RELIEF PROJECT

REVISION OF THE LOMG-TERM SEISMICITY OF THE GREATER MARMARA SEA REGION

PROGRESS REPORT
August 2004 – August 2005

N. Ambraseys, IC London

1). Reappraisal of location and surface magnitude of earthquakes in the Marmara Sea region

Table 1 shows the results of the assessment of locations and magnitudes for earthquakes in the Marmara Sea area for the period from 1500 onwards. For the period before 1500 the results of the assessment of these parameters by GSA, subcontractor of INGV, are not available.

Magnitude assessment Surface wave magnitudes M_{Si} of pre-1896 earthquakes were calculated from intensity data using the scaling formula

$$M_{Si} = -1.54 + 0.65(I_i) + 0.0029(r_i) + 2.14\log(r_i) + 0.32p \quad .... \quad (1)$$

which has been derived from 20th century earthquakes in the Middle East with recalculated surface-wave magnitude from the Prague formula (Ambraseys 1992). Intensities I_i, are on the Medvedev-Sponheuer-Karnik (MSK) scale, and distances r_i (in km) in the near-field are either site-source distances or distances from the closest point of the causative fault rupture. In the far-field r_i is the average radius of the isoseismal of intensity I_i which was calculated using the “kriging” technique (Olea 1999), a contouring method employed successfully for earthquakes in other parts of the Middle East

(Ambraseys Douglas 2004). In equation (1), which is valid for Ii < VIII, p is 0 for mean value and 1 for 84 percentile. Figure 1 shows equation (1) as a function of distance and intensity I_i.

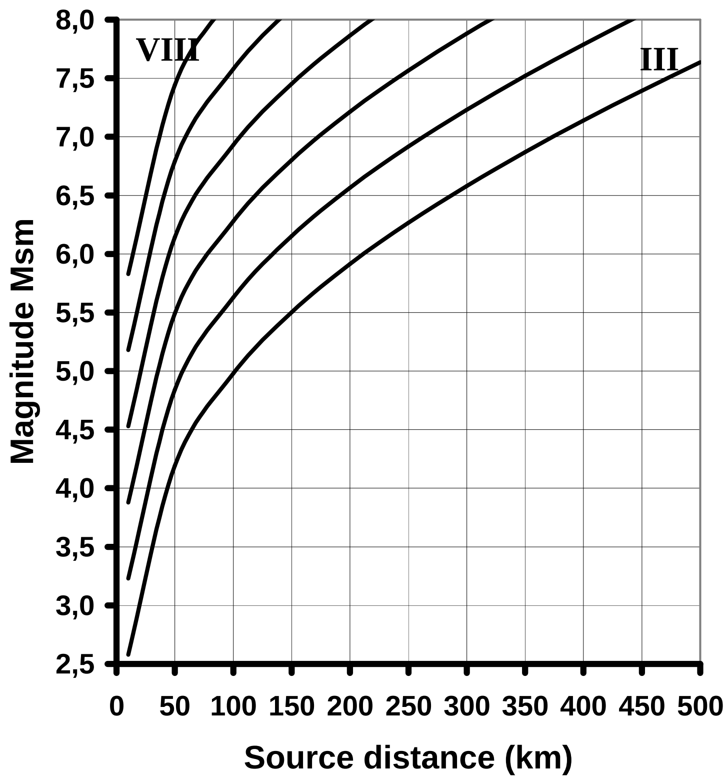

Figure 1. Plot of macroseismic magnitude M_{Sm} from equation (1) for intensities I_i = III to VIII (MSK) scale with source distance r_i (in km). In the near-field, r_i are site-source distances or site distances from the closest point of the causative fault rupture.

Errors in Ms

The usual procedure for the estimation of magnitude is that for a given historical earthquake, M_{sci} is calculated with equation (1) from as may site source distances or isoseismal radii as are available, using equation (1) and the average value of M_{sci} is the event magnitude M_S.

It is found that for historical earthquakes in the eastern Mediterranean the average standard deviation of a single M_{Si} determination σ_S is usually 0.4 to 0.5 Ms units, while the average standard deviation of the mean event magnitude σ varies between 0.15 and 0.30 M_S units. For events reported from very few places this value can be larger. As it is to be expected in certain cases, the paucity of data may contribute a rather large uncertainty in the assessment of Ms with no foreseeable possibility of reducing it.

For the instrumental period, after 1912, the standard deviation of station magnitudes $\boldsymbol{\sigma_S}$ remains nearly constant for the whole 100-year long period with a mean value of ±0.25 Ms units but with considerable scatter (±0.09**).** The standard deviation of the mean **σ** varies somewhat with magnitude and is on average ±0.10 in Ms units (±0.05) (Ambraseys and Douglas 2000).

TABLE 1) Reappraised locations and surface magnitudes

Y	**M**	**D**	**OT**	**N**	**E**	Ms
1509	09	10	2200	40.9	28.7	7.2
1509	10	23	0000	40.9	28.7	6.5
1511	05	26	0000	40.5	26.0	6.7
1556	05	10	2400	40.6	28.0	7.2
1557	00	00	0000	42.0	25.0	6.5
1567	10	01	0000	40.7	30.3	6.6
1577	00	00	0000	39.9	27.4	6.6
1595	09	22	0000	38.5	28.0	6.5
1625	05	18	2400	40.3	26.0	7.1
1645	05	31	0000	38.0	29.0	6.4
1651	06	07	0600	38.0	28.9	6.0
1653	02	22	0000	37.9	28.5	7.0
1656	01	24	0900	40.8	29.3	6.1
1659	02	17	1900	40.5	26.4	7.2
1661	00	00	0000	42.3	25.4	6.7
1664	06	02	2400	38.5	27.5	6.0
1667	11	00	0000	39.0	27.0	6.4
1672	02	14	0000	39.5	26.0	7.0
1688	07	10	1145	38.5	27.4	6.7
1702	02	25	0830	38.0	29.0	6.3
1719	05	25	1200	40.7	29.8	7.4
1719	07	23	0000	40.5	25.0	6.9
1728	09	16	1200	39.0	29.0	6.8
1730	06	10	0000	40.5	26.5	6.2
1737	03	06	0730	40.0	27.0	7.0
1737	03	19	0700	40.1	27.3	6.0
1739	04	04	0415	38.8	27.0	6.7
1751	06	18	0900	37.9	27.2	6.1
1752	07	29	1800	41.5	26.7	6.8
1754	09	02	2130	40.8	29.2	6.8
1754	09	14	0400	40.8	29.0	6.5
1754	10	02	0200	40.8	29.0	6.0
1765	03	20	0000	40.2	25.2	6.9
1766	05	22	0500	40.8	29.0	7.1
1766	08	05	0530	40.6	27.0	7.4

1766	08	07	0000	40.5	26.6	6.1
1767	03	26	0430	40.0	26.5	6.0
1778	07	03	0230	38.2	27.0	6.1
1794	08	05	0000	40.5	30.0	6.3
1809	02	07	0000	40.0	27.0	6.1
1826	02	08	2030	39.8	26.4	6.2
1829	04	11	1600	41.1	25.1	6.5
1829	05	05	1500	41.2	25.4	7.1
1841	10	06	0230	40.9	29.1	6.1
1845	10	15	0445	38.9	26.4	6.2
1850	04	19	2330	40.1	28.3	6.1
1855	02	28	0230	40.1	28.6	7.1
1855	04	11	1940	40.2	28.9	6.3
1859	08	21	1130	40.3	26.1	6.8
1860	08	22	1009	40.5	26.0	6.1
1865	07	22	2323	39.5	26.3	6.2
1873	11	09	2157	39.8	27.2	6.0
1893	02	09	1716	40.5	26.2	6.9
1894	07	10	1224	40.7	29.6	7.3
1894	07	12	1314	40.7	30.2	6.1
1899	09	20	0212	37.9	28.8	6.9
1901	12	18	0351	39.4	26.7	6.3
1905	04	30	1601	38.8	28.5	6.1
1912	08	09	0129	40.8	27.2	7.3
1912	08	10	0923	40.8	27.5	6.4
1912	09	13	2331	40.7	27.0	6.8
1919	11	18	2154	39.4	27.4	6.9
1924	11	20	2028	38.6	29.6	6.0
1928	03	31	0029	38.1	27.4	6.5
1928	04	14	0859	42.2	25.4	6.9
1928	04	18	1922	42.3	25.0	7.0
1928	05	02	2153	39.4	29.5	6.2
1935	01	04	1441	40.5	27.6	6.4
1935	01	04	1620	40.6	27.8	6.3
1939	09	22	0037	39.1	26.9	6.6
1942	10	28	0222	39.3	27.9	6.0
1942	11	15	1701	39.3	28.0	6.2
1943	06	20	1532	40.7	30.5	6.4
1944	02	01	0323	41.1	32.2	7.4
1944	06	25	0416	39.0	29.4	6.1
1944	10	06	0234	39.7	26.5	6.8
1949	07	23	1503	38.7	26.3	6.7
1951	08	13	1833	40.9	32.7	6.9

1953	03	18	1906	39.9	27.4	7.1
1953	09	07	0359	41.2	33.0	6.0
1956	02	20	2031	39.8	30.4	6.2
1957	05	26	0633	40.7	31.0	7.2
1963	09	18	1658	40.7	29.0	6.4
1964	10	06	1431	40.1	28.2	6.8
1967	07	22	1657	40.7	30.7	7.2
1968	09	03	0819	41.8	32.5	6.4
1969	03	23	2108	39.1	28.5	6.1
1969	03	25	1321	39.1	28.5	6.1
1969	03	28	0148	38.4	28.5	6.5
1969	03	28	0148	38.5	28.5	6.6
1970	03	28	2102	39.2	29.5	7.1
1975	03	27	0515	40.5	26.1	6.5
1981	12	19	1410	39.2	25.3	7.1
1983	07	05	1201	40.3	27.3	6.1
1992	11	06	1908	38.0	26.9	6.0
1995	10	01	1557	38.1	30.1	6.0
1999	08	17	0001	40.8	30.0	7.4
1999	11	12	1657	40.8	31.2	7.1
2002	02	03	0711	38.5	31.2	6.4
2000	06	06	0241	40.7	33.0	6.1

2)The Estimation of the Frequency of Occurrence of Earthquakes and Strain-Rates from Long-term Seismicity: the Sea of Marmara

Extract from the article by Ambraseys N. "Comparison of frequency of occurrence of earthquakes with slip rates from long-term seismicity data: the cases of Gulf of Corinth, Sea of Marmara and Dead Sea Fault Zone" Geoph. J. Intern. (accepted for publication: Aug.2005)

In this study I used the new and improved databases, chiefly of historical information, and also recent results from GPS measurements and models, as well as field measurements, to confirm general conclusions drawn earlier about the frequency districution and slip-rates which are based on historical seismicity.

Data

The long-term seismicity of the Marmara Sea region since the beginning of our era and the associated parametric data used in this analysis have been taken from Ambraseys (2000), improved during the APAME project. Table 1 lists the earthquakes identified in the study area.

Table 1. Conspectus of data used in the study.

	Marmara Sea Region	
Period examined	1.-2000	1900-2000
Region defined by corner co rordin.	39.5 - 41.5N	39.5 - 41.5N
	26.0 - 31.0E	26.0 - 31.0E
Length of the region (km)	420	420
Width of the region (km)	220	220
Surface area ($x10^4$) km2	9,2	9,2
Predominant style of faulting	RL	RL
Average seismogenic thickness km	10	10
Total number of events identified	937	566
Calculated event Ms	553	445
Number of events Ms > 5.0	176	75
Number of events Ms > 6.0	82	16
Number of events Ms > 6.8	52	8
Standard deviation of single observed Ms	0,35	0,2
Standard deviation of event Ms	0,15	0,05
Min. and Mx Ms used to assess velocity	6.8 - 7.4	
Mo contribution from small events	x1,7	

However, some remarks on the method used to estimate recurrence frequencies and slip-rates may be in order.

Seismic moments. Regarding seismic moments, for more recent earthquakes Mo values are either Harvard CMT estimates or calculated from P/SH modeling, taken from published sources.

For historical earthquakes or for events for which Mo is not available, seismic moments were estimated from surface wave magnitudes using the bilinear “regional” relation derived specifically for the eastern Mediterranean and the Middle East (Ambraseys and Jackson 2000).

The "global" logMo-Ms relations of Ekström and Dziewonski (1988) and Ekström's for "continental" earthquakes (Ekström 1987) were also used for comparison.

The "continental" relation yields the smallest Mo values for a given Ms > 6.0 while the "regional" relation yields Mo values, much closer to CMT estimates which are about 20 per cent smaller than those from the "global".

Frequency-Magnitude distribution For short-term observations, regional seismicity is well described by the Gutenberg's cumulative frequency-magnitude relation

$$\log(N/y.a) = \alpha - \beta M_S \quad \text{....} \quad (2)$$

in which (N/y.a) is the annual number of earthquakes of magnitude equal to or greater than M_S per unit area (a). However, as we shall see along a fault zone, the same type of distribution is not proper for the description of seismicity over a long period of time.

Contribution of small earthquakes to the total moment. For the assessment of slip rates, datasets need to be as complete as possible in terms of magnitude. However, in long-term seismicity studies the data are necessarily incomplete and restricted to the larger events, usually of magnitudes greater than 6.0.

Therefore the calculation of total moment release M^T_0 requires the addition to the known total moment the contribution from smaller magnitudes not accounted for in the summation. This depends on the range of M_S over which the moments are explicitly summed, as well as the likely size of the largest earthquake. It depends also on the exponent $\beta(M)$ in the frequency-magnitude relation, which may be the linear, piecewise linear or, at large Ms values, non-linear. Also depends on the choice of the scaling $\log(M_o)$-M_S law, (e.g. Molnar, 1979; Ambraseys and Sarma, 1999). M^T_0 may be expressed as $M^T_0 = q(M^M_0)$, in which M^M_0 is the known sum of moments calculated from the available magnitude range and scaling law.

Variation of slip rate with time. We summed the seismic moments of the earthquakes to obtain estimates of the variation of shear or extensional velocity with time for 300, 1900 and 2000-year long periods of observations using

$$u(t) = [(T)(H)(L)(\mu)]^{-1} \sum_{0}^{T}(M_0) \quad \ldots\ldots \quad (3)$$

where M_0 (dyn.cm) are the seismic moments of individual events during a period of observation of T years; H is the seismogenic thickness for strike slip faults or the width for normal faults; μ is the rigidity (3.0×10^{11} dyn.cm^2) and L is the length of the fault zone. We assume that each event contributes to this motion and used throughout an average seismogenic thickness of 10 km, regardless of actual crustal depths known in the region.

It is possible that some of the smaller events may have had fault mechanisms different from the predominant mechanism in the region, but we do not think that this assumption is an important source of error.

Note that the average slip-rate is not representative of the average long-term velocity for periods of observation which are too short to exhibit the repeat time of the larger earthquakes.

Marmara Sea region

This is a region is roughly bounded by 39.5^0N to 41.5^0N and 26^0E to 31^0E

Tectonics The region is dominated by the right-lateral North Anatolian fault zone which accommodates most of the westward motion of Turkey, a narrow and localised character, clearly defined by the predominantly strike-slip surface along its entire 1000-km length, associated with a series of major earthquakes.

The Marmara submarine fault system is the result of oblique extension and as such is segmented showing asymmetric slip partitioning with the faults that bound the north of the basin carrying more strike-slip motion than predicted from the Anatolia-Eurasia plate motion, and faults to the south having a perpendicular component (Armijo et al. 2002; Flerit et al. 2003).

Seismicity

The revised seismicity of the region over the last 2000 shows no evidence for truly large earthquakes of a size comparable to that further east on the North Anatolian Fault zone. Events are smaller in keeping with the known fault segmentation of the Basin.

Annual frequency distribution. Figure 2 shows the annual frequency-magnitude distribution per square degree for the region, derived from 20th century data. For $M_S < 6.5$ the distribution follows equation (2) with a β-value of about –0.7, which for larger magnitudes dips to much smaller β-values.

If the period of observations is extended to about 2000 years we notice that for large magnitudes, at the upper end of the recurrence curve, because the 20th century record is too short to disclose the repeat time of larger earthquakes, he relation shows an asymptotic behaviour suggesting a genuine departure from Gutenberg's equation (2).

The implication is that large earthquakes in the Marmara region are less frequent when predicted from the long-term dataset than from the usual 100-year instrumental period, making the notion of a recurrence time, in its usual definition, and of hazard assessment, questionable.

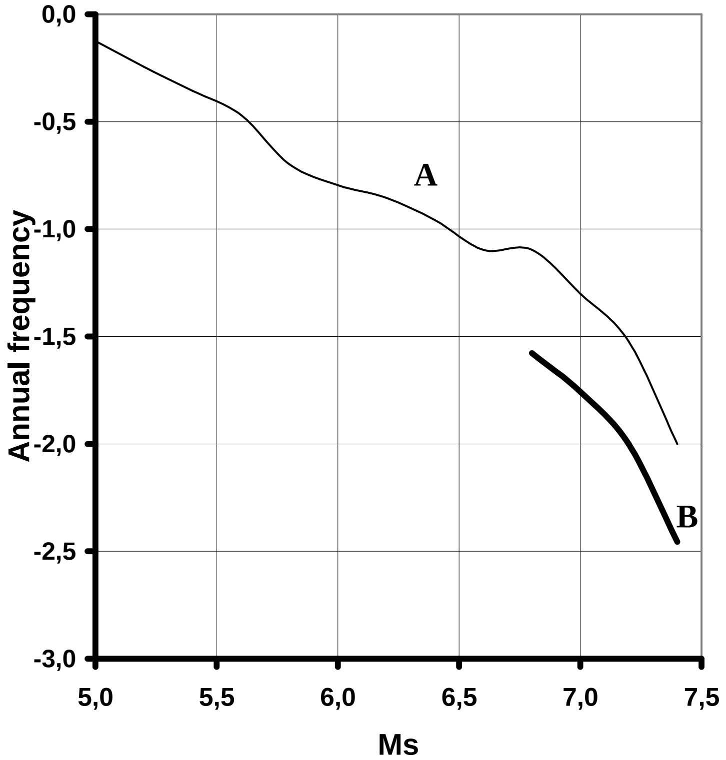

Figure 2. Annual frequency distribution per square degree for the region of the Sea of Marmara. Thick line (B) is for the period 1 to 2000, and thin line (A) for the 20th century.

Variation of slip rate with time. The variation with time of slip rates is shown in Figure 3, again for a seismogenic thickness of 10 km. If we assume that the typical thickness or locking depth is smaller, say 7 km (Mead et al 2002) this would increase the velocity by almost 40 percent.

With the exception of the irregularity of the velocity in the first centuries, the velocity for the rest of the period is quite constant with an average value of 2.0-±0.4 cm/yr.

The time interval between the first year and the year, beyond which the average slip rate becomes stable, may be a measure of the length of the repeat time between large events. However, confirmation of this would require the study of a much larger area over a longer period of time, which, at present, is not feasible.

Mead has shown that the northern straight strand of the North Anatolian in the Marmara Basin carries four times as much right-lateral motion as does the southern strand (Mead et al 2002). Historical seismicity cannot confirm this or the hypothesis of a single, through going, purely strike-slip fault (Le Pichon et al. 2001).

It does confirm, however, that the slip rate and the moment release along this straight fault geometry over the last 2000 years accounts for the known right lateral shear velocity across the Marmara region observed by GPS, with no evidence for truly large earthquakes in a size comparable to those in the North Anatolian Fault zone, earthquakes being smaller in keeping with the known fault segmentation of the Basin.

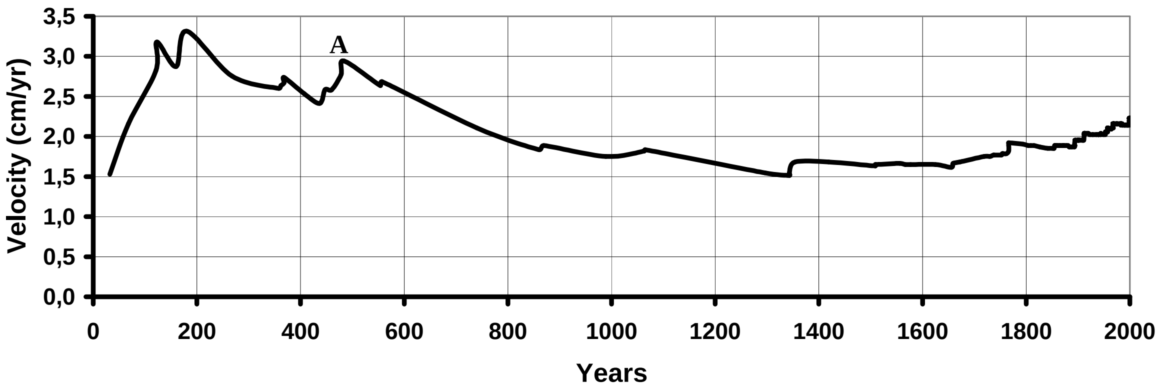

Figure 3. Variation of velocity of the region of the Sea of Marmara during the period 1 to 2000 calculated from the regional log(Mo)-Ms relation.

Measured slip rate. Slip rates from GPS measurements show values between 2.2 to 2.6 ±0.3 cm/yr (Straub 1996; Reilinger et al 1997) and correspond to the elastic strain to be accounted for by future earthquakes and seismic creep (Walcott 1984).

Results

I find that the level of uncertainty of the location of large historical earthquakes is good enough to guide field studies for further investigation of regional tectonics.

In some cases magnitudes are approximate and several factors could change these. Given the uncertainties in the original M_S values, the missing and unaccounted for seismic moment from sub-events, the uncertainties in the depth and in the $\log(M_0)$-M_S scaling law, it is difficult to estimate more realistic velocities from historical seismicity alone. Arguing that the seismogenic thickness for some of the earthquakes is as much as 15 km, would reduce the velocities by a third.

Also, uncertainties in slip-rates calculated from long-term historical data are relatively large but in well documented regions they are comparable to those calculated from field observations and GPS. In view of all these uncertainties, it is surprising that estimates from historical data are almost the same as those calculated from GPS and triangulation surveys.

I find that the major portion, perhaps effectively all of the long-term motion in the regions studied, including that due to missing events, is probably achieved by seismic slip on faults, and that aseismic creep, may be relatively unimportant. However, uncertainties in slip-rates are large enough to mask likely differences that may exist in various parts of a region, and answers to the problem of seismic *versus* aseismic slip might well come from geodetic observations.

A by-product of the present work, which concerns engineering seismology, is that in hazard modelling from short-term, 100-year long datasets, it is simply not reasonable to ignore the chance that much or all of our records may be from a quiescent or from an energetic period in seismic activity, particularly for small probabilities of exceedance. This is one of the possibilities that must be borne in mind in making assumptions with incomplete datasets. This is the principal reason why statistics alone cannot quickly and simply answer the question of seismic hazard evaluation.

3). Seismic hazard assessment

The assessment of seismic hazard involves M_S or M_0 in both constituent functions, i.e. in the ground motion estimation equation as well as in the magnitude-frequency distribution. The former function is based on observations derived from data covering a long period of time. It is obvious that the uncertainty in M_S is significant not only for the assessment of strong motion estimates for modern earthquakes, say of the last three decades, but more so for earlier events for which the standard error in event magnitude M_S rises to 0.35.

For historical events, whose M_S is estimated from semi-empirical scaling laws, σ values may reach 0.5 or more. Thus the uncertainty in M_S generally increases as we go back in time, particularly for the more rare, but important large early events, which plot near where the magnitude-frequency distribution curve steepens, see Figure 2.

In this context we note that extending the hazard curves to probabilities of the order 10^{-5} or 10^{-7} may have some formal meaning in statistics. Such low probabilities may reflect also the level of formal risk that the designer is willing to accept. On the other hand they do not say much when we address the real physical problem of regional continental seismicity. We know many regions, which have been active during the last few hundreds of years, and which border faults ceased to be active 10^3 to 10^4 years ago; the reverse is also true. In the time scale of more than about 10^5 years, regional seismicity is predominantly itinerant, and return periods of the order 10^6 to 10^7 are extremely judgemental in nature. Statistical extrapolations from 20th century data have little validity for periods of this great length.

From the 2000-year long history of the region, there is no macroseismic evidence for a major earthquake that could be associated with rupture of the offshore North Anatolian Fault all along the north coast of the Marmara Basin from the Gelibolu Peninsula to the Gulf of Izmit.

- **The seismicity of the last 2000 years can account for almost all of the expected 2.2±0.3 cm/yr right-lateral slip in the Marmara Sea region.**
- We find virtually no significant earthquakes in Thrace and a subdued activity in the southern part of the Basin.
- Large earthquakes in the Marmara region are less frequent when predicted from long-term datasets than from the usual 100-year instrumental period.
- Maximum magnitudes from short-time observations are overestimated making the notion of a recurrence time questionable.
- There is a regional and long-time dependence of seismic activity which renders particularly problematic the assessment of hazard from short-term observations.
- Clustering of seismic activity must be borne in mind in making statistical evaluation of hazard in this region.
- **Historical earthquakes in the Basin close to Istanbul have been smaller than those that have occurred east, in the North Analolian Fault zone, and west in the Ganos-Aegean region.**

4). Seismic sea waves in the Sea of Marmara.

One of the problems in early and later descriptions of seismic sea-waves is that one cannot be certain whether these events were due to an earthquake, abnormal weather conditions, submarine mass failure or local coastal landslides. Historical sources record large seismic-sea-waves, small waves not being spectacular enough to attract attention, and descriptions from which one can deduce their occurrence, size and effects, are relatively few and difficult to verify, particularly when the information is a second hand and the event is not well described. It follows, therefore, that for small events the record should be incomplete. The record should be more complete for large seismic sea-waves, responsible for serious loss of property or life, the kind of information that chroniclers would not have omitted to record and embelish in their writings.

Case histories

What follows is a summary of information culled from original sources about seismic sea-waves so far identified in the Marmara Sea; Table 1 gives the associated seismological parameters. This is followed by a summary of spurious events. For events between 1500 and 1799 and for the 19th century original source material can be found in [4] and [3] respectively.

358 08 24 Nicomedia**.** The information about this event implies that the sea waves were due to a storm. The earthquake that followed a wet period triggered landslides which carried houses down the hillsides and into the sea. At least for Izmit this implies that the wave was generated by landslides into the sea or by slumping of the coast. This does not mean that such a wave might not have been associated with the earthquake, but that simply there is no information about its origin.

447 11 06 Nicomedia. Near-contemporary chroniclers do not mention damage from a seismic sea-wave in Nicomedia. The says that some towns and estates in Bithynia were ruined because of continual rain over a long time and the flooding of rising rivers, as a result of which they collapsed and fell apart. Nicomedea, they say fell into the sea and in many parts of Bithynia the land slipped away and many waves flooded it; the sea then threw up dead fish, and many islands in the sea were submerged. Sea-going ships were seen on dry land, the sea having retreated**.**

478 09 25 Helenopolis. Details about the effects of this earthquake are given by many chroniclers but only one mentions damage caused by sea-waves. He says that the sea grew wild and rushed far inland, engulfing a part of what had previously been land, and destroyed not a few houses. The chroniclers do not say where this happened; presumably in the Gulf of Izmit.

740 10 26 Marmara. In this earthquake in the Marmara, at some places, which are not named, the sea drew back from the shores permanently, without returning to flood the coast.

989 10 25 Marmara. It is not clear whether the earthquake was accompanied by a genuine seismic sea-wave. Our sources say there were also high winds as a result of which waves set up in the sea between Thrace from Bythinia reached into Constantinople and destroyed a tower off shore of Istanbul.

1343 10 18a Ganos. The first shocks occurred in the morning during a day of violent storms and high seas. The sea was tossed and flowed beyond its bounds engulfing the nearby houses.

1343 Oct 18b Heraclea. Several hours later, in the night of 18 October 1343, there followed a larger shock so that the sea grew rougher.

Contemporary sources say that the sea surged up, and flowed out far into the dry land. And on flat land the sea flowed in for 1.8 km. In some places the sea crushed boats on land, drawning men, flocks and cattle. When it retired after many ebb and flows, the sea left the land littered with dead fish and covered with mud. At Constantinople, it is said that the sea rose against the sea-walls the sea flooding the city up as far as Beylerbey. In open places the sea flooded buildings built near the coast, caused the collapse of houses, even of fences the rubble blocking streets.

1419 Dec 18 This earthquake caused some damage in Constantinople, ruining a number of houses. It is said that as a result of the earthquake the sea flooded the land.

1509 09 10 Istanbul. In spite of the large number of sources of information that survive for this relatively large earthquake near Istanbul, little is said about sea-waves. There are only two short notices which say that in the narrows of the Golden Horn (Haliç), between Pera and Istanbul, the sea flooded the shores to a great depth and that waves crashed against the walls of the city.

1754 09 02 Izmit. This was a damaging earthquake in the Gulf of Izmit and caused material damage in Istanbul. It is said that in places the sea receded from the shore, for more than 60 metres.

1766 05 22 Marmara As a result of this earthquake Galata and the coast opposite were flooded by the sea which submerged the quays and stripped them of their landing gear. The same phenomenon was observed along the Bosphorus, and along the coast at Mudanya where some villages were flooded. Uninhabited islets in the Marmara Sea were said to have half sunk into the sea.

1859 08 21 Saros. It is said that during the large earthquake on 21 August 1859 which had an epicentre offshore in the Gulf of Saros, the sea in the Bosphorus, near its entrance to the Black Sea, was set in motion, sloshing against the shore.

1878 04 19 Izmit. There was a damaging earthquake in the region west of Sapanca Lake and Izmit. In the Gulf of Izmit the shock set up a sea-wave which propagated into the west where the earthquake was also felt on board ships, causing some concern.

1893 02 09 Saros. The relatively large magnitude earthquake in the Gulf of

Saros on 9 February 1893 caused damage which extended from the island of Samothraki along the coasts of the Gulf of Saros to the Sea of Marmara. The earthquake was associated with a seismic sea-wave which flooded the coast of Samothraki and of mainland Thrace. At Angistro the height of the wave was about one metre, but in places it was more, destroying two farm houses which had been left standing. About 15 minutes after the main shock the coast of Dedea_aç was flooded by a wave of more than one metre in height.

1894 07 10 The shock was associated with a seismic sea-wave which affected the epicentral section of the Marmara Sea coast. After the earthquake the sea was very agitated. In places it retired 200 m leaving many boats and vessels high and dry : at San Stefano the waters returning rose by 1.5 m above its normal level, overflowing the quay, flooding the shore and casting sailing ships on to the shore, causing damage. Depth soundings along the coast taken after the earthquake showed no changes. However, as a result of the earthquake the submarine cable between Kartal and the Dardanelles was ruptured in more than one place at a point about 5 km off Kartal . The mode of rupture of the cable suggested that it was sheared by the fall of slide material, and depth soundings at this place showed some chages in the bathymetry, suggesting submarine landsliding.

1912 08 09 Ganos

The earthquake of 9 August 1912 occurred in the Saros-Marmara area Along the coast of Tekirda_ and the Straits, the sea retired for a distance after the shock, before returning with some force, causing no damage.

Spurious events

120 AD This event is the result of confusion of the earthquakes in Nicomedia (Izmit) in 121, with the event at Cyzikus (Erdek) in 123, and with an early prophesy that Cyzikus will be destroyed by the sea. There is no evidence in the sources for an earthquake or sea-wave in Nicomedia or elsewhere in 120 AD [6, 10].

344 The earthquake of 344 happened in Neocaesarea (Niksar) and not in Nicomedea. It is said that the town "sunk" into the ground. The translation of "sunk", made out of context, could also mean "engulfed by the sea", a version wrongly adopted by some modern writer to imply the occurrence of a seismic sea-wave in Neocesarea which is more than 50 km away from the Black Sea. [2, 5, 6]

368 10 11 Nicaea. There is no information about the earthquake of 11 October

368 in Nicaea, except in an Ethiopic version of the chronicle of John Nikiu, a 7th century writer, who refers to seismic sea-wave of 358.[6]

407 05 01 Constantinople. There was a moderate earthquake in the Sea of Marmara on 1 May 407 which modern cataloguers associate with a seismic sea-wave.

The only mention of an earthquake during that month is that there was a great shower of hail with lightning, thunder and earthquake as a result of which the tiles of the Forum in Constantinople were scattered and many ships were damaged, and not a few corpses were cast up at Bakirköy. Other writers refer only to the damage caused by high winds.[6]

447 01 26 Constantinople. We could find no evidence or a hint in the sources that the earthquake of 26 January 447 was associated with a seismic sea-wave to which modern writers assign K_0 = III+ on the evidence of information that belongs to the earthquake of 6 November 447. [5, 10]

447 11 08 Erdek. This is a doublet of the earthquake of 6 November 447. [9]

450 01 Marmara. This is a spurious event.[2, 5]

542 Marmara. The earthquake of 542 is in fact that of 16 August 542, which a later writer amalgamated wrongly with the flooding of the south-west coast of the Black Sea in 544 [2, 5]

543 09 06 Marmara. There is no evidence that the earthquake of 6 September 543 was associated with a seismic sea-wave. This is probably the result of confusion of the earthquake with the flooding of the coasts of Odessus, Dionysipolis and Aphrodisium in the Black Sea which happened the following year, and which was not of seismic origin.[6, 7, 10]

975 10 26 There is no evidence for an earthquake and seismic sea wave in Constantinople on 26 October 975. This is the earthquake of 26 October 989 [2, 5].

1039 02 02 Constantinople. A contemporary writer reports that during an wet period, floods and continuing small shock happened in Constantinople, which started on 2 February 1039. He says that there were continual earthquakes and heavy rain which caused floods. [7] use this information to create a seismic sea-wave in Constantinople and an earthquake of magnitude 6.8.

1265 08 11 Marmara Proeconessus. The small sea-wave reported by an eyewitness on Marmara adasi was not seismic; it was caused by the collapse of a rock mass from a mountain near Galinolimena (C,,inarli) which was triggered by the shock of 11 August 1265. [10]

1331 02 12 Constantinople There was no earthquake or seismic sea-wave in Constantinople on 12 February 1331. An earthquake occurred on 17 January 1332, which was followed on 12 February 1332 by violent thunderstorms and sea-waves which burst through part of the sea-defences and brought down some of the houses and statues in the city. [10]

1344 10 18 Constantinople. The earthquake of 18 October 1344 comes from the amalgamation of a nuber of separate earthquakes in Istanbul in 1343-44. [9]

1646 04 05 Istanbul. The sea-wave on 5 April 1646 in Istanbul is a spurious event. [2, 5, 9]

1829 05 23 Istanbul. The event of 23 May 1892 in Istanbul is spurious [2, 5]

Conclusions

I can find no evidence for destructive seismic waves in the Sea of Marmara, and only few cases of damaging ones. The data is insufficient to quantify these events, to which modern authors, have assigned location and size. Our investigation shows that of the 30 cases of seismic sea-waves reported in modern literature 14 are spurious: [1, 8, 11, 12].

Seismic sea-waves in the the Marmara Sea area seem to be associated with sources in the Gulf of Izmit, Cinarcik, Central and Tekirdag basins. It is not possible to say to what extent these phenomena are due to sea-bottom dislocation of a fragmented system of faults or from submarine and coastal mass failures which seem to be the predominant mechanism; simply there is no information.

References

1 Altinok Y., Ersoy S. (2000) "Tsunamis observed on and near theTurkish coasts", *Natural Hazards,* vol. 21, pp.185-205

2 Ambraseys N. (1962) "Data for the investigation of the seismic sea-waves in the Eastern Mediterranean", *Bull. Seism. Soc. Am.*, vol.52, pp.895-913

3 Ambraseys N. (2000) The seismicity of the Marmara Sea area 1800 - 1899, *Journ. Earthquake Eng*., vol. 4, pp.377-401

4 Ambraseys N., Finkel C. (1995) *The seismicity of Turkey and adjacent areas 1500 - 1800* Eren, Istanbul

5 Antonopoulos J.(1978) "Contribution to the knowledge of tsunamis in the Eastern Mediterranean from ancient until recent", *Ann. Geol. Pays Hellen.*, vol.29, pp.540-575, Athens

6 Guidoboni E., Comastri A., Traina G. (1994) *Catalogue of ancient earthquakes in the Mediterranean area up to the 10th century,* pub. Istit. Nazion. Geofisica, Rome

7 Papadopoulos G. Chalkis B. (1984) "Tsunamis observed in Greece and the surrounding area from antiquity up to the present times", *Marine Geology,* vol.56, pp.309-317

8 Papadopoulos G. (1993) "Seismic faulting and nonseismic tsunami generation in Greece", *Proc. International Tsunami Symposium*, pp.115-123, Wakayama

9 Papazachos B., Koutitas C., et al. (1986) "Tsunami hazard in Greece and the surrounding area", *Ann. Geophys.*, vol.4B, pp.79-90

10 Papazachos B., Papazachou C. (1997) *The earthquakes of Greece,* pp.71-76, Ziti, Thessaloniki

11 Soloviev S. L. (1990) "Tsunami zones in the Mediterranean Sea", *Natural Hazards*, vol. 3, pp.183-202.

12 Soysal H. (1985) "Deniz tasmasi ve Türkiye kiyilarini etkileyen tsunamiler", *Deniz Bilim & Cor. Enstit. Bült.*, vol.2, pp.59-67,

N. Ambraseys
Imperial College, London
September 2005