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The seismic potential assessment for some seismogenic sources in the central northern Greece and its adjacent areas based on the maximum credible magnitude

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Abstract: *The identification and characterization of seismogenic sources are essential parts of seismic hazard evaluation because they enable forecasts to be made of locations, recurrence intervals and sizes of future large earthquakes. A difficulty is implicated in such studies because usually, the average repeat periods of large earthquakes on the seismogenic sources, are larger than the period covered by the data files used. In order to overcome such inconsistencies a procedure is applied, where parameters are estimated by the maximum likelihood method, by applying the Bayesian formalism and any additional geological or geophysical information (as well as all kinds of uncertainties) can be easily incorporated. The obtained parameters are the maximum credible magnitude* m_{max}*, the seismicity rate,* $\hat{\lambda}$*, and the* $\hat{\beta}$ *parameter of the Gutenberg-Richter relationship. This procedure is capable of giving a realistic assessment of seismic hazard in areas of both low and/or high seismicity, including the cases where the catalogues are incomplete. Central Northern Greece and its surroundings is an area where large and catastrophic earthquakes occurred with high average repeat periods (e.g. source 35- see Fig.1b) or even worst there was no information concerned the seismicity of the source (e.g. source 36- see Fig. 1b). Bearing these in mind an effort is made to assess the seismic potential of the seismogenic sources of Northern Greece and its adjacent area based on the maximum credible magnitude* m_{max}*. Moreover their earthquake hazard evaluation, in terms of the probability of exceedance of a specified value of magnitude in T-years, is undertaken.*

Keywords: *Maximum Credible Magnitude, Bayesian Formalism, Seismogenic Sources, Seismic Potential, Central Northern Greece.*

INTRODUCTION

Although there is no a generally accepted method for estimating the value of the maximum credible magnitude $m_{\max}$, the first effort was made by Cornell and VanMarcke (1969) who proposed an approach for determining $m_{\max}$. Later Consentino *et al*. (1977) suggested a modified form of what Cornell and VanMarcke (1969) proposed. According to Reiter (1990) the estimate of the maximum credible magnitude is consistent with the geological estimate of the maximum magnitude calculated from the notional fault length.

The most common method for estimating the maximum credible magnitude $m_{\max}$ is the procedure given by Kijko and Graham (1998) and this applied in the present study. This procedure is based on relationships between the magnitude and some parameters deduced from faults or other tectonic features. Such relationships for various seismotectonic regions and/or special type of faults are derived (Smith, 1976; Wyss, 1979; Schwartz, *et al*., 1984; Wells and Coppersmith, 1994) among others.

In order to estimate the uncertainty in the determination of the earthquake magnitude Tinti and Mulargia (1985) instructed the notion of the "apparent" magnitude, which is equal to the "true" magnitude, disturbed by a random error ε. The necessity of the uncertainty estimation is obvious because we dealt, in the present study, with both historical and instrumental records. Another useful necessity is to model the distribution of the magnitude of the earthquakes, which can significantly reflect to the results of the estimation either of maximum credible magnitude or/and seismic hazard estimation.

The Bayesian approach, which simply allows accounting the influence of the uncertainties of the earthquakes magnitude, provides the most appropriate tool for manipulation the uncertainties above referred. The Bayes statistics takes into account the uncertainty in parameters by regarding them as random variables (Raiffa and Schlaifer, 1960). This rather simple straightforward procedure of Bayesian formalism often requires numerical integration (Pisarenko, *et al*., 1996).

In fact in seismogenic areas of the world a numerous methods and techniques have been tested including seismicity analysis, seismotectonics and geodetical measurements among others. The term seismic potential has been used in a non-standard way by several investigators, while various definitions or approaches were introduced by many authors for regions with different seismotectonic regimes.

In the procedure, we applied in the present work, the Bayesian formalism does not require numerical integration. Here where the uncertainties are present in both magnitude and other related parameters, we have applied the formalism of compound distributions (Kijko and Graham, 1998), which arise when the parameters of the distribution of a random variable are treated by themselves as random variables. The paper confines itself to the evaluation of the seismic potential for some seismogenic sources of Central Northern Greece based on the maximum credible magnitude, and consequently their seismic hazard assessment.

DATA USED

The examined seismogenic sources exist in an area which is located between latitudes 34.8°-35.6° N and longitudes 23.2°-26.2° E. This study is of course restricted in shallow (h≤60 Km) shocks, only. The map with the epicentres of the shallow shocks in Greece and the adjacent area compiled by Papazachos(1999) is demonstrated in Figure (1a), while the seismogenic sources in which the whole examined area is divided (Papaioannou and Papazachos, 2000) are depicted in Figure (1b).

Information of the seismicity of Greece exist since the 6th century BC based on the descriptions of the macroseismic observations made by ancient Greeks and Romans followed then by Byzantines.

There is a large number of earthquakes since 550 BC in the data bank of the Geophysical Laboratory of the University of Thessaloniki. Not all of them have the three basic properties (completeness, homogeneity and accuracy) which are required for reliable estimation of various seismic parameters. For this reason an update catalogue has been recently constructed (Papazachos *et al*., 2000) which has such properties.

In this catalogue for the instrumental period (after the year 1911) the errors in the epicentres are less than 20 km while the uncertainties in magnitudes are ±0.25 magnitudes units. The errors concerning the historical data (550 BC - 1910) are of the same order, mainly because these data are strong earthquakes and for each one a lot of macroseismic information are available. Thus for the historical earthquakes (Papazachos and Papazachou, 1997) the errors in the epicentre and in magnitudes are less than 30 km and 0.4 magnitude units, respectively.

Shallow Earthquakes

Time Period	Magnitudes
550 BC- 2000	M=8.0-8.3
1500 AD – 2000	M=7.3-7.9
1845 – 2000	M=6.5-7.2
1911 – 2000	M=5.5-6.4
1950 – 2000	M=5.0-5.4
1970 – 2000	M=4.5-4.9

BASIC THEORETICAL CONSIDERATIONS

Suppose that the magnitudes of earthquakes M_1, M_2, ... ,M_n occurred in a given time span T, can be considered as independent and random variables each with cumulative distribution function $F_M(m\backslash m_{max})$, where m belongs to the magnitudes interval [m_{min}, m_{max}]. The procedure (see for details in: Kijko and Graham, 1998) compares the equation from which we can derive the maximum observed magnitude m_{max}^{obs} and the maximum expected magnitude $\in(M_n\backslash T)$ within a given time period T. The following equations derived for the estimation of m_{max} (Kijko and Graham, 1998) is:

$$m_{max} = \in(M_n) + \int_{m_{min}}^{m_{max}} [F_M(m \backslash m_{max})]^n dm \quad (1)$$

The estimator of m_{max} is obtained if the expected $\in(M_n)$ maximum magnitude is substituted from the maximum magnitude m_{max}^{obs} already observed:

$$m_{max} = m_{max}^{obs} + \int_{m_{min}}^{m_{max}^{obs}} [F(m \backslash m_{max}^{obs})]^n dm \quad (2)$$

noticed here that since the value of the integral in equation (2) is never negative, then consequently the value of m_{max} is never less than m_{max}^{obs} . Assuming, that the number of events which may occur in given area during a unit time T, governed by the Poisson distribution with parameter λ, equation (2) converted to:

$$m_{max} = m_{max}^{obs} + \int_{m_{min}}^{m_{max}^{obs}} [F_M(m \backslash m_{max}^{obs})]^{\lambda T} dm \quad (3)$$

with variance:

$$var(m_{max}) \cong \left\{ \int_{m_{min}}^{m_{max}^{obs}} [F_M(m \backslash m_{max}^{obs})]^{\lambda T} dm \right\}^2 \quad (4)$$

The probability distribution function of Bayesian exponential-gamma distribution is equal to:

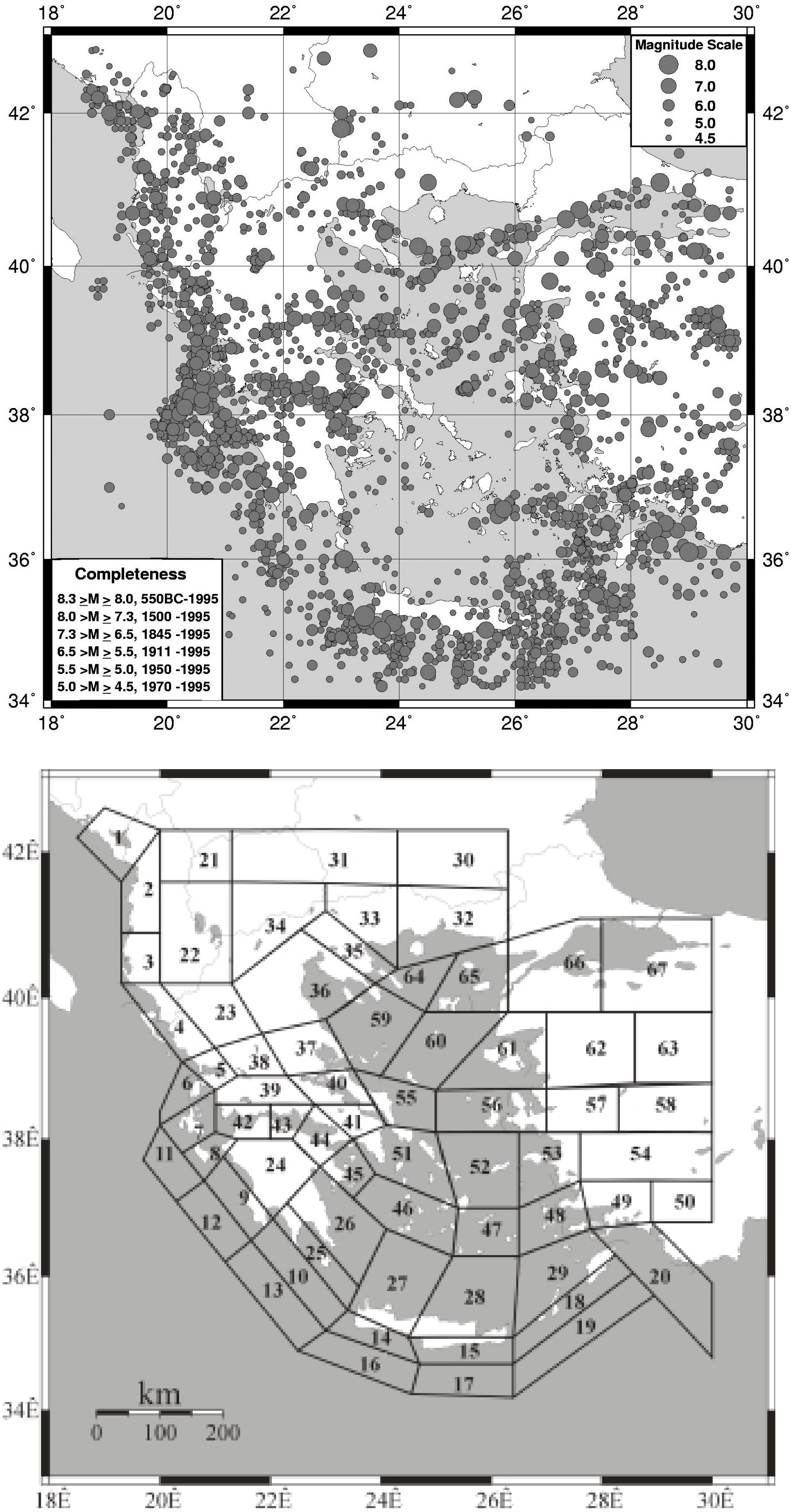

FIG. 1. The illustration of : a) the shallow earthquakes occurred in Greece and the adjacent areas (after Papazachos, 1999), and b) the seismogenic sources of Greece and its surrounding area (after Papaioannou and Papazachos, 2000).

$$f_M(m \backslash m_{max}) = \begin{cases} pqC_\beta\left[\dfrac{p}{p+m-m_{min}}\right]^{q+1} & \text{for } m_{min} \le m \le m_{max} \\ 0, & \text{for } m < m_{min},\ \ m \ge m_{max} \end{cases} \quad (5)$$

where C_β is a normalized coefficient, while p and q can be expressed through mean and variance of the β-value, and are defined as $p = \dfrac{\overline{\beta}}{(\sigma_\beta)^2}$ and $q = \left(\dfrac{\overline{\beta}}{\sigma_\beta}\right)^2$.

The Bayesian estimator, introduced by Kijko and Sellevoll (1989) is not a absolutely straightforward. By definition of equation (2) it requires the calculation of the integral:

$$\Delta = \int_{m_{min}}^{m_{max}^{obs}} \left[F_M\left(m \backslash m_{max}^{obs}\right)\right]^n = C_\beta^n \int_{m_{min}}^{m_{max}^{obs}} \left[1-\left(\frac{p}{p+m-m_{min}}\right)^q\right]^n dm \quad (6)$$

which only can be approximated. One of the simplest approximations can be obtained if we apply the Cramer's procedure in the derivation of asymptotic extreme distributions. Under this procedure and for large n the value of $\left[F_M\left(m \backslash m_{max}^{obs}\right)\right]^n$ is approximately equal to $\exp\left\{-n\left[1-F_M\left(m \backslash m_{max}^{obs}\right)\right]\right\}$ and therefore integral of equation (6) becomes:

$$\Delta = c_1 \int_{m_{min}}^{m_{max}^{obs}} \exp\left[-nC_\beta\left(\frac{p}{P+m-m_{min}}\right)^q\right] dm \quad (7)$$

where c_1=exp[-n(1-C_β)]. If we continue the calculations the following equation is obtained:

$$\Delta = \frac{pc_1}{q} \cdot \frac{1}{\delta - 1/q} \sum_{i=0}^{\infty} (-1)^i \frac{\delta^{i-1/q}\left[1-\left(\dfrac{p}{p+m_{max}^{obs}-m_{min}}\right)^{q^{i-1/q}}\right]}{(i-1/q)\, i!} \quad (8)$$

where δ=nC_β. This gives the Bayesian version of Kijko and Sellevoll (1989) estimator, which is the following:

$$m_{max} = m_{max}^{obs} + \Delta \quad (9)$$

with a variance:

$$\mathrm{var}(m_{max}) \cong \sigma_M^2 + \Delta^2 \quad (10)$$

The assessment of the maximum credible maximum m_{max}, as it follows from the equations above referred, needs the information of the seismic rate λ, and the β-value (alternatively b-value) of the frequency-magnitude relationship. The maximum likelihood procedure for the assessment of these two parameters is given through the following:

$$L(\lambda,\beta \backslash \mathbf{m}) = \prod_{i=0}^{n_s} L_I(\lambda,\beta \backslash \mathbf{m_I}) \quad (11)$$

This is the joint likelihood function, which is based, in both historical and instrumental data. The maximum likelihood estimates λ and β, are the values which maximize the likelihood function of equation (11). If then the equation (9) for m_{max} is applied we can obtain a set of equations determining the maximum likelihood estimates for λ, β and m_{max}. Kijko and Sellevoll (1989) proposed such equations, which are solved by an iterative procedure.

As it is referred the method allows the utilization of both historical (incomplete) and recorded (complete) data files. The complete part of the data can be divided into s subcatalogues each one complete for a specific time period and known magnitude mi. For each subcatalogue i, the m_i=(m_{ij}, σ_{Mij}) is the apparent magnitude with its uncertainty where j=1, 2,…,n_i denotes the number of earthquakes in each complete subcatalogue and i=1, 2, …,s.

SEISMIC POTENTIAL ASSESSMENT OF THE EXAMINED SEISMOGENIC SOURCES

Seismic zonation is one of the major problems in the very complex area of Greece. Papaioannou and Papazachos (2000) proposed a new regionalization of the shallow seismogenic sources which is based on historical and instrumental earthquake location data and on the stress field pattern as derived from reliable fault plane solutions. Thus, the whole Greece and the surrounding area was divided in 67 different seismogenic sources (Fig. 1b). In the present study we adopted the above seismic zonation. This study is focused on the seismogenic sources 30 (Philippoupolis), 31 (Kresna), 32 (Drama), 33 (Serres), 34 (Ptolemaida), 35 (Volvi), 36 (Kozani) and 64 (Athos) which covered almost the Central Northern Greece and its adjacent.

The determination of the maximum earthquake, for a known seismogenic source, allows the most direct application of geological and seismological data from both theoretical and practical point of view. The historical and/or instrumental files of the seismic activity which reflect the full potential of seismogenic sources (and/or faults), can be extended thousands of years back in order to obtain results of occurrence of maximum earthquake during the present and the past tectonic environment. An essential characteristic of the seismogenic sources is the estimation of the maximum credible magnitude m_{max}. This is based on the reasonable assessment of maximum earthquake potential with respect to the neighbouring current tectonic regime. Other related parameters which in our case are the source-specific mean seismic activity rate λ, and the well-known parameter β (b=βloge), which is the slope of the magnitude-frequency relationship. All the referred parameters are estimated by the application of the maximum likelihood method by applying the Bayesian formalism.

The reliable estimation of the seismic potential is essential for the seismic risk reduction in any earthquake-prone area. However, no single methodology has emerged for the seismic potential evaluation. A variety of approaches were proposed, which can distinguish in sto-

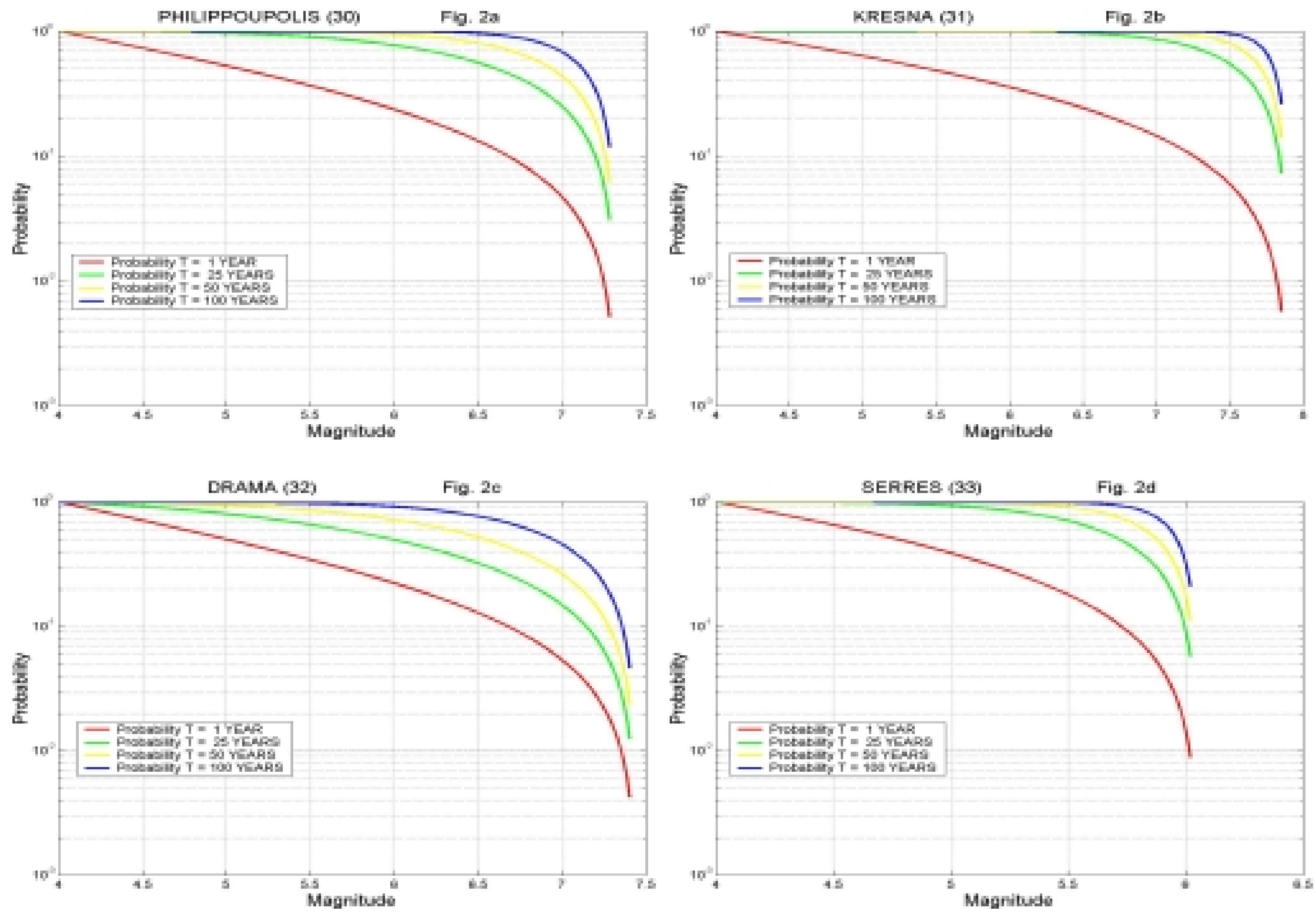

FIG. 2. The earthquake hazard curves which represent the probability of exceedance of a specified value of magnitude in 1, 25, 50 and 100 years for the seismogenic source of: a) Philippoupolis, b) Kresna, c) Drama and d) Serres. The number in the brackets at the top of the figure corresponds to the source number according to figure (1b).

chastic (Cornell, 1968; McGuire, 1978; Nishenko, 1989, 1991), deterministic (Slemmons, 1977; McCann *et al*., 1979; Wyss, 1979) or both (Wesnousky *et al*., 1984).

The maximum observed magnitude in the seismogenic source 30 (Philippoupolis) is 7.0 and occurred twice. In 622 AD (historical era) and in 1932 (instrumental part). The seismic potential of the source is estimated as m_{max}=7.32±0.36. The seismogenic source 31 (Kresna), is one of the most seismically active sources of the entire area, where large and catastrophic shocks occurred. Such an event is the one of 1904 with magnitude M=7.7 proceeded twenty minutes earlier by a foreshock of magnitude M=7.1. This is the largest recorded event in the source extracted from both historical and instrumental era. The size of this event is one of the most controversial (Miyamura, 1988; Matova *et al*., 1996; Shanov *et al*., 1999; Ambraseys, 2001)**.** The seismic potential is estimated as m_{max}=7.89±0.21. The maximum observed magnitude in the seismogenic source of Drama (32) is M=5.1 in 1939. The maximum credible magnitude is evaluated, by taking into account only the instrumental seismicity, equal to m_{max}=5.67±0.34. Considering this, we can lead to the conclusion that this source is of low seismicity. The Bayesian estimation of m_{max} allows the use of the historical events, which had occurred hundreds of years ago, because otherwise this information will be lost and we shall have wrong or erroneous picture of the seismicity of the source. In 1829, an earthquake of magnitude M=7.3 occurred. Based on this information the maximum credible magnitude which presents the seismic potential of the source is estimated as m_{max}=7.44±0.29. The data of this source are very limited and for this reason we apply the Monte Carlo procedure and a new synthetic catalogue of about 90 events is compiled. Based on this synthetic catalogue we re-assess the seismic potential and the obtained results show no much difference (m_{max}=7.53+0.43) from the maximum credible magnitude taken from the real data processing. The seismogenic source 33 (Serres) can be characterized of low seismicity. Three earthquakes of magnitude 5.5 occurred in 1905, 1936 and 1972. One can assume that the seismic potential of the source could be of that size. On the other hand, two earthquakes during the historical era, both of magnitude 6.0, occurred in 52 AD and in 1867 in the source. The seismic potential by considering also and these historical earthquakes is m_{max}=6.05±0.31. The seismogenic source of 34 (Ptolemaida), is one of the most interesting sources and due for further and much detailed study, because there are some of the most important plants which produced electricity power distributed in Northern Greece and the adjacent territories. These plants are supported by large dams, which are another kind of developed works in this source. The maximum observed earthquakes occurred in 1395 with magnitude 6.7 and in 1931 with the same magnitude. Another large earthquake can be considered the one occurred in 1812 with magnitude 6.5. Taken into account both historical and instrumental seismicity we found that the seismic potential of the source is $m_{\max}$=7.05±0.27. Another seismogenic source of special interest, is number 35 (Volvi), because the shocks occurred there, affected much the second largest city of Greece, Thessaloniki, which is one of the most industrial and high populated cities. From time to time large events occurred in the source like the one of 620 AD with magnitude 7.0, and also the large one of 1932 with magnitude 7.0. It is well known the event of June of 1978 with M=6.5 which caused heavy damages and about 43 deaths in the city of Thessaloniki and its vicinity area. The seismic potential here is equal to $m_{\max}$=7.07±0.30 as deduced from both kinds of data (historical and instrumental) which are available for this source. A study of active deformation and seismic potential only for the central part of the source was published by Voidomatis *et al*. (1990). For this reason the results are not comparable. A seismogenic source which is of importance because there are coal exploitation plants is Kozani (36), while the city of Kozani and the surroundings experienced a catastrophic earthquake in May of 1995 with magnitude M=6.6. A number of events greater or equal to M=6.0 occurred in the source since historical times like the one of 896 AD. The seismic potential of the source is estimated equal to $m_{\max}$=7.15±0.23. One of the largest earthquakes of the 20th century occurred in 1905 in the last examined seismogenic source Athos (64) with magnitude 7.5. Serious damages were referred to the surrounding area due to this event. A serious number of earthquakes (Papazachos and Papazachou, 1997) greater or equal to 6.0 experienced the source many times since historical epoch. The seismic potential is estimated, from all kind of the data, equal to $m_{\max}$=7.73±0.41. Based on the seismic history of the sources and on the obtained results we can conclude that the seismic potential is a bit higher than the maximum observed magnitude even if it belongs to the historical era or to the instrumental period. In order to check the reliability of the results two more estimators applied, for the assessment of the maximum credible magnitude. These are the estimator supplied by Gibowicz and Kijko (1994), and the one provided by Pisarenko *et al*. (1996). In Table (1), the three estimators for the evaluation of maximum credible magnitude $m_{\max}$, are presented, while Table (2) contains the resulting estimations of source-specific hazard parameters (except $m_{\max}$), which are the activity rate, $\hat{\lambda}$, of events above a specified magnitude and the doubly truncated exponential distribution of earthquakes magnitude with parameter $\hat{\beta}$ (where β=blog10), as they assessed from the Bayesian version of Kijko and Sellevoll (1989) estimator. An inspection in Table (2) reveals that the seismogenic sources Philippoupolis, Kresna, Drama and Serres have low activity rate $\hat{\lambda}$, with Drama having the lowest one. Regarding the b-values we can conclude that these are in good accordance with the ones found by Papaioannou and Papazachos (2000) by different procedure.

Table 1. The maximum credible magnitude, with the uncertainty of each examined seismogenic source of the Central Northern Greece and its surrounding area, as obtained by the application of the 3 estimators, a) Kijko-Sellevoll-Bayes, $m_{\max}^{K-S-B}$, b) Gibowicz-Kijko, $m_{\max}^{G-K}$, and c) Pisarenko *et al*., $m_{\max}^{P}$. The maximum observed magnitude $m_{\max}^{obs}$, in each source is also listed. Stars denote that $m_{\max}^{obs}$ occurred only in historical epoch.

Seismogenic source	$m_{\max}^{K-S-B}$	$m_{\max}^{G-K}$	$m_{\max}^{P}$	$m_{\max}^{obs}$
Philippoupolis (30)	7.32±0.36	7.38±0.42	7.64±0.40	7.0
Kresna (31)	7.89±0.21	8.13±0.48	8.20±0.41	7.7
Drama (32)*	7.44±0.29	7.52±0.33	7.80±0.37	7.3
Serres (33)*	6.05±0.31	6.08±0.35	6.20±0.38	6.0
Ptolemaida (34)	7.05±0.23	7.16±0.27	7.25±0.33	6.7
Volvi (35)	7.07±0.30	7.35±0.46	7.79±0.51	7.0
Kozani (36)	7.15±0.23	7.00±0.29	7.08±0.30	6.6
Athos (64)	7.73±0.41	7.88±0.49	8.01±0.55	7.5

Table 2. Source-specific seismic hazard parameters with their uncertainties. The parameter $m_{\max}$ is excluded from the present table. The results of the determination of the mean seismic activity rate $\hat{\lambda}$ and the $\hat{\beta}$-values, as they obtained by the application of the Kijko-Sellevoll-Bayes estimator, for the seismogenic sources examined in Central Northrn Greece.

Seismogenic source	$\hat{\lambda} \pm \sigma_{\lambda}$	$\hat{\beta} \pm \sigma_{\beta}$
Philippoupolis (30)	0.28 ± 0.05	1.90 ± 0.33
Kresna (31)	0.75 ± 0.09	1.63 ± 0.20
Drama (32)	0.12 ± 0.04	2.10 ± 0.42
Serres (33)	0.31 ± 0.06	2.15 ± 0.38
Ptolemaida (34)	1.09 ± 0.12	2.42 ± 0.24
Volvi (35)	1.28 ± 0.13	1.38 ± 0.14
Kozani (36)	2.52 ± 0.19	2.96 ± 0.21
Athos (64)	1.61 ± 0.14	2.52 ± 0.19

The earthquakes hazard is then accessed. The hazard of the eight seismogenic sources is expressed as the probability of exceedance of a given magnitude value in T (1, 25, 50 and 100) years. In Figure (2) the earthquake hazard, of the seismogenic sources of Philippoupolis,

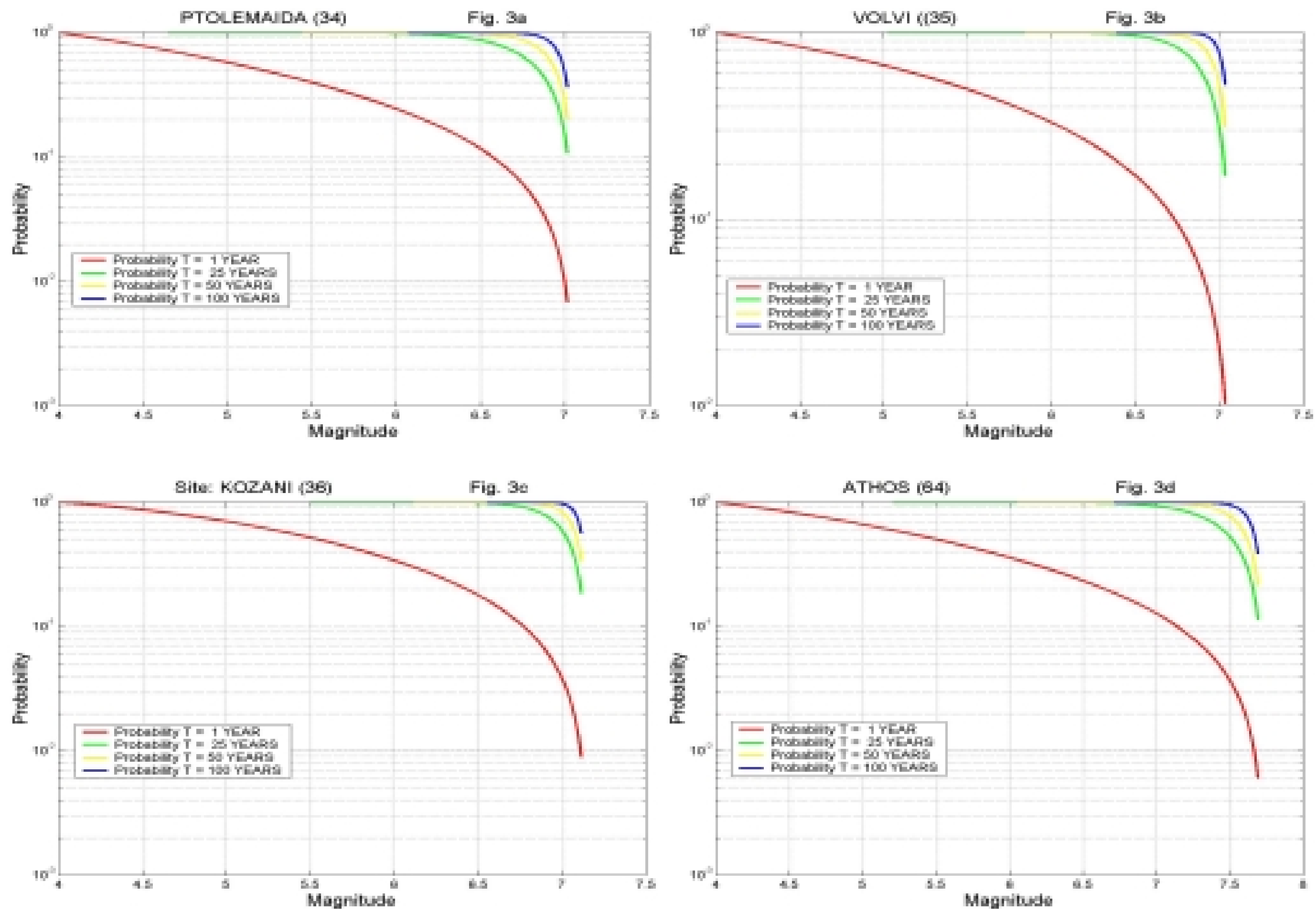

FIG. 3. The earthquake hazard curves which represent the probability of exceedance of a specified value of magnitude in 1, 25, 50 and 100 years for the seismogenic source of: a) Ptolemaida, b) Volvi, c) Kozani and d) Athos. The number in the brackets at the top of the figure corresponds to the source number according to figure (1b).

Kresna, Drama and Serres, is depicted. Figure (3) summarizes the earthquake hazard of the seismogenic sources of Ptolemaida, Volvi, Kozani and Athos.

DISCUSSION AND CONCLUSIONS

An effort is made to assess the seismic potential of the seismogenic sources of Central Northern Greece and its adjacent area based on the maximum credible magnitude m_{max} of earthquakes. This earthquake is based upon an evaluation of those processes, which are reasonably expected to be associated with an earthquake source (Kijko and Graham, 1998). It defines that the earthquake which is based on a reliable assessment of maximum earthquake potential in light of current tectonics (Reiter, 1990).

As it is referred, the maximum credible magnitudes estimated in the present study are comparable with the maximum ones ever recorded in each seismogenic source, although 2 exceptions to this generalization are observed. The most characteristic is the case of the source 36 (Kozani) where we never had any information for a magnitude greater of equal to 6.6. The large earthquake of 1995 was unexpected in the sense that it occurred in a region traditionally believed to be of very low seismic potential. The seismic potential suggests that, the release of a magnitude about 7.1 is possible. The return period of the maximum observed magnitude is 1450 years, while for the estimated maximum credible magnitude is 37255 years. This is a typical way of seismologists view that only the high seismicity areas are of interest. However the case of the event of Kozani shows that the low rate of instrumental seismicity is not the safe way to assess the seismic potential. The second case is the seismogenic source 34 (Ptolemaida) where the maximum observed magnitude is 6.7 (the return period of such magnitude is 1427 years), while the seismic potential is able for a magnitude equal to 7.0 (with return period 14797 years).

We observed that the first four seismogenic sources (Philippoupolis, Kresna, Drama and Serres) have a low seismic activity rate, while Drama has the lowest. On the other hand the maximum observed magnitude in this seismogenic source (32) is 7.3, while the seismic potential is 7.44. We also see that these four sources (an exception is Serres) have maximum observed magnitudes greater or equal to 7.0 and the seismic potential is of higher values, but they are within the limits of uncertainty. So we can conclude that in these sources large earthquakes occurred very rarely. The seismic potential are in quite good agreement with the maximum ever recorded (observed) magnitude.

We finally drew earthquake hazard curves which illustrated the probability of exceedance of a given magnitude in specific time period of 1, 25, 50 and 100 years. The curvature of the lines, which represents the hazard lines, are very characteristic of each seismogenic source. An interesting observation is that the seismogenic sources of Volvi shows the highest probability (0.387) for an earthquake of magnitude 6.5 during the time span of 25 years, while Kresna is the second most risky source with probability 0.215. But when we examine the probability for a magnitude 7.0 during a time period of 100 years an opposite condition is observed with Kresna coming first with probability 0.306 and then Volvi follows with probability 0.153. Many combinations can made by anyone who pay a special attention to these earthquake hazard curves of the seismogenic sources. We just underlined some of the most risky estimations. Thus we conclude that these curves are of special interest to any seismic hazard study.

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