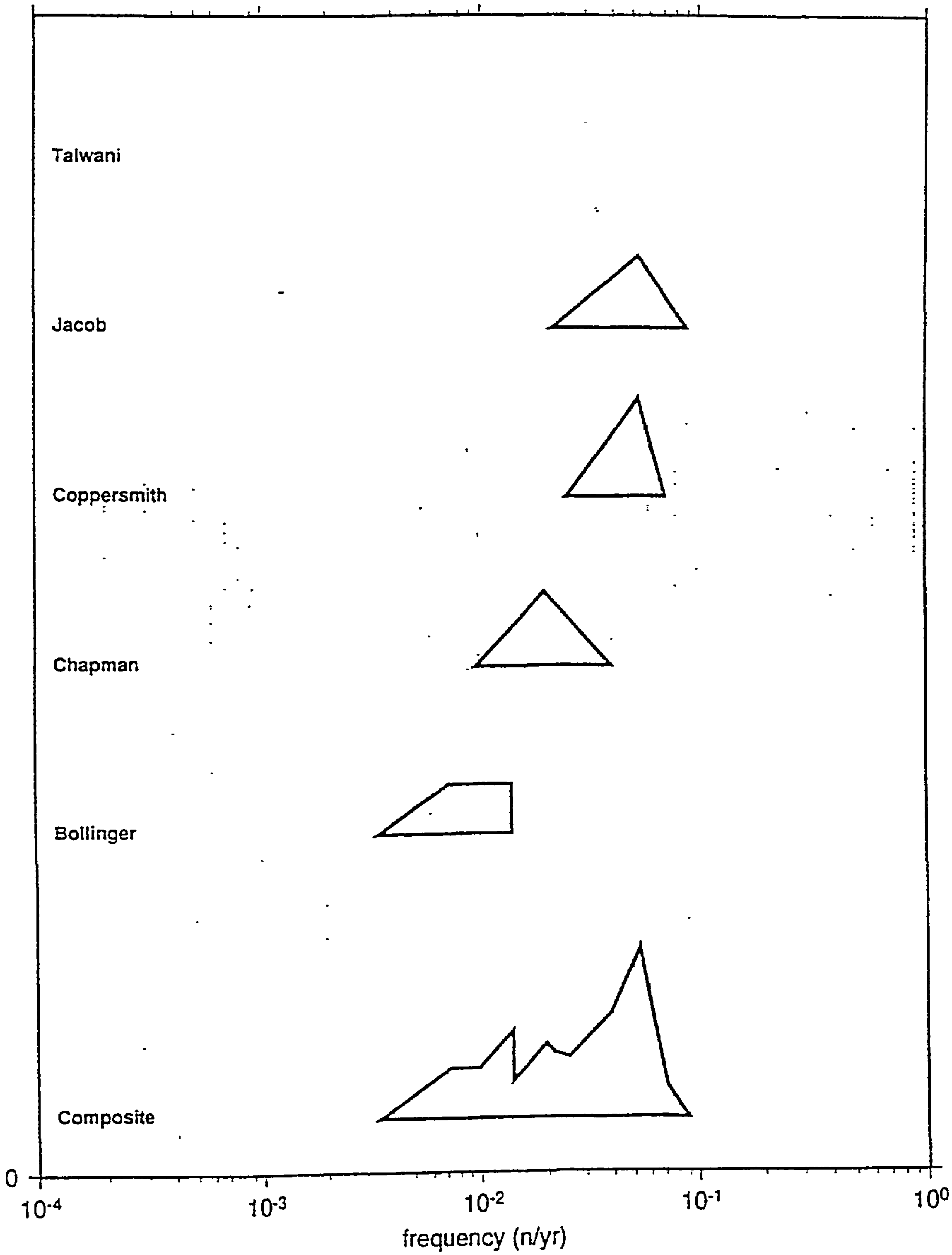



FREQUENCY at M4 ; ZONE 4a1+2+3
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
frequency (n/yr)

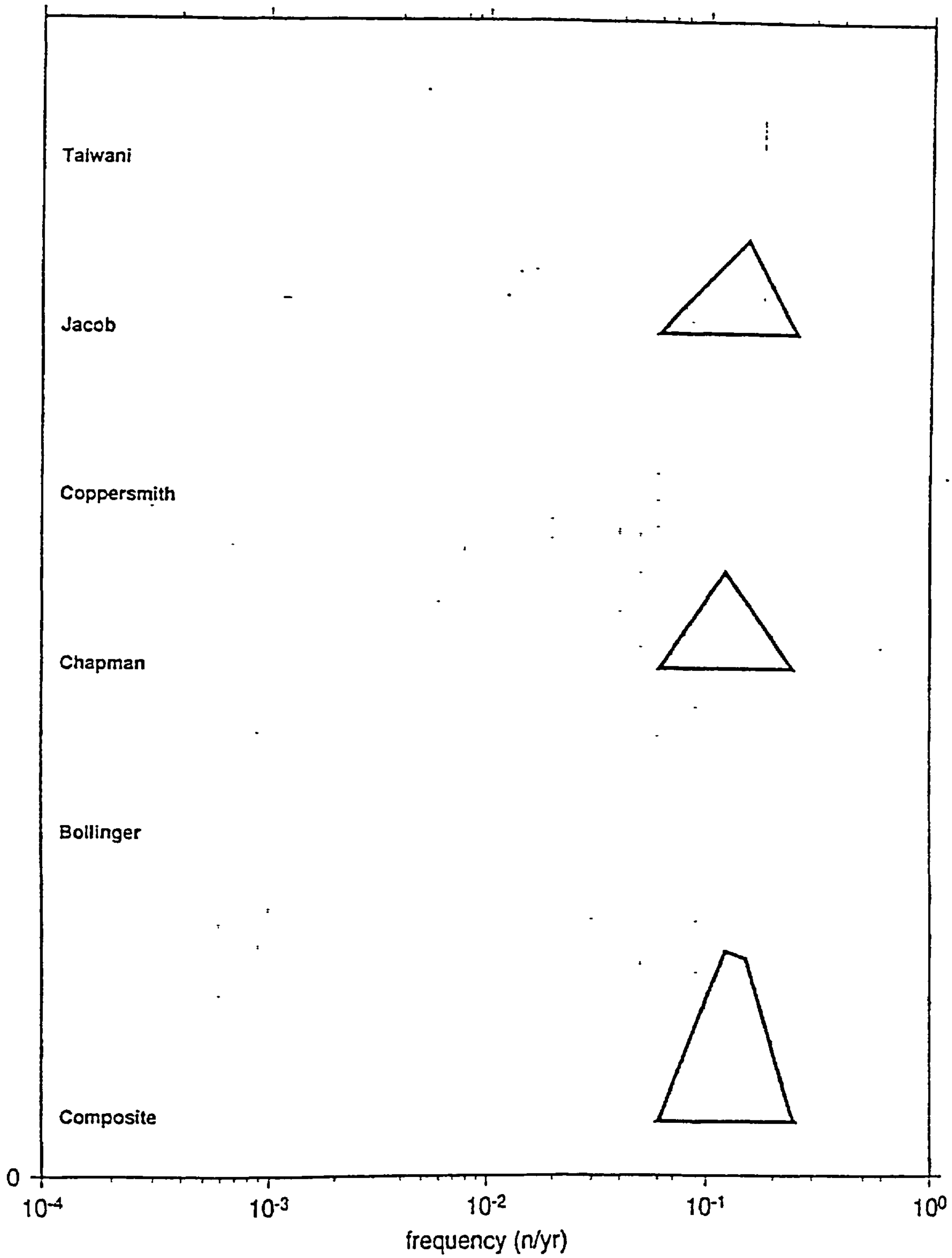
FREQUENCY at M4 ; ZONE 4b1



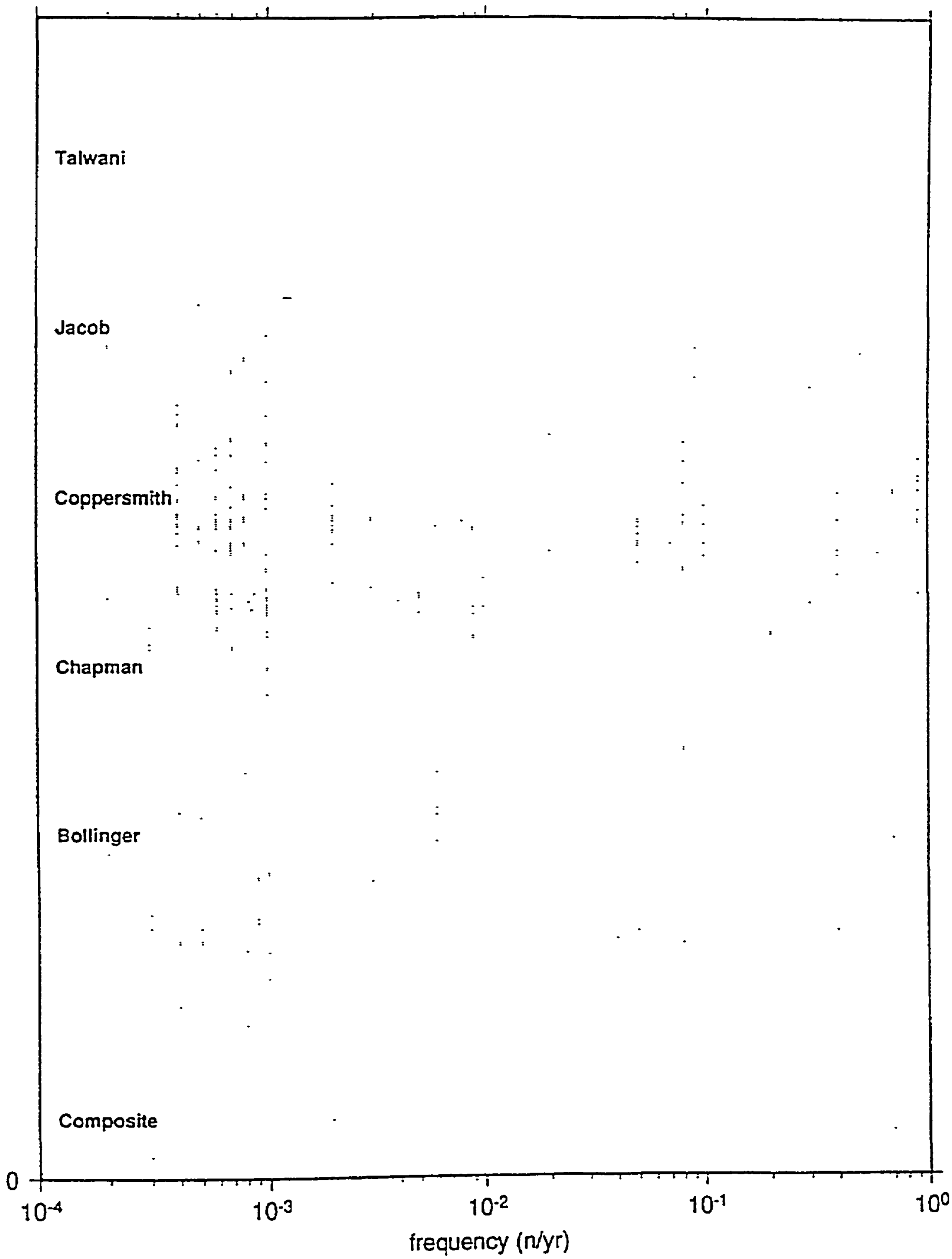
FREQUENCY at M4 ; ZONE 4b2



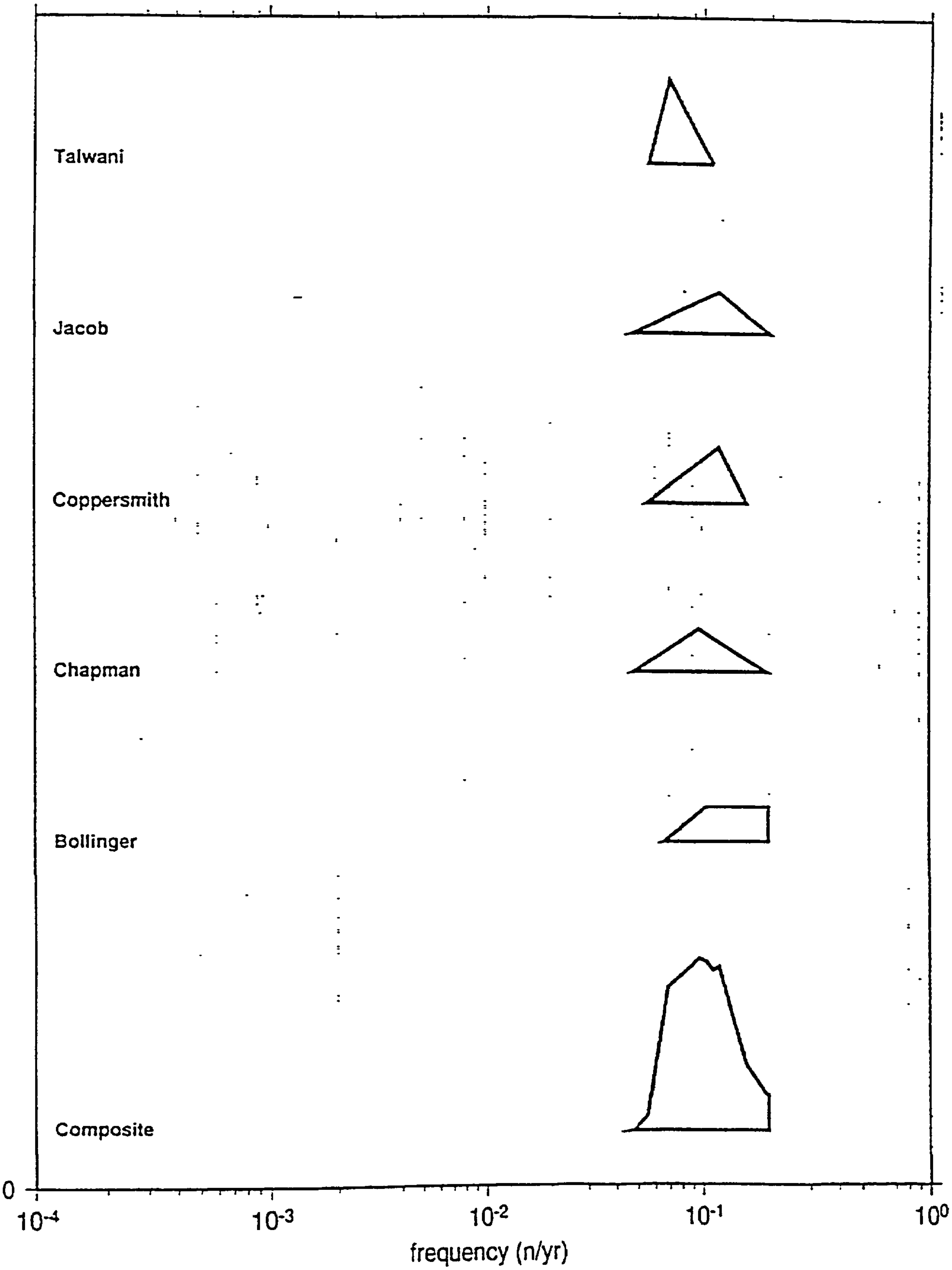
FREQUENCY at M4 ; ZONE 4c



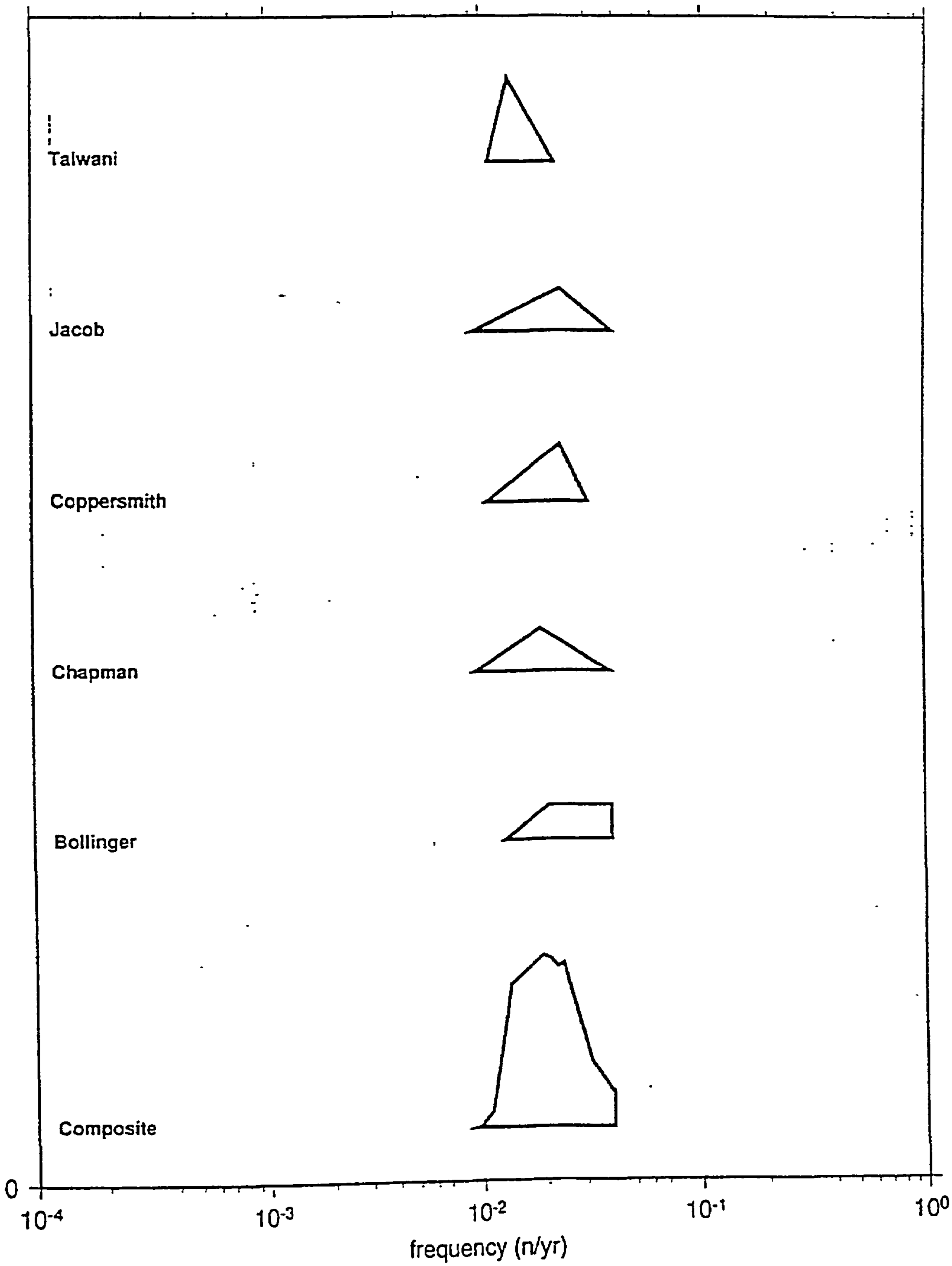
FREQUENCY at M4 ; ZONE 4d



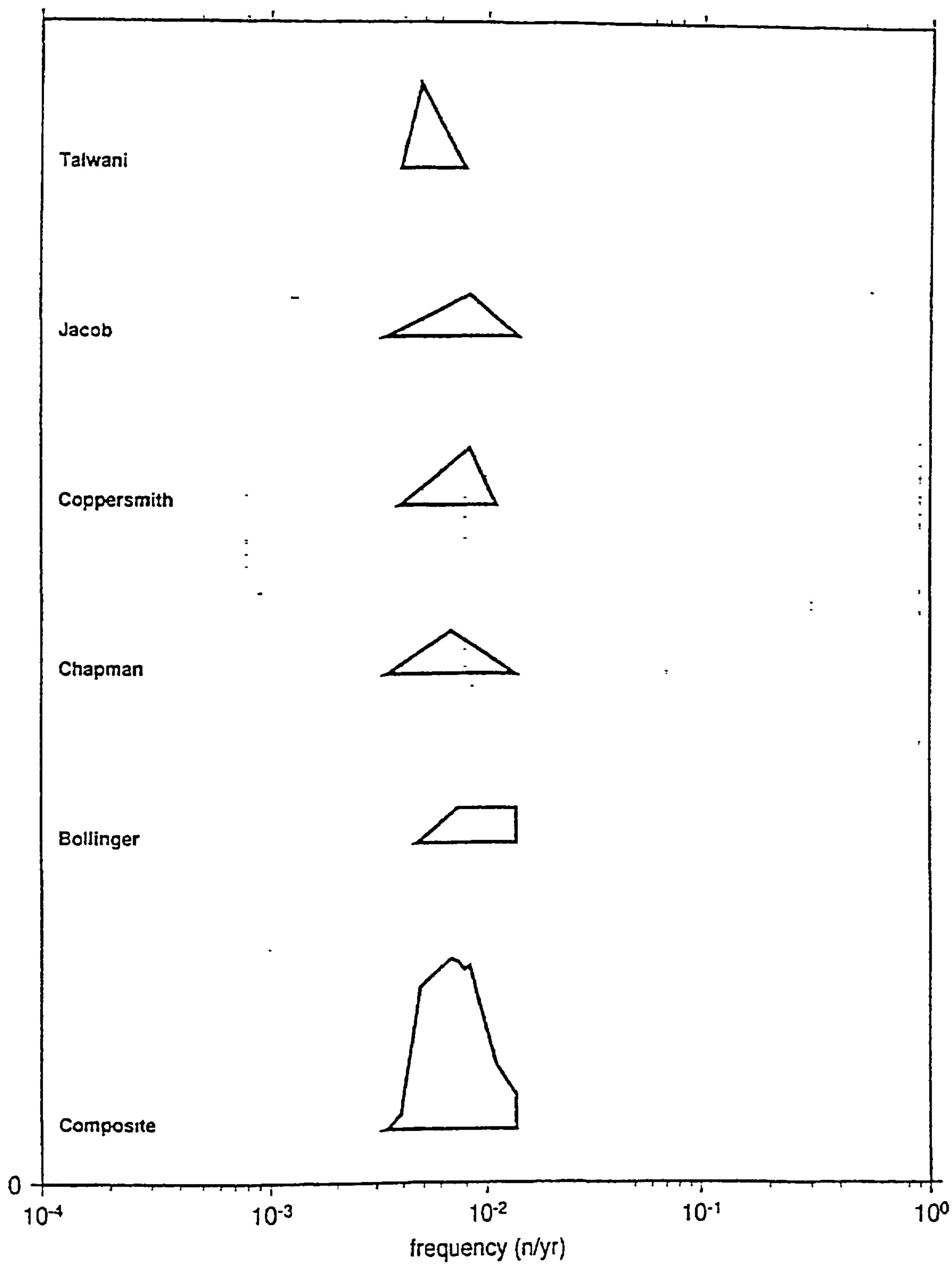
FREQUENCY at M4 ; ZONE 4e1



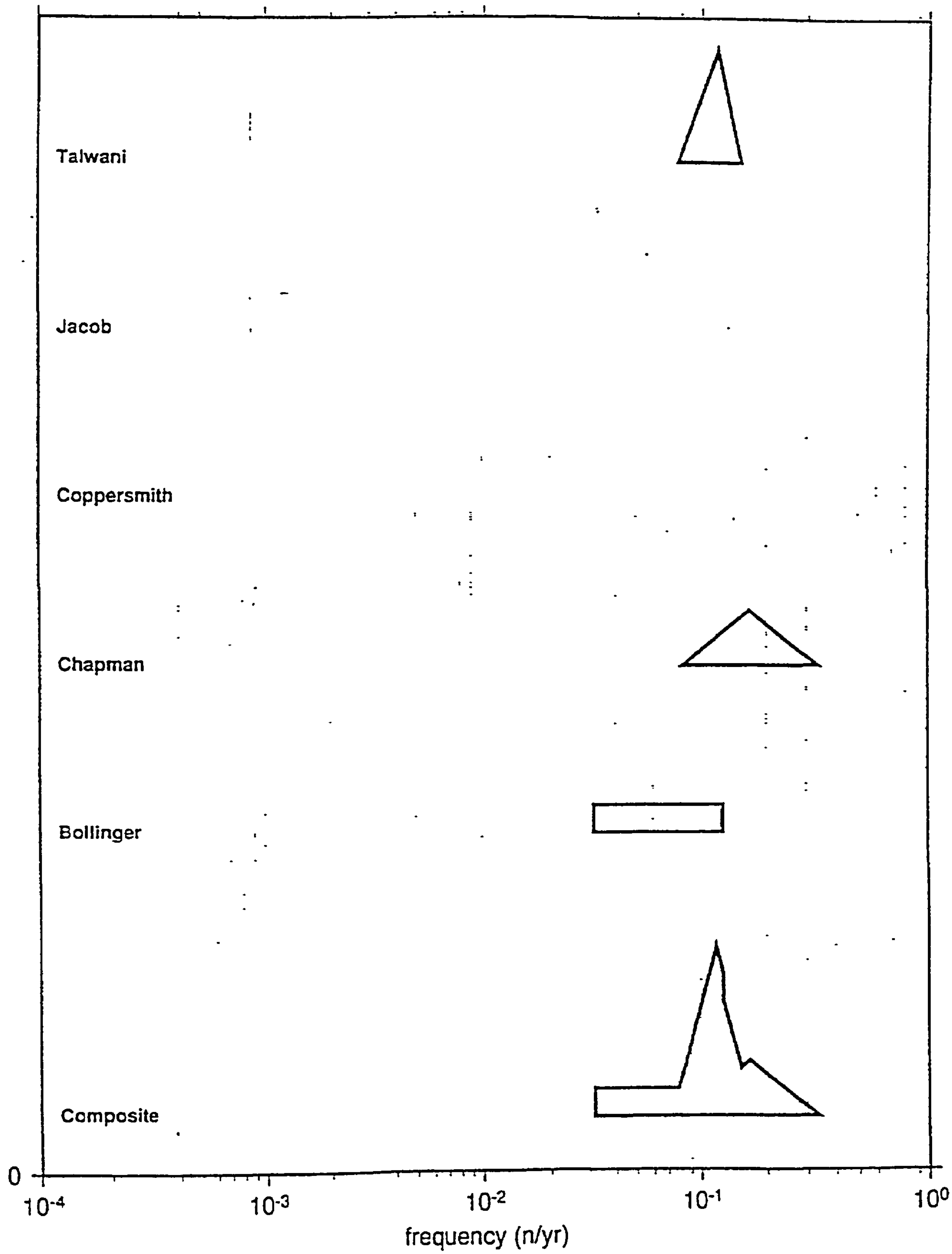
FREQUENCY at M4 ; ZONE 4e2



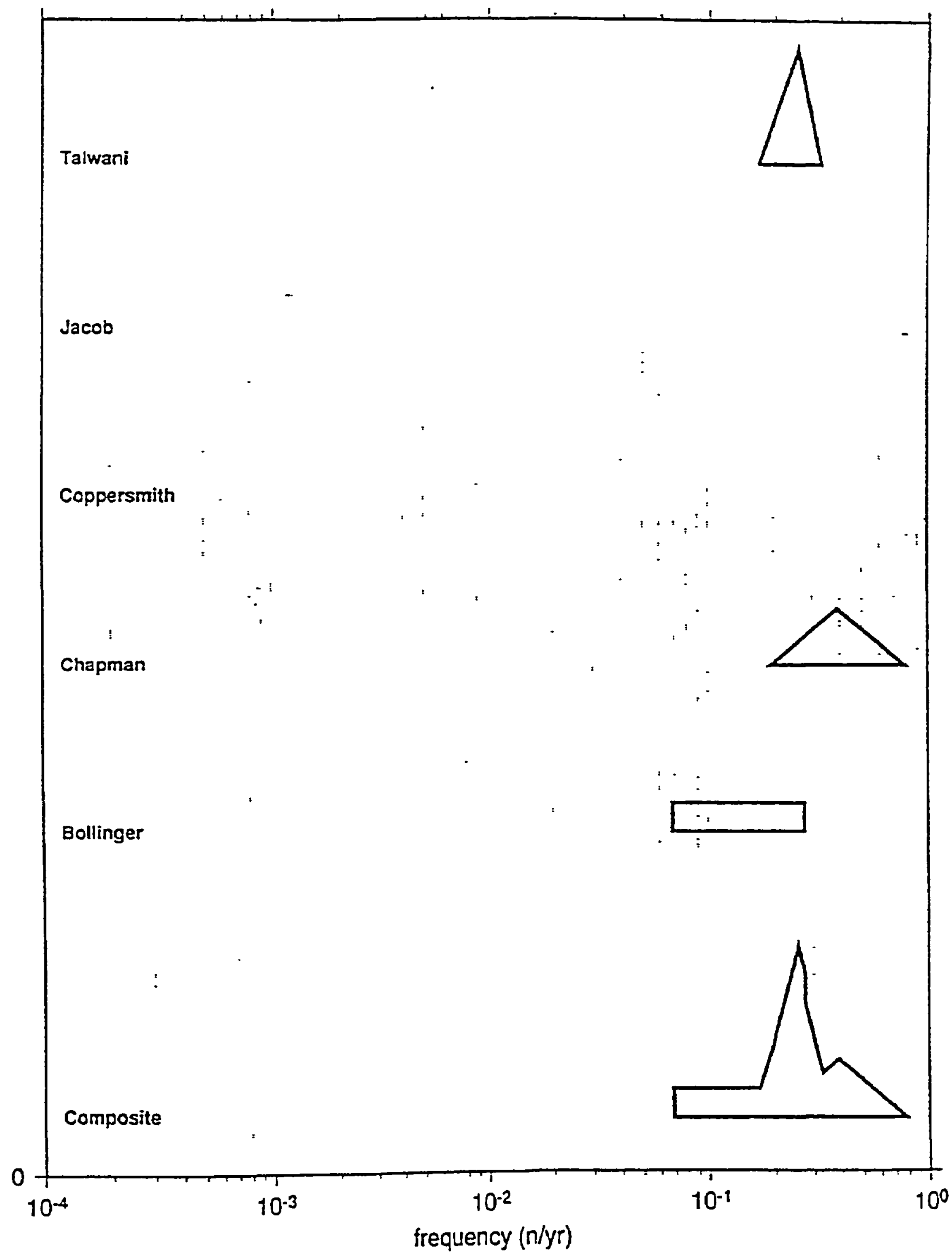
FREQUENCY at M4 ; ZONE 4e3

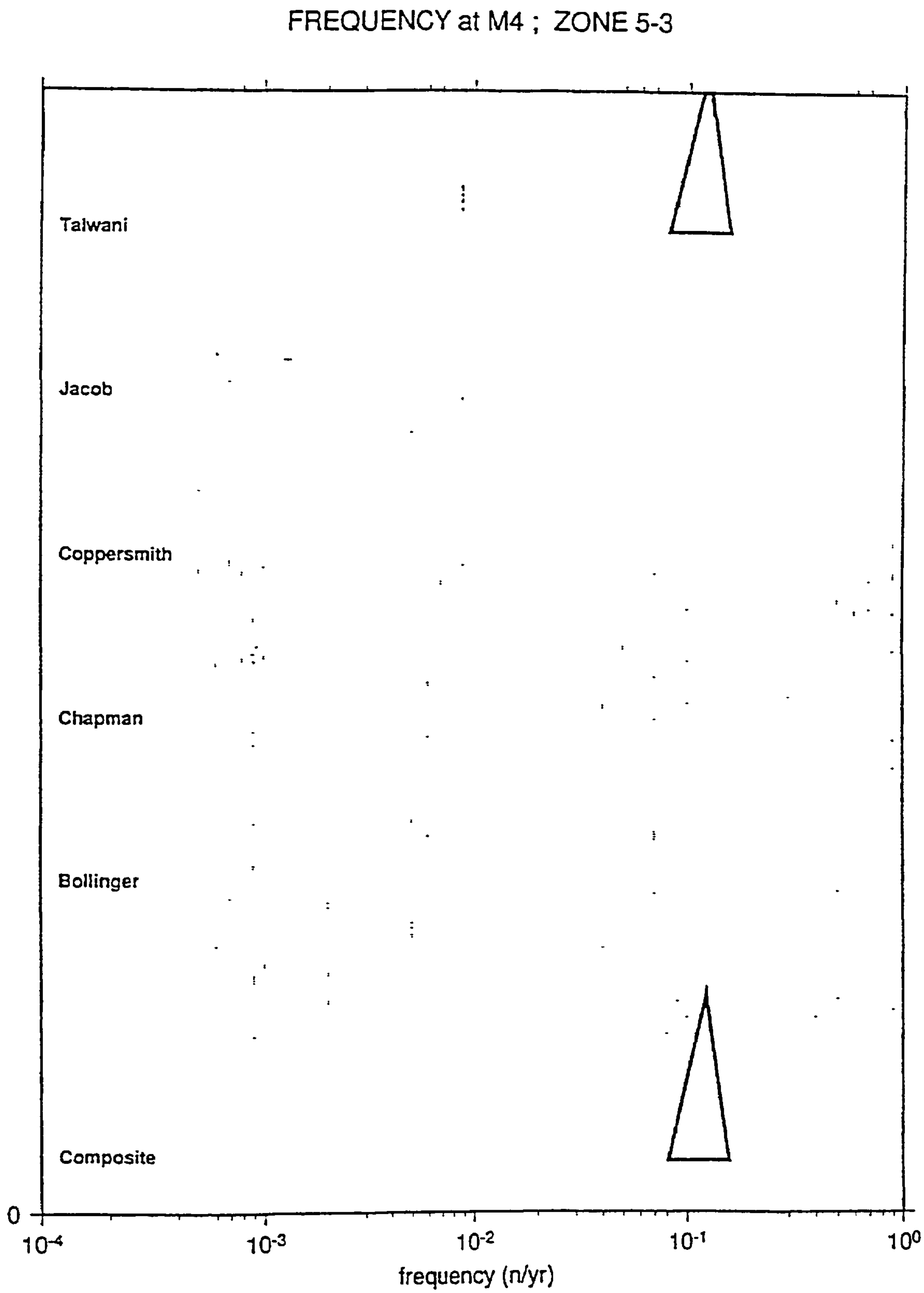


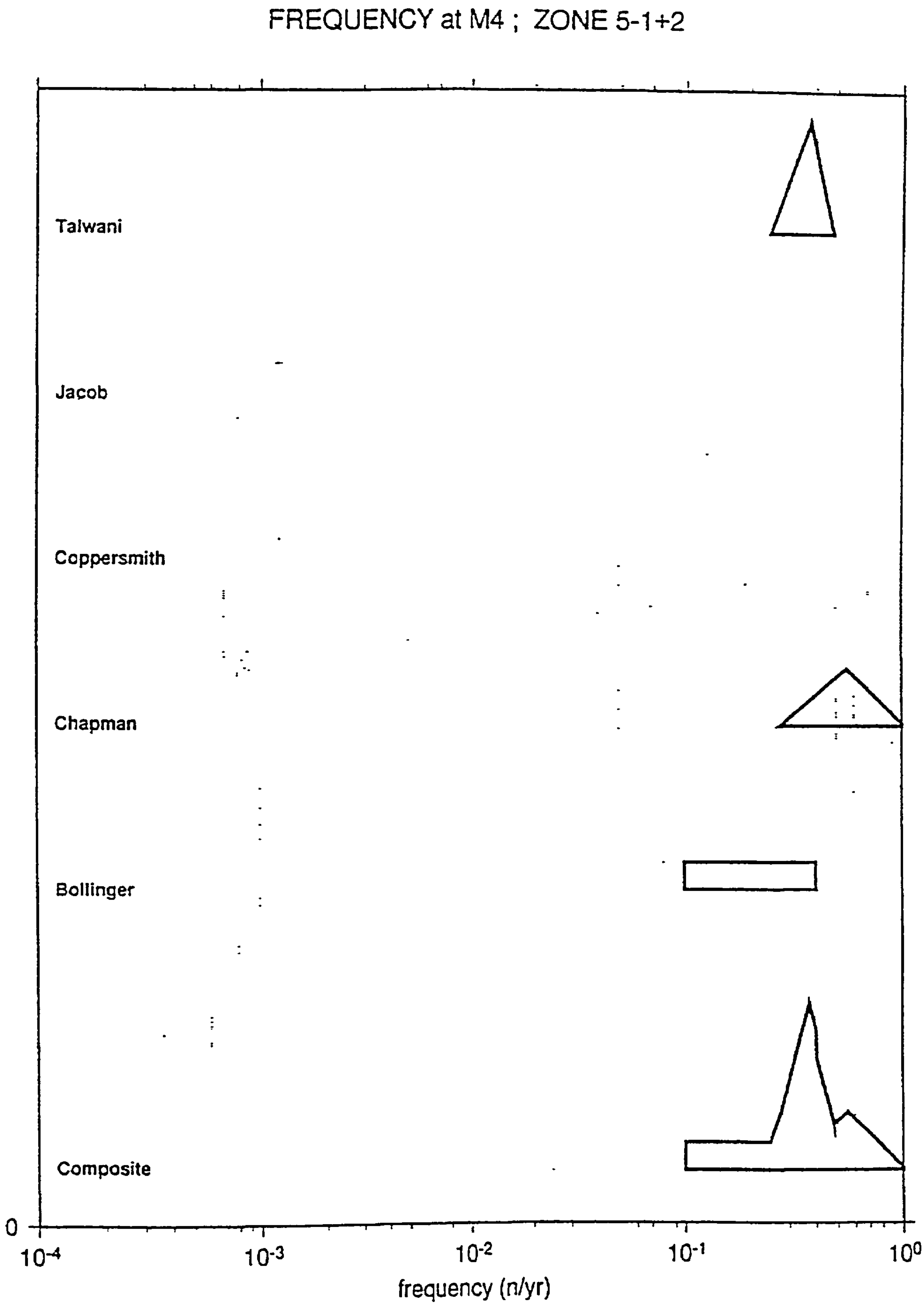
FREQUENCY at M4 ; ZONE 5-1



FREQUENCY at M4 ; ZONE 5-2




FREQUENCY at M4 ; ZONE 5-3
Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
10-4
10-3
10-2
10-1
100
frequency (n/yr)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Talwani
Jacob
Coppersmith
Chapman
Bollinger
Composite
0
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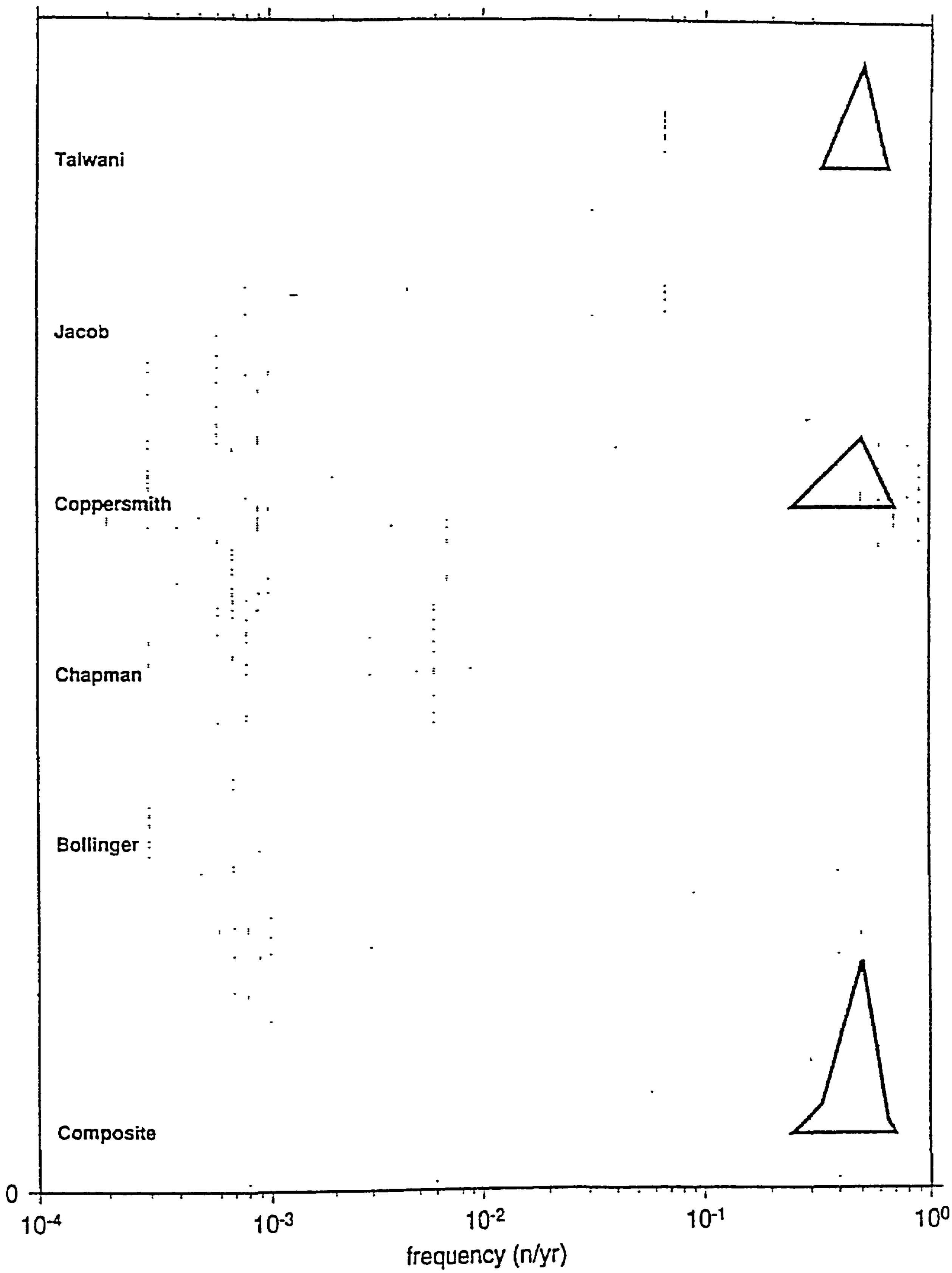
10^{-3}
10^{-2}
10^{-1}
10^{0}
frequency (n/yr)

FREQUENCY at M4 ; ZONE 5-1+2+3



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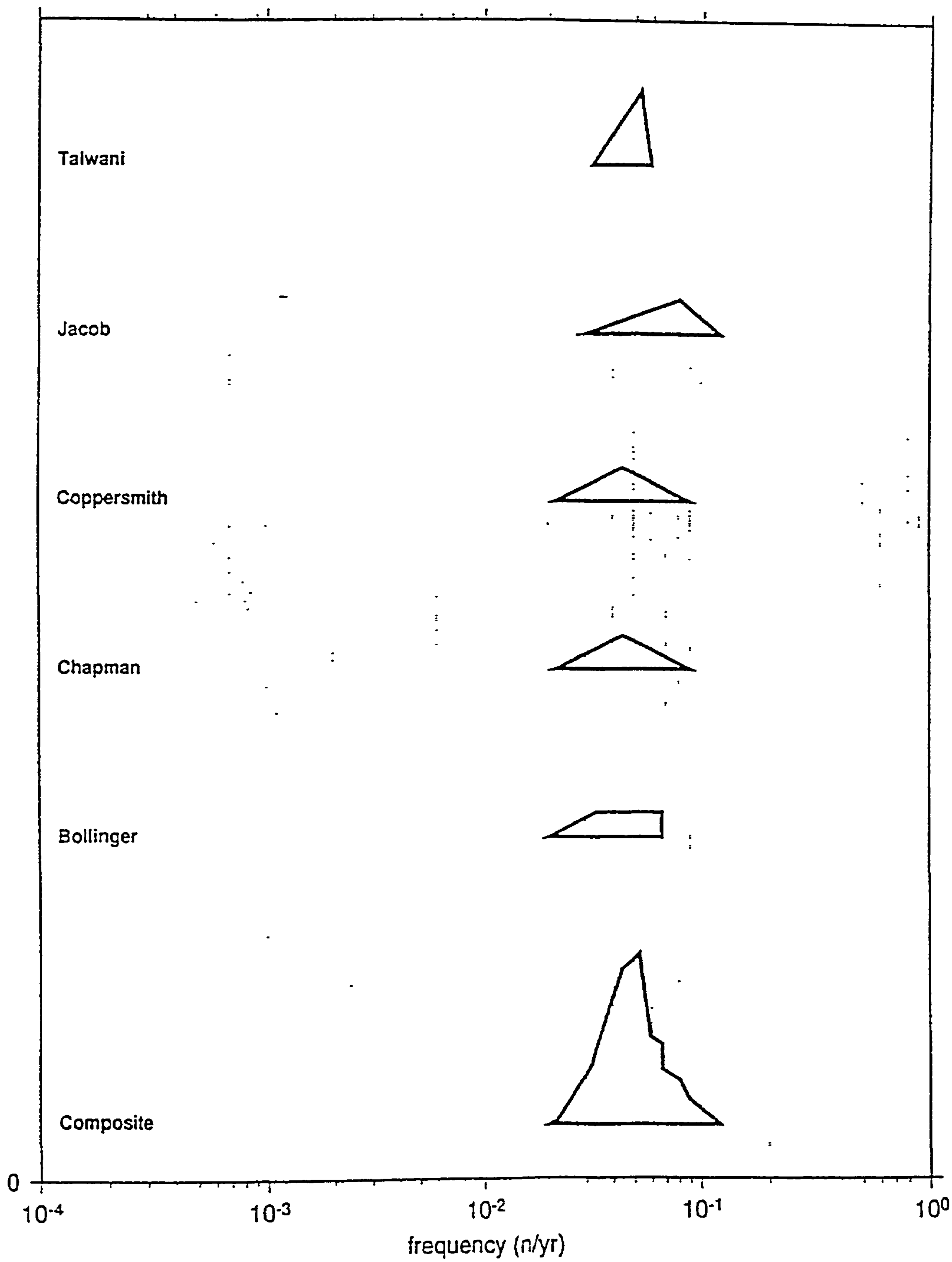

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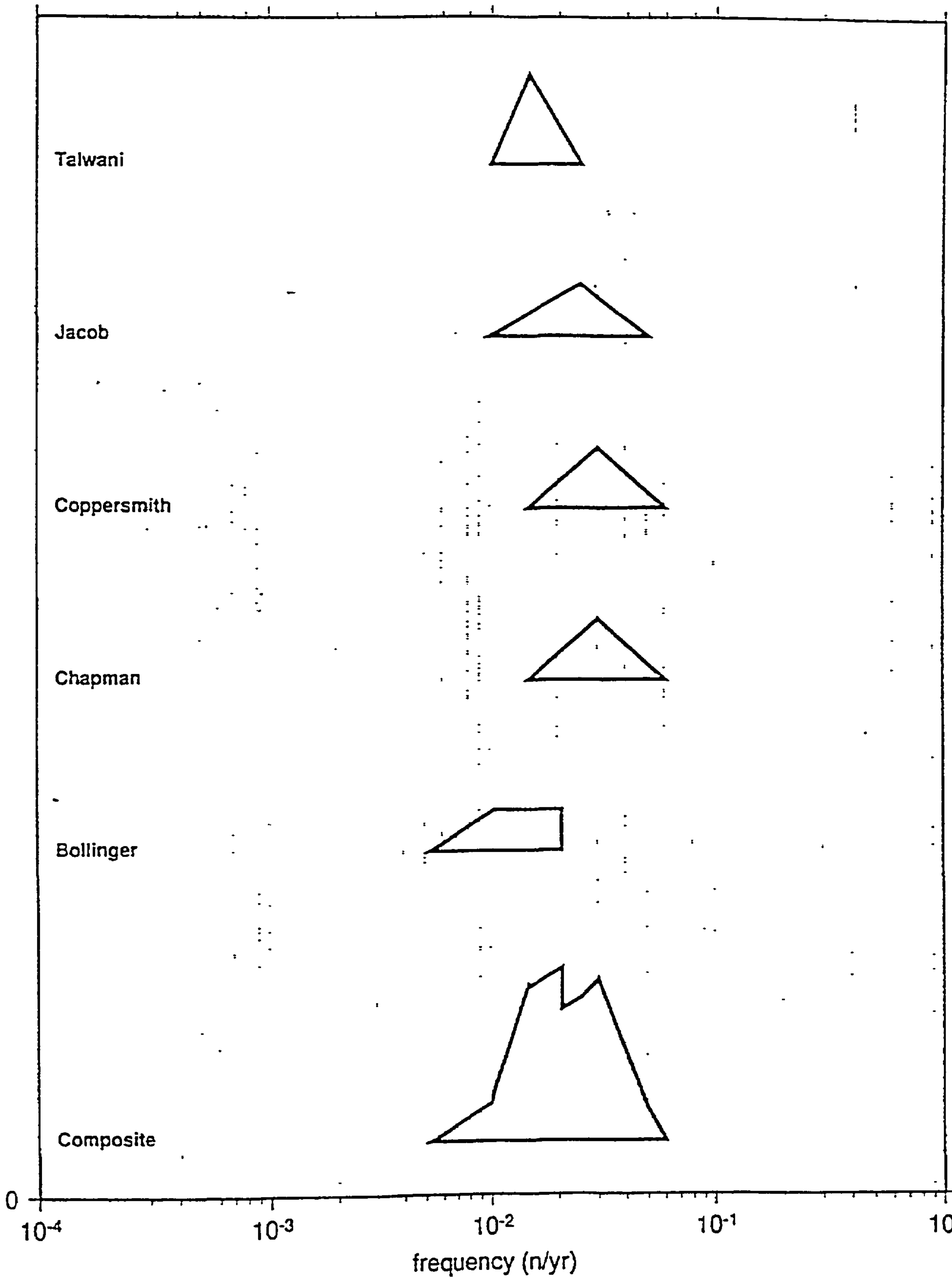

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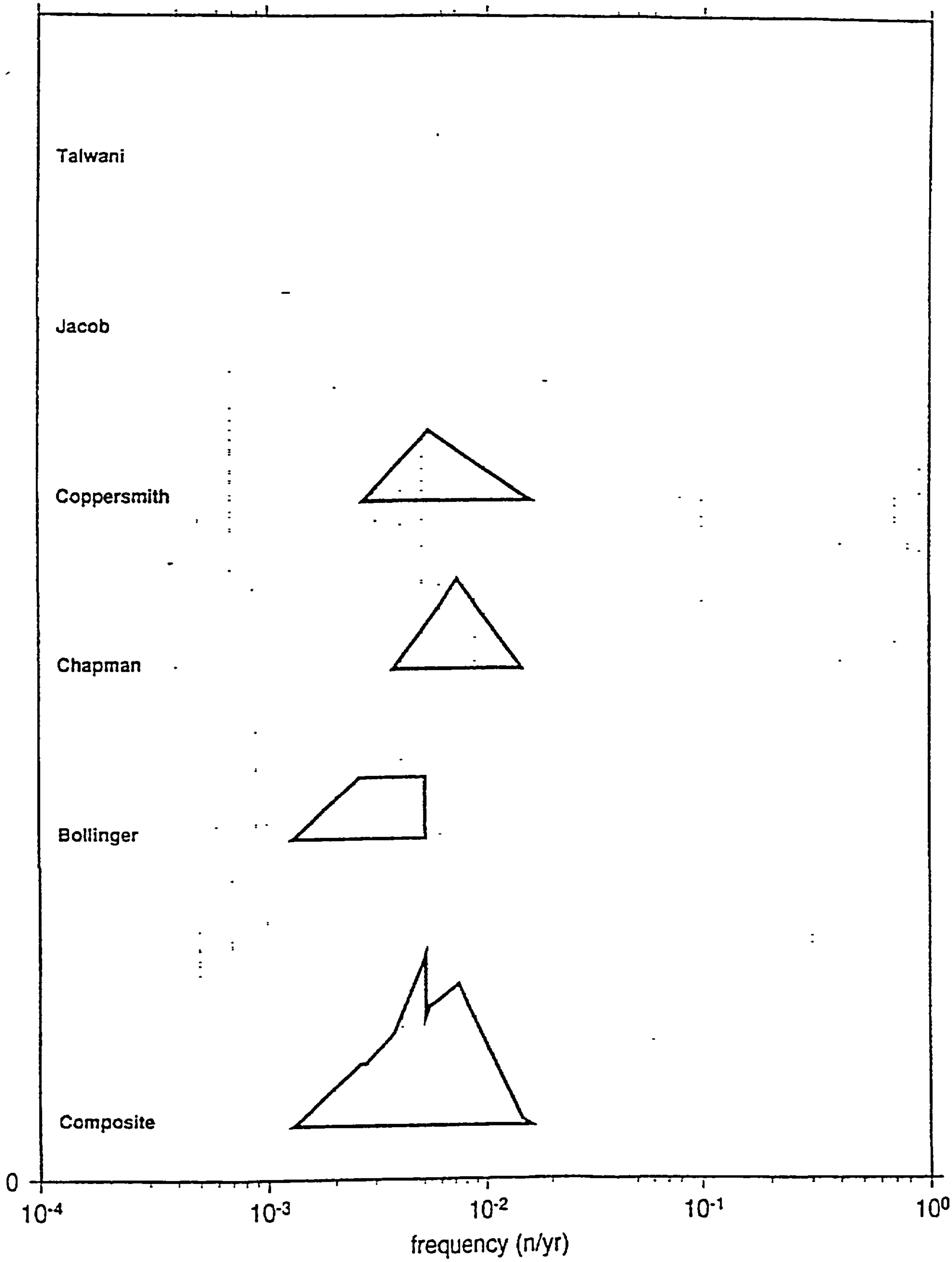

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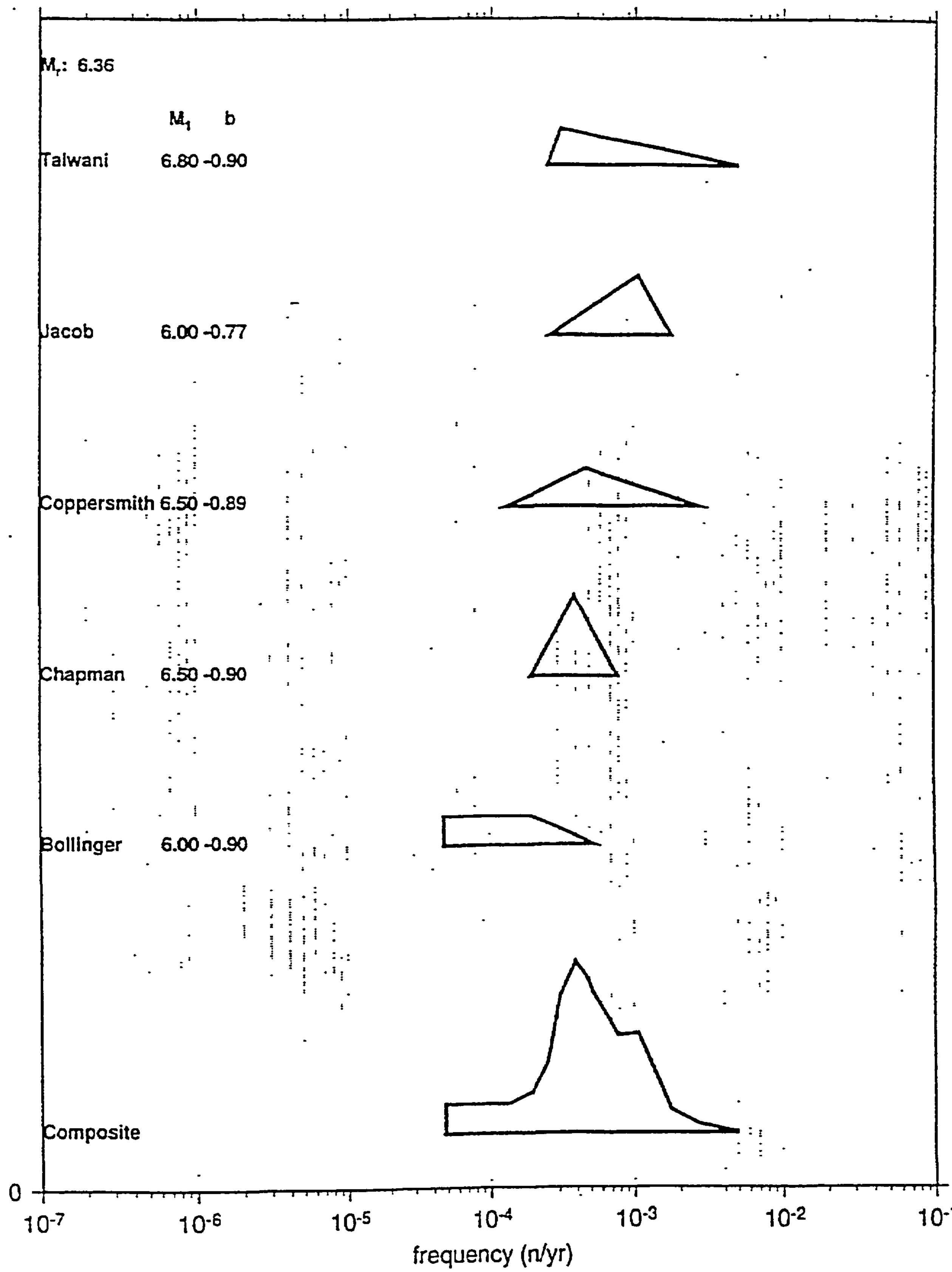

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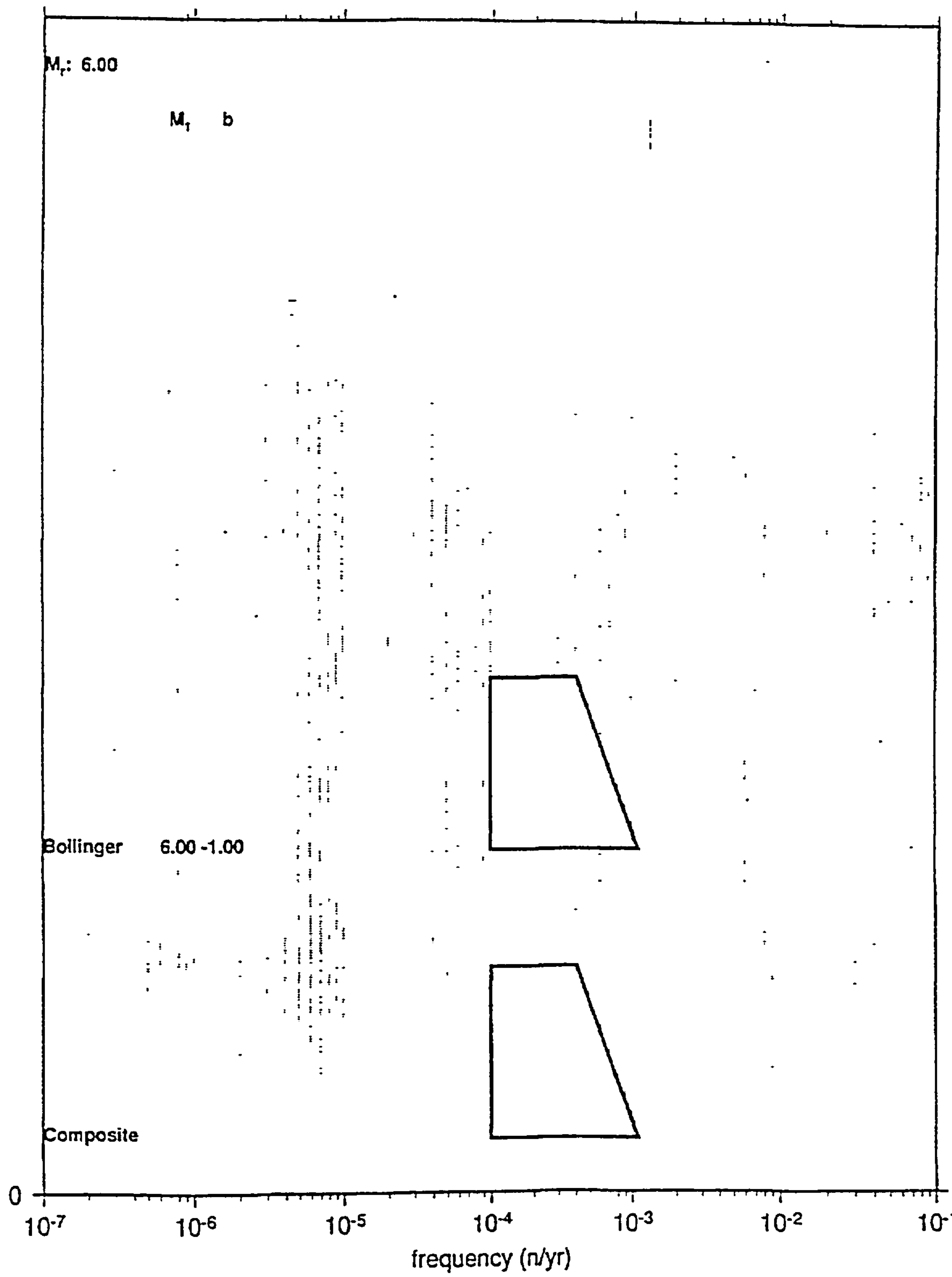

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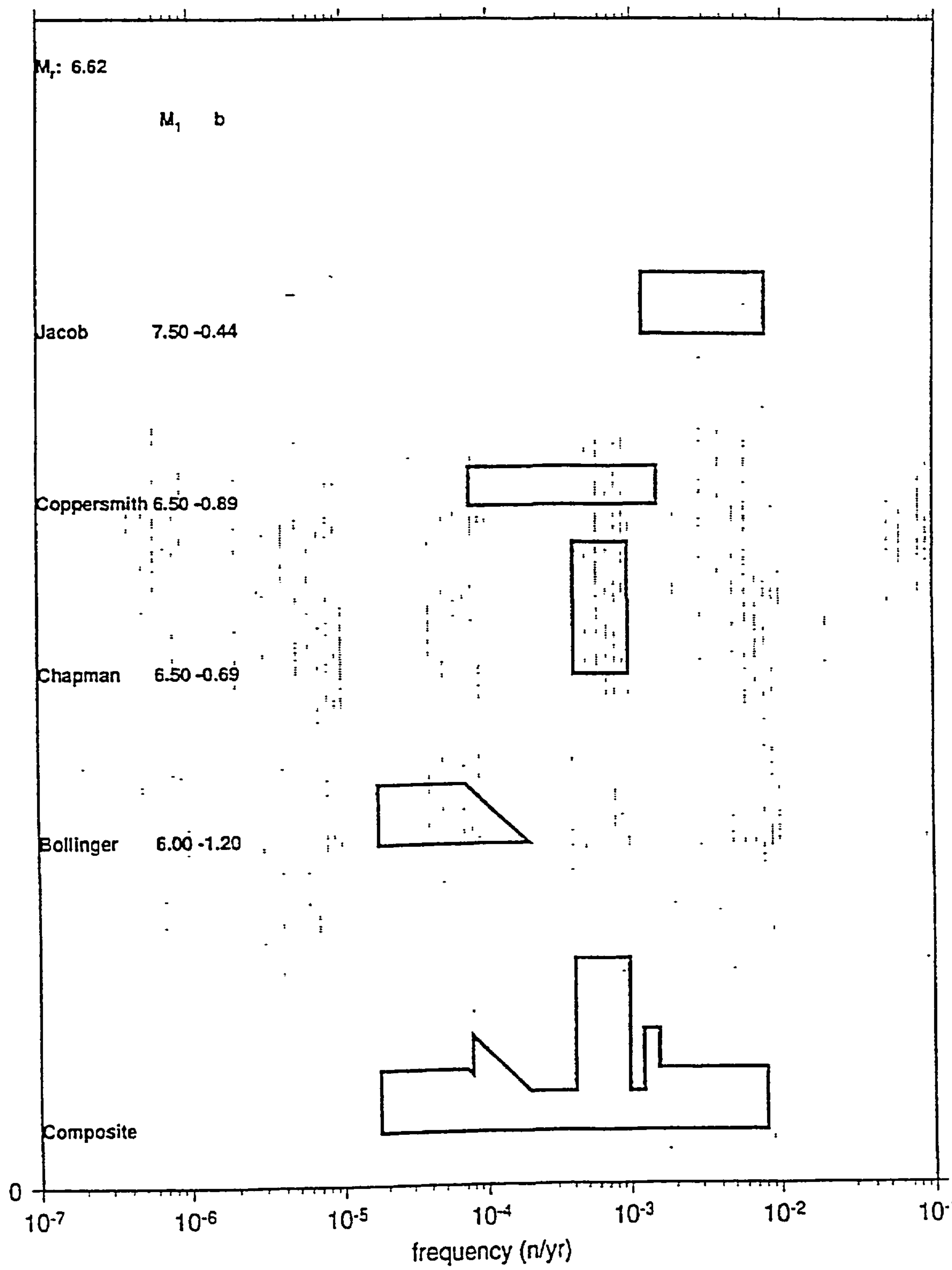

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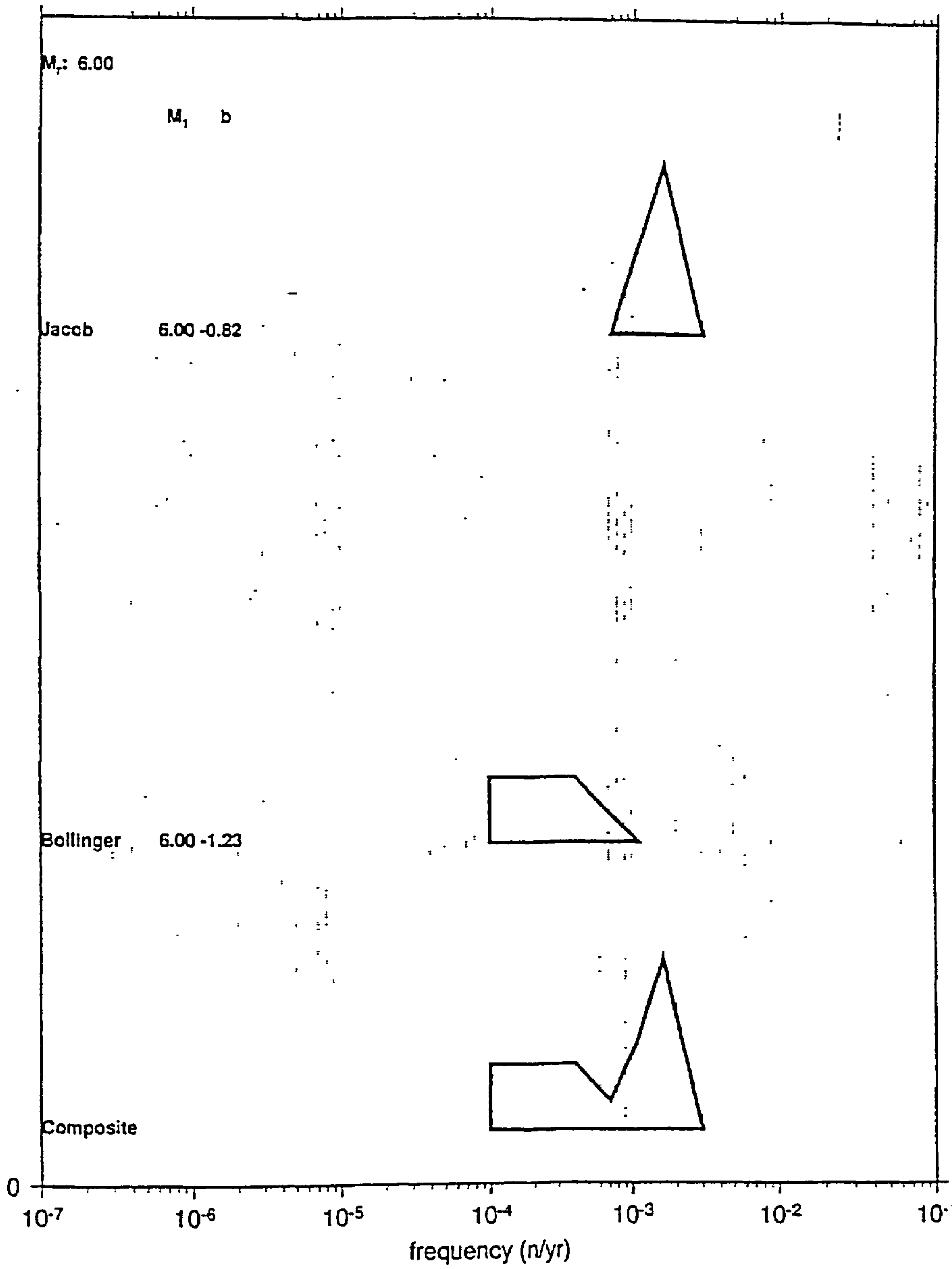

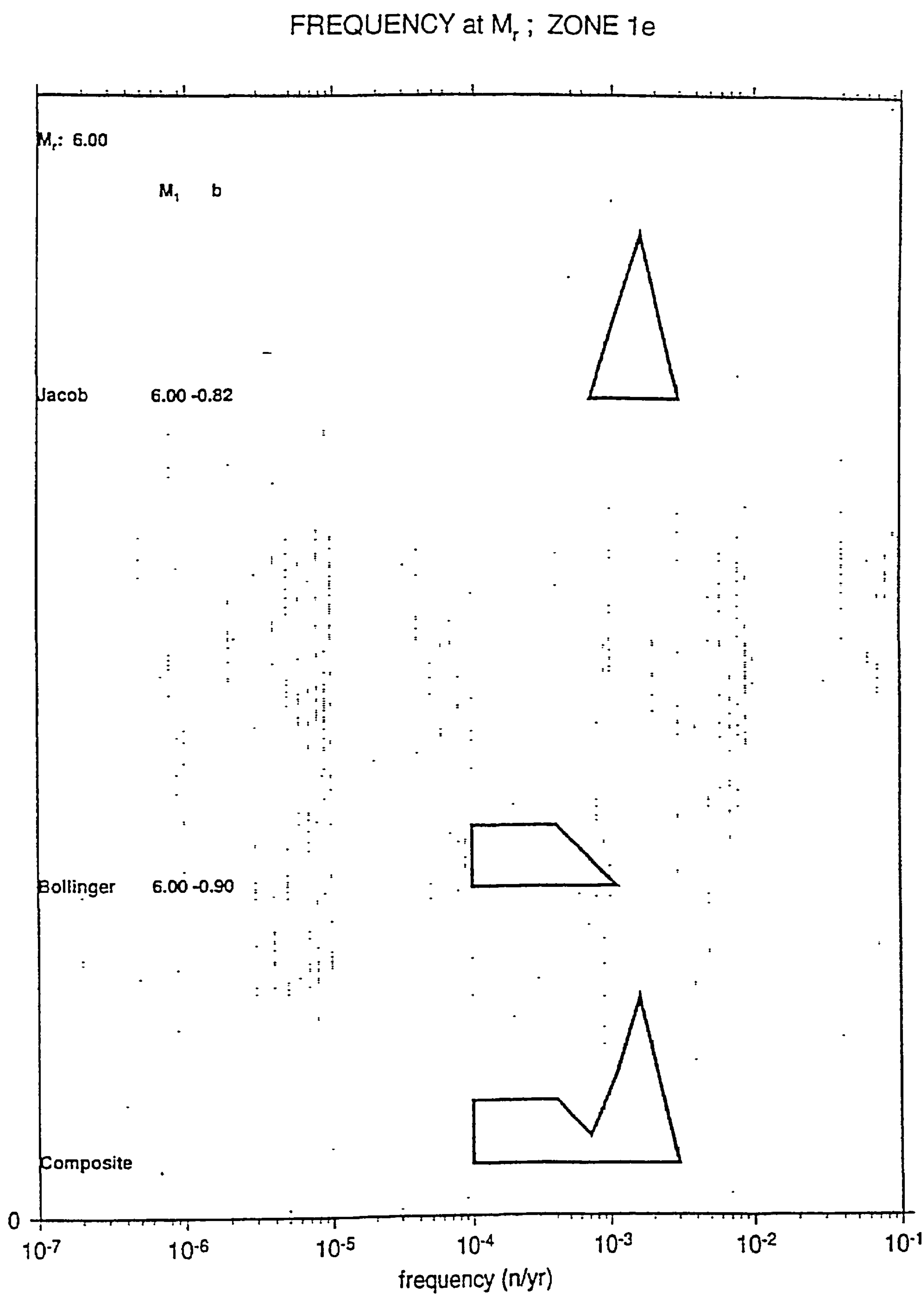
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M_r: 6.00
M_1 b
Jacob 6.00 -0.82
Bollinger 6.00 -0.90
Composite
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10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1}
frequency (n/yr)

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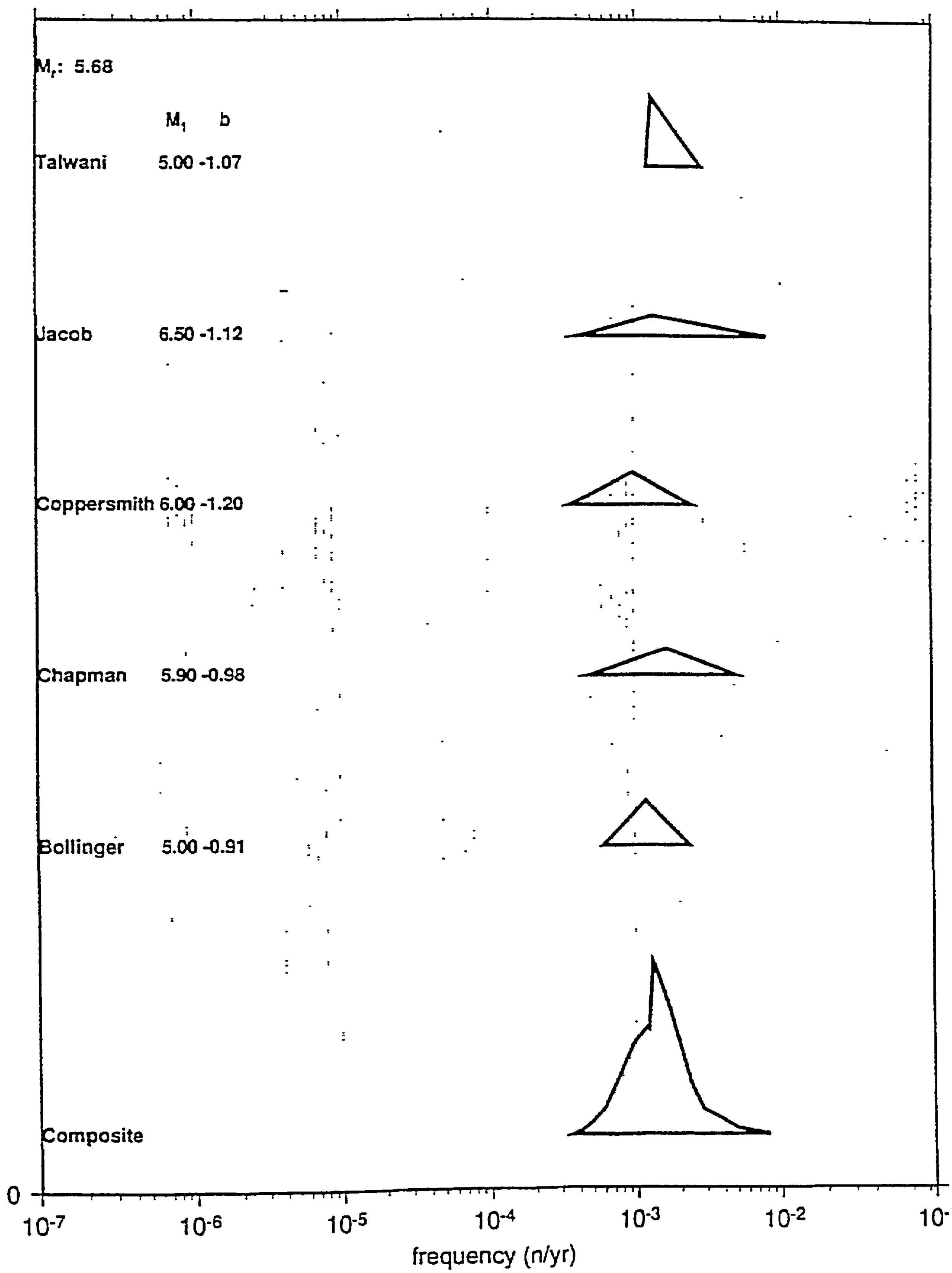

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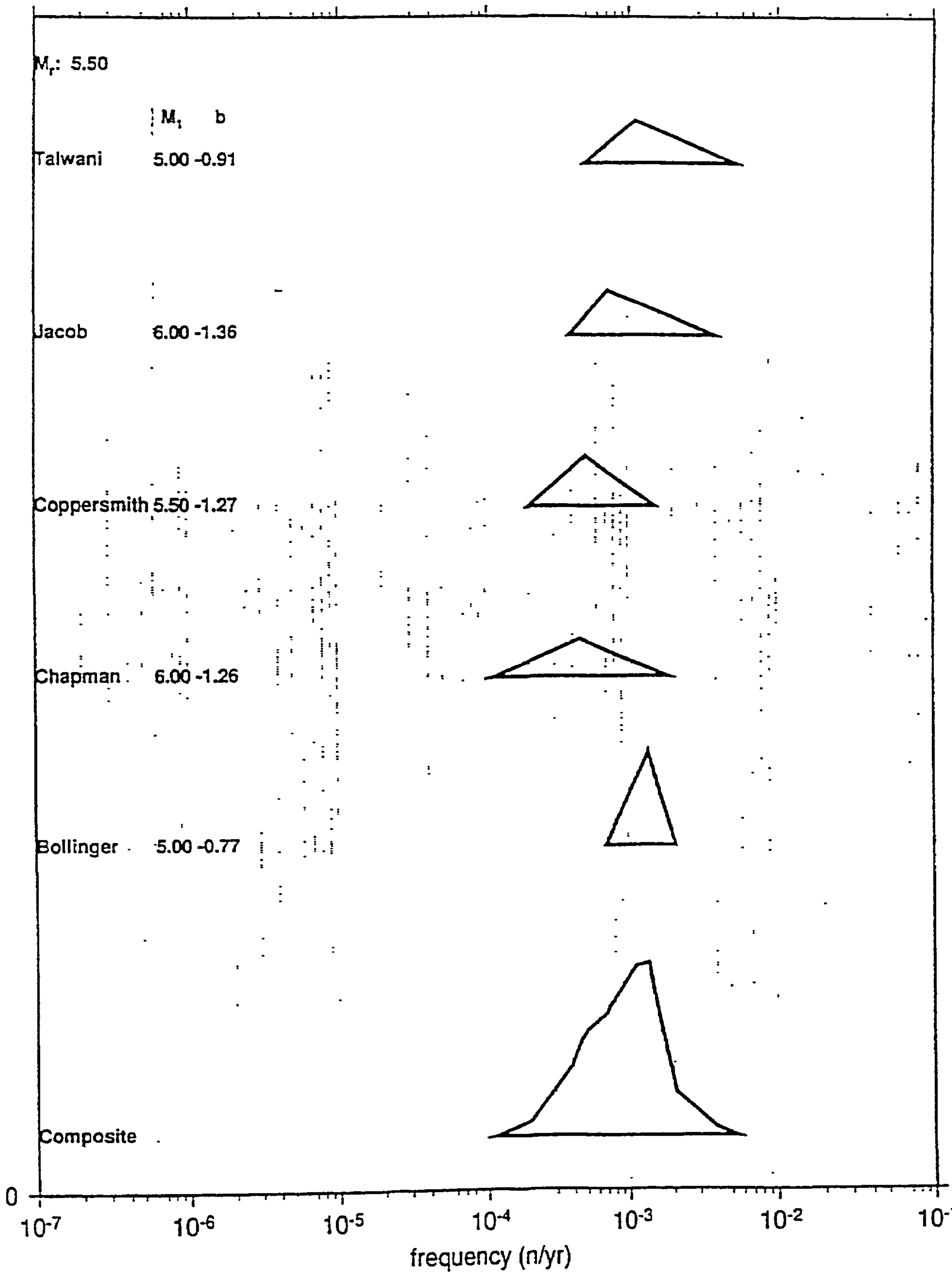

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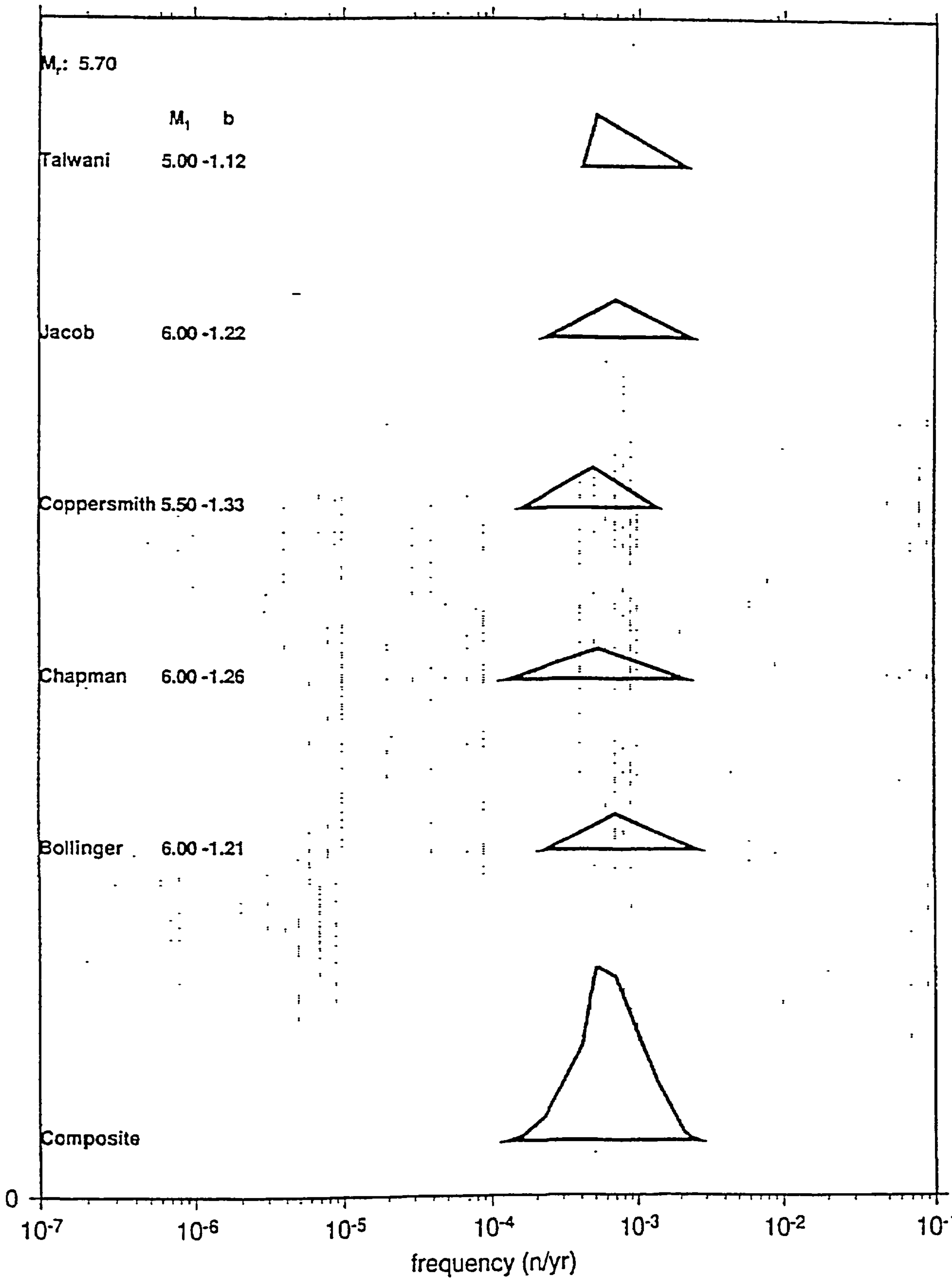

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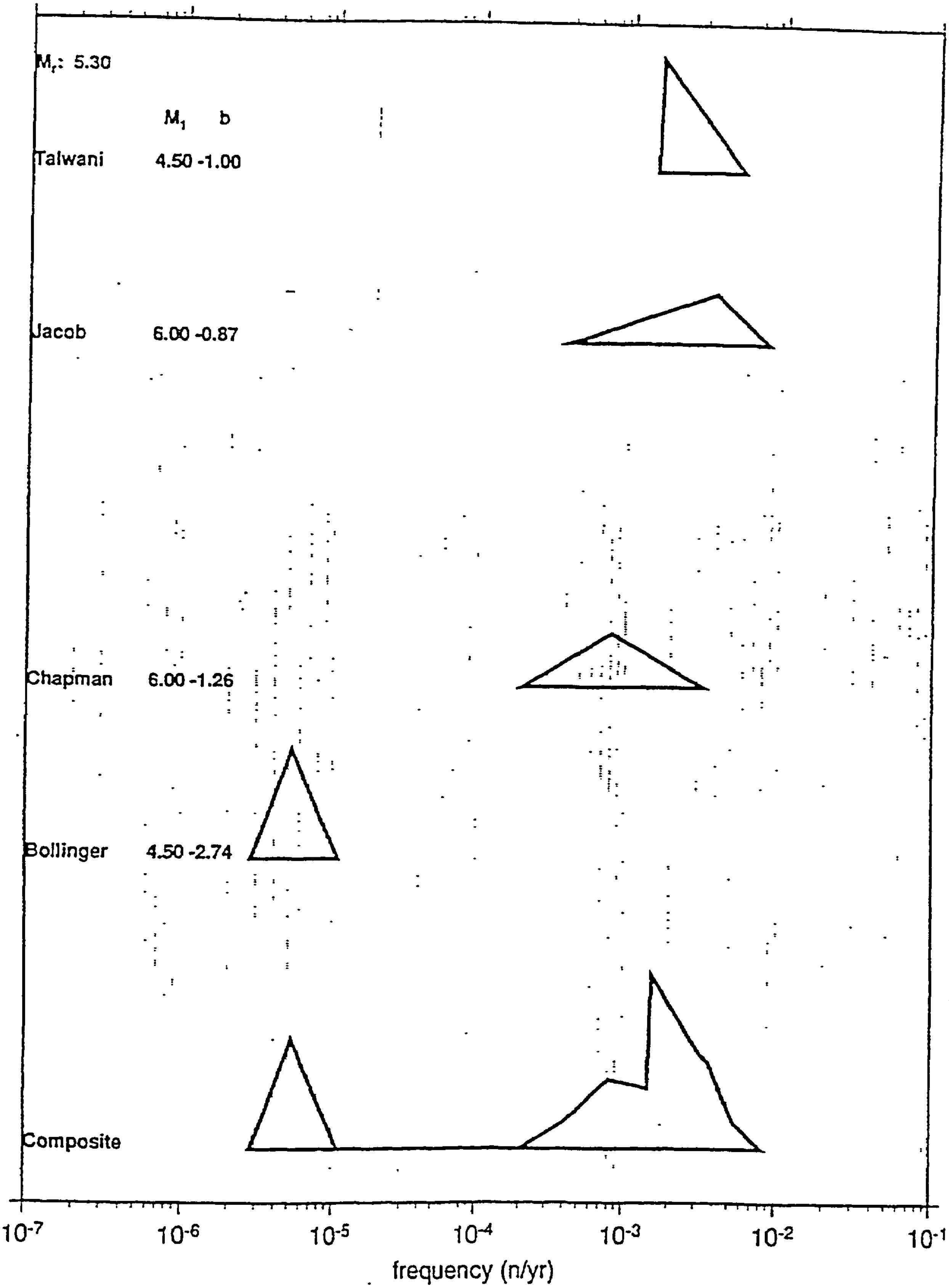

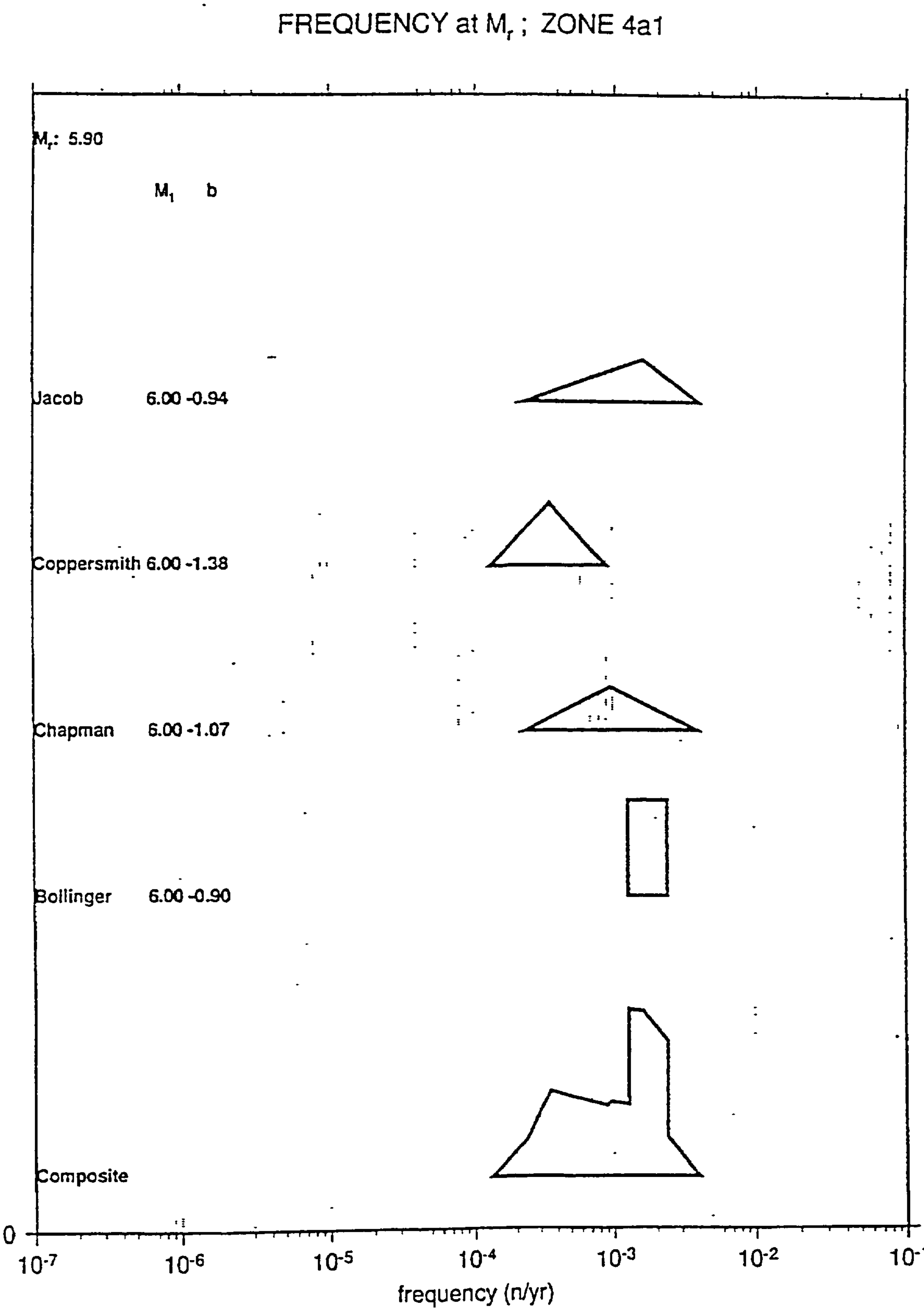
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Coppersmith 6.00 -1.38
Chapman 6.00 -1.07
Bollinger 6.00 -0.90
Composite
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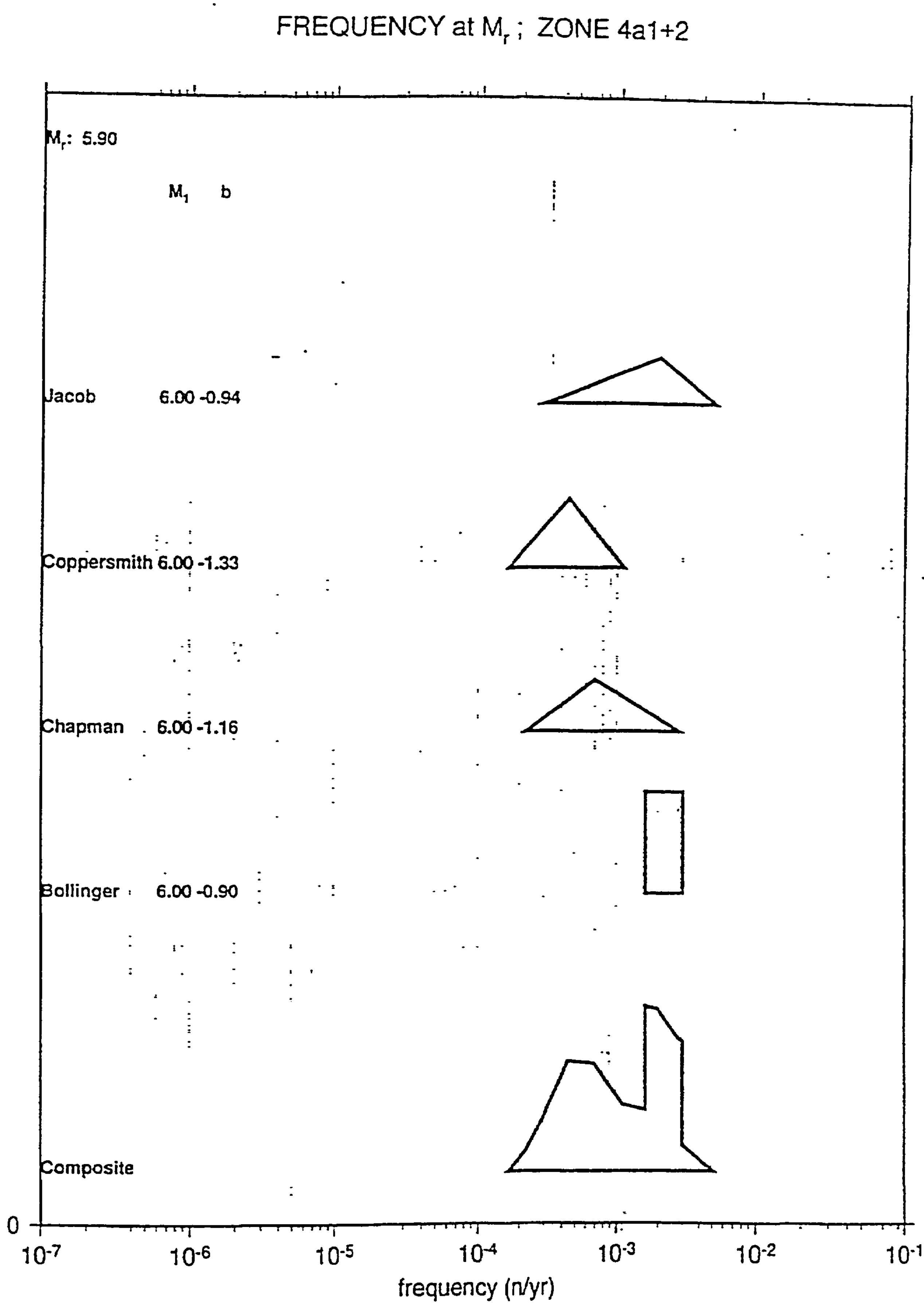
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
frequency (n/yr)



FREQUENCY at M_r ; ZONE 4a1+2
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M_1 b
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Coppersmith 6.00 -1.33
Chapman 6.00 -1.16
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Composite
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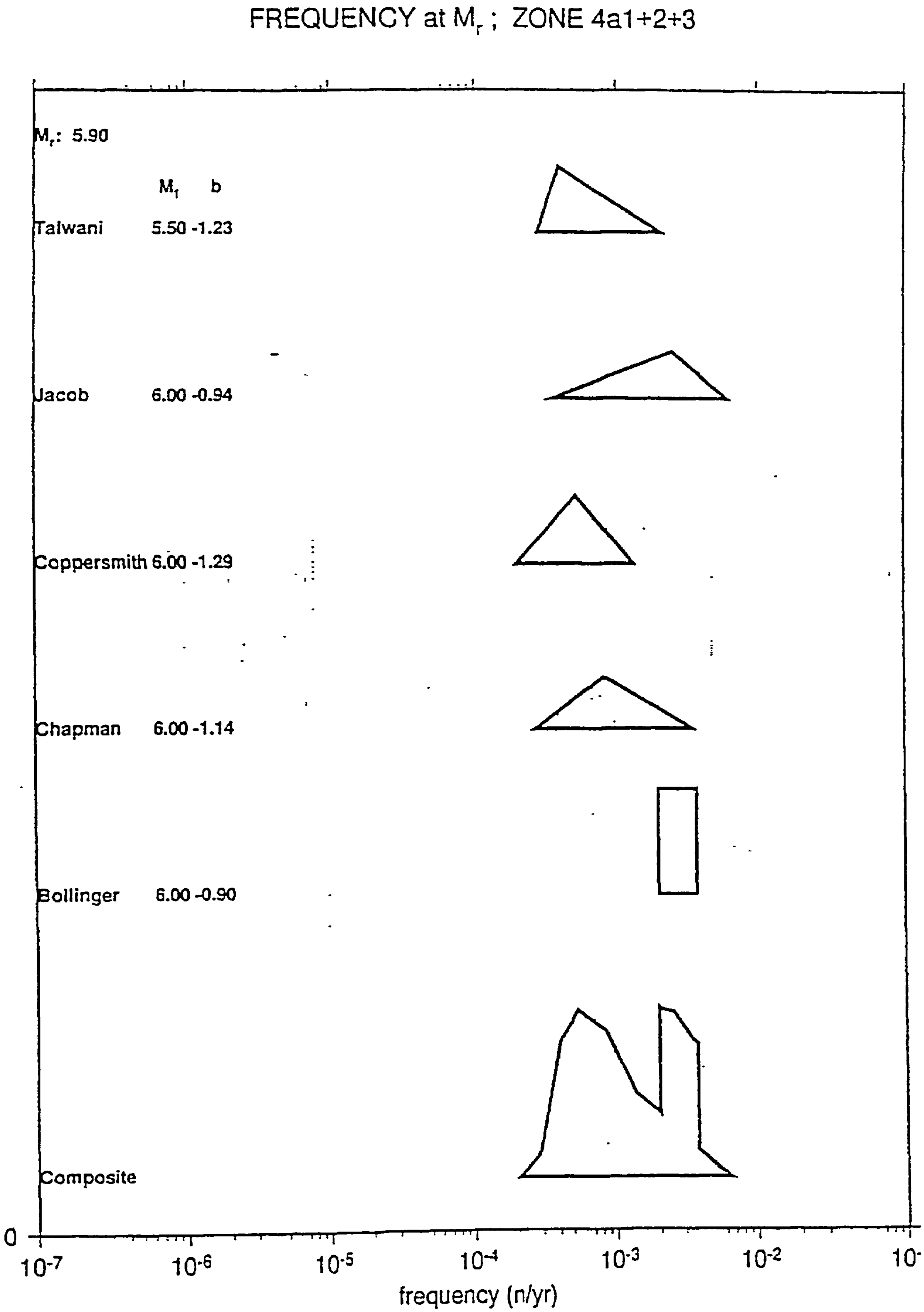
10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1}
frequency (n/yr)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M_f b
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Jacob 6.00 -0.94
Coppersmith 6.00 -1.29
Chapman 6.00 -1.14
Bollinger 6.00 -0.90
Composite
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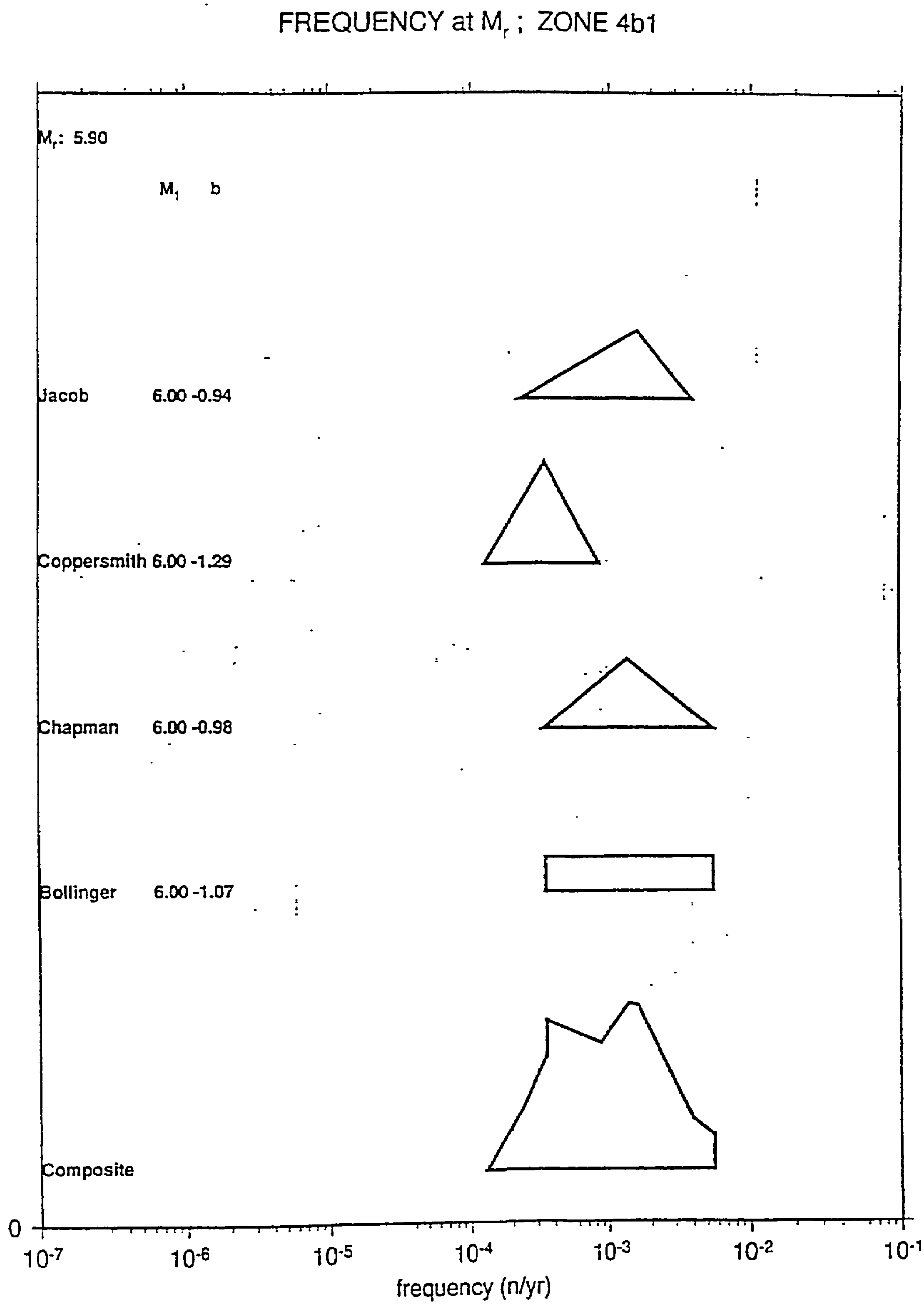
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
frequency (n/yr)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M_1 b
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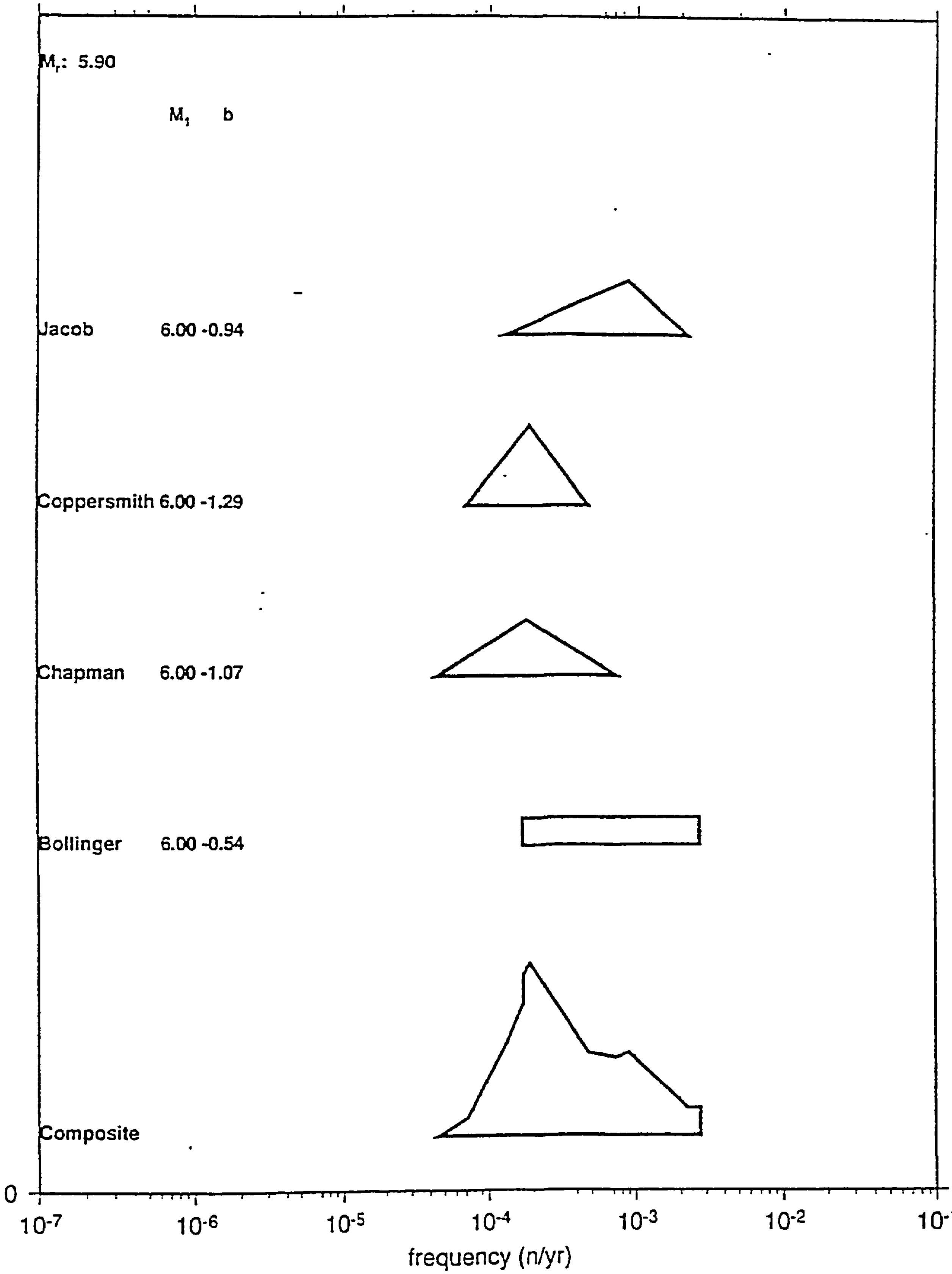
Coppersmith 6.00 -1.29
Chapman 6.00 -0.98
Bollinger 6.00 -1.07
Composite
0
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
frequency (n/yr)

FREQUENCY at M_r ; ZONE 4b2



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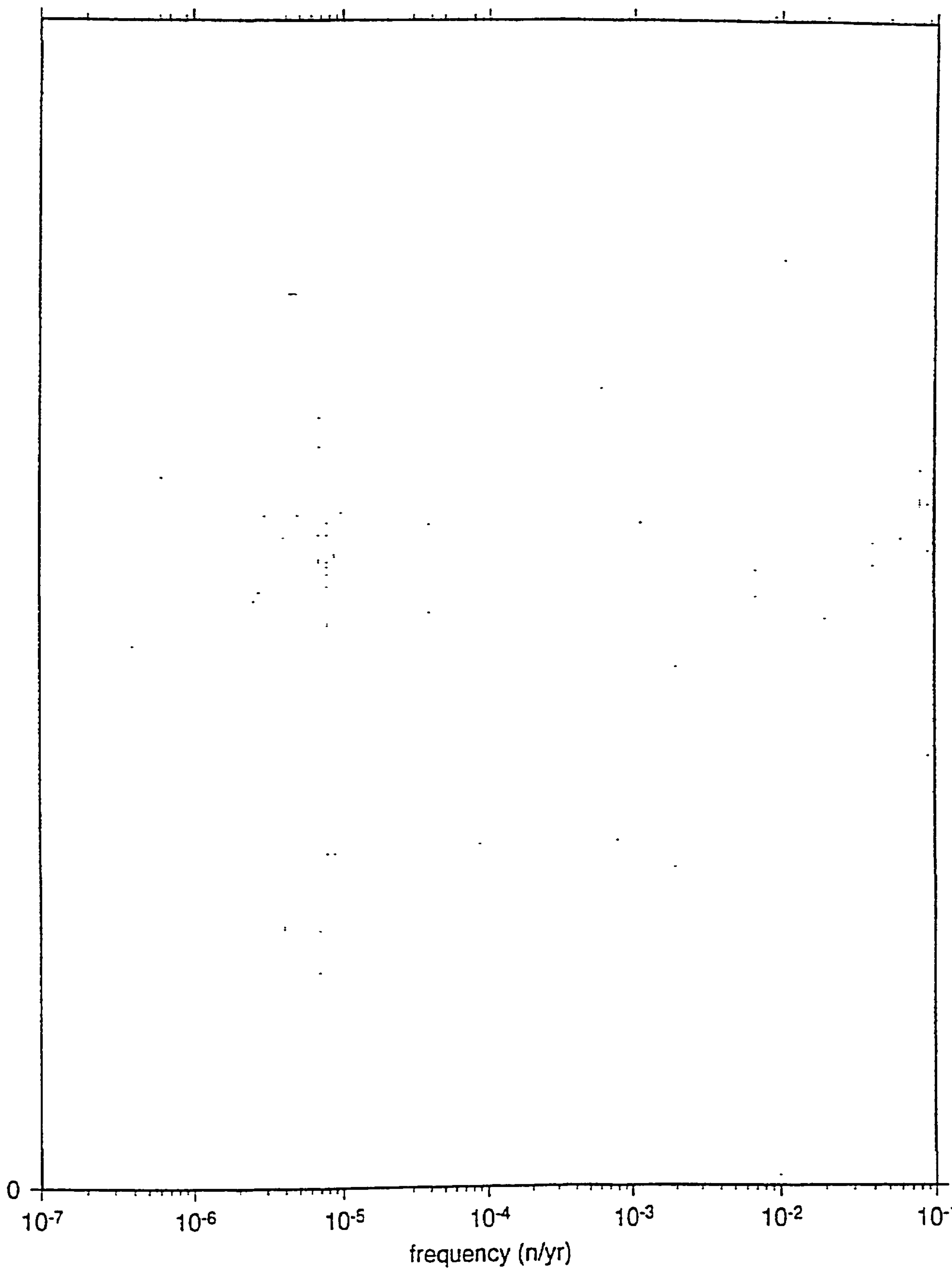

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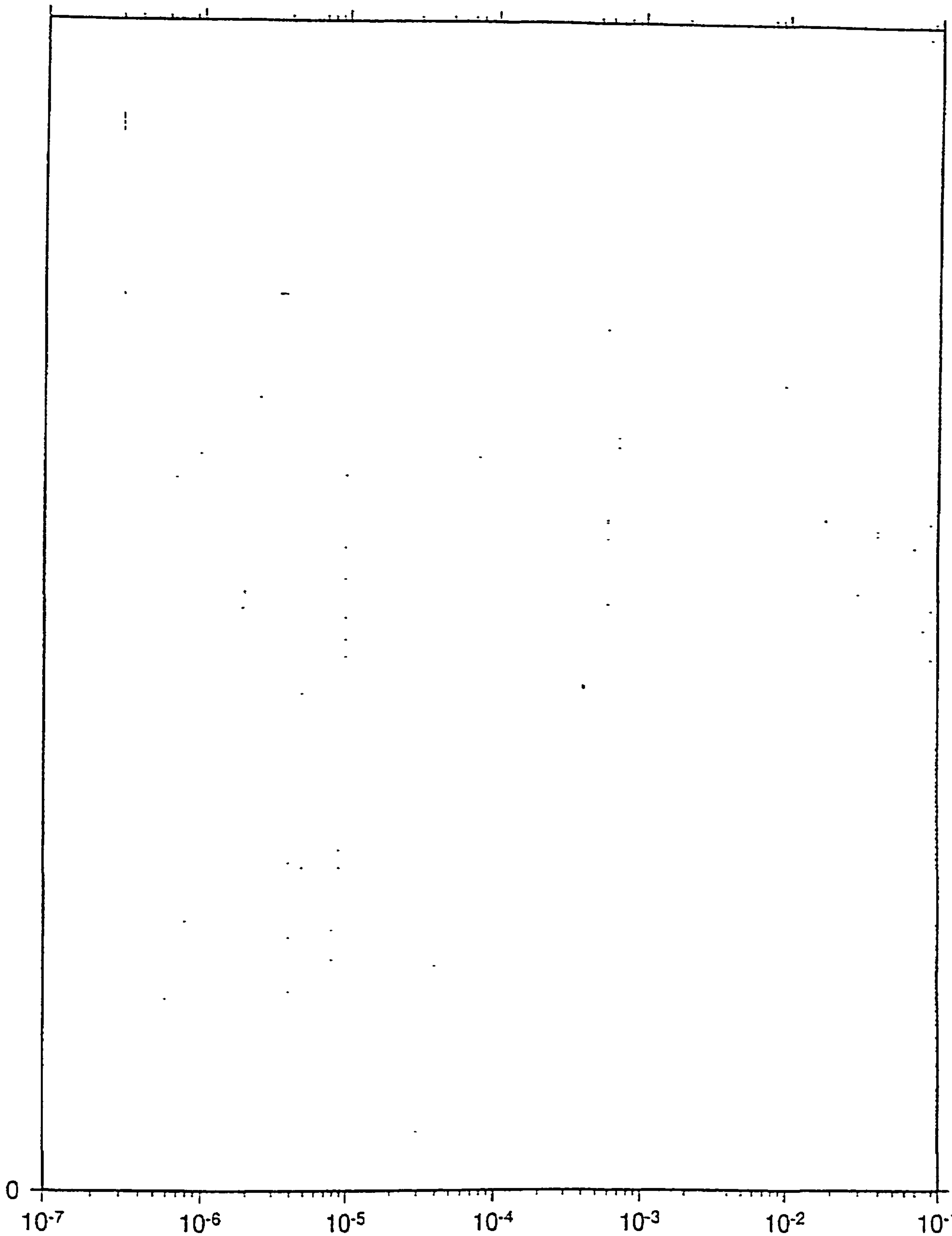

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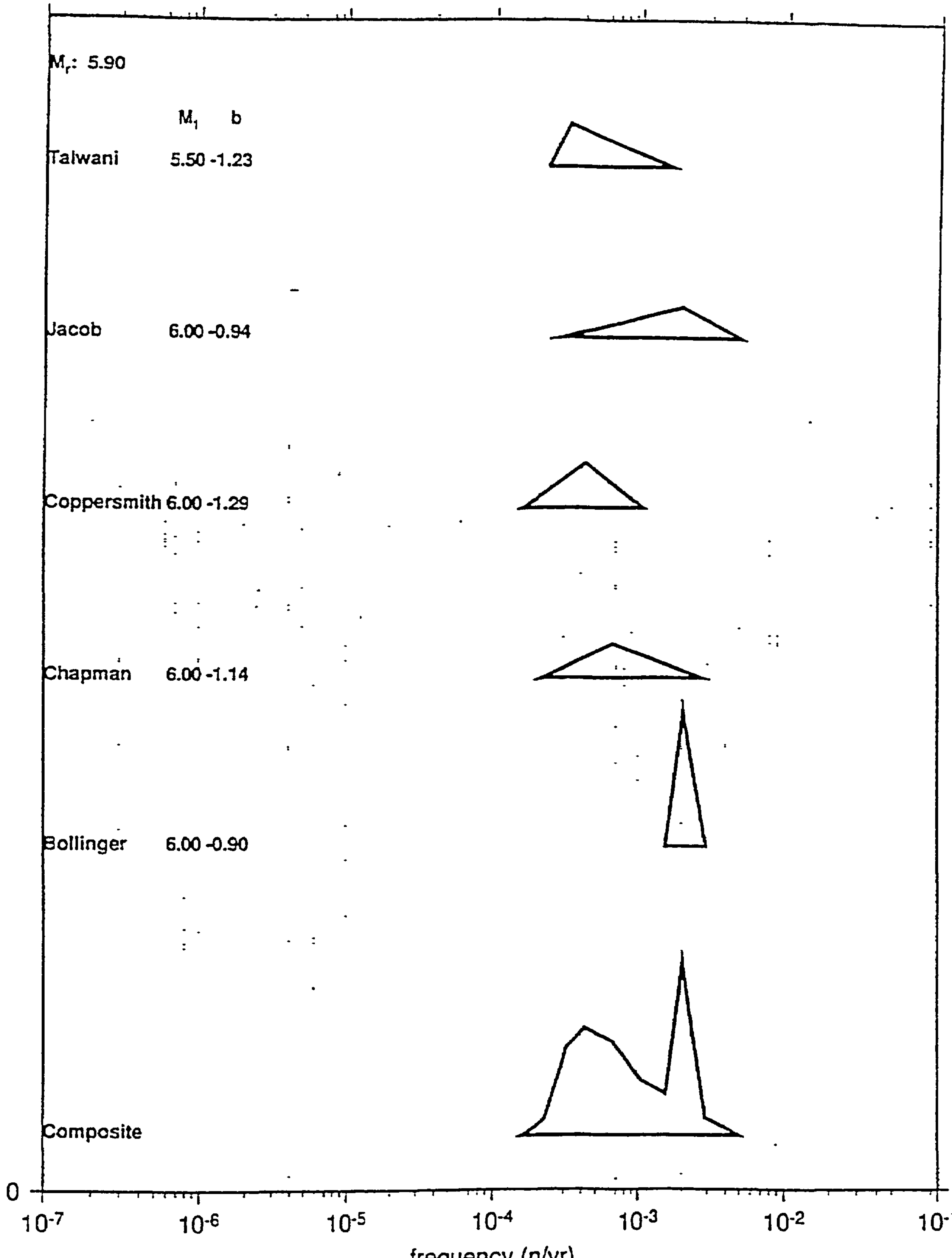

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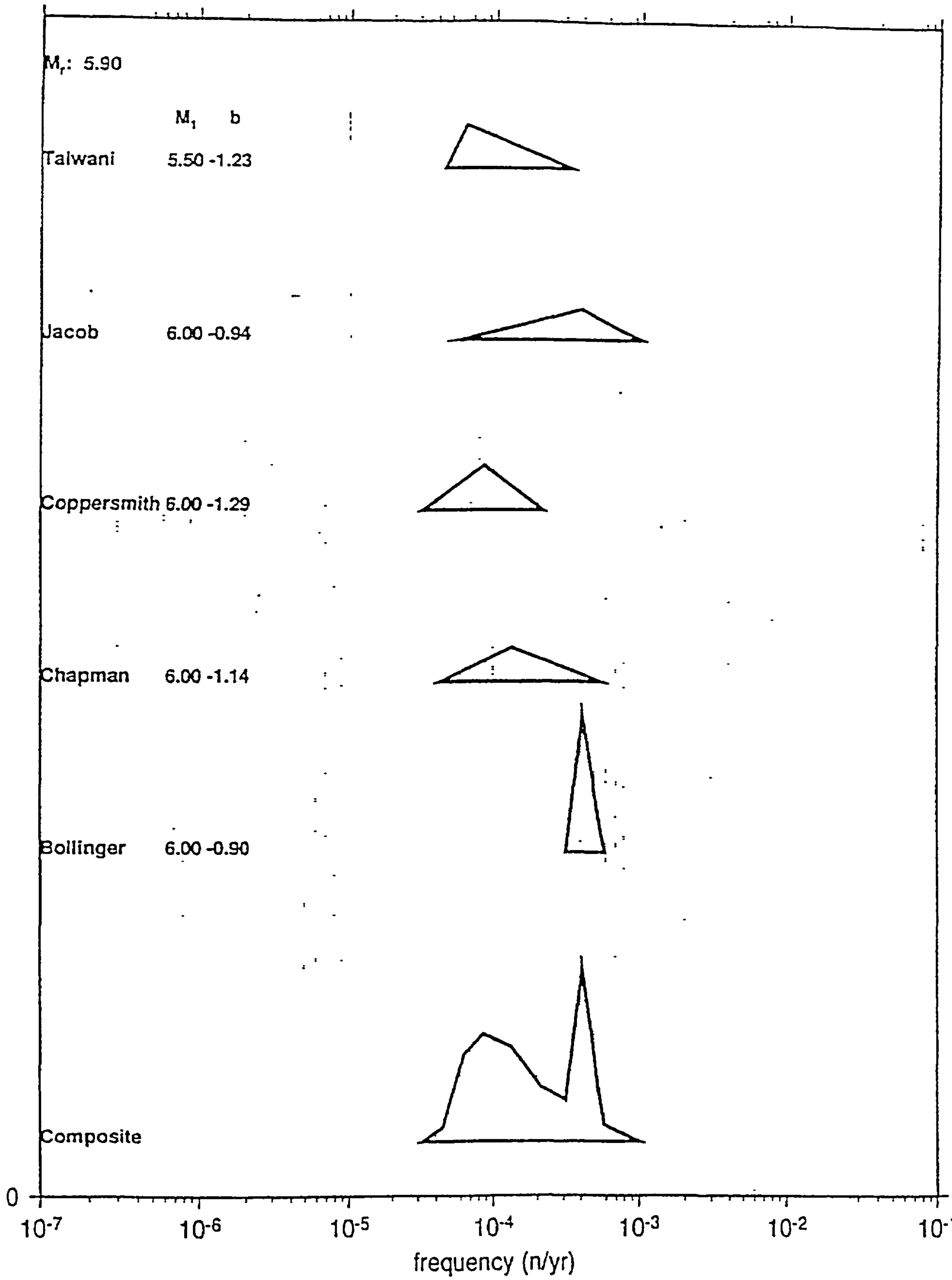

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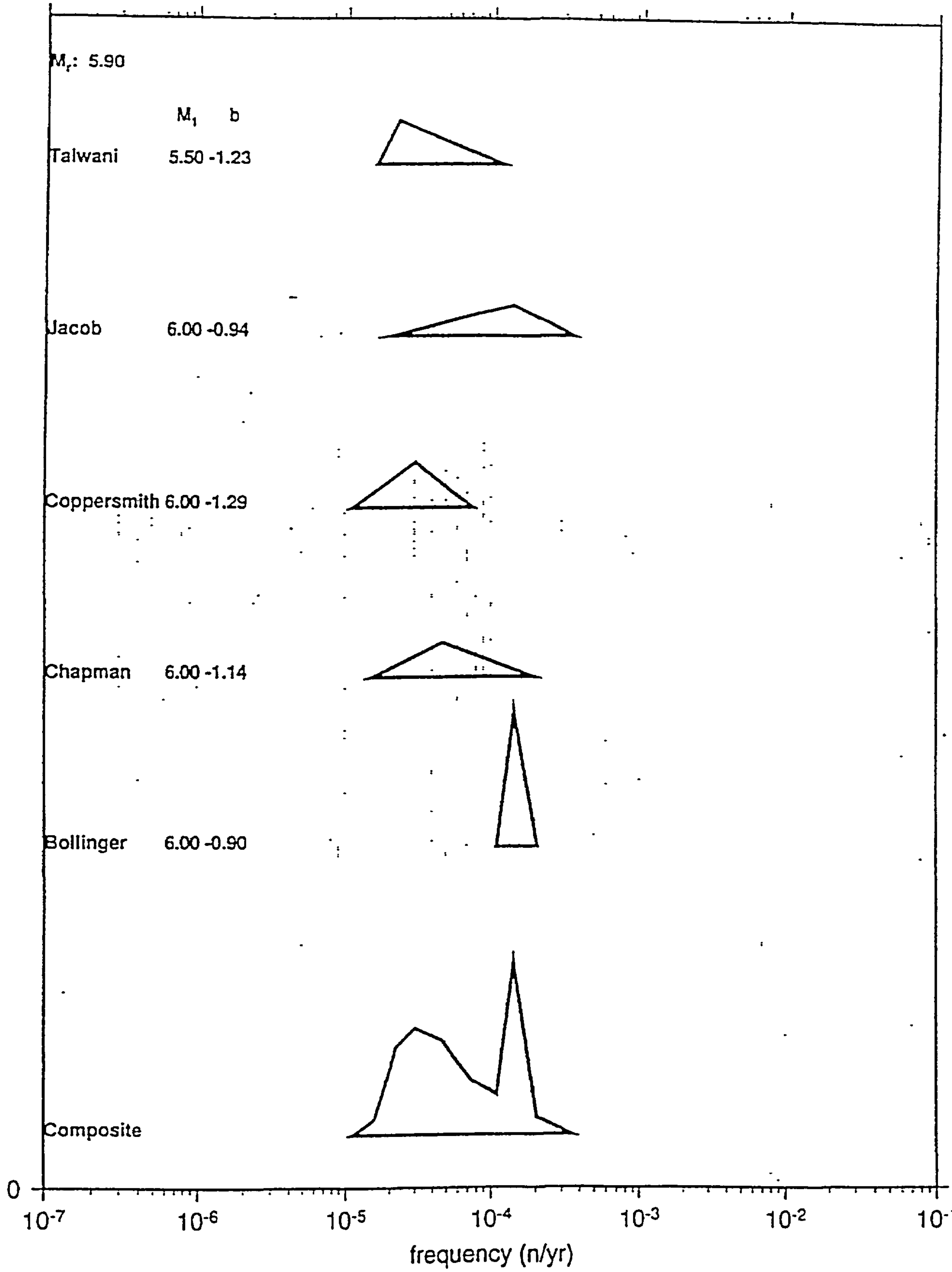

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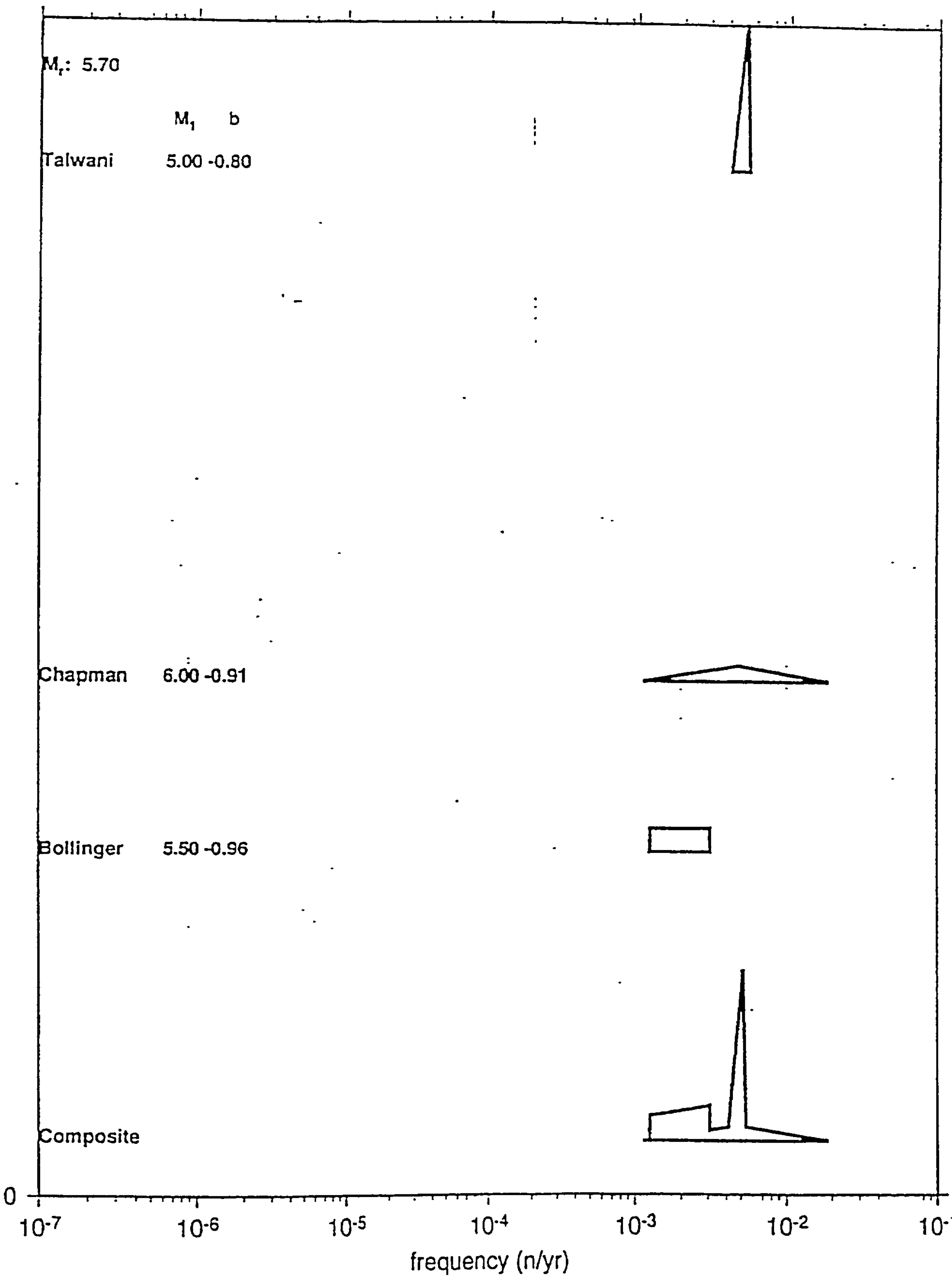

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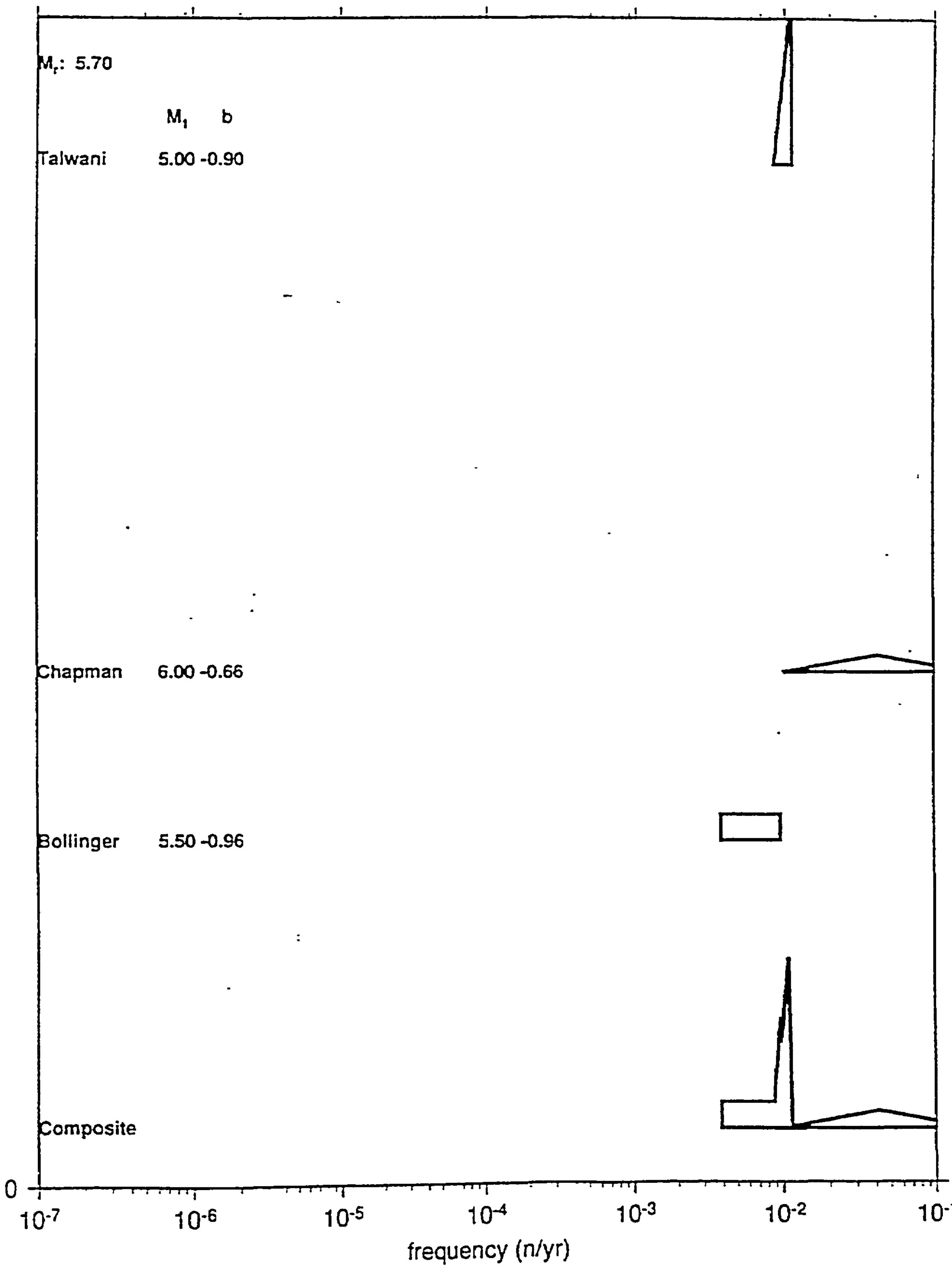

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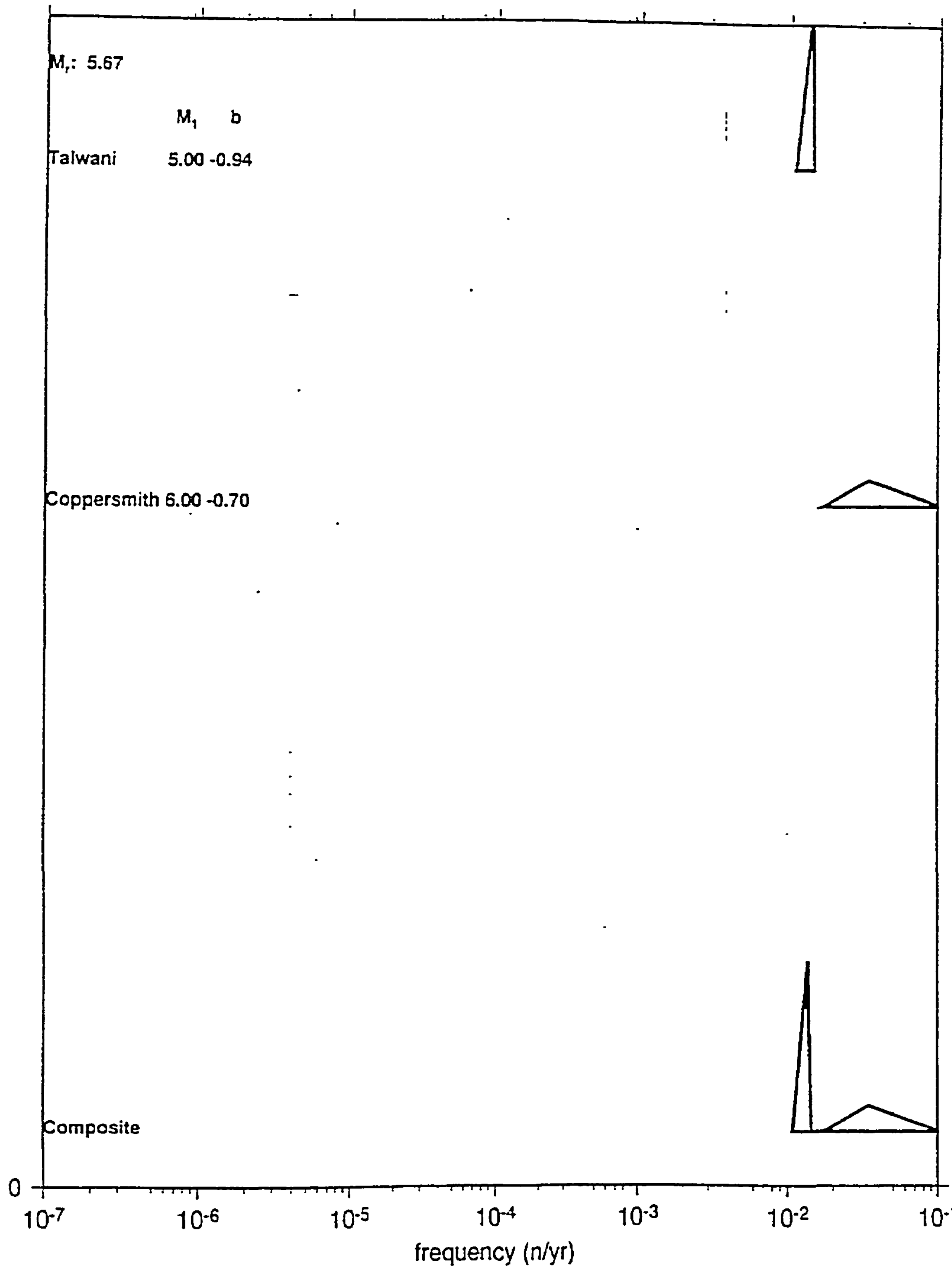

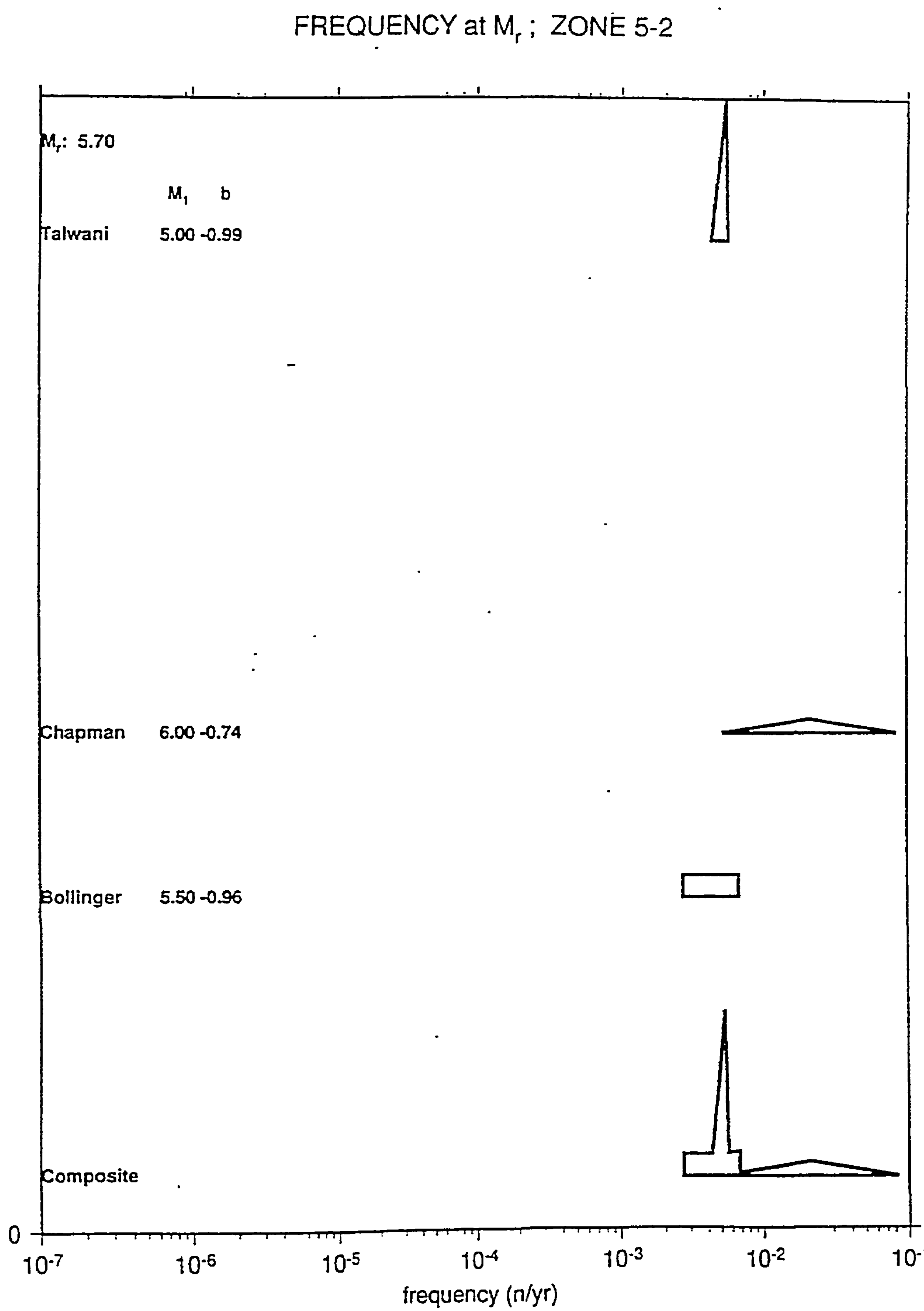
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M_r: 5.70
M_1 b
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Chapman 6.00 -0.74
Bollinger 5.50 -0.96
Composite
0
10^{-7}
10^{-6}
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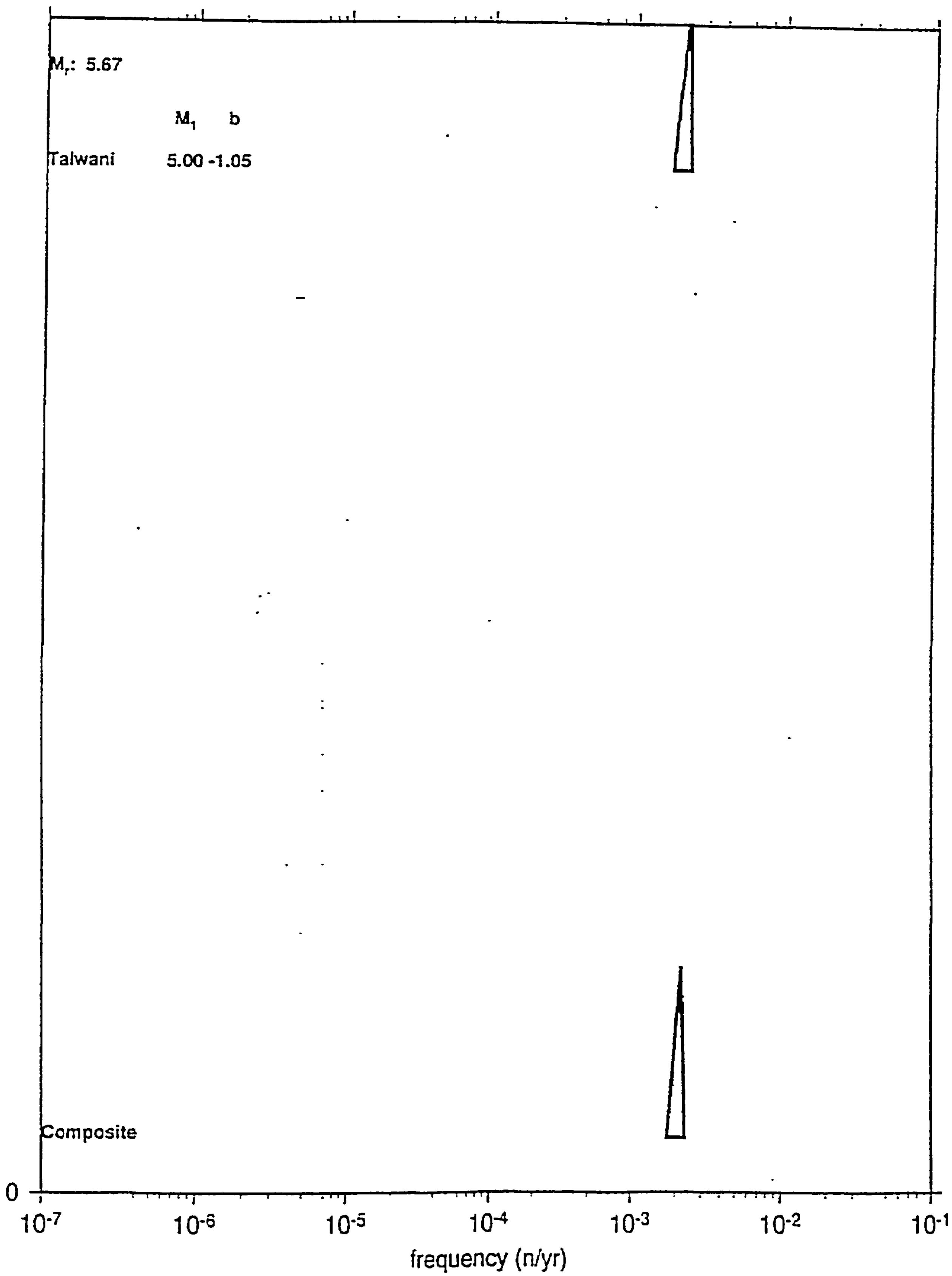
10^{-4}
10^{-3}
10^{-2}
10^{-1}
frequency (n/yr)

FREQUENCY at M_r ; ZONE 5-3



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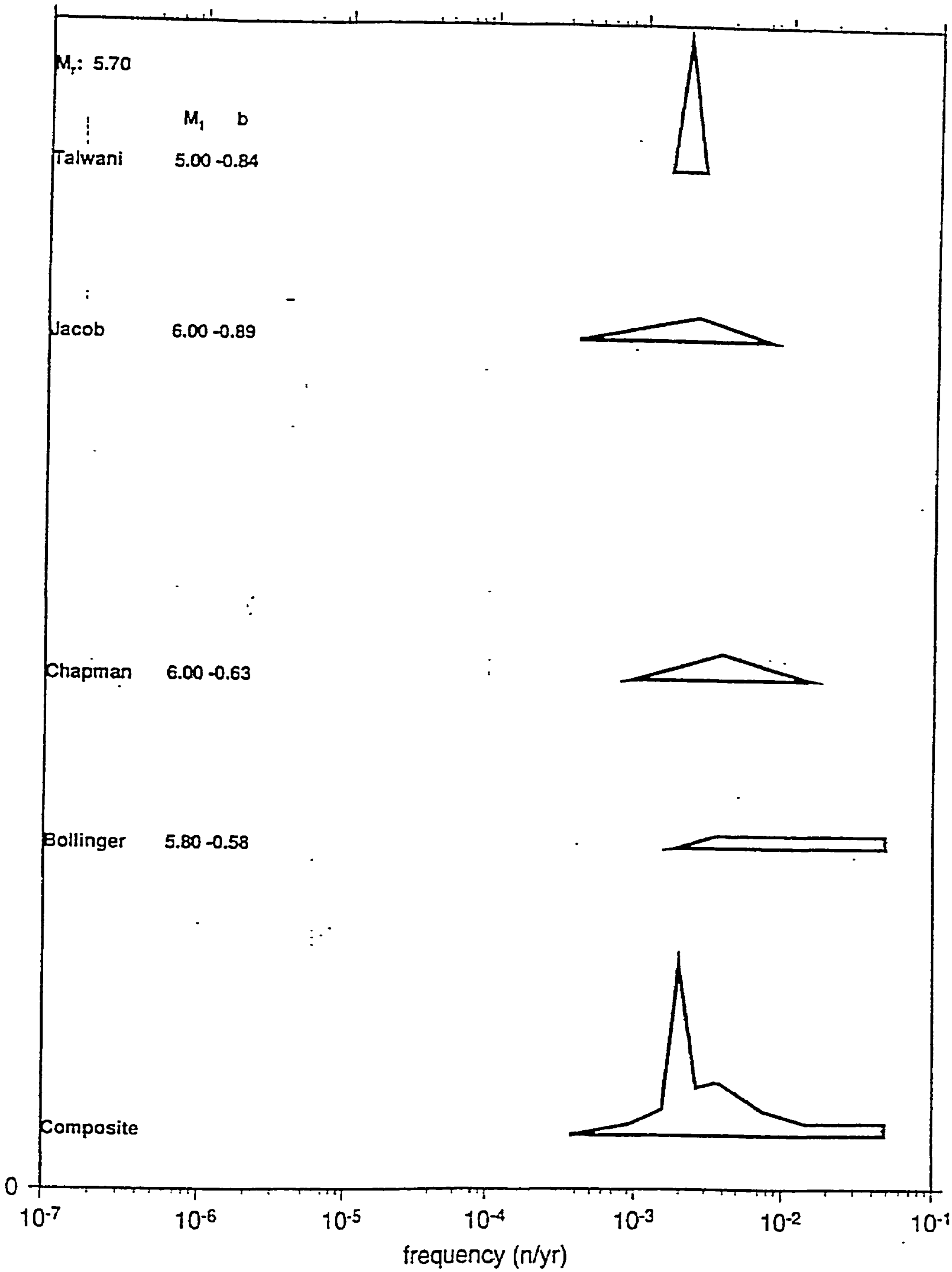

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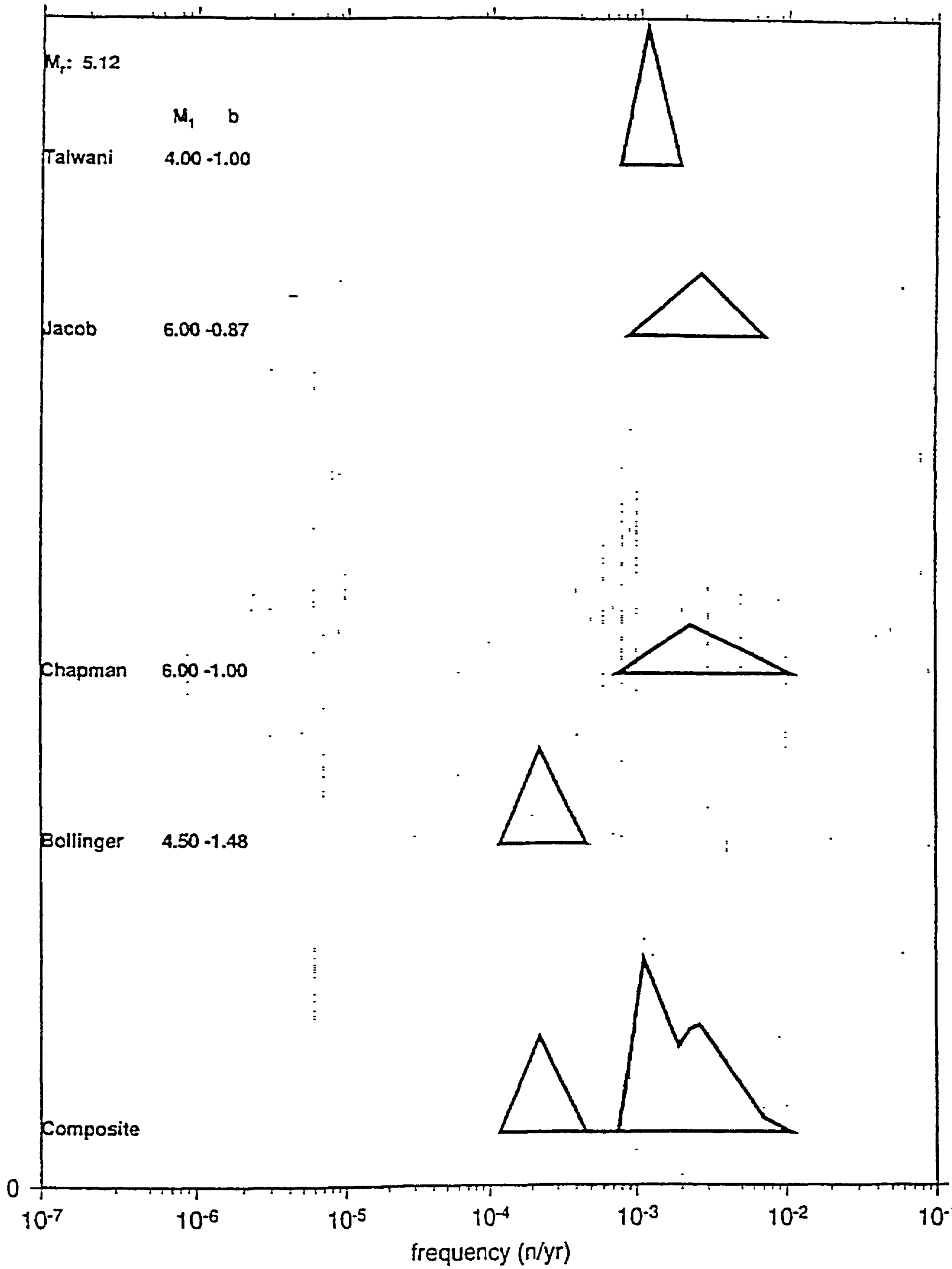

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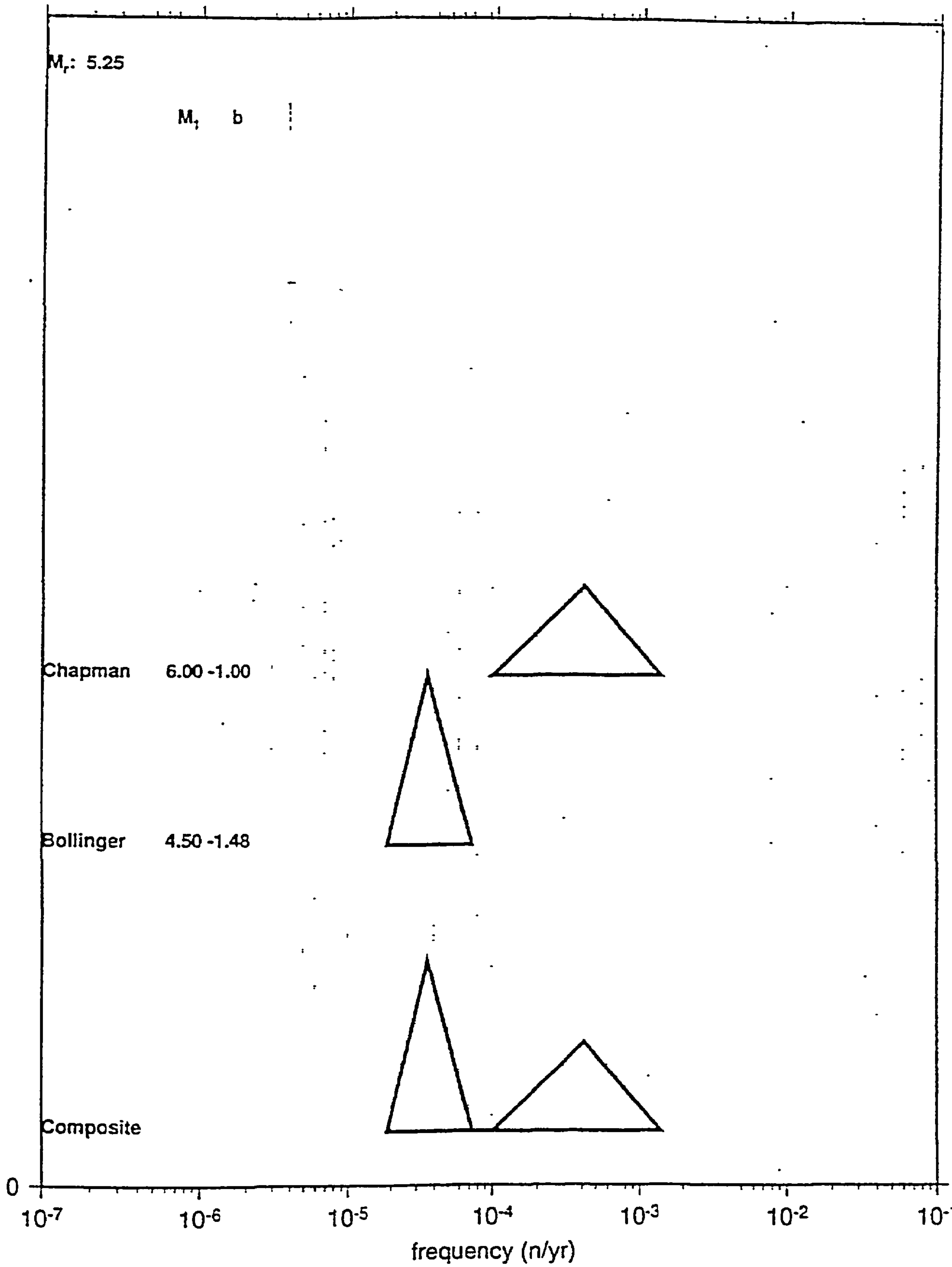

APPENDIX G: COMPARISON OF PROBABILISTIC SEISMIC HAZARD ANALYSIS RESULTS OF 1993 EASTERN U.S. UPDATE AND 1998 TRIAL IMPLEMENTATION PROJECT STUDIES FOR WATTS BAR

Comparison of Probabilistic Seismic Hazard Analysis Results of 1993 Eastern U.S. Update and 1998 Trial Implementation Project Studies for Watts Bar

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Washington, DC 20555-0001
NRC Job Code Y6245

ABSTRACT

From 1981 to 1989, Lawrence Livermore National Laboratory (LLNL) developed for the Nuclear Regulatory Commission a method for performing Probabilistic Seismic Hazard Analysis (PSHA) for the eastern United States; results were documented in NUREG/CR-5250. Improvements in the handling of the uncertainties led to updated results, documented in the 1993-EUS-Update study (NUREG-1488.) These results were substantially different from those of the utilities-sponsored study performed by the Electric Power Research Institute (EPRI, 1989.)

In order to understand the differences between the two studies, the NRC and the Department of Energy with EPRI co-sponsored a study led by the Senior Seismic Hazard Analysis Committee (SSHAC), whose task was to explain the differences and provide guidance on how to perform a state-of-the-art PSHA The work and conclusions of the SSHAC are documented in NUREG/CR-6372 (1997).

As a follow-up to the 1997 SSHAC study, the Trial Implementation Project (TIP) (UCRL-ID-133494, 1998, NUREG/CR-6607) made use of the SSHAC recommendations and developed a set of more detailed guidance for performing PSHA. The TIP project tested the more complicated issue of development of the seismic zonation and seismicity models on two sites: Watts Bar and Vogtle. It was found that the uncertainty generated by artificial disagreements among experts could be considerably reduced through interaction and discussion of the available data and by identifying the elements common to all experts' interpretation. By concentrating on those elements, it was possible to develop a consensus and eliminate large unnecessary differences.

The present study compares the results of the 1993-EUS-Update and the 1998-TIP studies and identifies the reasons for the differences, which were found to be:

1. Differences in the ground motion (GM) attenuation models.
2. The introduction of the Eastern Tennessee Seismic Zone (ETSZ) in the TIP study.

We found that these two factors accounted for a factor of 6 difference in mean estimates of peak ground acceleration (PGA) hazard at high GM levels. The agreement between the two studies improved at lower PGA values The results were in better agreement and differed only by about a factor of 2 at high ground motion levels when the same GM model was used with each seismicity model. Finally, it was found that the composite rate of earthquakes around the Watts Bar site was about a factor of 2 higher for the TIP composite seismicity model than for the composite 1993-EUS-Update seismicity model.

We identified some of the root causes for the differences in results and formulated several criteria that will help in determining whether a new evaluation using the latest available data is necessary.

Contents

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EXECUTIVE SUMMARY

Probabilistic Seismic Hazard Analysis (PSHA) is a methodology that estimates the likelihood that various levels of earthquake-caused ground motion will be exceeded at a given location in a given future time period. Due to large uncertainties in all the geosciences data and in their modeling, multiple model interpretations are often possible. This leads to disagreement among experts, which in the past has led to drastically different estimates of the seismic hazard at a site and can lead to disagreement on the selection of ground motion for design at a given site.

From 1981 to 1989, Lawrence Livermore National Laboratory (LLNL) developed for the U.S. Nuclear Regulatory Commission (NRC) a method for performing PSHA in the Eastern US; results were documented in NUREG/CR-5250. Improvements in the handling of the uncertainties led to updated results, documented in the 1993-EUS-Update study (NRC, 1993, NUREG-1488) These results were substantially different from those of the utilities-sponsored study by the Electric Power Research Institute (EPRI.)

To improve on the overall stability of the PSHA process, the NRC and the Department of Energy with EPRI co-sponsored a project to provide methodological guidance on how to perform a PSHA; the goal was to narrow the spectrum of possible estimates of hazard at a given site.

The project was carried out by a seven-member Senior Seismic Hazard Analysis Committee (SSHAC) supported by a large number of other experts, who examined ways to improve on the state-of-the-art, the results of which are documented in NUREG/CR-6372 (1997).

As a follow-up to the SSHAC study, the Trial Implementation Project (TIP) used the SSHAC recommendations and developed a set of more detailed guidance for performing PSHA. The TIP project tested the more complicated issue of development of the seismic zonation and seismicity models. It was found that the uncertainty generated by artificial disagreements among experts could be considerably reduced through interaction and discussion of the available data and by identifying the elements common to all experts' interpretations. By concentrating on those elements, it was possible to develop a consensus of the group on the way to characterize them and eliminate large unnecessary differences. The TIP study considered two sites with different seismic environment in the Southeast US: Vogtle, in South Carolina, which is affected by the issue of the Charleston earthquake, and Watts Bar, close to the Eastern Tennessee Seismic Zone (ETSZ), which is a theater of small-to-medium-magnitude seismic events. The results of the TIP study (this report) were found to be different from those of the 1993-EUS-Update study for the Watts Bar site.

This study compares the results of the 1993-EUS-Update and the 1998-TIP studies and identifies the reasons for the differences as:

1. Differences in the ground motion (GM) attenuation models.
2. Introduction of the ETSZ in the TIP study.

It was found that these two factors accounted for a factor of 5 difference in mean estimates of peak ground acceleration (PGA) hazard at high GM levels as shown in Figure Exec-1 below. The agreement between the two studies improved at lower PGA values. The results were in better agreement and differed only by about a factor of 2 at high GM levels when the same GM model was used with each seismicity model. Finally, it was found that the composite rate of earthquakes around the Watts Bar site was about a factor of 2 higher for the TIP composite seismicity model than for the composite 1993-EUS-Update seismicity model.

The root causes for the differences were found to be a combination of characteristics proper to the Watts Bar site, such as the site-specific source zones characterization, and more generic ones such as the modified GM model. Studies of other sites, depending on whether and what new information is available, could have similar conclusions (or not, such as in the case of Vogtle, for which the mean estimates of the hazard decreased between the EUS 1993 and the TIP 1998 studies).

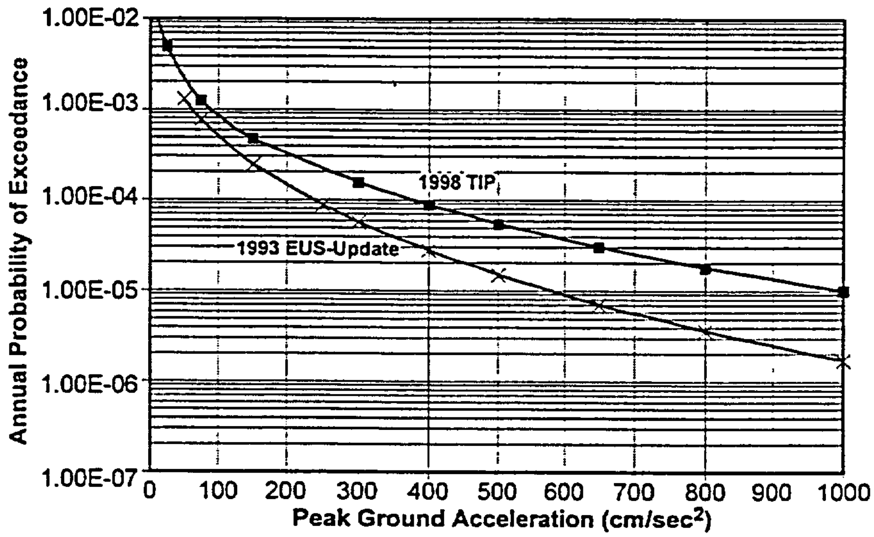

Figure Exec-1: Comparison of the Mean Estimates of the Seismic Hazard for the Watts Bar Site. The Curve with the Square Markers is for the Estimates of the 1998-TIP Study. The Curve with the Crosses is for the Estimates of the 1993-EUS-Update Study.

ACKNOWLEDGMENTS

This project was sponsored by the U.S. Nuclear Regulatory Commission (NRC). The project manager for the NRC was Ernst Zurflueh, and Jean Savy led the project for Lawrence Livermore National Laboratory. Don Bernreuter, who has been working on these methodologies and specifically on the NRC projects at LLNL since 1994, did all the calculations and sleuthing for sections 2 to 7.

ABBREVIATIONS

APE	Annual Probability of Exceedance
BE	Best Estimate
CEUS	Central and Eastern United States
DOE	Department of Energy
EPRI	Electric Power Research Institute
ETSZ	Eastern Tennessee Seismic Zone
EUS	Eastern United States
GM	Ground Motion
LLNL	Lawrence Livermore National Laboratory
NRC	Nuclear Regulatory Commission
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PSHA	Probabilistic Seismic Hazard Analysis
PSV	Peak Seismic Velocity
RP	Return Period (Inverse of Annual Probability of Exceedance)
SRS	Savannah River Site
SSHAC	Senior Seismic Hazard Analysis Committee
TIP	Trial Implementation Project

1. INTRODUCTION

1.1 Background

Probabilistic Seismic Hazard Analysis (PSHA) is a methodology that estimates the likelihood that various levels of earthquake-caused ground motion will be exceeded at a given location in a given future time period. Due to large uncertainties in all the geosciences data and in their modeling, multiple model interpretations are often possible. This leads to disagreement among experts, which in the past has led to disagreement on the selection of ground motion for design at a given site.

From 1981 to 1989, Lawrence Livermore National Laboratory (LLNL) developed for the Nuclear Regulatory Commission a method for performing PSHA in the eastern United States; results were documented in NUREG/CR-5250. Improvements in the handling of the uncertainties led to updated results, documented in the 1993-EUS-Update study (NUREG-1488.) These results were substantially different from those of the utilities-sponsored study performed by the Electric Power Research Institute (EPRI.)

In 1994, in order to review the present state-of-the-art and improve on the overall stability of the PSHA process, the U.S Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) with the Electric Power Research Institute (EPRI) co-sponsored a project to provide methodological guidance on how to perform a PSHA.

The project was carried out by a seven-member Senior Seismic Hazard Analysis Committee (SSHAC) supported by a large number of other experts.

The SSHAC reviewed past studies, including the Lawrence Livermore National Laboratory and EPRI landmark PSHA studies of the 1980s, and examined ways to improve on the present state-of-the-art.

The Committee's most important conclusion was that differences in PSHA results are due to procedural rather than technical differences. Thus, in addition to providing a detailed documentation on state-of-the-art elements of PSHA, the SSHAC report (NRC, 1997) provided a series of procedural recommendations. As part of the SSHAC effort, the recommendations of the SSHAC were partially tested in the development of a ground motion attenuation model for North America. That test had been selected because of the relative simplicity of formulation of the ground motion attenuation models. The issues to be discussed and the input to be generated are limited to the characterization of a few well-defined single parameters. In contrast to the case of the development of ground motion attenuation models, the development of seismic zonation maps involves the evaluation of multidimensional data sets. Descriptions of future seismicity by seismic zonation maps and occurrence models are multi-parameter models with very complex formulation and correlation structure.

Although the SSHAC did not test its recommendations on the development of zonation and seismicity models, it was understood that the recommendations provided were general enough to apply to any problems in which it is important to characterize epistemic uncertainty through the use of multiple experts' inputs, including the case of seismic source zonation modeling.

Under the TIP project (W6496, Testing and Implementation of SSHAC Guidelines), new expert elicitations and seismic hazard calculations were performed by Lawrence Livermore National Laboratory (LLNL) for the southeastern United States using the SSHAC guidelines. Included in the study were site-specific hazard evaluations for the Savannah River and Eastern Tennessee areas. It was found that, for the Eastern Tennessee area, the hazard in terms of annual probability of exceedance was several times larger than that of the previous regional LLNL hazard estimates for the central and eastern United States (CEUS) (1993-EUS-Update study).

This observation emphasizes the importance of conducting site-specific hazard assessments, for instance, for plant site investigations Because a part of the Eastern Tennessee Seismic Zone (ETSZ) was included in the specific location for which a hazard value was derived, the question of using an exclusion zone arises.

1.2 Purpose of the Study, Scope

This study investigates the causes of differences in probabilistic hazard estimate between the 1998-TIP and the 1993-CEUS-Update studies:

1. It evaluates the validity of the new results, which may be affected by the replacement of the ETSZ boundaries, the seismicity rates in the subunits of the ETSZ, and the choice of the ground motion attenuation parameters.
2. It compares the two studies and identifies the reasons for the differences.
3. It performs sensitivity studies to isolate the parameters responsible for the differences

2. DIFFERENCES IN HAZARD ESTIMATES

The 1993-EUS Update Study was actually an update of the 1989 study performed by LLNL for the NRC (Bernreuter et.al., 1989). The seismic zonation models were developed by sampling the interpretations of 11 experts and the ground motion attenuations were developed by sampling a set of 8 ground motion experts. In 1992, LLNL performed a new PSHA for the Savannah River Site (SRS), located at the boundary between South Carolina and Georgia. The concept of a composite ground motion model was developed for SRS and applied to the entire EUS. These results are summarized in Figure 2.1.

The development of the composite ground motion model was based on sampling the interpretation of the GM experts and generating an artificial database of estimates of ground motion for many pairs of distances and magnitudes. Including the full distributions of possible models for each expert included the epistemic uncertainty, and the physical correlation was modeled by preserving the correlation observed in the original models in the final composite model. The elicitation of the experts' interpretation was performed according to a process, which in large part became the process adopted by SSHAC. It had all the essential elements that constitute the SSHAC recommendations. This composite model was very different from the GM models used in the previous NRC study (Bernreuter et al. 1989) and warranted a re-estimation of the seismic hazard at the 69 EUS sites. The 1993-EUS-Update then essentially used the same seismic zonations as the 1989 study, but it used the newly developed SRS/EUS composite GM model, and in addition all of the seismicity experts' estimates of the seismicity rates were re-evaluated, with new elicitation of the experts' interpretations, to eliminate the unrealistic seismicity interpretations which had been identified for some of the zones of the 1989 study. The TIP study was performed later, to demonstrate that SSHAC principles could also be applied to the seismic zonation and seismicity modeling.

Figure 2.1 shows the final estimates of the mean annual probability of exceedance (APE) of the Peak Ground Acceleration (PGA) for the 1993-EUS-Update and 1998 TIP studies.

At higher PGA values (1000 cm/sec^2) the APE from the 1998-TIP study is about a factor of 5 higher than for the 1993-EUS-Update study. However, at low PGA values (100 cm/sec^2) the results from the two studies are in better agreement (a factor of 1.6).

Similarly, Figure 2.2 gives a comparison between the median in the APE. In this case, there is over a factor of 10 differences between the two studies at high PGA values and a factor of 2.5 at 100 cm/sec^2. Comparisons between other hazard estimators show similar differences. Figure 2.3 shows the comparison between the best estimate (BE) hazard curves from the two studies. The BE estimator is not a true statistical estimator. The so termed BE hazard curve is based on using only the mode of the probability distribution of each of the seismicity continuous parameters (such as rate, upper bound magnitude) and the highest weighted zonation map.

Figures 2.1 to 2.3 show consistently that there is a significant difference in the estimation of the seismic hazard between the two studies at long return periods. Since the Hazard calculation algorithms were common to the two studies, the reasons for these differences lie in the actual inputs to the calculations. The possible causes of differences in the APE estimates are listed below:

- Differences in ground models including uncertainty modeling.
- Differences in seismic zones.
- Differences in the estimation of the rates of occurrence of earthquakes (a and b values) and independent estimates for discrete magnitudes.
- Differences in the estimation of the upper bound magnitudes.
- Differences in the uncertainty modeling.

In the following sections, we examine these issues and their impact on the estimation of the seismic hazard at the Watts Bar site and draw conclusions on the causes of differences.

It is interesting to note the hazard estimates from the two studies are in reasonable agreement at return periods of less than 1000 years (PGA levels less than 0.1G) where estimates are primarily controlled by the data rather than by predictive models, which inherently include greater uncertainties for lack of sufficient data.

At long return periods (PGA levels greater than 0.5G), the estimates are controlled as much by the uncertainty models as by the historical seismicity data

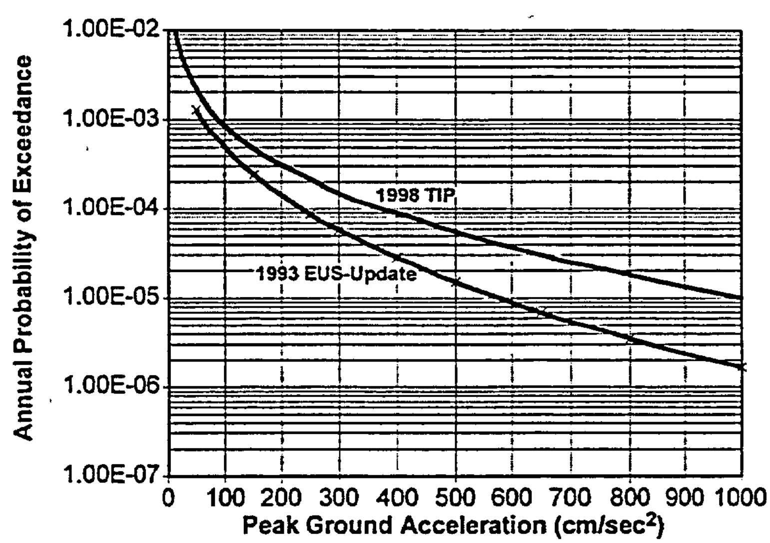

Figure 2.1: Mean PGA hazard estimates for Watts Bar.

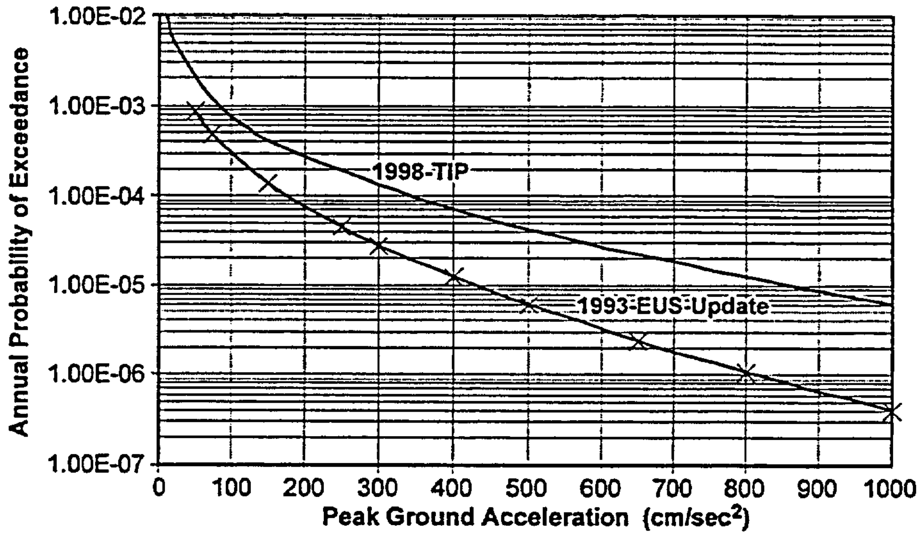

Figure 2.2: Median PGA Hazard Estimates for Watts Bar.

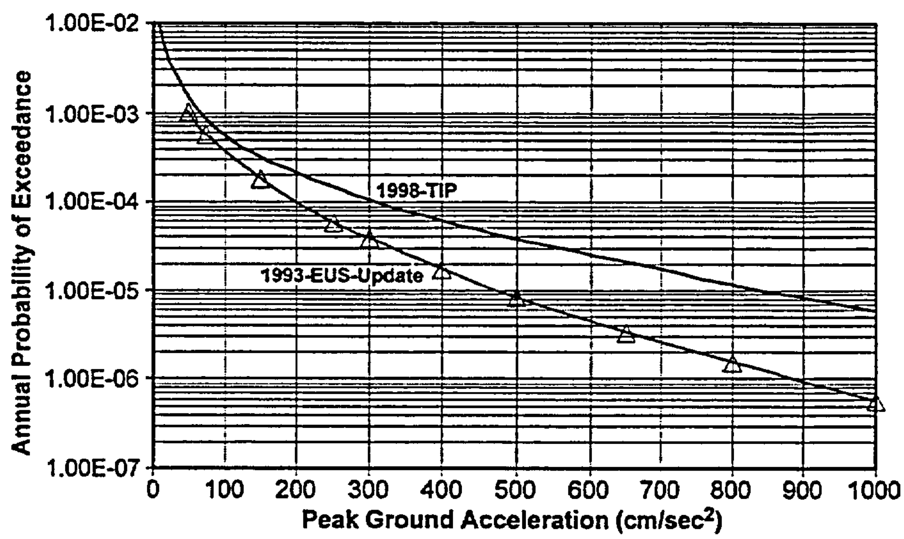

Figure 2.3: "Best Estimate" PGA Hazard for Watts Bar.

3. IMPACT OF THE GROUND MOTION MODELS

3.1 Direct Comparison of the Ground Motion Models Used in the Two Studies

Two different composite GM models were used in the two studies. For ease of reference, the GM model in the TIP study is referred to as the 1998-TIP GM model, and the model in the 1993 study as the 1993-EUS-Update GM model. Let us first examine the two GM models in terms of estimates of PGA for given pairs of magnitudes and distances. Figure 3.1a shows a comparison between the median estimates of ground motion for three magnitudes and a range of distances between 5 and 100 km. The 1993-EUS-Update model had a built-in saturation at 10 km, meaning that the median estimate of the PGA ground motion for distances less than 10 km is equal to its value for 10 km.

These estimates are shown to be in reasonable agreement for distances between 10 km and 100 km, which is the range of distance in which most of the available data fell at the time of the two studies. For distances smaller than 10 km, the saturation imposed on the 1993-EUS-Update model makes it lower than the other model. That area immediately around the site generally does not contribute enough seismicity to have an impact on the total hazard.

The epistemic uncertainty in the 1998-TIP study was included by providing a probability distribution function on the standard deviation on the natural logarithm (σ), with a minimum bound of 0.36, a mode of 0.63 (also labeled BE, for "Best Estimate"), and an upper bound of 0.94.

Combining the inputs of eight GM Experts and using a simulation process to include their complete uncertainty developed the 93-EUS-Update GM model The experts' input was in the form of estimates of the probability distribution function of the ground motion (PGA or peak seismic velocity, PSV) at the sites for a selection of distances and magnitudes. The resulting model was obtained as an empirical distribution of several of the percentiles (a different empirical model for each percentile.)

By contrast, the 1998-TIP model used a similar approach with the inputs from five GM experts. It assumed that the probability distribution function of GM for a given magnitude and distance is lognormal, with a given median and σ, the standard deviation of the log (GM). Thus, when comparing the two models, it is important to refer to the appropriate percentiles. For example, in this study, at times, the medians are compared, i.e., the 50% percentile model for the 1993-EUS-Update and the "mean attenuation" for 1998-TIP. Similarly, in other instances the 85^{th} percentile 1993-EUS-Update and the (mean + 1σ) values are computed.

To directly compare the 1998-TIP model to the 1993-EUS-Update model would have required us to run a simulation over the range of sigma, then develop the percentiles. We did not attempt to carry out this simulation. The effect of the relative difference between the two models is shown in Figure 3.2a where we compare the 1-sigma value of the 1998-TIP GM model using the BE estimate for sigma (0.63) to the 85 percentile estimate for PGA from the 1993-EUS-Update GM model.

Figure 3.2b shows clearly the relative impact of the two models for the range of conservatism frequently used in seismic design parameters. It shows the ratio of GM estimates (1998-TIP/1993-EUS-Update) at the 85^{th} percentile level, between 10 and 100 km of distance and for magnitudes between M5 and M7.

In the magnitude range of 5-6 and distance ranges 0-30 km Figure 3.1b shows that the 1998-TIP GM model gives higher PGA estimates than the 1993-EUS-Update GM model. A strict comparison of the two simulated distributions could probably have led to slightly different observations. This would have made the differences between the two models even larger in the most important range of magnitudes between 5 and 6.

Comparing Figure 3.1b with 3.2b shows that the total uncertainty is larger for the 1998-TIP than for the 1993-EUS-Update GM model. Since the aleatory uncertainty was in the same order of magnitude, the observation shows that the epistemic uncertainty was higher in the 1998-TIP than in the 1993-EUS-Update study.

3.2 Comparison of the Hazard Estimates

In order to understand better how the GM model affects the results, it is necessary to determine the magnitude and distance range that contribute most to the estimates of the hazard as shown in Figures 3.3, 3.4, and 3.5 for the 1998-TIP study.

These figures show that 80 percent of the hazard comes from the distance range 0-40 km and a magnitude range 5-6, which was shown in Figure 3.2 to be the region where the two GM models significantly differ. In addition, the uncertainty in sigma for the 1998 TIP GM model would also increase the differences between the two GM models. Thus, everything else being equal, it is expected that the two GM models would lead to potentially different hazard results, with higher estimates for the 1998-TIP GM model.

3.3 Sensitivity to the Ground Motion Models

Using a common zonation and seismicity model, namely the 1998-TIP model, the hazards estimates are compared directly in terms of the mean hazard curves in Figure 3.6, and the median hazard curves in Figure 3.7, for both 1998-TIP and 1993-EUS-Update GM models.

Similarly, Figures 3.8 and 3.9 compare the mean and median hazard curves using the 1993-EUS-Update zonation and seismicity, and alternatively the TIP and 1993-EUS-Update GM models.

Figures 3.6 to 3.9 show that, as expected, changing GM models has an impact on the hazard. It is interesting to note that the difference in the hazard estimates is larger for the median hazard estimate than for the mean hazard estimate. The impact of the GM model is less for smaller PGA values than larger PGA values. Lastly, it is observed that the effect of changing GM models is larger for the 1993-EUS-Update seismicity model than for the 1998-TIP seismicity model. This last observation is consistent with the fact that the 1993-EUS-Update study had larger area source zones including the Watts Bar site, whereas the 1998-TIP study had smaller zones and local faults, farther from the site. In the latter, the seismicity appeared to be restrained to be more distant from the site.

Figure 3.10 shows the contribution of magnitudes to the mean and median hazard curves at PGA levels of 150 and 1000 cm/sec^2 for the Watts Bar site using 1998-TIP seismicity and the 1998-TIP GM model.

A similar comparison using the 1993-EUS-Update is difficult because there are 11 seismic zonation and seismicity models and some sort of averaging would be required. However, it was found that expert 3's (Bollinger) results were a good proxy representation of the combined 1993-EUS-Update results as shown in Figure 3.11. Based on this figure, we conclude that for the needs of this study, expert 3's seismicity model is a reasonable proxy model for the 11 1993-EUS-Update experts. Figure 3.12a shows results similar to those shown in Figure 3.10 but based on expert 3's seismicity model. Figure 3.12b compares the contribution to the hazard for 1G PGA, from Figures 3.10 and 3.12a.

Figure 3.12a is similar to Figure 3.10 but shows that earthquakes in the magnitude 5.5 ranges contribute more to the hazard. This is also apparent in Figure 3.12b. Thus, we might expect that the change in the GM model would have more effect for the 1993-EUS-Update seismicity case than for the 1998-TIP case, as seen in Figures 3.8 and 3.9.

3.4 Sensitivity to the Seismic Zonation and Seismicity Models

Figure 3.13 compares the mean hazard curves for the case of 1998-TIP seismicity and GM model to the case of the 1993-EUS-Update seismicity and the 1998-TIP GM model. This figure shows the 1998-TIP results to be a factor of 2 greater than with the 1993-EUS-Update seismicity, as compared to a factor of 6 observed from Figure 2.1 when different GM models were used.

Figure 3.14 compares the median hazard curves between the case of 1998-TIP seismicity and 1998-TIP GM model to the case of the 1993-EUS-Update seismicity and the TIP GM model. We see from this figure that the difference between the two hazard curves is about a factor of 2.3 as compared to a factor of 10 observed in Figure 2.2. When the same GM model is used for the two sets of seismicity models, the difference between the two studies is greatly reduced.

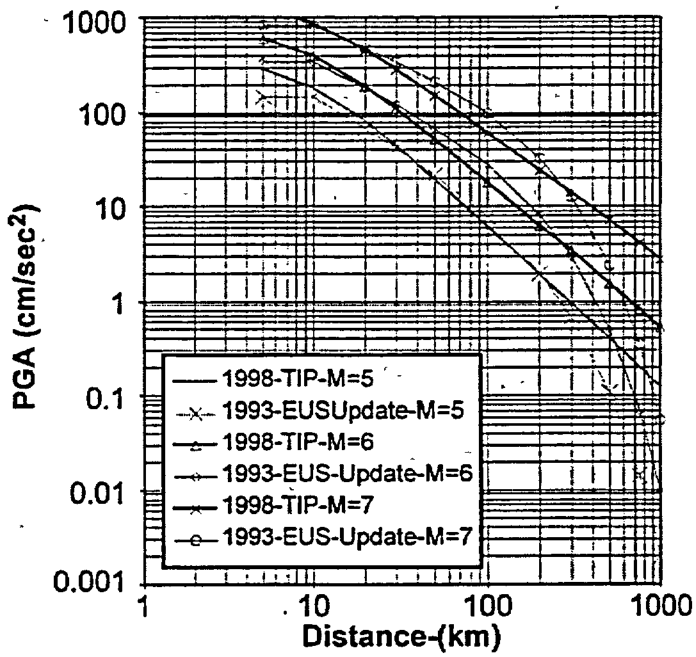

Figure 3.1a: Comparison of the Median Ground Motion Attenuation Models for the 1993-EUS-Update and 1998-TIP Studies for Magnitudes 5, 6, and 7.

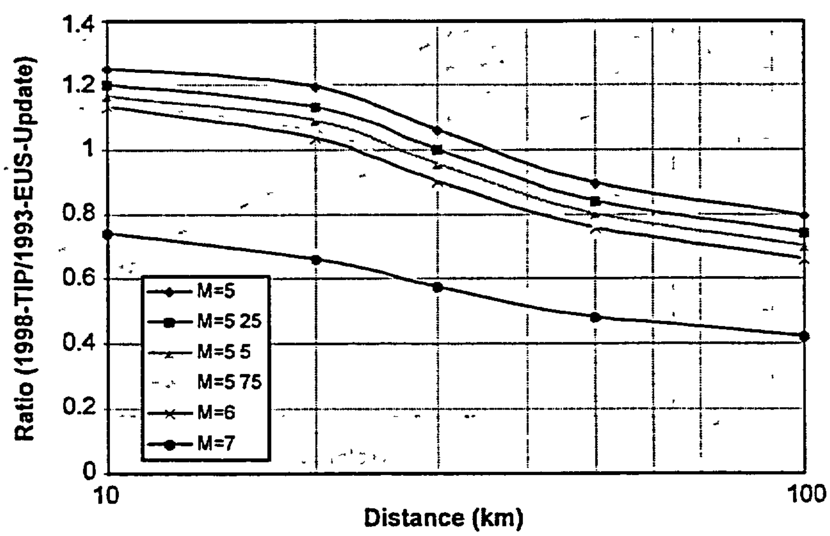

Figure 3.1b: Ratios of the Median PGA Estimates from the 1998-TIP Study, Divided by the 1993-EUS-Update Median Estimates, as a Function of Distance.

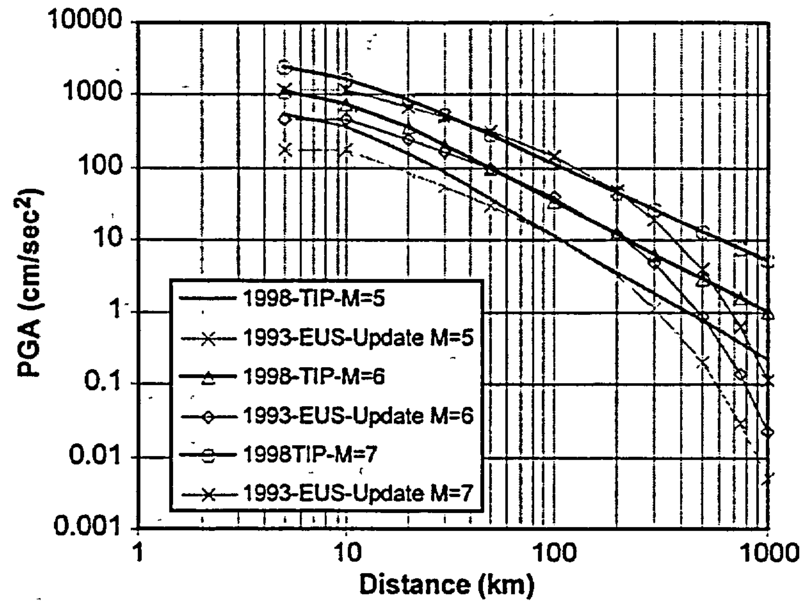

Figure 3.2a: Comparison Between the 1-sigma 1998-TIP and the 85% 1993-EUS Updated Ground Motion Attenuation Models.

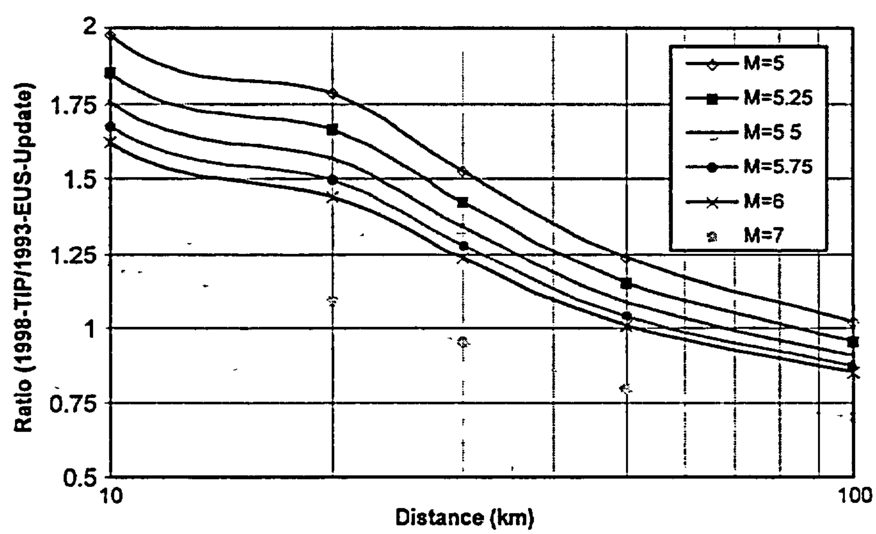

Figure 3.2b: Ratios of the 1-Sigma PGA Estimates from the 1998-TIP Study, Divided by the 1993-EUS-Update Median Estimates, as a Function of Distance.

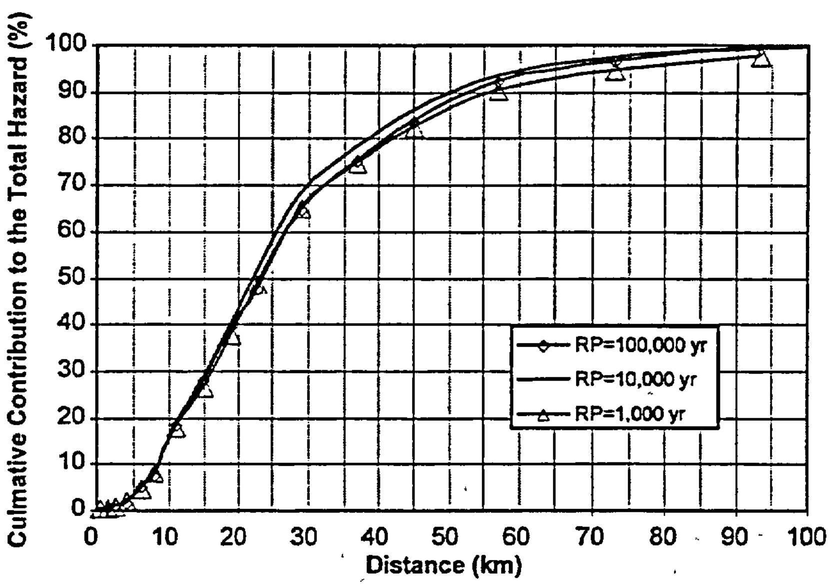

Figure 3.3: Cumulative Contribution of the Distance Bins to Hazard in the 1998-TIP Study. Seismic Source Zones within 40 km of Watts Bar Contribute Approximately 80% of the Total Hazard.

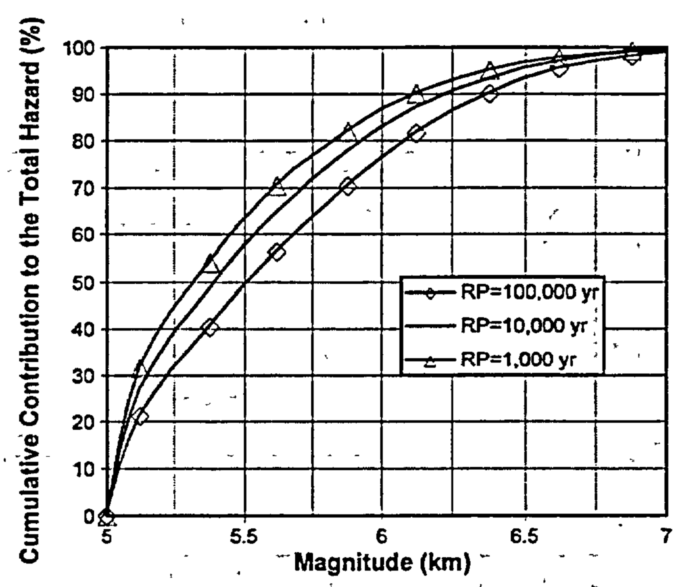

Figure 3.4: Cumulative Contribution of the Magnitude Bins to the Hazard in the 1998-TIP Study. Magnitude Events Smaller Than 6 Contribute Approximately 80% of the Total Hazard.

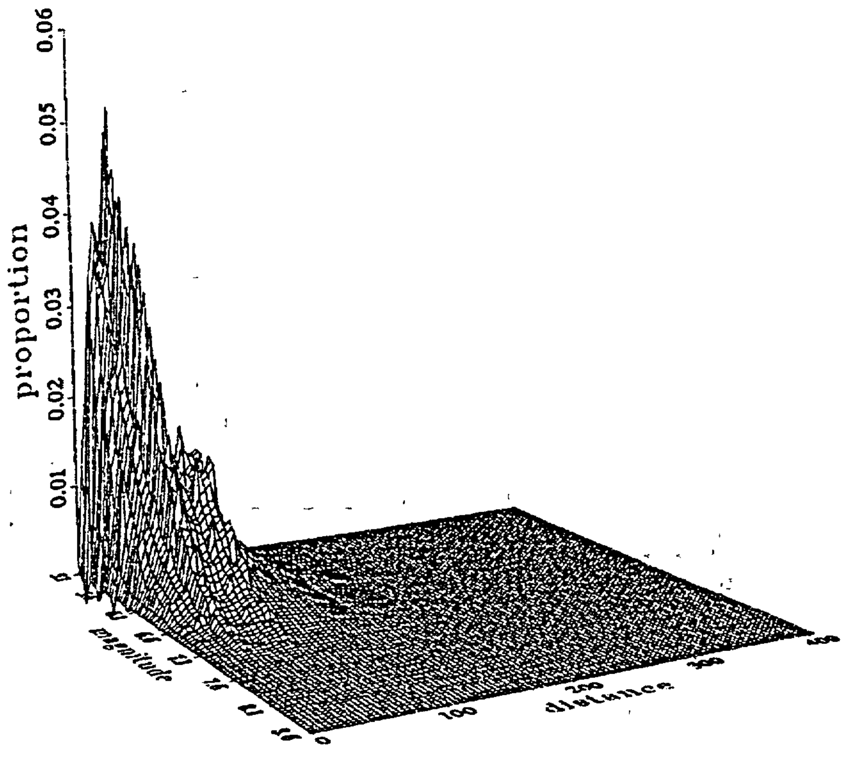

Figure 3.5: Contribution of the Magnitude–Distance Bins to the Total Hazard for a 10,000-Year Return Period.

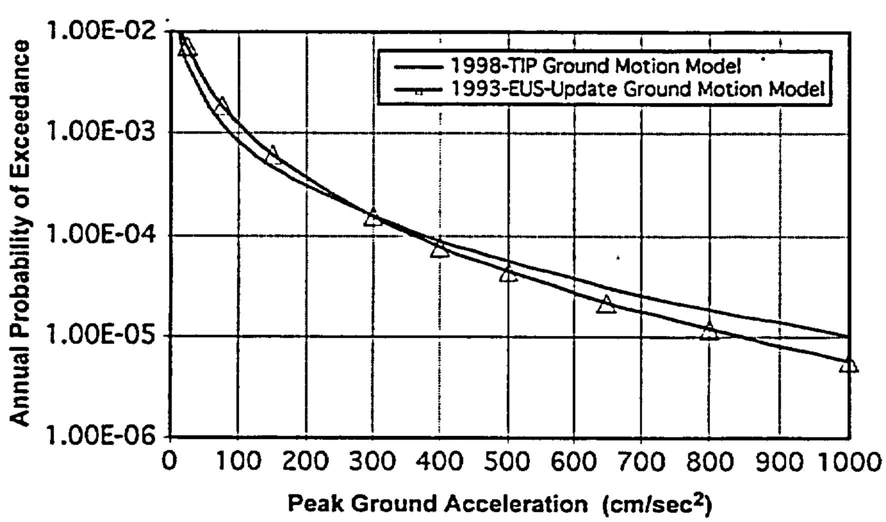

Figure 3.6: Estimates of the Mean Hazard Using the 1998-TIP Seismic Zonation. Comparison between the 1993-EUS-Update and 1998-TIP Ground Motion Attenuation Models.

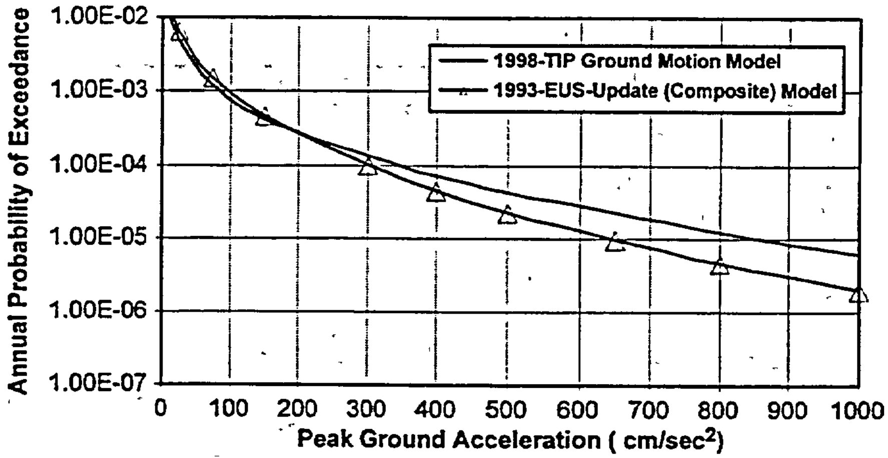

Figure 3.7: Estimates of the Median Hazard Using the 1998-TIP Seismic Zonation. Comparison between the 1993-EUS-Update and 1998-TIP Ground Motion Attenuation Models.

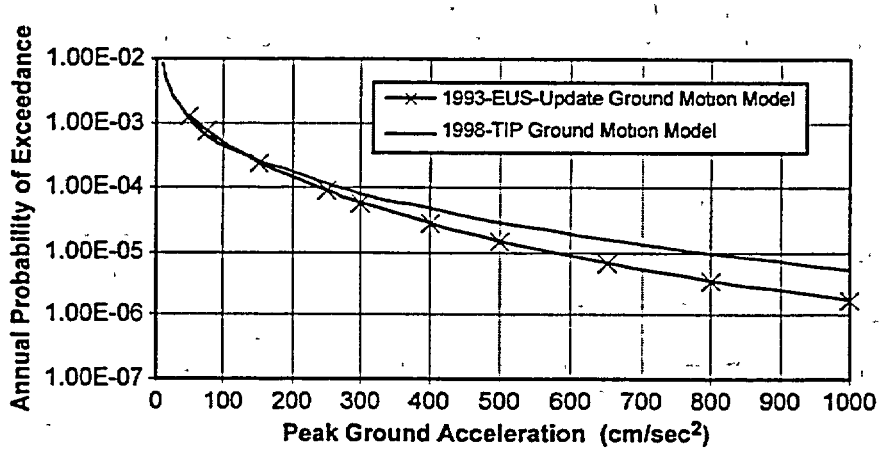

Figure 3.8: Estimates of the Mean Hazard Using the 1993-EUS-Update Zonation. Comparison between the 1993-EUS-Update and 1998-TIP Ground Motion Attenuation Models.

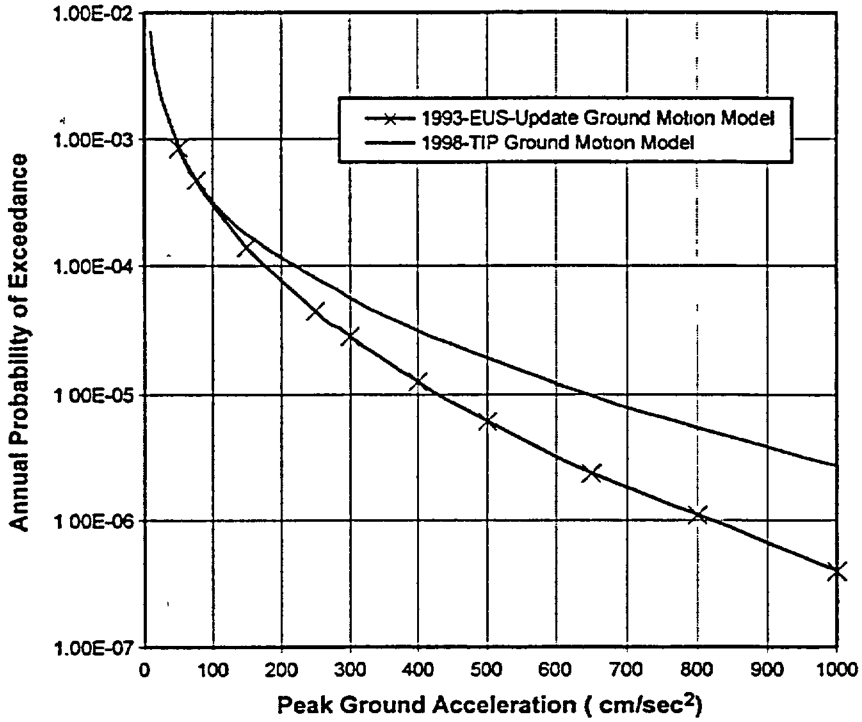

Figure 3.9: Estimates of the Median Hazard using the 1993-EUS-Update Seismic Zonation. Comparison between the 1993-EUS-Update and 1998-TIP Ground Motion Attenuation Models.

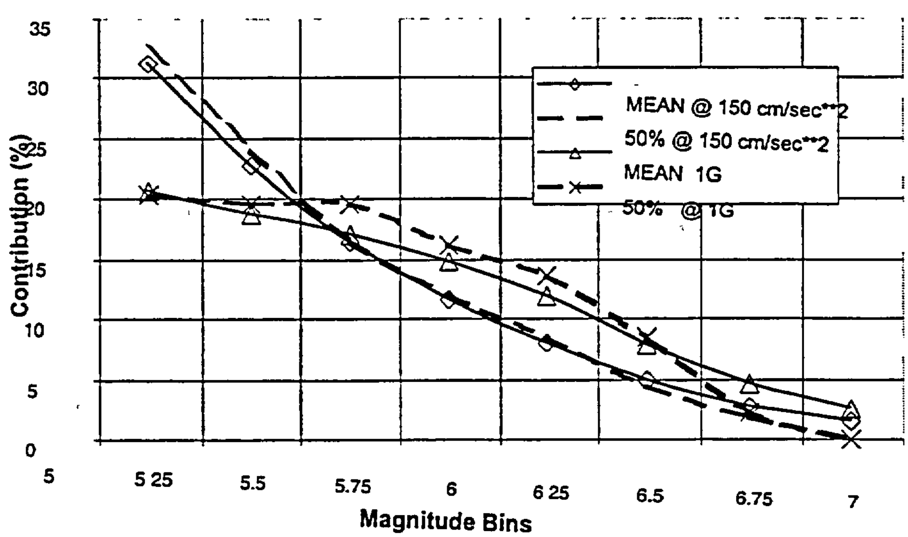

Figure 3.10: Contribution of Magnitude Bins to the Total Hazard in the 1998-TIP Study for Two Peak Ground Acceleration Levels.

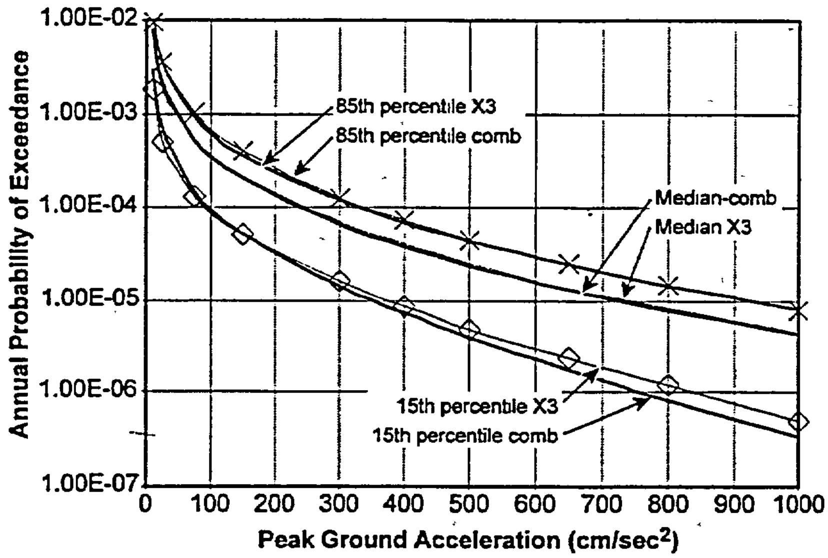

Figure 3.11: Results of the 1993-EUS-Update Study. Comparison of the Mean Estimates of the Hazard between the 11 Experts (comb) and Expert 3 (X3).

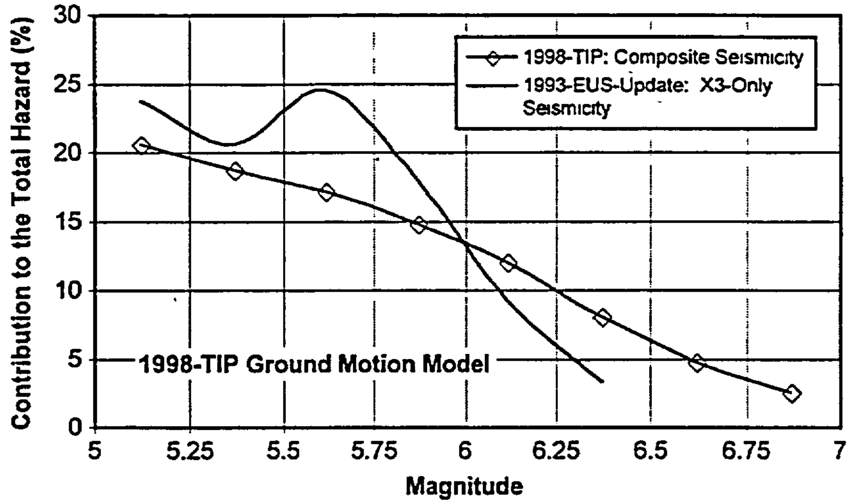

Figure 3.12a: Contribution of Magnitude Bins in the 1993-EUS-Update Study for Two Peak Ground Acceleration Levels for the Case of Expert 3.

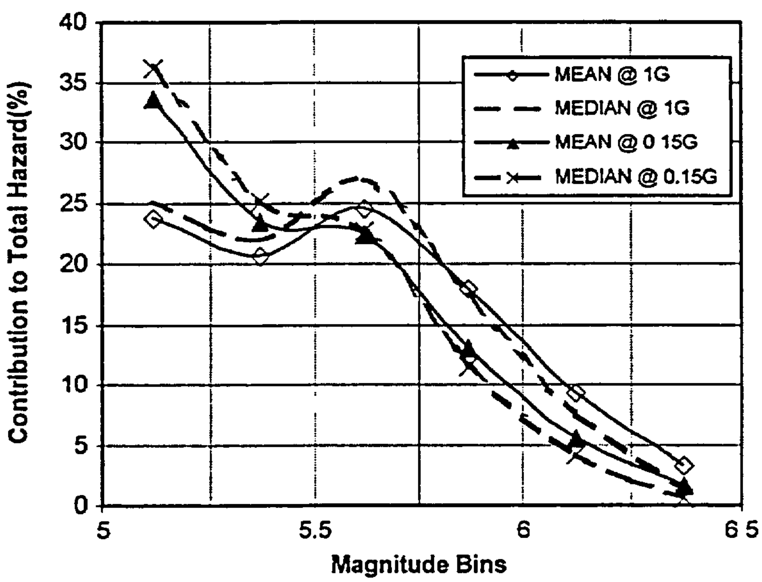

Figure 3.12b: Comparison of the Magnitude Contributions for a 1G PGA Using the 1998-TIP Ground Motion Model. The Seismicity of Expert 3 (X3) Leads to a Strong Mode at M5.6 and the 1998-TIP Composite Seismicity Leads to a Monotonically Decreasing Contribution.

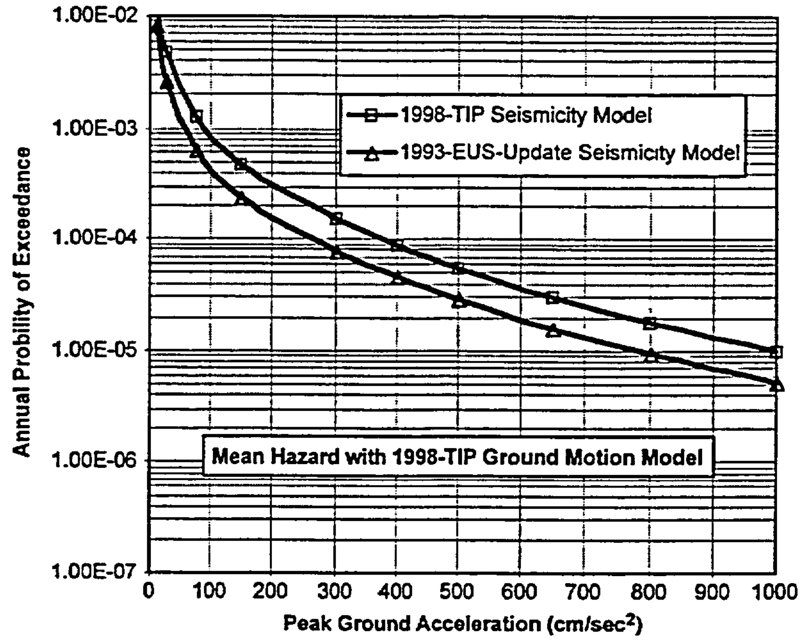

Figure 3.13: Sensitivity to the Seismicity and Zonation Model. The Two Curves Represent the Mean Hazard Estimated with the 1998-TIP and with the 1993-EUS-Update Seismicity-Zonation Models. Both Are with the Same 1998-TIP Ground Motion Attenuation Model.

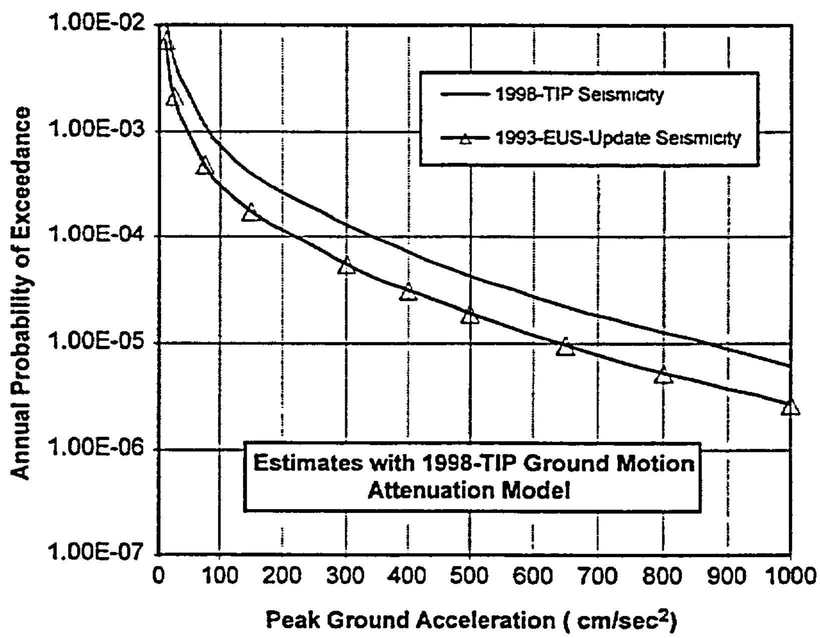

Figure 3.14: Comparing the Median Hazard Curves between the Cases of 1998-TIP Seismicity to the Case of 1993-EUS-Update Seismicity, Both with the Same 1998-TIP Ground Motion Model.

4. IMPACT OF THE SEISMICITY MODELS

4.1 Methodological Differences

This section examines the differences in the zonation and seismicity models between the two-studies. The 1993-EUS-Update study used 11 seismicity experts, each giving his own characterization of the seismic zones and their seismicity parameters. In the 1998-TIP study, five experts were used. One expert was common to both studies—Dr. Bollinger. Dr. Bollinger was labeled expert 3 in the 1993-EUS-Update study. In the rest of this study, Dr. Bollinger is referred to as expert 3 when referring to his contributions to the 1993-EUS-Update study.

The 1993-EUS-Update study used the inputs from the eleven seismicity experts as independent inputs. Each represented the interpretation of one expert. It fully described the seismic environment with the uncertainty that each expert independently perceived. The probabilistic hazard was performed for each pair of seismicity and attenuation experts and the final estimates were a weighted average of all the (paired) hazard curves. The 1998-TIP study used a different approach, similar to that of the approach used in the development of the GM models in the 1993-EUS-Update study and following the recommendations of the SSHAC (NRC, 1997). The basic principle was to decompose each of the seismicity experts' interpretations into an exhaustive set of elemental zones, feature, or physical processes that globally could be used as a "LEGO" to build any of the interpretation of the experts. Consequently, every single part of this "LEGO" no longer belonged to a single expert's interpretation but several, and often all of them. Thus every single one of these elemental parts could be the object of a reflexion, analyses, review discussions, challenges, comparison with data, by all of the experts, thereby automatically including the epistemic uncertainty, by assuming that the sample of experts represented an unbiased sample of the community at large.

In the 1998-TIP study, nine maps were introduced. Figure 4.1, taken from Savy et al. (1998), gives a typical map of the seismic zones near the Watts Bar site.

The region of most interest around the Watts Bar site is shown in Figure 4.2 as an enlarged view of the region.

4.2 Differences of Interpretation of the Data by the Experts

Figure 3.3 showed that 95 percent of the total hazard comes from the zones within 70 km of the site Figure 4.2 shows that the corresponding important zones within this distance are zones 4A-3, 4A-2, 4A-1, 5-2 and 5-1. The 4A zone is labeled "The Eastern Tennessee Seismic Zone" (ETSZ). The nine alternative maps contain interpretation of the data and different models of the ETSZ. See Savy et al. (1998) for details.

A great deal of research on the seismicity was performed in the late 1980s and early 1990s due to the observation of enhanced seismicity of small events in the eastern Tennessee area, leading to an evolution of the experts' thinking on the zonation of seismicity modeling of that area In particular, this led to significant differences between the models of the early 1980s and those of the early 1990s.

For the 1993-EUS-Update study, each of the eleven seismicity experts had a number of maps. These maps were first developed during the 1980s; see Savy et al. (1993), and Bernreuter et al. (1989). None of these maps recognized the ETSZ. The details of each expert's map differ considerably. For example, Figure 4.3 shows seismicity expert 3's zones that impact the Watts Bar Site. Figure 4.4 shows seismicity expert 1's zones that impact the Watts Bar Site.

The seismic hazard is directly influenced, in the first order, by the seismicity rate in the zones around the site. Since the hazard at Watts Bar is contributed mostly by the areas within 35–40 km from the site, a budget of events predicted by the models of zonation and seismicity of each of the experts in the 1993-EUS-Update study is calculated and shown in Figure 4.5.

Figure 4.5 shows the BE rate of earthquakes within 35 km of the site for each of the eleven seismicity experts' inputs. In this case, the mode (BE) of the distribution of seismic rates is used.

For some experts, more than one seismic zone may be within 35 km of the site.

Figure 4.5 shows the diversity between the eleven experts. It also shows the relative agreements for the magnitudes below 5.5. The experts had to evaluate the data to determine the maximum ever possible magnitude event for each of their postulated seismic source zones. Each came up with specific probability distribution functions, which globally represent the epistemic uncertainty on this parameter. In Figure 4.5, this translates into a range of maximum magnitudes between 6 and 7.25.

In Figure 4.6, we compare the median of the distribution of rate curves shown in Figure 4.5 to the similarly constructed BE rate curve based on the composite 1998-TIP seismicity model. It can be seen that the BE 1998-TIP rate is about a factor of 2 higher than the BE rate for the 1993-EUS-Update study which is about the difference we observed in Figures 3.13 and 3.14 between the hazard curves based on the two seismicity models using the same 1998-TIP GM model.

It is instructive to see how Dr. Bollinger's seismicity model has changed between the two studies. Figure 4.3 shows expert 3's seismicity zones used in the 1993-EUS-Update study and Figure 4.1 shows his seismicity zones for the 1998-TIP study. Comparing these two figures shows that the major change in seismic zones is the introduction of the ETSZ in the 1998-TIP study. The real test is not so much in how the zone boundaries have changed but how these changes impact the seismicity models. Figure 4.7 compares the BE seismicity models for the region within 35 km of the Watts Bar Site for Dr. Bollinger's inputs to the two studies.

4.3 Case of the Local Zones

Figure 4.7 shows that the rates in the new ETSZ are much higher than that of the zones in the 1993-EUS-Update study where the Watts Bar Site is located in the large zone 5. Comparing Figure 4.7 to Figure 4.6 shows that the experts' rates are about a factor of 2 higher than the composite 1998-TIP seismicity model.

The BE rate of earthquakes of $M \geq 3.5$, shown in Table 4.1, are calculated for the 1998-TIP composite model and Bollinger's model for the region within 33 km of the Watts Bar site for the five highest-weighted maps. Table 4.1 shows that Bollinger's rates are significantly higher than the rates of the composite1998-TIP model for the two highest-weighted maps (maps 1 and 2) within 33 km of the site.

Table 4.2 gives the rate of earthquakes of $M \geq 3.5$ for the zones within 33 km of the Watts Bar site that are incorporated in Maps 1 to 5. The rates are each zone's contribution to the total rate; i.e. the rates for each zone listed in Table 4.2 are equal to:

(total zone rate) × (area of the zone within 33 km of the site) / (total area of the zone)

The rates in Table 4.1 are for the same surface area but may be for more than one zone.

The zone number is an arbitrary labeling system used in the computations. The zone name refers to the names in Figures 4.1 and 4.2. (Additional details can be found in Savy et al., 1998). Bender Cylinder refers to a type of zone with uncertain (fuzzy) boundaries modeled by a series of cylinders of constant seismicity rates.

Tables 4.1 and 4.2 show that the most important zones are zones B1, B2, and zone 35 with respect to the hazard at Watts Bar. In Figure 4.2, zone B2 is zone 4A-3 and zone 4A-2 combined into a single zone. Zone B1 is zone 4A-3 as an independent zone. Zone 35 is made up of zones 4A-1 and 4A-2. Figure 4.8 shows this zone and the historical seismicity in this zone. (See also Figure 4.1.)

Let us examine the recurrence model in zone 35. It is a zone with significant seismicity, and the recurrence model should be reasonably well defined by the earthquake data. Figure 4.9 compares the raw counts of earthquakes in zone 35 for three time frames (normalized to a yearly rate) to both the 1998-TIP composite and Bollinger's recurrence models.

Figure 4.9 shows that there is sufficient data in Zone 35 to define the recurrence model. Both Bollinger's and the composite 1998-TIP's models agree reasonably well with each other and with the "budget" of historical earthquakes in the zone.

A similar comparison is shown in Figure 4.9 for Zone B1 (using data from only two time frames this time) There is much less data in Zone B1 than in Zone 35 to estimate a recurrence model; however, there is sufficient data to make a reasonable estimate of the recurrence model for the zone. Figure 4.10 shows that both Bollinger's and the composite 1998-TIP's models agree reasonably well with each other and the data.

Finally, Figure 4.11 gives the data in Zone B2 showing that there are too few earthquakes for completeness, for any of the three time frames, probably due to the relatively small size of the zone. Because there is so little data in Zone B2, it is not meaningful to talk about a "budget" of earthquakes. To develop a recurrence model for this zone the experts must bring other factors into their estimates for the recurrence model. This leads to a considerable difference between Bollinger's model and the composite 1998-TIP recurrence models as was discussed in Savy et al. (1998) in Section 4.2.6.3.

In Figure 4.12, the recurrence model for expert 3 in the 1993-EUS-Update study is compared to the "budget" of earthquakes in zone 5 (see Figure 4.3), showing that the recurrence model reasonably fits the "budget" of earthquakes in this zone.

Figures 4.9 to 4.12 show that for the zones where there is sufficient data to establish a budget of earthquakes, the recurrence models developed by the experts are in reasonable agreement amongst themselves and with the data. However, in a site-specific study, small seismic zones can be defined on the basis of geological or geophysical data that are not necessarily associated with sufficient seismicity in the historical record to adequately define the recurrence model. This has been the case in previous studies (e.g., Savannah River Site hazard study, 1992), and was extensively discussed at the SSHAC interactive working meetings (NRC, 1997). The lack of knowledge in the characteristics of Zone B2 leads to a single expert's higher uncertainty and consequently higher mean hazard estimate than in the composite. Zone B2 is such a zone. The experts highly weighted this zone so it appeared in the most important maps and thus has a significant impact on the estimation of the seismic hazard. This point is illustrated in Figure 4.13, where the mean estimates of the seismic hazard at the Watts Bar site based on the 1998-TIP composite model are compared with Bollinger's model that appear to be the highest, simply due to the impact of Zone B2.

Table 4.1: Best Estimate Earthquake Budgets of Earthquakes with Magnitudes Greater than 3.5 within 33 km of Watts Bar in the 1998-TIP Study, for Bollinger Alone and for the 1998-TIP Composite Seismicity Model			
Maps Ranked by Relative Weight	**Relative Weight of the Maps**	**1998-TIP Bollinger**	**1998-TIP Composite**
1	1.0	0.071	0.034
2	0.89	0 072	0.036
3	0.57	0.032	0.038
4	0.51	0.044	0.044
5	0.27	0.054	0.065

Table 4.2: Contribution of Selected Seismic Zones to the Budget of Earthquakes Greater Than Magnitude 3.5 within 33 km of Watts Bar, in the 1998-TIP Study. "Tip Rate" Refers to the Rates from the 1998-TIP Composite Seismicity Model and "Bol Rate" Refers to the Seismicity Rates from Bollinger Only, in the 1998-TIP Study									
Zone #	**Bol Rate**	**Tip Rate**	**Map1**	**Map2**	**Map3**	**Map4**	**Map5**	**Zone**	**Name**
28	0.006	0.0096		Yes		Yes		{5-1} +	{5-2}
29	0.012	0.0094	Yes	Yes				B1	
30	0.054	0.017	Yes	Yes				B2	
32	0.014	0.017					Yes	4A-1 Bender	Cylinder
33	0.026	0.03					Yes	4A-2 Bender	Cylinder
34	0 0084	0.01					Yes	4A-3 Bender	Cylinder
35	0.023	0.027			Yes	Yes		4A-1 +	4A-2
46	0.03	0.03						Fault6	

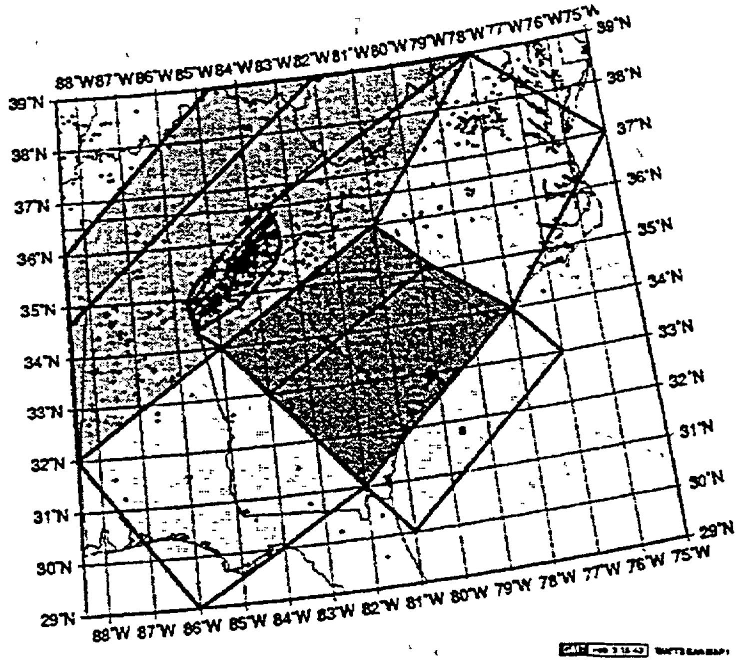

Figure 4.1: First-Order Regional Seismic Sources Zonation Map for the Study of the Watts Bar Site in the 1998-TIP Study.

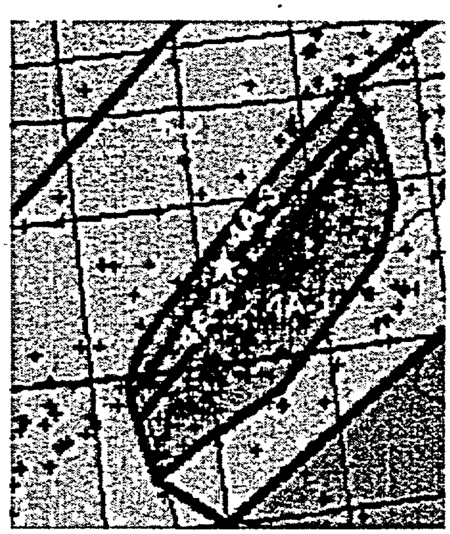

Figure 4.2: Detail of the Geometry of the Local Seismic Source Zones Considered in the 1998-TIP Study.

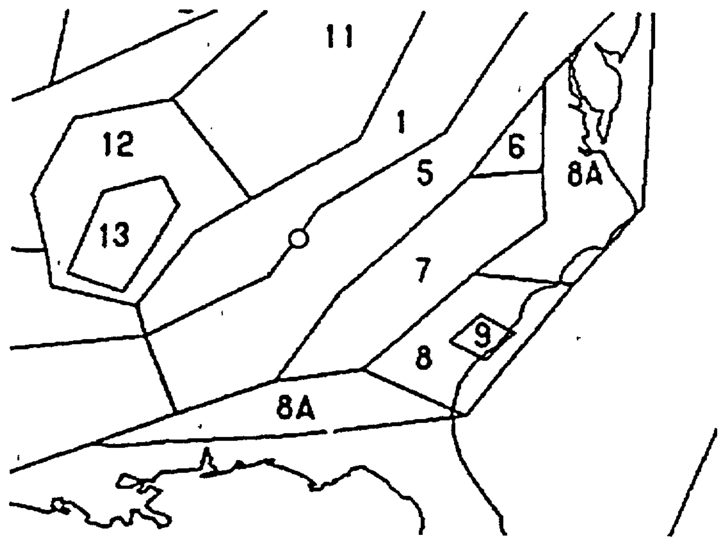

Figure 4.3: One of the Seismic Source Zone Maps Submitted by Seismicity Expert 3 in the 1993-EUS-Update Study. The Site Location is Shown by the Circle on the Map.

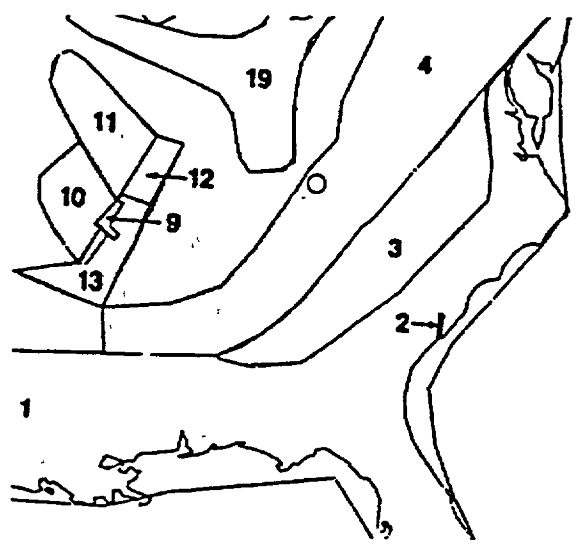

Figure 4.4: One of the Seismic Zone Maps Submitted by Seismicity Expert 1 in the 1993-EUS-Update Study. The Location of the Site is Indicated by a Circle on the Map.

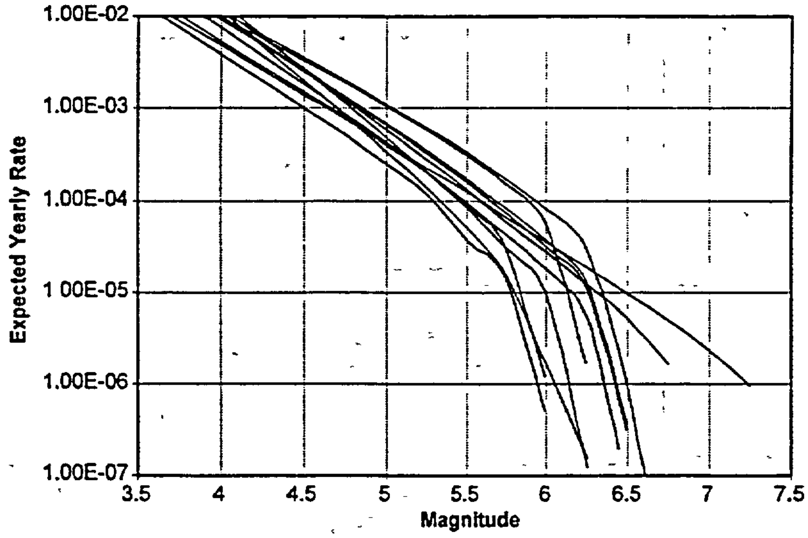

Figure 4.5: Expected Budget of Earthquakes within 35 km of Watts Bar from the Zonation and Seismicity Models of the 11 Seismicity Experts of the 1993-EUS-Update Study.

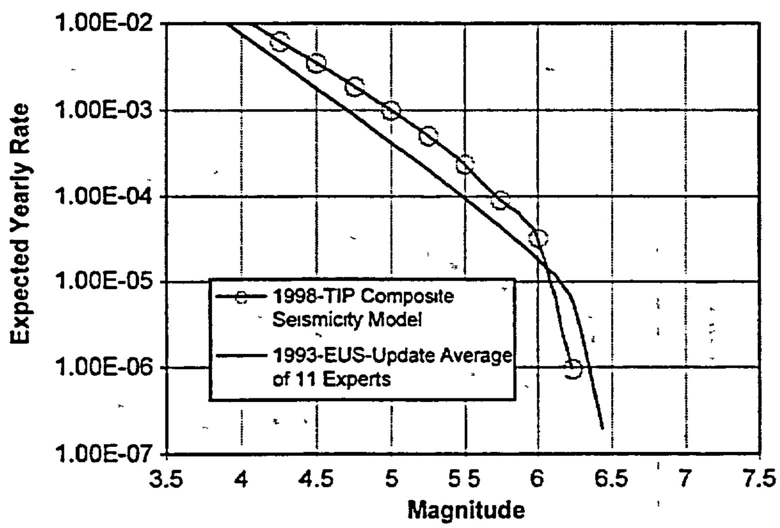

Figure 4.6: Comparison of the Earthquake Seismicity Budget within 35 km of Watts Bar for the 1993-EUS-Update and the 1998-TIP Seismic Zonation and Seismicity Models. The 1993-EUS- Update Curve is an Average Over the 11 Seismicity Experts; the 1998-TIP Curve is from the Composite Zonation and Seismicity Model.

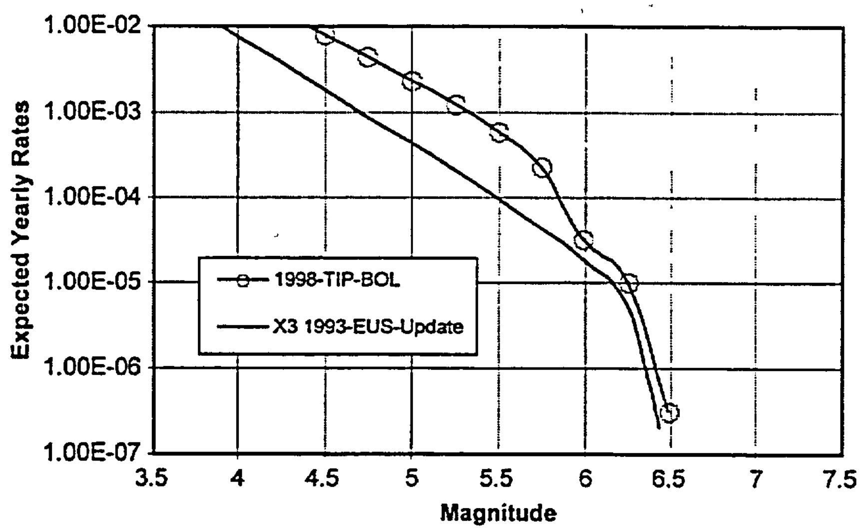

Figure 4.7: Comparison of the Best Estimate Seismicity Budget for a Region within 35 km of Watts Bar, Provided by Expert 3 (X3 1993-EUS-Update) in the 1993-EUS-Update Study and by G. Bollinger in the 1998-TIP Study (1998-TIP-BOL).

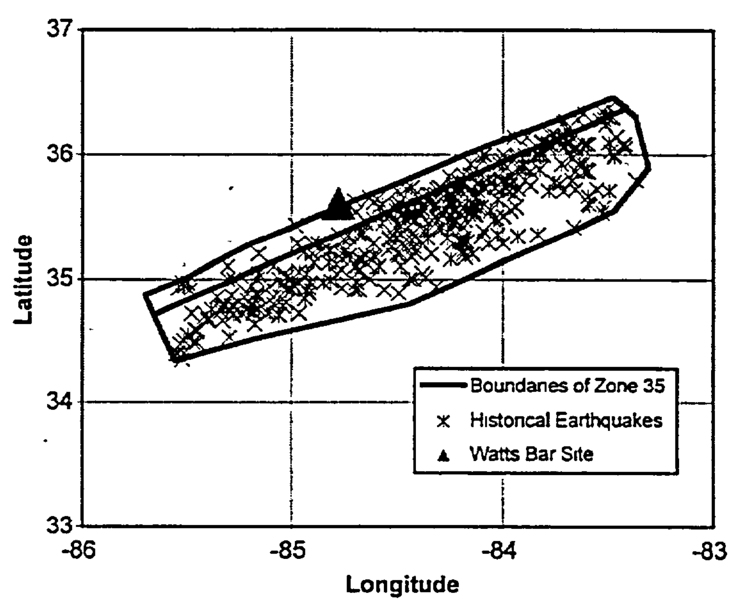

Figure 4.8: Historical Seismicity in Zone 35 of 1998-TIP.

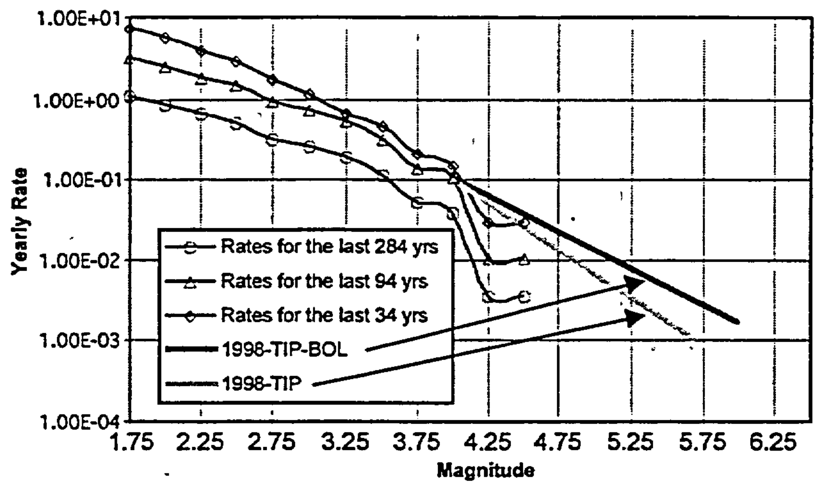

Figure 4.9: Comparison of the Budget of Historical Earthquakes with the Expected Estimates in Zone 35 of 1998-TIP. The Composite Seismicity Model Including All Experts' Input is Labeled "1998-TIP" and "1998-TIP-BOL" for Bollinger's Input Only.

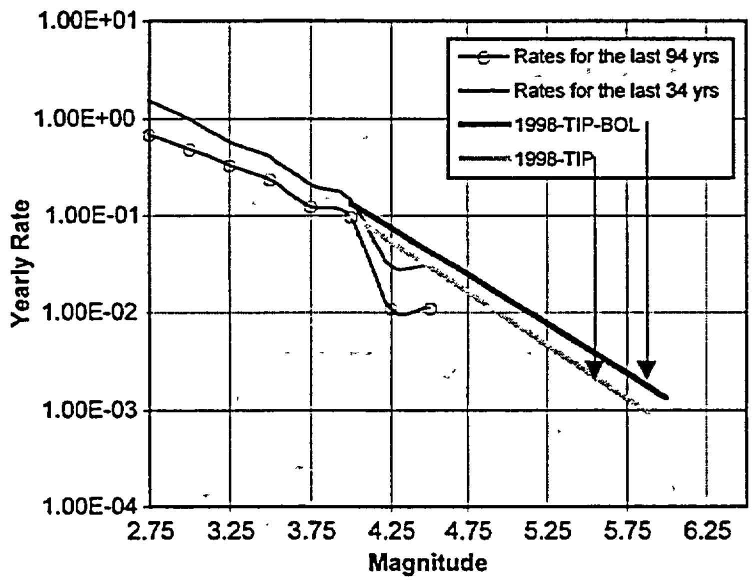

Figure 4.10: Comparison of the Budget of Historical Earthquakes with the Expected Estimates in Zone B1 of 1998-TIP. The Composite Seismicity Model Including All Experts' Input Is Labeled "1998-TIP" and "1998-TIP-BOL" for Bollinger's Input Only.

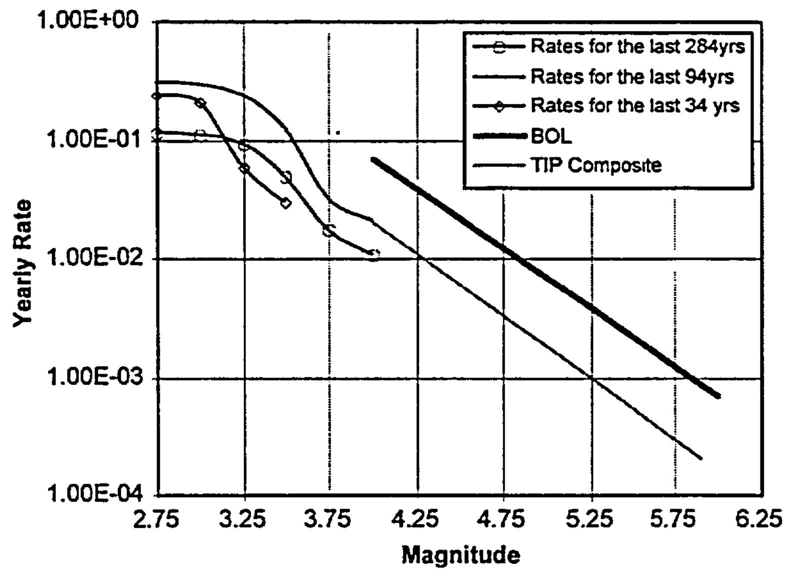

Figure 4.11: Budget of Historical Earthquakes and Modeling for Zone B2 in 1998-TIP.

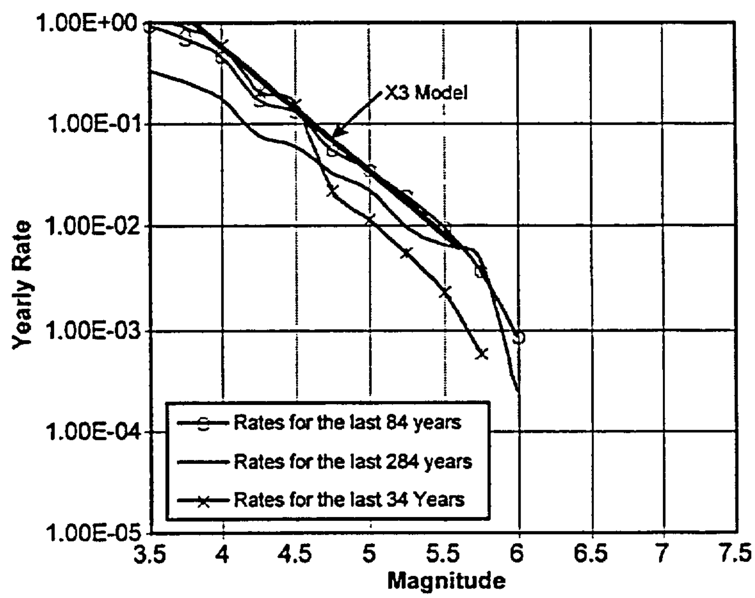

Figure 4.12: Yearly Rates in Zone 5 for Expert 3 of the 1993-EUS-Update Study. "X3 Model" Refers to Expert 3's Estimates. The Other Curves are for Historical Earthquakes.

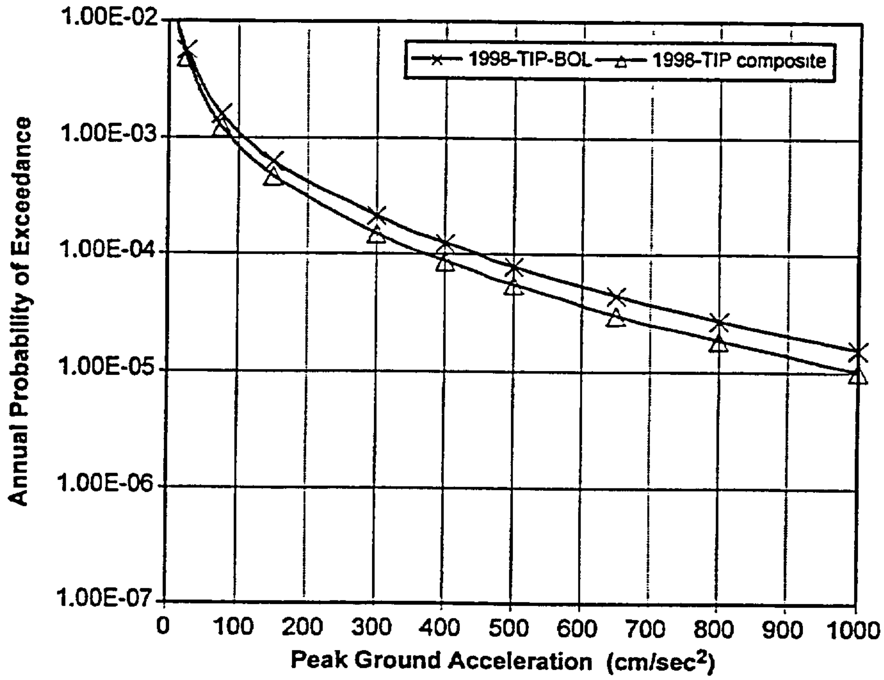

Figure 4.13: Mean Estimates of the Seismic Hazard at Watts Bar Using the 1998-TIP Composite Seismicity Model (1998-TIP composite) and Bollinger's Model (1998-TIP-BOL). The Ground Motion Model is the 1998-TIP Model.

5. UNCERTAINTIES AND SENSITIVITY STUDIES

5.1 Parameters of Interest

The methodological differences between the two studies lead to differences in the modeling of the epistemic uncertainty in the formulation of the zonation maps. In this section, the impacts of those differences are analyzed as well as other causes of differences such as whether an analysis is regional or local. The level of refinement of the seismicity and zonation model is examined by evaluating the impact of considering faults, rather than area zones, for modeling the seismicity in the ETSZ. Finally, the issue of saturation in the GM models is evaluated.

Figure 5.1 shows the predicted mean annual rate of occurrence within a 33-km radius of Watts Bar, for the five highest-weight zonation maps of the 1998-TIP study (see relative weights in Table 4.1). This figure shows that the difference between the lowest curve (Map 1) and the highest (Map 4) in the magnitude range of 4.5 to 6 is a factor of 2 to 3, which is reasonably small, and not likely to generate a large uncertainty in the hazard estimates.

5.2 Sensitivity to the Formulation of the Zonation Maps

The general approach to model the epistemic uncertainty in the estimation of the seismicity is to use a range of zonation maps with the seismicity rates probability distributions corresponding to each seismic zone, or fault. Table 4.1 gives an example of five such maps used in the 1998-TIP study. The set of maps, with the associated weights, constitutes the discrete probability distribution of maps and thus quantifies the uncertainty in the zonation. The total seismic hazard is a weighted average of the hazard calculated for each map.

It is seen that although Map 5 has the highest rate at M≥3.5, Map 4 has the highest rate in the range of interest of M5 to H6 25. Figure 5.2 compares the mean estimate of the hazard for each of the five highest-weighted maps as well as the total mean hazard curve. When the weights are applied to each of the maps, actual impact on the hazard is smaller than shown in Figure 5.2. Hence, the various alternative maps do not introduce significant uncertainty in the final hazard estimates.

The actual uncertainty introduced by the different maps might even be less than the amount implied by Figure 5.2, as some of it is actually introduced by the simulation process itself (see the discussion in section 5.3 below).

5.3 Sensitivity to the Parameters of the Monte-Carlo Simulation

In performing the simulations, the size of the samples was determined by the limits of the computation capabilities in 1993. Given this limited number of simulations, the choice of the seed introduced some variability in the estimates of the hazard. At the time this number of simulations was selected after a careful consideration of that variability, with sensitivity analyses showing that the selected seeds were adequate for the purpose (see Bernreuter et al., 1989). The order of magnitude of this uncertainty is shown in Figure 5.3 in the comparison of the mean hazard curves for four different random seeds. It shows that this variability in the mean hazard curve is small but must be considered before drawing conclusions, such as in section 5.2 above.

5.4 Site-Specific versus Regional Studies

One important difference between the 1993-EUS-Update study and the1998-TIP study was the introduction of the ETSZ in the 1998-TIP study.

Would the experts of the 1993-EUS-Update study have introduced an ETSZ if it had been a site-specific study that focused on the Watts Bar site?

To answer that question, the issue of modeling the seismicity of the region around the site is examined. Figure 5.4 shows the earthquake locations in zone 5 of expert 3 of the 1993-EUS-Update study. The figure shows that there is a high density of earthquakes in the region assigned to the ETSZ. This points out one of the possible differences between a site-specific study and a broad regional study—namely, a broad regional study might miss a small zone of increased seismicity near a specific site. On the other hand, as discussed above, site-specific studies can introduce problems by defining zones too small to have sufficient data to adequately develop a recurrence model, and other less reliable methods might have to be used to develop the recurrence model.

5.5 ETSZ versus Local Faults

One interesting feature of the 1998-TIP seismicity model was the introduction of faults to replace the ETSZ (see Figure 5.5). The estimate of the hazard at the site could possibly be increased by the fact that Fault 6 is very near to the site. Little is known about these possible faults and the experts had no additional data to use to model the recurrence model for Fault 6, other than distribute the seismicity of the zone among the faults. Because of this, introduction of the faults into the seismicity model did not have a significant impact on the estimate of the hazard at the Watts Bar site. Figure 5.6 compares the BE estimate of the hazard based on the highest-weighted map to the BE estimate of the hazard based on a typical fault map.

It is seen from Figure 5.6 that the hazard estimate is lower for the fault model than for the zone model. This is in part an artifact of the way the recurrence model was assigned to the fault. If there had been sufficient information about Fault 6 to make an independent assessment of the recurrence model for the fault, then the fault model might have supplied a better estimate of the hazard than the zone model.

5.6 Ground Motion Saturation

Figure 3.1 shows one major difference between the GM models. The 1993-EUS-Update GM model saturates at 10 km and the 1998-TIP GM model does not. To see what impact this has we ran a sensitivity study modifying the 1998-TIP GM model so that it saturated at 10 km. Figure 5.7 shows a comparison of the BE hazard estimates between the 1998-TIP GM model and the modified (saturation of PGA at 10 km) 1998-TIP GM model. This figure shows that saturation of the GM at 10 km has little effect on the estimated hazard.

At first, it may seem surprising that there is so little impact on the hazard between the saturated version of the 1998-TIP GM model and the unsaturated version. However, referring to Figure 3.3 shows that only approximately 15 percent of the hazard comes from the distance range 0-10 km. In addition, in this same distance range the saturated 1998-TIP GM model also contributes almost a similar amount to the hazard. Figure 5.8a gives a plot of the percent contribution to the hazard as a function of the distance to the site, using the 1998-TIP GM model, for a range of return periods. Figure 5.8b gives the same information for the saturated 1998-TIP GM model. These two figures show that the shapes of the percent contribution curves are similar. The net effect is that the resultant hazard curves are very similar, with the hazard for the saturated GM model being slightly lower.

5.7 Uncertainty in the Ground Motion Models Estimates

Figure 3.1 showed a significant difference in the rate of attenuation of PGA for distances greater than 200 km. However, Figure 3.3 also showed that over 99 percent of the hazard comes from the earthquakes within 100 km of the site. Thus, the difference in attenuation has little impact on the hazard at the Watts Bar site.

In Section 3, it was noted that the uncertainty in the 1998-TIP GM model is greater than that of the 1993-EUS-Update GM model. This difference in uncertainty models can impact the identification of those factors that contribute most to the hazard.

For example, Figure 5.9 shows the range of earthquake magnitudes that contribute to the hazard for the 1998-TIP seismicity model combined with the 1993-EUS-Update GM model. This should be compared to Figure 3.10 where the 1998-TIP seismicity model was combined with the 1998-TIP GM model.

It is seen that at longer return periods (higher PGA levels) the range of magnitudes that contribute most to the hazard changes depending on which uncertainty model is used for the GM model.

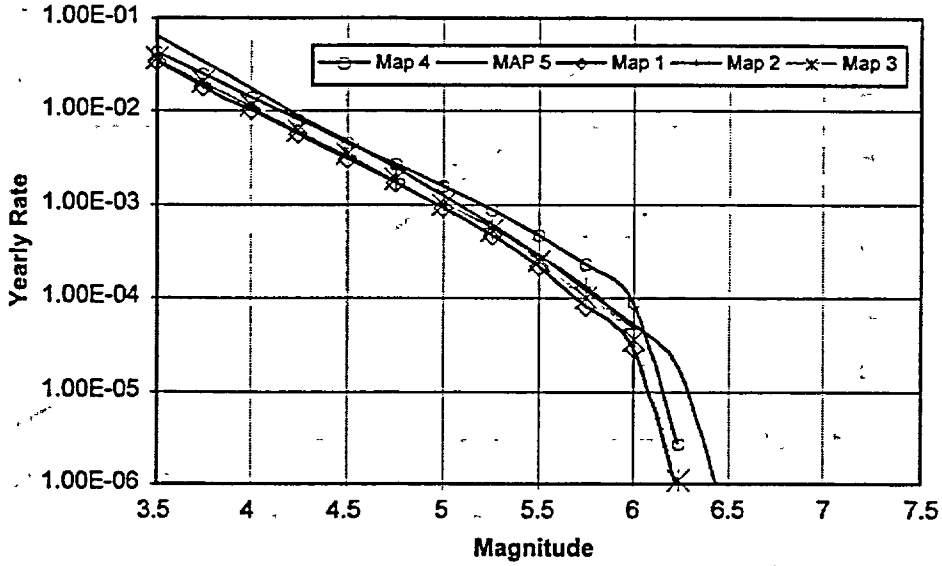

Figure 5.1: Comparison of the Annual Rates of Occurrence of Earthquakes within 33 km of Watts Bar, for the 5 Highest-Weighted Zonation Maps of the 1998-TIP Study. The Relative Weights of the Maps Are Given in Table 4.1.

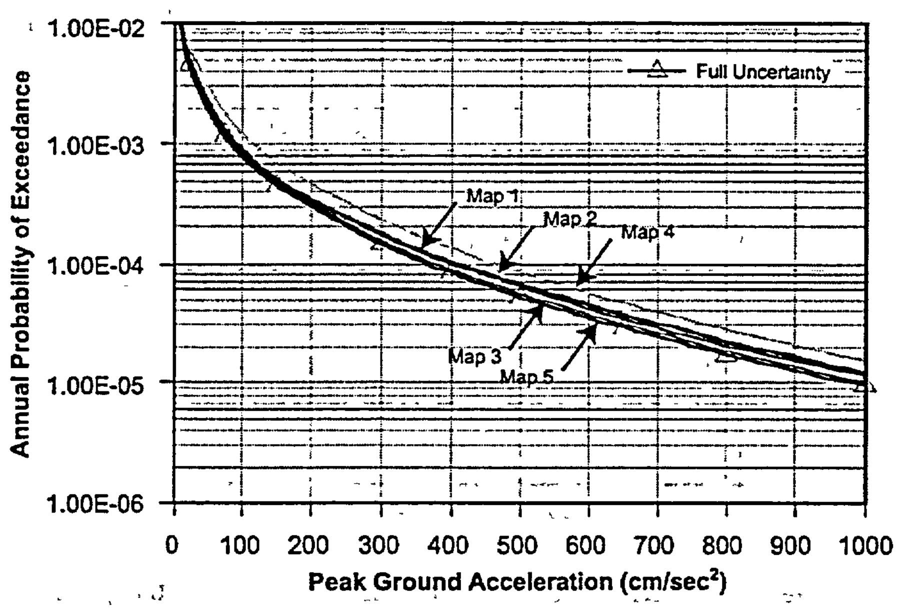

Figure 5.2: Comparison of the Mean Estimates of the Hazard for Each of the Five Highest-Weighted Maps with the Overall Mean Hazard.

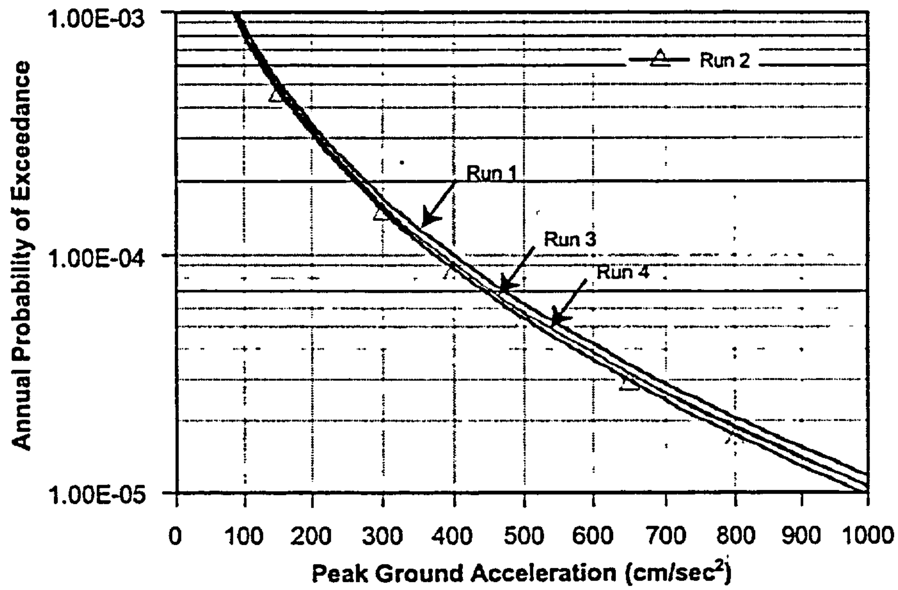

Figure 5.3: Sensitivity of the Mean Estimates to the Seed of the Monte-Carlo Simulation.

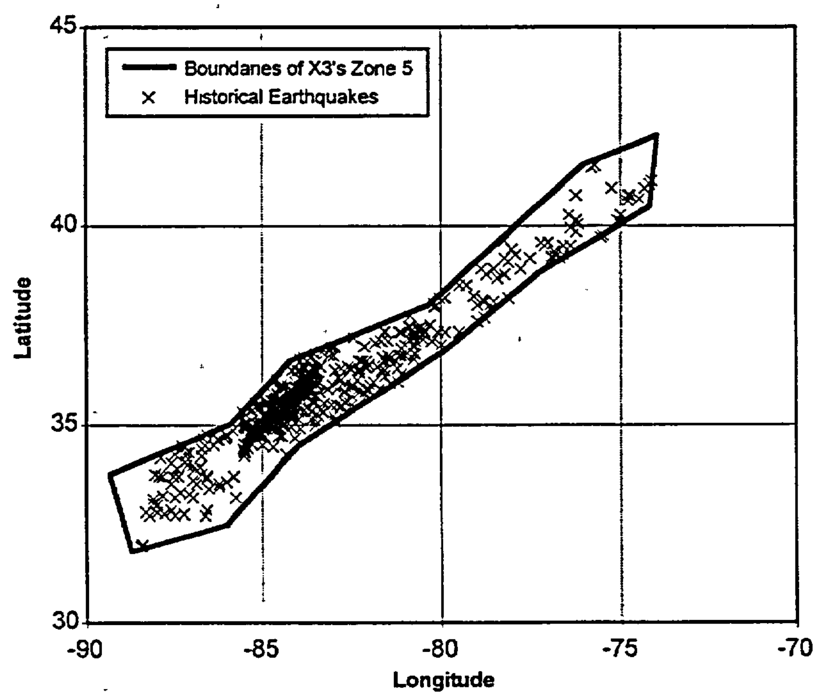

Figure 5.4: Historical Seismicity in Expert 3's Zone 5 of the 1993-EUS-Update Study.

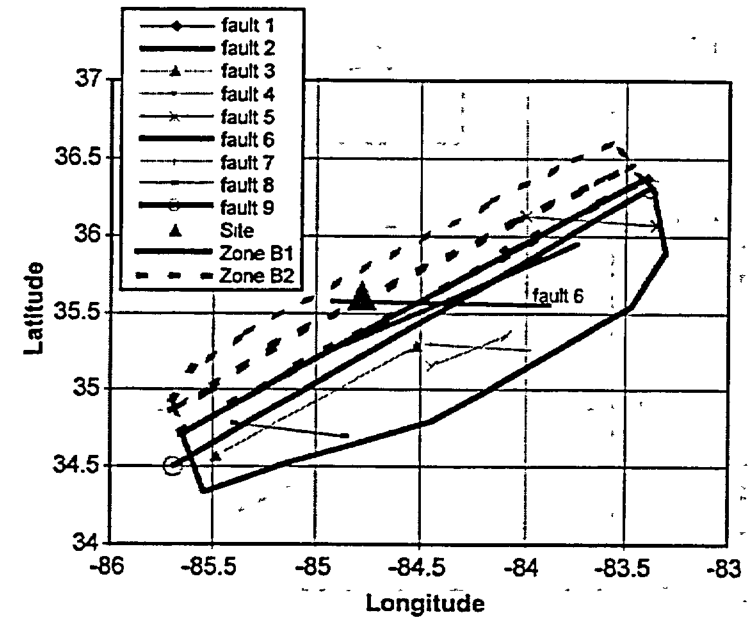

Figure 5.5: Location of the Faults Relative to the Site and the Eastern Tennessee Seismic Zone (ETSZ).

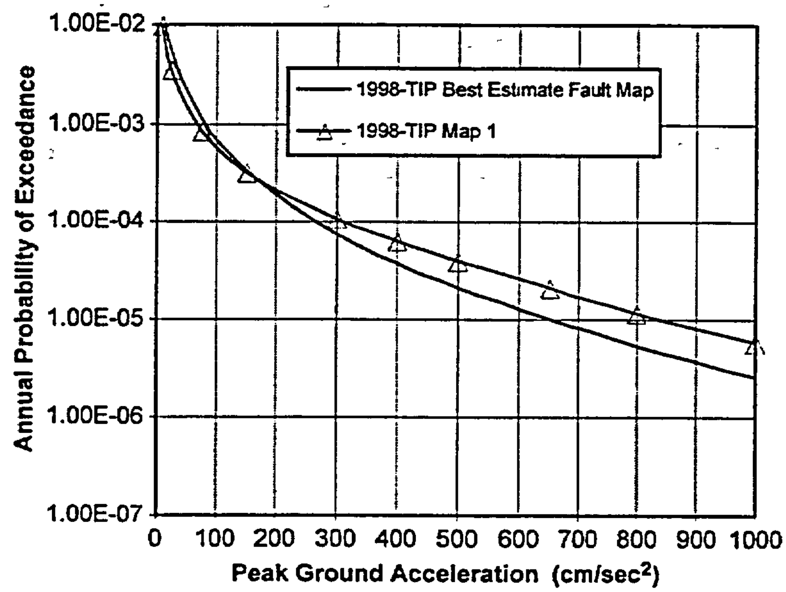

Figure 5.6: 1998-TIP Study. Comparison of the Best Estimate Hazard Curves Obtained Using the Highest Weighted Map (Map 1) to that of a Typical Fault Map.

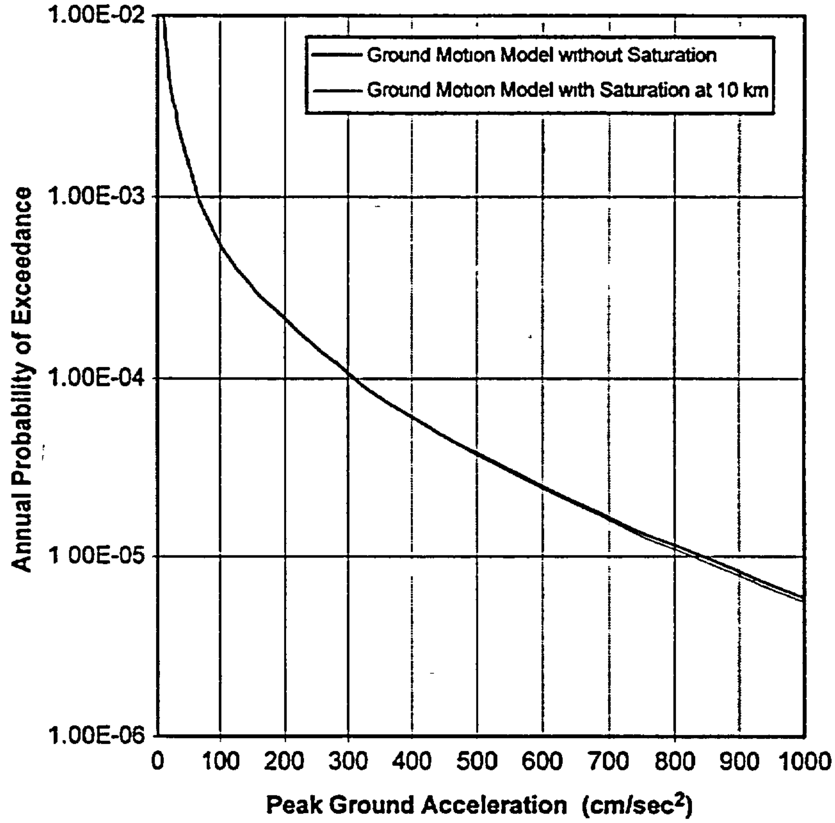

Figure 5.7: Effect of the Ground Motion Saturation at 10 km in the Ground Motion Model. Comparison of Best Estimate Hazard Estimates with and without Saturation.

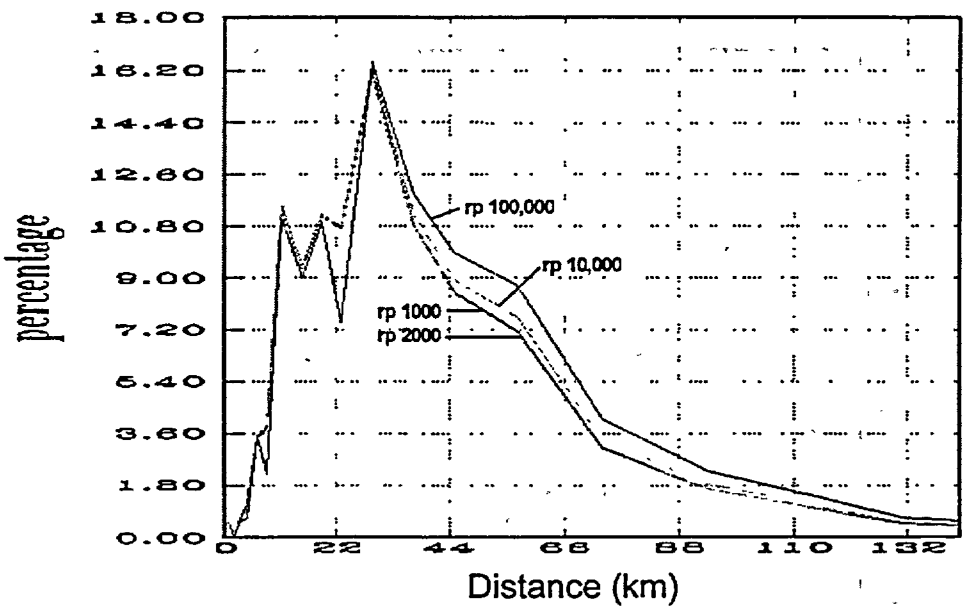

Figure 5.8a: 1998-TIP Study. Contribution of the Bins of Distance to the Total Hazard at the Watts Bar Site with the Non-Truncated Ground Motion Model.

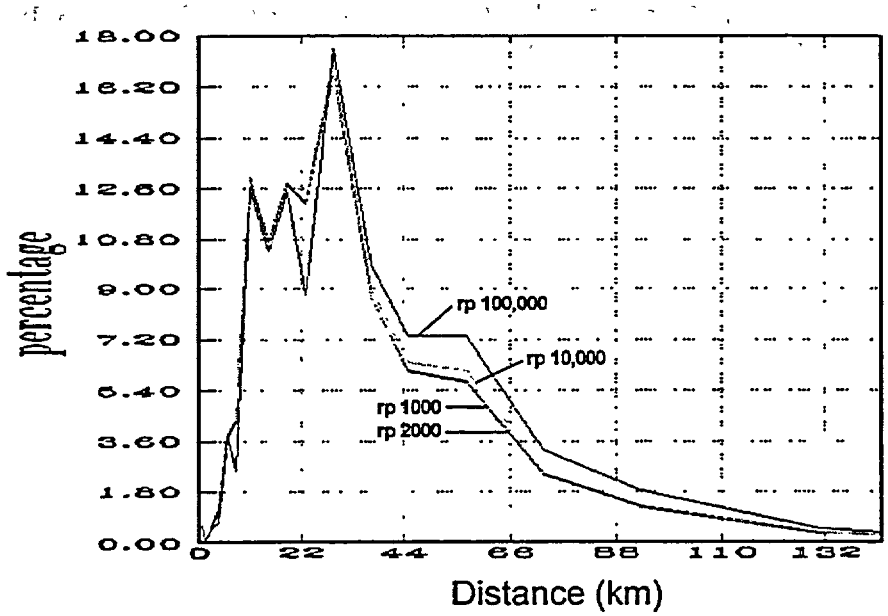

Figure 5.8b: 1998-TIP Study. Contribution of the Bins of Distance to the Total Hazard at the Watts Bar Site with the Ground Motion Model Truncated at Distances below 10 km.

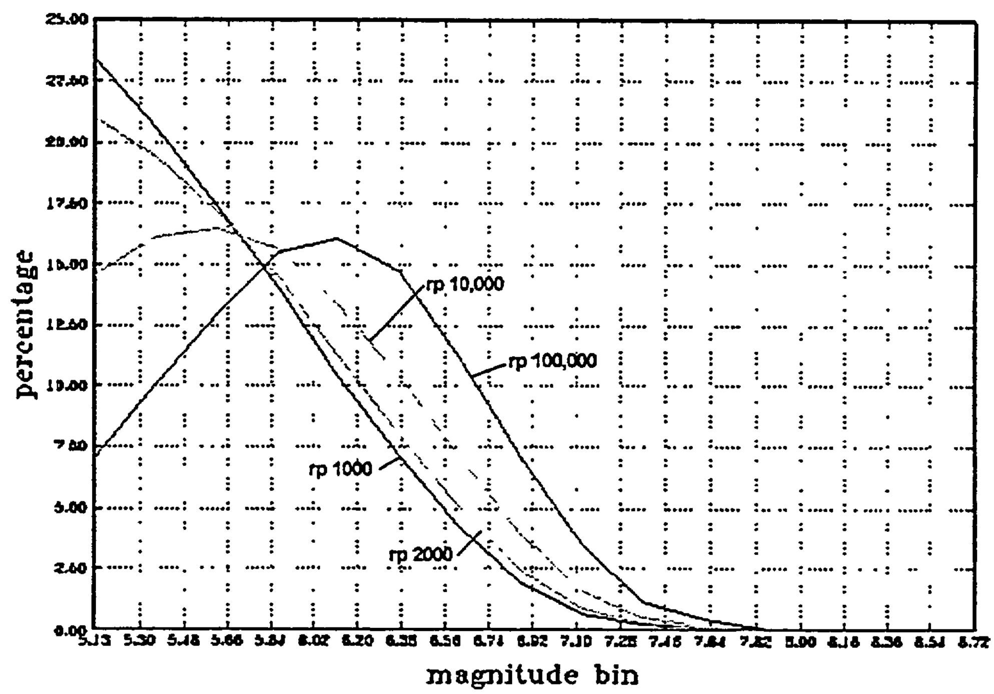

Figure 5.9: Range of Earthquake Magnitudes that Contribute to the Hazard for the 1998-TIP Seismicity Model Combined with the 1993-EUS-Update Ground Motion Model.

6. CASES OF THE 2.5- AND 25.0-HZ RESPONSE SPECTRAL VELOCITIES

Up to this point, the two studies were evaluated on the basis of comparisons of the hazard of the ground motion at high frequency, namely the PGA. This section examines the case of lower-frequency ground motion, for 2.5 Hz and 25 Hz. Certainly it is expected that more distant larger-magnitude earthquakes will be more important because smaller-magnitude earthquakes do not generate as much long-period ground motion as larger earthquakes.

The uniform hazard spectra for return periods of 100,000 and 10,000 years between the 1998-TIP seismicity model and expert 3 of the 1993-EUS-Update study, both using the 1998-TIP GM model, are shown in Figure 6.1.

The spectral velocities of the 1998-TIP study are a factor of 2 higher than those of the 1993-EUS-Update study at 1 Hz. They are only a factor of 1.5 at 25 Hz, and approximately 1.8 at 2.5 Hz.

Figure 6.2 gives the mean spectral hazard curves for 2.5 Hz and 25 Hz using the 1998-TIP GM model and both the 1998-TIP and expert 3 seismicity models.

For a spectral velocity of 21 cm/s at 2.5Hz, the 1998-TIP hazard curve is about a factor of 3.4 times larger than expert 3's hazard curve. At 41cm/s, it is a factor of about 3.8 larger. To understand why the 2.5-Hz hazard curves are so different we need to examine both the distance ranges and the magnitude ranges that contribute to the hazard at this frequency. The distance and magnitude ranges that contribute to the 2.5-Hz hazard curve are similar to the PGA shown in Figures 3.3 and 3.4. Figure 6.3 shows cumulative distribution of the contribution of magnitude to the 2.5-Hz hazard curve for the 1998-TIP seismicity model and Figure 6.4 shows the cumulative distribution of distance to the 2.5-Hz hazard curve.

Figures 6.3 and 6.4 show that larger distant earthquakes contribute much more significantly to the 2.5-Hz hazard curve than to the PGA and 25-Hz hazard curves. Thus, in order to understand why there is such a large difference between expert 3's and the 1998-TIP 2.5-hz hazard curves, there is a need to examine the rate of earthquakes in regions around the site larger than the 35-km radius region used in Section 3. Figure 6.5 shows a comparison between the yearly rate of earthquakes within 75 km around the Watts Bar site for the BE 1998-TIP seismicity model, the median BE 1993-EUS-Update seismicity model, and the expert 3's seismicity model.

Figure 6.5 shows that expert 3's rate of earthquakes is lower in the 75-km region around the site than the median rate of earthquakes based on the 1993-EUS-Update seismicity model. Referring to Section 3, the region within 35 km of the site, expert 3's rates were about the same as the combined 1993-EUS-Update seismicity model. This is illustrated in Figures 6.6 and 6.7. In Figure 6.6, the rate of earthquakes around the site using the TIP seismicity model for distance of 33 km, 81 km, and 156 km all normalized to 35 km. This is compared to Figure 6.7, for a similar plot using expert 3's seismicity model for distances of 35 km, 75 km, and 150 km.

Note the differences in radius of the areas considered: 33 and 35 km, 75 and 81 km, and finally 150 and 156 km. Due to some selection of parameters when performing the calculations of the 1993-EUS-Update study, it was not possible to have a perfect match of these radii. In each case, the closest radius was selected. Therefore, being tied by the 1993 values of 35, 75, and 150 km, the closest 1998-TIP values were 33, 81, and 156 km radii. Although the comparison is therefore not perfect, analyzing the differences in yearly rates, normalized, is still meaningful, due to the relatively minute error introduced by this approximation.

Figure 6.6 shows that, for the TIP seismicity model, the rate of earthquake activity around the Watts Bar site stays relatively constant with increasing distance. On the other hand, Figure 6.7 shows that the rate of activity around the site based on expert 3's seismicity model decreases with increasing distance. For example, at magnitude 5.5 there is a factor of 3.5 difference between the rates using the largest distance. Thus the difference between expert 3's 2.5-hz hazard curve and the 1998-TIP 2.5-hz hazard curve is primarily due to the difference in the rate of activity between the two seismicity models around the Watts Bar site. Why expert 3's seismicity model shows such a strong dependence on the radius of the region around the Watts Bar site is an issue needing special examination. This is done by examining expert 3's complete seismic zone map shown in Figure 6.8, where zone 1 is a very large background zone. Because of this, the activity rate in this zone is very low compared to zone 5. Thus, as the radius of the region used to evaluate the rate of activity is increased for expert 3, more and more of zone 1 is included. By contrast, Figures 4.1 and 4.2 show that the 1998-TIP seismicity model introduced a zone 5-2 which has a much higher seismicity rate than expert 3's zone 1.

Examining Figures 6.3 and 6.5 shows that the uncertainty in the maximum magnitude is important, as Figure 6.5 indicates that the BE for the maximum magnitude is about 6. However, Figure 6.3 shows that larger-magnitude earthquakes contribute to the hazard.

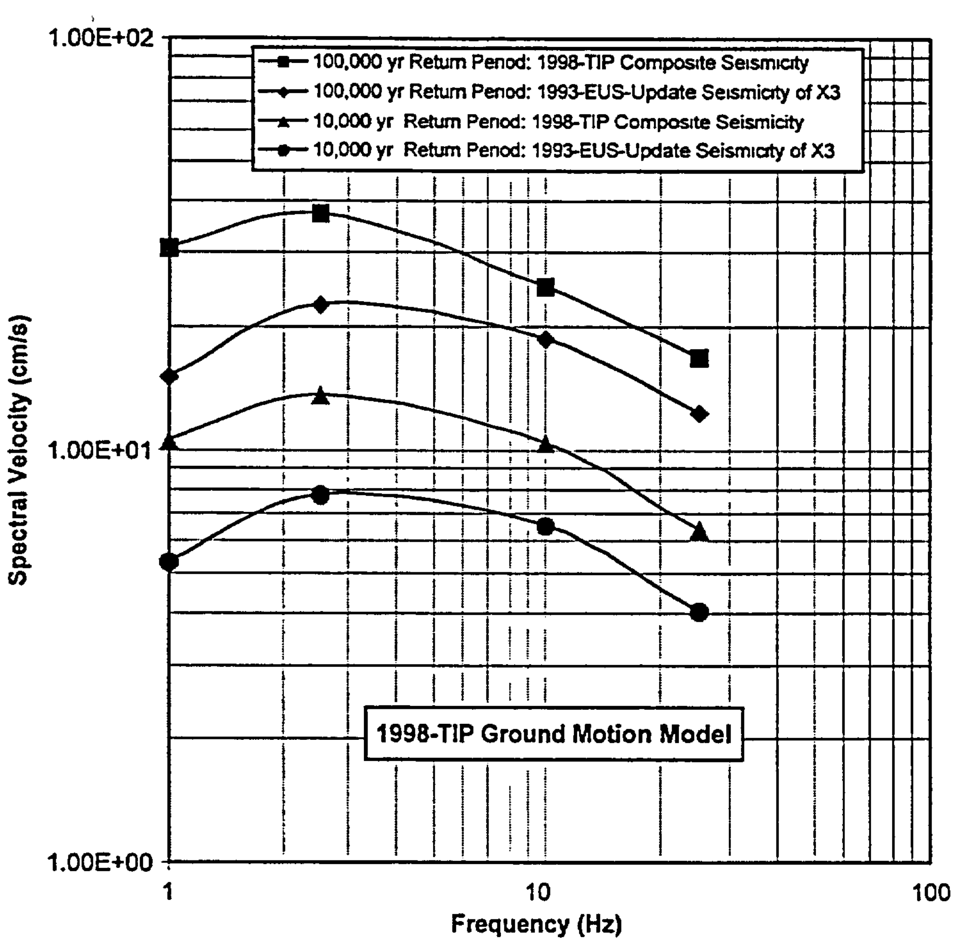

Figure 6.1: Comparison of the Mean Uniform Hazard Spectra for Return Periods of 100,000 and 10,000 Years Between the1998-TIP Seismicity Model and Expert 3 of the 1993-EUS-Update Study Both Using the TIP Ground Motion Model.

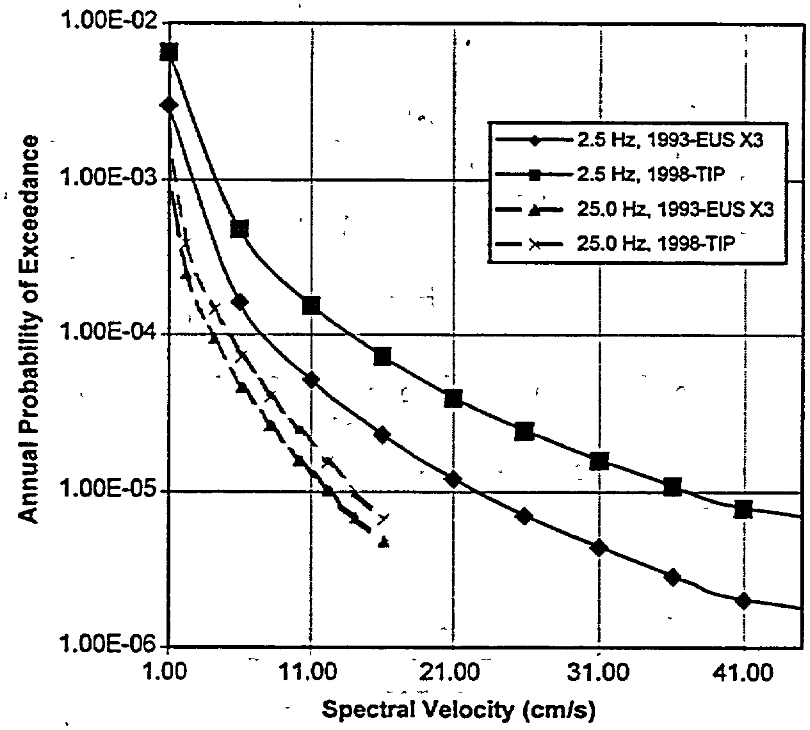

Figure 6.2: Mean Spectral Hazard Curves for 2.5 Hz and 25 Hz using the 1998-TIP Ground Motion Model and both the 1998-TIP and 1993-EUS-Update Expert 3 Seismicity Models.

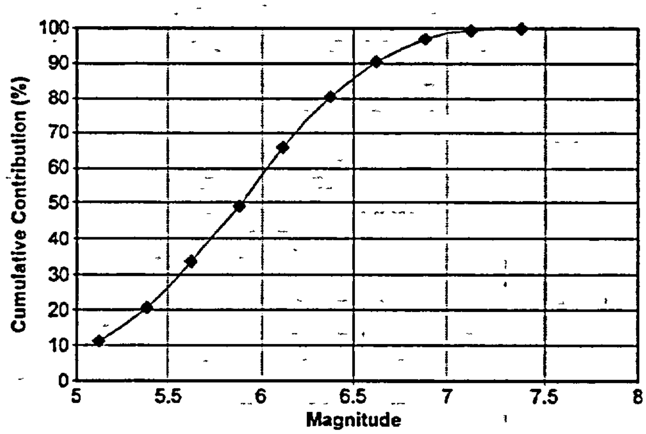

Figure 6.3: Cumulative Contribution of the Magnitude Bins to the Total Hazard for a 100,000-yr Return Period at 2.5 Hz.

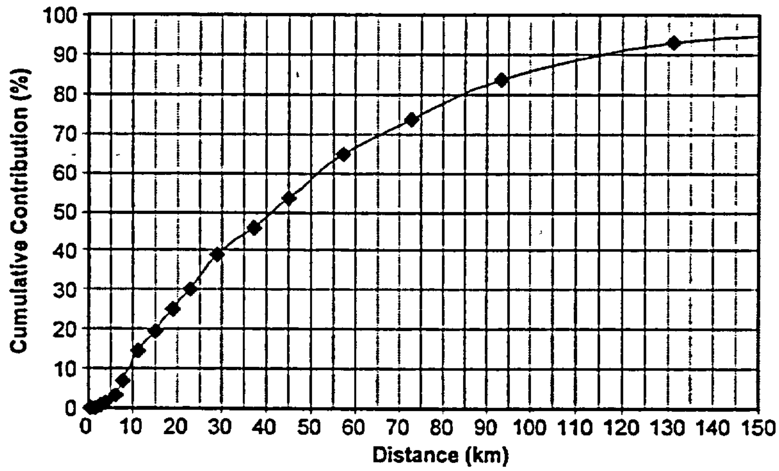

Figure 6.4: Cumulative Contribution of the Distance Bins to the Total Hazard for a 100,000-yr Return Period at 2.5 Hz.

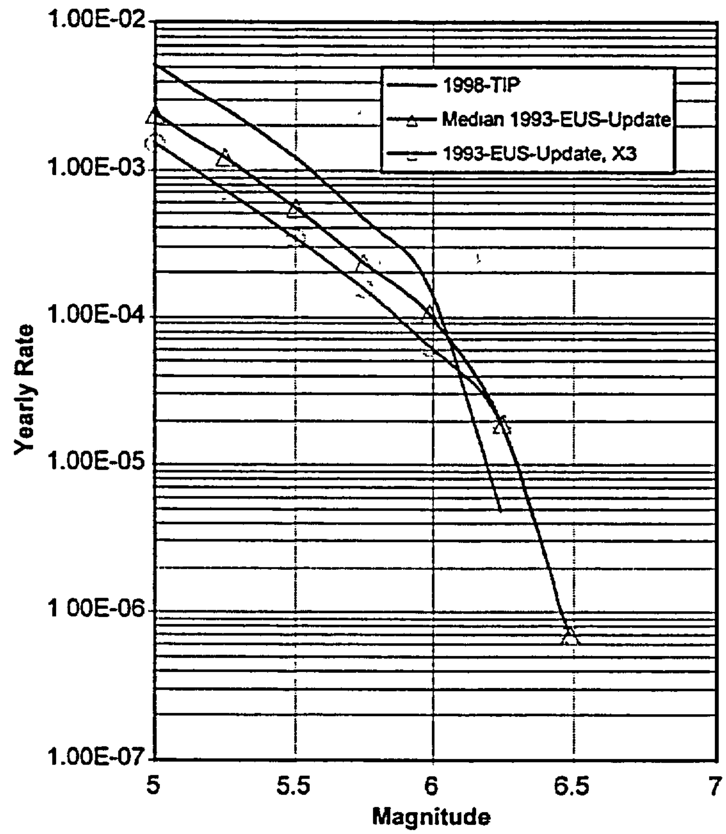

Figure 6.5: Comparison of the Yearly Rate of Earthquakes Occurrence within 75 km of the Watts Bar Site between the Best Estimate 1998-TIP Seismicity Model (Map 1), the Median Best Estimate 1993-EUS-Update Seismicity Model, and Expert 3's Seismicity Model.

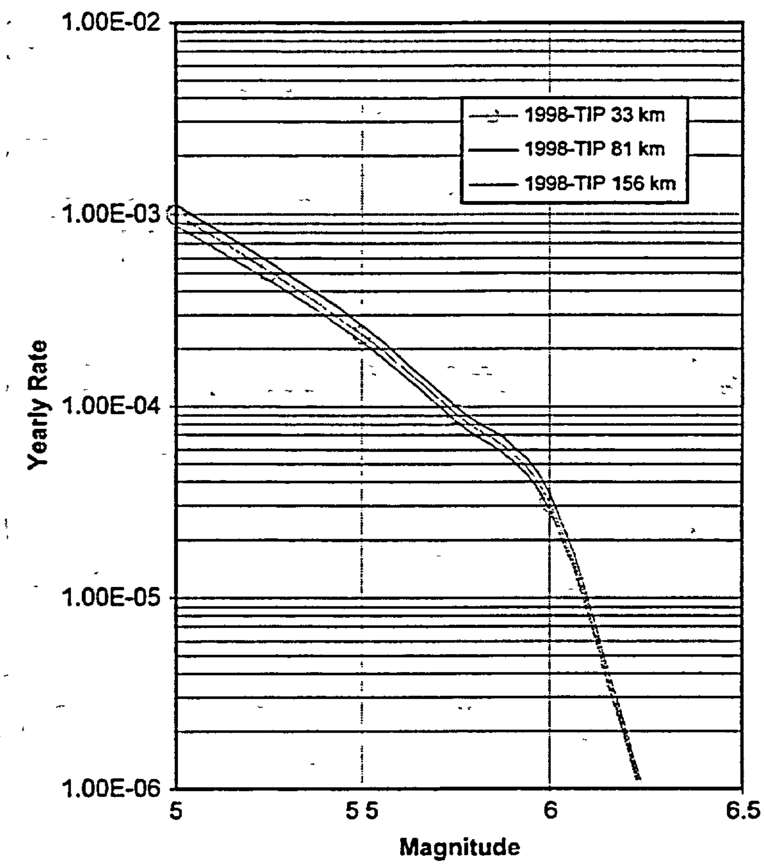

Figure 6.6: Rate of Earthquakes Versus Magnitude around the Site Using the 1998-TIP Seismicity Model for Distances of 33 km, 81 km, and 156 km All Normalized to 35 km.

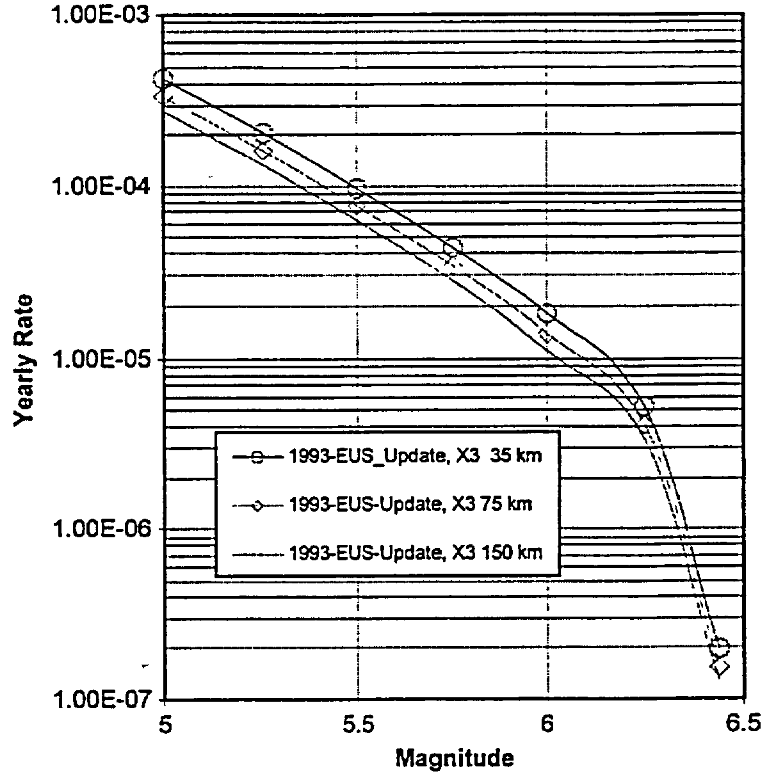

Figure 6.7: Rate of Earthquakes around the Site Using the 1993-EUS-Update Expert 3's Seismicity Model (X3), for Distances of 35 km, 75 km, and 150 km, All Normalized to 35 km.

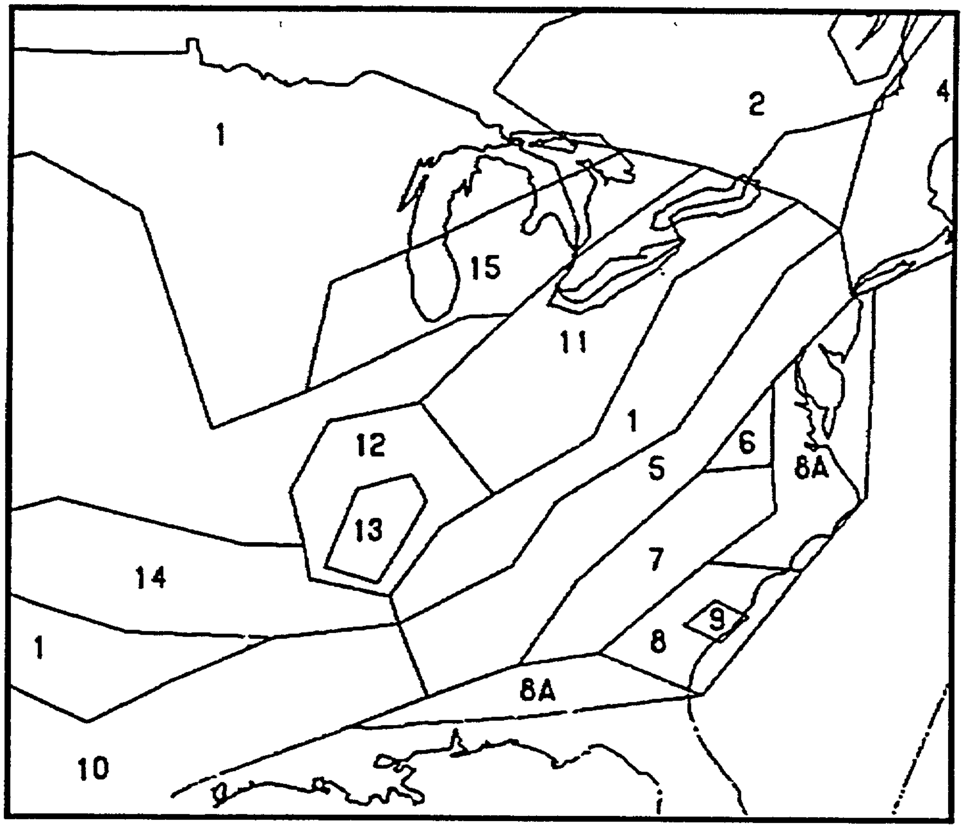

Figure 6.8: Enlarged view of Expert 3's Seismic Source Map Showing Zone 1 as a Large Background Zone with Low Rate of Seismicity.

7. DISCUSSION

7.1 General Findings

The differences over the 11 experts' seismicity model estimates of the seismic hazard at the Watts Bar site between the 1993-EUS-Update and the 1998-TIP studies are due to two main factors:

1. Differences between the GM models used in the two studies.
2. The introduction of the ETSZ in the 1998-TIP study.

We found that these two factors lead to about a factor of 5 difference between the two studies for the mean estimate of the PGA hazard at high GM levels. At 100 cm/sec^2 the agreement between the two studies was much better (about 1.6). We also found that if the same GM model was used in each seismicity model the results were in better agreement and only differed by about a factor of 2 at high GM levels. The composite rate of earthquakes around the Watts Bar site was about a factor of 2 higher for the 1998-TIP composite seismicity model than the rates in the 1993-EUS-Update averaged over the 11 experts' seismicity model.

By comparing Figures 2.1, 2.2, and 2.3, it is also apparent that the median estimates follow approximately the same trend as the mean curves, and that the uncertainty in the estimates is greater in the 1993 study, increasing with increasing PGA values.

In this section, we attempt to uncover some of the possible root causes of these differences and formulate a set of criteria to determine in what cases such differences would be likely to be observed for other sites of the 1993 EUS study.

7.2 Causes for the Differences in Hazards Estimates

7.2.1 Ground Motion Models

The ground motion models were used in a generic fashion in both studies, independently of the type of source zones and of their position with respect to the sites. Both composite models were based on the same approach, but the 1998 model benefited from the most recent analyses of strong motion data that were not available at the time of the 1993 calculations. This led to an elimination of the limitation of motion amplitude in the distances smaller than 10 km, a slight decrease for distances between 20 and 200 km, and large increases beyond 200 km. Therefore, aside from the uncertainty estimates, overall the ground motion models are not very different and their impact depends essentially on the location of the dominant source zones. In the case of Watts Bar, the dominant source zones are relatively close to the site, and the dominant magnitude is between M5 and M6, so that the net effect on the hazard is a slight increase, as shown by Figure 3.8. It is very likely that different conclusions would be reached for other sites. Sites dominated by close-by faults, within 10 to 15 km, would definitely see a large increase in the mean hazard estimates. Sites whose dominant sources are between 30 km and 200 km would actually see a decrease in the estimates, and sites dominated by distant sources, beyond 200 km, would see an increase from the ground motion model alone.

7.2.2 Source Zones and Seismicity Models

There were substantial differences between the source zonation in the two studies. The 1993 study, based on the zonation models of the 1989 study, was primarily a regional study that did not concentrate on the details of the geology and tectonics of each of the sites. On the contrary, the 1998 study deliberately emphasized the importance of local tectonics.

In addition, the community of seismology experts had begun formulating a number of new tectonic models for the Eastern Tennessee region. These studies, which were posterior to the date of formulation of the source zones in the 1993 study, were based on micro-seismicity studies. They led to the determination of the existence of active faults near the Watts Bar site. Because of the immediate importance of these new sources on the estimate of the hazard at Watts Bar, the TIP study spent much effort in characterizing them. The experts were first asked to write white papers explaining their understanding of the data. They were asked to present their models to the groups of experts, and debate the merits of each proponent model. In the end, the group of experts formulated a number of alternative models that included previous models of the 1993 study, but that also included new models with faults located near the site. These new faults included the possibility of rare but large events.

To de-emphasize the impact of these new source zones near the site, the TIP study allowed for the boundaries of the ETSZ to be randomized, to express the uncertainty on their location because no firm evidence actually exists on their actual position.

These differences between the two studies, in themselves, do not necessarily mean that the estimates of the hazard would be different since the hazard also depends on the seismicity rates of each source. However, in this case, this "micro-zonation" had the effect of shifting the spatial distribution of the earthquakes, from a smooth uniform distribution over a large region, to a more localized peak of activity near the site, thereby increasing the hazard estimates.

7.2.3 Regional Versus Site-Specific Window: Impact on Uncertainty

One important difference between a regional vision and a local vision is in the considerations of uncertainty in the estimates of the seismicity rates of the sources.

In the regional vision, a small number of sources is fitted to a robust budget of events, and it is easy to ascertain whether a seismicity cluster belongs to one source or another.

In the local vision, smaller sources, to which are assigned small subsets of the catalogue of historical events, are used to estimate the uncertainty in the seismicity rates. It is common practice to analyze each source separately, as statistically independent items, when we evaluate the seismicity rate and their uncertainty. This practice, however, is not realistic since it does not account for the correlation between all the sources, resulting in estimates of the uncertainty that seem correct for each independent source, but that most likely overestimate the uncertainty for the entire map of source zones. To our knowledge, no general method exists to resolve this issue. One possible approach could be based on a Monte-Carlo simulation from the alternative source zonations, and feedback corrections based on comparisons with the original set of catalogue data, as we are planning to develop in the next generation of methodology.

The impact of this overestimation of the uncertainty for the smaller zones and faults is to increase the mean estimate of the hazard, but not the median. To some extent, this effect is shown in the next section for the Vogtle site.

7.2.4 Comparison with the Vogtle Site

Contrary to the Watts Bar site, the Vogtle site did not have any new zones or faults in its vicinity. Although the source zonation is different from that of the 1993 study, it is made mostly of large source zones, with the exception of the Charleston area (that does not dominate the estimate of the hazard). Contrary to the models in the Watts Bar site analysis, the Vogtle models appear to be more of a regional nature than local. The uncertainty in each of the contributing sources is therefore still well constrained, like it was in the regional study that was the EUS 1993 study, and consequently the median estimates of the hazard are comparable in the two studies, as shown in Figure 7.1. Furthermore, because the rigorous SHHAC method was applied to identify the alternative models and root out the unrealistic alternatives or unnecessary differences between experts, the overall uncertainty in the source zonation and seismicity rates models was reduced, by comparison to the EUS 1993 study. This resulted in a lower mean estimate of the hazard in the 1998 results, as shown in Figure 7.1.

7.3 Criteria for Formulating Conclusions at Other Sites

The main parameters that determine whether a new site-specific study is likely to result in different estimates the EUS 1993 study are the following:

- Existence of local sources or faults. Newly discovered clusters of activity will lead to more localized near seismicity and will tend to increase the estimates of the hazard.
- Refining the definition of a large dominant source into a number of smaller independent dominant sources will likely lead to an increase in the hazard mean estimate without necessarily increasing the median estimate.

- Non-existence of new local sources will tend to lead to unchanged results
- Distance of the site to the dominant sources, depending on the shape of the ground motion model, will lead to either higher or lower estimates. A comparison of the ground motion model will be necessary before making a conclusion.

The above generic observations can be used to evaluate the possible consequences of re-doing the PSHA for a site for which estimates by the EUS 1993 study are available. In all likelihood, a cursory first evaluation of the present available data would be done to determine which of the above elements apply.

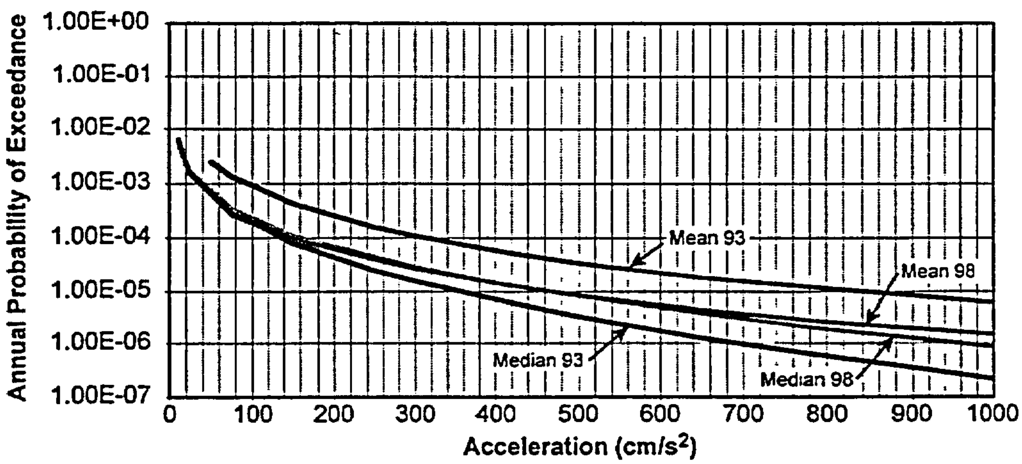

Figure 7.1: Comparison of Results for Vogtle.

8. CONCLUSIONS

In the 1998-TIP study, we found that the ETSZ enhanced the activity rate around the Watts Bar site as compared to the 1993-EUS-Update study by about a factor of 2. If the 1993-EUS-Update study had been a site-specific study like the 1998-TIP study, it is very likely that most, if not all, of the 1993-EUS-Update seismicity experts would have included a more detailed model representing the ETSZ. This would have brought the composite seismicity models between the studies into even better agreement because, as was shown in Figure 5.2, the various models for the ETSZ did not result in significant changes for the estimated hazard.

Although there are significant differences in the two studies' hazard estimates for the Watts Bar site, there are also areas of stability. We found that the largest contributor to the difference in the GM models was resting in the uncertainty models. The estimate of the hazard at a site is very sensitive to the uncertainty in the GM model. There is little hope of reducing or stabilizing the uncertainty in the GM model because very little GM data exists from EUS earthquakes. It is unlikely that this will improve in the near future because of the relatively low rate of activity in the EUS and the low density of strong ground motion data recorders Considering the actual length of time between the time when the seismic zones were identified (mid 1980s) for the 1993-EUS-Update study and the time when the 1998-TIP study was performed, the seismicity models between the two studies were in good agreement. It appears that one possible cause of the differences between the two studies was the difference in scale between the two studies. Namely, the 1993-EUS-Update study was a large regional study covering the entire region east of the Rocky Mountains, whereas the 1998-TIP study was site-specific.

The last point was also demonstrated to be associated with a possible overestimation of the uncertainty in site-specific analyses due to the possible creation of myriads of poorly defined zones with large uncertainties in their characteristics One possible remedy to such a situation is to impose criteria on the budget of earthquakes and its uncertainties for a small region around the site (say, 15 km) in these studies.

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11 ABSTRACT *(200 words or less)*

From 1981 to 1989, Lawrence Livermore National Laboratory (LLNL) developed a Probabilistic Seismic Hazard Analysis (PSHA) method for the eastern United States (NUREG/CR-5250), followed in 1993 by improvements in the handling of the uncertainties (NUREG-1488). Differences between these results and those of a utilities-sponsored study (Electric Power Research Institute, 1989) led to the formation of the Senior Seismic Hazard Analysis Committee (SSHAC) to identify the sources of differences and give guidance on how to perform a state-of-the-art PSHA (NUREG/CR-6372, 1997).

The present study is a trial implementation of the SSHAC guidance. As part of the project, additional guidance was developed and proposed for performing a PSHA. The trial implementation project tested the issue of development of the seismic zonation and seismicity models for two sites: Watts Bar and Vogtle. It was found that the uncertainty generated by disagreements among experts could be considerably reduced through interaction and discussion of the data, and by concentrating on the elements common to all experts' interpretations. The present study includes analyses of the differences between its results and the NUREG-1488 results (Appendix G).

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