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ADDIS ABABA UNIVERSITY

SEISMIC ZONING IN ETHIOPIA

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BULLETIN OF THE GEOPHYSICAL OBSERVATORY
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SEISMIC ZONING IN ETHIOPIA

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The President of the University and His Excellency the Minister of Public Works and Water Resources requested the Geophysical Observatory to undertake the study of the seismicity of Ethiopia. The research was partially financed by grant 3-P-74-0018 from the International Development Research Centre, Ottawa, Canada.

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Corrigenda

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	9	Line 3	Solve worse problems . . .
		9	will tomorrow sever
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	26	Line 6	peak amplitude values
	29	bottom line	major fault belts
	36	line before last	protection of lives:

SEISMIC ZONING IN ETHIOPIA

An interim and abridged report to the Ethiopian National Earthquake Commission.

1. INTRODUCTION

The Building Code for Ethiopia *(revised draft, part E, 1974)*[1] recommends "that the country be divided into zones of approximately equal seismic risks based on the known distribution of past damaging earthquakes. There should be four zones ...." numbered and classified as follows:

- 0 Zone of *no* damage.
- 1 Zone of *minor* damage. Its grading should correspond to intensities V and VI on the Mercalli Modified (MM) intensity scale.
- 2 Zone of *moderate* damage corresponding to intensity VII.
- 4 Zone of *major* damage in which the seismic ground shaking amplitude would produce intensities VIII and above.

Note that there is no zone 3. Note also that the Code does not specify which techniques should be employed to delineate these zones. It only indicates the grading reference: the Mercalli Modified (1931) scale of intensity.

This report presents to the National Earthquake Commission such a Seismic Zoning map for Ethiopia along with the

Figure 1A. Earthquake in Central Afar, March-April 1969. The town of Serdo was completely destroyed; faults, cracks and subsidences altered the topography of the site. Twenty five people were killed instantaneously and 163 were injured out of a population of 420. Fifteen died later from injuries.

Figure 1B Fault across the Combolcia-Asseb highway, 8 kilometers east of Serdo. The maximum displacements as indicated by the 3 geology hammers were about 90 cm vertical and 75 left lateral.

basic elements necessary to understand how such a map was constructed and what are some of its limitations. Strictly speaking, this report is not presented in a scientific fashion, in that sense that it is not adorned with the required paraphernalia of a real scientific report such as justification of the techniques, mathematical proofs, references, acknowledgments, bibliography, etc... This omission is not an oversight but an intentional omission in order to produce a short practical and informative working paper for immediate use in a discussion. In a sense such a presentation is justified, even from a scientific point of view, if this present report is considered as an expanded Abstract of the complete survey on the seismicity of Ethiopia which will be comprised of two rather lengthy sections: the first covers the history of earthquakes in Ethiopia and the Horn of Africa from A.D. 1400 until to-day; the second contains the analytical treatment of these five hundred and seventy five years of information and the technical results required by Ethiopian structural engineers.

It is hoped that constructive comments will be made in time to be incorporated in the final version of this study.

2. SEISMIC HAZARDS IN ETHIOPIA: A HISTORICAL FACT

Due to its geographic location in the vicinity of two recognized seismically active tectonic features, namely the major tectonic plate boundary which divides continental Africa from the Arabian peninsula and the major break in the earth's crust due to the East African rift systems, Ethiopia has experienced the effects of earthquakes and volcanic activity throughout its history. Its scarred landscape and rows of volcanic centers bear witness to the earth's convulsions which jolted the country in recent geological times.

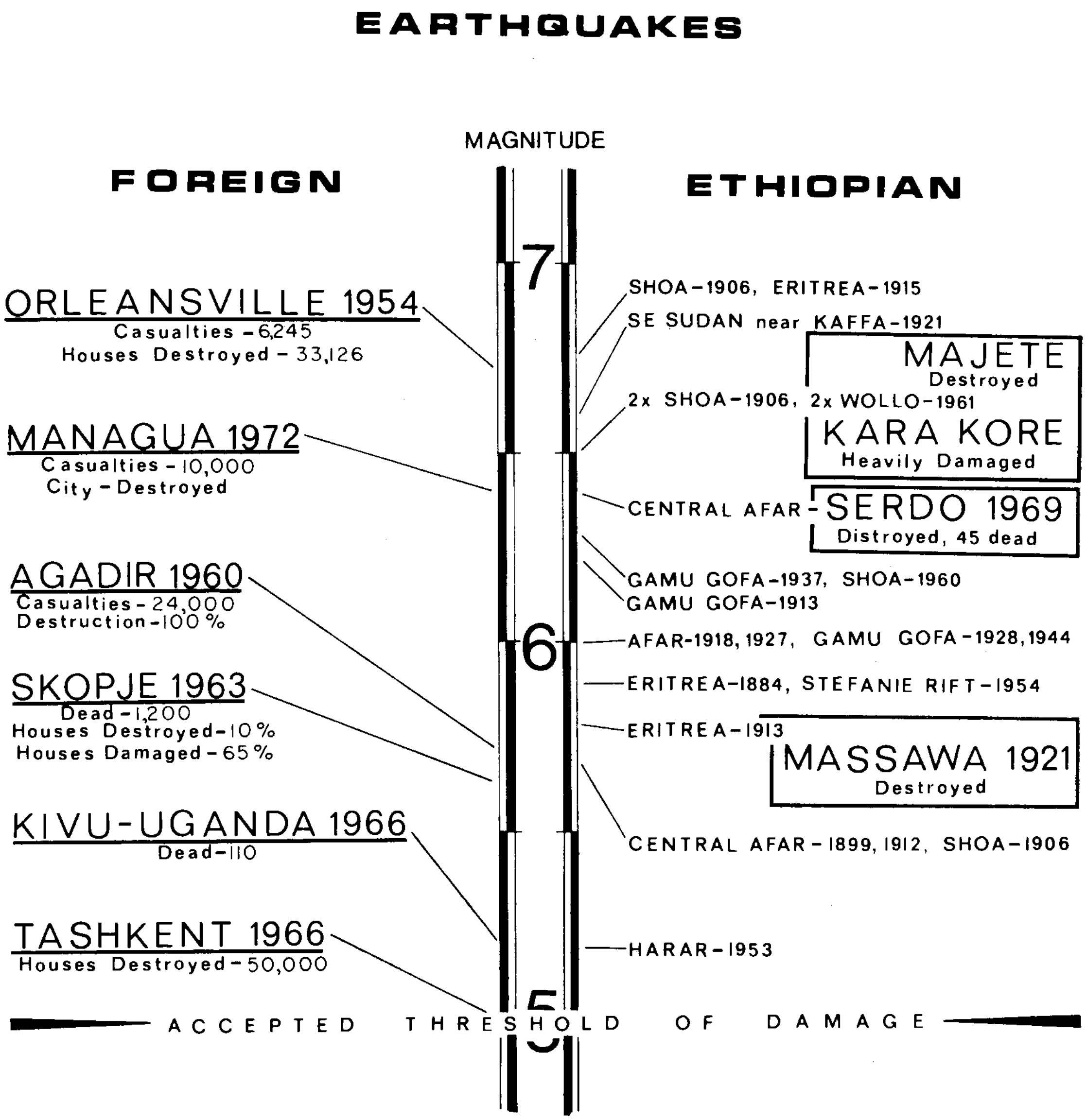

Figure 2 Comparative potential damage-causing power of earthquakes illustrated by well known earthquake case histories. The listing of Ethiopian earthquakes is not complete; the few events chosen show the distribution of seismic activity throughout the country.

Written history of earthquakes in Ethiopia, as presently known, starts in A.D.1400 with the eruption of the Dubbi volcano, some 120 kilometers north of Asseb. The earth tremors which accompanied this volcanic eruption were felt not only in Ethiopia but across the Red Sea, on the coast of the Yemen. Since then, official chronicle writers and individual authors have often recorded and commented upon the occurrence and effects of earth tremors especially if they concurred with historical time-references such as coronation of kings, fighting of glorious battles, or unusual astronomical occurrences such as solar eclipses and comets.

The maximum magnitude of reported earthquakes in Ethiopia is of the order of $6\frac{3}{4}$ on the Richter scale, equivalent to 3.3×10^{21} ergs when expressed in energy units. Some of the epicenters were located in the vicinity of important cities such as Addis Ababa, Asmara, Dessie, Harar and Massawa. Their potential damaging power can be illustrated by a comparison: the earthquake which destroyed Managua, the capital city of Nicaragua, on 23 December 1972 and caused 10,000 deaths was of magnitude $6\frac{1}{2}$. It released energy equal to 1.4×10^{21} ergs. It should therefore be realized that the Managua earthquake was 2.4 times less powerful, and under equivalent conditions 2.4 times less destructive than 4 of the earthquakes which are known to have shaken Ethiopia during the last 70 years.

Figure 2 illustrates possible earthquake damage in Ethiopia by comparison with the damage produced elsewhere from earthquakes of comparable magnitudes. Note that the absolute dimensions of the disasters in foreign lands mentioned in Figure 2 do not compare with those described in the historical records of Ethiopian earthquakes of similar magnitudes. This is due to the fact that cultural and environmental conditions were not the same in both sets of cases. Ethiopia of Yesterday was a pastoral and agricultural country with a dispersed population living in low-rise houses and with no need for numerous man-made complex structures. Despite these living conditions which are classified as being of minimum seismic risks, the Serdo earthquake of 25 May 1969, for instance, killed 10% of the population of a desert town. In relative terms, this constitutes a very high casualty rate which, if transferred to more populated urban areas, would spell a natural disaster.

Other examples are given in Section One of the survey.

The comparison of the potential damaging power of individual earthquakes within the magnitude range of those known to have occurred recently in Ethiopia gives an idea of the hazards that earthquakes of magnitudes $M \leq 6\frac{3}{4}$ create in the country. That idea is informative but incomplete in the sense that the hazards caused by an earthquake of magnitude, say, 6.8 which could occur every 500 years do not carry the same weight in engineering seismology as an event of the same 6.8 magnitude which is bound to happen on the average every 50 years. The information should therefore be completed by a comparison of the rates of recurrence of such earthquakes in other regions of the world whose seismicity is known. Such a comparison can be achieved through the use of the parameter known as the *b-coefficient*.

Earthquakes are the result of the stress accumulated within the earth's crust. The amplitude of the stress is obtained from the relationship which exists between the frequencies and the magnitudes of the earthquakes which occur in a defined region. In other words, the number of earthquakes of a given magnitude which are bound to occur within a certain time interval and in a definite region is statistically related to the number of earthquakes of higher and lower magnitude categories occurring in the same region. This relationship is commonly expressed by the formula

$$\log_{10} N = a - bM \qquad (1)$$

where N is the cumulative number of earthquakes which are of magnitudes equal to or higher than M and 'a' and 'b' are regional constants. Constant 'b', previously referred to as the seismic b-coefficient is considered by seismologists as an index of the stress condition in the crust of the earth under a particular region. It is therefore also an indication of the rate at which earthquakes of given magnitudes have occurred and will most probably continue to occur in the next hundreds of years.

Comparison of published 'a' and 'b' values is valid only when these values are obtained by similar analytical techniques. Otherwise they are bound to exhibit substantial variations with a change either in the reference magnitude M, or in the range of the magnitude categories, or in the length of the sampling period, or in the size of the area elements or of the total region under study. Figure 3 presents data from two different sources; it intends only to give a rough idea of how the seismicity of Ethiopia compares with that of East Africa* and of some other regions of the world. Among the 43 regions for which Kaila and Narain (1971)[2] could compute the 'a' and 'b' values, East Africa (including Ethiopia) stands fourth for the importance of its seismicity. Square (□) symbols single out Ethiopia and TFAI. The spread of the 'a' values for Ethiopia originates from the difference in the length of the three sample periods.

The two figures 2 and 3 situate Ethiopia on the seismicity map of the world. Figure 2 has a more disturbing impact because it looks at individual disasters irrespective

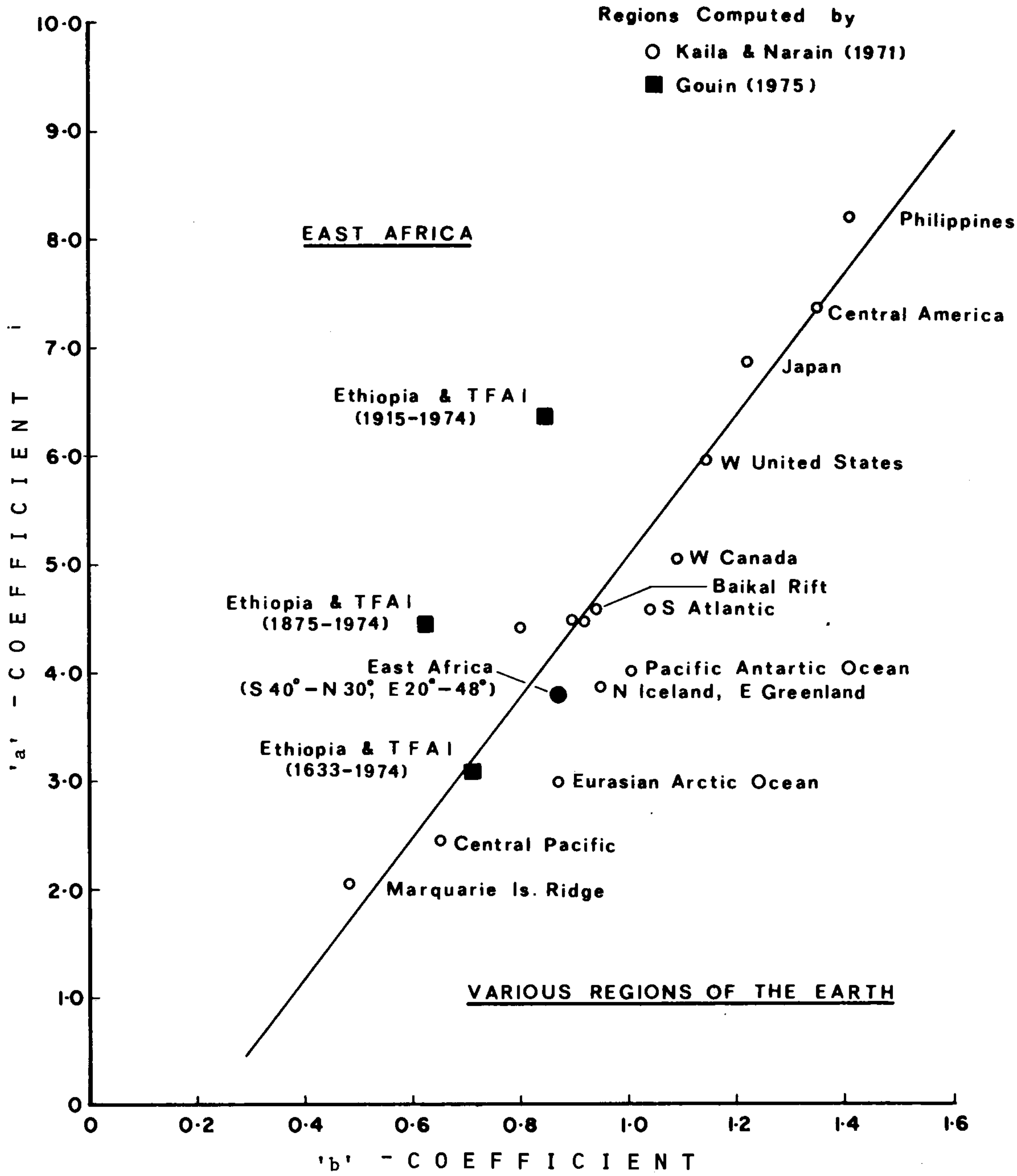

Figure 3. Seismicity of various regions of the earth

* *East Africa, in this context, does not refer to the political entities bearing the same name; it refers to a seismic region of the world defined by the geographic coordinates S40°, E20°, E48° and N30°. (Kaila and Narain, 1971).*

of the recurrence time element; a healthy balance is restored by Figure 3 which shows that many other countries have to face and solve worst earthquake problems.

A final remark on Figures 2 and 3 : the potential amplitude of the damage caused by earth tremors increases exponentially with the degree of modernization of a country. An earthquake which yesterday left a fissure in the soil across the foot-path of a village will to-morrow severe electric power-lines, water supplies, sewage conduits...... and damage expensive buildings. The fissure in the soil was obliterated at no cost by the following rainy season; the second fissure, across a paved street, may cost the nation millions of dollars.

3. EVALUATION OF THE SEISMIC HAZARDS IN ETHIOPIA

3.1 A QUALITATIVE APPRAISAL

All the records of seismic activity collected during the last 575 years do not have the same scientific value. Older ones, even if they refer to real events which might have produced considerable damage, are not complete enough in number nor in the precision of their description to justify using them in any statistical analysis. On the other hand, they are not to be discarded because of the high probability that they represent the earth tremors of the highest felt intensities and are therefore of prime interest to the design engineer. They, therefore, indicate a probable upper limit to the magnitudes of earthquakes experienced in this country during the last five or six centuries. The more modern events, those reported during the last 100 years or so, most of which are confirmed by instrumental recordings from either local or foreign seismic stations, are more scientifically reliable.

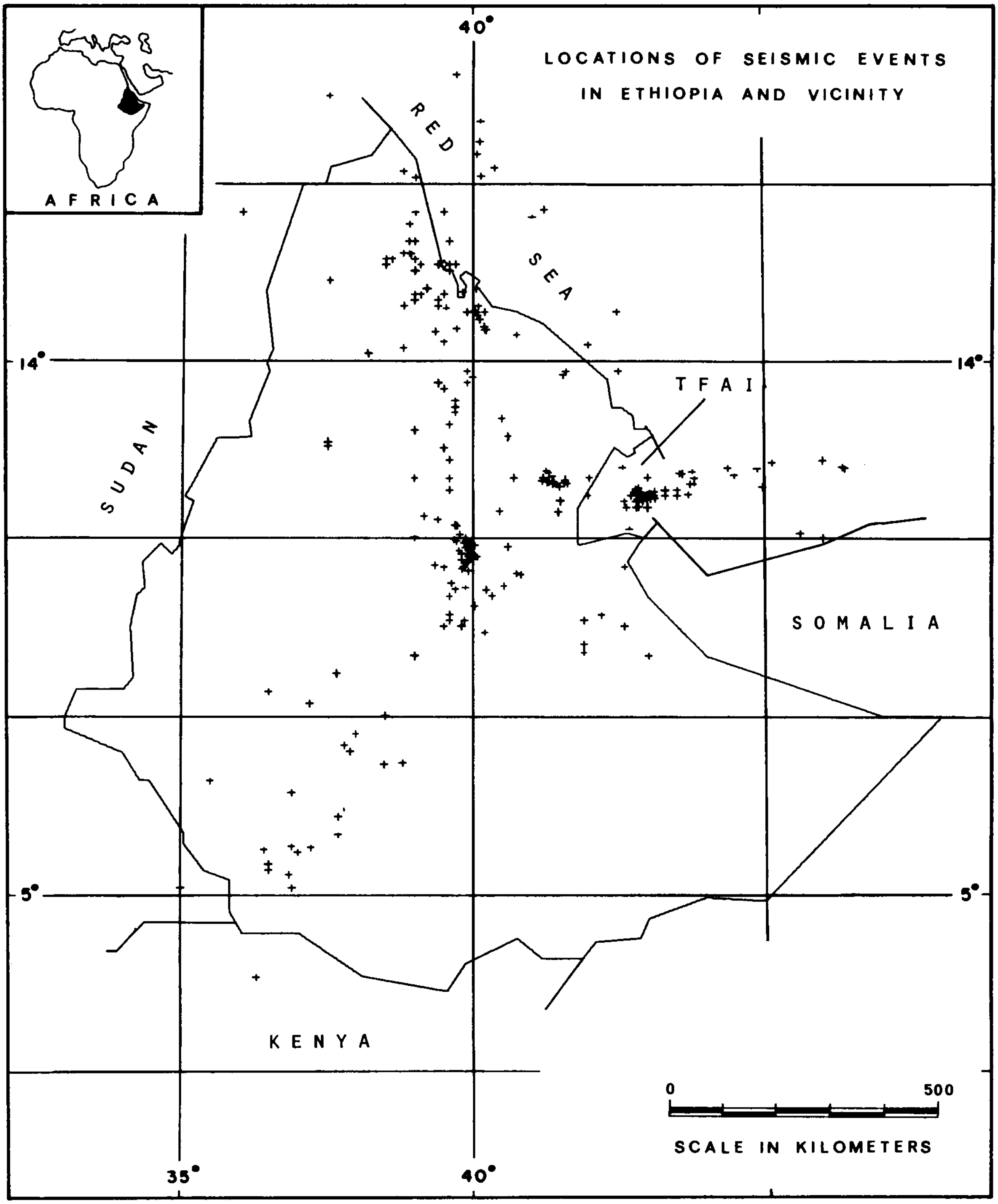

Figure 4A. Computer plotted map of all seismic events (sites of felt tremors and instrumental epicenters) described with enough accuracy to be assigned reliable geographic coordinates.

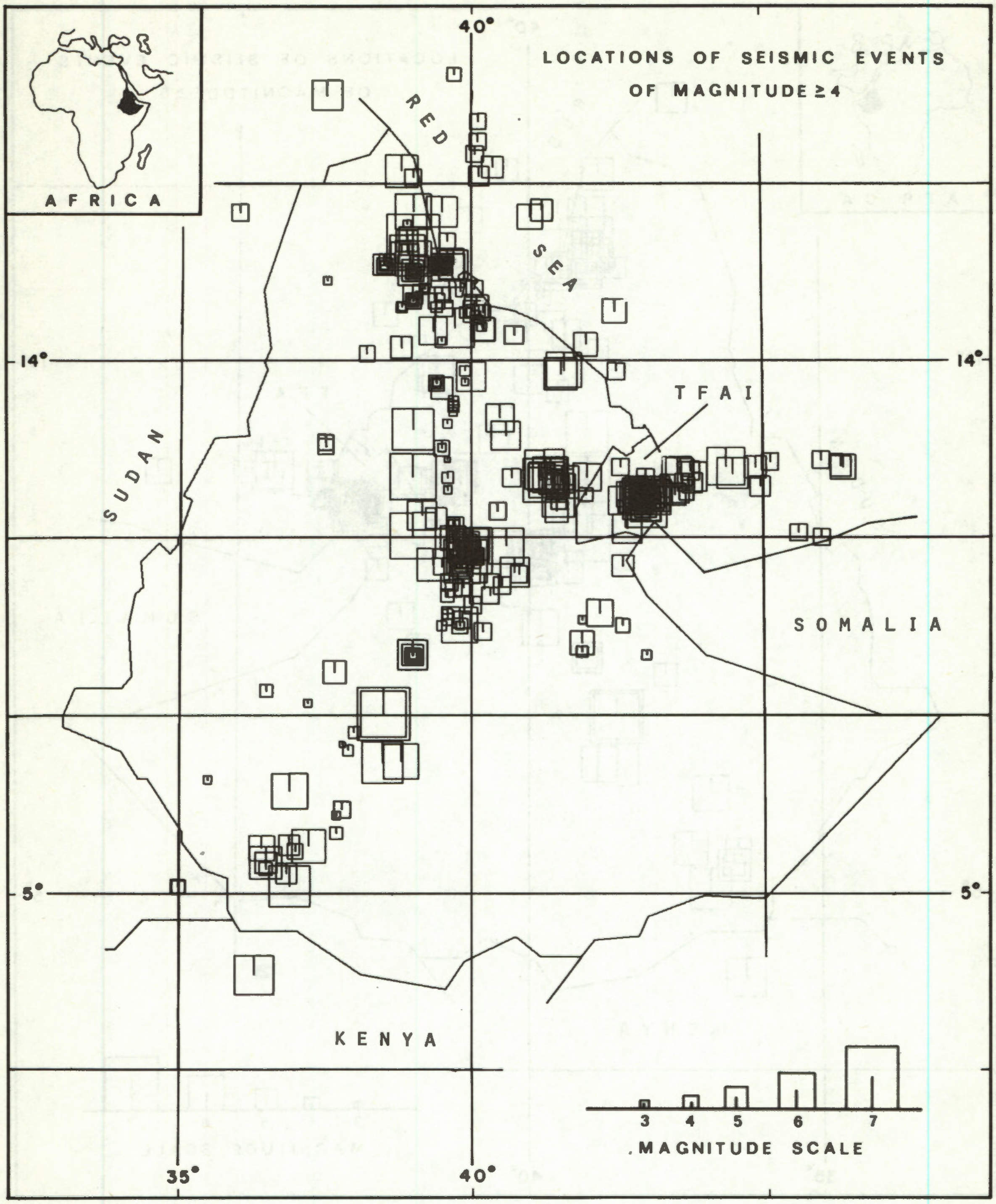

Figure 4B. Locations and estimated magnitudes of all events plotted in Figure 4A. The majority of the magnitudes ≤ 4 refer to sites of reported-felt tremors.

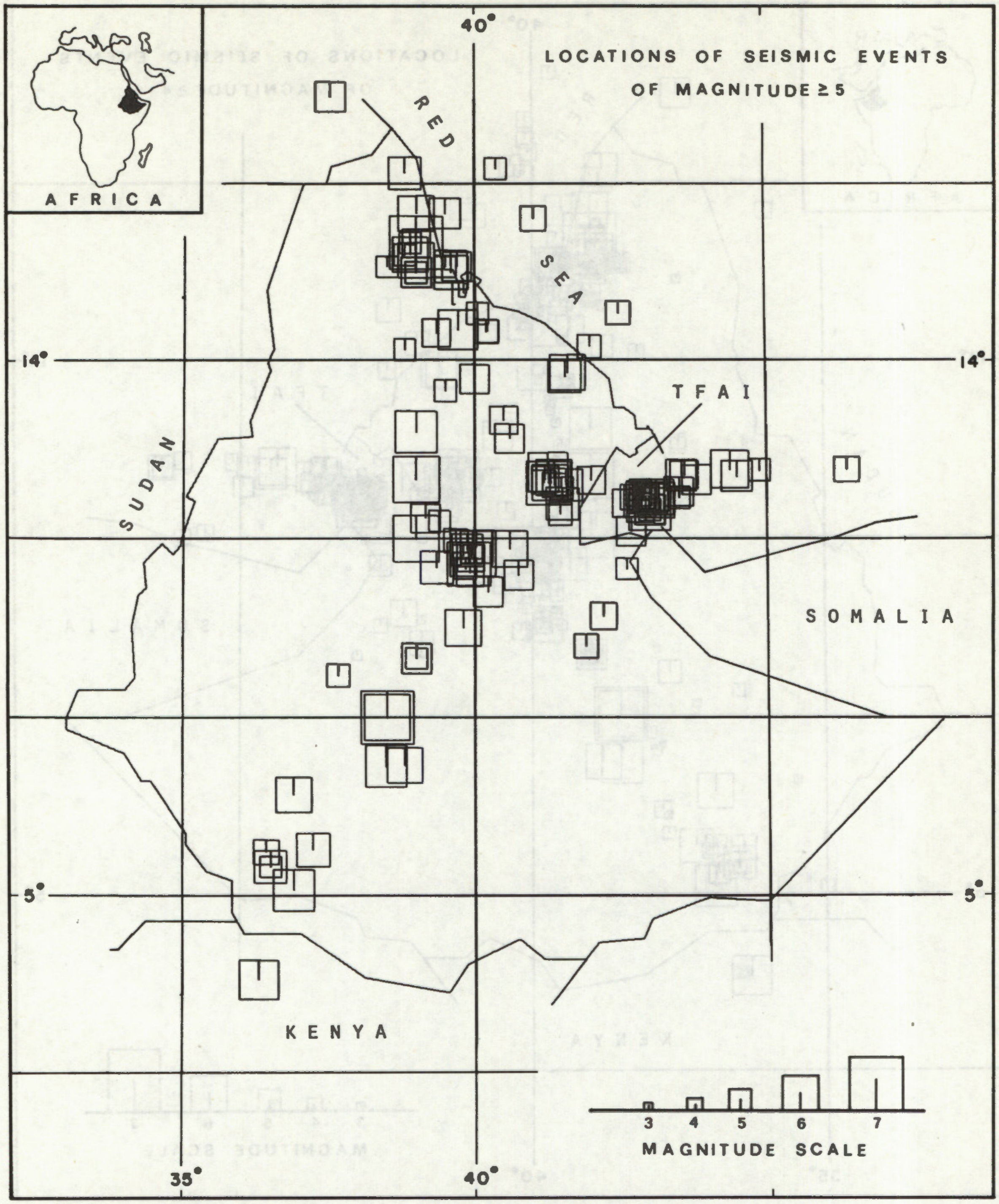

Figure 4C. Epicentral locations of earthquakes with magnitudes ≥ 5 in Ethiopia and surrounding areas. All sites of reported felt-intensities are eliminated.

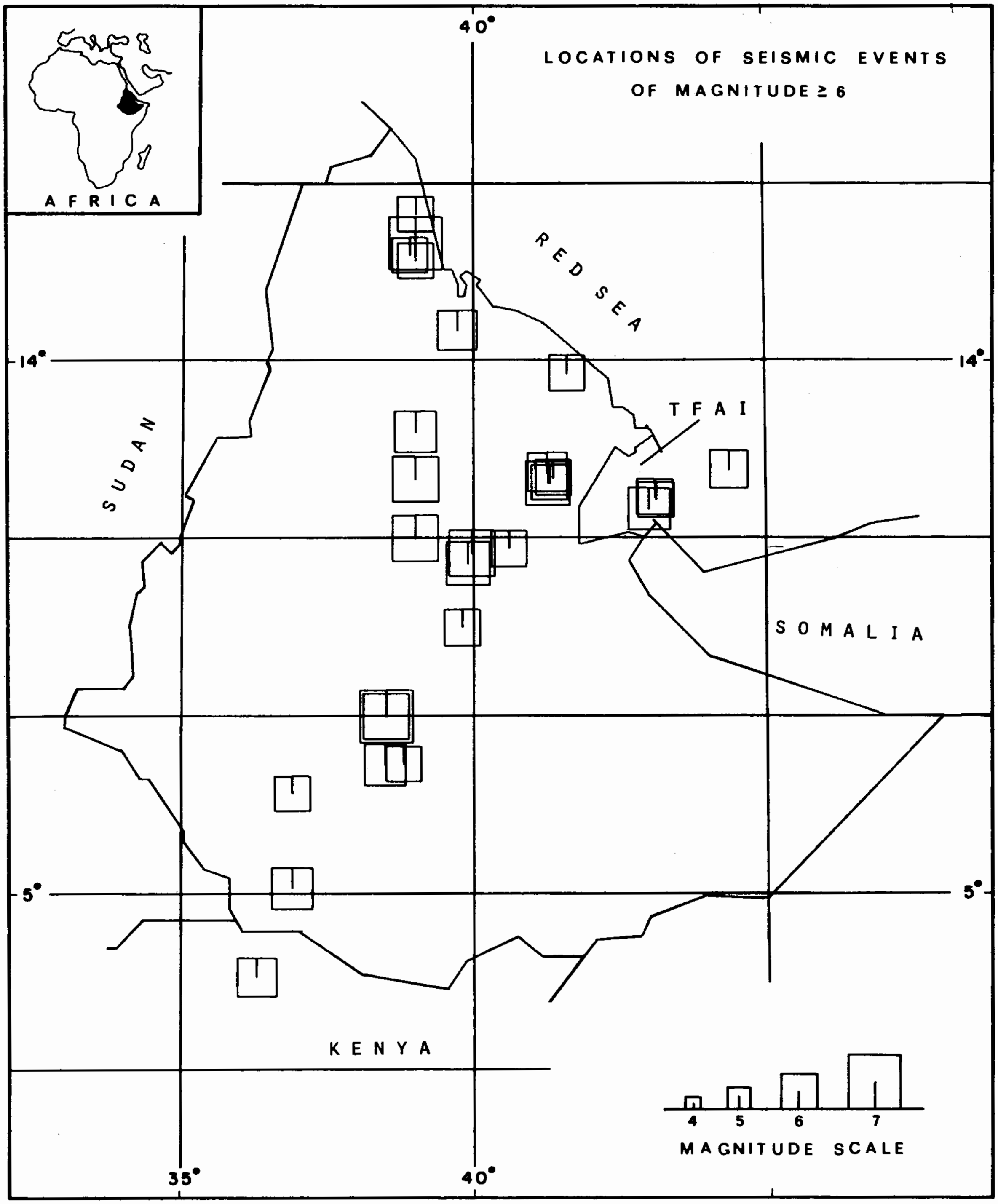

Figure 4D. Epicentral locations of earthquakes with magnitudes ≥ 6 in Ethiopia and surrounding areas.

They form the data bank from which the seismic hazards in Ethiopia are evaluated in this report.

Felt tremors and instrumental reports which are described with enough precision and accuracy to be assigned reliable geographic locations and amplitudes have been plotted on the base-map of Ethiopia. From this information, four epicentral location maps have been produced. Maps 4A and 4B indicate the location of all seismic events reported with the degree of accuracy described above; note that the number of epicenters plotted on these two maps represent a small fraction not only of the absolute number of earthquakes estimated to have occurred but also of the total number of events reported because of the insufficient accuracy of many descriptions. Maps 4C and 4D classify the epicenters by order of magnitudes equal to or above the level of potential damaging force. In this report, magnitude 5 is considered as the threshold of damage for Ethiopia. Maps 4C and 4D also show which regions of Ethiopia have experienced the strongest earthquakes; by the same token, they single out the areas where the seismic hazards are at their highest.

To show the significance of seismic hazards on Ethiopian life, three other maps give the present political divisions of the country, the location of the major earthquake-causing tectonic features and the density distribution of the population.

The correlation between these maps is self-evident, striking, and disturbing. The gravest hazards either due to the destructive power of the shocks themselves or to their secondary effects such as landslides and rockslides unfortunately coincide with the most densely populated regions of Ethiopia.

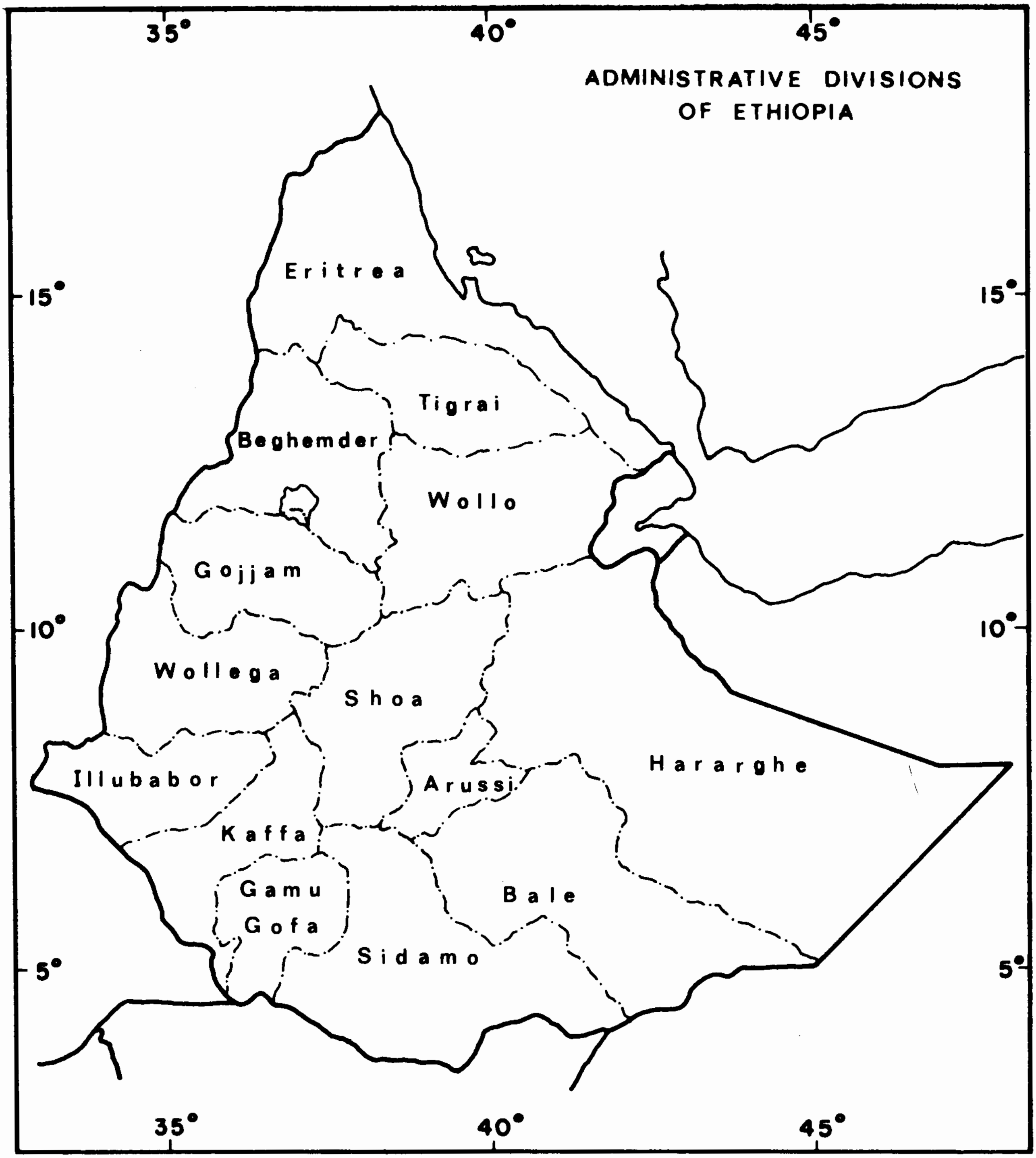

Figure 5A. Administrative divisions of Ethiopia. The boundaries indicated are not to be considered authoritative.

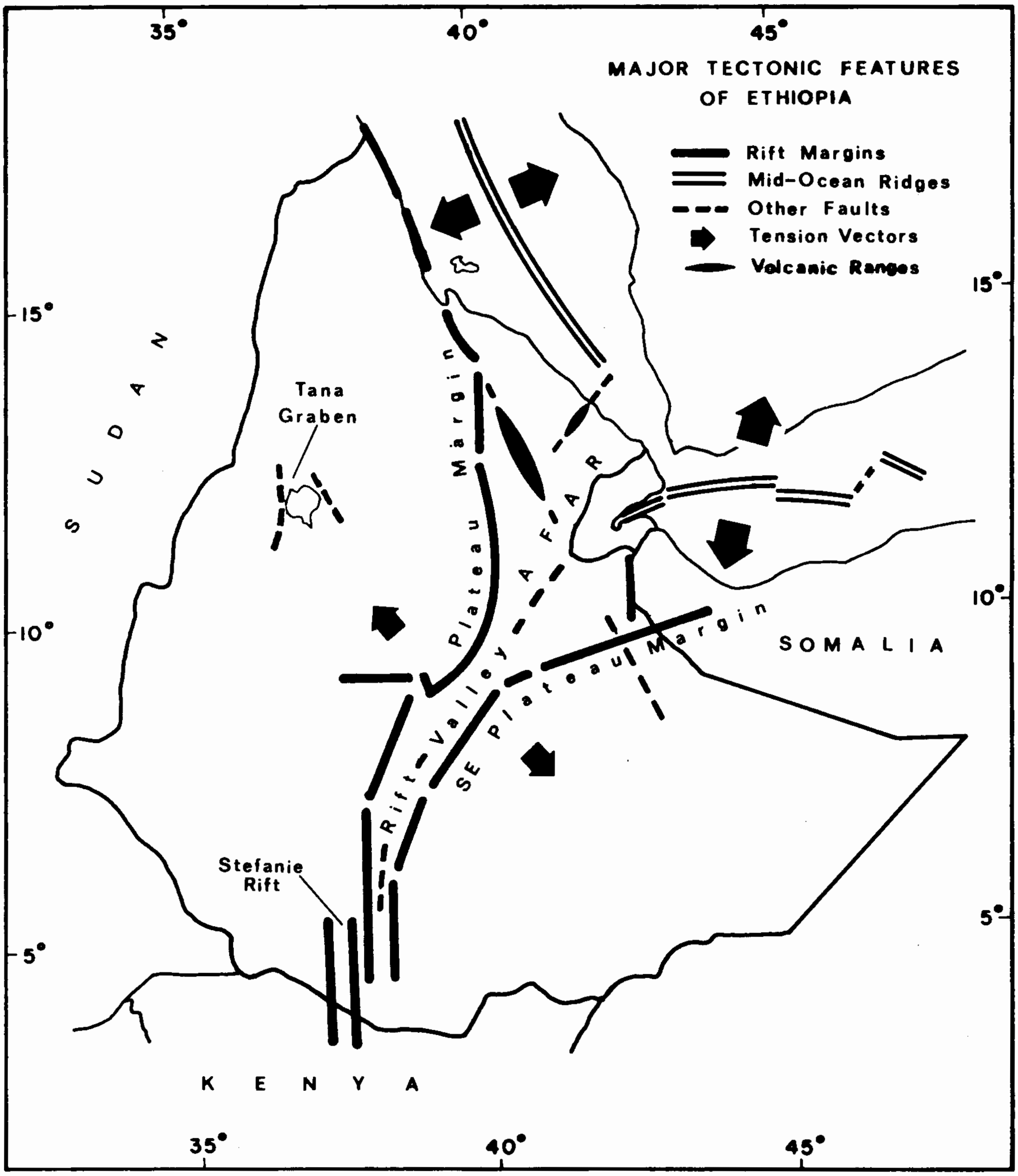

Figure 5B. Diagrammatic map of the major earthquake-causative tectonic features of Ethiopia.

(Note: the term AFAR used in this context is not an administrative division of Ethiopia; it is a practical term internationally adopted by earth scientists to designate

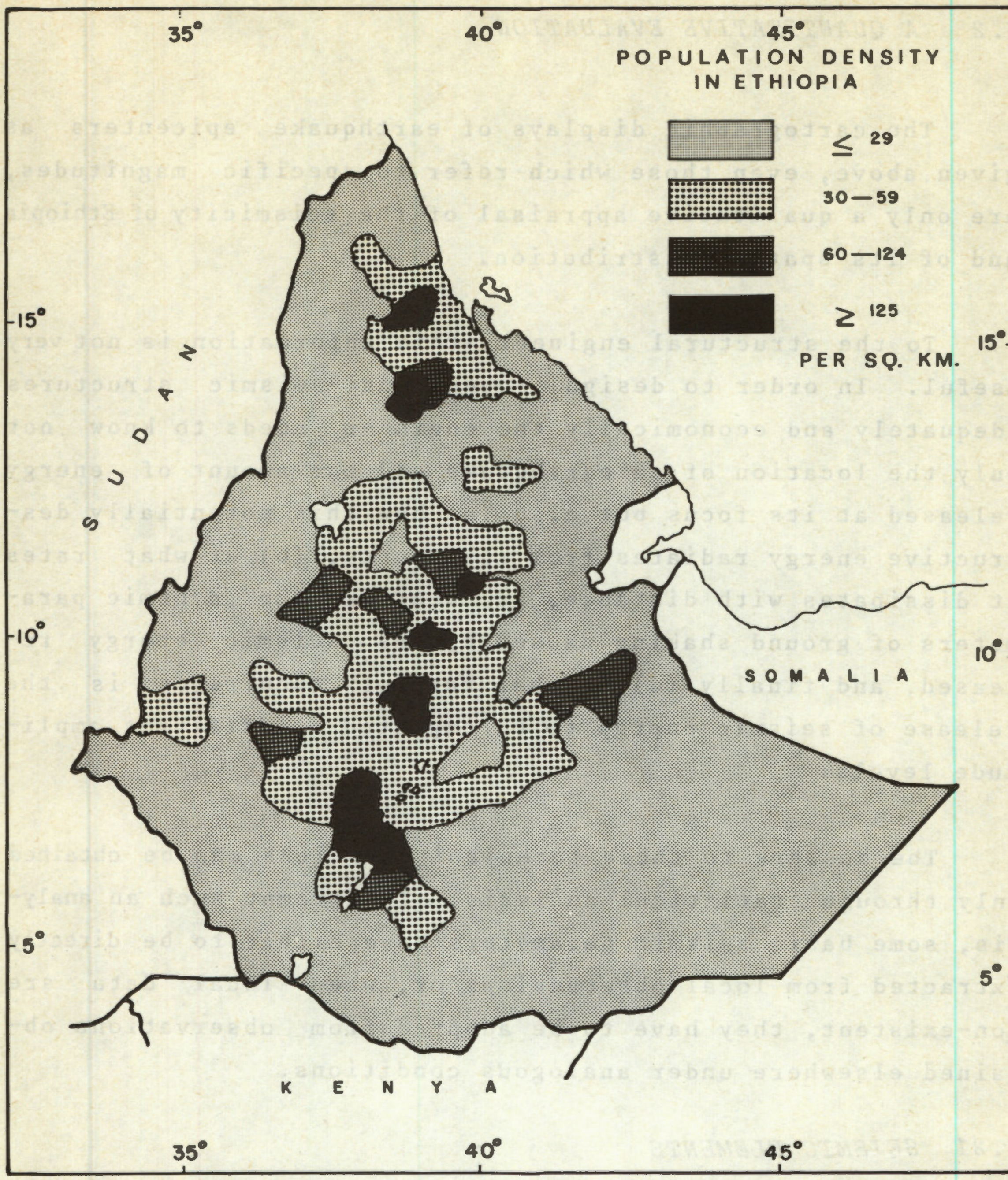

Figure 5C. Population density distribution in Ethiopia (adapted from the survey of Mesfin Wolde Mariam, 1970)[5].

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the desert regions of northeastern Ethiopia which presently overlap the boundaries of four provincial administrative divisions).

3.2 A QUANTITATIVE EVALUATION

The cartographic displays of earthquake epicenters as given above, even those which refer to specific magnitudes, are only a qualitative appraisal of the seismicity of Ethiopia and of its spatial distribution.

To the structural engineer, this information is not very useful. In order to design sound anti-seismic structures adequately and economically the engineer needs to know not only the location of an earthquake and the amount of energy released at its focus but also (a) how this potentially destructive energy radiates from its source, (b) at what rates it dissipates with distance, (c) what are the dynamic parameters of ground shaking caused by the seismic energy released, and finally (d) at what rate of recurrence is the release of seismic energy to be expected at different amplitude levels.

The answers to these technical questions can be obtained only through statistical analysis. To attempt such an analysis, some basic seismic parameters have either to be directly extracted from local observations or, when local data are non-existent, they have to be adopted from observations obtained elsewhere under analogous conditions.

3.21 SEISMIC ELEMENTS

The relevant seismic elements needed for the statistical analysis are:

3.211 The selection of a reliable data bank of information,
3.212 The choice of energy attenuation rates,
3.213 The choice of relationships between diverse amplitudes.

3.211 DATA BANK OF SEISMIC INFORMATION USED IN THE ANALYSIS

As previously mentioned, the data file for the 575 years of earthquake history, on the whole, is not sufficiently accurate nor numerically complete enough to be submitted to statistical analysis. It was therefore necessary to select, within that historical period, a time interval which could be considered as the best representative sample of the current seismic activity. The selection criteria included not only the accuracy and completeness of the scientific information available but also the minimum span of time necessary for the sampling period to cover enough fluctuations in the seismic regime to represent the real long-term trend of the activity.

Statistical tests of the whole data file reveal that the quality of the information obtained from 1875 to 1974 meet these requiremments for analytical treatment. Hence in this report, the evaluation of the seismic hazards in Ethiopia is based on the seismic activity of the last one hundred years.

3.212 SEISMIC ENERGY ATTENUATION RATES

Each earthquake is a discrete source of energy which radiates its damage-causative power within a certain radius around its epicenter. This power is termed 'Intensity' (I). Under normal circumstances, the intensity peaks in the immediate vicinity of the epicenter; it decreases with distance. The rate of attenuation of seismic energy with distance constitutes a regional parameter mainly determined by the nature of the local earth crust through which it propagates. Ideally, the attenuation rates for any region should

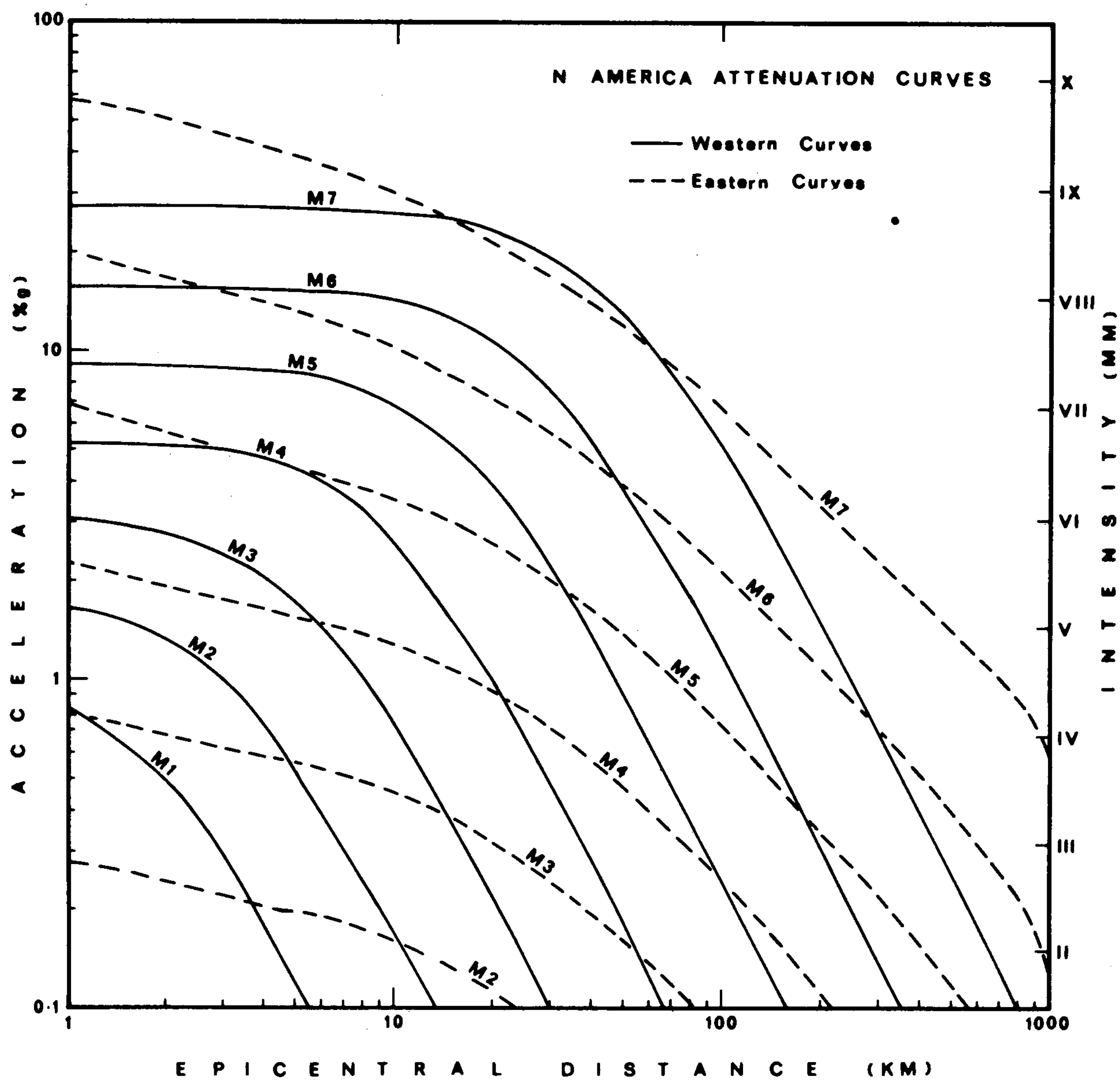

Figure 6A. Amplitudes - versus - epicentral distances for earthquakes in North America according to equations (2) and (3).

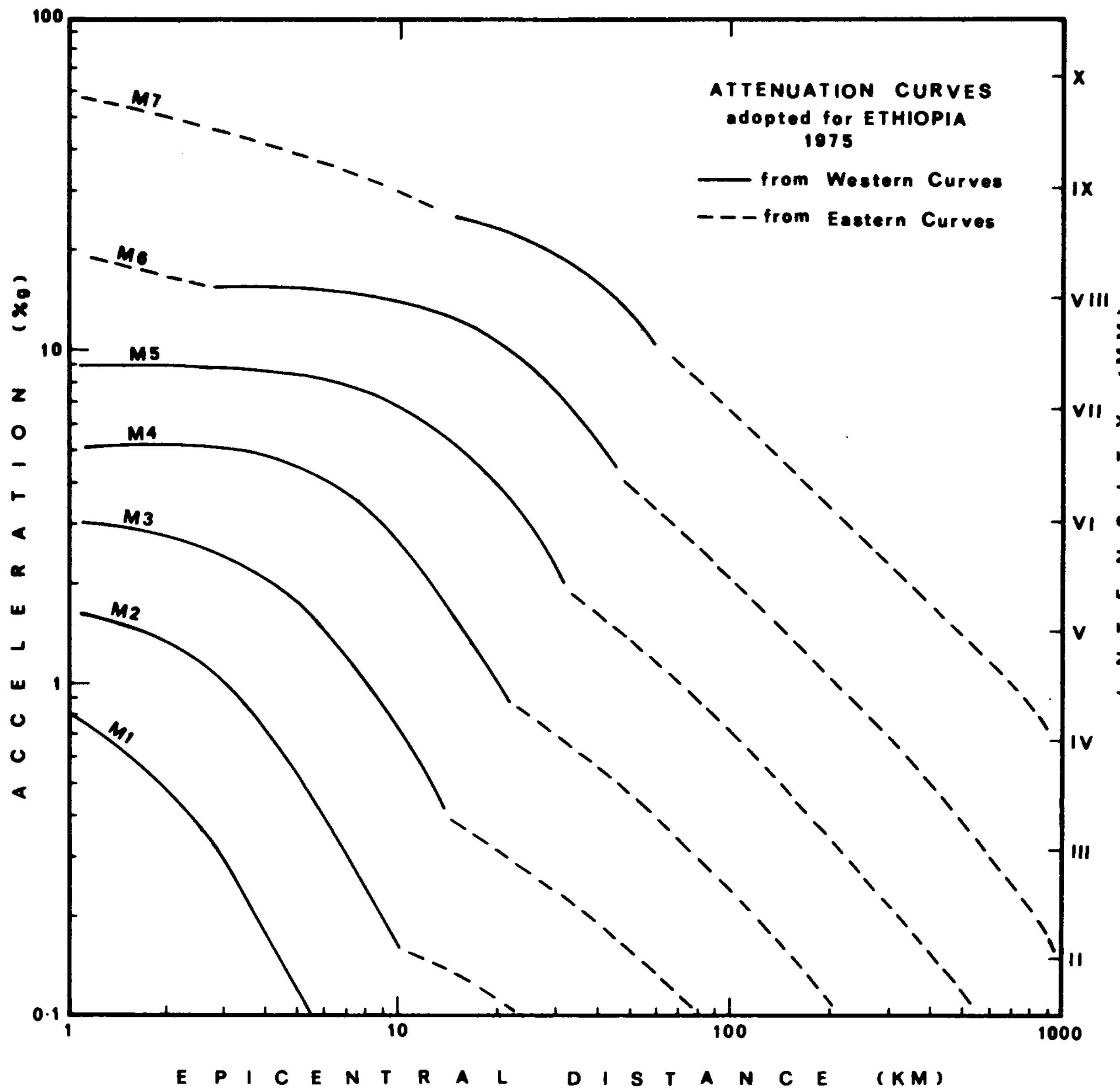

Figure 6B. Adopted attenuation curves for earthquakes in Ethiopia. These curves have been generated from the maximum amplitudes of each of the curves of Figure 6A for a determined magnitude.

be extracted from local observations.

Measurements of seismic energy propagation in Ethiopia are almost non-existent; there is therefore no other alternative at present than to select among the rates of attenuation obtained under quasi-equivalent geological and crustal conditions those which best fit crustal structures in Ethiopia. For practical purposes, these conditions are classified in this paper in two categories: the Rift structures and the Plateau structures. (We ignore, for the moment, the unusual crustal structure under the Danakil lowlands). A suitable analogy to these two crustal structures occurs on the North American continent where the Rocky Mountains can be approximated to the tectonically disturbed rift regions of Ethiopia and Eastern Canada to the conditions under the Plateaus. Of the few observations made in Ethiopia none contradict this choice.

Until such a time as local attenuation curves become available and as a first approximation, the Western and Eastern North-American attenuation curves have been adopted. The equations for these attenuation curves are respectively for

Western North America:

$$\text{Acc.} = \frac{0.69e^{1.64M}}{1.1e^{1.1M} + \Delta^2} \tag{2}$$

and for Eastern Canada:

$$\text{Acc.} = 3\log_{10}(I_7 - 9.66 - 0.00370\Delta + 1.38M + 0.00528\,\Delta.M) + 4.5 \tag{3}$$

where Acc. = Acceleration in percentage of gravity, e = constant 2.71828, M = magnitude, Δ = epicentral distance, and I_7 =

the intensity produced in Eastern Canada by an earthquake of magnitude 7. These two equations are empirical expressions best fitted to the attenuation rates observed in California and in Eastern Canada. (Milne and Davenport, 1969)[4]. Contrary to equation (2) which directly generates attenuation curves for any set of M and Δ values, equation (3) pre-requires the standard curve I_7 to generate attenuation curves for magnitude values other than M7.

Families of curves from equation (2) and (3) are plotted in Figure 6A. The sectors of maximum amplitudes of each curve in Figure 6A have been adopted for Ethiopia. They form the graph shown in Figure 6B.

Since there are no reliable determinations of earthquake focal depths (h) in Ethiopia, this factor has been left out of all equations. Mathematically this assumption produces a higher than normal intensity (I_o) in the immediate vicinity of the epicenter since the range of focal depths evaluated between 4 and 45 kilometers in Ethiopia is reduced to zero. This anomaly is apparent only. Strong-motion accelograph records from US and Japan reveal that observed I_o especially in the vicinity of a fault or over a fault system exceeds by far the I_o computed by an equation such as equations (2,3). The difference may be 2 to 10 times higher.

3.213 ADOPTED AMPLITUDE RELATIONSHIPS

A seismologist expresses the size of a seismic event in units of magnitude (M) and energy (E) released at the focus: this information is obtained directly from the amplitudes of the traces on the seismograms and from the frequency-response and sensitivity of the recording system. The structural engineer, on the other hand, evaluates the size of the same event by the amplitudes of the ground motions it produces at a given site away from the epicenter and by the intensity (I) of damage to structures of different classes. The intensity of damage is a cumulative result of many tri-dimensional ground motion parameters such as acceleration, velocity, displacement, period of oscillation, duration of motion, etc... all of which are altered from site to site by soil conditions. While the magnitude of an earthquake is easily obtained from standard seismograms, it is practically and economically impossible at present to record all the ground motion parameters that the engineer would need. When one only of these parameters it to be selected, the choice of the engineer usually goes to *acceleration* despite the facts (a) that different types of structures or even different sections of the same structure respond to different periods of oscillation and (b) that the accelerations indicated by the seismologist who has no accelerographs at his disposal is usually a peak value with no reference to any particular period of oscillation.

For the present study, the instrumental information from the data bank provided magnitudes; the macroseismic evidence provided some of the intensities. The reciprocal conversion of magnitude and intensities, and the computation of ground accelerations make use of the following relations:

The magnitude M of each earthquake was first determined. The energy (E) was then calculated from Richter's equation

$$\mathrm{Log}_{10}\ E = 1.5\ M + 11.4 \tag{4}$$

To find the acceleration at the epicenter (Acc_o), equations (2) and (3) were used where Δ was made to equal 0

$$Acc_o \text{ for } M > 5 = 3\log_{10}(I_7 - 9.66 + 1.38M) + 4.5 \tag{5}$$

$$Acc_o \text{ for } M < 5 = \frac{0.69e^{1.64M}}{1.1e^{1.1M}} \quad (6)$$

Finally, the intensity was obtained from the relation

$$\text{Intensity} = 3(\log_{10}Acc + 1.5) \quad (7)$$

Conversion of magnitudes into ground displacements and velocities has been attempted, but the results did not appear to be realistic enough for Ethiopia. They will have to be revised before being accepted.

3.22 ELEMENTS NEEDED FOR THE PROCESSING OF THE DATA

3.221 REFERENCE GRID POINTS

The seismicity distribution over the country was obtained by summing up and contouring the amplitudes experienced at a series of selected reference points distributed over Ethiopia. These points form a grid the density of which has been made variable to match the non-uniform distribution of the seismicity as shown in Figures 4. From the epicentral maps, it is apparent that the regions directly connected with or neighbouring the rift system are more seismically active than, say, Western Ethiopia or the south-eastern Ogaden region. The density of the grid was therefore adapted to this situation. Four points per square geographic degree form the basic grid; four points per half square degree cover the more active regions. To these reference points were added 32 important population centers as well as the locations of all the existing and projected reservoirs and power dam sites; all in all, a total of over 650 reference points. To avoid fringe effects in the computations and mapping, the grid was extended 200 kilometers outside Ethiopia's international boundaries.

For each reference point on the grid, the amplitudes experienced from each event registered in the data bank for the period 1875 to 1974 were computed in terms of intensities and ground accelerations. Intensities are given in Mercalli Modified (MM) units as required by the Building Code and the accelerations, in percentage of gravity (% g). The peak amplitudes values computed for each site were plotted on the basemap and then smoothly contoured at the intensity levels indicated by the Code to produce maps 7 and 8 . Numerical values for amplitudes expected at important sites are given in the Appendices 7.2 and 7.3.

3.222 RATE OF RECURRENCE OF EARTHQUAKES

The results obtained up to this point indicate the number, amplitude and location of past Ethiopian earthquakes; they fail to indicate the rate at which these earthquakes have occurred and probably will continue for some time. The analytical method selected to compute the probable rates of recurrence of Ethiopian earthquakes is based the *Extreme Values Statistics* developped by Gumbel[3] and applied to the analysis of seismic hazards by Milne and Davenport[4]. These statistics make use of only the yearly peak amplitudes experienced at each reference grid point. The reason for using only one value over a determined period of time, in this case one year, is to filter out the effects of foreshocks and aftershocks. Note that other seismologists choose screening time intervals much shorter than one year. Note also that the statistics used do not yield absolute peak values but the maximum amplitudes which have a 1% annual probability of being exceeded.

In practice, rates of recurrence can be expressed in two ways: either (a) by giving the recurrence periods corresponding to a fixed set of amplitudes, or (b) by giving the maximum amplitudes corresponding to a fixed set of periods. Table 1 illustrates the two types of presentation for the maximum ground accelerations to be expected at Addis Ababa. The common opinion of Ethiopian engineers is that projected amplitudes should be given to them according to the second (b) prescription as in Table 1 where the periods are fixed and the amplitudes variable.

Table 1.

Probable rates-of-recurrence of ground acceleration amplitudes at Addis Ababa

Technique (a)		Technique (b)	
Accelerations	Return Periods	Return Periods	Accelerations
(% g)	(Years)	(Years)	(% g)
1	13.4	10	0.7
3	41.8	50	3.6
6	86.5	100	6.9
10	148.3	200	13.3
20	308.2	300	19.5

In the original computations, return periods ranging from 3 to 1000 years have been evaluated. Strictly speaking only the periods from 50 to 100 years are significant. In general, fifty years is considered to be the minimum time interval to cover enough cycles of the current seismic activity to represent its real trends; longer than 100 years would be an extrapolation over and above the length of the sampling interval. In the case of Ethiopia, however, 200 and 300 years could be used with caution since their maximum intensities can always be checked against the data of a 575 - year data file.

3.23 SEISMICITY MAPS OF ETHIOPIA

The results of the evaluation of the seismic hazards in Ethiopia are presented here in the form of three maps. These maps are based on the amplitudes to be expected during a 100-year return period with, on the average, a one per cent annual probability that these values will be exceeded. Note that it is pure coincidence if both the sample interval and the return period selected are of 100 years. Had the sample interval been any longer, the probable amplitudes adopted would have been reduced to those expected during 100 years. A one hundred year return period seems a good compromise in terms of security and economy when the life span of important structures and public buildings are considered.

Note also that two out of three of these seismicity maps are not entitled "seismic risks" maps but "seismic hazards" maps. Such a distinction between 'risks' and 'hazards' is not commonly made in engineering seismology; these terms have no strict accepted meanings. For instance, the term 'risk' could mean "the probability that a ground motion of some determined amplitude will occur every so often at a site"; for engineers, the term 'risk' is usually restricted to "the product of the probability of shaking multiplied by the probability of loss produced by that shaking". For the sake of clarity, in this context, 'hazards' are understood as the chance events which produce a potential damage, if unrestricted; 'risks' imply the acceptance of a calculated minimum level of damage dictated by engineering and economic principles. The relationship between seismic hazards and seismic risks is expressed by the weight given to factors such as R and I in the equation which defines the minimum seismic forces that a structure should withstand in order to resist minor earthquakes without damage and the largest predicted shocks without collapse. This equation is of the form

$$V = k.f(R, K, C, I, F, W) \tag{8}$$

where V = the lateral seismic forces at the base of the structure; K, C, F and W could be classified as structural factors; R = the weight given to each seismic zone; k=a constant; I = an *importance factor* determined by the special role that the building plays in the community at large. In the Ethiopian Code, the highest value of the *importance factor* (I = 1.5) goes to general public utility services such as communications, water supplies, hospitals, schools and those buildings which when disturbed constitute a permanent public danger such as chemical plants, ammunition factories, etc.... In this context, only the Zoning Map is a Seismic Risks map since the weight of the seismic factor R is included in the classification of the zone. This explains why there is no zone number 3.

3.231 GROUND ACCELERATION MAP

The first seismic hazards map, Figure 7 , shows the distribution of probable maximum ground accelerations in Ethiopia. These values are estimated for solid ground conditions only. Let it be remembered that before applying these values to a structural design at a given location, it is imperative to take into consideration the magnification of the ground motions due to less favorable soil conditions. To give an example; in California, amplification ratios of 2.5:1 for periods of oscillation in the order of 8 seconds and 4:1 for the shorter periods between 0.2 - 1.5 seconds have been observed on different types of geological formations. Hazards are much higher on unconsolidated soils and on major faults belts than on solid rock.

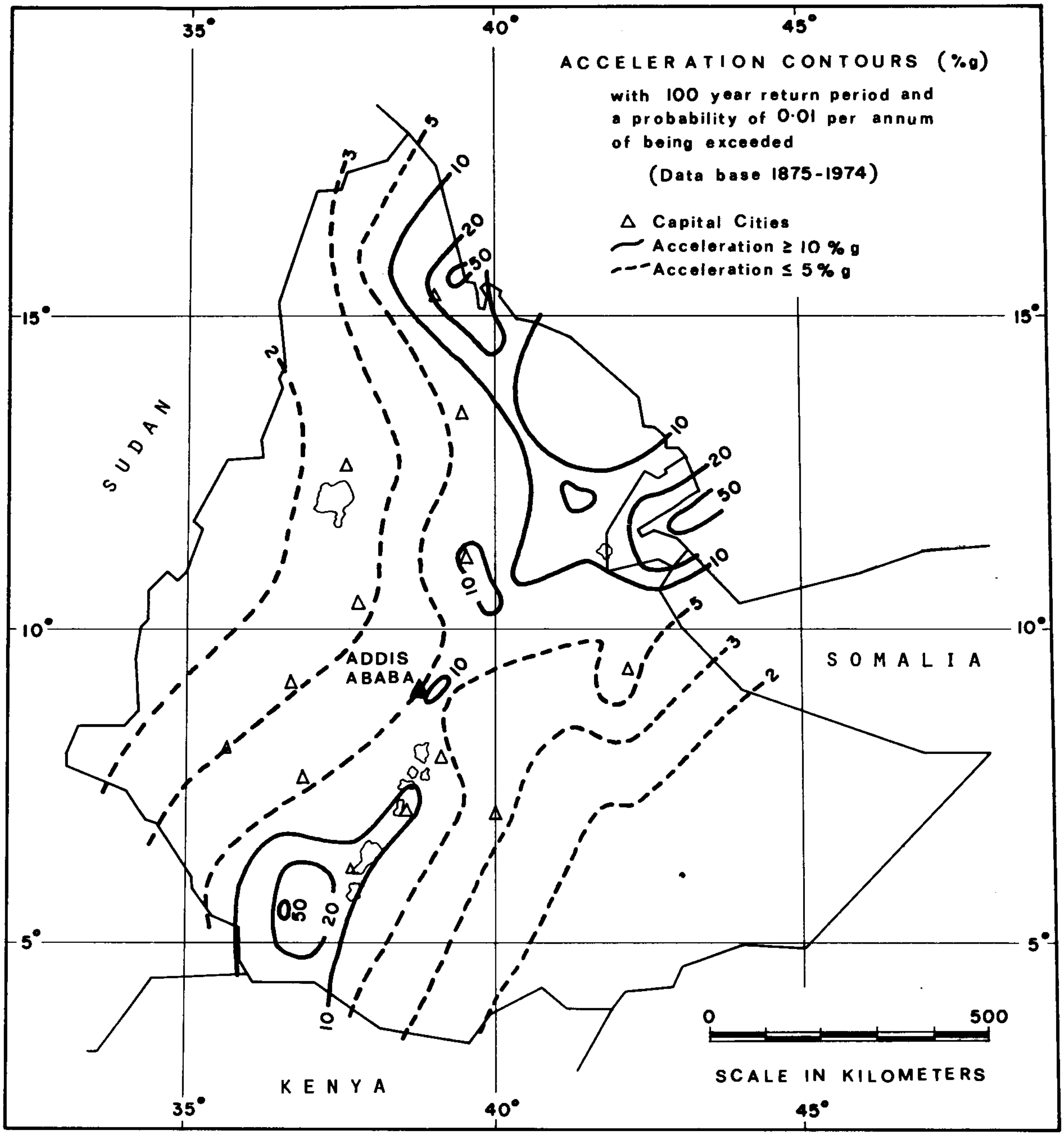

Figure 7. Predicted ground acceleration map of Ethiopia based on a 100-year recurrence period and on a 1% annual probability that the maximum values will be exceeded.

It should also be emphasized that the accelerations presented in the Appendix of this report for individual sites and which were used in the construction of Map 7 are very CONSERVATIVE indeed due, among other factors, to the type of statistics used, to some incompleteness in the information, and to the one-year length of the screening period for aftershocks. The case of Addis Ababa will illustrate this point.

The maximum acceleration predicted for Addis Ababa over 100 years is 6.9 per cent of gravity (70 cm sec^{-2}) corresponding to intensity VII. This 6.9%g value was obtained by a least squares fit straight line passing through observed data points scattered between 8.3 and 5.8%g at the 95% statistical confidence level and 9.0 and 5.4%g at the 99% confidence level. So that accelerations of 9%g at Addis Ababa would, in a way, be more realistic than 6.9%g. And if one considers the possibility of error in locating the 1906 earthquakes of magnitudes 6.8 and 6.5 at 71 kilometers from the center of Addis Ababa instead of, say, 50 or 30 kilometers as is always possible in the case of earlier events, then the predicted accelerations could be of the order of 14-15% instead of a conservative 6.9%g. It would be a prudent practice, therefore, to use a security factor X2 for all acceleration values given for individual sites.

3.232 INTENSITY MAP

The grid intensity values contoured to generate Intensity Map 8 were obtained from the conversion of the computed peak accelerations at each site into MM intensity grades using the following relationship:

$$I_{MM} = 3(\log_{10} A + 1.5) \tag{7}$$

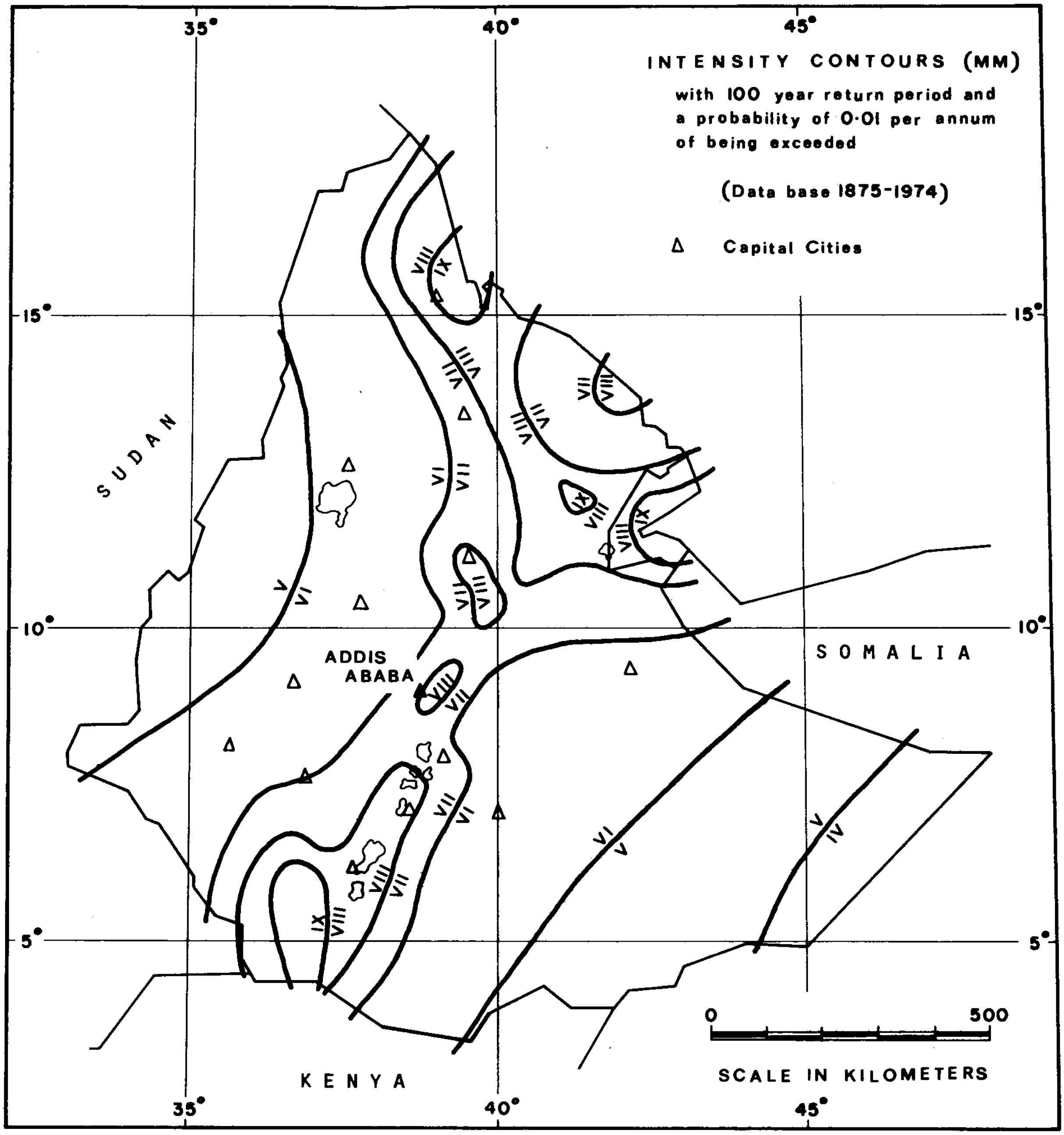

Figure 8. Predicted Intensity map of Ethiopia based on a 100-year recurrence period and on a 1% annual probability that the maximum values will be exceeded.

in which A is reckonned in cm/sec^2. Intensity grades being always considered as integers only (Roman numerals), the results of equation (7) were rounded off to the nearest integer. Such a procedure automatically decreased the relative weight of the inaccuracies observed in estimated accelerations when transformed into intensities. An intensity grade covers a relatively wide range of accelerations (for instance, 4.6%g < VII < 10%g) and therefore, the security factor X2 recommended above for accelerations will evidently not affect the intensity ratings by more than one unit.

The observation has already been made (para. 3.231) that geological conditions affect intensity ratings. It is a common opinion that rocky and semi-rocky unweathered soils are the least affected by earth tremors; map 8 has been computed for such geological conditions. Consequently, in the interpretation of this map, it is recommended that the predicted intensity values be up-graded by one unit in the case of average soil conditions (not too well consolidated formations) and by two units in the case of water saturated, sandy, or loamy soils.

3.233 ZONING MAP

The Zoning Map required by the Building Code (1974) is given as Figure 9. This map is a reproduction of the maps 7 and 8 on which the new contours follow the amplitude levels specified by the Code, that is Intensity (MM) levels V, VII and VIII corresponding to ground acceleration levels 1, 4, 6 and 10% of gravity (10, 40, 60 and 100 cm sec^{-2}). The Risk Zones defined by the isolines are numbered after their respective assigned seismic R-factors (equation 7). The remarks previously made concerning the interpretation of the predicted acceleration and intensity values apply to the interpretation of this zoning map.

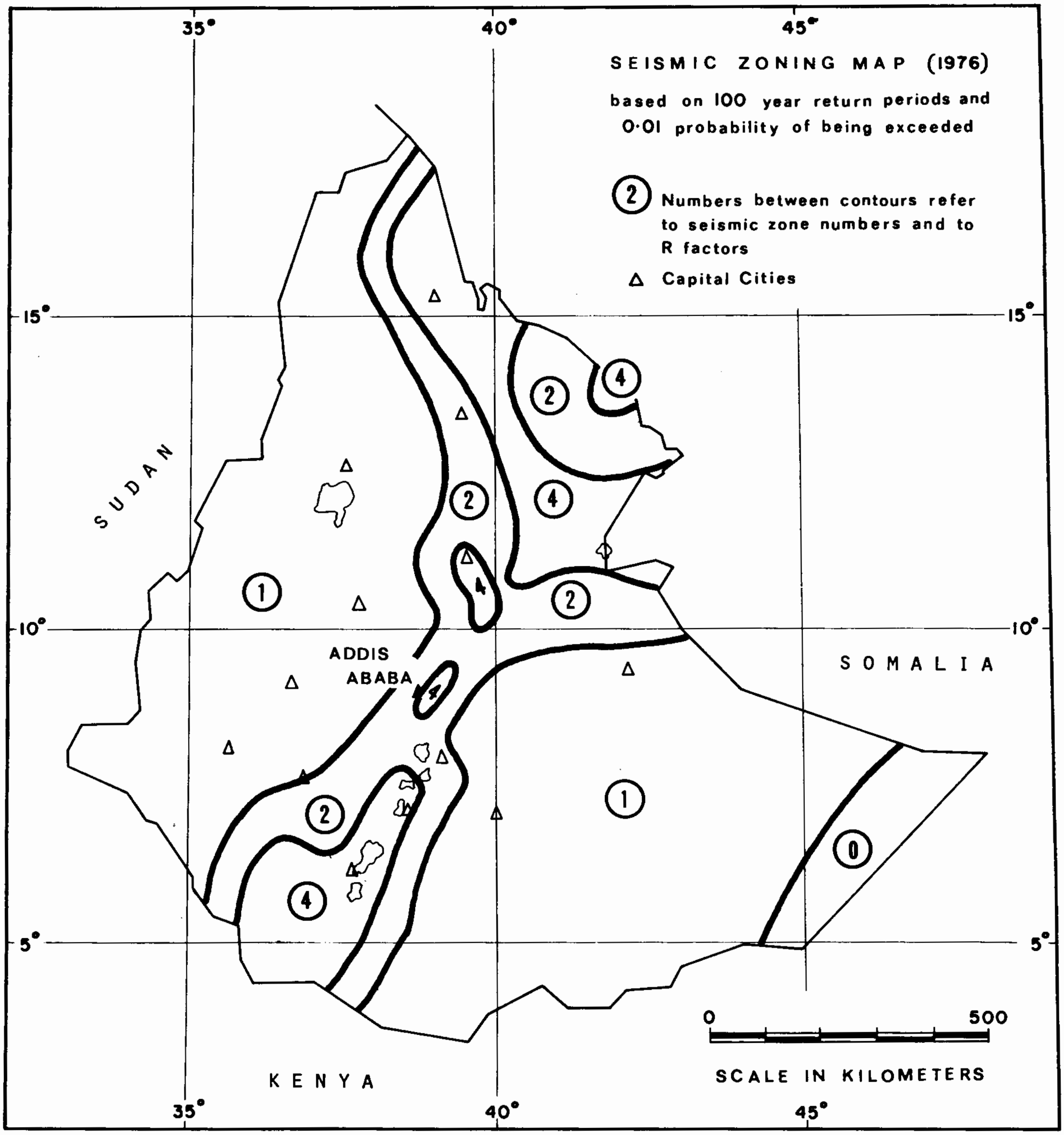

Figure 9 Seismic Zoning in Ethiopia based on the requirements of the Building Code revised draft 1974. The contours are based on a 100-year sample interval, 100-year recurrence period and a 1% probability that the maximum values will be exceeded.

The delineation of the risk zones on map 9 (1976) is based on the maximum ground shaking amplitudes expected during a 100-year period when these amplitudes are evaluated by the statistical methods described in this report. The use of a different mathematical approach or the choice of a different recurrence period as a reference will alter the location of the zone borderlines. In the absence of specifications from the Code, I chose the elements which in 1976 appeared to me the most realistic.

It is evident from the areal coverage of each zone that the average degree of seismic risks assigned to an entire zone levels out the higher and lower risks of many individual sites. In terms of security, therefore, some of the sites within the same zone are somewhat overcompensated while others are undercompensated. This state of affairs is inevitable until regional microzoning maps are produced. To compensate some of the limitations of map 5C, seismic amplitudes for a few important individual sites are given in Appendix. Let it be repeated that the amplitude values given in Appendices 7.2 and 7.3 apply only to solid ground conditions; they have to be altered in the case of less consolidated geological formations.

4. CONCLUSIONS

It is generally agreed that a Security Building Code is intended to provide the public with the assurance that its buildings and important structures will be so designed that (a) they will not collapse during earthquakes of the maximum amplitude expected and that (b) the damage they will suffer during moderate and minor earthquakes will not be significant. This assurance is to be understood as a calculated compromise between the expected hazards, the original costs of providing stronger structures, the probable future loss from earthquakes of specific magnitudes and the economic conditions of the community. The lower bound of this assurance is determined by the minimum security level that the Code has selected.

The minimum security level will, on the average, be obtained in structural design by the use of the ground shaking parameters given in this report. It should be strongly emphasized that the minimum values indicated for each amplitude, due to the nature of the statistics used and to the assumptions made about the basic seismic parameters, are very conservative.

The Seismic Zones Map was constructed from the distribution of the maximum intensities expected during return periods of 100 years. History shows that these amplitudes are realistic. However, considering (a) the size of the area covered by each zone and (b) the fact that these zones are graded according to the mean value of the peak amplitudes experienced over the whole zone, it is evident that some regions within the same zone, from a security standpoint, are overcompensated and some others undercompensated. This situation could have been avoided only by the micro-regionalization of each zone; such an approach, at present, is not realistic from a seismic as well as from an administrative angle. It is an ideal to keep in mind.

Lastly, the solutions presented in this report are not to be considered final; they will have to be revised with the obtention of new seismic data, with a more realistic evaluation of the country's needs and perhaps also with a different humanistic understanding of the notion of security. At present, the priorities are in the following order: (1) security of property and (2) security of human life. It is conceivable that the order be altered to (1) protection of lifes and then (2) protection of material property.

A first revision concerns the important sites at present located on or in the immediate vicinity of a borderline between two zones. A good example is Addis Ababa. From an administrative point of view, it might be difficult to enforce the application of two sets of building regulations within the same city. The contour line, therefore, surrounding Addis Ababa needs to be altered immediately.

A longer-term revision of the seismic maps should include local seismic parameters at present not available such as earthquake focal depths, focal mechanisms, more accurate location of active fault zones, seismic classification of soils, etc.. a whole spectrum of information which cannot be obtained without expanding the present seismic recording facilities in the country.

To facilitate future revisions and even allow complete recomputation of the seismicity of Ethiopia without having to duplicate the research on principal facts, (1) the arguments for my own interpretation of each case are given in Section One of the Survey and (2) all the seismic information of the data file which could be digitized is available on punch cards and magnetic tape.

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The typing of this report has been made by W/t Bekelech Degefe and the drafting by Ato Theodros Tsigé.

7. APPENDIX

7.1 MERCALLI MODIFIED (1931) EARTHQUAKE INTENSITY

(an abridged version)

I. Not felt except by very few under favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings; vibration like the passing of a lorry. Parked cars might rock slightly.

IV. During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sounds.

V. Felt by nearly everyone, many awakened. Few instances of cracked plaster; unstable objects overturned.

VI. Felt by all, many frightened and run outdoors. Some heavy furniture displaced. A few instances of fallen plaster. Damage slight.

VII. Everybody runs outdoors. Damage *negligible* in buildings of good design, *slight to moderate* in well built ordinary structures; *considerable* in poorly built or badly designed structures.

VIII. Damage *slight* in specially designed structures; *considerable* in ordinary, substantial buildings, with partial collapse; *great* in poorly built structures.

IX. Damage *considerable* in specially designed structures; great in substantial buildings with partial collapse. Ground cracked conspicuously.

X. Most masonry structures destroyed as well as some well built wooden structures. Ground badly cracked; rails bent. Landslides and rockslides.

XI. Few, if any, masonry structures remain standing, bridges destroyed. Broad fissures in the ground. Earth subsidence and landslides in soft ground.

XII. Damage total.

Note: A request to adapt this scale to Ethiopian building conditions is being circulated among the engineering profession in Addis Ababa.

PREDICTED EARTHQUAKE INTENSITIES (I*) AND GROUND ACCELERATIONS (A**)

CAPITAL CITIES AND IMPORTANT TOWNS

LOCATIONS			ESTIMATED PROBABILITY							
Sites	Coordinates		1/50 Years		1/100 Years		1/200 Years		1/300 Years	
	N^o	E^o	I	A	I	A	I	A	I	A
Addis Ababa	09.00^o	38.77^o	VI	3.6	VII	6.9	VIII	13.3	VIII	20
Adigrat	14.30	39.50	VII	5.1	VIII	10.0	VIII	19.3	IX	28
Aksum	14.13	38.92	VI	2.8	VII	4.9	VII	8.5	VIII	12
Arba Minch	06.00	37.70	VII	5.7	VIII	13.8	IX	33.4	X	56
Asayita	11.60	41.40	VII	7.6	VIII	16.7	IX	36.6	X	58
Asella	07.98	39.12	VI	2.8	VII	5.5	VIII	10.5	VIII	15
Asmara	15.33	39.00	VIII	12.7	IX	28.8	X	64.7	XI	104
Asseb	13.00	42.67	VI	3.1	VII	5.7	VIII	10.3	VIII	15
Awasa	07.05	38.52	VII	5.2	VIII	12.2	IX	28.5	X	47
Awash Station	09.00	40.20	V	2.0	VI	3.4	VII	5.8	VII	8
Bako	05.80	36.50	VIII	11.4	IX	34.2	XI	103	XI	195
Bonga	07.30	36.20	VI	2.4	VII	4.7	VII	9.4	VIII	14
Debre Berhan	09.30	39.30	VI	2.9	VII	5.3	VIII	9.7	VIII	14
Debre Markos	10.35	37.75	V	1.7	VI	2.8	VII	4.7	VII	6
Debre Zeit	08.75	38.98	VI	3.4	VII	6.6	VIII	12.7	VIII	19
Dembidollo	08.60	34.80	V	1.2	VI	2.2	VI	4.0	VII	6
Dessie	11.10	39.50	VII	5.7	VIII	12.0	IX	25.1	IX	39
Gondar	12.60	37.50	V	1.5	VI	2.4	VI	4.0	VII	5
Gore	08.15	35.57	V	1.6	VI	2.9	VII	5.3	VII	8
Hagare Mariam	05.60	38.30	VI	2.8	VII	5.3	VIII	6.8	VIII	8
Harar	09.30	42.10	VI	3.5	VII	6.8	VIII	13.2	VIII	19

LOCATIONS			ESTIMATED PROBABILITY							
Sites	Coordinates		1/50 Years		1/100 Years		1/200 Years		1/300 Years	
	N°	E°	I	A	I	A	I	A	I	A
Jimma	07.65	36.82	VI	2.4	VII	4.8	VII	9.3	VIII	14
Lekempt	09.10	36.55	V	1.6	VI	2.9	VII	5.2	VII	7
Massawa	15.60	39.50	IX	26.0	X	68	XI	176	XII	> 300
Mekele	13.45	39.47	VII	4.6	VII	9.1	VIII	18.0	IX	27
Mizan Teferi	06.90	35.50	VI	2.4	VII	5.1	VIII	10.6	VIII	16
Moyale	03.53	39.02	V	1.3	VI	2.5	VII	4.8	VII	7
Nazareth	08.63	39.28	VI	2.4	VI	4.4	VII	7.8	VIII	11
Serdo	11.98	41.20	VIII	9.9	IX	23.2	X	54.2	X	89
Tessenei	15.12	36.68	V	1.3	VI	2.2	VI	3.7	VII	5
Yavello	04.80	38.10	VI	2.4	VII	5.1	VIII	10.8	VIII	17
Yirga Alem	06.73	38.40	VI	3.9	VIII	8.7	VIII	19.0	IX	30

Note:

*I = Intensity in Mercalli Modified (1931) units.
**A = Ground accelerations in percentage of gravity.

7.3

PREDICTED EARTHQUAKE INTENSITIES (I*) AND GROUND ACCELERATIONS (A)**

WATER RESERVOIRS AND DAM SITES

LOCATIONS			ESTIMATED PROBABILITY							
Sites	Coordinates		1/50 Years		1/100 Years		1/200 Years		1/300 Years	
	N°	E°	I	A	I	A	I	A	I	A
A:										
Zula	15.25	39.60	VIII	12	IX	27	X	61	X	98
Fincha	09.58	37.33	V	1.7	VI	3.0	VII	5.2	VII	7
Koka	08.43	39.15	VI	2.5	VII	4.5	VII	8.2	VIII	12
Awash II	08.40	39.33	VI	2.3	VI	4.1	VII	7.3	VIII	10
Melka Wakana	07.22	39.40	VI	2.6	VII	5.1	VIII	9.9	VIII	15
Two-Bis (Kul-dash)	06.95	42.12	V	1.4	VI	2.6	VII	4.7	VII	7
B:										
Anseba	15.83	38.48	VII	8.3	VIII	18	IX	39	X	62
Shagoulgoul R.	15.32	38.23	VI	3.9	VII	7.4	VIII	14	VIII	20
Ferter R.	15.20	38.35	VI	4.1	VII	7.7	VIII	14	VIII	21
Carbasha R.	15.38	38.45	VII	6.0	VIII	12	IX	25	IX	37
Tesenei Dam	15.10	36.70	V	1.3	VI	2.2	VI	3.7	VII	5
Tesenei Flow Regulation	15.10	37.12	V	1.6	VI	2.7	VII	4.6	VII	6
	14.95	37.27	V	1.6	VI	2.8	VII	4.7	VII	6
	14.80	37.43	V	1.7	VI	2.9	VII	4.9	VII	7
	14.92	37.95	VI	2.3	VI	4.0	VII	6.9	VII	10
	14.70	38.25	VI	2.5	VI	2.4	VII	7.6	VIII	11
	14.48	38.42	VI	2.5	VI	4.3	VII	7.4	VIII	10
	14.45	38.62	VI	2.8	VII	4.8	VII	8.4	VIII	12
Upper Mereb	14.90	39.07	VII	7.1	VIII	14	IX	29	IX	44
	14.83	39.12	VII	6.6	VIII	13	IX	26	IX	39
Tedrer Plain	14.93	38.97	VII	7.4	VIII	15	IX	31	X	47
Upper Tekeze	13.70	39.52	VI	4.4	VII	8.6	VIII	17	IX	24
Medium Tekeze	13.47	38.70	VI	2.3	VI	4.0	VII	6.9	VII	10

LOCATIONS			ESTIMATED PROBABILITY							
Sites	Coordinates		1/50 Years		1/100 Years		1/200 Years		1/300 Years	
	N°	E°	I	A	I	A	I	A	I	A
C: <u>BLUE NILE RIVER</u>										
Rahab 1	12.56	36.27	V	1.1	V	1.8	VI	2.9	VI	4
Galegu	12.20	35.98	V	1.1	V	1.7	VI	2.8	VI	4
Dinder	12.05	35.83	V	1.0	V	1.7	VI	2.8	VI	4
	12.00	36.20	V	1.1	V	1.9	VI	3.1	VI	4
Barder Power Plant	11.22	35.10	VI	0.9	V	1.6	VI	2.6	VI	3
Dangur Power Plant	11.08	35.85	V	1.1	V	1.8	VI	2.9	VI	4
Ker Qousguram	11.40	37.02	V	1.3	VI	2.2	VI	3.7	VII	5
Debekam Mariam	11.35	37.02	V	1.3	VI	2.2	VI	3.7	VII	5
Umbari Mariam	11.18	37.00	V	1.4	VI	2.2	VI	3.7	VII	5
Sawesa Mariam	11.17	37.18	V	1.4	VI	2.3	VI	3.9	VII	5
Megetch	12.48	37.45	V	1.4	VI	2.3	VI	3.8	VII	5
Ribb 1	12.03	37.98	V	1.7	VI	2.8	VII	4.6	VII	6
Gumara	11.75	37.80	V	1.6	VI	2.7	VI	4.5	VII	6
Upper Bir	10.78	37.42	V	1.5	VI	2.6	VI	4.3	VII	6
Debohila	10.68	37.10	V	1.4	VI	2.4	VI	3.9	VII	5
Mendaia	10.07	35.57	V	1.1	V	1.9	VI	3.1	VI	4
Mobil	10.32	36.65	V	1.3	VI	2.3	VI	3.8	VII	5
Karadobi	09.87	37.68	V	1.7	VI	3.0	VII	5.1	VII	7
Giamma	09.92	38.88	VI	2.3	VI	4.0	VII	6.0	VII	10
Boo	09.48	35.95	V	1.3	VI	2.2	VI	3.8	VII	5
Dabana	08.95	36.02	V	1.5	VI	2.6	VII	4.7	VII	7
Lekempt	09.43	36.50	V	1.5	VI	2.6	VII	4.5	VII	6
Angar 1	09.68	36.73	V	1.5	VI	2.6	VI	4.5	VII	6
Amerti	09.78	37.28	V	1.6	VI	2.8	VII	4.8	VII	7
Neshi	09.80	37.28	V	1.6	VI	2.8	VII	4.8	VII	7

LOCATIONS			ESTIMATED PROBABILITY							
Sites	Coordinates		1/50 Years		1/100 Years		1/200 Years		1/300 Years	
	N°	E°	I	A	I	A	I	A	I	A
Chancho	09.32	38.73	VI	2.6	VII	4.7	VII	8.5	VIII	12
Bello	08.87	37.67	VI	3.2	VII	6.5	VIII	13	VIII	20
	08.88	37.68	V	2.8	VII	5.4	VIII	11	VIII	16
Amerti-Neshi	09.80	37.30	V	1.6	VI	2.8	VII	4.8	VII	6
Angar 2	09.43	36.43	V	1.5	VI	2.6	VI	4.4	VII	6
Dabus Project 1	09.98	34.90	V	1.0	V	1.7	VI	2.9	VI	4
Dabus Project 2	09.65	34.92	V	1.0	V	1.7	VI	3.0	VI	4
Lower Project	10.57	37.27	V	1.5	VI	2.5	VI	4.2	VII	6
Beles	11.68	36.73	V	1.3	V	2.1	VI	3.4	VI	4
Gumara	11.77	37.72	V	1.6	VI	2.6	VI	4.3	VII	6
Ribb 2	12.03	37.90	V	1.6	VI	2.7	VII	4.5	VII	6
Rahad 2	12.58	36.23	V	1.1	V	1.8	VI	2.9	VI	4

Note:

*I = Intensity in Mercalli Modified (1931) units.

**A = Ground accelerations in percentage of gravity.