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Some Features of Finnish Earthquake Data

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Abstract

Some features of the Finnish earthquake catalog are investigated. A general look is taken at the data available with the help of administrative information. Suitable stochastic models to describe the sequence of occurrence times and strengths of earthquakes are tested against actual data. The gamma, two-parameter lognormal, normal, and Weibull distributions are fitted to data sets of the largest events. For complete subcatalogs, the general assumption of earthquake occurrence following a Poisson distribution seems to be justified for the data available despite the difficulty of establishing the criterion to identify dependent events. The testing procedure employed does not reject the central assumption of this model when dependent events are included in the sample, but the results improve when these events are removed. The binomial distribution may be used parallel to the Poisson distribution. The details of the testing of the stochastic models are discussed.

Key words: seismology, earthquake catalogs, stochastic models, dependent events

1. *Introduction*

Earthquake data may be regarded as the realization of stochastic processes. This approach is useful in describing earthquake occurrence in a given region, where the mechanics of earthquakes are not necessarily fully understood, and inherent in assessing seismic hazard.

A sound analysis of the pattern of earthquake occurrence requires either complete data sets, or methods designed for incomplete data. The first alternative usually leads to using the recent observations only, as the degree of completeness of the data is closely related to the data acquisition methods during the span of the catalog. Also, earthquake data, as all observations, are subject to many kinds of errors. The concept of apparent earthquake magnitude was first introduced by *Tinti* and *Mulargia* (1985a,b) to account for the uncertainty of observed magnitude values.

This study aims at investigating some features of Finnish earthquake data. A search for homogeneous subcatalogs is performed. It utilizes administrative information and remains to a large extent descriptive. A study of suitable stochastic models to

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describe the sequence of occurrence times and strengths of earthquakes is undertaken. The ultimate aim is that relevant ideas about the mechanism of earthquakes may be produced by this type of analysis. An abundant literature exists for interplate seismic events, while the present data are intraplate observations. Owing to low seismicity levels, the standard hypotheses might not be obvious here.

2. *Earthquake data*

The data were taken from the computerized file of Finnish earthquakes, updated at the Institute of Seismology, University of Helsinki. Explosion removal in event analysis is based on the site and origin time of events, and the spectral content. The most recent published version of this catalog gives the events available in 1610-1990 (*Mäntyniemi* and *Ahjos*, 1990). In the present study, individual ultramicroearthquakes were omitted as these were recorded only locally (cf. *Saari*, 1991). With the observations for the years 1991-1994 added, the data set comprises a total of 536 entries.

The earthquake size indicator used was the local magnitude m_L. The magnitude values associated with the entries of the catalog were homogenized to obtain a more meaningful investigation of the data: the macroseismic magnitude according to *Wahlström* and *Ahjos* (1984) was computed for the historical observations. It is compatible with the local magnitude basically estimated for the instrumental data. Details of magnitude determination during the last four years of the time interval under study may be found in *Uski* and *Pelkonen* (1992,1993) and *Uski et al.* (1994, 1995).

3. *Features of the data*

3.1 *Description of the catalog*

Fig. 1 shows the apparent magnitudes and sites of the events available. Although the total span of the catalog is 385 years, the data do not cover this period uniformly. Prior to the 1730s, only four observations are available, and major gaps in reporting can be noted later as well, particularly between 1805-1818, 1865-1878, and 1942-1950. The apparent magnitude range is fairly narrow, 2.2-4.5 for most of the catalog; it is only since the 1970s that magnitudes below 2 have been determined. The number of events of $m_L \geq 4$ is 11. Disregarding magnitude uncertainties, which may be quite large for historical data, a concentration of the strongest earthquakes seems to have occurred between 1882-1931. Epicenter maps can be found e.g. in *Mäntyniemi* and *Ahjos* (1990).

The percentage of events in different magnitude classes at different times is shown in more detail in Fig. 2. The area of each class corresponds to its absolute number of events. There is an increase in the number of reported events if they are compared to the preceding time interval during the latter half of both the 1700s and the

1800s, and during both halves of the 1900s. Almost one half of the events available are 20th century earthquakes of apparent magnitude 2-2.9.

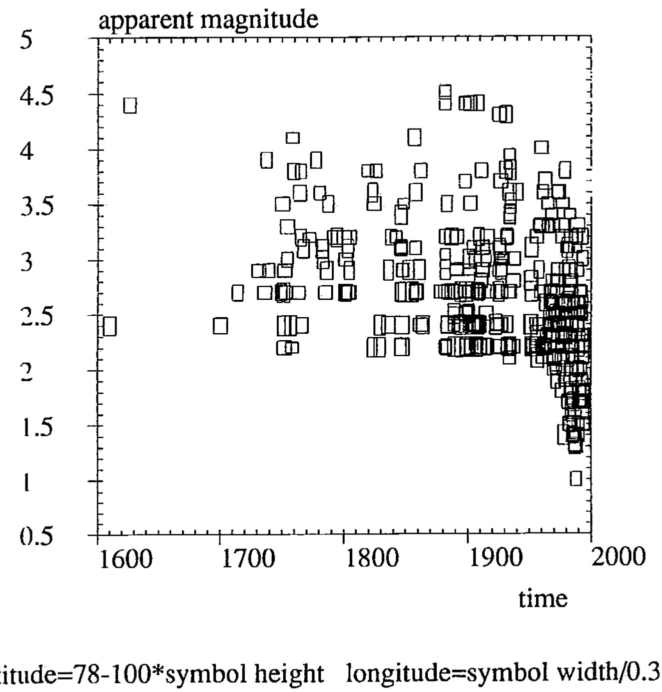

Fig. 1. Sites and apparent magnitudes of the earthquake data available. E.g., the symbol height of the 1610 event corresponds to about 0.17 units on the y-axis, thus giving 78-(0.17*100)=61°*N* as latitude, and the approximate longitude in °*E* is obtained as 10.2/0.38 ≈ 26.8 from the symbol width. Location uncertainties are not illustrated.

The number of reported events in a time window of 10 years in moving increments of 2 years is displayed in Fig. 3. The improvement of event detection with time is dominant, although an increase in the number of records may have been followed by a period of scarce or non-existent data. The mid-1880s and mid-1960s constitute clear boundaries of a stepwise larger increase in the number of observations.

The upper part of Fig. 3 denotes times of more systematic macroseismic work. The continuous line corresponds to those years The Geographical Society of Finland was responsible for the collection of felt observations with the help of questionnaires. Thus the interval 1882-1942 is relatively clear from an administrative point of view, although this activity was somewhat semi-official prior to 1891 (cf. *Mäntyniemi*, 1996). Political circumstances sometimes diminished the resources available, and the longest gaps in the reporting of events in this interval are between 1918-22 and 1939-42, i.e. they coincide with wars. The broken line corresponds to later macroseismic work, which is administratively more mixed. The earliest post-war events available are from

1951 but only from one site; by 1956-57 the epicenter distribution becomes more versatile. During 1956-1965 macroseismic data were still of major value, as the seismograph network was gradually improved.

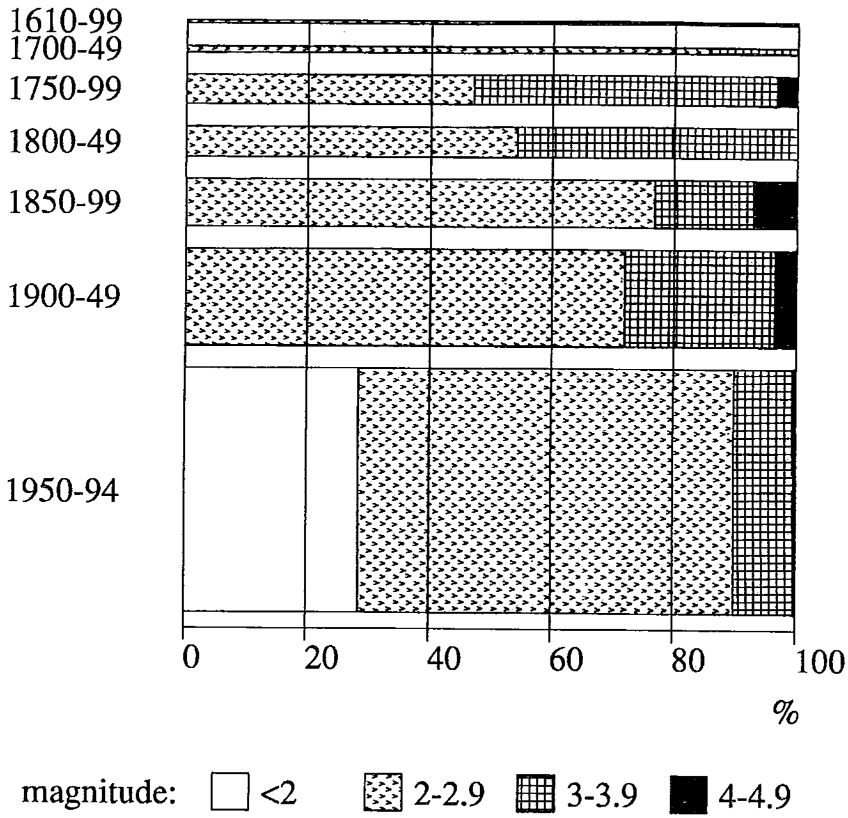

Fig. 2. The percentage of events in different magnitude classes at different times. The areas are proportional to the absolute number of events available.

Fig. 4 illustrates the numbers of observed events and seismic stations of the national network in 1950-1994. A station refers to a site with a one- or three-component seismograph in operation for at least six months during the respective calendar year; more detailed instrumental information has been excluded here (cf. *Teikari* and *Suvilinna*, 1980). The increasing trend in the number of events reported since the mid-1960s may reasonably be attributed to the installation of new seismograph stations. During the 60s and 70s events of $m_L \geq 2.2$ dominate, while the 1980s display an increase in the reporting of smaller events.

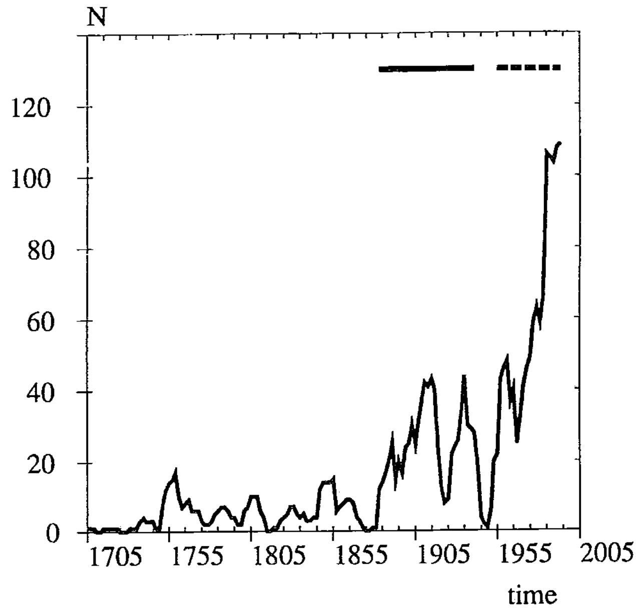

Fig. 3. Number N of reported events in a time window of 10 years in increments of 2 years. The full and broken thick horizontal lines denote times of more systematic macroseismic work.

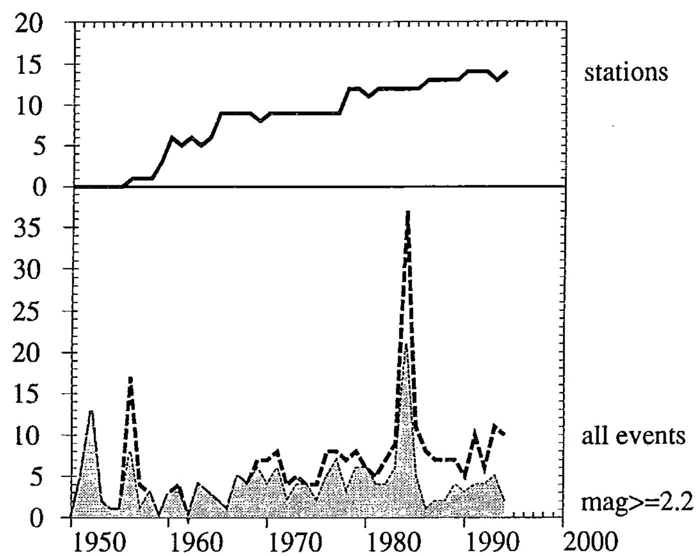

Fig. 4. Number of observed events and seismic stations in 1950-1994. The thick broken line corresponds to the total number of observations each year, and the shaded area to events of magnitude ≥2.2.

3.2 *On the identification of dependent events*

Dependent events, i.e. fore- and predominantly aftershocks, occur temporally and spatially close to the main event which is by definition larger than them. Appropriate time-space windows can be applied to the data to filter these earthquakes, if needed. The sizes of the windows depend on the respective catalog, as the constants c_i, i=1,...,4, in relationships of the type

$$\log T = c_1 + c_2 M \quad (1)$$

$$\log L = c_3 + c_4 M \quad (2)$$

are derived from the data (e.g., *Gardner* and *Knopoff*, 1974; *Console et al.*, 1979). Where, T denotes the duration of the aftershock sequence in days, L is the length or radius of the aftershock zone, and M denotes the earthquake magnitude. Eqs. (1) and (2) imply a linear increase of the logarithm of the duration and size of the aftershock sequence with the magnitude of the main event. Here, the paucity of the data does not allow a proper evaluation of the constants.

The output of a simple experiment on aftershock identification is presented in Table 1. Time windows of different lengths were applied to a data set extending from July 1, 1957 to June 30, 1994. The space window used was equal to 0.7 degrees in diameter. The data were first scanned to find earthquake clusters, and each time window then applied to the largest shock of a cluster, in an attempt to capture as many events as possible inside the window. The first two columns show an increase in the the proportion of dependent events with a longer time window. When the time window is equal to 15 days (360 hours), about 16% of the events available become classified as dependent (cf. Section 3.4.2). Larger proportions are reported in the literature: e.g. *Gardner* and *Knopoff* (1974) remove about two thirds and *Tinti* and *Mulargia* (1985c) about half of their catalogs.

Space windows between 0.3-0.9 degrees in diameter were tried out, but the different values did not have a strong influence on the output. A large proportion of the temporal clusters of events seem to be fairly local. This is reasonable considering the low magnitudes of the events available, i.e. a weak shock does not trigger activity at remote distances.

Table 2 is a list of the earthquake occurrences within one day during the past few decades which were not related to swarm-type patterns. They can be regarded as a main shock and one aftershock, or one foreshock and a main shock type of events, respectively. The ones in the Bothnian Bay (numbers 3 and 7), at least, might be called double shocks, as in these cases two events occurred in less than one minute. The apparent magnitudes of the main events vary between 2.4-3.8 and those of the accompanying events between 2.0-3.0. Thus, occurrences of this kind do not appear to be restricted in the magnitude range available.

Table 1. An example of aftershock identification with different time windows. The data cover the interval July 1, 1957 - June 30, 1994, and are estimated to be complete above magnitude $m_L \geq 2.2$. The space window is 0.7 degrees in diameter.

T	#	%	λ	σ^2	χ^2	df	P-value
0	0	0	4.03	8.46	2.67	3	0.45
3	16	6.4	3.76	6.13	0.72	3	0.87
6	22	8.8	3.73	5.66	0.61	3	0.89
12	23	9.2	3.70	5.40	0.52	3	0.91
24	23	9.2	3.70	5.40	0.52	3	0.91
48	27	10.8	3.62	4.51	0.31	3	0.96
72	29	11.7	3.62	4.51	0.31	3	0.96
120	30	12.1	3.59	4.13	0.27	3	0.97
132	32	12.9	3.57	3.81	0.23	3	0.97
168	33	13.3	3.51	3.38	0.19	2	0.91
240	34	13.7	3.51	3.38	0.19	2	0.91
336	39	15.7	3.46	3.38	0.80	3	0.85
360	40	16.1	3.46	3.38	0.80	3	0.85

T: length of the time window in hours
#: number of events defined as dependent
%: proportion of identified dependent events among the 249 of the sample
λ: estimated mean of the Poisson distribution
σ^2: estimated variance of the Poisson distribution
χ^2: value of the chi-square test statistic in fitting the Poisson distribution
df: degrees of freedom

Table 2. Two-event occurrences of the last few decades not related to swarms.

No.	Year	Date	Time hh:mm:ss	Lat. °N	Long. °E	m_L	Region
1	1973	Dec 10	20:03:50	66.6	25.9	3.6	Rovaniemi
			20:07:56	66.6	25.7	2.9	
2	1977	Jun 1	10:38:48	65.8	30.0	3.2	Kuusamo
			12:16:39	65.9	29.8	2.5	
3	1978	Jul 4	16:49:24	63.7	22.0	2.3	Bothnian Bay
			16:49:30	63.7	22.0	2.6	
4	1979	Feb 17	17:31:22	63.1	23.9	3.8	Lappajärvi
			17:40:58	63.1	23.9	2.6	
5	1981	Jun 22	18:53:18	59.8	22.4	3.1	Huittinen
			19:27:38	59.5	22.7	2.6	
6	1990	Feb 6	22:33:19	63.1	22.2	2.0	Vöyri
			22:55:43	63.2	22.3	2.4	
7	1993	Nov 11	23:44:23	64.2	23.0	3.2	Bothnian Bay
			23:44:31	64.3	22.8	3.0	

3.3 *On the thresholds of completeness*

The minimum magnitude threshold for complete reporting, m_c, was estimated for some subcatalogs in an attempt to check on the internal consistency of the data. Fig. 5 is a cusum chart, a plot of the cumulative number of events as a function of the magnitude, of the data from 1967-1994. For larger magnitudes, the plot was fitted with a straight line, and m_c determined as the level at which the data fall below it. This relies on the validity of the empirical linear magnitude-frequency distribution according to *Gutenberg* and *Richter* (1949). To account for the magnitude uncertainty, the earthquakes were also grouped in magnitude classes of different sizes (0.2-0.4) and boundaries. The threshold magnitude of completeness was estimated to m_c=2.1±0.1 for 1967-1994, and for a longer subcatalog, covering the data from 1957-1994, to m_c=2.2±0.1.

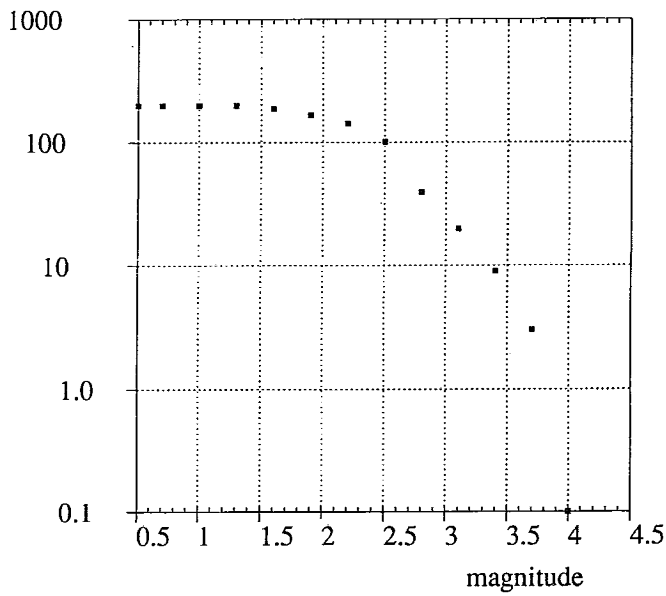

Fig. 5. A cusum chart of the data from 1967-1994.

As a simple graphical check, the cusum chart has certain limitations. The selection of the time interval is crucial, as the plot is based on magnitude-frequency data only. Long intervals may comprise heterogeneous subparts, while brief intervals may not possess enough observations. Also, the cumulative frequency is not that sensitive to lost data, so events above the determined threshold magnitude may still be missing. The cusum chart is therefore not considered very appropriate, especially if it is not based on all possible information about the data collection at different times.

3.4 *Stochastic models for earthquake data*

Stochastic models to describe the sequence of occurrence times and strengths of earthquakes are presented both for data sets of the largest events and for a subcatalog regarded as complete.

3.4.1 Models for the largest events

In this approach, the largest events for equal time periods were used. It has the advantage that it depends only on the size of the largest earthquake in each time interval, which is assumed to reduce sensitivity to data incompleteness. It must be noted, however, that the largest earthquake in each time interval might not have been correctly reported. This applies particularly to historical data.

Time intervals of different lengths were tried out, and the chi-square (χ^2-) test was used in comparing the actual data with a given distribution. In this test, consecutive classes are combined, if necessary, to guarantee that the expected frequency of a class is equal to or greater than 5 by default. The level of significance of the test employed was chosen at 5% and 1%, and the SURVO 84C system (*Mustonen*, 1992) was used.

Fig. 6 is a histogram for the maximum events for 1.5-year intervals between Feb 1, 1956 and Jan 31, 1995. (Since no earthquakes occurred during January 1995, this month was included in order to have one more event in the sample.) Different stochastic models were fitted to these data, including the gamma, the (two-parameter) lognormal, the normal, and the Weibull distributions. The probability density functions (pdf's) of these distributions are given as follows (e.g., *Johnson* and *Katz*, 1970):
for the gamma distribution

$$f(x;\mathrm{p,r})=\frac{x^{\mathrm{p}-1}\exp(-x/\mathrm{r})}{\mathrm{r}^{\mathrm{p}}\,\Gamma(\mathrm{p}),} \qquad (3)$$

where x,p,r > 0 and Γ(p) is the gamma function; and for the lognormal distribution with parameters (μ,σ^2)

$$f(x;\mu,\sigma^2)=\frac{1}{\sigma x\sqrt{2\pi}}\exp\frac{-(\log x-\mu)^2}{2\sigma^2} \qquad (4)$$

The pdf of the common normal distribution with parameters (μ,σ^2) is

$$f(x;\mu,\sigma^2)=\frac{1}{\sqrt{\sigma^2}\sqrt{2\pi}}\exp\frac{-(x-\mu)^2}{2\sigma^2} \qquad (5)$$

and that of the Weibull distribution can be written as

$$f(x;\mathrm{a,b})=\mathrm{ab}\,x^{\mathrm{b}-1}\exp\left[-(\mathrm{a}x)^{\mathrm{b}}\right], \qquad (6)$$

where $x \geq 0$, and a and b are parameters with a,b>0.

All distributions (3)-(6) belong to the exponential family (e.g., Lehmann, 1991), and there are certain relations among them. E.g., if a random variable X is lognormal, then $Y=\log X$ is normal. With p=1 in Eq. (3) and b=1 in Eq. (6), these two relations are the exponential distribution. The cumulative distribution functions of models (3), (4), and (6) can be found e.g. in *Utsu* (1984).

The fitted distributions are shown in Figs. 6 a-d together with the evaluated parameters. They were computed from the data by the method of maximum likelihood using the polytope algorithm (*Nelder* and *Mead*, 1965; also in *Walsh*, 1975, p. 81-84) when maximizing the likelihood function. For the gamma distribution (Fig. 6a), the estimated parameters are p=66.34±20.35 and r=0.049±0.015, with the correlation coefficient r(p,r)=-0.997. This fit yields the test statistic χ^2=0.42, with one degree of freedom, and a respective P-value P=0.52. The fit of the lognormal distribution (Fig. 6b) with the estimated mean and variance (1.16,0.015) gives χ^2=0.47 and P=0.50 while fitting the N(3.23,0.15) distribution for the test gives the following statistical values: χ^2=0.38, and P=0.54 (Fig. 6c). The Weibull distribution was also fitted to these data: the parameters had values equal to a=3.40±0.08 and b=9.29±1.42, with a correlation coefficient r(a,b)=0.33. The test statistics is equal to χ^2=0.18, and the P-value is P=0.67 (Fig. 6d). In all these cases, the number of degrees of freedom is equal to one. The result of the test does not imply that the hypothesis, that these data follow the given distributions, should be rejected at the 5% or 1% significance levels.

Owing to the small number of degrees of freedom, however, the output is affected by the way the events were classified. In this histogram, equal classes of 0.3 magnitude units were used. This is well justified because of magnitude errors. In the two other choices of class boundaries, some of the frequencies of consecutive magnitude classes showed too large differences for a straightforward interpretation of the pattern. This behaviour was also demonstrated with the help of simulations. Synthetic normal and lognormal observations were created, and distributions were fitted to various classifications of these data. When the sample size is close to that of the real data, the value of the test statistics may differ by up to an order of magnitude according to the classification of a sample, even if observational errors are not taken into account. The simulated magnitude error did not have to be very large for some classifications of the data not to pass the test at both levels of significance. However, some data created with a fairly large standard error of the added perturbance were able to pass the test well.

For comparison, the four distributions in Fig. 6 were also fitted to histograms of the maximum events for different choices of one-year and 1.5-year intervals from subcatalogs covering the past 30-40 years. The advantage of a longer subcatalog and a one-year interval is that the number of degrees of freedom is often bigger than previously, but the problem of missing data is soon encountered. A longer time span was utilized by selecting the largest event for each decade between 1714-1993. For these data, the class width was increased to 0.4 magnitude units because of the uncertainty of the historical data; an even larger value would be reasonable, but the scarcity of the data makes this not feasible. The output was similar to that for the previous tests.

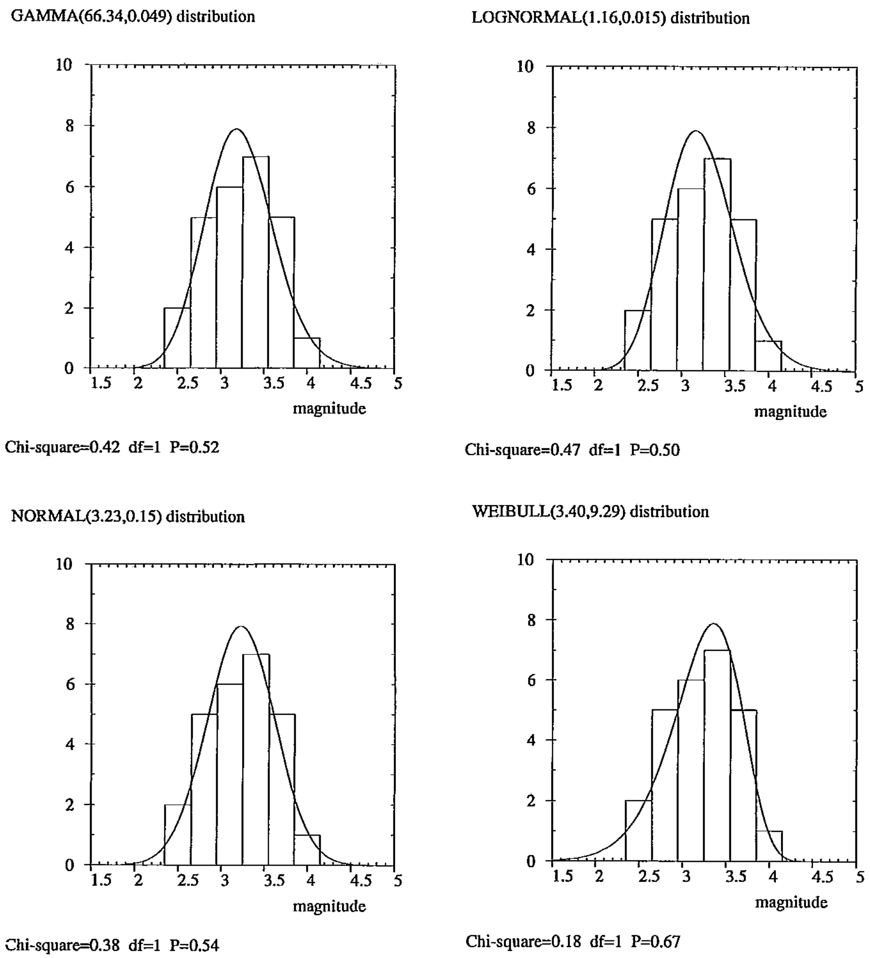

Fig. 6. The histogram for the maximum events for 1.5-year intervals between Feb 1, 1956 and Jan 31, 1995 and the fit of the a) gamma b) lognormal c) normal, and d) Weibull distributions with the respective χ^2- and P-value, and degrees of freedom (df). The evaluated distribution parameters are shown.

3.4.2 Models for earthquake occurrence

Another problem is the appropriate model of earthquake occurrence. It is not uncommon to suppose that earthquake events are Poisson-distributed (see, for example, *Madhava Rao* and *Kaila*, 1986, for a brief review of the literature). The assumption of earthquake occurrence following a Poisson distribution requires the identification and removal of dependent events, as the model relies on the conditions that the probability of an event remains constant in time and the probability of having two contemporary events is zero (e.g., *Lomnitz*, 1974). The probability function of the Poisson distribution is

$$P(X = k) = \frac{\lambda^k \exp(-\lambda)}{k!} \tag{7}$$

where $k = 0,1,2,...$ and $\lambda > 0$.

If the occurrence of events follows the Poisson distribution, then the intervals between events are exponentially distributed, whereas the converse is not necessarily true (e.g., *Udías* and *Rice*, 1975).

Fig. 7 displays the histogram of the data set of 1957-1994, regarded as complete above the previously estimated threshold magnitude. The histogram was drawn for the number of intervals with the given number of shocks versus the number of shocks in one year. A year is a period of 12 successive months starting on July 1, 1957. Dependent events were filtered using a time window of 5.5 days (132 hours; cf. Table 1). The Poisson distribution with the parameter $\lambda = 3.57 \pm 1.95$ has been fitted to these data (Fig. 7a). This yields a test statistic equal to $\chi^2 = 0.23$ with three degrees of freedom, and a *P*-value equal to $P = 0.97$, while the variance is equal to $\sigma^2 = 3.81$, thus it is not that far from the estimated mean. Fig. 7b shows the same data and a fitted binomial (37,0.096) distribution. In this case, the test statistic is $\chi^2 = 0.13$ with three degrees of freedom, and the *P*-value $P = 0.99$.

The probability function of the binomial distribution is given as

$$P(X = k) = \binom{N}{k} p^k (1-p)^{N-k} \tag{8}$$

where $k = 0,1,2,...,N$ and $0 \le p \le 1$.

It can be shown that Eq. (8) approaches Eq. (7) when the total number of events, N, increases and the probability p decreases provided that N^*p remains equal to a constant λ. This then applies to $k = 0,1,2,...$ and to all $\lambda > 0$ (e.g., *Dudewicz* and *Mishra*, 1988, p. 95). Here N=37 and p=0.0964, thus giving $N^*p = 3.5668 \approx 3.57$. The variance is now $N^*p^*(1-p) \approx 3.22$.

If the Poisson distribution is fitted to the data not filtered for dependent events, the test statistic equal to χ^2=2.67 and a *P*-value equal to P=0.45 are obtained with three degrees of freedom. The mean is equal to λ=4.03±2.91 and the variance is σ^2=8.46 (Table 1). Thus the null hypothesis of the data following a Poisson distribution is not rejected at the chosen significance levels, but the ratio of the variance to the mean exceeds unity, and the process may be said to be over-dispersed relative to the Poisson distribution (*Vere-Jones*, 1970). This is attributed to hidden heterogeneity, i.e., variation in the expectation of an event, which increases the variance of the distribution relative to the mean. As shown in Fig. 4, the annual number of events may vary due to e.g. swarms, and in such occurrences one event may be understood to increase the probability of another. The longer the time window used to identify dependent events, the smaller the variance (cf. Table 1): for time windows which are long enough the process becomes under-dispersed. Although the numerical values of testing as displayed in Table 1 varied from one data sample to another, those tests showed a similar behaviour.

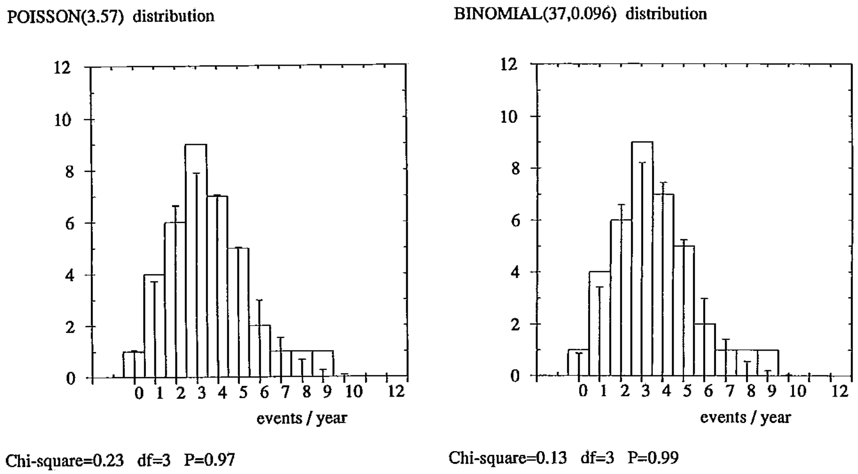

Fig. 7. A histogram of data from 1957-1994 regarded as complete above magnitude ≥2.2, drawn for the number of intervals with the given number of shocks versus the number of events in one year, and the fit of the a) Poisson and b) binomial distributions with the respective χ^2- and P-value, and degrees of freedom (df). The evaluated distribution parameters are shown.

4. *Discussion*

A general look was taken at the data available. Some of the common obstacles of earthquake data were observed: incompleteness due to wars, for instance, and other kinds of heterogeneity. Some insight into the consistency of the catalog was acquired with the help of graphical checks as well as administrative information.

Different distributions were fitted to data sets of the largest events for equal time intervals. The lengths of these time intervals were one year, 1.5 years, and one decade; the use of a much larger choice of intervals is not possible owing to the scarcity of the data. The results obtained for the different data sets were similar to each other; however, the P-values obtained for the ten-year maximum events were somewhat lower, though acceptable, than for the other data. This may be attributed to the more doubtful reporting of the historical events.

One feature of these data sets for the two shorter time intervals is that they have an apparent magnitude range of almost the same width as that of all complete observations. This tells us something about the rare occurrence of events that belong to the upper part of the magnitude range available during the years investigated. The proportion of events of magnitudes above 3.4 is bigger among the maximum events of decades than in the other samples.

Various distributions were accepted as possible models to describe the data sets of the largest events. These include the gamma, the two-parameter lognormal, the normal, and the Weibull distributions, all of which belong to the exponential family. No case for strong preference for any of these distributions can be made. The values of the test statistics, and the *P*-value, depend also on the way the data are classified: one choice of magnitude classes may give the most successful output for one model, while another choice indicates the superiority of a different one. The sample displayed in Fig. 6 is somewhat skewed, and thus especially the Weibull distribution seems to hold some advantage over the other models; its applicability may be attributed to the notable flexibility of this distribution. However, this does not hold true for all the samples tested.

The four distributions of Fig. 6 have previously been used in seismology usually in recurrence interval studies to describe the time interval between successive events. Examples can be found in *Udías* and *Rice* (1975), *Utsu* (1984), and *Rikitake* (1991), among others. The gamma model was applied to a series of occurrence times of Californian microearthquakes to account for the temporal clustering of events (*Udías* and *Rice*, 1975), while *Utsu* (1984) used the gamma, exponential, lognormal, and Weibull distributions as renewal models for different sets of large events in Japan. *Rikitake* (1991) applied the lognormal and Weibull models to a set of recurrence intervals of earthquakes that caused damage in Edo (now Tokyo) and concludes, also on the basis of earlier studies, that these models fit most of the existing recurrence data from a number of subduction zones fairly well.

Subcatalogs regarded as complete were also tested against different stochastic models. With these data, the threshold of completeness is crucial when designing samples, in addition to the ever-present obstacle of magnitude uncertainties.

A study of the problems encountered in fitting distributions to complete earthquake data, with special reference to choosing an appropriate counting interval, has been undertaken by *Papadopoulos* (1993). In this paper, it is proposed that the counting interval should be non-arbitrarily chosen and taken to be equal to the mean return period of earthquakes with magnitude equal to or greater than the lower magnitude of the sample. Here the results have been presented for a counting interval of 12 months (Fig. 7), which does not violate this recommendation. If the counting interval is increased, the number of intervals soon becomes quite small while decreasing it means getting more intervals with zero observations. The Poisson distribution allows for a different number of zero observations according to the value of the mean, but one way to deal with the zero-class could be the use of the positive Poisson distribution whose probability function is given as

$$P(X=k)=\frac{\lambda^k \exp(-\lambda)}{k![1-\exp(-\lambda)]} \tag{9}$$

where k=1,2,3,..., (e.g., *Johnson* and *Katz*, 1969, p. 104), that is, the class of zero events per time interval is omitted as non-informative.

For comparison, *Knopoff* (1964) used a time window of ten days for the southern California earthquake data, and *Madhava Rao* and *Kaila* (1986) 30 days for the data from the Alpide-Himalayan belt. A one-year period was used by *Schenková* (1973) for shallow European earthquakes.

In testing the actual data for a Poisson distribution, the ratio of the variance to its mean was monitored (Table 1). The testing procedure employed - the common χ^2-test - did not imply the rejection of these data following the Poisson distribution even when the dependent events were included in the samples tested. However, the ratio exceeded unity in these cases. The increased variance relative to the mean may be described by a negative binomial distribution (*Williamson* and *Bretherton*, 1963). Applications of this distribution to earthquake data have been reported by *Schenková* (1973) and *Madhava Rao* and *Kaila* (1986). With the present data, attempts to model the temporal variations with the help of the negative binomial fail, whereas the binomial distribution may be used parallel to the Poisson distribution.

The total time span of the data tested is one factor affecting the sample size. It is generally assumed that a longer complete subcatalog gives a smaller error of estimation than a shorter one. This holds true for the present data, as repeating the experiment shown in Table 1 to a shorter subcatalog, e.g. 1962-1994, follows the general features in output but gives larger χ^2-values. However, here the data available do not allow for much experimenting with subcatalogs of different lengths, taking into account both the completeness and the number of degrees of freedom of a sample. It will be interesting to see if future data will in any way alter the conlusions obtained here. The time spans covered by the complete subcatalogs available are, of course, negligibly brief in terms of the geological time scale involved in the seismicity of a region.

An appropriate choice of the boundaries of the region from which data are investigated is a major issue, and it is well-recognized that national catalogs pose severe problems in this respect. However, from the data collection point of view, national data may be consistent in ways observations from contiguous nations are not.

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