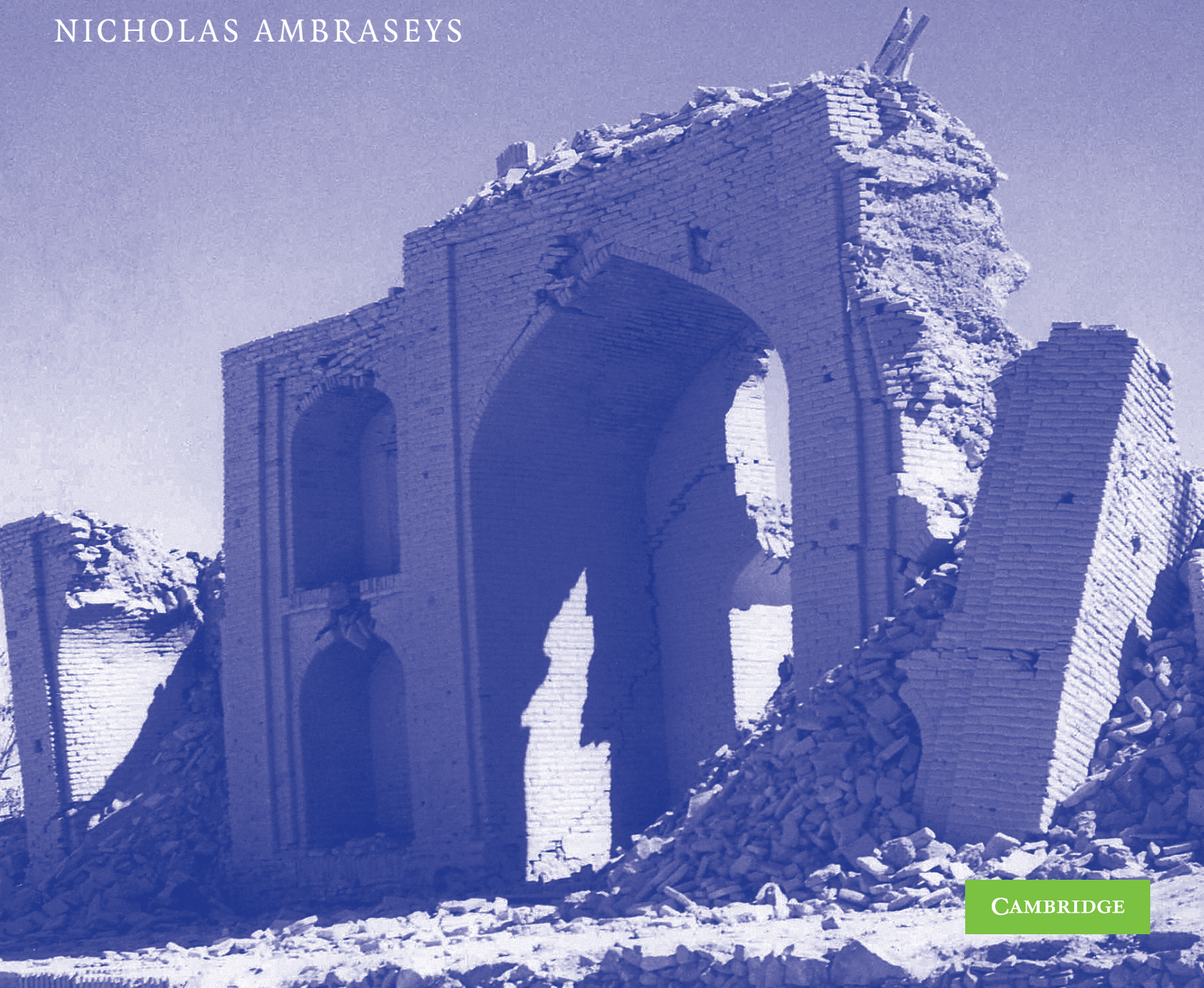


Earthquakes in the Eastern Mediterranean and the Middle East

A Multidisciplinary Study of Seismicity up to 1900

NICHOLAS AMBRASEYS



CAMBRIDGE

Earthquakes in the Mediterranean and Middle East

The ability to predict future earthquake hazards in a particular region requires an understanding of seismic activity far back into history – long before the advent of modern seismographic instruments. This book uses a multidisciplinary approach to examine historical evidence from the last 2000 years for earthquakes in the eastern Mediterranean and Middle East and attempts to answer the following questions. When and where have large earthquakes happened in the past? Is it possible to assess the location and magnitude of earthquakes from literary and archaeological sources? How can this evidence contribute to our scientific understanding of earthquake activity?

Early chapters review techniques of historical seismology, including assessments of macroseismic data. The main body of the book comprises a catalogue of more than 4000 earthquakes that have been identified from historical sources. Each event is supported by textual evidence extracted from primary sources and translated into English. Most of these events are also evaluated in terms of location, magnitude and associated physical and societal effects. The area covered encompasses southern Rumania, Albania, Bulgaria, Macedonia, Greece, Turkey, Lebanon, Israel, Egypt, Jordan, Syria and Iraq. The book documents past seismic events within that region, places them in a broad tectonic framework, and provides essential information for those attempting to prepare for, and mitigate the effects of, future earthquakes and tsunamis in these countries.

This volume is an indispensable reference for all researchers studying the seismic history of the eastern Mediterranean and Middle East, including archaeologists, historians, Earth scientists, engineers and earthquake-hazard analysts.

A parametric catalogue of the seismic events presented can be downloaded from www.cambridge.org/9780521872928.

NICHOLAS AMBRASEYS was trained at Imperial College of Science and Technology, London, as a civil engineer, specialising in soil dynamics and engineering geology. He later became Professor of Engineering Seismology and Head of the Engineering Seismology Section at Imperial College. Since 1994 he has been a Senior Research Investigator and Fellow in the Department of Civil Engineering. Professor Ambraseys is a Fellow of The Royal Academy of Engineering, The European Academy and The Academy of Athens, and has been awarded medals from The Royal Geographical Society (1975), The Geological Society of London (2002) and the Seismological Society of America (2006). He is currently Vice-President of the European Association for Earthquake Engineering, Director of the International Association for Earthquake Engineering, Chairman of the International Commission for the Protection of Historical Monuments and co-editor of the *Journal of Earthquake Engineering*. He is the author of two other books for Cambridge University Press: *A History of Persian Earthquakes* (1982) and *The Seismicity of Egypt, Arabia and the Red Sea* (1994).

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Imperial College, London



ΑΚΑΔΗΜΙΑ ΑΘΗΝΩΝ
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Preface

Throughout the ages earthquakes have been one of the most destructive natural hazards, if not to human life itself, then most certainly to the works of man. Earthquake hazards are not always perceived to their full extent. They have long been associated with crises in human affairs, and they are seen as having certain effects or consequences that are rarely specified in advance or fully understood. In a developing country of limited resources and with investments concentrated in seismic areas, the consequences of a large earthquake should be feared as much as the phenomenon itself.

The literary and field studies of ancient and modern earthquakes show that people view differently the challenges and hazards of their natural environment. In historical times the damage and sudden crippling of the economy of a state led to population movements, emigration and crises in political affairs, triggering invasions and wars and even truces between belligerent states. The loss of life must have been considerable but is difficult to estimate. Also in modern times, particularly in developing countries, earthquakes have caused economic and political crises, increases in taxation and undesirable, though necessary, borrowing from other countries.

The average number of people killed today annually is certainly much smaller than the annual number of persons killed by drugs, famine, undeclared wars and motor cars. At the present level of technology, earthquakes cannot be prevented. However, subject only to budgetary constraints, their disastrous effects can be minimised. Earthquakes are destructive because man has made them so by investing his wealth with a disregard for the hazards he knows that Nature may have in store for him. This disregard stems from a variety of reasons, the most important being simply the lack of awareness and technical knowledge to alleviate such risks. Another cause is often the apathy of the populace, which is

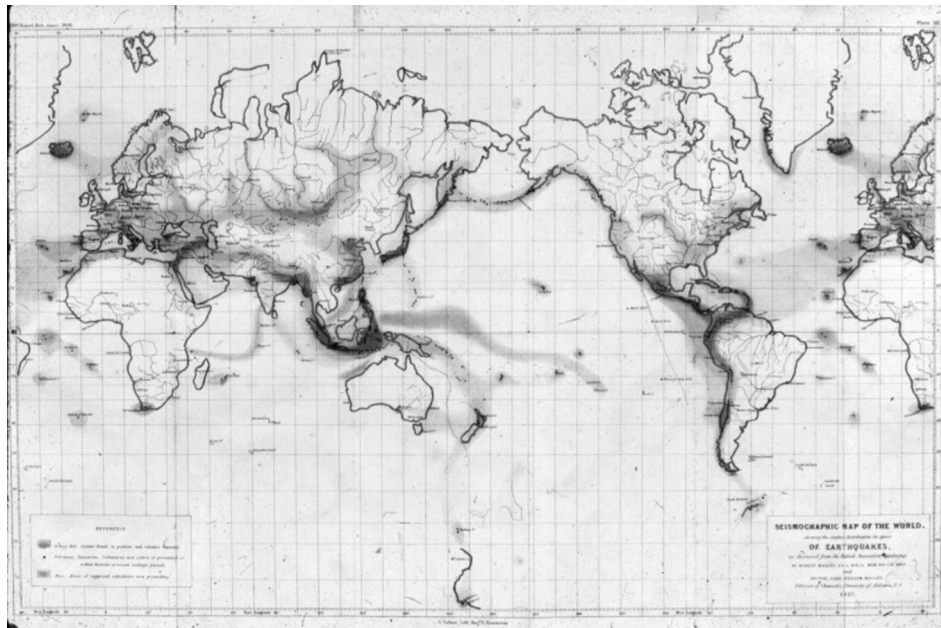


Figure 1 A map of worldwide seismicity before 1851, determined from literary sources by Mallet in 1857.

probably due to ignorance. It was, and to some extent still is, not uncommon for people to accept earthquakes and their effects as acts of God about which very little can be done.

The differences in attitude to earthquake hazards found both in historical and in modern times cannot be explained in terms of the magnitude or frequency of such disasters alone. It is the perception of the disaster that controls the attitude and stimulates awareness. For instance, very little improvement in building materials and in methods of construction results from an earthquake that destroyed or destroys today remote villages in a developing country. After a very short period of enthusiasm for a restoration plan, the interest of the few concerned dies out. Apart from those afflicted, few in the country will be affected and soon the whole problem will be forgotten. In contrast, the damage or destruction of a capital city or of a major engineering structure on which the economy of the country depends will stimulate a completely different degree of awareness. Here, the disaster may or might not affect the economy of the country, but the strain will be felt by all, but again will soon be forgotten.

Since we cannot know what will happen in the future, to estimate likely earthquake hazards we have to find out what happened in the past and extrapolate from there a little. Previous research has uncovered evidence of destructive earthquakes in areas where only small earthquakes have been experienced within the last century or so. This is not surprising: the timescale of geol-

ogy is vastly different from that of human history, so some parts of the world may suffer violent earthquakes over a very short period of the geological timescale. It follows, therefore, that, if we took account only of information about the last century, during which earthquakes have been recorded by instruments (and even then not uniformly throughout the globe), we would have no way of knowing whether an apparently seismically 'quiet' area today is in fact at risk from a damaging earthquake.

A striking illustration of the value of historical data, and one of the germinal impulses leading us to study the long-term occurrence of earthquakes, came primarily from comparing two maps of world seismic activity. The first, Mallet's map, [Figure 1](#), was compiled in the mid-1800s by a painstaking, solitary scientist, and the second, [Figure 2](#), was compiled in the mid-1900s, by a group of seismologists as the result of a worldwide multi-million-dollar effort.

Both the similarities and the differences between these maps show that the former was anticipatory of later discoveries. One can see almost all the plate boundaries and seismic zones we know today depicted solely from historical data. The data Mallet used to construct this map are as crude as the hypothesis or theory of plate tectonics that makes one look for such boundaries. However, on the same map one can also see seismically active regions, such as the Dead Sea fault and Eastern Anatolian fault zones ([Figure 3](#)), these being shown as almost totally inactive on the twentieth-century map.

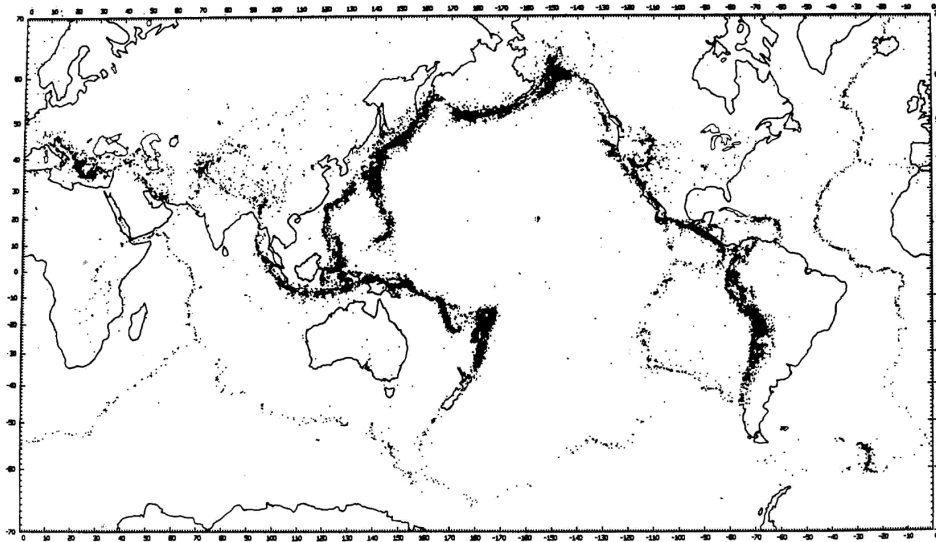


Figure 2 The worldwide distribution of instrumentally determined locations of earthquakes 1962–1967 (Barazangi and Dorman 1969).



Figure 3 A detail of Mallet's 1857 seismicity map focusing on the general area of our study. The highest seismicity is shown for the Red Sea, the Dead Sea Fault zone and its extension along the East Anatolian Fault Zone, regions that have been seismically quiescent for more than 150 years.

In fact any interested scientist before the turn of the twentieth century, or any scholar much earlier, could have gained access to historical data for early earthquakes dating from before Mallet's time. Had it occurred

to him to do so, he would perhaps have discovered plate tectonics and almost all the main deforming belts in the region we know today, as well as the world distribution of seismic hazard.

There is more to be seen in Mallet's map than appears to be there at first sight. In particular, it shows the results of interdisciplinary research that can come to fruition not through the agency of a national or international committee for planning or financing research in global or regional seismicity, which would probably cause the project to founder by setting up unimaginative constraints, such as an unrealistic time limit, but by the efforts of dedicated individuals such as Mallet, in the days when one had time and was able to read and write in languages other than computer language.

The need to test observations of short-term seismicity against longer-term trends identified from historical studies requires one to resort to original material that can best be assessed from an interdisciplinary study that gives a far fuller understanding of earthquake hazard, because it is based on human experience of earthquakes over a much greater segment of the geological timescale, namely 2000 years or more under favourable conditions, than the mere 80 years or so of the instrumental record of earthquakes. Such information is invaluable, not only in the study of earthquakes *per se*, but also regarding the climate and weather, and can guide the engineer to design structures to resist the forces of Nature without being taken by surprise by unexpected events.

When, in the early 1960s, I first started the systematic study of historical earthquakes in Iran, it was not

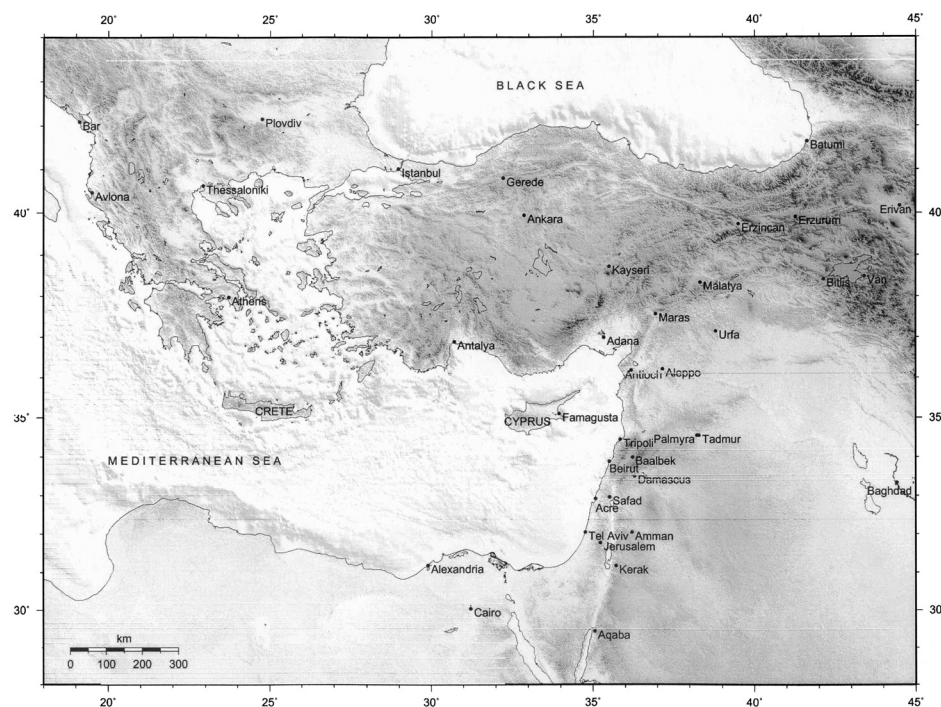


Figure 4 A map of the region under investigation.

clear in advance just how much their study could lead to a better understanding of their generic cause and the associated hazard. The benefit of being able to refer to observations over a period more than ten times longer than the 80 years or so that has elapsed since the advent of modern seismology, however, was obvious. Soon the work extended to neighbouring regions and ended up with the whole of the Eastern Mediterranean and the Near East, an area confined between 28° and 43° N and 18° and 45° E, extending from Greece to Iraq and from the Danube to Egypt, [Figure 4](#).

Much of the region is tectonically active, with a seismic history that is amply, but not uniformly, documented throughout the past two millennia. This region is an outstanding natural laboratory for the investigation of earthquakes and seismic sea-waves (the so-called *tsunamis*) because its tectonic motions are rapid and varied and reasonably well understood.

At the same time attempts were made to acquire for comparison an insight into the long-term seismicity of less-well-documented, but equally seismically active, regions, such as Afghanistan, Pakistan and northern India, including parts of Tibet, East and West Africa and Central America, with varying degrees of success. The cursory study of the seismicity of the European area, that is, of Iceland, northwest Europe including the UK, Holland, Norway and Sweden, as well as of Switzerland was incidental and not as thorough as it should have been, but was useful nonetheless in demonstrating the diverse

problems that arise from the exposure of various types of constructions to earthquakes, from the various ways of reporting earthquake effects and the historiography of different parts of the world.

At the outset of this work, in the early 1960s, I began with a reappraisal of existing descriptive earthquake catalogues and of field reports. Soon it became clear that these, as well as later works, including some of my earlier works, had many shortcomings: some of them were lacking the approach necessary for clarifying problems of dating and location, in particular the assessment of the area over which a particular earthquake was felt or caused damage, which is important for the estimation of its magnitude. Other works lacked clear perspective and originality, and the purpose for which they were written was not evident.

This led to an attempt to purge these catalogues of errors and spurious events, but disentangling complications and rectifying the various errors was found to be such a time-consuming process that it prompted a fresh start, by resorting directly to original sources. The work started from primary sources quoted in pre-1963 earthquake catalogues, which drew on both occidental and oriental sources that for many years had been standard references concerning historical earthquakes for the region. Into this improved database, gradually, over a long period of time and with the great help of Charles Melville, Jean Vogt, Caroline Finkel and Dominic White among others, I incorporated a much larger body of

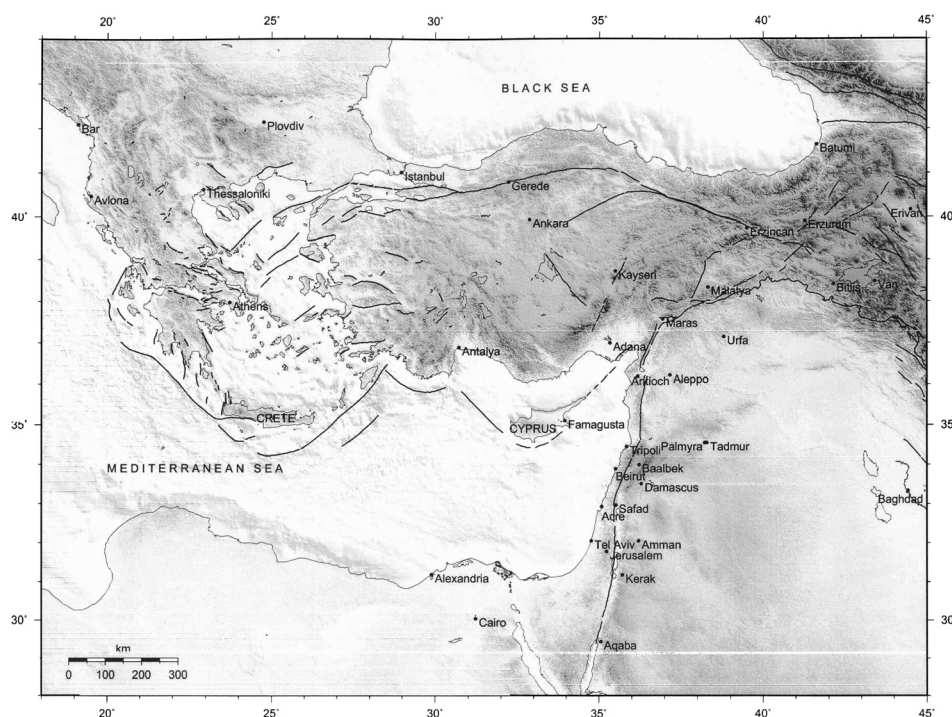


Figure 5 Major tectonic elements of the study region.

information from a wide variety of primary sources, both published and unpublished. We have gone to some lengths in the treatment of sources to point out the errors I perceive in some of these works, particularly recent. The intention towards their authors is not vindictive – rather I view this scientific debate as a positive step forward for the whole academic community involved.

The principal justification for returning to primary sources was to improve on previous interpretations, by adopting a consistent and systematic approach to all the pertinent material, which is easier to say than to do. In so doing, of course, one is not simply looking to verify the information of existing catalogues. Using the experience gained from field studies and applying knowledge derived from the available information and history of the region, which requires the appropriate specialist skills, invariably allowed an enormous increase in data, not only for known but in particular for previously unknown earthquakes.

Most of this information came from local historians and chroniclers. For the better-documented regions where ancient civilisations and developed cultures have flourished, information about earthquakes can go as far back as 2500 years ago. However, clearly, if such literary sources, which are written in both dead and living languages, are to be useful to modern science, they must be read and the evidence they provide must be subjected to a rigorous critical analysis, informed by an awareness of the nature of the evidence they provide and of the context in which they were written. If these sources tell us

enough about past earthquakes, we can, using modern techniques, estimate their size and location and the likely effects should they happen again. In the same way, identifying the time intervals between destructive earthquakes can help to establish a continuous or clustered pattern for their occurrence and for the long-term seismicity in that region.

Naturally, the prime purpose was not so much to investigate only the historical implications of earthquakes for the social, political and economic life of past centuries. Historiography and linguistic problems are relevant when they have a direct bearing on the understanding of the earthquake(s) being described, for example by revealing any bias or unreliability of the author concerned, the quality of information and the use he made of the earlier sources available to him. Purely historiographical research, interesting though it is, is ancillary in this context and is not the main end in itself. When we consider the diversity of sources, the diverse languages involved and the paucity of libraries of the relevant types of material, it is clear that such research is extremely time-consuming. This is especially true with respect to the retrieval of earthquake-related material from oriental sources.

The book is written with the Earth scientist, engineering seismologist, economist and ‘decision maker’ in mind, and aims primarily at producing a corpus of original information regarding the long-term seismicity of the Eastern Mediterranean and of the Middle East, the area

bounded by 28° and 44° N, and 18° and 44° E, shown in Figure 5. Some readers may find it disappointing that the book does not deal much with recent earthquakes or with their effects on modern types of structures or with purely seismological and engineering questions, but I must say that the bias towards other material is intentional.

The book reviews the basic principles of engineering seismology and of active tectonics, the field evidence for coseismic surface faulting and the uniform reassessment of earthquake parameters for early and recent events and, in a separate chapter, presents in some detail macroseismic information on historical earthquakes before 1900, which is the principal objective. This information is brought together with twenty-first-century knowledge of tectonics and seismology and with field observations regarding the vulnerability, chiefly, of early, old or rural structures, distilling this diverse information, which can then be used to calibrate and compare present-day earthquake activity with the seismicity of the region in earlier times.

This comparison is then used to assess, in general terms, earthquake hazard, i.e. the frequency of occurrence of past earthquakes, two of the most important factors in describing seismicity. It is shown that this will be possible only when historical information is converted into numbers representing the epicentral location and magnitude of the events concerned, accompanied by an estimate of the reliability of their assessment. It is shown that this can be done, making it possible to address fundamental questions such as the following. How can accounts of ancient events contribute to our scientific understanding of earthquake activity? When and where have earthquakes happened in the past? Is the instrumental record of the twentieth century a guide to past seismicity and earthquake hazard, and sufficient to allow us to predict what might be expected in the future? Fortunately, the region covered by this study is one of the very few that lends itself to such a long-term perspective, northeast China and perhaps Japan being similarly good candidates (Gu Gongxu *et al.* 1983, Utsu 1990).

Earthquake risk

The results from this work are important not only for the Earth scientist but also for the engineering seismologist and physical planner who are interested in the mitigation of natural risks. It is important that the notion of earthquake risk be understood at the outset.

As we will see, earthquake risks are created not only by Nature but also by man, who chooses hazardous sites on which to build vulnerable structures. Earthquake risk is also closely connected with our technological development. Although these risks cannot be prevented,

their magnitude and after-effects can be minimised. In order to mitigate risk one must first view the problem in its entirety, as originally defined by UNESCO in 1978 (Algermissen *et al.* 1979, Fournier d'Albe 1982). It is a multidisciplinary issue, in its simplest form best portrayed by the relation

$$[\text{Earthquake Risk}] = [\text{Earthquake Hazard}] \\ \times [\text{Structural Vulnerability}] \times (\text{Value}) \quad (1)$$

This equation tells us that earthquake risk is made up of the earthquake hazard, the vulnerability of the structure and the value or loss, each of which involves a range of specialities. The definition of risk makes a clear distinction between earthquake hazard, which deals with tectonics, seismology and engineering seismology, specialities that belong to the Earth sciences, and vulnerability, which is concerned with building materials, foundations, structural engineering and retrofitting, subjects that belong to the field of earthquake engineering. Note that in equation (1) the [Earthquake Hazard] and [Structural Vulnerability] terms must be interdependent functions.

Hazard, in its simplest definitions, is the chance of a damaging earthquake happening within a specific period of time and given area. Earthquake hazard is beyond human control, but an accurate knowledge of it, of its spatial distribution and, as far as possible, of its fluctuations in time, is essential for any rational assessment of risk. An important obstacle to the assessment of hazard at present is the lack of information about old earthquakes. Assessment of earthquake hazard is the subject matter of Earth sciences.

Vulnerability is the degree of structural damage or loss resulting from an earthquake of a given magnitude and is the subject matter of earthquake engineering. Vulnerability is determined by the physical characteristics of structures; it can therefore be controlled and reduced by appropriate action, though sometimes at a cost that must be justified by a diminished probability of loss.

However, while it is possible to control the vulnerability of new structures, it is difficult to estimate the vulnerability of existing buildings in which the great majority of people in seismic areas will have to live and work for a considerable time to come. Furthermore, the vulnerability of human settlements depends not only on that of individual buildings but also on that of all the essential services, such as transport, communications and water supply, which allow it to function. A further complication in seismic regions is the assessment of the vulnerability, which for man-made structures increases with time due to damage caused by near or distant earthquakes, improperly executed repairs and badly designed strengthening.

Measures to reduce vulnerability can be thought of either as long-term, e.g. earthquake-resistant design and construction, appropriate physical planning of settlements, or as short-term action in response to the post-earthquake exceptional hazard. The decision to undertake such measures will presumably be based on assessments of the risk to the community and on judgement as to whether these risks are acceptable.

Value may be taken either in the sense of capital value or in terms of the production capacity of a vulnerable element, such as lives and property, exposed to the hazard.

Area of study

The study is concerned with a relatively large area defined by the coordinates 28°–43° N in latitude and 18°–45° E in longitude, [Figure 5](#). This area includes Albania, part of Armenia, Bulgaria, Cyprus, upper Egypt, a part of Georgia, Greece, part of Iraq, Israel, Jordan, Lebanon, Macedonia, Montenegro, Palestine, Syria and Turkey, a region of high seismicity and well-developed tectonic activity, offering thus the opportunity for extensive field studies.

In studying this region from a long-term historical perspective one has to deal with more than a dozen languages but also with a relatively well-documented history for which there is a variety of source materials. The same applies to secondary sources, such as specialist studies on its history, geography and archaeology, and to scientific publications.

A note on transliteration

Place names are often spelt as they are written in the script of the country in which they are located; this generally involves a transliteration. Because of the fluctuating demarcation of boundaries over the long period covered, and because places formerly in one country were once in another, it is in practice necessary to refer to places as they were known in the historical context in which they were cited. Their equivalents are given as identified, together with other modern names conforming to the current indigenous spelling. In some areas names are given a standard spelling, chosen arbitrarily for its familiarity.

A note on chronology

Several calendars have been used to date earthquakes recorded in the Eastern Mediterranean region and in the Middle East, notably the Indiction (Ind.), Annus Mundi Alexandrian (A.M.Alx.), Annus Mundi

Byzantine (A.M.Byz.), Armenian with variations (Ar.), Muslim hijra (a.H.), Old Style (O.S.) and New Style (N.S.).

Details of these and others less frequently employed can be found in Grumel (1958), Freeman-Graville (1963), Altinay (1930) and Unat (1984), which have been used to convert dates in the Christian era. The Muslim Hijra calendar is lunar and began on 16 July AD 622. Conversions are calculated from the tables of Cattenoz (1961).

Throughout the book, dates are given in AD unless otherwise indicated.

In England the change from Julian or Old Style to Gregorian, New Style dating took place in September 1752. The Old Style system continued to be used by Greek Orthodox countries as late as the first decades of the twentieth century.

If the year of an event is given in an early calendar, the conventional year of the event shown at the head of an entry is the year which covers the greater part of the year.

Headings in square brackets indicate a spurious event.

Acknowledgements

It would be impossible to mention here the names of all the people and institutes that have provided information, facilities, or financial assistance over the years to carry out this work.

Initially this work included field studies, which were supported by the UN/USECO, consisting of well-designed fact-finding and follow-up missions of long duration after earthquakes. These missions had the advantage that because of their international character they enjoyed the full participation of scientists from host countries, transportation facilities and minimal restrictions on movement in the field.

Then followed an equally long period of low-budget field and desk studies, sponsored by the Natural Environment Research Council, UK (NERC), and the Engineering and Physical Sciences Research Council, UK (EPSRC), that also provided support for the analytical study of field observations such as local tectonics, assessment of strong ground motions, ground liquefaction, slope stability and post-earthquake planning.

My participation in major UN (UNDRO) reconstruction projects after earthquakes, such as of the city of Skopje over a period of six years, of Managua and shorter missions elsewhere in the region, added to the collection of additional field data about another, equally important aspect of earthquakes, that is, their impact on social and economic life, particularly in developing countries.

The late Dr Michael Fournier d'Albe of UNESCO, an Oxford scientist with an absurd sense of humour, did so much to make this work possible during its early and difficult stages that he must be mentioned before any other. Equally, I must admit that this book could not have been written without the great help I had over the years from Charles Melville, a Persian scholar in Cambridge, who once described his contribution to the project as that of a foster parent growing a child, from Caroline Finkel, a SOAS Ottoman historian who spent a long time digging into Ottoman archives in Istanbul, and in particular from my old collaborator Dominic, a Cambridge polymath classicist, now Fr. Dominic White OP.

The help I had in my field work from Dr John Tchalenko, a colleague from Imperial and an excellent organiser whose opinion commanded respect, was invaluable. I must also thank Rafi Freund, Ian Alpan and those alumni of Imperial College who helped in the field.

My early mentors, the late Alec Skempton and John Sutton of Imperial College, as well as Norman Falcon and Vladimir Belousov of the University of Moscow, were among those whose help and ideas in the early stages of this work contributed more than they realised.

I would like to thank James Jackson particularly for always being prepared to have his brain picked and also for his critical comments and contribution to some of the chapters of this book, particularly the chapter on tectonics.

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Finally, I find it rather embarrassing to see now that this work is loaded with a large number of references to my own work. I can assure the reader, however, that this was not done on purpose, or as a pretext to publicise the importance of my work.

The Academy of Athens provided final support for putting on record the results of this work, and I thank Cambridge University Press for publishing it.

Abbreviations

AAE	Archives du Ministère des Affaires Etrangères
AAE AA	Archives des Affaires Etrangères, Paris
AAE CCC	Correspondance Consulaire et Commerciale
AAO	Archivio Arcivescovile di Otranto, Otranto
ACCM	Archives de la Chambre de Commerce de Marseille
ACP	<i>Annales de Chimie et de Physique</i>
Act. Mor.	<i>Actes relatifs à la principauté de Morée</i> , Perrat Longnon, 1967
ADV N	<i>Arşivi Divan</i> , Istanbul
AE	Archives Nationales, Archives des Affaires Etrangères, Paris
AG	Archivo General de Simancas, Sección de Estado, Valladolid
AGAH	Archives du Ministère de la Guerre, Archives Historiques, Paris
AGS	Archivo General de Simancas, (S. Est) Sección de Estado
AMH	Archaeological Museum of Heraklion, Crete
AN	Archives Nationales, Paris.
AN AE	Archives Nationales, Paris. AE: Affaires Etrangères
AN BI	Archives Nationales, Paris. AE: Correspondance Consulaire
AN AMAE	Archives Diplomatiques, Nantes: Ministère des Affaires Etrangères
AN CADN	Centre des Archives Diplomatiques de Nantes
AND	Archives Diplomatiques, Nantes
Anecd. Brux.	<i>Anecdota Bruxellensia</i> , Brussels
ANK	Kadi Sicilleri, Ankara
ANM	Archives Nationales, Marine, Paris

ANSC	<i>Correspondences des consuls de France au Levant</i> ; BLW.P.D.482 & 482/1, and Svoronos, Paris, 1951	BBA MMD	Başbakanlık Osmanlı Arşivi
ARG	Allgemeen Rijksarchief te s'Gravenhage, The Hague	BBA ŞD	Maliyeden Müdevver Defterler
ASM	<i>Archivio ducale Visconteo-Sforzesco, potenze estere, Turchia; miscel.</i>	BBA Y	Başbakanlık Osmanlı Arşivi, Şikayet Defteri
ASV	Archivio di Stata di Venezia, Senato, Dispacci, Provveditori da Terra e da Mar	BBA YA	Başbakanlık Osmanlı Arşivi, Mtv.
ASV(P)	Archivio di Stato di Venetia, Provveditori da Terra e da Mar, Venice	BBL	Başbakanlık Osmanlı Arşivi, Hus
AtsGVI	Fond Tsentral'nogo Gosudarstvennogo Voenno-istoricheskogo Arkhiv, Moscow	BC	Breisgau Badisches Landesarchiv, Breisgau
BAAS	British Association for the Advancement of Science, Seismology Reports	BCH	Biblioteca del Museo Civico Correr, Venice
BAP	Bundesarchiv, Potsdam	BDP	<i>Bulletin de Correspondance Hellénique, Paris</i>
BASOR	Bulletin of the American School of Oriental Research	BEO	Deutsche Presseforschung, Universitätsbibliothek, Bremen
BBA	Başbakanlık Osmanlı Arşivi, Istanbul	BHA	Bulletin d'Etudes Orientales, Damascus
BBA A AMD	Başbakanlık Osmanlı Arşivi, Bab-i Asafi, Amedi Kalemi	BIFAO	Bayerisches Hauptstaatsarchiv, Munich
BBA AE	Başbakanlık Osmanlı Arşivi, Ali Emiri Tasnifi	BL	Bulletin de l'Institut Français d'Archéologie Orientale, Cairo
BBA CA	Başbakanlık Osmanlı Arşivi, Cevdet-Askeriye	BM	Bayazit Library, Istanbul
BBA CB	Başbakanlık Osmanlı Arşivi, Cevdet-Belediye	BMC	British (Museum) Library, London
BBA CD	Başbakanlık Osmanlı Arşivi, Cevdet-Dahiliye		British Museum Catalogue of Coins of the Roman Empire, 1923–, London
BBA CE	Başbakanlık Osmanlı Arşivi, Cevdet-Evkaf	BMCCV	Biblioteca del Museo Civico Correr di Venezia, Venice
BBA CM	Başbakanlık Osmanlı Arşivi, Cevdet-Maliye	BMV	Biblioteca Nazionale Marciana, Venice
BBA CS	Başbakanlık Osmanlı Arşivi, Cevdet-Saray	BN	Bibliothèque Nationale, Paris
BBA CT	Başbakanlık Osmanlı Arşivi, Cevdet-Tezakir	BNCF	Biblioteca Nazionale Centrale, Florence
BBA D BŞM	Başbakanlık Osmanlı Arşivi, Bab-i Defteri, Başmuhasebe Kalemi	BNL	Biblioteca Nacional, Lisbon
BBA D BŞM BNE	Başbakanlık Osmanlı Arşivi, Bab-i Defteri, Bina Emini	BRG	Bibliotheek Rijksuniversiteit Gent, Ghent
BBA ID	Başbakanlık Osmanlı Arşivi, Irade Dahiliye	BRT	Biblioteca Reale di Torino, Turin
BBA IE	Başbakanlık Osmanlı Arşivi, Ibnülemin Tasnifi	BSB	Bayerische Staatsbibliothek, Munich
BBA IMV	Başbakanlık Osmanlı Arşivi, Irade Meclis-i Vala	BSGRT	Bibliotheca Scriptorum Graecorum et Romanorum Teubneriana, Leipzig
BBA MD	Başbakanlık Osmanlı Arşivi, Mühimme Defter	BSN	<i>Bulletin des Sciences Naturelles</i>
		BSSI	<i>Bolletino della Società Sismologica Italiana, Rome</i>
		BV	Bibliothek Vadiana, St Gall
		BVI	<i>Bolletino Vulcanologia Italiana</i>
		CIG	Corpus Inscriptionum Graecarum, Berlin
		CIL	Corpus Inscriptionum Latinarum, Rome
		CMS	Church Missionary Societies Archives, Birmingham
		CNL	Cairo National Library, Cairo
		CRAI	<i>Comptes rendus de l'Académie des Inscriptions Belles-lettres</i>
		CRAS	<i>Comptes rendus de l'Académie des sciences, Paris</i>

CSCO	Corpus Scriptorum Christianorum Orientalium	LAS	<i>L'Astronomie</i> , Paris/Bruxelles
CSEL	Corpus Scriptorum Ecclesiasticorum Latinorum	LBS	Landesbibliothek, Stuttgart
CSHB	Corpus Scriptorum Historiae Byzantini, Bonn, 1828–1897	LCL	Loeb Classical Library, London
CSO, Ar.	Corpus Scriptorum Orientalium, Scriptores Arabici	LNL	Lenin Library, Zapiski Otdela Rukopisy, Moscow
CUL	University Library, Cambridge	MAT	Matenadaran Library, Yerevan
CWLIV	<i>Correspondenzblatt des Württembergischen Landwirtschaftlichen Vereins</i> , Stuttgart	MGHS (MGS)	<i>Monumenta Germaniae Historica Scriptores</i> , Berlin 1877–1898
DAW	Deutsche Akademie der Wissenschaften, Berlin, J. Schmidt Nachklaus 1859–1877	MIFAO	<i>Mémoires de l'Institut Français d'Archéologie Orientale</i>
DBM	Dijon Bibliothèque Municipale, Dijon	MKA	Milli Kütüphane, Ankara
DMA	Deniz Müzesi Arşivi, Istanbul	MKA KS	Milli Kütüphane, Kadi sicilleri
DSB	Deutsche Staatsbibliothek (E), Berlin	MLI	Millet Library, Istanbul
<i>EI</i>	<i>The Encyclopaedia of Islam</i> , Brill, 1960–	NH	<i>Neos Hellinonimion</i> , Athens, 1904–1930
EXP	<i>L'Exploration</i> , Paris, 1880	ODB	<i>Oxford Dictionary of Byzantium</i> , Kazhdan <i>et al.</i> (eds), OUP, 1991
EZB	Evangelisches Zentralarchiv, Berlin	PAA	Politisches Archiv des Auswärtigen Amts, Bonn
FGrH	<i>Fragmente der griechischen Historiker</i> , ed. F. Jacoby, Leiden, 1923–	PAAZ	<i>Amsterdamsche Argus</i> , Amsterdam
FHG	<i>Fragmenta historicorum graecorum</i> , ed. Muller, Langlois, Paris, 1883	PAC	<i>Augsburger Allgemeine Zeitung</i> , 1860–
FHTA	<i>Fragmenta historica Tusculana</i> , ed. Migne, PG 85	PAI	<i>Akropolis</i> , Athens, 1883–1899
FO (PRO)	Foreign Office, London	PAK	<i>Aion</i> , Athens, 1838–
FO SP (PRO)	Foreign Office, Special Papers	PAM	<i>Akhbar</i> , Algiers, 1870
GDI	<i>Sammlung der griechischen Dialekt-Inschriften</i> , ed. Collitz & Bechtel	PAN	<i>Amaltheia</i> , Smyrna, 1838–1922
HHL	Holkham Hall Library, Norfolk (before 1970)	PAOP	<i>Ankara</i> , Ankara, 1870
HHW	Haus-, Hof- und Staatsarchiv, Vienna	PAR	<i>Augsburger Ordinari Postzeitung</i> 1805–
ID	<i>Inschriften von Didyma</i>	PAT	Annual Register, London 1757–
IG	<i>Inscriptiones Graecae</i> , ed. Fraenkel, Berlin, 1902– (14 volumes)	PATH	<i>Anatolikos Tachidromos (& Astir)</i> , Constantinople, 1861–1891
IGR	<i>Inscriptiones Graecae ad res Romanas pertinet</i> , Cagnat, Paris, 1906–11	PAU	<i>Athena</i> , Athens, 1831–
IGSKl	<i>Inschriften griechischer Städte aus Kleinasien</i> , Merkelbach, 1972	PAV	<i>Augsburger Allgemeine Zeitung</i> , 1861–
IHB	<i>Inscriptions historiques de Byzance</i> , ed. Feissel, 1985, Berlin (1941)	PAZ	<i>Avgi</i> , Athens, 1858–
ILS	<i>Inscriptiones Latinae Selectae</i> , ed. Dawson, Berlin, 1872–1916	PBL	<i>Allgemeine Zeitung</i> , 1850–
ISC	International Seismological Centre, Edinburgh/Thatcham	PBM	<i>Bulgaria</i> , Sofia, 1859
IUL	Istanbul University Library, Istanbul	PBS	Agamennone, G. (1894–6)
JHS	<i>Journal of Hellenic Studies</i> , London	PBT	<i>Basiret</i> , Istanbul, 1870–
JOAI	<i>Jahreshefte des Österreichischen Archaeologischen Instituts</i>	PBU	<i>Bombay Times</i> 1851
JSAH	<i>Journal of Social and Architectural History</i>	PBW	<i>Biulgariia</i> , Constantinople, 1843–1864
		PCB	<i>Bremer Wochenblatt</i> , Bremen, 1812
		PCF	<i>Correspondenzblatt</i> , Stuttgart, 1830
		PCH	<i>Courrier Français</i>
		PCM	<i>Ceride-yi Havadis</i> , Istanbul, 1841–
		PCO	<i>Cosmos</i> , 1886–
		PCP	<i>Courrier d'Orient</i> , Constantinople, 1865–
		PCR	<i>La Constitutionnel</i> , Paris, 1766–1834
		PCS	<i>La Croix</i> , 1887
		PCU	<i>Le Courier de Smyrne</i> , Smyrna, 1829
		PCZ	<i>Le Courier Universel</i> , Paris, 1862–
		PDA	<i>Casseler Zeitung</i> , Kassel, 1829
		PDE	<i>Das Ausland</i> , 1835
			<i>Diarium Europei</i>

PDGA	<i>Dresdnische Gelehrte Anzeigen</i> , Dresden, 1756	PHCH	<i>Hellenika Chronika</i> , Mesolongi, 1824–1826
PEB	<i>Echo du Parliament Belge</i> , Brussels, 1867–	PHH	<i>Hollandsche Historische Courant</i> , Stadsarchief, Delft, 1754–
PEF	<i>Ephimeris</i> , Athens 1879–1892	PHL	<i>Illustrated London News</i> , London 1867–
PEH	<i>Extraordinaire Harlemse</i> <i>Donderdaegse Courant</i> , Amsterdam, 1688–	PHR	Historiae Relationis/Continuatio = PRHS
PEL	<i>Eleftheria</i> , Larisa, 1981–88	PHZ	<i>Havazelet</i> , Jerusalem, 1872–
PELP	<i>Elpis</i> , Athens	PIL	<i>L'Illustration</i> , Paris 1894
PEM	<i>Europische Mercurius (Nederlandsch</i> <i>Gedenkboek)</i> 1719–1766	PILN	<i>Illustrated London News</i> , London, 1894, no. 2876
PEMS	<i>Echo du Monde Savant</i> , Paris, 1831–	PIM	<i>L'Impartial</i> , Smyrna, 1848–1879
PEO	<i>Echo de l'Orient</i> , Constantinople, 1841–46	PIN	<i>Iran-i Nau</i> , Tehran, 1909–
PEP	<i>Ephimeris tis Prousis</i> , Prusa (Bursa), 1872–	PIP	<i>L'Institut</i> , Paris, 1860–
PEPB	<i>L'Echo de Parlement Belge</i> , Brussels, 1870	PIR	<i>Iran</i> , Tehran, 1880–
PEPT	<i>Epitheorisis</i> , Athens, 1878–1900	PIZ	<i>Illustrierte Zeitung</i> , Hamburg 1849–
PES	<i>Europische Staats-Secretaris</i> , 1754–	PJC	<i>Journal de Constantinople</i> , Constantinople, 1843–
PEST	<i>Estia</i> , Athens, 1891–	PJD	<i>Journal des Débats</i> , Paris, 1791–1869
PESY	<i>Ephimeris Syzitiaseon</i> , Athens, 1890–	PJH	<i>Journal Historique</i> , Paris, 1708–1783
PET	<i>Ethnophylax</i> , Athens. 1866–	PJOJ	<i>Jackson's Oxford Journal</i> 1780–
PETH	<i>Ethnophylax</i> , Athens, 1860	PJS	<i>Journal de Smyrne</i> , Smyrna, 1834–1838
PEXR	<i>Extraordinariae Relationes</i> , Cologne	PJT	<i>Journal de Salonique</i> , Thessaloniki
PEZ	<i>Ephimeris ton Syzitiaseon</i> , Athens, 1867–	PKA	<i>Karteria</i> , Syros, 1873–
PG	<i>Patrologia Graeca</i> , ed. J.-P. Migne, Paris 1857–1906	PKM	<i>Die katholische Missionen</i> , 1872–1905
PGB	<i>Gazzetta di Bologna</i>	PKRZ	<i>Keiserliche</i> <i>Reichsoberpostamtszeitung</i> , Cologne, 1766–
PGC	<i>Gazette de Cologne</i> , Cologne, 1767–	PKV	<i>Kavkaz</i> , Tbilisi, 1852–1883
PGF	<i>Gazette de France</i> , Paris, 1660–1855	PKZ	<i>Kölnische Zeitung</i> , Cologne, 1822–42
PGFU	<i>Gazetta di Fuligno</i> 1691	PL	<i>Patrologia Latina</i> , ed. J.-P. Migne, Paris 1844–1952
PGG	<i>Gazzetta di Genova</i> , Genova, 1820–	PLC	<i>The London Chronicle</i> , London, 1790–
PGI	<i>Giornale d'Italia</i> , 1766–	PLD	<i>Leydse Courant</i> , Leyden, 1728–1732
PGLO	<i>Gazeta de Lisboa Occidental</i> , Lisbon	PLE	<i>Logios Hermes</i> , Vienna 1815–
PGM	<i>Grazer Morgenblatt</i> , Graz, 1800	PLH	<i>Levant Herald</i> , Constantinople, 1874–1914
PGM	<i>Gentleman's Magazine</i> , London	PLI	<i>L'Institut</i> , Paris, 1843–
PGMD	<i>Gazette de Midi</i> , 1841	PLM	<i>al-I'lam</i> , Cairo, 1886–
PGMT	<i>Gazzetta di Mantova</i> , Mantova, 1710	PLN	<i>La Nature</i> , Paris, 1880–
PGRM	<i>Gazzetta di Roma</i> , Rome, 1636	PLS	<i>Lisan al-Hal</i> , Beirut, 1877–1932
PGRS	<i>Giornale del Regno delle due Sicilie</i> , Naples, 1854–	PLT	<i>Levant Times</i> , Constantinople, 1874–
PGS	<i>Giornale del Regno delle due Sicilie</i> 1854–	PLZ	<i>Leipziger (Illustrierte) Zeitung</i> , Leipzig, 1829–
PGU	<i>Gazette d'Utrecht</i> , Utrecht, 1769	PMA	<i>Moniteur Algérien</i> , Algiers 1855–
PGUV	<i>Gazzetta Uffiziale di Venezia</i> , Venice	PMC	<i>Les Missions Catholiques</i> , Paris, 1869–
PGV	<i>Gazzetta di Venezia</i> , Venice, 1625	PMdF	<i>Mercur de France</i> , Paris, 1718–1790
PGZ	<i>Gothaische Zeitung</i> , Gotha, 1826	PME	<i>Mercurio de España</i> , Madrid, 1785–
PHB	<i>Historischer Bildersaal</i>	PMF	<i>Mercur Français</i> , Paris, 1612–1640
PHC	<i>Hamburger Correspondenz-Blatt</i> , Hamburg, 1830–	PMG	<i>Naval and Military Gazette</i> , Malta, 1850–

PMH	<i>Mercurius Historicus</i> , 1712	PRHS	<i>Relationis Historiae Semestrialis/</i>
PMHp	<i>Mercure Historique (et Politique)</i> , Paris, 1692–1791		<i>Continuatio</i> 1598–1737
PMHP	<i>Mercurio Historico y Politico</i> , Madrid, 1760–1782	PRO	Public Records Office, Chancery Lane/Kew
PMK	<i>al-Muktataf</i> , Cairo, 1877–	PRO PR	Public Records Office, Kew
PMN	<i>Messiniaka Nea</i> , Athens, 1967	PRV	<i>Ruznameh-yi vaqa'i-yi ittifaqiyyeh</i> , Tehran, 1851–1860
PMO	<i>Moniteur Ottoman</i> , Constantinople, 1832–1841	PSA	<i>Samos</i> , Samos, 1872–1875
PMSH	<i>Missionary Herald</i> , 1835–1882	PSB	<i>Sabah</i> , Istanbul 1894–
PMT	<i>The Malta Times</i> , Malta, 1850–	PSC	<i>S'Gravenhaege Courant</i> , The Hague, 1756
PMU	<i>Moniteur Universel (Moniteur)</i> , Paris, 1790–1863	PSO	<i>Stoa</i> , Athens, 1879–1884
PMV	<i>Moskovskoe Videnie</i> , Moscow, 1839–	PST	<i>Stambul</i> , Constantinople, 1876–1893
PMZ	<i>Mamuret al-Aziz</i> , Istanbul, 1882	PSV/PSVG	<i>Selaniki Vilayet Gazetleri</i> , Solun, 1868–
PNA	<i>Neologos tis Anatólis</i> (<i>Constantinopleos</i>), 1867–1899	PSW	<i>Der Schweizerbote</i> , 1815–
PNAV	<i>Nouvelles Annales des Voyages</i>	PSX	<i>Salpinx</i> , Larissa 1890–
PNC	<i>Neologos Constantinoupoleos</i> , 1870–	PTA	<i>Tercuman-i Ahval</i> , Istanbul, 1862–
PNB	<i>Der neue Weltbote</i> , 1727	PTE	<i>Theatrum Europaeum</i> , Frankfurt, 1617–1721
PND	<i>Nederlandsch Mercurius</i> , The Hague, 1766–	PTH	<i>Tercuman-Hakikat</i> , Istanbul, 1881–
PNDM	<i>Notizie del Mondo</i> , 1768–	PTI	<i>Theatis</i> , Athens, 1936–
PNE = PNEX	<i>Nouvelles Extraordinaires</i> , 1762	PTL	<i>Telegraphos tou Vosporou</i> , Constantinople
PNEE	<i>Nea Ephimeris</i> , 1886–	PTM	<i>The Times</i> , London
PNF	<i>Nea Efimeris</i> , Athens, 1883–1892	PTS	<i>Tasvir-i Efkar</i> , Istanbul, 1863–
PNH	<i>Natur und Heilkunde</i> , Weimar, 1833–	PTT = PT	<i>The Times</i> , London, 1790–
PNL	<i>Neologos</i> , Athens, 1874–	PTV	<i>Takvim-i Vekayi</i> , Istanbul, 1833–
PNM	<i>Nordischer Merkur</i> , Hamburg, 1667–	PUB	<i>L'Union Bourguignonne</i> , 1859–
PNP(R)	<i>Nederlandscher Postryder</i> , 1749–	PUZ	<i>Ulmer Zeitung</i> , Ulm, 1930
PNT	<i>Nature</i> , London, 1871–	PVE	<i>Veltiosis</i> , Athens, 1860–
PO	<i>Patrologia Orientalis</i> , various editions, Turnhout	PVI	<i>Vaqai Ittifaqiyyeh</i> , Tehran, 1851–
POB	<i>Oesterreichischer Beobachter</i> , 1817	PWB	<i>Wöchentliche Bönische Anzeige</i> , Bonn, 1766–
POH	<i>Oprechte Harlemse Saturdaegse</i> <i>Courant</i> , Amsterdam, 1688–	PWD	<i>Wieneriches Diarium</i> , Vienna, 1750–
PON	<i>Opinion Nationale</i> , 1835	PZM	<i>Zhurnal Ministerstvo Vnutrennosti</i> <i>Del'</i> , Saint Petersburg, 1840–
POR	<i>Ora</i> , Athens, 1880–1885	PZOM	<i>Zeitschrift Österreichischen</i> <i>Gesellschaft für Meteorologie</i> , Vienna
PORR	<i>Ordinariae Relationes</i> , Köln, 1766		The Queen's College Library, Oxford
PPA	<i>Pandora</i> , Athens, 1850–	QCO	<i>Regestes des Délibérations du Sénat de</i> <i>Venise</i> , Thiriet, Paris, 1961
PPL	<i>Paligenisia</i> , Athens, 1870–	RDSV	<i>Recueil des historiens des Croisades</i> , Académie des Inscriptions
PPO	<i>Press d'Orient</i> , Constantinople, 1854–	RHC	<i>Belles-lettres</i> , Paris
PPR	<i>Parnassos</i> , Amfissa 1867		<i>Recueil des historiens des Gaules et de</i> <i>la France</i> , Paris
PPS	<i>Preußische Staatszeitung</i> , 1825	RHG	<i>Rerum Italicarum Scriptores</i> , ed. L. Muratori, Milan, 1723–1751
PPV	<i>Pravitel'stvennii Vestnik</i> , Saint Petersburg, 1883–	RIS	<i>Revue de l'Orient chrétien</i>
PPY	<i>Pythia</i> , Amfissa, 1871	ROC	<i>Staatsarchiv</i> , Hamburg
PRCH	<i>Ruzname-y Ceride-y Havadis</i> , Istanbul, 1860–	SAH	<i>Staatsarchiv</i> , Wiesbaden
PRD	<i>Ruznameh-yi daulat-i 'aliyyeh-yi Iran</i> , Tehran, 1860–1871	SAW	<i>Staatsbibliothek</i> , Berlin
PRG	<i>Rumeli Vilayet Gazetesi</i> , 1872–	SBB	<i>Supplementum Epigraphicum</i> <i>Graecum</i> , Leiden, 1923–
PRGV	<i>Rumeli Vilayet Gazetesi</i> , 1870	SEG	
PRH	<i>Ruzname-y Ceride-y Havadis</i> , Istanbul, 1868–		

SGUA	<i>Sammelbuch griechischer Urkunden aus Ägypten</i> , Preisigke, 1926	SSB	Staats- und Stadtbibliothek, Augsburg
SHA	<i>Scriptores Historiae Augustae</i> (LCL)	T. Cam.	<i>Tituli Camirenses</i> , ed. S. & P. Caratelli, Rome, 1952
SL	Süleymaniye Library, Istanbul	TKSA	Topkapi Sarayi Archives, Istanbul
SLRI	<i>Scriptores Rerum Langobardicarum et Italicarum</i>	TKSL	Topkapi Sarayi Library, Istanbul
SOAS	School of Oriental and African Studies Library, University of London	UD	Universitätsbibliothek Düsseldorf
SOC	<i>Scriptores originum Constantinopolitarum</i> , ed. Preger, Leipzig, 1907	UML	University of Malta Library, Msida
SRG	<i>Scriptores rerum Germanicorum</i>	WIL	Wellcome Institute Library, London
		WLB	Württembergische Landesbibliothek, Stuttgart
		ZL = VZ	Zagora Library, Zagora
		ZZB	Zürcher Zentralbibliothek, Zurich

1

Macroseismic information

1.1 A brief description and evaluation of documentary and archaeological source material

The sources on which we relied for the early period were of three types, archaeological, epigraphic and literary, whereas for later periods the chief sources were literary.

Archaeological data

With archaeological information one has to be very cautious when using it to locate and in particular to date earthquakes. I found that dating was frequently based on, or influenced by, literary sources, which often provided examples of how their assumed accuracy, coupled with inaccurate commentaries, has influenced archaeologists' interpretation and dating. This has developed into a circular process in which archaeological theories were transformed into facts and used by scientists to confirm the dates of their events.

Archaeological evidence for an earthquake is not always unambiguous. Displaced, leaning, damaged or collapsed walls in an excavation or in extant historical monuments are features that are often assigned by archaeologists to an earthquake as a *deus ex machina*. However, they can be due to other, non-seismic, causes such as differential settling, particularly arising from leaching or weathering of the foundation materials over the ages, a deterioration process that may be assisted by occasional earthquakes, particularly when these structures have been rendered more vulnerable by deliberate damage and acts of warfare. This is why the observed fractures in walls and pavements may wrongly be attributed to earthquakes. Damage can also be the result, perhaps cumulative, of more than one earthquake, even a long while after the abandonment of the site.

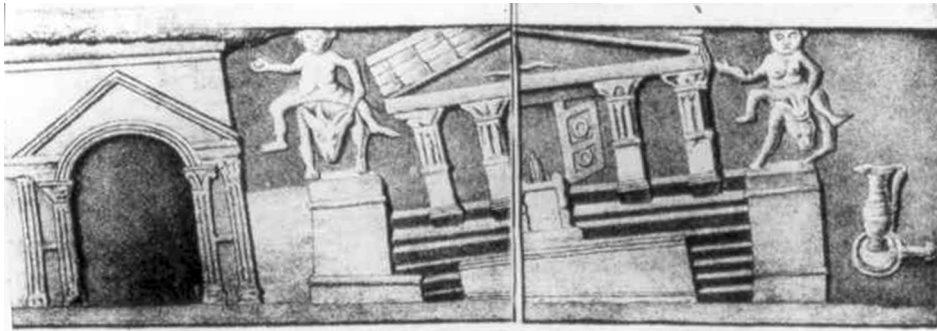


Figure 1.1 Pompeii relief.

Epigraphs and inscriptions

One of the earliest inscriptions is a letter from Nineveh describing an Assyrian earthquake in the eleventh century BC, see Figure 3.1. It says...*on 21 Elul an earthquake took place; all the back part of the town is down; all the wall at the back of the town remains except 30.5 cubits therefrom being strewn and fallen on the near-side of the town; all the temple is down... let the chief architect come to inspect...* (BM 123358: TH.1932-12-10,301).

Perhaps the most representative relief of an earthquake is that shown in Figure 1.1, which depicts the temple of Jupiter in Pompeii in the act of falling during the earthquake of 5 February 62 AD.

For some of the early events, information comes from inscriptions that explicitly mention earthquake destruction or extensive repairs after an earthquake. Epigraphic material may also refer to remission of tribute or taxes following an earthquake. The practice of inscribing such public proclamations on the walls of mosques in Iran, for example, is attested in the late seventeenth century and doubtless continued beyond that time, though no examples involving earthquakes are known. Since they are almost always contemporary, inscriptions provide valuable and indisputable evidence for the location and, quite often, the effects of earthquakes, which, either because of the remoteness of the site or for other reasons, are not recorded in literary sources. Following the same principle for epigraphy as for literary sources, excursions into linguistic or literary questions are, for present purposes, useful only when they contribute to our understanding of the earthquake in question.

Literary sources

In contrast with historical earthquakes after the Middle Ages, for which there is much unpublished information awaiting retrieval from archives and repositories, for the Classical and Roman periods in the BC era all the sources are well known, of a limited number and

published. This makes it feasible to examine the original sources rather than relying on the interpretations of modern cataloguers, in order to guarantee a homogeneous and complete body of data, free of duplication and exaggerations, and thus suitable for assessing seismicity with an accuracy adequate for scientific and applied purposes.

Later periods

For later and more recent periods, and for most areas, information becomes fuller and the sources of historical data more numerous as we approach modern times. Partly, this is a function of the greater survival rate of relevant documents. In the Middle East, the accumulation of material in European and Middle Eastern sources greatly extends the opportunities for retrieval of 'new' information from old records. Partly, also, it reflects the increased production of written material and, in the European context, the growth in literacy and secular learning associated particularly with the Renaissance. Commensurate with this is a broadening of the range of sources that may preserve accounts and details of earthquake activity.

Chronicles and annals remain the preponderant source of such data, in some areas in the East even well into the twentieth century for Arabic works, supplemented only occasionally by biographical, geographical or topographical works. In contrast, European writings provide an ever-growing volume and range of data. Compilation of chronicles gives way to antiquarian study, travel literature, private diaries, personal letters and official archives, including diplomatic correspondence.

By the eighteenth century in Europe and the nineteenth century in the Eastern Mediterranean and the Middle East, newspapers (the modern equivalent of the annals of old, in their indiscriminate reportage of ephemera, trivia and the sensational alongside matters of serious material or moral concern), provide an accurately dated and reasonably full record of newsworthy events (as differently perceived in various places and at different

times). It is symptomatic of cultural changes since the First World War that, as instrumental, electronic or other mechanical reporting of events has grown, and news is increasingly disseminated by radio and television, a parallel decline is visible in both the volume and the quality of documentary and descriptive accounts of earthquakes in the twentieth century. While such information allows considerable gains to be made, much material is still unpublished, often difficult of access and hard to read.

There is no doubt that much remains to be discovered in Middle Eastern archive collections, particularly in Turkey and Egypt. Such work is time-consuming and presents serious hurdles. Nevertheless, pursuit of such data in recent decades has spawned a new generation of earthquake catalogues and studies of regional seismicity.

Insofar as **European (Occidental)** sources are concerned, in contrast with the period after around 1400, for Classical, Roman and Byzantine times almost all the sources are well known, and they are relatively limited in number and mostly published. This makes it feasible to re-examine the original sources, rather than rely exclusively on modern cataloguers, who may have been working from a variety of different standpoints. The result should be a body of data that is homogeneous and as complete as possible, free of duplications and exaggerations, and therefore suitable for assessing seismicity with accuracy adequate for scientific and applied purposes.

The main **Arabic** historical sources too, while relatively numerous in the 'classical' age of the Islamic period, that is from approximately the eighth to the thirteenth century, have generally been identified and published. These are for the most part narrative histories, usually arranged in annals, which report events in a precise chronological framework.

However, little or no archival material survives from this early period. Many works known to have been composed have not been discovered, but such information as they may have contained about earthquakes has very probably survived in the work of later annalists.

The most significant events are frequently recorded, with characteristic details, by several authors. Critical comparisons of the various accounts are normally sufficient to identify and resolve small inconsistencies in dating, which have often found their way into modern earthquake catalogues (see, for one example, Ambraseys & Melville (1988)).

The **Ottoman** archival material utilised for the present study consists for the most part of the documents from the Maliyeden Müdevvar (MMD) series in the Ottoman central archives, the Başbakanlık Osmanlı Arşivi (BBA) in Istanbul. This is an important source of

information since the Ottoman empire covered the whole of the study area for most of the time of interest.

These documents are in registers into which they were copied for the records of the central bureaucracy and are extremely disparate in topic, but have in common that they all concern financial matters, as do most of the other Ottoman documents utilised here. The aim of the writers of the documents which refer to earthquake damage was chiefly to assess the exact cost for the repair or reconstruction of structures affected by the shock, to dictate the administrative route to be followed in effecting the repairs and to ensure that the money assigned was spent as decreed.

Another series of Ottoman documents, which might have been useful and have given further information from different sites, is the records of the kadi courts, but these cannot easily be located.

Among the most detailed documents are those relating to the repair of public buildings, in which are found a record of the dimensions of the damaged part of a structure and a complete accounting for the costs involved. The material relating to each event located is copious, but in isolation is of little value since it almost always relates to damage to individual buildings and in particular to military structures. It is only rarely that there is any reference to damage elsewhere or to casualties and material losses. So, for the region and later period under investigation here, such vital features of an earthquake must be retrieved from these types of non-Ottoman or Venetian sources.

Most Ottoman documents relating to earthquakes provide no date for the events they describe and only a *terminus ante quem* can be established from the date of their issue. This makes it almost impossible to establish simultaneity, so the association of such information with earthquakes known from other sources can only be tentative. Some of the cases may relate to the same event but at present there is not sufficient information to justify their amalgamation, or their association with known events.

Another difficulty in assessing the severity or grade intensity of an earthquake at a particular locality is that in many cases earthquake damage in Ottoman documents is reported together with damage arising from other causes, such as ageing, weathering, neglect and military operations, or as the result of more than one earthquake.

The collapse of or damage to a dilapidated building therefore is not always an indication of severe earthquake shaking but rather a measure of the vulnerability of the structure. Large, distant earthquakes can destroy buildings of this class at distances of hundreds of kilometres from where the earthquake happened,

particularly those built on soft and saturated ground, and their collapse can give the false impression of severe shaking. The lack of interest of the Ottoman administration in the maintenance of public buildings then contributes to false or exaggerated estimates of intensity.

Events known only from Ottoman sources and their retrieval provide a clue to direct further research. We have found it to be the case that while many large known earthquakes go unmentioned in the Ottoman sources, equally, even what are clearly large earthquakes may remain undocumented except in Ottoman sources. Nevertheless the contribution of Ottoman and Venetian source material is of significance in cases where more macroseismic information is added to that for poorly known events. This not only improves the understanding of the location and size of the earthquake in question but also increases the reliability of the estimates.

When we consider the diversity of sources, the numerous languages involved and the paucity of libraries of the relevant types of material, it is clear that such research is extremely time-consuming. This is especially true with respect to the retrieval of earthquake-related material from Ottoman sources.

Venetian archival sources cover a long period of observations, chiefly from coastal regions of the north-east part of the Mediterranean. They provide interesting, although not always useful, information, since these registers and correspondence refer, like some of the Ottoman material, only to the rebuilding and repair of those structures, chiefly defensive, which were of interest to the Republic of Venice.

Venetian correspondence relating to earthquakes shares some of the same characteristics: both Ottoman and Venetian sources suffer from a lack of information regarding non-pecuniary matters, the very information which is of most interest to the scientist. Both Ottoman and Venetian documents rarely name affected sites other than those that had petitioned for or required financial assistance for repairs or reconstruction, seldom mention casualty figures and hardly ever list sites at which an earthquake was felt without damage.

In general each type of source reflects the concerns of its author. In contrast with the narrow administrative concerns of the Ottoman and Venetian bureaucracy, the contemporary accounts of merchants and travellers, for instance, provide an impressionistic and personal picture of the effects of an earthquake, often grossly exaggerated, while the authors of church records are often careful in giving the date of an event, which the Ottoman records usually do not. Consular reports and newspapers give a wider view of the event but are few until well into the seventeenth century.

1.2 Descriptive and parametric catalogues

There is a large number of descriptive and parametric, global, regional and country-specific catalogues of historical earthquakes. Obviously the value of parametric catalogues will be only as good as that of the descriptive catalogues. The following descriptive earthquake catalogues are published and readily available.

Manetti's work is the earliest-known compendium of earthquakes and contains an annotated list of earthquakes in the Eastern Mediterranean and elsewhere up to 1456. Manetti does not always cite his sources and quite often the year of an earthquake is recorded only by reference to other events.

Al-Suyuti's earthquake catalogue was compiled in the early part of the sixteenth century and extended by his continuators to the year 1588. It is a reliable source of information for the Muslim world, covering the region from Morocco to Transoxania (Sprenger 1843, Ambraseys 1961, Sa'adani 1971).

Bonito's large world earthquake catalogue is an invaluable compendium of information about earthquakes that ends with 1690. Its 822 pages contain a wealth of information culled from a variety of sources, which Bonito quotes and occasionally annotates. His work provides an excellent starting point for the identification of earthquakes in Europe and in the New World (Bonito 1691).

Coronelli's work, although prepared as a global catalogue of earthquakes up to 1693, deals mainly with events in the central and eastern Mediterranean. Annotations are kept very brief, making no reference to sources of information and occasionally neglecting to give the full date of an event (Coronelli 1693).

An anonymous compilation of earthquakes throughout the world was published in a series of issues of the *Dresdenische Gelehrte Anzeigen* in 1756, and is a useful source of information for earthquakes worldwide during the sixteenth and seventeenth centuries up to 1691 (PDGA 1756).

Von Hoff's general catalogue of earthquakes is a valuable work, covering events worldwide for the period up to the end of the seventeenth century. It is an accurate and methodical study, drawing on a variety of published sources, which are cited (Hoff 1826–35).

The compilation of Seyfart's work on earthquakes was prompted, like many similar works of the mid eighteenth century, by the large Lisbon earthquake of 1755. It contains interesting entries, mostly extracted from published material in Europe, such as flysheets and

newsletters, as well as from the European press (Seyfart 1756).

Berryat's long chronological list is an annotated collection of information about earthquakes up to 1760. The author does not cite his sources but they seem to include, among others, earlier catalogues and information from the European press (Berryat 1761).

Von Hoff compiled twelve annual earthquake catalogues for the years 1821–32. He extracted much of the information from press reports, travel diaries and correspondence. His work is of interest for areas outside Europe (Hoff 1840–41).

Mallet's catalogue occupies nearly 600 pages and contains almost 7000 events worldwide. Although it is based on several earlier catalogues, especially those of Hoff and Perrey, his catalogue for the period after the seventeenth century contains a considerable amount of information from relatively early press reports, some of which are useful for investigating the seismicity of the Americas and the Far East (Mallet 1850–58).

Perrey's annual lists of earthquakes for the 28 years 1844–71 are invaluable. They occupy 28 papers and the total number of pages in these *Mémoires* is just over 2500. Perrey collected much of the material by correspondence and also gleaned information from the international press. His annual lists are a vast storehouse of facts; for the most part he was content to leave discussion of the results to others. There is seldom any attempt to determine the position of the epicentre, and none to discover the relation between main shock and aftershocks or the relation between shocks felt at the same time at different places (Perrey 1848–75).

Schmidt's catalogue for the Southern Balkans and Asia Minor is one of the most important sets of data for the region. It depends very little on previous lists or catalogues and, from about 1800 onwards, is the result of his own labours. From after about 1858 to the end of 1878, his catalogue contains just under 4000 entries, derived chiefly from correspondence with observers, travellers and consuls throughout the Eastern Mediterranean and from the press in Athens, Istanbul, Izmir and other places in the area (Schmidt 1867a, b, 1879).

A long memoir containing lists of earthquakes for the 20 years 1865–84 was published by Fuchs. These lists include nearly 10 000 entries altogether, containing a substantial amount of information for earthquakes worldwide. In common with some other catalogues, this work must be used with caution, for nowhere does Fuchs cite his sources and it is accordingly difficult now to appre-

ciate the value of the information which he retrieved (Fuchs 1886).

Mushketoff and Orloff's earthquake catalogue for the Russian empire ends in 1888. It is based on previous catalogues but also on contemporary national and local Russian press reports and, to a lesser extent, on unpublished documents. Events are fully annotated and sources are given in full. This is a very useful source of information (Mushketoff and Orloff 1891).

Milne's world catalogue of destructive earthquakes up to 1899 is based entirely on previous lists. It is devoid of information from original sources, except for the first decades of the period for which information comes from unpublished documents (Milne 1911).

Montessus de Ballore's world catalogue consists of 171 434 entries covering the period up to 1906. Only a small fraction of this enormous volume of information, which covers mainly the second half of the last century, has been published, and it remains little known. However, the published information is not of very great value; the unpublished files, kept in the *Département des Cartes et Plans, Depot de la Société de Géographie* of the *Bibliothèque Nationale* in Paris, where they occupy 30 metres of bookshelf, did not prove, on examination, to be as useful as had been expected. Much of the information in these files was extracted from previous catalogues and press reports, with little original material derived from correspondence with observers (Ballore 1900, 1905, 1924, 1925).

Sieberg's annotated world catalogue of earthquakes contains a considerable amount of information, including isoseismal maps for the larger historical earthquakes worldwide up to 1930. His work, he admits, is subjective, influenced by his experience as a professional architectural engineer who in the first quarter of the twentieth century visited many sites of earthquakes. He was one of the first in Europe to test models of buildings on shake-tables.

However, his catalogue contains many errors and duplications in entries and gives little indication of his sources of information, despite which this highly inaccurate work has for many years been regarded as a standard reference on the subject (Sieberg 1932a, b).

Stepanian's annotated catalogues of earthquakes in Greater Armenia are a useful set of documents. They are based on a considerable number of primary published Armenian sources. These Armenian catalogues of Stepanian are little known; they are accurate and methodical, and contain about 800 events (Stepanian 1942, 1964).

Byus' book of earthquakes in the Caucasus and adjacent regions is a systematic compilation of information from previous catalogues, in some cases critically selected, as well as from local Georgian, Armenian and Russian sources, including local newspapers and reports. This 600-page-long work contains a wealth of information about events in the Middle East (Byus 1948).

Rethly's book of earthquakes in the Carpathian region and central Europe is a serious piece of work. It includes extracts from original sources and is fully referenced. This work is invaluable for the identification of events that affected southeast Europe (Rethly 1952).

Ambraseys' three-volume *Corpus of Documents* of early earthquakes in the Near and Middle East is a collection of little-known Greek, Arabic and Syriac sources of information, compiled for UNESCO during the period 1961 to 1970 in Ambraseys (1970b), *Early Earthquakes in the Near and Middle East 17–1699 AD*:

Part I: *Documentation of Historical Earthquakes in the Middle East*, UNESCO Report SC/1473/1969, 410 pp.;

Part II: *Historical Earthquakes after 17 AD*, UNESCO Report SC/2129/1970, 45 pp.;

Part III: *North Africa and South-east Europe*, UNESCO Report SC/2129/1970, 40 pp.

The survey of the seismicity of the Balkan region carried out by UNESCO in the mid 1970s contributed a summary of the material available at that time for the assessment of regional seismicity. Isoleismic maps for a few events before 1900 and a parametric catalogue were published, but they must now be used with caution (Shebalin, Karnik and Hadzijeovski 1974).

The catalogues of earthquakes in the Middle East and along the Dead Sea Rift by Ben-Menahem (1979, 1991) contain information extracted from earlier catalogues of varying quality and from secondary works. These lists, which include a parametric catalogue going back to 2050 BC, must be used with very great caution.

The earthquake catalogue of the former USSR covers a large geographical area for the period before 1977 (Kondorskaya and Shebalin 1982). It is based chiefly on secondary macroseismic sources but includes a detailed procedure for the systematic quantification of historical events.

The catalogue of Poirier and Taher (1980) covers the seismicity of the Middle East, listing nearly 200 events up to 1800. It summarises information taken from a thorough survey of Arabic source material, presented in Taher's doctoral thesis at the Sorbonne (Taher 1979). References are properly identified and cited. Though the

catalogue contains various errors and duplications, this is a considerable improvement on earlier works. A more extended summary of the primary data, although regrettably without any reference to modern studies of the last two decades, is currently in progress (Taher 1996).

A useful catalogue by Russell (1985) for Palestine in the period up to the mid eighth century presents the texts of the accounts of earthquakes in the region from contemporary sources and attempts to resolve discrepancies in dating. The catalogue also provides archaeological evidence of damage that has been adduced to support the dating of some of these events, or to be dated by them.

The books by Ambraseys and Melville (1982) and Ambraseys *et al.* (1994) present a thorough re-evaluation of the long-term seismicity of Iran, Saudi Arabia and the Red Sea, based as far as possible on primary Persian, Arabic and occidental sources. These works present in some detail the methodology proposed to assess historical seismicity by combining instrumental data and macroseismic information.

The paper by Guidoboni (1989) is a descriptive catalogue of information on earthquakes in Italy and in the eastern Mediterranean as a whole and covers the period from the eighth century BC to the tenth century AD. Events are annotated and texts originating from sources in Greek and Latin are given in their original script with a translation into Italian. Generally no attempt is made to discuss and assess the seismological aspect of the information it presents.

The part of the Catalogue (and Map) of the Global Seismic Hazard Assessment Programme (GSHAP 1992, Giardini 1999) that refers to the eastern Mediterranean region is the result of a compilation of heterogeneous data taken from a kaleidoscope of national catalogues.

The book by Ambraseys and Finkel (1995) covers Turkey and parts of the Middle East for the period from 1500 to 1800. Its value is chiefly the presentation of unpublished Turkish and occidental sources of information for this period about earthquakes.

The catalogues of Papazachos and Papazachou (1989) cover the historical seismicity of Greece and adjacent regions. These are annotated compilations essentially based on previous catalogues without scrutiny, adding little or no new information.

The book by Guidoboni, Comastri and Traina (1994) deals with earthquakes in the Mediterranean area up to the tenth century AD. Events are annotated and texts originating from sources written in Hieroglyphic, Greek, Hebrew, Latin, Syriac, Coptic,

Armenian, Aethiopic and Arabic are given in their original scripts with a translation into English, obviously for the very many readers who are not familiar with these languages. The book is decorated with maps, figures and photographs.

The work by Spyropoulos (1997) is an exhaustive annotated corpus of extracts from original but chiefly secondary sources relating to historical earthquakes in Greece.

Sbeinati, Darawcheh and Mouty (2005), ‘The historical earthquakes of Syria: an analysis of large and moderate earthquakes from 1365 BC to 1900 AD’, *Annals of Geophysics*, **48**, 347–435.

The book by Guidoboni and Comastri (2005) consists of a compilation of information about earthquakes in the Eastern Mediterranean region and in the Middle East over the period 1000 to 1499. This impressive catalogue is 1037 pages long. It is written in the same style as the earlier book by Guidoboni, Comastri and Traina and lists 383 events, of which 154 belong to Italy and 229 to the rest of the region.

The existence of all these readily available descriptive catalogues does not, of course, mean that no further research remains to be done and no new sources remain to be discovered. A catalogue at best can sum up the state of knowledge at the time it was written, and provides a basis for new work with a view to promoting knowledge of studies on local seismic activity and to evaluating their contribution to the previous state of knowledge.

Unfortunately, some authors of twentieth-century descriptive catalogues then go on to do a disservice to the study of historical seismicity and go backwards rather than forwards. Their work, which is supposed to be a critical review of the data and a comparative study of seismicity, becomes in fact neither critical nor comprehensive in scope. They accept much of what previous catalogues say without further inquiry, and no attention is paid to other recent works devoted to the seismicity of the region except for their own published work. Despite the fact that some of these works epitomise the twentieth-century trend towards indiscriminating cataloguing, they have been standard references on the subject for historians, archaeologists and Earth scientists.

Early descriptive catalogues are few and necessarily summary, and cannot go into all the details that exist in manuscripts, tracts and pamphlets, which are numerous and difficult to locate.

There is relatively little I could find in unpublished manuscripts, much of which is in short, almost tele-

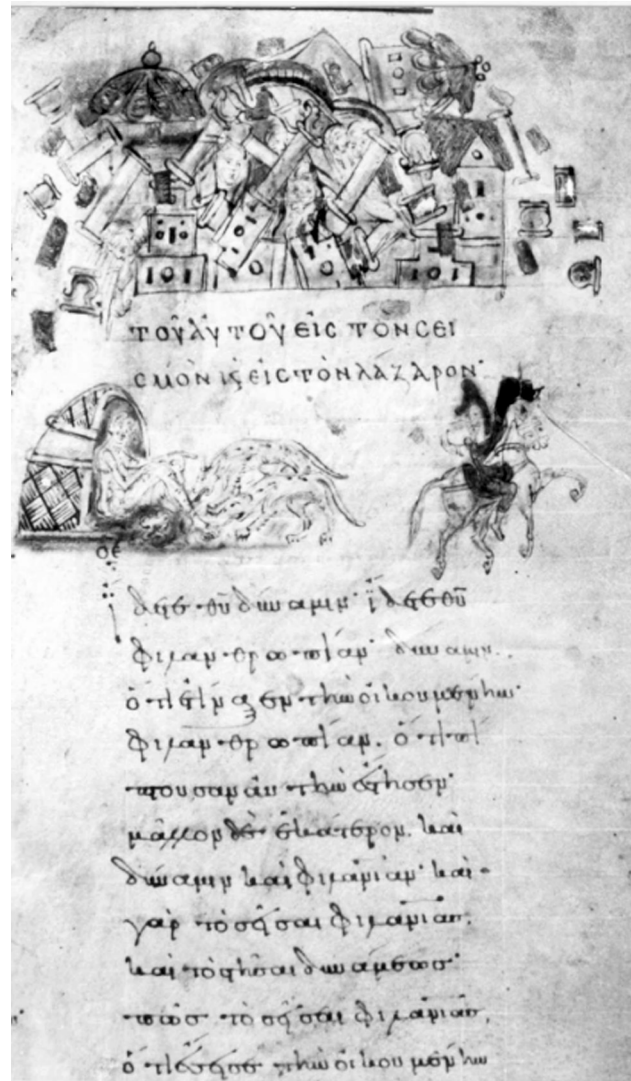


Figure 1.2 A manuscript depicting the horrors of earthquakes (Exposition de l'Art Byzantin, no. 350, Athens 1964).

graphic, notices, see Figure 3.12, or in general references of the period from the fourteenth to the sixteenth century to events illustrated with imaginary wood-cuts or drawings (Figures 1.2 and 1.3).

One of the few interesting manuscript notes of that period is that of Leonardo da Vinci, who describes the effects of the earthquake of 1481 at sea near Cyprus, Figure 3.13. The year he gives is clearly written as '89, probably a slip of the pen for '81. From the style of his account it seems that Leonardo was not an eyewitness of the earthquake, but it is known that in late 1480 or early 1481 he was in Cyprus. There is also an interesting news-sheet of 1545 that gives first-hand information for an earthquake in central Greece about which little is known from other sources, Figure 3.18. The same



Figure 1.3 A late sixteenth-century mural in the monastery of St Dionysios, Mt Athos, in northern Greece. The artist has sought to evoke the nightmare atmosphere of a violent earthquake by depicting, in addition to collapsing buildings, haloes around the Sun and Moon and falling stars.

applies to a few other sixteenth-century news-sheets that report earthquakes in Thrace; one of them is shown in Figure 3.17.

There is a lot of information that can be found in tracts and pamphlets written at second or third hand of this and of later periods, but tracts would focus, understandably, on the local information available for a particular event rather more than would be appropriate in a more general work. Accounts at second hand were published for calamities, among which earthquakes, for Cyprus and Palestine, Figure 3.19, as well as in Dutch pamphlets, bringing to light events little known or unknown from other sources, Figure 1.4. Turkish court documents referring to repairs of public buildings after earthquakes show quite often that damage was far less

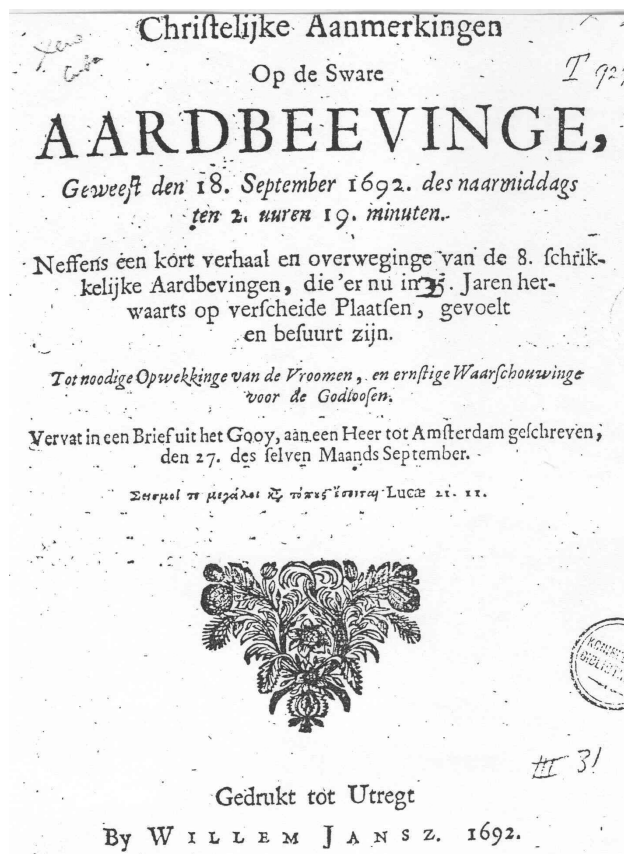


Figure 1.4 One of the Dutch pamphlets of the period 1690–1710 that referred frequently to earthquakes worldwide (J. Vogt).

serious than that presented by church writers and the occidental press reports, Figure 3.29.

The effects in Istanbul of the earthquake of 10 September 1509 in the Sea of Marmara have been grossly exaggerated in secondary sources, to the extent that the earthquake became known as *küçük kıyamet* (little apocalypse). Figure 3.16 shows a wood-cut made in 1529 by Coecke, illustrating the Fatih mosque with truncated minarets attributed to the 1509 earthquake. That the minarets would have remained unrepaired for 20 years seems rather strange and an inspection of another print of this wood-cut, kept at the British Library, shows some damage in that area such that a portion of the minaret and dome may have been lost. Later prints from a better pressing from the same block at the British Library show no flaw and the tallish minarets built outside the body of the mosque, so that the only indication of their collapse is the misinterpretation of Sanuto's statement that '...il marati del Signor vechio va in rovina et la mazor parte de le mochee...' In fact *marati* should be *imarets*, the ancillary buildings of the mosque, not minarets.

Many earthquakes are illustrated with contemporary wood-cuts and prints, almost all of them accompanied by a caption written with some poetic licence, [Figure 3.32](#). The earthquake of 14 January 1546 in Palestine is considered by late sources to be one of the most important earthquakes to have occurred in Jerusalem and its district. It caused some slight damage in the region, but in contemporary sources and wood-cuts the reported damage was grossly exaggerated. Voldrich, a Czech pilgrim, who was in Jerusalem very early in the summer of 1546 noticed that only the top part of the church of the Holy Sepulchre collapsed because it was heavy, revetted with sheets of lead. A view of the Holy Sepulchre and its square was drawn by Voldrich's companion, Dominik de la Greche, and appended to his book, [Figure 3.21](#). The detailed panoramic view of Jerusalem also drawn by de la Greche shows no other tall structures missing or the collapse of the dilapidated city walls, [Figure 3.20](#).

Even in more recent times damage and loss of life reported in private correspondence, for instance after the destructive earthquake of 1894 from the region between Adapazari and Lake Izni in Turkey, is not mentioned in the Turkish press, which concentrated chiefly on the effects of the earthquake in the capital. This supports the opinion expressed by foreign eyewitnesses at the time that news in the press about the disasters in Turkey was being systematically censored, [Figure 1.5](#).

There is also a substantial number of 'original' descriptions of destructive earthquakes, reported not only in contemporary sixteenth- and seventeenth-century fly-sheets (*flugblätter*) but also in early documents, regarding which on examination the information proved to be spurious. This shows that the fact that the information is coeval or even eyewitnessed is not a guarantee that it is not spurious, biased or invented for political reasons, or a figment of the religious imagination.

For instance, [Figure 3.25](#) shows the front page of a tract published in the last quarter of the sixteenth century regarding a destructive earthquake somewhere in Palestine or northern Arabia. The whole episode, for which neither the exact year of its occurrence nor its exact location can be fixed, might well be a pious fiction, with a tinge of Biblical Gomorrah when it refers to an earthquake and fire from Heaven destroying the region.

The *flugblatt* shown in [Figure 3.26](#) describes a damaging earthquake in 1661 affecting much of Bulgaria and Panonia, not mentioned in any other contemporary document, which is in need of authentication.

Also [Figure 3.24](#) is an illustration in a contemporary fly-sheet that shows imaginary damage in Istanbul in an earthquake in 1542. This is a typical theme of the contemporary European press, which was wont to pub-

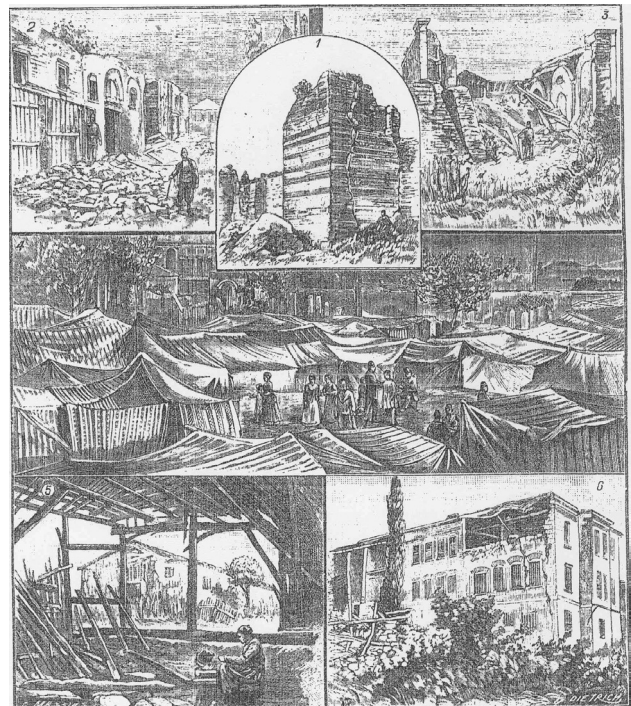


Figure 1.5 Scenes of the effects of the earthquake of 1894. (1) Damage to the Constantinian walls of Istanbul. (2) An aspect of a street in Istanbul after the earthquake. (3) The ruins of the library of the theological school on Princes Island. (4) A refugee camp in the Garden of Dervishes in Pera. (5) A ruined house in Adapazari. (6) Damage to the theological school at Chalki (*La Nature* 1894, no. 1114).

lish such 'news' concerning the Ottomans at times when relations were unstable, or on the occasion of an Ottoman military victory, in order to encourage confidence that they would be overcome by the West (Anonymous 1542a, b, c).

1.3 Archaeoseismology

An incidental benefit from the study of literary and archaeological field data is a warning of caution for those who find it easier to ascribe the demise of a city, the end of a civilisation or the ruins found in an excavation to earthquakes. If the solution to a problem is not immediately obvious, amateurs eagerly consider a catastrophe theory that the pioneers of this discipline developed to account for the collapse, for example, of the Aegean Bronze Age.

Previous research has uncovered evidence of destructive earthquakes in areas of the eastern Mediterranean where only small events have been experienced recently, with the evidence drawn from realistic physical considerations and input data. For earthquakes before

our era, however, historical and archaeological data have attracted interpretations that are influenced by the dogma of catastrophism, attributing to earthquakes the obliteration of the eastern Mediterranean region in the Bronze Age, large movements of peoples and the demise of flourishing city-states.

In the early part of the nineteenth century geology was under the influence of the dogma of catastrophism, the hypothesis that changes in the Earth occurred as a result of isolated major catastrophes of relatively short duration, as opposed to the idea implicit in uniformitarianism, namely that small changes are taking place continuously. Catastrophism passed off the scene, now more or less completely discarded, and uniformitarianism took over.

However, the last few decades have seen a gradual re-emergence of neo-catastrophism, this time in the field of archaeoseismology, particularly for earthquakes before our era in the Eastern Mediterranean, bringing back into prominence the ideas of Velikovski (1950). To mention a few of the propounders of this dogma, Marinatos in the late 1930s postulated a catastrophic eruption of the volcano of Santorini and a seismic sea wave responsible for the demise of the Minoan civilization (Marinatos 1939). Then followed Schaeffer (1948), who attempted to account for gaps in the sequence of civilizations in the third or second millennia BC in the Middle East within a relatively short period by invoking a series of major seismic upheavals. He was followed by, among others, Galanopoulos, who suggested another catastrophe that became quite controversial and is still being debated today, namely that the island of Santorini was the lost continent of Atlantis. Galanopoulos claimed that it was the sinking of Santorini into the Aegean Sea c. 1500 BC that wiped out the Minoans in a single volcanic eruption that was as 'cataclysmic as nuclear war' (Galanopoulos and Bacon 1969). Then, Kilian contributed with another, more local, catastrophe at the end of the late Bronze Age, one that allegedly caused the collapse of Mycenae and all of Peloponnesus due to a massive earthquake (Kilian 1980, 1988, 1996). Others followed in more recent times, attributing to earthquakes the obliteration of the eastern Mediterranean region in the Bronze Age and the demise of flourishing city-states, including Troy. The reason for the revival of catastrophe hypotheses is perhaps that they are easy to explain. They are too simple, too obvious and too coincidental, particularly when they are based on inadequate or biased historical evidence and also because they have become fashionable in recent years. If the solution to a problem is not immediately obvious, a catastrophe theory, which attracts considerable publicity, can account for it (Lewis and Terris 2002).

It is not suggested that destructive earthquakes are unlikely to happen in the Eastern Mediterranean region but rather that there are good reasons why one should be careful not to accept such theories at face value. Conclusions about the significance of early earthquakes, particularly those that happened before the recent historical era, must be drawn from realistic physical considerations and data so that theories and uncertainties can actually be verified by testing the data.

It is too much to expect that this kind of information can be gleaned from archaeological evidence alone, which is always ambiguous and can seldom be used to provide the more precise answers that are needed by the engineer in order to assess earthquake hazard. Nevertheless, archaeological evidence can potentially provide confirmation of long-term seismicity rates and, with greater collaboration between disciplines, it is likely that many refinements of the existing results will be possible.

We may mention here three of the earliest earthquakes to which modern cataloguers invariably give a cosmic dimension, the primary sources for which hardly support such an interpretation.

Regarding the earthquake in Jericho, some Bible readers have supposed that an earthquake toppled the walls of the city. However, the account of Israelites conquering the city contains no reference to earthquakes. Moreover, we have no conclusive evidence to associate the fall of Jericho either with the earthquake damage preserved on the site of the old city or with the damming of the River Jordan at Al-Damieh, which may be the result of earthquakes over a long period of time (Kenyon 1978a, p. 36; see also the section on Case Histories). Archaeological reports give little or no technical justification to support the conclusion that the destruction was due to an earthquake and, if so, due to the very same earthquake as that mentioned by Amos, while the available stratigraphy cannot rule out the possibility that the observed damage resulted from later earthquakes.

Searching for archaeological evidence for the earthquake destruction of Jericho (which is not mentioned in the Bible narrative, our only source), occurring at the time of the Israelite invasion (the date of which is uncertain), reminds one of **Kaplan's parable** of the drunkard searching under a street lamp for his house key, which he had dropped some distance away, but he searches there because there is more light.

About the effects of Zechariah's earthquake, one is left with even more questions. For instance, on what evidence is the meagre historical information in the Bible translated according to Ben-Menahem (1979, p. 262) into a catastrophic earthquake of magnitude M_L 8.2 (*sic.*), shaking Jerusalem with intensities VIII to IX. Why has this earthquake been associated so precisely by Austin

et al. (2000) with a coseismic left-lateral break of the Jericho fault, about 25 km east of Jerusalem and from the Mount of Olives. Finally, how authoritative is the geological map of The Survey of Israel, which shows the fault break running east–west through the southern part of modern Jerusalem? (*Atlas of Israel* 1985). These are common-sense questions and they should have been answered long ago.

The earthquake that allegedly occurred at the time of the Crucifixion and Resurrection of Christ in Jerusalem is another spurious event. The source for this information is St Matthew's Gospel, where we find two earthquakes. The first, at the time of the Crucifixion, which caused the rock-tombs to break open, revealing the bodies of the Just, who then rise after Christ's resurrection, symbolises both Nature's response to Christ's death and a prefigurement of the Resurrection. The second earthquake occurred after the Resurrection in order to let the women into the tomb so that they could see that Christ is not there. The year of these events is problematic since it is incompatible with certain chronological elements concerning the life and passion of Jesus, so that researchers can only narrow the possible years down to 33 and 34 AD, the former being more likely to be correct (Pratt 1991). These two shocks are mentioned only by one Evangelist and by chroniclers who used St Matthew as their sole source. It seems that St Matthew was more interested than any of the other Evangelists in Old Testament precedents, and he probably recorded these events because he had Amos' earthquake in mind. It would also be consistent with St Matthew's style for these two earthquakes to be two accounts of the same event, from different witnesses, both included for their theological significance.

Later writers seem to opt for the Crucifixion earthquakes in order to symbolise the cosmic proportions of Christ's death, but in fact they link these events that occurred in Jerusalem to the earthquake and eclipse of the Sun which, in fact, occurred a year earlier in Ol.202/Tib.18 (32–33 AD), not in Jerusalem but in Nicaea in Bithynia (Oppolzer 1887). The earthquake in Nicaea is also mentioned by St Jerome, who, however, does not mention Jerusalem. Eusebius does not mention the solar eclipse but he does notice, in passing, the earthquake at Christ's crucifixion, which he dates to the 19th year of Tiberius (33 AD). Orosius' account (early fifth century) is very similar to Eusebius', adding that Emperor Tiberius exempted the damaged cities in Bithynia in Asia Minor from tribute and gave generous donations towards repairs. Orosius also does not mention Jerusalem.

The fact that these earthquakes in Jerusalem are not mentioned by contemporary pagan writers, or by

three of the four Evangelists, suggests that they may have been inspired by the *topos* of Nature's reflecting events of great importance, and they must not be considered as referring to historical earthquakes.

It is interesting that the interpretation of St Matthew suggests that the earthquake at the time of the Resurrection was associated with the opening up of the rock beneath the Chapel of the Exaltation of the Cross, possibly as a result of surface faulting. This 'crack' in the bedrock is said to be still visible (Lavvas 1998, 2004). Its general location in the Chapel and a close-up view of the 'crack' are shown in [Figures 3.7 and 3.8](#).

However, the geology of the whole region and in particular the site of the Holy Sepulchre shows no evidence of recent faulting. The lower part of the traditional Calvary Hill is natural, and the upper part is very likely to be so. It is of soft white nummulitic limestone and stratigraphically concordant with such beds elsewhere in the region, as can also be seen on lower levels in the basilica. The strike of fissures and joints in the rock is east–west, practically the same as that of the veining of the rocks roundabout, the fissures broadening eastwards (Wilson 1886, Israeli 1977, Gil 1996). It is interesting that the open structure of the rock in the vicinity of the Holy Sepulchre was noticed after its restoration and it is stated by Soewulf in 1102, who says that the ground was '*...much cracked near the fosse of the Cross ...*'. The fissure in the limestone beneath the Holy Sepulchre is nothing more than one of the many weathered joints in the rock foundation, perhaps the result of stress relaxation of the rock masses due to nearby excavations, quarrying, erosion or some other cause of non-seismic origin.

Doubt can be cast on whether the earthquakes at the Crucifixion were 'natural'. Had there been an earthquake with coseismic faulting of the Golgotha Hill, the causative earthquake should have been strong enough to destroy Jerusalem, for which there is no evidence. Perhaps the earthquake in Jerusalem was borrowed from a surrogate destructive earthquake that took place at about the same time elsewhere, most probably in Bithynia.

In conclusion, the value of this summary review of the earthquake at the Crucifixion is that it draws attention to the fact that modern Bible exegesis in its interpretation uses what have been called 'literary genres', that is, certain descriptions do not have to correspond necessarily to historical facts, but are re-decorational elements, included to make a religious point with greater emphasis. The earthquakes at the Crucifixion and Resurrection may fall into this category and they do not correspond to the occurrence of an actual earthquake. The text of St Matthew might not refer to any historical earthquake

and these events need not be taken into consideration in estimation of the seismic hazard of Israel and neighbouring countries.

It is disappointing that, in spite of what has been said above, some writers today accept the occurrence of this earthquake in Jerusalem, to which they assign the magnitude of a catastrophic event of $M_{L(sic)}$ 8.2 (Ben-Menahem 1979, 262; Amiran *et al.* 1994).

Biblical history cannot be conveniently synchronised with the stratigraphic sequence of archaeological sites. The want of agreement between biblical chronology and archaeological stratigraphy makes it almost impossible to estimate with confidence seismological parameters for earthquakes before the Archaic Period (fifth century BC).

It is important not to presume that what we identify as earthquake damage in an excavation is the effect of one of the very few events known from literature, however well attested in the sources, and date the damage to this particular event. It could well have been one of the many missing earthquakes not mentioned in the Bible

that caused the damage. Assigning all documented damage to a known earthquake is attractive and economical, but no more than that.

The chief problem with neo-catastrophe theories is that their propounders do not seem to have read their original sources carefully and have perhaps paid little attention to the evidence presented by others or data from outside their own field of expertise. Moreover, they tend to trespass into disciplines in which they seem to have little or no training.

Neo-catastrophists must realise that their assessment of the location and size of early earthquakes is likely to be used at face value by Earth scientists and engineers in their calculations of long-term slip rates, recurrence rates and design parameters for small probabilities of exceedance. Their assessments have a direct bearing on the mitigation of earthquake risk and they must be trustworthy.

It is regrettable that even today it seems that no historical earthquake can remain without dramatised reconstructions.

2

Evaluation of macroseismic data

2.1 Topographical material

It is almost impossible to provide each of the 2000 historical earthquakes in this work with a location map, which in most cases can be found in the references quoted. Maps 1–19 show a considerable number of the historical sites mentioned in the text, while modern sites quoted can be found on 1 : 250 000-scale maps.

For place names in our study area in which the languages are Albanian, Arabic, Aramaic, Armenian, Bulgarian, Farsi, Georgian, Greek, Hebrew, Pushtu, Russian, Serbo-Croat, Turkish and Urdu, there is no accepted standard treatment. The proper transliteration of their alphabets into English is beyond the scope of this work. Where places are well known under English names, we have abandoned the local forms. Otherwise, local forms were used but we have decided not to use the latest names of places but rather retain as much as possible the contemporary names given in the references and maps at the time of the earthquake, dropping all diacritical symbols for the sake of simplicity. Broadly speaking, our policy has been to leave un-compounded names in their original forms, but to translate or adapt wherever possible the topographical appellatives of compounded names. However, the problem of using contemporary names is critical since most place names have been changed officially, in some cases more than twice during the past century. We cannot lay claim to complete consistency of our method; where consistency would have led us into absurdity, we have preferred inconsistency.

Of the large number of maps, particularly for the nineteenth century and early twentieth century, available at The Royal Geographical Society in London, the following general maps were found useful for the identification, location and spelling of old and new place names:

- Calder, W. M., Bean, G. E. (1950) Classical map of Asia Minor, 1 : 2 000 000
- Kiepert, R. (1904) Karte von Kleinasien, 1 : 400 000
- Lynch, H., Oswald, F. (1901) Map of Armenia and adjacent countries, 1 : 1 000 000
- K. k. Militär. Geographisches Institut, Vienna, Balkan-Kleinasien, 1 : 200 000
- War Office Geographical Section, GS (1908–1915), 1 : 250 000
- Harta Genel Müdürlüğü (1931, 1937, 1945, 1951) Turkey, 1 : 200 000
- Generalkarte von Mitteleuropa: Balkan (1941), 1 : 200 000
- US Army Map Service CE, 3-AMS Edition (1960), 1 : 250 000

One of the most annoying restrictions imposed on scientists working in some countries in the region was being forbidden the use in the field of large-scale topographic maps and air photos. In the 1960s and 1970s therefore, not having access to modern small-scale maps, I often resorted to quarter-million-scale Greek, Turkish and European issues dating from before the Second World War, the advantage of which over modern maps was that they showed original place names rather than the new ones in use after place names were changed almost throughout the region during the 1920s.

Maps 1–19 include intentionally a large number of some of the more obscure or little-known locations of places mentioned in the text.

2.2 The value of local information

Experience dictates viewing information about earthquakes from local people with caution and the following examples may be of some interest to those who take for granted and without scrutiny the validity of local information, even when they understand or speak the language.

In some parts of the Balkans and eastern Turkey, there was, and to some extent still is, a genuine lack of local information about earthquakes that happened during the first three decades of the twentieth century and earlier. Much of what one can learn from local people today is hearsay. This is the case because most of those whom one can interview are first- or second-generation newcomers to the region, coming from families displaced from neighbouring countries during wars, persecutions and enforced settling of nomads.

It is interesting that quite often local people hardly believe that foreigners could be interested in old and forgotten earthquakes in their country, which hap-

pened well before their time, or that they would come to search for faults and cracks in the ground, to the extent that they would travel thousands of miles away from home merely for research purposes. I have heard many different explanations proposed for their motives, including searching for mineral deposits or diamonds, looking for archaeological treasures and antiquities, searching for archaeological sites and simply spying.

I find surprising the effect that the passage of an earthquake-investigation field party of foreigners often has on the imagination of local people, be it in the Balkans or in the Middle East. The news that they are looking for evidence of earthquakes and asking questions about damage, landslides and cracks in the ground spreads quickly, quite often amplified. The passage of more than one field party asking the same questions has an astonishing effect on their education in Earth sciences. They would not only lead you right away to the putative surface fault break or old ruin you asked to see, but also, surprisingly enough, offer a sensible explanation of why earthquakes occur, often echoing the discussions between members of the party they overheard or the quasi-scientific explanations that the party's jeep driver had given them.

A case in which local information, on examination, proved to be misleading is that of an alleged coseismic surface fault break during an earthquake in 1937 in the Darya-yi Namak area in central Iran, south of Tehran. According to the local people the break ran for 8 km, in places showing a throw of about a metre, which information was attested to by more than one person. After a day's driving to the likely site, I found that this feature was nothing more than the result of the partial collapse of a straight line of shallow qanats (underground water-supply conduits) resulting from a flash flood at about the time of an earthquake.

Another case is that local people of Martino and Atalanti in Greece, having been subjected to visitations of many geological field parties, native and foreign, looking for clues about the 1894 earthquake, to our surprise told us more about the surface fault ruptures of 1894 than most of the geologists who visit the region for the first time could put together.

For very recent cases of faulting, local intelligence is invaluable, but for older events it must be used with caution. A positive example was in the region north-west of Birjand in Iran, where an elder of Muhammadabad gave us valuable information about the 1941–47 and earlier earthquakes in the region. His story, partly heard from older people, strongly suggested that these events should have been associated with surface faulting. Our informant not only described this in detail, but also showed us where faulting was still discernible on

the ground, about ten kilometres from his village. A few years later I returned for more details and also for the purpose of installing strong-motion instruments near the village. Unfortunately, in the meantime our old informant had died. However, to our surprise, his son, whom we had not met before, volunteered exactly the same information as had his father and guided us along almost the entire length of the zone, about which he had known as a child when he helped his father to collect bulbs along the margin of the salt flats in the spring.

Field reports, particularly of earlier earthquakes, should not be considered always to provide authentic information solely because their authors have visited the site. This applies particularly to reports from fleeting visits to the epicentral region. It is amazing how fault mapping has been drawn in some cases. Out of six field reports written on the Dast-i Bayaz earthquake in Iran in 1968, by six different field groups; in one, mapping of the fault break was done from a helicopter in four hours' flight. In another the 90-km-long surface break was mapped on the ground in four days only, whereas in yet another it took 36 days.

In most recent cases, interpretation of surface ruptures is greatly helped by additional information from seismology (size, focal mechanism and depth of the event, regional tectonic setting, satellite imagery and increasingly SAR interferometry), most of which was unavailable ten years ago. To some extent, therefore, the interpretation of ground ruptures of older earthquakes is necessarily subjective, since we must base our judgement on imperfect information supplemented by our knowledge of what happened in other, similar, earthquakes in the region. The association of historical earthquakes with a probable style of faulting is often a judgement based on the known style of faulting. Reports are rarely explicit enough to be unequivocal, especially about horizontal displacements observed in the field many years or decades after the event. Vertical displacements are nearly always better preserved.

Quite often much of the information from local sources about damage in their own or in neighbouring villages from old earthquakes was grossly exaggerated or suspect. Frequently the damage and loss details they could remember were those from relatively recent earthquakes confused with earlier ones. When the information was difficult to verify or when in doubt, I discarded it.

An interesting observation that can be made some time after a damaging earthquake is the indifference with which people, particularly in rural regions, view future earthquakes. In 1967, after the Mudurnu Valley earthquake in Turkey, I came across the reconstruction of a small house across the fault scarp near Taşkeste, [Figure 2.1](#). This, I was told was done intentionally to



Figure 2.1 A rural house under repair at Taşkeste (40.567° N, 31.031° E). It was built after the Abant earthquake of 22 July 1967, intentionally straddling the fault break in order to economise on building walls; it was built on stilts in the front and at the back on the upthrown block; away from the house the fault scarp was levelled off.



Figure 2.2 The 'house' shown here was built immediately after the earthquake. Its back is dug into the foot wall of the fault break to save building walls.

economise on building side and back walls. The owner of the house felt that Nature had offered him the opportunity to build a two-storey house, an opportunity that he took. As for the next earthquake, his answer was 'God only knows'.

A similar indifference of the local people I noticed in eastern Anatolia regarding people who, after the Varto earthquake of 1966, rebuilt their destroyed houses on the fault break. This they did by digging against the footwall of the scarp and building there dwellings that were partly subterranean, thus economising on building extra walls, [Figure 2.2](#). Again here consideration of the possibility of a future earthquake had a low priority.

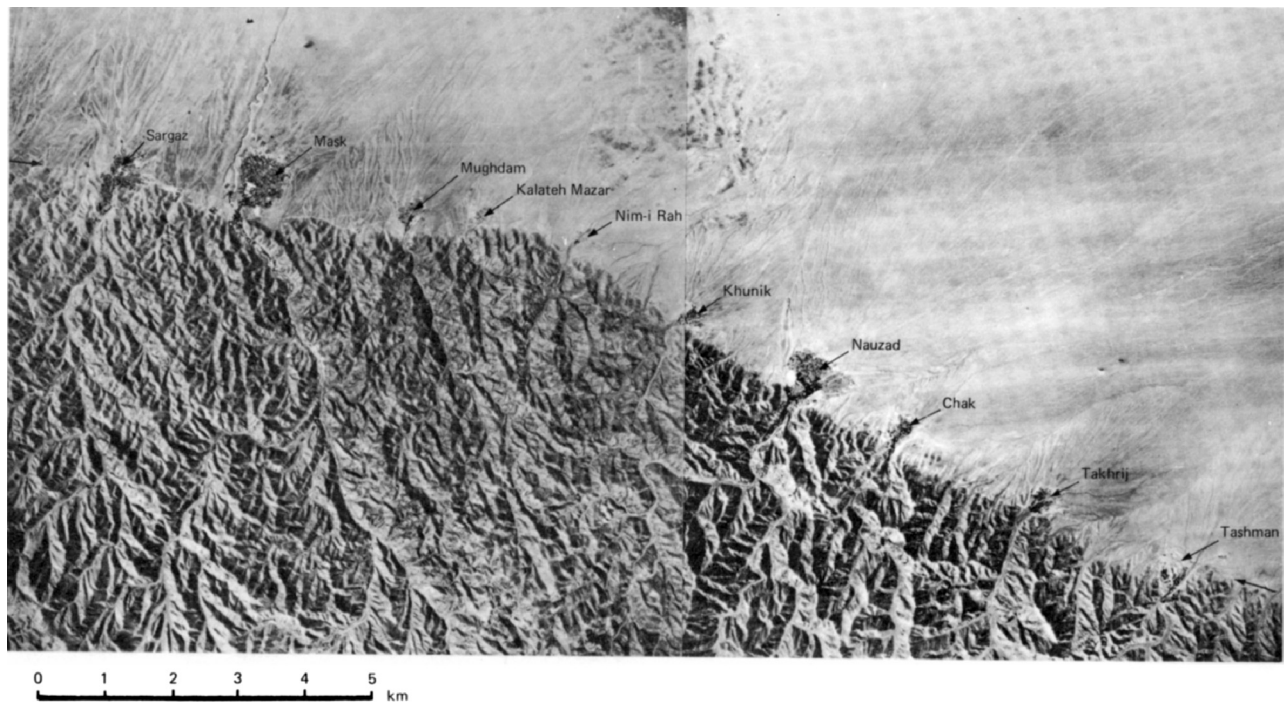


Figure 2.3 Fifteenth-century historical sources mention by name villages that were destroyed by the earthquake on 10 January 1493 (33.0° N, 59.8° E).

2.3 Field studies

It is from an efficient field study that the economic and social repercussions of an earthquake can be identified, thus helping to avoid undesirable effects of future events. Also it is only through field studies that some of the well-established tools of hazard quantification, such as intensity, can be assessed and judged to be inadequate. I find, for instance, that for the study of earthquakes conventional intensity scales are too subjective and quite often misleading, especially when these scales have been designed to describe conditions in other parts of the world with different building traditions, materials and type of construction. Also, existing building codes and building regulations, as well as the efficacy of their enforcement and implementation, can be tested only after an earthquake.

It is from field studies that one realises that local damage information is more often than not grossly exaggerated. There is always a tendency for the local sources to put the onus for the damage on an exceptionally severe earthquake and on a high intensity rather than on a high vulnerability of their houses for which both owners and local authorities should have been responsible. A high intensity would exonerate the builders from blame for the damage and at the same time please owners because of the generous compensation they could receive for reconstruction.

In early times, and still today, an earthquake disaster is often considered to be the effect of uncontrollable forces of Nature or an act of God, which could not have been prevented or avoided. Unfortunately, an act of God today can be an act of criminal negligence tomorrow.

As our knowledge of the complexity of earthquakes and of their effects has increased, we have become more and more aware of the limitations which Nature has imposed on our capacity to interpret and understand, on purely theoretical bases, ground motions and the performance of the ground, of man-made structures, or of a community.

To anyone who is really concerned with the study of historical seismicity it is becoming increasingly apparent that the site of a damaging earthquake is a full-scale laboratory in which significant discoveries may be made. The locations of larger historical earthquakes have been found to be known well enough to guide field studies for further *in situ* investigations. Properly run field studies provide reliable observations for the assessment of damage, intensity and its distribution, ground effects and surface faulting. Field studies of old earthquakes are time-consuming and often present subtle problems, but they are essential. Theories may come and go but the results of field observations will retain permanent value, and should be tied to theory as little as possible.



Figure 2.4 A surface fault break at Sandergan associated with the 1909 earthquake in Silakhor. This photograph was taken by the Russian Cossack mission, members of which are seen in the background (Lenin Library, Moscow, E. Savarenski).

A Persian fifteenth-century historical document describes an earthquake on 16 January 1493 as a result of which some villages, the names of which are given, were destroyed. This led to their identification, most of the villages being found to align with the Muminabad fault, Figure 2.3.

Russian consular documents kept in the Lenin Library in Moscow were found to contain detailed information and photographs of the Silakhor earthquake and surface faulting of 1909 in Iran. Figure 2.4 shows the fault break with the ruins of Sandergan in the background, photographed by the Russian mission to Iran shortly after the event. These documents, supplemented by the diaries of British consuls in Persia, helped to locate and map those parts of the surface break which were still visible (Ambraseys 1974).



Figure 2.5 An aerial view of the Kuhbanan fault associated with the Gisk earthquake of 19 December 1977 of M_S 5.9. The village in the centre is Dartangal. (Scale: the distance between Dartangal and the tip of the arrow in the right-hand corner of the figure, which marks the fault, is 8 km.)



Figure 2.6 An ERTS image of the Saros–Marmara fault zone (between the arrows) associated with the earthquake of 9 August 1912.

Figure 2.5 shows the Kuhbanan fault in central Iran. Although this earthquake was a relatively small event in a remote part of Iran, it confirmed a much larger, early-nineteenth-century earthquake documented in a local history, which damaged the towns of Zarand, Ravar and Kerman and most probably originated from this fault. I could get no confirmation of this earlier event from the local people, since almost all of them were early-twentieth-century settlers.

A similar case is that of the 1912 earthquake in the northwestern part of the Sea of Marmara, the detailed field report on which, written by a Serbian army officer, almost immediately after the earthquake, remained unpublished for 16 years. Figure 2.6 shows the surface fault break associated with the earthquake which was mapped 57 years after it had occurred (Ambraseys and Finkel 1987b).

There is evidence that the fault zone of Dasht-e Bayaz, where the earthquake of 31 August 1968 hap-

pened, has been active in the recent past. This is shown by the displacement of qanats that straddle the fault in Figures 2.7 and 2.8. (For the construction of qanats in the region see Beckett (1953).)

The fault break extends to the west of the fault segment shown in Figure 2.9, a small section of the rupture of length nearly 90 km.

There are a few places along its course to the west where old weathered scarps confirm this, Figure 2.10. It is of interest to note that in the Nimbluk valley, which is bounded to the north by the Dasht-e Bayaz fault, qanats are double or triple where they cross the 1968 fault zone and that the general alignment of the older shafts shows left-lateral offset across the fault zone of as much as 10 m.

It appears that the most recent line of shafts and adits across the zone is in fact a detour around that portion of the original qanat across the zone which was destroyed by earlier fault movements. In Figures 2.7

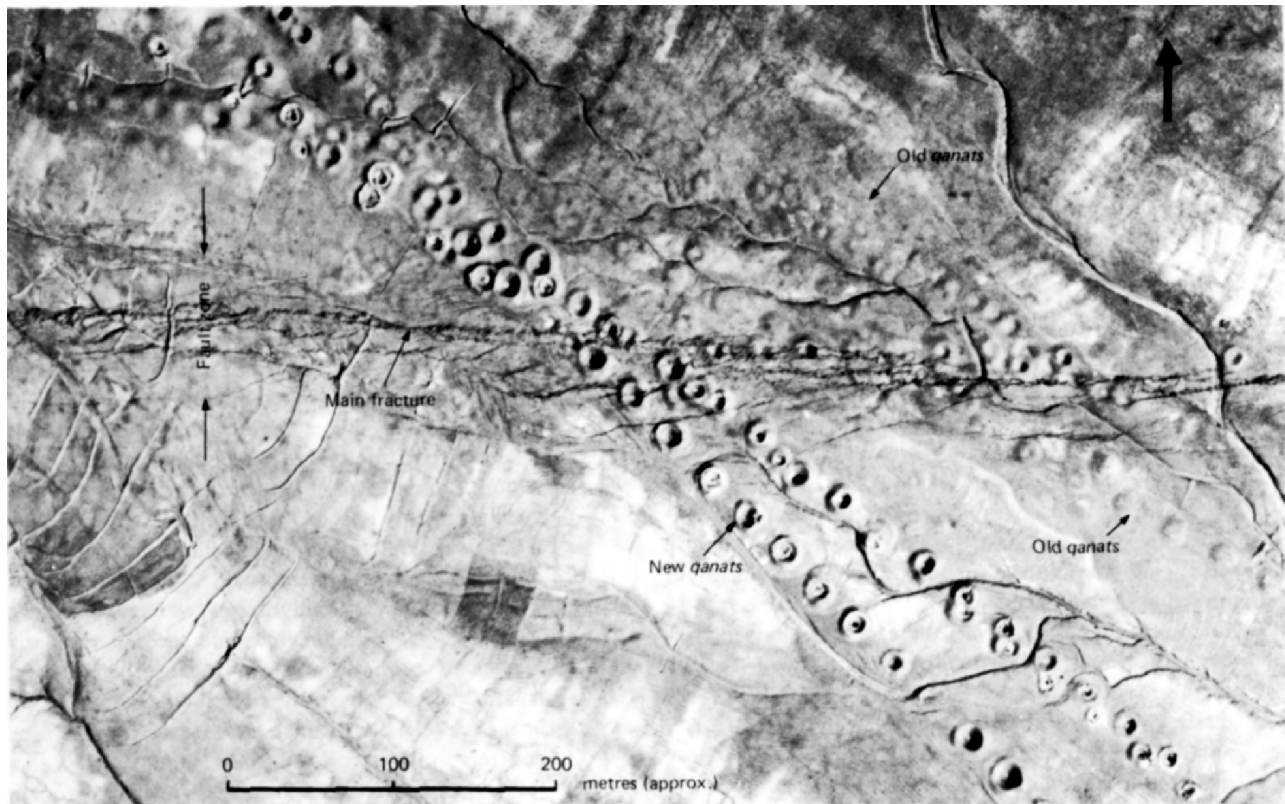


Figure 2.7 An aerial view of the fault break north of Miam in Khorassan, Iran, associated with the earthquake of 31 August 1968, with interconnected en echelon fractures with offset stream beds. Two lines of qanats cross the zone; note the left-lateral displacement of the abandoned qanat lines and another abandoned line of old east–west qanats that runs parallel to the east, part of which follows the 1968 fault break. These were most probably built to trap the aquifer which had been dammed at depth by previous movements of the fault zone. The sense of horizontal movement is predominantly left-lateral throughout.

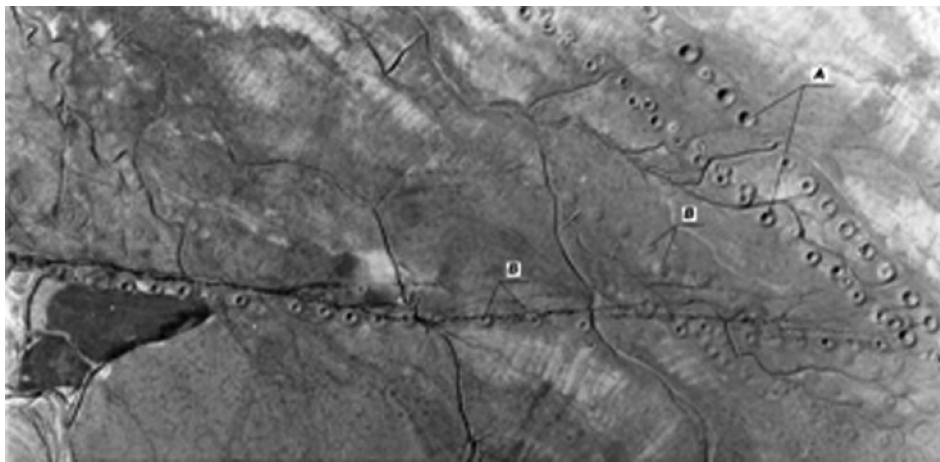


Figure 2.8 An aerial view of the 31 August 1968 fault break north of Miam in Khorassan, Iran. Note the old east–west qanat line, built before 1968, along the 1968 trace to trap the aquifer dammed by old fault movements. Points A to C are the shaft locations where attempts were made to investigate underground deformations and fault movements. (North is pointing to the bottom of the picture.)



Figure 2.9 An aerial view of the fault break northeast of Miam in Khorassan, Iran, associated with the earthquake of 31 August 1968. Note the left-lateral 4.5-m displacements of ponding ridges.



Figure 2.10 The Dasht-e Bayaz earthquake of 31 August 1968, showing the fault trace southeast of Boskabad. The uphill side was downthrown locally by 60 cm with 20 cm left-lateral displacement. The trace follows closely a pre-existing, recent fault scarp.

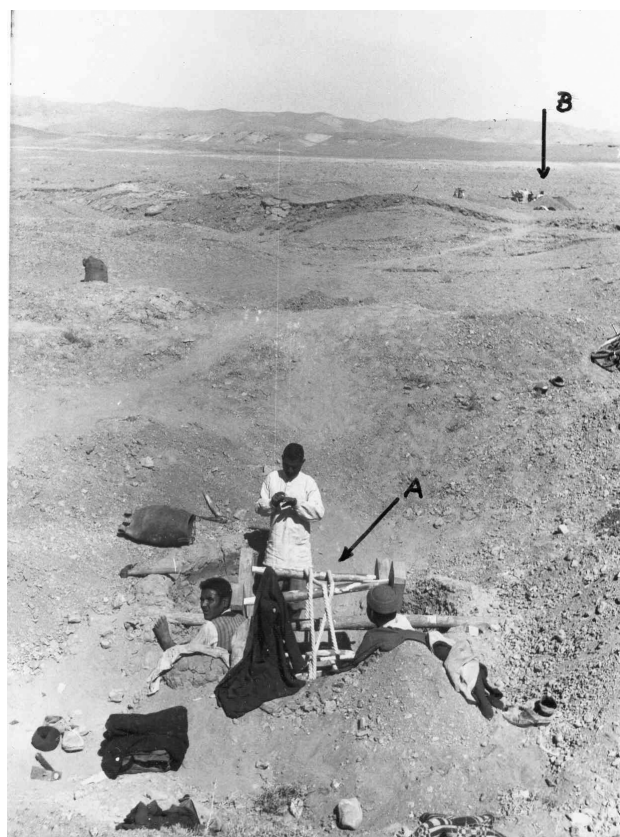


Figure 2.11 A ground photograph of sites A and B shown in Figure 2.8. Roger Bilham's adventures in the qanats were limited to about a dozen descents, each of which scared the living daylights out of him. Geoff King, another Cambridge researcher in the team, with his impressive bravery once descended without a rope using the footholds made by the muqqanis, but Roger used the man-powered mechanical winch. A helmet would have been nice. About one third of the little pebbles that came down the side of the alluvial shaft whining as they approached terminal velocity at depth 26 m were destined for one's head. The worst bit was climbing into the top of the shaft and estimating the fragility of the splintery old poplar of the capstan/cutlass assembly and the whimsical strands of the ancient rope. The plan was to map the ground fractures in several qanats to make an underground map of the en echelon system that seemed to be simpler at depth: three at the surface and two at the bottom. By careful measurements of the intersections on the surface and subsurface one could map the three-dimensional shape. However, after about one hour of this fun the flashlight gave out, and Roger was plunged into utter darkness. He then realised what a terrible condition it is to be blind in a qanat accompanied only by a vivid imagination. It was a low tunnel only high enough to crawl through, and the floor was damp but not running with water as he started inching his way towards the shaft. It was only 18 m away but with each shove he would hit his head or scrape his back on the cobbles in the roof. His anxiety to find the vertical shaft caused him to hasten, which only increased the severity of these collisions. All was well until his imagination fired with

and 2.8 old qanat lines that run along the fault zone suggest that earlier fault movements had dammed the aquifer towards the valley, creating an underground reservoir of water that was tapped by the construction of a new east–west qanat branch.

Unfortunately, it was not possible to establish, even approximately, the dates of construction of the various branches of the old qanats in the Nimbluk, which could have given some idea of earlier large events in this remote part of Iran. We know that the small town of Gonabad in the Nimbluk Valley was already famous in the tenth century for its extensive qanat system, which was often described as 19 km long and in places 63 m deep (*sic.*), which is said to be an extension of an earlier system built originally by the Gabrs (Zoroastrians), that never ran dry. According to local information, the qanat system until recently was *waqf* property of the shrine of Imam Reza in Mashhad, which was built 900 years ago. Local historians and *muqqanni* claim that the oldest qanats in this part of Khorasan belonged always to the Sufi shrine in nearby Bidokht, so they should not be more than 300 years old. Some of us, in 1969, and, more persistently, in 1974, Roger Bilham, then a young research student at Cambridge, spent some time underground, trying to assess the age of the qanats, some of which had caved in in 1973. Some branches collapsed early in 1974, putting an end to the search for information on the basis of which to evaluate their age, Figure 2.11.

Returning to Figure 2.8, the left-lateral motion observed on the fault surface was also found at some depth, with very similar striations, Figure 2.12.

‘what about snakes?’. The terror peaked when he placed his hand on a soft squally thing that jumped from him in the dark, presumably a toad, but was it a rat? Fortunately a tiny glimmer of light from the distant shaft appeared as he rounded the natural bend where the two driven tunnels met and he began to see the end of his fears. Geoff and Roger employed the muqqanis for one year to dig some shafts for strainmeters. The conditions were appalling. Whether they used candles or oil lamps Roger doesn't recall, but he does remember the foetid smell and the thick dust that had all of them coughing for days. They asked for ten men and got only six or seven, he remembers, stopping when they ran out of funds because they had encountered tough consolidated alluvium. Three of them worked shifts at the face, hauling down the tunnel and pulling up the shaft. In the dust-laden atmosphere they installed the strainmeters and ran cables up to the surface, and even strung the data cable to the nearest shack on poles. The data were recorded on charts that inevitably went off scale, but they did get some data of interest. An interesting footnote is that Roger wrote a proposal to the National Science Foundation in the USA to map properly the three-dimensional fractures in the qanats of Dasht-e Bayaz, but it was turned down.



Figure 2.12 The exposed fault surface of the Dasht-e Bayaz earthquake of 31 August 1968, looking north; the striations are dipping 22° to the east.

An interesting observation made in follow-up field trips to Dasht-e Bayaz was the confirmation of the scale invariance of the shear pattern in fault zones. The fault trace, for instance in Figures 2.7 and 2.8, shows only the largest scarps. When the numerous minor surface fractures in the fault zone are taken into account, the main fault break can be seen to lie within a shear zone one kilometre wide. The structure of this zone bears a strong resemblance to that of shear zones of much smaller scale, and a comparative study reveals that many fractures of the main fault scarp can be interpreted in terms of the kinematic restraints imposed at the boundaries of

the shear zone (Tchalenko and Ambraseys 1970). The shear pattern observed along a number of segments of the zone is particularly interesting. For example the segments shown in Figure 2.8 and to the east of it exhibit fractures with horizontal displacements (right-lateral) in a direction opposite to the regional sense of movement (left-lateral). This pattern mapped on the ground and shown in Figures 2.13 and 2.14 is typical of left-lateral shear strains distributed along a comparatively wide zone.

This independence of scale en echelon shear pattern was seen in many faults before and after 1970, as well as in the shear mode of failure of a variety of work-hardening materials, in tiled floors, Figure 2.15, on wall plaster, Figure 2.16, on asphalt road pavements, Figure 2.17, and as centimetre down to $10\text{-}\mu\text{m}$ -long en echelon shears, Figures 2.18 and 2.19, confirming the scale invariance of the shear pattern.

Figure 2.20 shows a summary of the scale invariance of strike-slip fault patterns, either as a single trace or in a fault zone, depending on the scale with which it was mapped.

2.3.1 Coseismic faulting

What is known to us today shows that faults that appear to be quiescent today have been active in the past. For some cases faulting could not have been predicted from twentieth-century activity. In other cases it could have been expected, but has not been observed during the instrumental period.

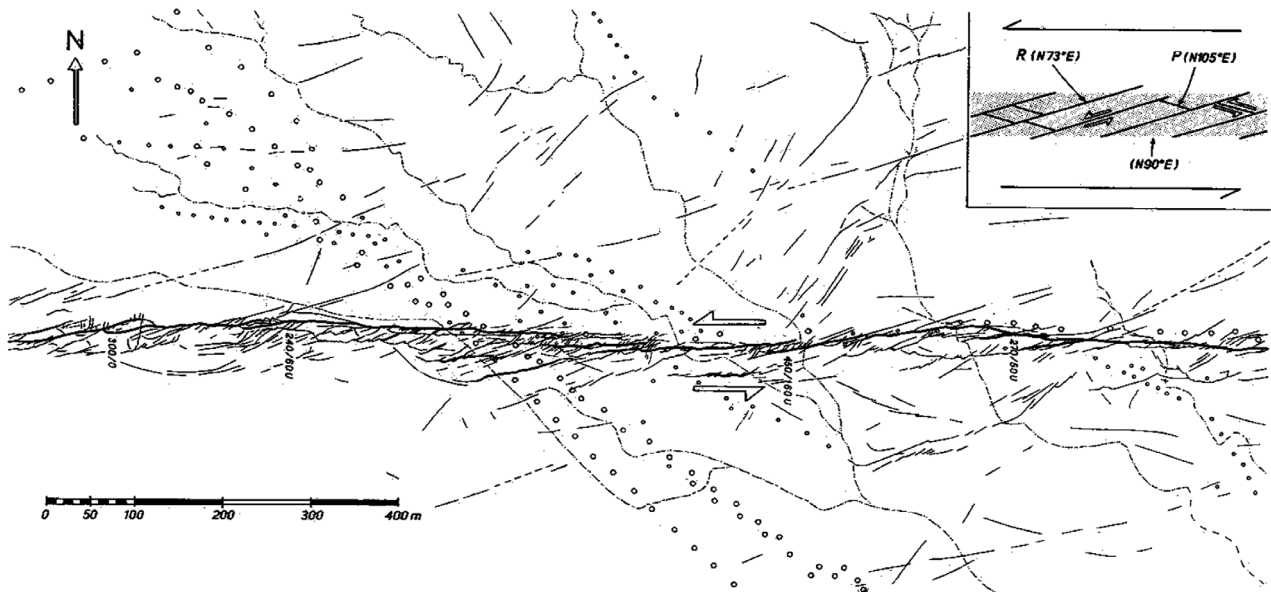


Figure 2.13 Detail of mapped secondary en echelon ground ruptures within the shear zone of the strike-slip fault break associated with the earthquake of 1968 at Dasht-e Bayaz.

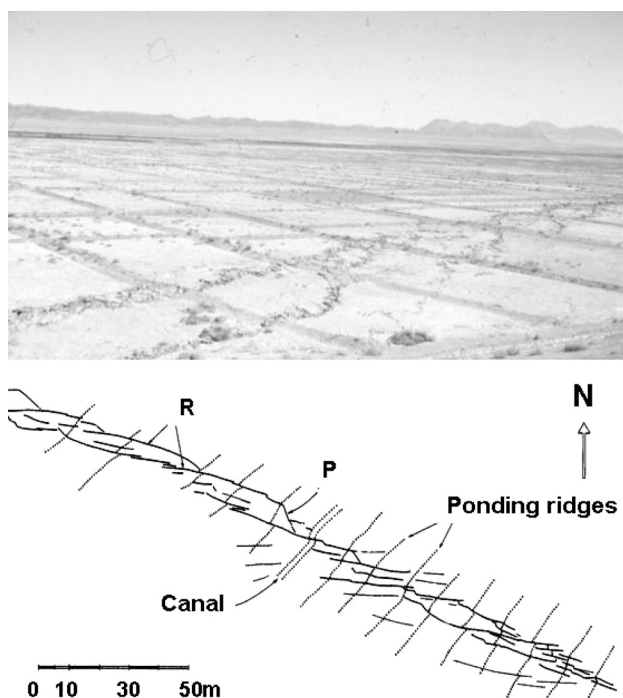


Figure 2.14 The formation of smaller-scale en echelon ground deformations of the strike-slip ruptures in Figure 2.13.



Figure 2.15 En echelon shear ruptures a few centimetres in length in tiled kitchen floor of a single-storey house straddling one of the traces of the fault zone associated with the Managua earthquake of 1972.

In spite of the importance with which we now view coseismic surface faulting, the reporting of such features prior to about 1960 outside the USA and Japan was mostly erratic and imprecise. Throughout the region of this study, reports of surface faulting were rather rare, and those that are known are usually vague and cursory, having been noted by people who were often regarded as eccentrics at the time. In short, up to the 1960s few people in Europe thought such faulting to be significant

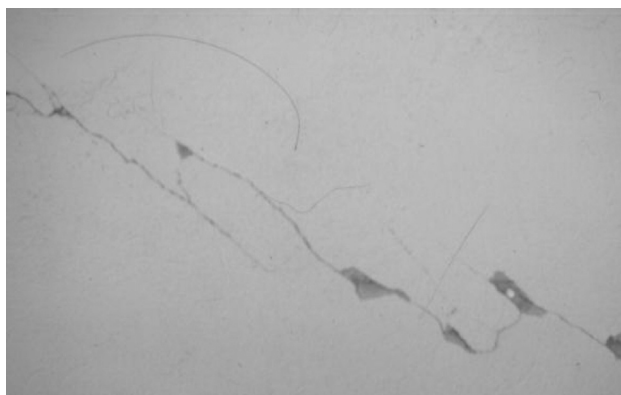


Figure 2.16 Plaster wall cracks in room R.554 of the Civil Engineering building at Imperial College in London shortly after it was occupied in 1964. This is one of the observations that prompted the investigation of the idea of invariance of fault patterns.

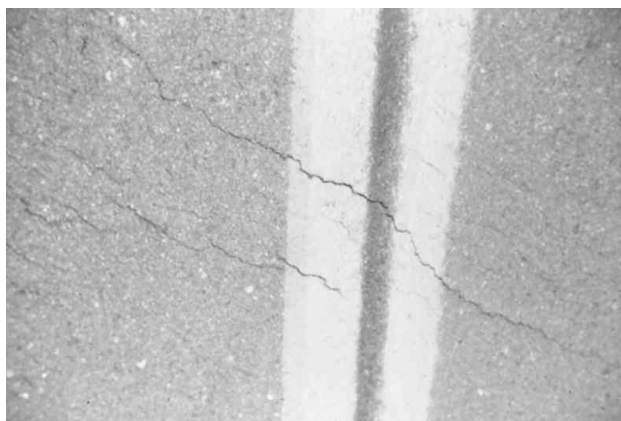


Figure 2.17 Detail of the shear deformation of the asphalt floor of one of the roads in Managua where it crosses one of the fault zones associated with the Managua earthquake of 1972.

and worth describing, but since then interest has grown steadily.

Thus, for example, although the fault break which was associated with the Locris earthquakes of 20 and 27 April 1894 (M_S 6.4 and 6.7) in Greece, was reported in great detail in a contemporary paper (Skouphos 1894), it took more than a century for geologists to map and examine it in some detail (Pantosti *et al.* 2001, 2004). Until very recently, geologists simply did not generally accept the tectonic origin of these features, which were thought to be superficial effects of large-scale regional slumping of the ground.

A thorough search in the archives of the East African Geological Survey Departments in Nairobi, Entebbe and Dodoma, during a UNESCO earthquake reconnaissance mission in East Africa early in 1963,

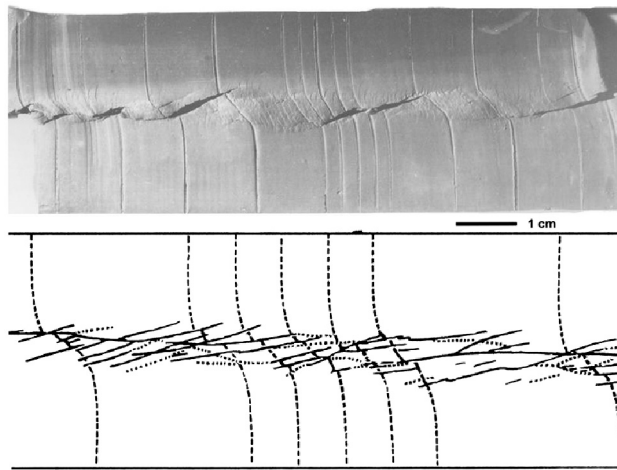


Figure 2.18 En echelon sub-ruptures persisting down to a fraction of a centimetre in length, measured on thin sections of a clay sample sheared in the shear box at large displacements.

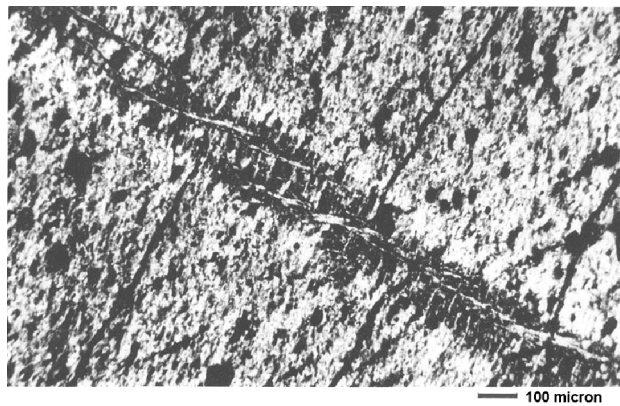


Figure 2.19 The en echelon pattern's scale invariance tested down to length scales of microns (Tchalenko 1967).

disclosed a considerable number of unpublished reports on the earthquake and surface fault break of 6 January 1928 (M_S 6.9), one of which is summarised in Richter's book of *Elementary Seismology*. Unfortunately, the leader of the mission, who was a geologist, was not convinced that the reported many kilometres of long ground cracks in the Subukia Valley were important enough to merit a visit by the mission. Fortunately, late the same year a follow-up mission to Kenya made it possible to carry out a reconnaissance of the Subukia Valley that confirmed a reasonably well-defined 40-km-long trace of coseismic rupture, Figure 2.21. For a variety of non-technical bureaucratic reasons the 1963 field report could not be published for 30 years (Ambraseys 1991).

Also, of the 360-km-long surface rupture associated with the large earthquake of 26 December 1939 (M_S 7.7) in Erzincan in eastern Turkey, only the western

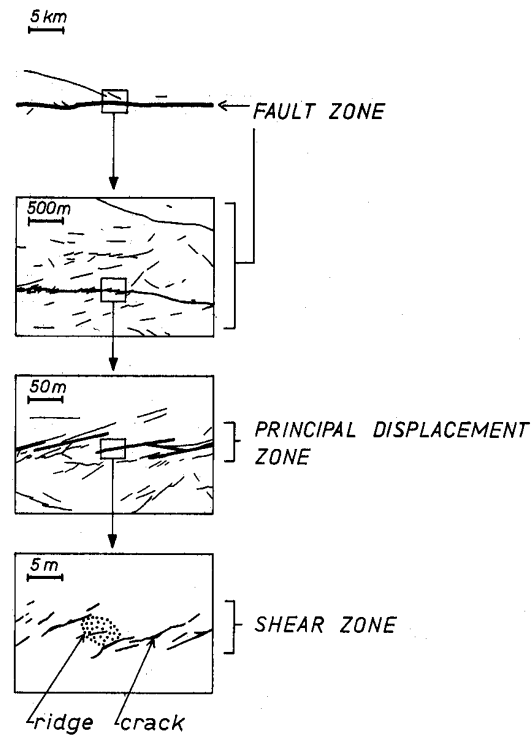


Figure 2.20 A summary of scale-invariant fault patterns.

half was visited and only a small part of it was sketched, rather than mapped, on a 1:1 000 000 scale; measurements of the fault displacement were reported from only one location (Ketin 1948). Mapping of the 1939 surface break had to wait 44 years to be done properly by Barka (1992, 1996).

Similar uncertainty and vagueness applies to descriptions of other interesting surface fault ruptures prior to 1960 in Anatolia, Iran and Greece.

Even in the 1960s most geologists in Europe were sceptical about the significance of surface faulting. During a cursory site visit to the Gibellina region immediately after the Belice earthquake sequence in Sicily of 14–25 January 1968 (M_S 5.8) (Valensise *et al.* 2004), a series of ground cracks running intermittently for a few kilometres in a north–south direction was located about 5 km east of Ninfa and Partanna. However, because of the weather conditions it was not possible to study in detail these features which seemed to me to be secondary. When I reported these observations to colleagues in Rome, asking for their assistance to return to Sicily and map these features properly, their answer was that these features were scientifically unimportant since ‘surface faulting does not occur in Italy’.

A similar attitude prevailed among colleagues in Athens when I asked them to help in the field to study the ground deformations caused by the earthquake of 5 April

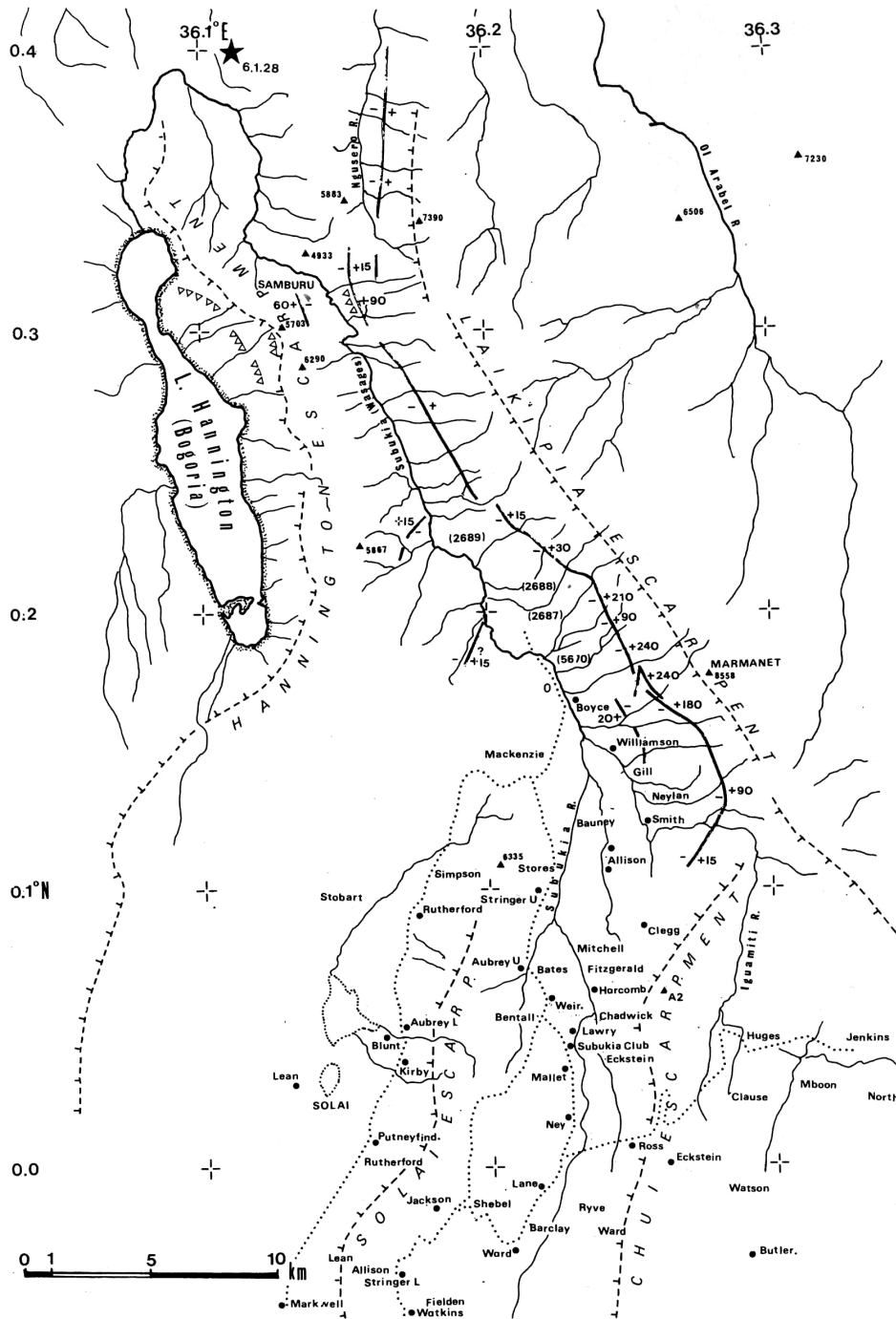


Figure 2.21 Main surface breaks associated with the forgotten Subukia Valley earthquake of 6 January 1928, and locations of farm houses in the epicentral area. Surface rupture is shown with a heavy line; numbers with plus signs represent measured or estimated amounts of vertical displacement, in centimetres, shown on the upthrown side. Open triangles show areas of rock falls and slides. Dotted lines show unpaved roads in 1928. Houses existing in 1928 are shown by solid circles followed by the name of the owner. Names without a dot indicate, for the sake of orientation, sites that did not have houses built on them. Numbers in brackets are Land Office registration farm numbers. Solid triangles show monuments of the geodetic network with altitude in feet. The solid star is the adopted instrumental location of the epicentre of the main shock. All place names are those current in 1928. From UNESCO field missions 1963–64.

1965 (M_S 5.9) in Megalopolis. They declined politely, saying they believed that these ground features had nothing to do with the earthquake (Ambraseys 1967).

Even the reviewer of a paper on the Varto earthquake of 19 August 1966 (M_S 6.8) (Wallace 1968), which I had submitted for publication to a European journal (Ambraseys and Zatopek 1968), objected to the idea that the event could have been associated with surface faulting and drew my attention to a paper by Evison (1963) in which we read that ‘... only a small proportion even of large shallow earthquakes are accompanied by significant fault movement at the surface. This suggests that fault movement could be an occasional effect of earthquakes rather than their cause...’

Occasionally surface faulting has a particularly subtle geomorphological expression, so that even modern geologists would not think of checking, meaning that they would miss the fault break unless they are guided to it by local information, e.g., in 1990, Rudbar in Iran (Berberian *et al.* 1992; Zareh and Moinfar 1994).

With the advantages of hindsight and the additional tools of modern seismology and geodesy, it is easy to appreciate from recent examples why surface ruptures were often missed or misinterpreted in the past, especially for small earthquakes. The surface faulting is sometimes in remote places, well away from habitation and inaccessible, particularly in winter, e.g., in 1980, Irpinia, in Italy (Westaway and Jackson 1984).

However, this swing of the pendulum may cause confusion when authors do not distinguish significant from unimportant features and map every crack in the ground, with the result that some observations would be found to agree with a postulated new or old fault trace. Scarps caused by spreading of the soil and by incipient slides, both in modern and in historical studies, are often candidates for such misinterpretations.

Evidence for coseismic surface faulting in historical earthquakes in the Eastern Mediterranean and the Middle East is of importance to all modern studies of tectonics and seismicity and required extensive field work. Such evidence not only confirms that known tectonic structures are active, but also can identify new ones. Despite shortcomings in the documentary evidence, information about surface faulting can be found in contemporary accounts and this provides a valuable reference point in the palaeoseismological record of faults. Such knowledge is particularly important when, for example, the activity of a fault is to be researched by trenching methods, since it allows the completeness of the palaeoseismological investigation to be assessed.

I find that in the Eastern Mediterranean and the Middle and Near East there are 78 cases of pre-1900 actual or inferred faulting in need of authentication, and

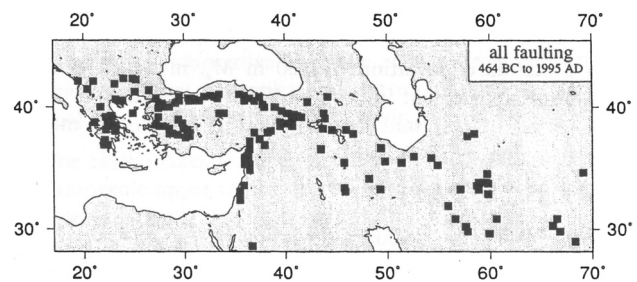


Figure 2.22 Locations of earthquakes associated with actual and inferred surface faulting for the whole period before 1995.

72 cases after 1900, Figure 2.22. All the cases of pre-1900 coseismic surface faulting active more than once in historical times, as well as a number of hitherto unknown active faults, have been investigated. Only some of these cases are included in the interesting works of Wells and Coppersmith (1994) and Yeats *et al.* (1996), and comparison with the post-1900 record shows that, in some cases, recurrence of historical faulting has not been observed during the instrumental period.

The data are sufficient to allow the derivation of regional relationships between magnitude and rupture length. Historical sources record large surface fault ruptures only, small ruptures not being spectacular enough to attract attention. Descriptions from which one can deduce faulting are relatively few and hard to verify, particularly when the sources are secondary and the recorded ground deformations are not well described. One of the problems both in early and in later descriptions of surface faulting is that one cannot always be certain whether ground deformations associated with an earthquake were of tectonic origin or due to landslides, liquefaction or slumping of the ground. In some cases, ground deformations genuinely of tectonic origin can be identified from the description of ground ruptures that extended continuously or discontinuously along considerable distances, but relative displacements are seldom given for vertical, and never for horizontal, slip. The information which is usually available for this period, therefore, may be classified into three broad categories according to the following criteria.

- (A) Strong evidence for surface faulting explicitly (A) or implicitly (a) described in the sources. The length of the rupture is rarely given, and only in relatively few cases can it be reckoned from the distances between the localities which it traversed.
- (B) Surface faulting that is not supported by clear evidence can be inferred from the alignment of a long and narrow epicentral region of a large-magnitude earthquake close to or along a known fault. Occasionally the length of a break can be

reckoned from the length of the long axis of the epicentral region which contains an assumed rupture. Clearly this would not tell us exactly how far the fault rupture extended, but would suggest that the shock was probably associated with a surface rupture that can be investigated today in the field. In these cases, historical information will not reveal the exact location and rupture length, but it can help to define the time and the segment of the zone that was probably ruptured.

- (C) Faulting assumed because of the large size ($M_S > 7.0$) of the associated shallow earthquake and its proximity to a known active fault zone. This category is more tenuous than category (B), but it is included to guide further field studies. There are many events of $M_S > 7.0$ that might have been associated with faulting, such as those in and around the Sea of Marmara, in Eastern Anatolia and Iran, but these are omitted since their epicentral area is ill defined.

Of these three categories, (A) involves some ruptures that might not previously have been associated with known active or Quaternary faults. Categories (B) and (C) merely date probable breaks of segments of known faults and help assign size to these events. All these cases indicate recent activity, because the proximity of these earthquakes to known faults was part of the evidence assigning them to these categories (Ambraseys and Jackson 1998).

We see that not only is historical information about surface faulting not always clear, being in many cases inconclusive, but also even for a number of earthquakes in the first half of the twentieth century evidence for surface faulting is poor and occasionally insufficient. In hardly any of the historical cases do documentary sources, even up to the end of the nineteenth century, provide more than a minimum of information about faulting, and neither the length nor the attitude of the break can be deduced with certainty.

Most of the cases in categories (A) and (a) are associated with well-known major fault zones such as the North and Eastern Anatolian fault zones, the Dead Sea fault system confirming the long-term and almost continuous activity of these zones. The most interesting historical faulting is that which has happened where its occurrence could not be predicted from twentieth-century activity or, alternatively, where it could be expected from twentieth-century seismicity but has not been observed this century.

The importance lies, therefore, not so much in the similarities but rather in the differences between the distributions of cases depicted in Figures 2.23(a) and (b). For

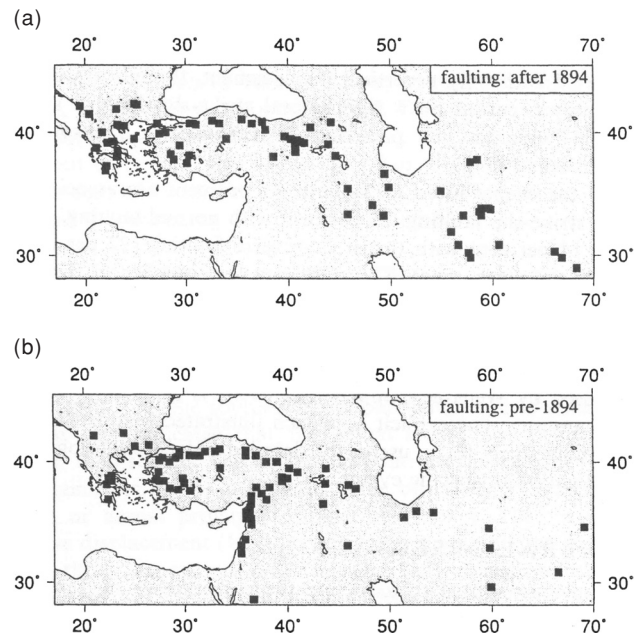


Figure 2.23 Locations of earthquakes associated with surface faulting (a) for the instrumental period, 1894–1996; and (b) in the pre-instrumental period before 1894.

instance, in Figure 2.23(a) the faulting pattern in the modern period shows no ruptures along much of the Eastern Anatolian fault zone, the Dead Sea fault zone and northern Iran.

In contrast, for the historical period, Figure 2.23(b) shows that these zones had already been ruptured in places before this century, and that the two sets of figures complement each other, with historical cases often forming a negative or mirror image of the distribution of modern cases and apparent gaps in the twentieth century being filled in by historical cases. Like the North Anatolian fault zone which was delineated by a series of surface fault ruptures during this century from east to west, so in the last century were the conjugate Eastern Anatolian fault and its Levantine extension delineated by a succession of fault breaks.

Accounts of coseismic surface ruptures in earthquakes are of interest in all assessments of natural hazard. Firstly, such evidence, which could be obtained only from field studies of earthquakes, can positively identify the faults responsible for earthquakes, confirming that structures already known from their associated Quaternary geomorphology are active today as well as revealing previously unknown ones.

Secondly, such accounts can help clarify the nature of the earthquake source, allowing estimates of the rupture size, fault attitude, slip, magnitude and direction. This is particularly important for earthquakes in

the period before about 1963 (the year of installation of the WWSSN), for which reliable fault-plane solutions and focal depths are usually not available. For pre-instrumental earthquakes prior to about 1900, such accounts may be used to provide constraints on the size of the earthquake.

Knowledge of the amount of coseismic slip, when combined with some estimate of the long-term slip rate on faults identified from GPS data, palaeoseismology or late Quaternary offsets, can give some idea of the expected long-term recurrence interval or slip deficit since the last earthquake. Precise identification of the coseismic rupture terminations is important for an assessment of how slip on one fault affects the state of stress on neighbouring active faults and perhaps the likely triggering of future earthquakes (e.g. Stein *et al.* 1997).

Finally, knowledge of past surface faulting is important when the activity of a fault is to be researched by trenching methods, since it allows the completeness of the palaeoseismological investigation to be assessed and gives some indication of whether the trench site is likely to be representative of the rupture as a whole.

For 62 of the 150 cases of surface faulting retrieved we have both uniformly reappraised surface-wave magnitudes from instrumental data and reasonably reliable rupture lengths from field observations. These events are all in the instrumental period, with 55% of the data coming from strike-slip, 30% from normal and 15% from thrust faults, excluding cases of quality (B) and others for which the rupture length is imperfectly known.

A straightforward orthogonal regression between M_S and $\log L$ (here and throughout, logarithms are to base 10) gives

$$M_S = 5.13 + 1.14 \log L \quad (2.1)$$

with L in kilometres, with a standard deviation of 0.15 in M_S . Alternatively, regressions of M_S on $\log(L)$ and of $\log(L)$ on M_S give

$$M_S = 5.27 + 1.04 \log L \quad (2.2)$$

and

$$\log L = -4.09 + 0.82 M_S \quad (2.3)$$

respectively, with almost the same standard deviation of 0.22 in M_S for both cases, while a non-linear fit results in

$$M_S = 5.06 + 1.42 \log L - 0.14(\log L)^2 \quad (2.4)$$

with a slightly larger standard deviation (Ambraseys and Jackson 1998).

For 58 of the 62 earthquakes used to derive Equations (2.1)–(2.4) we have also horizontal (H) and vertical (V) maximum surface displacements but the fit improves little, being given by

$$M_S = 5.11 + 0.86 \log L + 0.21 \log R \quad (2.5)$$

with a standard deviation of 0.20 in M_S , in which R is the resultant displacement from H and V, in centimetres.

In terms of resultant displacement R alone, M_S may be approximated by

$$M_S = 5.21 + 0.78 \log R \quad (2.6)$$

with a rather large standard deviation of 0.36 in M_S and the resultant displacement R is about $5.0 (\pm 4.0) \times 10^{-5} L$, regardless of mechanism. This value for R is no surprise and is similar to that found in global compilations of more modern datasets (e.g. Scholz 1982). However, the size of the sample is insufficient and the scatter too large to allow a better estimate of R as a function of mechanism.

It is important, particularly for palaeoseismological investigations, to have some indication of whether the rupture length and offset estimated from historical sources are likely to be seriously under- or over-estimated given the magnitude of the event or vice versa. This is a principal use of magnitude–length relationships. For an assessment of individual events or particular regions, it may be more informative to make such estimates from a combination of first principles and more closely constrained empirical relationships, along the following simple lines (Ambraseys and Jackson 1998):

- (i) For earthquakes that rupture the entire thickness (d) of the seismogenic upper crust, the down-dip width of the fault is $d/\sin(\theta)$, where θ is the fault dip, and the moment is then

$$M_0 = (cd\mu/\sin\theta)L^2 \quad (2.7)$$

where μ is the rigidity modulus and c is the ratio of average displacement (u) to fault length (L), which is observed to be close to $5 \times 10^{-5} L$ for intra-continental earthquakes (Scholz 1982).

- (ii) Both observationally and theoretically it is known that for such earthquakes the relationship between moment and magnitude (M , either M_S or M_W) is of the form

$$\log M_0 = A + BM \quad (2.8)$$

where A and B are constants, with $B = 1.5$ for events with M not smaller than about 6.0.

- (iii) Combining these expressions gives a relationship between moment and fault length of the form

$$M_0 = \log(\mu cd/\sin\theta)/B - A/B + 2(\log L)/B \quad (2.9)$$



Figure 2.24 The fault scarp associated with the Hebgen earthquake in Montana of 17 August 1959. Note that the 6-m-high vertical face of the scarp in colluvium did not collapse or slide off during the earthquake which was generated by the very same fault rupture.

For illustration, if we take $m = 3 \times 10^{-3} \text{ N m}^{-2}$, $c = 5 \times 10^{-5}$ and $B = 1.5$, then for a seismogenic layer of thickness $d = 15 \text{ km}$ and a vertical strike-slip fault ($\theta = 90^\circ$) the relationship is

$$M_W \text{ or } M_S = 4.9 + 1.33 \log L \quad (2.10)$$

with L in km, which is similar to the empirical relationship (2.1).

2.3.2 Transient ground motion close to the fault

Intensity scales are based on three characteristics of ground shaking: perception by people, performance of man-made structures and changes caused to the natural environment, such as faulting, the last of which is characteristic as a criterion for the top of the intensity scales.

The question of whether surface faulting should be considered as a criterion of very high intensity and consequently of high ground acceleration I first discussed at length with the late Jim Sherrard, taking as an example the stability of the 6-m-high vertical fault scarp in colluvium which was produced by the Hebgen Lake earthquake on 17 August 1959, Figure 2.24. We argued that, if, instead of a 6-m fault scarp we had the vertical face



Figure 2.25 A 2-m normal fault scarp in soft marls near Tuzluburun Tepe associated with the Gediz earthquake of 28 March 1970, looking southeast (April 1970).



Figure 2.26 A 2.8-m-high fault scarp in soft topsoil in the Mudurnu earthquake of 1967 in Turkey.

of a 6-m deep excavation in colluvium, even under static conditions, it should have required the construction of a retaining structure to prevent the face from collapsing. In the present case the fault scarp was standing up with a free vertical face, having been produced by an earthquake. A stability back-analysis of scarp showed that it should have collapsed had the horizontal acceleration been greater than about $0.25g$. As other, similar cases show, viz. Figures 2.25, 2.26 and 2.27, proximity to a fault



Figure 2.27 Panic during an aftershock of the El Asnam earthquake of 10 October 1980 in Algeria.



Figure 2.28 A timber-framed house straddling the fault of the Mudurnu earthquake of 1967 in Turkey.

break does not always imply high intensities or ground accelerations.

Also the behaviour of houses suggests that proximity to a coseismic surface break is not necessarily an indication of ground motions much higher than those at some distance away from the rupture. Figures 2.28 and 2.29, for instance, show timber-frame houses straddling the shear zones of the Mudurnu and Gediz earthquakes in Turkey, and Figure 2.30 a brick house, 10 m away from the scarp of the Mudurnu earthquake, that suffered very little damage. In contrast vulnerable structures such as rustic houses made of adobe or stone, will collapse regardless of their proximity to a coseismic surface fault break.

Another example of relatively low intensity along a fault break was noticed also along the east–west branch of the Gediz fault. Figure 2.31 shows the fault break which passes right through the village of Erdoğmuş. Along its course damage to stone masonry and to brick



Figure 2.29 One of the many timber constructions built on the fault break of the Gediz earthquake of 1970 in Turkey that survived even with their plaster intact.



Figure 2.30 Kiln brick construction within the fault zone, a few metres away from one of the fault breaks in the Mudurnu earthquake. The only damage done was the loss of its short chimney stack.

houses reinforced with timber was relatively small. The house shown in Figure 2.32 can be seen also in the background of Figure 2.31, just behind the tents. With the exception of the loss of its chimney and cracked plaster, it survived the earthquake, like many other houses in the village, with reparable damage. In contrast, adobe houses in Erdoğmuş and at considerable distances away from the village were shattered with loss of life.



Figure 2.31 A view of the village of Erdoğan which straddles the fault break associated with the Gediz earthquake of 28 March 1970 in Turkey. Most houses and the standing minaret in the background were damaged but not destroyed.

2.3.3 Fault creep

Creep movements too slow to radiate seismic energy have been observed on faults of all scales in many parts of the world, and may occur before or after earthquakes. Faults that exhibit creep usually have earthquakes as well, and, like other active faults, produce geomorphological features that greatly aid their recognition. It was thought that in systems of active faulting the release of seismic moment in earthquakes accounts for a considerable part of the overall motion, viz. of India and Africa northwards into Eurasia, and that the reset of this motion was assumed to take place by aseismic creep (Chen and Molnar 1977).

There is little evidence to assess creep from historical sources. Today fault creep can be monitored only by instruments installed close to a fault, and, where it has been detected, it is usually found to be clustered.

I have found very little or no conclusive evidence from field observations of post-earthquake creep. One case is that of a masonry fence wall of the Turkish Railways Repair Depot at İsmet Paşa station, built in 1957

and shown in Figure 2.33, which straddles a strand of the North Anatolian fault zone, not far from the location where railway tracks had been displaced by fault movements in the earthquakes of 1944, 1950 and 1951. When this location was first visited in the spring of 1967, and again a year later, the wall facing east was found to have been sheared off and displaced in a right-lateral sense by about 24 cm. Measurements of the continuing displacements after 1970, taken by Alkut Aytun, clearly showed a creep rate of 20 mm/year, Figure 2.34. For more recent measurements see Çakır *et al.* (2005).

Another case, shown in Figure 2.35, is that of a dirt road on level ground, leading from the south to the village of Erdoğan in Turkey, which crosses the fault break of the earthquake of 28 March 1970. The dominant motion was normal, showing a downthrow of about 40 cm to the southwest and a small left-lateral offset of about 15 cm. A few days after the earthquake the fault scarp and the small graben in front of it were filled in and the road surface was levelled off. When, ten days after the earthquake, I visited the site I found that during the intervening period ruts on the repaired road surface, which were made originally by the passage of wheeled carts after heavy rains after the earthquake, had been offset in a right-lateral sense by a few centimetres with no evidence of vertical displacements, Figure 2.36.

At first glance, similar observations elsewhere seemed to show strike-slip fault displacement and a reversal of the sense of horizontal movements. However, the detailed mapping of a number of similar fractures on flat ground in the vicinity demonstrated that invariably fissures were arranged in a zigzag pattern rather than en echelon and that all of them were open, showing no preferential lateral displacement on a large scale. A likely explanation would be that zigzag fractures opened directly; they cannot be explained in terms of strike-slip displacement. Such ground deformation would necessarily have produced compression features or at least significant changes in the opening of these fractures along their trace. What is certain is that these displacements continued to grow after the earthquake.

Another inconclusive case is the fault break associated with the Mudurnu Valley earthquake of 22 July 1967, which along its course crosses a fence at Akyokuş with a 110-cm right-lateral displacement, Figure 2.37, and, after passing under a timber-framed house, the foundations of which were distorted, the trace continues to the east. According to local information, the faulting associated with the earlier Abant earthquake of 1957 had followed almost exactly the same trace as the 1967 rupture. The lateral offset of the fence immediately after the earthquake was about 90 cm and at the time of our visit

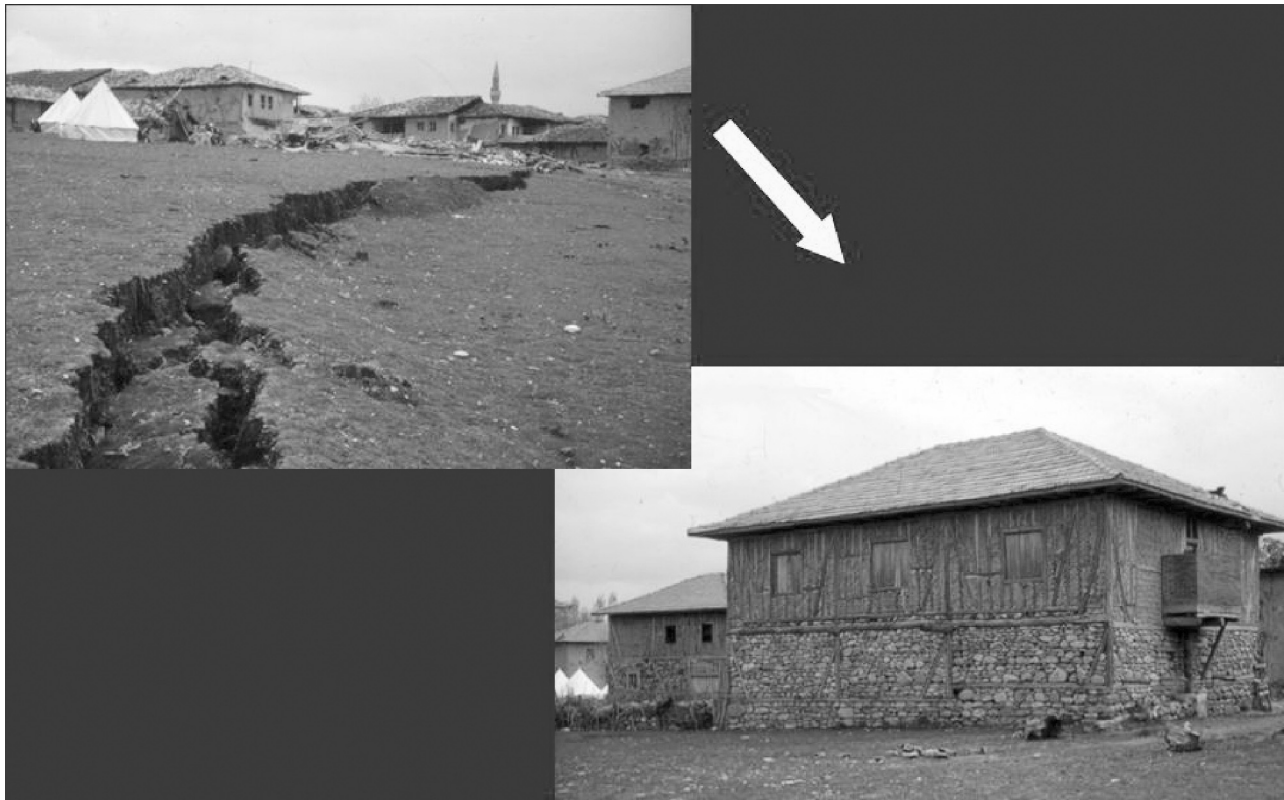


Figure 2.32 A traditional Turkish stone-masonry and timber-frame house, shown in the background of Figure 2.31 behind the tents, only 25 m from the fault scarp, suffered only plaster damage and the loss of its short chimney.



Figure 2.33 A masonry fence wall, built in 1957, straddling the North Anatolian fault zone at İsmet Paşa railway station, displaced by creep movements associated with the earthquake of 1951.

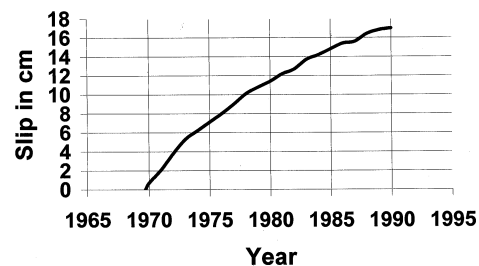


Figure 2.34 Recorded horizontal slip displacements after 1968 of the wall facing east at İsmet Paşa, shown in Figure 2.33.

it had increased by 'one hand', that is to about 110 cm. However, here displacements vary erratically and they must have been controlled by movements of an old slide, so it is not certain whether the post-earthquake increase in slip was due to creep or slope movement.

Attempts to monitor creep after other earthquakes have, for various reasons, been unsuccessful. An attempt to monitor the opening up of small grabens produced by the earthquake of 10 October 1980 in El Asnam, Figure 2.38, over a period of four years, Figure 2.39, revealed very high slip rates that most probably were



Figure 2.35 A dirt road that crosses the fault break caused by the earthquake of 28 March 1970 in Turkey was repaired a few days after the event. The rut on the repaired road was made by the passage of wheeled carts after heavy rains that followed the event. The figure shows the rut offset after its formation.



Figure 2.36 Detail of the rut displaced due to creep shown in Figure 2.35.

enhanced by incipient sliding of the lower part of the slope.

2.4 The effect of earthquakes on local houses

Archaeological sites in the Eastern Mediterranean today often display impressive ancient buildings and free-standing colonnades, which, however, are the result of relatively modern restoration rather than having remained in their original condition. In their original condition, displaced, leaning or collapsed colonnades are features that invariably are associated with earthquakes. It has been noticed, however, that in epicentral



Figure 2.37 A fence at Akyokuş straddling the fault associated with the 22 July 1967 earthquake in Turkey, offset by 110 cm. This fence had been displaced at the same point by the Abant earthquake of 1957.



Figure 2.38 Secondary normal ground deformations in the form of grabens forming in the upthrust block of marls as a result of the El Asnam earthquake (M_s 7.2) in Algeria of 10 October 1980. These secondary features give the impression of normal surface faulting produced in an earthquake of thrust mechanism.

regions well-built, slender, free-standing structures, such as columns, can come through an earthquake unscathed.

In almost every destructive earthquake in the region during the nineteenth and twentieth centuries, many simple structures, such as columns of Greek and Roman monuments and much later slender buildings, such as bell-towers and minarets, have survived many earthquakes while ordinary local buildings all



Figure 2.39 The same feature as that shown in Figure 2.38 four years later, showing the widening of the grabens locally.



Figure 2.40 The spire of the Mustapa Paša *jamija* (mosque), built c. 1493, after the earthquake of July 1963 in Skopje. Its tip was knocked so far sideways that the minaret seems to defy the laws of equilibrium. In spite of the violence of the earthquake, there was no structural damage.

around them have collapsed or been badly damaged, Figure 2.40.

In contrast with other types of relatively robust structures, that appear to be more stable under earthquake shaking, free-standing columns on solid foundations are generally more resistant to near earthquakes than might be expected. Consequently their survival over the centuries is neither surprising nor to be interpreted as

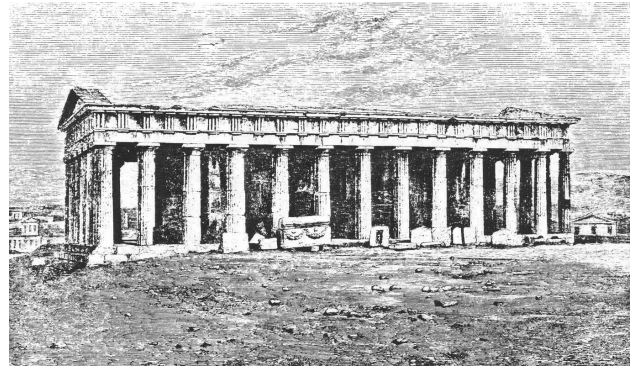


Figure 2.41 A general view of Theseio in the mid 1850s.

implying low seismic activity of the region in which they have been erected.

In spite of its simplicity and uniformity, the response of a column to an earthquake is unique, much depending on the properties of the column itself and on its foundation conditions as well as on the characteristics of the ground motion, which are not known before the earthquake. Field observations and numerical analysis show that the response is literally chaotic and unpredictable.

Many of the columns overturned by earthquakes and high winds recently had already been weakened by deliberate hewing of their base drums in order to remove the lead dowels or their foundations had been weakened by leaching and erosion. It is interesting that historical sources seldom attribute collapse of columns specifically to earthquakes. Occasionally it is ascribed to deliberate demolition for use as building material or for making lime.

An interesting case of columns that are still standing but with displaced drums is that of the temple of Hephaistos at Theseion in Athens, built c. 415 BC, which, owing to its conversion into a church, is one of the best preserved of extant Greek temples, Figure 2.41. The building is almost wholly of Pentelic marble, except for the lowest of the three steps, which is limestone and stands on a knoll, directly on dressed bedrock with the exception of the southwest and southeast corners, which are on a fill of porous limestone (Dinsmoor 1941). Figure 2.42 shows the monument today, 2400 years after its completion, viewed from the southeast.

What is difficult to explain is the way in which the columns of the north face of the temple, and to a lesser degree those of the south face, have been distorted and their drums displaced and rotated, Figures 2.43 and 2.44. There is no literary evidence that these effects were caused by one or more of the few known earthquakes that shook Athens, or to indicate when these

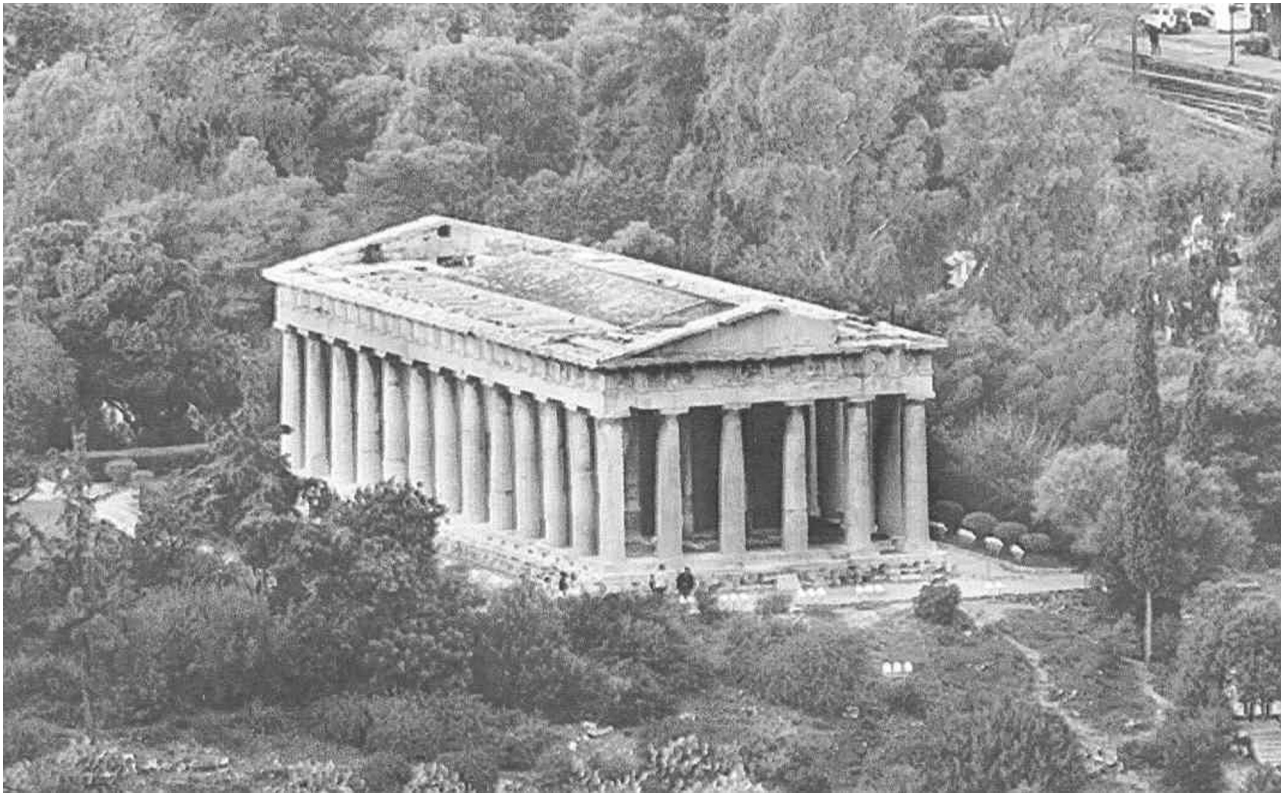


Figure 2.42 The temple of Hephaistos at Theseion in Athens, built c. 415 BC, which, owing to its conversion into a church, is one of the best preserved of extant Greek temples.

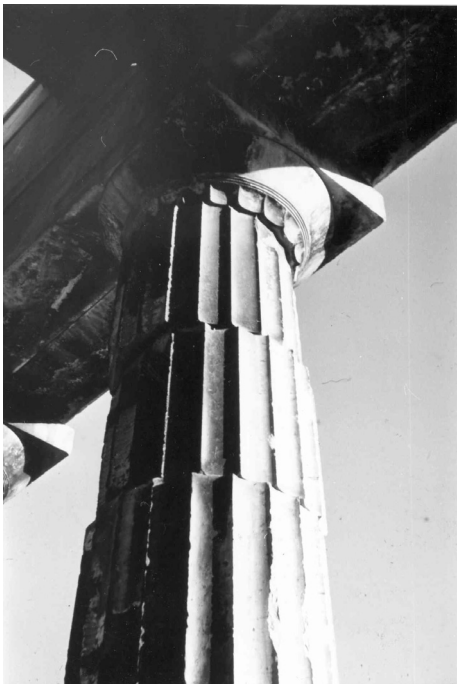


Figure 2.43 Detail of the column with displaced drums shown in [Figure 2.44](#).

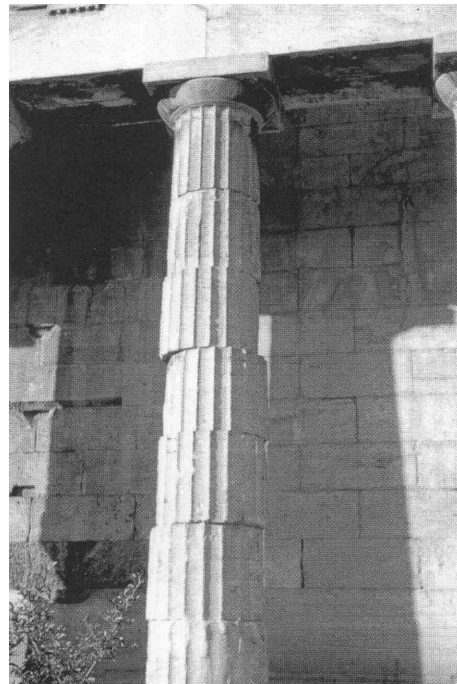


Figure 2.44 Displaced and rotated drums of one of the columns of the temple at Theseio in Athens shown in [Figure 2.41](#).



Figure 2.45 The temple of Zeus at Aizani (Çavdarhisar), one of the best preserved of Roman temples of the second century AD in Turkey, seen before the Gediz earthquake of 1970 (Akurgal 1973, 267–270, Figure 49).

displacements of the drums were first noticed. Modern writers like Galanopoulos (1956b) attribute this to an earthquake sometime after the conversion of the temple to a church, but they do not quote their sources of information. Mere differential settlement of the base of the temple, which rests partly on a rock outcrop and partly on fill material, does not explain the preferential distortion of only some of the columns.

A typical example where the reason for, and mode of, collapse of columns are known is the case of the temple of Zeus at Aizani (modern Çavdarhisar), near Gediz in Turkey, which dates back to the first century BC. The temple was shaken on 28 March 1970 at a distance of about 20 km from the epicentral region of the Gediz earthquake, which had magnitude M_s 7.1. Figure 2.45 shows three free-standing columns, which were standing even after, together with other columns of the temple, they had been damaged a century or so earlier by the deliberate hewing off of their bases and also by the earthquake of 25 June 1444, Figure 2.46. The damage was repaired and the columns strengthened with cement pil- lows, Figure 2.47.

It is interesting that the only columns that collapsed in the earthquake of 1970 were those which had been ‘strengthened’ a decade earlier, Figure 2.48.

Another case of the adverse effect of recent interventions intended to restore early structures can be seen in the recent earthquake of 1999 in Kocaeli in Turkey. In Istanbul, the only part of the old city walls to collapse was a tower that had been completely reconstructed in new masonry only a few years earlier (Langerback 2002).

In the temple of Apollo at Vassae in the Peloponnese, which I happened to visit twice, on my second visit, shortly after the earthquake of April 1965, some of the



Figure 2.46 Characteristic damage to one of the columns of the temple of Zeus at Aizani caused by the deliberate hewing off of its base drum, probably for the lead of its dowel.



Figure 2.47 Detached corner repair with cement at the base of one of the columns carried out before the Gediz earthquake of 28 March 1970.

columns were found to be leaning over rather excessively and some of their architraves to be on the verge of collapse. There was no other damage to the structure except for the indication that the foundations were in places eroded as a result of the location of the temple just below a small catchment area. This and the fact that the corner columns rested on good-quality stylobates while their foundation material had settled had caused the columns to lean over.

Identifying, assessing and dating damage in excavations and extant ruins is frequently based on, or influenced by, literary sources rather than by any precise internal archaeological indicators. Stratigraphy alone, without some hard evidence such as coin finds or proper dating, is insufficient to establish a chronological association between earthquakes that might have been entirely unrelated. The key point here is that the documentary record is incomplete and many destructive historic and prehistoric earthquakes of which no written description



Figure 2.48 Two of the three columns of the Roman temple of Zeus at Aizani which had been repaired well before the earthquake, shown on the right in Figure 2.45, after their collapse in the Gediz earthquake of 28 March 1970. In the background is the village of Çavdahisar, which was badly damaged.

exists or survives undoubtedly occurred. Yet this attitude often develops into a circular process, whereby the conclusions of the archaeologists have been taken as factual evidence of earthquake activity and then used in turn by earthquake cataloguers to confirm the dates in their literary sources.

Furthermore, the archaeological evidence for an earthquake is not always clear or unambiguous. Displaced, leaning or collapsed walls in an excavation or of extant historical structures are often explained as being due to earthquakes, invoked as a *deus ex machina* (cf. Di Vita 1995). However, they can be due to other, non-seismic, causes such as differential settlements, particularly due to leaching or weathering of the foundation materials over the ages. Occasional earthquakes may indeed assist this process of deterioration, particularly

when these structures have been rendered more vulnerable by acts of warfare. Random or coursed rubble masonry walls laid in clay mortar may deform excessively with time, even without the help of earthquakes, while originally badly aligned polygonal and rectangular dry walls can easily fracture even as a result of small differential settlements of their lower courses or of their foundations, giving the impression of structural failure as a result of lateral or vertical earthquake loading. Deliberate damage and military operations can also leave effects that may be misinterpreted. Furthermore, damage can be the result, perhaps cumulative, of more than one earthquake that happens even a long while after the abandonment of the site. Great caution must be applied when using archaeological data to identify, locate and, in particular, date early earthquakes.

2.4.1 Vulnerability of structures

It is obvious that for the proper assessment of intensity and in particular of the earthquake risk we must take into account the vulnerability of the man-made structures which are exposed to an earthquake. It must also be noted that the intensity scales used today have been devised for twentieth-century, chiefly modern Middle European, houses, so there arises the question of how much the vulnerability of the building stock of today differs from that of, say, 1000 or even 50 years ago in South-east Europe and the Middle East. Up to the middle of the last century houses in rural areas and small urban centres in the region were not so much different from those that existed in earlier times, so the study of their behaviour side by side with modern buildings in recent earthquakes is an important consideration.

Adobe constructions (**A**) have walls made of tamped clay soil, sometimes mixed with straw, or of adobe bricks of various sizes, and are built usually without proper foundations. The strength of the adobe walls varies widely and depends on the consistency of the soil, that is, of the clay and silt available locally.

Adobe houses are one or, more rarely, two storeys high and in arid regions often have a sub-basement, the soil from which had been used for making the bricks with which the house was built. These houses have few openings and they are covered with roofs similar to those of the rubble-masonry type. They are built by their owners and they were found in central Turkey, but also in western Anatolia, northern Greece, and up in the mountains of Lebanon and Anti-Lebanon.

Around Aleppo, the region is almost treeless, timber is consequently expensive, so the people roof their adobe houses with conical domes built of mud bricks. This is an ancient method of roof construction; there are



Figure 2.49 Disintegration of a fence-wall of kiln bricks laid in silty clay mortar, as a result of the earthquake of Gisk of 19 December 1977. Notice the adobe house in the background which was damaged but still stands.



Figure 2.50 Disintegration of a stone-masonry wall laid in clay mortar caused by moderately strong shaking.



Figure 2.51 Remains of the mosque of Kakhk after the earthquake of 31 August 1968. Massive adobe brick walls, clad with kiln bricks, were disintegrated by the shock.



Figure 2.52 This is what is left of a large village of adobe houses after the Gisk earthquake of 19 December 1977 in Iran (M_s 5.7).

representations of similar huts on Assyrian reliefs. The ground plan of a house is generally square and several of them are clustered together in the family courtyard, which is surrounded by a mud-brick wall.

In central Syria and the Euphrates region houses are of a common eastern type, built generally of adobe or wattle and daub, with flat roofs, and standing in, or against, the walls of the mud-brick enclosure. The plans of ancient houses of the same pattern can be seen on old sites of many periods.

What makes this class of houses extremely vulnerable, and the reason why their collapse causes great loss of life, is that they are laid in clay mortar, a bonding material that disintegrates even under moderate shaking, turning walls into a heap of rubble (Figures 2.49–2.51) and villages into a mass of ruins, Figures 2.52–2.54.



Figure 2.53 A view of a village near Karakurt in the Varto area, eastern Turkey, which was totally destroyed by the earthquake of 19 August 1966.

Very often one finds adobe villages razed to the ground with better-built constructions standing unscathed. Heavy roofs and the way in which rural houses in many villages and towns are built together in a 'bee-hive' construction contribute to their destruction, [Figure 2.55](#), particularly when adobe is used to build two- to three-storey-high houses, [Figures 2.56](#) and [2.57](#).

Rubble-masonry constructions (**R**) have walls 50–70 cm thick, made of broken pieces of rock set in clay mortar, often with small stones keyed in between larger ones. In valleys and along rivers, cobbles are used instead of broken stone, the walls having few and small openings. Rubble-masonry houses rarely have proper foundations and are usually one storey high, being situated occasionally on sloping ground built partly below street level. They are covered with flat heavy roofs made of rammed

earth or mud mixed with straw. In regions where this type of construction predominates, treated timber for rafters and beams may be scarce, so untreated timber, usually tree trunks either whole or split axially, rarely straight and often weakened through exposure, is the sole roof-supporting material. Layers of twigs and branches are usually used in lieu of boarding, covered with 20–60 cm of rammed earth; this constitutes a roofing system that provides a good insulation but weighs five times more than a tile roof. These types of houses are low-quality, vulnerable constructions, built as in earlier times by their owners and their extended families, who are not always good builders, [Figure 2.58](#). They were found mainly in east and southeast Turkey and in Syria, less often now than four decades ago, where they constituted the bulk of rural housing and shanty suburbs of towns.

(a)



(b)



Figure 2.54 (a) The ruins of an abandoned village in Buyin Zara, seen four years after the earthquake of 1 September 1962. (b) The remains of highly vulnerable adobe constructions after the Iran earthquake of 1972, seen two years later.

‘Reinforced’ rubble and adobe constructions (S) have walls made either of worked stone set in clay mortar or of adobe, and reinforced with timber baulks, laths or wood bond strips that are built into the walls and spaced 80–150 cm apart vertically, framing window and door openings and used as spreaders under roof timber beams. Some of these houses contain a very light

braced timber frame built into the walls and occasionally free-standing internal timber columns or wooden poles supporting roof beams. This type of construction is usually one and occasionally two storeys high and its roofing system consists of timber rafters carrying a sheeting of branches or planking, covered by a relatively thin layer of tamped earth, 20–30 cm thick, the roof having a slight



Figure 2.55 Typical earthquake damage to mud-wall and vaulted-roof constructions observed in Bidokht caused by the earthquake of 31 August 1986. The heavy domed roof, built of wafer kiln bricks and covered by adobe for insulation, caved in. In contrast the elevated windshaft (*badghir*) in the background, built wholly of kiln bricks, survived intact.

pitch. Reinforced adobe houses of more recent construction often have roofs made of tile or more rarely of corrugated sheet steel. Their construction requires some professional skill and the use of traditional techniques. They were found in northern and eastern Turkey, northern Syria and Iraq. Like (R), (A) and (s) constructions, they age rapidly and often, particularly during the wet period, collapse without any help from earthquakes.

Stone masonry constructions (S) have walls 40–80 cm thick made of worked stones set in lime mortar. They are also built of cut stone laid in cement mortar and are usually one to three or more storeys high, with timber floors and tile, or, more rarely, slate roofs, all supported by triangular trusses of sawed lumber. Occasionally, floors are of reinforced concrete cast *in situ* and rarely of jack-arch construction. This type of house, which is encountered today throughout the region, is constructed by professionals or with the help of experienced builders with materials obtained locally. In general, how-



Figure 2.56 Traditional buildings in Yemen ruined by the earthquake of 13 December 1982 (Adnan Niazi).

ever, historical as well as relatively new stone masonry houses in the region suffer from ageing, improper repairs after earthquakes and lack of maintenance.

Figure 2.59 shows a classical example, one of many in the centre of Venzona in Italy, which was destroyed by the earthquake of 6 May 1976. Most of the houses in the historical centre were old, vulnerable constructions of stone masonry laid in lime or clay mortar, some of which had already been repaired after earlier earthquakes and damage sustained as a result of warfare at the end of WWII. In the background, a more recently built brick house suffered absolutely no damage, Figure 2.60.

The ungraceful ageing of buildings in the East was partly because of the custom of allowing buildings to fall into rack and ruin which was universal in the Eastern Mediterranean region and the Middle East. No one repaired what his predecessor had built, or an earthquake had damaged; he preferred, if he could afford it, to build something new, which could bear his name and flatter his vanity. In this way, great works of utility and beauty were allowed to tumble into ruins and others, still extant, become progressively more vulnerable to earthquakes. This is the opinion shared by most seventeenth- to mid-twentieth-century European travellers who passed through the region.

In timberless areas, such as the Hauran, instead of wood the people use stone for all manner of purposes: in the old days they made small doors, window frames and shutters from slabs of the local basalt. Ceilings also are



Figure 2.57 Another view of traditional buildings in Yemen ruined by the earthquake of 13 December 1982 (Adnan Niazi).



Figure 2.58 A house in a Kurdish hamlet, southeast of Üstükran, in Turkey, destroyed by the Varto earthquake of 1966 and rebuilt exactly the same.

made, as in the classical period, of stone beams carried on a series of transverse arches that divide every room into a number of open compartments; such roofs are indestructible.

Along the Syrian and Lebanese coast the houses were built of relatively good stone masonry, the favourite type of house being a two-storey house with a deep wide-arched veranda on the upper floor where the occupants can see, and be seen by, every passerby. This way of life is diametrically opposite to that in some other

parts of the Middle East where houses were restricted to one storey, in some cases because people disliked rooms raised above the ground floor, because these would allow neighbours or strangers to observe their domestic arrangements. Even minarets, it is said, had to be pulled down because they commanded a view of the interior of houses.

Stone masonry houses in eastern Turkey, Armenia and northwest Iran were usually old, one- to three-storey constructions, most of them in a permanent state of dilapidation. Figure 2.61 shows two panoramic views of the devastation caused by the earthquake of May 1930 at Dilman, in which few people survived. When visited 38 years later, the small town had been rebuilt, with few exceptions, with exactly the same types of construction.

However, properly built houses made of stone masonry laid in lime mortar were strong enough to resist severe earthquakes with reparable damage. According to local sources the sixteenth-century bridge on Murat Nehri (the Euphrates) near Muş in eastern Turkey shown in Figures 3.42 and 3.43 has survived many earthquakes. Some of its arches have had to be repaired and one of them and a pier had to be rebuilt.

In contrast with adobe and stone masonry, houses made or reinforced with wood (**T**), although they could be damaged beyond repair in a severe earthquake, rarely collapsed completely and did not cause great loss of life,



Figure 2.59 Destruction of the historical centre of Venzone in Italy by the earthquake of 6 May 1976. Most of the houses were old, vulnerable constructions of stone masonry laid in lime or clay mortar, some of them having been repaired after earlier earthquakes and warfare at the end of WWII. In the background, a modern brick house suffered negligible damage (see Figure 2.60).



Figure 2.60 This house, shown on the right of Figure 2.59, was one of the few modern houses in the historical centre of Venzone which was not damaged by the earthquake of 6 May 1976. It was a reinforced kiln-brick construction built on a thin raft. Notice the small number of windows.

Figures 2.62–2.64. It is remarkable that timber-framed houses built during the mid 1850s in Lefkas (Santa Maura) in the Ionian Islands, by carpenters of the British Navy, are still occupied after so many destructive earthquakes, Figures 3.34 and 3.35.

Figure 2.65 shows the type of wooden frame used in the Ionian Islands, which, with small variations, is very similar to that used in Turkey, Figure 2.66, where walls can be of light, plaster laths, timber, adobe bricks and a mixture of mud and straw, cobbles or stones. Figure 2.67 shows details of some of the very few proper timber-framed houses built in Turkey after recent earthquakes.

Timber-frame constructions are usually one storey high, but they can be two or three storeys high, being built with braced timber frames of hand-hewn logs or sawed lumber, which carry all the structural loads (Porphyrios 1971). This type of construction goes back to the classical period, with construction details very similar to those shown in Figures 2.65 and 2.66, a heritage handed

(a)



(b)



Figure 2.61 Panoramic views of the destruction of Dilman (Shahpur), in the Salmas plain on the borders of Turkey and Iran caused by the earthquake sequence of May 1930; (a) the Armenian church and (b) a general view from a private photograph collection.

down through the millennia from the Mycenaean Age, or rediscovered in more recent times (Blegen and Rawson 1966).

Pitched roofs over timber rafters are covered with tiles or more rarely with planks. On steep slopes on hilly ground one side of the house may be one storey high while the other, down-hill, side may be two or three storeys high. On level ground wooden stilts are driven into the ground and the ground floor is built above street level or on stonework to dado height. This was typical construction for areas not far from timber sources in north and northwest Turkey and northern Greece. Near forests, walls are made of laths or timber infilled with a

mixture of clay and straw. In areas distant from forests, heavier and less-durable materials are used for building walls. Timber-frame constructions were built by skilled builders who were familiar with local materials and traditional techniques.

A general observation about the typical timber-framed house is that its inherent strength is considerable but variable and, although its vulnerability to earthquakes is rather low, unfortunately its vulnerability to fire is high, this danger ranking much higher than that due to earthquakes, [Figures 2.68 and 2.69](#).

There are, of course, combinations of the above types of construction, such as adobe construction



Figure 2.62 The 'soft-ground-floor effect' is exhibited by this timber-framed house in the Gediz area, the first floor of which, although caused to drift 60 cm with respect to the ground by the earthquake of 28 March 1970, remained standing. As a result of the yielding of the ground floor, horizontal accelerations on the first floor were reduced to such an extent that flower pots standing on the window sill, shown in Figure (2.63) were not disturbed.



Figure 2.63 Detail of Figure 2.62.

reinforced with timber, and a two- or three-storey framed house with a stone masonry ground floor.

The most vulnerable combination of building materials is that shown in Figure 2.70. This two-storey house was built on top of an existing stone ground floor, the walls of which were made of old stonework and cement blocks. The materials used to build the first floor included hollow cement blocks, kiln bricks and 'bağdati' supporting a tiled roof. In the first shaking the diverse building materials disintegrated.

Brick-wall-bearing houses (B) are built of proper kiln bricks or cement blocks set in lime or cement mortar. They are one to three storeys high with reinforced concrete floors, lintels, ring beams and staircases cast *in*



Figure 2.64 After a series of damaging earthquakes in the Ionian Islands in the mid 1800s, a new type of timber-framed houses was introduced by carpenters of the British Navy, who used ship-building techniques, such as dove-tailed wooden elbows, to enhance the lateral resistance of the posts, as shown in Figure 2.67.

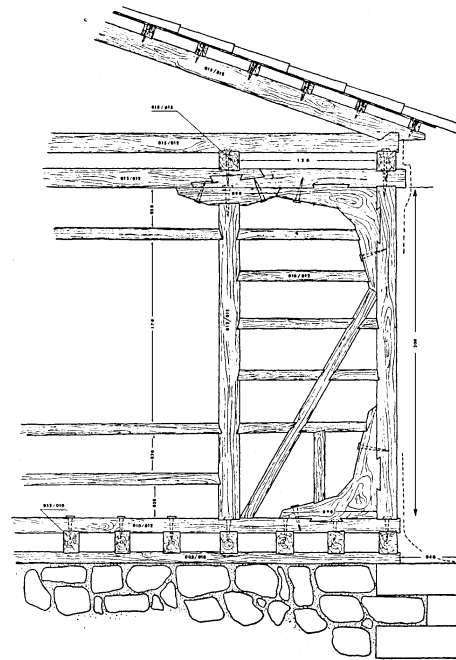


Figure 2.65 A wooden frame used for the reconstruction of houses in the Ionian Islands.

situ. Roofs may be of tile or of reinforced concrete slabs. These constructions are, with few exceptions, properly engineered structures, built under supervision. For the last half century or more they have been the standard type of construction throughout the region.

This relatively modern class of houses built during the early part of the last century (C) proved in many cases to be as vulnerable as traditional constructions.



Figure 2.66 One of the few timber-framed houses under construction after the Mudurnu earthquake in Turkey, of a traditional type that replaced the more fashionable, but vulnerable, unreinforced hollow-brick and low-quality reinforced-concrete houses.



Figure 2.67 Another low-vulnerability traditional timber-framed house in the Gediz area, of a type too expensive to build in the reconstruction of the rural areas.



Figure 2.68 The ruins of a village in the Gediz area, almost entirely of timber-framed houses, which survived the earthquake of 28 March 1970 with reparable damage, but was burnt down by fires started by the shocks.

Buildings with reinforced concrete frames are normally engineered structures, built by professional builders, usually under state control. Today they constitute a considerable and increasing percentage of the total number of houses built in the region. However, as recent earthquakes have shown, in the absence of proper building codes and, in particular, without enforceable regulations, the introduction of new materials and methods of construction has produced a class of highly vulnerable structures, the excessive damage of which in an earthquake gives the false impression of severe ground shaking. Note that in some countries earthquake codes and the enforcement of regulations are instructions, whereas in others they are suggestions and in quite a few they are merely empty words.

Figure 2.71 shows what is often observed in recent earthquakes: modern reinforced concrete constructions collapsing while adjacent houses built with traditional materials and construction methods survive the earthquake unscathed; see also Figures 2.72–2.75.

There are also earthquake-resistant construction methods developed in other parts of the East that are worth mentioning here. Traditional houses in some parts of the Northwest Frontier Province of Pakistan are made of hand-placed stones laid without mortar, reinforced with horizontal timber ring beams spaced about 40 cm apart or less, Figure 2.76. They are built on rock, with no external windows, and they have survived over the years both earthquakes and tribal warfare, but not rockfalls or fire, Figure 2.77. The method of reconstruction of one of these houses, which was destroyed by rock slides triggered by the earthquake of 28 December 1974, is shown in Figure 2.78.

Elsewhere in that region, in spite of the apparent vulnerability of the sites on which they are built, both in the Hazara and Pattan Provinces and along the Karakorum Highway, constructions of this type have survived earthquakes, avalanches and ground settlements, Figures 2.79–2.82.

Finally, there is a type of dwelling, the ‘yurt’ (*ger* in Mongolian and *kigizui* in Kazakh) used by nomads in Turkmenistan and northeast Iran, in which people lived, and some still did in 1957, which they can move from place to place. They are made of woven lengths of black goat-hair with hangings to divide the men’s part from the women’s, and with very long guy ropes to withstand the wind, which do without the use of a central supporting pole, Figure 2.83. Obviously, barring fire, their earthquake vulnerability is literally nil. This in part explains the very low casualty figures in rural areas reported for historical and modern earthquakes in the northern parts of the Near East and in Asia.

There are also earthquake-proof houses of unorthodox design, one of which, the ‘Furutan model’



Figure 2.69 Another village in the Mudurnu region, which was burned down by fires started by aftershocks two days after the main earthquake.



Figure 2.70 This is what is left of a house built out of five different kinds of material.



Figure 2.71 Contrasted response to the Managua earthquake of 23 December 1972 of two contiguous structures of different materials and methods of construction. An engineered, but badly built, reinforced-concrete four-storey building collapsed completely, while the adjacent one-storey house, built with traditional wood and pumice-block materials (*takazal*) with a light tin roof, suffered no serious damage.



Figure 2.72 The effect of the main shock of 28 March 1970 on a three-storey house of mixed reinforced-concrete and brick construction in Gediz.



Figure 2.73 The fatal effect of one of the belated strong aftershocks of the earthquake of 28 March 1970 on the already-damaged building shown in Figure 2.72. Notice the penthouse which was added after the three-storey house had been built two years earlier.

was built in 1970 on high ground above Tehran in the form of a sphere, [Figure 2.84](#). This, and another house of similar shape, were built but never occupied for fear of an earthquake, high winds or a rowdy party on the third floor that would set them rolling down the sloping ground on which they were built.



Figure 2.74 A three-storey reinforced-concrete building in Skopje after the earthquake of 26 July 1963.

It is not possible to present information on the spatial and temporal distribution of building types except in a very coarse manner. Even 30–40 years ago the representative class or type of house concentration in the region varied from district to district and even within individual departments and towns, making it difficult to associate a typical class of building with a particular region. The vulnerability of the ordinary house in the historical period and later should have been similar to that of the adobe and stone masonry and timber-frame dwellings that existed up to the last century.

Information with regard to building types is therefore available only on a coarse scale. This, for the period 1900 to 1980, has been extracted from a variety of sources, such as country statistics, national field reports and observations, and refers chiefly to the rural or semi-rural areas typical of earlier historical periods. Excluding buildings of more than four storeys with reinforced concrete frames, built before the 1950s, houses in the region may be classified into seven classes.

There is, however, a further complication. The assessment of vulnerability of houses should include not only a classification according to their type of construction and building materials, but also one according to their state of repair. It is obvious that in a seismic region both urban and, in particular, rural houses have suffered considerable damage from earthquakes during their lifetimes, as well as from improper repairs, alterations and ageing. For public buildings additional factors may increase their vulnerability, such as damage resulting from wars, neglect and lack of proper repairs to the extent that they remained uninhabited for many years.

In order to get a rough estimate of the vulnerability rating I used 122 earthquakes of the period 1900–1980 for which it was possible to find damage returns and population statistics in terms of the numbers of houses of



Figure 2.75 Total collapse of a seven-storey reinforced-concrete hotel in Budva in the Montenegro earthquake of 15 April 1979 due to structural failure of the ground floor. It is said that the upper storeys collapsed just after the main shock. None of the four-storey reinforced-concrete blocks of flats in the background (behind the trees) suffered any serious damage.

various types which were destroyed or damaged beyond repair or casualty statistics.

The data were culled from a variety of sources: from the Archives of the Union International de Secours, the League des Sociétés de la Croix-Rouge, the Fichier Séismologique de l'Union International de Secours, reports of the various ministries in Athens regarding losses caused by earthquakes during the years 1928–65, the Ministry of Reconstruction and the State Planning Organisation in Ankara, the Public Records Office in Kew for Palestine, Transjordan, Iraq and Egypt; UNESCO monographs for 1976, the local press and damage statistics obtained from local authorities during earthquake field missions.

Figure 2.85 shows a plot of the number of housing units of various types destroyed or damaged beyond repair during the period 1900–1980 by earthquakes of magnitude M_S . Q is the number of housing units destroyed by a shallow earthquake with an epicentral region on land, of magnitude M_S , normalised with respect to a population density of 50 per square kilometre.

The scatter of some of the data points is due to the unavoidably coarse classification of building type in areas of mixed building types, and arises particularly for more recent events that happened during periods of rapid construction during which traditional building techniques and building materials were contaminated with modern ones. The important qualitative conclusion to be deduced from Figure 2.85 is that the type of construction seems to overshadow the influence of all other variables, including foundation conditions and ageing.

2.4.2 Vulnerability of the ground: landslides

Early descriptions of what was really a large landslide often give the wrong impression of surface faulting, particularly when they refer to the scarp produced at the brow of the slip and the heavily broken up slide material down the slope. Descriptions such as ‘...and the earth was rent asunder in many places and formed chasms. Now some of these openings came together again so that the earth presented the same form and appearance



Figure 2.76 A traditional construction in the Northwest Frontier Province of Pakistan, of rubble masonry walls reinforced with timber work with no windows, built to resist earthquakes and tribal warfare (see Figure 2.77).



Figure 2.77 A traditional construction near Law on the Variorum Highway in the Northwest Frontier Province of Pakistan, built on rock with dry masonry walls, about 80 cm thick, reinforced with longitudinal and transverse timber ring beams, built to resist earthquakes and tribal warfare. Such houses have only one entrance and no external windows; ventilation is through openings on the roof and from the internal courtyard. The roof is supported independently by timber columns. Not a single house of this type was damaged by the Pattan earthquake of 28 December 1974.

as before, but in other places they remained open, with the consequence that the people in such places are not able to intermingle with each other except by making use of many detours... and *'... the shock caused the mountain to split in two, one side of which dropped by as much as the height of a man...*' are hard to interpret. Also statements in later, mediaeval, documents are sometimes more difficult to interpret, particularly when coeval and near-contemporary writers describe them as an earthquake or surface faulting.



Figure 2.78 Detail of the method of longitudinal and transverse reinforcement of hand-placed stone walls with wood, as used in the buildings shown in Figures 2.76 and 2.77. Buildings of this type of construction, which are dominant in the Indus gorge, are constructed with 0.5–1.2-m-thick flat stone walls and coursed horizontal timber beams arranged in two dimensions at closely spaced intervals, 0.4–0.6 m apart; floors and roofs are supported by timber beams resting on columns, which are built independently of the wall. Some of the structures built for defence purposes (*shingris*) rise to heights of 10 m above the ground. These towers, as well as other buildings of similar construction, usually suffer little or no damage in earthquakes.

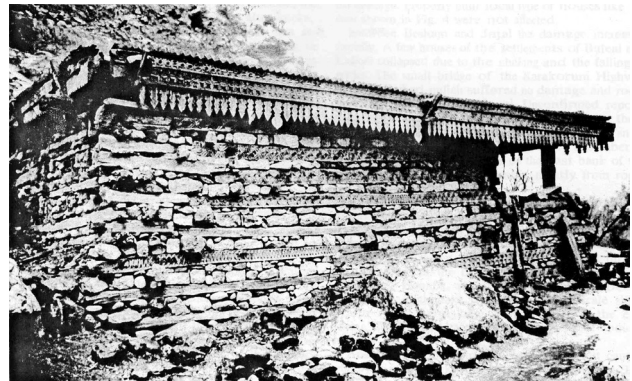


Figure 2.79 A number of houses of the type shown here, spread along the southern part of the Karakorum Highway and located in the epicentral region of the earthquake of 28 December 1974, survived without serious damage both from the earthquake and from rock falls.

Figure 2.86 shows a late-seventeenth-century woodcut of a massive landslide from the lower slopes of Monte Auda, opposite Cevallaria and Caprizi di Socchieve in northern Italy, that dammed the river Tagliamento to a height of about 80 m (*sic.*). The slide spread across the Tagliamento valley as a one-kilometre-wide lobe with sufficient velocity to push up the other side of the valley at least 100 m and destroy a settlement, killing



Figure 2.80 A view of the Indus gorge through the Northwest Frontier Province, half-way between Palas and Lew, looking east. The Karakorum Highway to China can be seen high up on the left bank (on the Patan side), as can a group of houses like those shown in Figure 2.79, perched above and below the Highway. Houses of lighter construction built on an old slide by the river on the right bank were ruined by the earthquake of 4 February 1975 due to excessive spreading of the ground.

53 people. In fact this happened following an exceptionally wet summer in 1692, not during an earthquake.

One of the earliest field observations regarding landslides caused by an earthquake was that made by Mallet in connection with the Neapolitan earthquake of 1857. He says that the magnitude and the superficial extent of landslides depend, albeit very subordinately, *'upon the power, or energy of the earthquake, and were mainly dependent upon the condition of unstable equilibrium presented by great masses of material through the configuration of the country'* Mallet (1862.ii.366). Mallet drew in his book one of the earliest realistic cross sections of a landslide, which shows clearly the retrogressive development of circular slip surfaces and the associated permanent displacements of the soil mass, Figure 2.87.

Field observations show that fracturing and cracking of natural and man-made slopes such as of earth dams in strong earthquakes is a common phenomenon. Whether a particular slope causes a landslide in an earthquake depends on the details of material strength, slope configuration and earthquake ground motion. The questions are (a) under what conditions can displacements induced by earthquakes produce large downslope movement of earth and soft rock materials; (b) what displacements and slip velocities of the sliding material are likely to be produced for a particular slope in an earthquake;

and (c) is a landslide an indication of severe ground motion or high intensity?

Deformation and sliding caused by earthquakes of natural and man-made slopes may develop in three consequent stages.

In the first stage, which is coseismic, gravity as well as seismic forces, which during the relatively short duration of an earthquake may bring about instability, can produce a failure surface or activate a pre-existing slip surface, causing permanent but finite displacements of the slope. Coseismic displacements, unless the residual strength of the soil in which they occur drops to very low values during shearing, are usually small and they are controlled by the magnitude and duration of application of the earthquake inertia forces, by the geometry of the slope and by the undrained strength of the material mobilised during the earthquake.

The second stage, which is post-seismic, will follow immediately after the earthquake has ceased if the 'fast' residual undrained shear strength on the slip surface generated by the shock is now less than that required to maintain static equilibrium. A drop in resisting forces will thus lead to an acceleration of the slope mass downslope. In this case the downslope displacements induced by the earthquake will continue with an outward movement of the toe of the slope, the velocity of motion of the fill providing the kinetic energy necessary for further transport



Figure 2.81 A close-up view of a settlement perched on the right bank of the Indus gorge (on the Hazara side) further to the north of that shown in Figure 2.80. All houses made of stone without reinforcing wooden beams were damaged beyond repair and a few were carried away by small local slides.

of slide material. As a result of this, when the mass comes to rest in a new position of equilibrium the displacements will be large, even catastrophic.

During this second stage, the driving forces will be purely due to gravity while the resisting forces will continue to depend on the undrained residual strength available on the slip surface generated during the first stage and on the resistance due to the growth of the toe of the slide. In this stage displacements will be large if the drop in strength is large or if toe support is drastically reduced or lost due to unfavourable topography or extreme loss of strength.

A third stage of displacement may follow. In this stage further movements may develop as a result of creep and consolidation of the material, as well as from destabilising hydrostatic forces if deep open cracks produced by the shock are filled with surface or ground water. Additional slow movements may take place, which will be associated with progressive failure and drained strength of the soil (Ambraseys and Srbulov 1994).

It is obvious therefore that it is not possible without a proper stability analysis to know how much or how little shaking is required in order to produce a new landslide or to activate a pre-existing one, a kind of ground failure that occurs more often without help from an earthquake than with it, and that landslides should not be considered as a measure for severe shaking and used as a criterion in the assessment of intensity in any scale.

Permanent deformations of level ground may also occur during strong shaking, particularly in soils of low strength. Figure 2.88, taken from Milne's photographic collection of 1892, shows the permanent deformation of railway tracks caused by the Mino Owori earthquake of 28 October 1891 in Japan.

2.5 Assessment of intensity

2.5.1 Earthquake intensity scales

Earthquake intensity is a convenient means of conveying in a single rating the effect of an earthquake on man-made structures and on the ground itself at a



Figure 2.82 A view of the Karakorum Highway on the left bank of the Indus, opposite Close Bandar, looking south, destroyed by slides of saturated weathered gneiss. Above it can be seen the trace of an aqueduct built by the locals, which was also breached by slides.



Figure 2.83 A yurt, a portable felt dwelling used by nomads in Turkestan, after the Karnave earthquake of 30 July 1970. Damage and loss of life in yurt settlements in the epicentral region was, obviously, nil.

particular place. The effect is rated on the basis of an earthquake intensity scale, with grades indicated by Roman numerals from I to XII.

As early as the middle of the eighteenth century, investigators of earthquakes realised the usefulness of some kind of scale for earthquake intensity at a given



Figure 2.84 One of two allegedly earthquake-proof 'spherical' three-storey houses built on high ground in the outskirts above Tehran in the 1970s. Their architect claimed that 'it can rock during an earthquake but it cannot collapse'. However, the local authorities ordered their demolition in case they rolled downhill in the event of an earthquake.

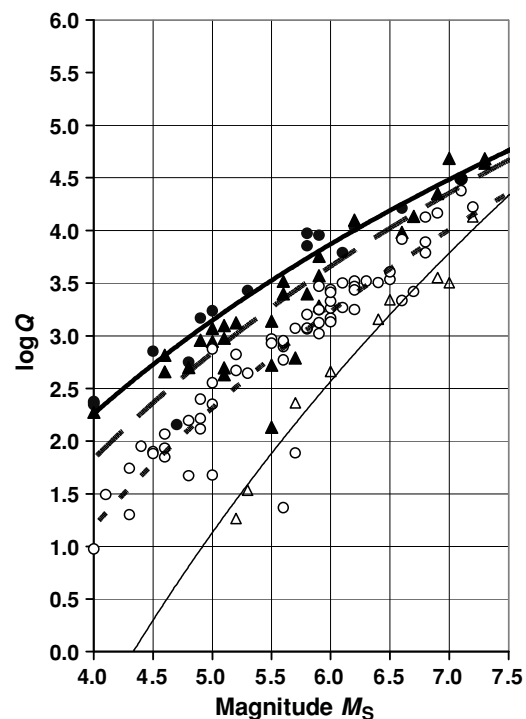


Figure 2.85 Numbers of houses of various types destroyed or damaged beyond repair during the period 1900–1980 by earthquakes of magnitude M_s . Q is the number of housing units of particular types destroyed by shallow earthquakes with an epicentral region on land, of magnitude M_s , normalised with respect to a population density of 50 per square kilometre. The solid regression line is for rubble-masonry data shown by solid circles. The dashed regression curve and full triangles are for adobe. The dotted curve and open circles are for stone masonry. The thin line and open triangles are for brick and timber houses.

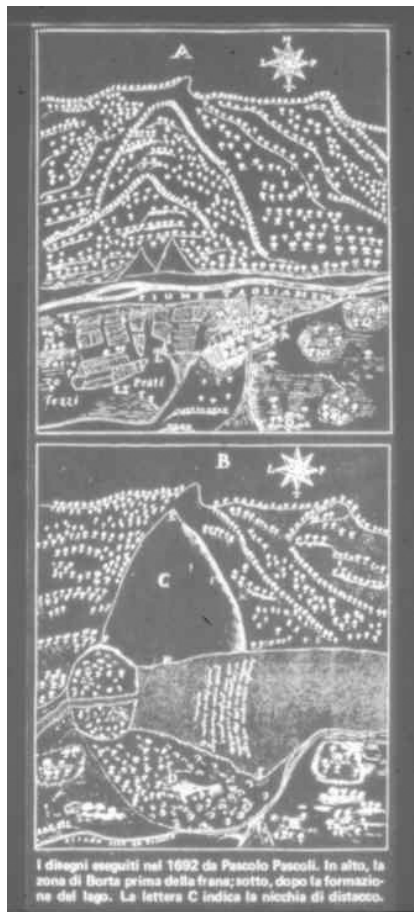


Figure 2.86 This figure shows a late-seventeenth-century woodcut of a massive landslide from the lower slopes of Monte Auda, opposite Cevallaria and Caprizi di Socchieve in northern Italy, that dammed the River Tagliamento to a height of about 80 m. The slide spread across the Tagliamento valley as a 1-km-wide lobe with sufficient velocity to push at least 100 m up the other side of the valley and destroy a settlement, killing 53 people. This happened following an exceptionally wet summer in 1692, not an earthquake. Part A shows what seems to be a pre-existing slide and part B, below, the damming of the river after its collapse.

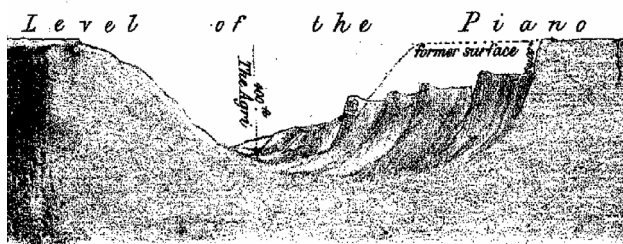


Figure 2.87 A cross-sectional view of a landslide in the Piano di Mettine on the River Agri near Viggiano caused by the Neapolitan earthquake of 1857, drawn by R. Mallet (1862, ii, 14).



Figure 2.88 Permanent ground deformation associated with the Mino Owori earthquake of 28 October 1891 in Japan (Milne *et al.* 1892).

point and since then more than 60 different intensity scales have been devised worldwide, either to express the relative intensity of different earthquakes at a locality or to trace the variation in intensity of a single earthquake over the affected area in the form of an isoseismal map. There are indications that standard expressions to describe an intensity grade had been coined well before the eighteenth century; in describing the earthquake of 1434 in Cairo, Ibn Habib says that in Cairo the shock ‘... *made those sitting down stand up, and those standing up sit down*’ (Ibn Habib, *Tadhkirat*. iii. 58–60).

Most of the existing intensity scales have been designed chiefly for twentieth-century European-type constructions, the vulnerability of which differs enormously from that of historical dwellings and from that of the types of construction used today in the rural Middle East, India and Africa. The latest scale proposed for use in Europe is the European Macroseismic Scale 1998 (EMS-1998) (Grünthal 1998).

Until the last two decades, much of the rural and to a lesser extent urban building stock in southeast Europe and in the Middle East was relatively old. As we have seen, houses had been weakened by previous earthquakes, by inadequate repairs and through ageing. They had an inbuilt vulnerability that is not accounted for in any intensity scales. The result is that at medium–high intensities of VII to VIII the intensity scale ‘saturates’, that is, at these intensities almost all rural stone or brick masonry houses are ruined, while timber-framed dwellings are damaged beyond repair, so that any town

or village would thus appear equally, but no more, devastated at higher intensities (Tresilian 2002).

Also, the rating of the upper grades of intensity, which describe damage (say over and above intensity VI or VII), is regionally biased rather than regionally dependent. This is, firstly, because of local differences in the geological environment or in the soil profile that may actually exist between different geographical regions or sites. Secondly, there are local, cultural differences in the predominant type of building stock that is exposed to an earthquake. A third bias lies in the limitations to the application of intensity scales and in the way they are interpreted and used. Furthermore, authors of intensity data are seldom explicit about the grading system they have followed to arrive at their assessments.

The differences in vulnerability of buildings make it difficult to assign an intensity, because the damage or collapse of substandard ageing dwellings, public buildings and city walls is an indication of their high vulnerability, rather than the result of severe shaking. The absence of additional corroborating evidence such as from standard structures makes it difficult to assess intensity.

Also the assessment of intensities at large epicentral distances poses problems because intensity scales become too subjective and potentially misleading, particularly if they are designed to describe near-field conditions in a different part of the world, or they include criteria concerned with ground effects, such as considering landslides or faulting as diagnostics. At large epicentral distances earthquakes may cause the collapse of a few important but vulnerable constructions, for which there may be archaeological or historical evidence. This information alone should not be taken to mean that all other man-made structures at the site have been destroyed. The observed effects can be due to the action of long-period, sustained ground motions on free-standing long-period structures, rather than due to the severity of the shock.

Quite often comparison of epicentral intensities assessed at a site independently by different observers can reveal unacceptable differences, particularly when the assessment is made from reports without visiting the site or from the maximum reported intensity rather than from the mode of observed estimates at different places. Such a comparison shows how sensitive the method is to the experience of the assessor and to the means and time at his disposal to survey.

It is often overlooked that by definition intensity is a rather vague measure of the strength of the earthquake ground motion, of the weakness of man-made structures and of the ground itself, or of both. Also, criteria based on secondary effects, such as landslides and faulting, should not be incorporated into the scale. Unfortunately, there

has been more emphasis on development of methodology to analyse intensity data than on the intensity data themselves.

However, as we have seen, it remains true that the assessment of the degree of ground shaking in terms of its effects on man-made structures depends largely on the vulnerability of the structures themselves rather than on the earthquake forces. As Sieberg put it almost 65 years ago ‘intensity scales contrary to the widely spread opinion, display only the effect, but never the seismic intensity itself. The building and the soil conditions are hidden in the visible picture of the damage’ (Sieberg 1943, 40).

2.5.2 *Loss of life in historical earthquakes*

Loss of life is not always a diagnostic criterion of high intensity. It is rather a criterion of the high vulnerability of the building stock, the rate of house occupancy and in general of regional population density, and also depends on the time of day at which an earthquake occurs. Moreover, establishment of casualty figures requires some sort of national census, which would not be available until the early part of the twentieth century. Before that it is difficult to assess even roughly the number of inhabitants in any rural, particularly tribal, area, or even in an urban region. People in some parts of the Middle East not only disliked censuses, but also considered them wrong, and connected them with either a poll tax or conscription. As late as the early part of the twentieth century they looked upon a census as a wicked proceeding. Even in the 1960s and 1970s, on driving into remote villages in some parts of the region, on arriving one would notice the absence of young men, including the village fool: the coming of our jeep had alerted those, and they were many, who had failed to do their military service or to pay their taxes, who had fled.

Casualty figures are rather difficult to check and are anyway not necessarily indicative of the magnitude or intensity of an earthquake. Also, because of the emphasis on effects predominantly in major urban centres, reported casualty figures depended to a large extent on the population distribution and density of the centre. Even today, with fuller coverage of events, the same bias exists, although this need not reflect the genuine situation: quite often the largest proportions of people killed are in small towns and villages away from urban centres.

Useful types of information to have after historical earthquakes, however, are statements referring to fatalities among leading citizens, large-scale reconstruction undertaken by the state, remission of taxes, new coinage, adverse effects on trade or emigration, all suggesting a large destructive event. Some of these effects are not always recorded together with or attributed to

an earthquake but can be inferred from internal evidence and from the historical context of the event.

Exaggeration in historical and modern sources is also a problem, which, however, is not difficult to detect. Consideration of the authenticity of the source, the style of its narrative and internal evidence in the account, in the light of experience gained from processing this kind of information, usually allows a realistic, albeit subjective, estimate of the degree of impact or the extent of the area over which earthquake effects were serious. If one is in doubt, it is preferable not to report these parameters.

For instance, statements informing us that after a 'destructive' earthquake in Istanbul people took refuge in churches or mosques, or that immediately after the earthquake they organised religious processions in the city, suggest that the shock was not in fact all that 'destructive'. There are also cases where a historian would unintentionally exaggerate damage by reporting collectively effects from more than one earthquake, or earthquake effects together with those from fire or thunderstorms. Intentional exaggeration of damage, or association of an earthquake with political or religious happenings, is also known. The substance of such accounts is the same, but the impressions they leave about the seriousness of the event on those who use historical data without scrutiny or at second hand are very different. These questions are discussed elsewhere in connection with the assessment of intensities in the region (Vogt 1996; White 2000; Ambraseys 2002a).

All these problems arise because partly the description of intensity-scale ratings is not precise enough and partly because damage is not consistent enough for one to do otherwise. In addition, intensities are often assessed by inexperienced or 'arm-chair' observers. It is immaterial, therefore, how precisely one cares to treat the intensity values at one's disposal, since large uncertainties in their original assessment must always exist; in many cases, these are so large that their correlation with other measured and more reliably determined earthquake parameters contaminates the final results.

The most recent EMS-1998 intensity scale (Grünthal 1998) is an attempt to overcome some of these difficulties, but this does not alter the fact that all of our existing intensity data come from earlier scales and events. Furthermore, the EMS-1998 scale is too idealised and cumbersome to use in practice. Under the circumstances, one is inclined to sympathise with users of these earlier scales: inasmuch as we are not in a position to be rigorous in our definition of various intensity ratings, the experienced investigator should be allowed enough leeway to use his own judgement without being hemmed in by a scale that is too rigorous or specific. It must be pointed out that intensity estimates for historical

earthquakes are accurate only to ± 0.5 intensity unit, in the sense that two assessors assigned intensities differing by one unit; and occasionally for some early events estimates are accurate to ± 1 unit.

The assessment of intensity in this study was made on the MSK (Medvedev–Sponheuer–Karnik) scale, somewhat simplified by disregarding criteria meant for modern structures, which allows consistent subjective observations and correlation with intensities estimated from twentieth-century earthquakes. This simplification is also dictated by the fact that local conditions in the region, such as siting of settlements and towns, building materials and techniques had changed little over much of the period under review, up to the mid 1900s. For the use of the simplified MSK intensity scale in a different region see Ambraseys and Douglas (2004).

It is not suggested that the simplified version of the MSK scale chosen in this study is a panacea. It was chosen because it was devised for a built environment similar to that in the Eastern Mediterranean and the Middle East that included the Asiatic part of the USSR, rather than to that in Western or Central Europe, and also because I was more familiar with its use in the field.

2.6 The use of earthquake intensity

In this section I shall discuss how the earthquake parameters which are needed in order to assess earthquake hazard are defined, measured instrumentally and calculated. It is obvious that the assessment of hazard for earlier periods, before the advent of instruments, will be possible only when historical information is converted into numbers representing the epicentral location and magnitude of the events concerned, accompanied by an estimate of their reliability.

Data provided by historical sources for earthquakes on land are adequate to permit the general location of the epicentral area, particularly for the larger events. In its simplest definition the epicentral region of a historical earthquake may be taken to be the area of maximum intensity, and the primary intention of the assessor is to avoid as much as possible the amalgamation of different earthquakes closely spaced in time into one earthquake. Other things being equal, the larger the epicentral region, the greater the total damage and magnitude of the event.

Early earthquakes which show some clustering towards large centres of habitation are less well located and it is often difficult to ascertain their true epicentral regions. However, for the larger events, aided by what we know today about local tectonics and seismicity, there is rarely great ambiguity about their general positions.

Allowing for exaggerations in the sources, the notification of any damaging or destructive event reflects its seriousness and significance. For the early period, while it is certain that many small-magnitude shocks must be missing from the record, we can reasonably assume it more likely than not that those of which damage details survive were important events.

The additional particular value of the study of twentieth-century earthquakes is that it permits correlations between their effects and those from historical earthquakes. This is possible despite shortcomings in the documentary evidence, for one can, in many cases, determine from internal or contextual evidence such details as the size of the area affected and the extent and type of damage caused, the duration of aftershocks and the association of the event with ground deformations, such as surface faulting, landslides and proximity to known active faults. All such details, ideally to be found in or inferred from historical sources, when calibrated against similar information derived from the study of modern events, permit assessment of the different intensities experienced throughout the affected area and estimation of the magnitude of the historical earthquake.

For events with epicentres at sea, we have attempted to associate earthquakes with active faults. This is often judgemental, based on knowledge of the general location and magnitude of the event and on the nearest known fault that could accommodate the associated release of seismic moment.

Dating of historical earthquakes is not always easy. Several calendars have been used to date earthquakes over the last twenty centuries. Details of the various dating systems in use may be found, for instance, in Grumel (1958). Dating errors in primary and in particular in secondary sources are common, so one has to query regarding all the events in the sources whether they were really distinct or whether there was some possibility of distinct reports of the same event having been dated as distinct events. Failure to identify and eliminate doublets or amalgamated events, a common mistake in modern parametric catalogues, renders assessment of the epicentral area and magnitude particularly problematic.

Another difficulty in identifying historical events and assessing their size is the issue of simultaneity, that is, that the earthquake mentioned in various places in the sources happened at the same time. This is not always specifically stated by early authors, who refer to several places being shaken or damaged within a particular period of time. This confusion occurs chiefly with early chroniclers, who mention all the events of a particular period in a single description. Failure of earthquake compilers to recognise lack of simultaneity often results in spurious doublets or in the amalgamation of differ-

ent events, which leads to entries in catalogues of great earthquakes the sizes of which are grossly exaggerated. Also one must be aware of the possibility that two or more separate historical earthquakes can be transformed into a large earthquake. This, in view of the tendency of early writers to amalgamate or duplicate seismic events, is understandable.

It is also important to establish the simultaneity of the damage observed at distinct archaeological sites. It may have been caused by separate historical earthquakes that occurred during the same week, month or year but are not differentiated in the sources or by results from excavations. This amalgamation of information leads to an over-estimation of the size of the damage area and hence of the magnitude of the inferred earthquake.

2.6.1 Intensity distribution and isoseismal maps

Like other empirical measures, intensity, in spite of all the uncertainties in its estimation, when assessed for an earthquake at a large number of points and drawn as an isoseismal map shows regular distribution patterns and dimensions of the areas where it is felt, separated by isoseismal lines drawn as boundaries between regions of successive intensity ratings. These indicators have in the past helped seismologists to make a rough estimate of the size and relative depth of an earthquake.

An isoseismal map provides an estimate of the sizes of the areas over which an earthquake was felt with various intensities, which is an indirect measure of the size or magnitude of the event. In the absence of instrumental measurements, the magnitude of a historical earthquake may be assessed from the size of the area over which a shock was felt, which can then be calibrated against macroseismic information about similar, twentieth-century, earthquakes for which reliable instrumental magnitudes are available. Such calibration relations may be used to assess the magnitudes of historical events for which isoseismal maps can be drawn.

Thus, although intensity at a given point tells us little about the size of the earthquake or of the ground motion, isoseismal maps, in the construction of which intensity estimates undergo a significant amount of averaging and smoothing of inherent bias, provide a useful means with which to assess magnitude.

With few exceptions, intensity contours (isoseismals) are drawn by eye, using procedures that may, but need not, include smoothing by an averaging process. Almost all existing isoseismal maps for past earthquakes in the region had been drawn by eye around points of maximum intensity observed within a

given area, in the process disregarding other points of lower intensities. Some of these isoseismals are purely diagrammatic, representing what their shape would probably be if we assumed that attenuation was isotropic and the local foundation conditions and buildings were uniform everywhere. This approach introduces a bias towards higher estimates.

Methods of contouring are to some degree as subjective as the assessment of intensity from questionnaires and they do not overcome the difficulty that arises when a few isolated high intensities exist within a background of many sites of much lower intensity and, conversely, when isolated low intensities exist within a background of sites where the shock was not felt. The latter situation has a considerable effect on the determination of the radius of perceptibility (III MSK), which is often grossly overestimated by considering the furthestmost location at which the shock was perceived.

In order to avoid subjectivity as much as possible in drawing isoseismals, we carried out the contouring of intensities by 'kriging' (Olea 1999) the intensity data, disregarding the fact that intensity is not a continuous function and taking into account sites at which the earthquake was perceptible (II MSK). Kriging is a form of generalized linear regression for the formulation of an optimal estimator in a minimum-mean-square-error sense. By this procedure, local variants of intensity between isoseismals become averaged and damped out by the surrounding regional intensity and only those anomalies that become fortified through association gain an encircling contour. In kriging, the distances from each gridpoint to each intensity point are calculated and weights based on these distances are computed, by assuming an underlying spatial correlation function, which are then used to estimate the intensity at the gridpoint. Therefore, at gridpoints close to known intensity points the estimated intensity is similar to the nearby measured values, but for gridpoints far from observed intensities the estimated intensity is based on a weighted average of distant intensities. [Figures 3.9, 3.10, 3.11](#) and [3.48](#) show the isoseismals for four historical earthquakes produced by kriging. Kriging, which we used throughout this work, has been used in the past for earthquake ground-motion contouring, including intensity data, and is identical to spline interpolation for specific semi-variogram models.

Felt areas or average isoseismal radii may be used in calibration relations to estimate magnitude, from which the zero period or spectral ordinates of ground motion can be estimated using modern procedures. In this way ground motions are approached via magnitude and source distance rather than via intensity (Howell and Schultz 1975, Ambraseys 1985a).

It is important, therefore, that isoseismal maps for correlation with magnitude are uniformly drawn and not regionally biased, which is not always the case. For instance, in the annual US earthquake publications for the period 1929–69, isoseismal maps were prepared by staff members of the US Coast and Geodetic Survey from a listing of small towns or suburbs all having the same intensity. The maps were prepared, as was then their custom, by assuming that, if in a small town or suburb the intensity varied through a range of values, the highest value should be used for the whole area, rather than the mode of the observations. In contrast, Russian practice was to use the mode of intensity ratings observed within a particular area.

Regional bias also has an effect on intensity attenuation laws, and is influenced by the personnel responsible for drawing national intensity maps or the agencies involved in their preparation. This becomes apparent with earthquakes affecting more than one country, for which individual intensity maps prepared separately for each country frequently do not match across national borders, mismatching by as much as three intensity grades (Ambraseys and Moinfar 1988).

2.7 Seismic sea waves

Recently there has been a proliferation of papers written with a tinge of exaggeration about historical seismic sea waves (tsunamis) in the Eastern Mediterranean and in the Aegean Sea. In what follows I shall try to answer the question of how much is reliably known about historical seismic sea waves in the region generated directly or indirectly by earthquakes. Historical sources usually 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.

One cannot always be certain from the descriptions of early and later seismic sea waves whether these events were truly due to crustal movements, or due to secondary causes such as submarine mass failure, local coastal landslides, seiches and standing waves or even caused by storms and abnormal weather conditions that occur without earthquakes.

Also, for minor sea waves and for waves along sparsely inhabited coasts, the record is very incomplete, becoming more complete for larger seismic sea waves, namely those responsible for loss of property or life, this being the kind of information that chroniclers would not have omitted to record and also embellish in their writings.

Original information, in [Chapter 3](#), confirms that genuine seismic sea waves in the region were rarely destructive and very few were damaging. Most of them were reported from a single location or from an unspecified stretch of the coast, not all of them unambiguously.

With the exception of the catastrophic sea wave which was produced by the eruption of the volcano of Santorini about 3500 years ago, and the alleged collapse of Etna 8000 years ago, there is no evidence for truly destructive seismic sea waves and there have been only relatively few cases of damaging ones. In most cases, the data are insufficient to help us quantify these events. There is some evidence, however, that the earthquake of AD 365 originating from the region between western Crete and the Peloponnese was of an unprecedentedly large magnitude and that the wave that followed played havoc with the coastal regions of the southern Peloponnese and Egypt (Shaw *et al.* 2008). Also the source mechanism of some of the more localised waves should have

been due to submarine and coastal mass failures, which seem to be the predominant mechanisms.

Of the 87 cases found in the historical record before 2000, there are only 25 earthquakes that seem to be associated with damaging seismic sea waves of intensity ≥ 5 on the Sieberg–Ambraseys tsunami scale. Another 24 earthquakes caused general flooding of the coasts with little or no damage, of intensity 4 SA, while another 6 shocks were innocuous events of only intensity 3 SA.

The remaining 32 cases of flooding where noticeable fluctuation of the sea level occurred during the last 200 years resemble seiches and standing waves in harbours and bays as well as waves due to coastal slumping and subaqueous sliding or to meteorological conditions. In fact there is no evidence to justify the large number of destructive seismic sea waves reported by some modern writers whose papers epitomise the recent trend towards indiscriminating cataloguing.

3

Catalogue of earthquakes

3.1 Notes on the descriptive catalogue

The source material used is summarised in this chapter of case histories. The full database provides the source material that has been found to contain information and relates the record of events to specific earthquakes. For events up to 1500 and after 1800, all the source material, which is in various languages, has been translated into English, whereas for events between 1500 and 1800 the full database includes a much revised and updated version of excerpts from Ambraseys and Finkel (1995) and Ambraseys, Adams and Melville (1994). The full database of information is then used to assess epicentral areas, intensities and magnitudes, which are not listed in this book. The intricacies of the interpretation of the literary information in the sources have been presented *in extenso* elsewhere (Ambraseys 2002a, b) and some may be mentioned here.

As we have seen, the location of a historical earthquake can be assessed from its macroseismic effects and its magnitude can be estimated by comparing its intensity distribution with that of a twentieth-century event the magnitude of which is known from instrumental measurements.

Other types of information, such as the human and material losses, and the social and economic impact and consequences of the event, although they are of interest more to the historian than to the Earth scientist, can help to assess intensities. Thus the study aims to be indicative, exposing points for further analytical clarification, rather than prescriptive, since in fact the prescriptions have to be based on rather arbitrary assumptions.

For the early period those wishing to consult existing catalogues should be aware of the need to judge the principles according to which they have been compiled and ensure that they are suitable for their purposes. It is best not to take any such material purely at face value.

Even the most recent catalogues, including this catalogue, are putting forward one interpretation of the available historical evidence and others are possible. Ideally, therefore, even the best modern catalogues are a starting point for an evaluation of hazard or seismotectonics appropriate to the specific concerns of the investigation.

In the descriptive earthquake catalogue I chose to enter historical events of all sizes, ranging from catastrophic ones to shocks reported as having been barely felt, a selection criterion that may sound excessive. The reason for this is that small shocks can be aftershocks and knowledge of their sequence and duration may supplement information about the size of the main event. Also, the absence of aftershocks following a large earthquake may suggest a lower-crust or subcrustal event. Moreover, small shocks felt at one or more sites can be the far-field effect of a distant, but unknown as yet, large earthquake, which can lead to its location on land or offshore by further studies. After all, a genuinely seismically quiescent period in a region can be confirmed by the regular reporting of small events only. An equally important reason for including small earthquakes is to prevent their reinstatement and enhancement in future catalogues as strong earthquakes, on the assumption that they were omitted here by oversight.

Each entry in the descriptive catalogue consists of three parts: a case history of the event, discussion and notes. For earthquakes after the sixteenth century, the system of dividing entries into three parts is gradually abandoned and replaced by a single entry, supported by its own references, which are quoted either in the text or in footnotes.

The case histories present a general description of the effects of an earthquake. Regardless of their importance, some earthquakes have been given little space, either for lack of details or in cases where the sources quoted provide all the information without complication or need for further comment. In other cases in which the source material is ample only a selection of sources of information is given. Accounts of these events are written with the Earth scientist, engineering seismologist and researcher in related fields in mind.

All the earthquakes discussed, as a matter of principle and for the sake of completeness, are documented as fully as possible; inevitably, however, there are cases where such thoroughness is misplaced and references are omitted when on examination they add no relevant details, which is the case with most recent catalogues.

As many as possible of the works that have been found to contain useful information are referred to in the course of these various accounts, particularly when they contribute valuable or original material; any less useful statements they contain, which might not have been

referred to, on examination may easily be seen in perspective by the reader.

References and source material, when their number and frequency does not distract the reader, are given in the discussion part of the entry and more explicitly in the notes.

In the discussion, experience has shown that it is not always sufficient merely to exclude false earthquakes without showing why they have been omitted. As we have said, the tendency for them to be reinstated in later uncritical publications remains, presumably on the grounds that they were omitted by oversight.

I have therefore gone to some lengths in the discussion section of entries to point out some glaring errors and false events, from which the chief victims of this operation are apparent.

For those who would like to reappraise the assessment made in the estimate of the earthquake parameters they should know that in quite a few entries, when the sources are too complicated to present *in extenso* or because of space limitations, only a summary or abstract of the available information is given, and they should consult the full text in the sources quoted. These summaries contain the essential data available and an assessment of this material in the light of the relevant factors, thus illustrating some of the problems associated with evaluating seismicity. Items of original information on separate topics connected with an earthquake are brought together at the end of each entry.

The notes present a considerable amount of the information on the basis of which the effects of an earthquake have been summarised and discussed. The diversity and large volume of source material has defeated the effort to give full bibliographical detail in the discussion or in the notes. Most of the data I have found by my own perusal of the sources appear most fully. Some of the sources I retrieved in the 1960s and early 1970s or that were provided by colleagues lack some information found in the original authority. Some of these omissions have been rectified, but there remain a number of instances where it has been impossible now to complete the bibliographical information.

For early events the notes in general consist of texts written in italics, which are free translations into English of selected excerpts from pertinent texts written in various languages, sufficient to help those who wish to re-evaluate an event, with the understanding, however, that readers should go back to the source quoted and read the original material in the context of the whole text in which it is quoted. For some readers the translations might be boring, but they have been included for those who may wish to re-evaluate a particular event.

The notes present the style in which historical information appears in the sources and the way it changes with time, for example from telegraphic in the classical period to exceedingly pedantic and exaggerated in the Middle Ages.

Adjectives used by chroniclers, church writers, historians and the press to describe the degree of severity of an earthquake, such as 'light', 'slight', 'perceptible', 'strong', 'very strong', 'damaging', 'destructive', 'catastrophic', and 'not seen or heard before', often have little or no relation to the actual effects of an event. They are descriptions that, if taken at face value, can have 'catastrophic' effects on the assessment of the event.

Also, references may be consulted for information pertinent to particular aspects of the event, such as their historical or archaeological context. However, because of space limitations these excerpts do not always contain all the information that can be found scattered in a particular long text.

In order to avoid confusion modern sources and catalogues that give debatable or inaccurate information are generally not mentioned in the description of case histories, except when their use may lead to serious misinterpretations.

For events for which there is a large number of references that need to be included in the text, these are numbered and given throughout the entry.

An anomaly should be noted: the abbreviation (sa) indicates that relevant details are found *sub annum*, that is, under the heading for the year in question.

The main burden of textual analysis, critical documentation and support for interpretations offered in the case history falls, therefore, on the discussion and notes to each entry, which may be ignored by those prepared to accept statements in the case history part of the entry as they stand without further ado.

Note: Entries with bracketed date and place of occurrence refer, in my opinion, to spurious events.

3.2 Descriptive catalogue

2100–1700 BC Sodom, Judaea

The story of Sodom and Gomorrah has long been viewed as a legend created to communicate moral principles. However, throughout the Bible this story is treated as if it echoes a historical event, which later Greek writers seem to confirm.

The destruction of Sodom and Gomorrah is first mentioned in Genesis: '*... By the time Lot reached Zoar, the sun had risen over the land. Then the Lord rained down burning sulphur on Sodom and Gomorrah – from the Lord out of the heavens. Thus he overthrew those cities and the entire plain, including all those living in the*

cities – and also the vegetation in the land... Early the next morning... he [Abraham] looked toward Sodom and Gomorrah, and toward the surrounding country, and saw, and beheld, a flame went up from the earth, as the smoke of a furnace...' (Gen. xix. 24, 25, 27, 28).

'... and he looked toward Sodom and Gomorrah, and toward all the land of the Plain, and beheld, and, lo, the smoke of the land went up as the smoke of a furnace...' (Gen. xix. 24; Masoretic version).

'... the whole land thereof is brimstone, and salt, and burning, that it is not sown, nor beareth, nor any grass groweth therein, like the overthrow of Sodom and Gomorrah, Admah and Zobo'im, which the Lord overthrew in his anger and in his wrath...' (Gen. xxix. 23).

The destruction of these two cities is also mentioned by several prophets of the Old Testament who refer to Genesis (Deut. xxix. 23; Isa. xlii. 19; Jer. xxxix. 18). A much later, but independent, reference to Sodom may be found in third- and first-century-BC Greek writers. Strabo, describing Lake Sirbonis (should read Asphaltites lacus) says that '*... it is large; in fact some state that it is one thousand stadia [185 km] in circuit; however, it extends parallel to the coast to a length of slightly more than two hundred stadia [37 km], is deep to the very shore, and has water so very heavy that there is no use for divers... It is full of asphalt. The asphalt is blown to the surface at irregular intervals from the midst of the deep, and with it rise bubbles, as though the water were boiling... With the asphalt there arises also much soot, which is smoky...'* (Str. XVI. ii. 42/LCL. vii. 297).

He goes on to say that '*... Many other evidences are produced to show that the country is fiery; for near Moasada are to be seen rugged rocks that have been scorched, as also, in many places, fissures and ashy soil, and drops of pitch that emit foul odours to a great distance, and ruined settlements here and there; and therefore people believe the oft-repeated assertion of the local inhabitants, that there were once thirteen inhabited cities in that region of which Sodom was the metropolis, but that a circuit of about sixty stadia [11 km] of that city escaped unharmed; and that by reason of earthquakes and of eruptions of fire and of hot water containing asphalt and sulphur, the lake burst its bounds, and rocks were enveloped with fire; and, as for the cities, some were swallowed up and others were abandoned by such as were able to escape. But Eratosthenes [third century BC] says, on the contrary, that the country was a lake, and that most of it was uncovered by outbreaks, as was the case with the sea...'* (Str. XVI. ii. 44, *apud* Eratosthenes).

The narrative in Genesis is used again by the Apostles in their teachings (Matt. x. 15. 2; Pet. ii. 6; Jude I. 7; Luke xvii. 29).

According to Genesis, the cities destroyed are Sodom, Gomorrah, Admah and Zebo'im, that is, four of

the five 'Cities of the Plain' mentioned in Genesis. The fifth city is Zoar (also known as Bela), which according to Genesis was not affected (Gen. x. 19). All five were situated in the Valley of Siddim, an area at the southeast end of the Dead Sea. It is reported that there were once thirteen cities in the environs of Sodom, but that many of them were swallowed up in earthquakes. It is not clear whether Sodom should be included in the list of destroyed cities according to an account from a classical author, although, in the Bible, both Sodom and Gomorrah were destroyed, while nearby Zoar was spared.

What led archaeologists to search all around the southwest coast of the Dead Sea for the sites of the other four lost cities was the fact that on the Madaba Mosaic Map, a sixth-century Byzantine map found in Madaba, Safi could be identified with some certainty as Zoar, one of the Cities of the Plain. Five sites dating to the late Bronze Age or shortly after were identified in this area, two of which, Sodom and Gomorrah, could be Bab el-Dhra and Numeira, respectively, although this is not entirely certain. Field evidence in support of this is that at Bab el-Dhra and Numeira thick layers of destruction, including beds of charred timbers, were found. Roof beams burned only from above were found in some rooms, while in others, fragments of human bone and cooking implements with food residue were found. These were taken as evidence of a sudden destruction by '*fire and brimstone from above . . .*', clues that are thought to confirm the passage in Genesis, see Wood (1983) and Shea (1988). From the remaining Cities in the Plain, Admah was identified as Feifa, Zeba'im as Khanazir and Zoar as Safi, the five sites stretching along a straight line for about 50 km from east of Lisan to the south (MacDonald 2000). The question here is whether these sites are the original ones or Mike Sander's 'mirror' Cities of the Plain.

Different locations for Sodom have been suggested. Harris and Beardow identified Sodom and Zoar, to which Lot escaped in the Bible account, as sites that probably stood on a fan of Nubian sandstone detritus, on the Lisan peninsula. Harris and Beardow maintain that the principal cause of the destruction of Sodom and Gomorrah was massive liquefaction of the loose, silty clays on which they were built due to an earthquake (Harris and Beardow 1995). The actual location of most of these sites is uncertain. A summary of evidence that could help Earth scientists to understand the reasoning and arguments employed by archaeologists and historians to evaluate the cause for and effects of the destruction of Sodom and Gomorrah may be found in the notes.

From the evidence above it appears that, although both Sodom and Gomorrah were destroyed, nearby Zoar

was spared. This is consistent with Strabo's statement that damage was confined to within a radius of only 11 km around Sodom. Whatever the cause was, therefore, the destruction was much localised, not extending beyond Zoar. The implication of this is that the identification of the damaged sites of Admah and Zebo'in as Feifa and Kanazir, which are located further south of Zoar, is questionable.

Both Sodom and Gomorrah are located within the Dead Sea fault zone, which is potentially seismic, but it is rather unlikely that their destruction can be attributed to an earthquake, for this would not have failed to be mentioned in Genesis if one had occurred in this case, since such events were quite often employed to show divine intervention. The suggestion that the conflagration was caused by fire that 'fell from heaven', which was not seen, seems to be legendary. Was what Abraham saw, at a point east of Hebron, 50 km northwest of the scene, a column of smoke rising from the ground? The assumption that the destruction was caused by a volcanic eruption is also improbable because geological studies show that the last volcanic activity in the region occurred quite a few thousand years before Abraham's time (Neev and Emery 1995).

The information in Genesis, when taken at face value, suggests that the disaster that befell Sodom and Gomorrah, the location of which is not entirely certain, was not due to an earthquake or volcanic eruption. A physical explanation for the destruction could be the retrogressive ignition of large emissions of methane and petroleum over a large area; however, we cannot become advocates of such a hypothesis on the basis of inadequate information.

Historical evidence dates the destruction of Sodom and Gomorrah to some time between 2100 and 1700 BC. Archaeological evidence puts the destruction of Bab el-Dhra and Numeira between 2350 and 2070 BC.

Notes

Estimated period of occurrence: c. 2350–2070 BC.

For Bab el-Dhra an extract of pertinent evidence relating to earthquake damage written by the excavators is

'Field XIV. The chief feature discovered was part of a building consisting of two intersecting mud brick walls, Walls 10 in Field XIV.4 and 45 in Field XIV.6 (fig. 6). In the southwest corner of this building a hearth of flattened cobblestones (Locus 63) was covered with carbonised matter. Soils around this area isolated for flotation yielded a large number of seeds and grains. The same type of cobblestone hearth was discovered in a room near the town wall at Numeira during 1979.

The bricks of the building were rectangular, conforming closely to bricks of other EB III buildings at the site. Occupants

of this area faced the difficulty, however, of containing the soft Lisan marl, which sloped sharply to the south. Their solution was to construct a battered retaining wall of mud brick (Locus 14 in Field XIV.4) against the marl, part of which was excavated during 1977. In a new square opened during 1979 it was discovered that a portion of this wall had slumped from its original position and was lying horizontally across much of the area excavated, leaving the natural marl and gravel exposed (fig. 6). Thus, even though the section found was not in its original position, it is clear that the retaining wall had continued across the slope.

The slippage of this part of the retaining wall seems to have occurred in connection with events that caused Walls 10 in Field XIV.4 and 45 in Field XIV.6 to bend down sharply in a northerly direction (fig. 6). In other words, all preserved architectural features at this level in Field XIV had experienced some dislocation. What caused this disturbance is not yet clear, but either gradual erosion or earthquake are possibilities' (Rast and Schaub 1980, 29).

That an earthquake occurred at the time the cities were destroyed is clear from the work of geologist Jack Donahue of the University of Pittsburgh. At Bab edh-Dhra he found that during the period of occupation there was sedimentation, or infilling, and a build up of cultural debris (Donahue 1985, 135). Following the destruction, this changed to an erosional regime, brought about by an uplift of the area (Donahue 1980, 50; 1985, 134–136). The uplift produced an increase in the elevation differential between the town site and the Wadi Kerak on the north side of at least 28 m (92 ft). This resulted in severe erosion on the north side of Bab edh-Dhra, eventually causing the north wall to collapse into the wadi (Donahue 1985, 136; Wood 2005, 1).

For Numeira, 'Evidence for abandonment of the town prior to the final destruction is primarily negative, but it includes the following.

- 1 Most identifiable doorways from the latest phase of occupation had been deliberately blocked; they were clearly not in use. A modern parallel in the same region provides a possible explanation; when inhabitants of a house leave for some time, they frequently block their windows and occasionally their doorways with conderblocks or wood.
- 2 Very few small finds of any value were found at the site. Nevertheless, large quantities of pottery were found *in situ*; these may have been left behind because of the difficulty of transport when a hasty departure was required.
- 3 None of the storage facilities found so far – stone-lined pits, subterranean silos, and storage jars (both above and below floor levels) – had primary contents; all were filled with soils similar in composition and inclusions to those of their context, and systematic flotation of the soils failed to uncover a higher proportion of (carbonized) grains or other goods that might have been stored in them.
- 4 No human skeletal remains were found in the ashy debris of the final destruction in the center of the town. With the exception of the unroofed area immediately

west of the eastern tower, no rooms, courtyards, or public areas contained the remains of inhabitants who might be expected to have perished in a sudden catastrophe.

A possible explanation for the final destruction of Numeira, based on a combination of archaeological and geological evidence (Donahue below), is as follows.

The inhabitants of the site, and, indeed of the region, were well aware of the potentially devastating effects of earthquakes. The destruction of the earliest phase of the eastern end of the town was probably due to seismic activity; the similar design of the city walls of Numeira and Bâb edh-Dhrâ' in EB III is best explained as a technique that would limit earthquake damage to the fortifications (Rast and Schaub 1980, 42).

Warned of the possibility of an impending earthquake by preliminary tremors (and perhaps by other biological factors, such as unusual animal behavior or the like), the inhabitants of Numeira abandoned the site for safer locations, perhaps in the open. Some botanical evidence suggests a date in late spring, but outdoors survival in any season would not have been difficult in the Ghor. The inhabitants may have planned to return when the danger had passed, but, since they took the time to gather their foodstuffs and valuables and to block their doorways, they presumably were prepared for an absence of some duration.

Not all of the inhabitants deserted the town. Some remained as guards, or returned as squatters; it was their skeletons that were found adjacent to the eastern tower. When the major tremor occurred, it may have been their fires that provoked the conflagration; at the same time, the walls and roofs collapsed, pinning them under the debris.

This first shock probably also caused the initial shift in the course of the stream, bringing the water up against the eastern outer face of the tower. Subsequent tremors of after-shocks completed this hydraulic process and eventually eroded an indeterminable amount of the northern part of the town. The rapidly down cutting action, probably along a fault line, separated the site from an easily accessible water supply and rendered it unsuitable for habitation. There was no subsequent occupation at Numeira.

The latter seismic activity also caused further collapse of the town's fortifications and domestic structures; some of the brick and stone debris lay over the ashy destruction layer.

This reconstruction is, of course, speculative. Further excavation is necessary to confirm, modify, or disprove it' (Coogan 1984, 80–81).

'Numeira had a short occupational sequence during just a portion of Early Bronze III and was terminated by one or possibly two closely-spaced, destructional sequences. Three individuals found adjacent to the tower during the 1981 excavations apparently were killed in the collapse of a portion of the tower. Although the matter can be debated, there seems to be no direct evidence for warfare during the destruction. Another explanation is that the tower collapse and extensive burn layers over the site were caused by an earthquake generated by fault movement (Coogan 1984). The epicenter or fault movement may have been distant from Numeira, but vibrations caused by such movement could easily have caused partial collapse of the tower and buildings. Such a movement would not necessarily generate actual

fissures. The extensive burn layer was probably caused by collapse and ignition of wooden roofing materials.

After occupation, the major change that occurred at Numeira was down cutting and erosion of the northern half of the alluvial fan on which the site is located. This was in direct response to an increased gradient in the Wādi Numeira, probably caused by fault movements along the eastern border fault of the Dead Sea rift. The wādi stream that originally flowed past the site of Numeira shifted its course slightly northward and eroded the northern half of the alluvial fan. The exact timing of this erosion and the amount of the northern portion of Numeira that has been destroyed by erosion are not known' (Donahue 1984, 87–88).

'It is suggested here [at Numeira] that the tower collapse and extensive burn layers over the site were caused by an earthquake generated by fault movement' (Donahue 1985, 139).

The earthquake caused either an uplift in the vicinity of the site or a down dropping of the rift valley to the west, resulting in a 50 m (164 ft) increase in elevation differential between the town site and Wadi Numeira to the north (Donahue 1984, 86; 1985, 137). It also caused a change in direction of the Wadi Numeira, which flowed south of the site during the period of occupation (Donahue 1984, 86, 88; 1985, 138). Heavy erosion following the event resulted in the loss of the north part of the settlement, including the north defensive wall (Donahue 1984, 87; 1985, 138, 139).

Evidence found at Numeira suggests that the residents fled the town in haste. Most identifiable doorways from the latest phase of occupation had been deliberately blocked. This apparently was an attempt to strengthen the homes against damage. In addition, no valuable small finds were discovered and there were no foodstuffs in the storage facilities. On the other hand, large quantities of pottery evidently too heavy and bulky to transport in the hasty evacuation, were found on the floors of the houses. It appears that the residents had some early warning, such as preliminary tremors, and did what they could to prepare. They shored up their houses, gathered up their valuables and as much food as they could carry, and fled their homes, never to return (Coogan 1984, 80–81; Wood 2005).

1400 BC Jericho

It is generally believed that an earthquake occurred during the siege of Jericho (Tell el-Sultan) by the Israelites in c. 1400 BC. This event caused the strong walls of Jericho to collapse, allowing Joshua to take possession of the place and burn it down. The Bible, the only literary source for this earthquake, does not attribute the collapse of the walls of Jericho to an earthquake, but rather to the besieging Israelites, who '*by shouting and blowing their horns caused the walls to come tumbling down*' (Josh. vi. 20–21). If the timeline of the Bible is followed, then the invasion of the Israelites into Palestine is usually placed 440 years before the foundation of the Temple in Jerusalem by Solomon in 960 BC. Jericho, therefore, would have been destroyed about 1400 BC, but not necessarily by an earthquake. Alternatively, if the views

of those scholars who have attempted to reconcile the description of events with Egyptian history are accepted, a date of 1260 BC is inferred. Another option would be to follow those who reject the historicity of Joshua in favour of belief in peaceful conquest and accept a date far later than 1400 BC (Lemonick 1990).

Turning to the question of what archaeology can contribute to this impasse, the earliest excavation at Jericho, at the beginning of the last century, concluded that the city had already been abandoned before the invasion of the Israelites and that it had been destroyed, probably by earthquake, before 1400 BC (Selling and Watzinger 1913). A second series of excavations in the 1930s supported the biblical account of an earthquake in c. 1400 BC (Garstang 1948). A third series of excavations at Jericho in the 1950s, however, found no archaeological evidence to corroborate the biblical account of the fall of Jericho, dating the event back to a period well before 1400 BC (Kenyon 1957). The walls of Jericho were repaired or rebuilt no fewer than 16 times in its known history and, of the layers identified by Kenyon, not one could be singled out as providing special hints for destruction by the hand of Joshua rather than another conqueror, or by earthquake.

In 1997 a limited excavation by Nigro and Marchetti on the fringes of Kenyon's trenches, which was shrouded in political intrigues, found no evidence for destruction from the time of Joshua (Nigro and Marchetti 1998). Wood (1990), however, who examined the results of the excavations by Kenyon, Nigro and Marchetti, claimed that they had found the same evidence as that which in earlier excavations had fitted the Biblical story of the destruction of Jericho in c. 1400 BC. The conclusion is that the date or the period of the earthquake, if an earthquake did in fact occur at all, remains highly debatable, and archaeology does not help much to establish the invasion period with any degree of certainty. In Jericho and in other sites in the region the evidence points more towards deliberate human destruction.

From the examination of the available data, taking into consideration the doubts regarding Kenyon's dating raised by Wood, and those regarding Garstang's raised by Kenyon, it is prudent, until archaeologists come up with a better unbiased evaluation, to accept tentatively Kenyon's estimates. Until a better consensus is reached it is important to be aware that the time of the siege and destruction of Jericho by Joshua is very uncertain, being bracketed within a rather broad chronological range.

It is natural for archaeologists to seek earthquake effects in strata belonging to the conventional period of the fall of Jericho in c. 1400 BC, which dating, as we have seen, is far from being certain. It was to be expected, with Jericho located in the Dead Sea fault zone, which is

capable of producing destructive earthquakes, that there is no lack of archaeological evidence to show that during the Bronze Age the site of Jericho was damaged a number of times, probably by more than one earthquake of unknown location and magnitude.

The problem here is that archaeological evidence for an earthquake is rarely unambiguous, and its dating is frequently based on, or influenced by, literary sources, which often, as in this case, provide examples of how their assumed accuracy, coupled with occasional inaccurate commentaries, may influence archaeologists' interpretations and dating. This then develops into a circular process in which the uncertain date of an earthquake is transformed into a fact and used to confirm the dates of the proposed destruction strata.

From Kenyon's estimates there are three layers in Jericho that show some good evidence of earthquake damage, namely during the periods of 8500–7000 BC (stratum PPNB), 3400–3100 BC (stratum EBA I) and 2300–1950 BC (stratum EBA IIIB), none of which, however, can be associated with Joshua and the fall of Jericho.

Neither does archaeological evidence from c. 1400 BC support the interpretation of a catastrophic earthquake. If the fall of Jericho had been due to an earthquake that was strong enough to flatten the massive walls of the city, it should have razed to the ground all the rickety dwellings within the city, the granaries and the water supply, with great loss of life, for which there is no evidence. Indeed, it is known that part of the city wall on the north side of the site was left standing (Heb. xi. 30–31). Joshua also says that the Israelites entering Jericho 'utterly destroyed all that was in the city, men and women alike'. Had there been a destructive earthquake that flattened the city walls, the Israelites would have found very few standing houses to destroy, or people alive to slaughter. It seems unlikely that the prophets or later chroniclers would not have mentioned such a 'newsworthy' event as a catastrophic earthquake.

It is natural to attribute the presence of skeletons buried under rubble to a sudden death caused by the collapse of a building in an earthquake. However, in the case of Jericho this is not a safe assumption. If the normal burials around Jericho, which date to the Middle Bronze Age, and Garstang's finds, which are not dated, are excluded, the only dated skeleton on site was not an earthquake victim. It belongs to a woman found in a room by the city wall and provides evidence for violence against the people. The woman was tightly contracted, suggesting that she had been bound in that position before being decapitated, the vertebrae of the neck having been severed (Kenyon 1981, 217).

Regarding the earthquake in Jericho, some Bible readers have supposed that an earthquake toppled the

walls of the city. However, the account of Israelites conquering the city contains no reference to earthquakes. Moreover, there is no conclusive evidence to associate the fall of Jericho with the earthquake damage preserved on the site of the old city, or with the damming of the River Jordan at Al-Damieh, which may be the result of a series of earthquakes over a long period of time (Kenyon 1978a, 36). Archaeological reports give little or no technical justification to support the conclusion that destruction was due to an earthquake and, if so, due to the very same earthquake as that mentioned by Amos. Available stratigraphic data cannot rule out the possibility that the observed damage was the result of later earthquakes.

Notes

Jericho

Estimated period of occurrence c. 2300–1950 BC.

Extract of pertinent statement by author relating to earthquake damage:

Trench I

'Intermediate Early Bronze Age–Middle Bronze Period.

In Stage XLI there was apparently a period of EB–MB camping occupation during which there is no evidence of solid buildings. During this period the W-shaped ditch of Stage XXXIX gradually silted up. In the silt were shards of EB–MB pottery.

In Stage XLII, phase IIV, the first EB–MB houses appear. They are terraced into the underlying deposits. An area of erosion between a western and eastern complex has removed any stratigraphical links. The western complex is built over the stage XLI fill in the ditch. In it were two solid clay blocks in adjacent rooms, which might be altars. A foundation burial beneath the dividing wall and a bin that could have been for offerings could support the suggestion of a cult center, but this is not certain. The eastern complex, of irregular plan, on three widely different levels, is terraced into the EB deposits, on the south side cutting back into the final EB town wall. All the walls are of the characteristic EB–MB type, a single brick-course thick, and the bricks are of the distinctive greenish clay of the period.

After a period of which the length is indicated by a considerable number of occupation levels, and some rebuilding, there was in phase IIV a considerable rebuilding. In the eastern complex this consisted only of slight extensions of the middle terrace and a considerable raising of level in the western terrace. In the western complex most of the original walls are rebuilt and the wall dividing the original two rooms disappears, as do the solid clay blocks. A new division in the eastern part of the complex is only just within the excavated area.

In the western complex there is above the phase IIV floors a considerable collapse and a raised floor, with a new wall creating a passage.

The collapse of the final EB–MB buildings is marked by a tumble of bricks on the floors. A ragged gully that has removed the western walls of the eastern complex may be evidence of an earthquake. The collapse and the gully are covered by a silt wash that must indicate a period of abandonment and erosion before the

MB bank was constructed. Within this erosion period, a gully cut down deeply on the south side of the excavated area and was then refilled' (Kenyon 1981, 16).

'XLII. Tr. 1 In the eastern complex, wall JD is at the north side of the trench cut down into the burnt debris against the face of EB Town Wall M (pl. 88a), the final EB town wall, and into the underlying fill, to the depth of 2 m. To the east, the contemporary floor sealed the EB wall, while to the west the floor was nearly at the foot of wall JD; the difference in level was 1.85 m. The original wall JD only survives for a short distance beyond the earlier line, and is then extensively patched in stone. To the south, beyond the patch, the wall angles sharply back to the south-east, and cuts right into the brickwork of wall M, with its foundations resting on the stone foundations of that wall (pl. 88b). At the point where wall JD angles back, wall JE runs up to it from the west.

The original west wall of the room west of wall JD was JF, which likewise cuts down into the EB levels. The original level to the west of JF was presumably at the foot of the wall, and therefore 0.55 m. below that to the east. The existing surfaces, however, run up to a steep slope at the foot of wall JF, and the earliest surviving is 0.50 m. beneath the foot of the wall. This was presumably the result of erosion, followed by a period when occupation levels gradually raised the floor nearly to the base of the wall. The pit against the western foot of JD may also be the result of erosion, filled by subsequent occupation. The fill of these erosion areas is hatched as IIV (E) b.

The western end of this complex is lost in a ragged gully (section I, pl. 236, c. 17m. W.), which cuts it off from the western complex. Presumably somewhere in the area destroyed by the gully there was a wall bounding this terrace, and there was either a lower terrace joining the two complexes, or a connecting surface; in either case evidence was removed by erosion at the end of the EB-MB period. The gully is covered by the wash of this erosion period; it could be a rain-water gully, but is perhaps more likely to be in origin an earthquake crack' (Kenyon 1981, 106–107).

A collapse of EB-MB buildings (indicated by the fall of bricks on the floors) was apparently caused by a gully which could suggest evidence of an earthquake. The collapse and the gully are covered by a silt wash that must indicate a period of abandonment and erosion before the MB town was constructed.

Estimated period of occurrence: c. 1365–1275 BC.

'L'étude minutieuse à laquelle nous nous sommes livré, nous a permis d'établir que les couches de destruction et d'incendie de Beit Mirsim, niveau CI, celles du Bronze Récent II de Jéricho... ont été la conséquence du même tremblement de terre qui a ravagé Ugarit vers 1365 avant notre ère' (Schaeffer 1948, 5).

'Selon ces indices et étant donné la nature des trouvailles, il est permis d'admettre que la destruction du second palais et d'une partie de la ville de Jéricho par un tremblement de terre correspond à la destruction due à la même cause du niveau CI de Beit Mirsim et de l'Ugarit Récent 2, vers 1365. Cette date est donc plus basse que celle proposée par le fouilleur pour la destruction du second palais, env. 1425 avant notre ère.

Une tablette incomplète et brûlée en cunéiformes a été retirée de la couche correspondant au second palais. D'après Mr. Sidney Smith, la tablette semble être du XIV^e siècle et il pense qu'elle n'est pas plus ancienne que l'époque d'El Amarna. Etant donné son état de conservation, il y a donc une forte chance qu'elle soit antérieure au tremblement de terre et à l'incendie de Jéricho de 1365. Cette conclusion s'accorde avec le fait qu'à Ras Shamra toutes les tablettes jusqu'ici trouvées sont aussi antérieures au séisme de 1365.

Comme nous l'avons observé à Ras Shamra, à Jéricho aussi les bâtiments avaient été relevés ou réparés après le tremblement de terre et utilisés pendant la dernière période du Bronze Récent. Ils ont tous été détruits de nouveau, cette fois au cours d'une conflagration générale qui avait consumé la dernière ville du Bronze, appelée ville D par le fouilleur. La destruction a été suivie par un hiatus et une occupation intermittente' (Schaeffer 1948, 139).

'The LB II levels at Jericho appear to end c. 1275 BCE, so that Schaeffer's c. 1365 BCE date is much too high' (Dever 1992, 31 n. 3).

c. 1274–1234 BC Nineveh, Mesopotamia

The earliest documented Assyrian earthquake ruined the Great Gate of the Lions' Heads of the Great Court of the Temple of Ishtar in Nineveh. It was subsequently restored by Shalmaneser I, who was king at that time.

This event is recorded on a tablet found in Nineveh, on which Shalmaneser I (king c. 1274–1234 BC) records how he restored the temple of Ishtar which had been ruined in an earthquake (Thompson and Hamilton 1932). This is also documented on another tablet written some 150 years later, which mentions this and a second earthquake in the same place (see entry below for 1187–1150 BC; for Thompson 1937).

Notes

'(5) When the Temple of Ishtar, the lady of Nineveh, my lady, fell in ruins [which] aforetime Shamshi-Adad (6) had built (and) after him Ashur-uballit, my father, had restored: that temple [was ruined] throughout by an earthquake (7) ... its weaknesses I bonded and (its) fallen part from its foundation to [its roof] I built: the stone tablet] and stone cylinders of Ashur-uballit. [I restored] (8) anew to their places...!' (Thompson and Hamilton 1932; see entry for 1187–1150 BC for Thompson 1937).

1187–1150 BC Nineveh, Mesopotamia

A severe earthquake in Nineveh ruined the Great Gate of the Lions' Heads again in the reign of Ashur-dan. It is probable that his grandson, Ashur-rish-ishi, pulled down some of the ruins and rebuilt the entire palace on a grander scale.

Ashur-rish-ishi (c. 1120 BC), in an account written on a tablet from Nineveh, mentions the two destructions of the Great Gate of the Lions' Heads of the Great Court

of Ishtar in Nineveh (Thompson 1937). When Ashur-rish-ishi mentions Shalmaneser, he is almost certainly referring to Shalmaneser I. Ashur-dan ruled between c. 1187 and 1150 BC, so the second earthquake must date from the second quarter of the twelfth century BC.

There is also archaeological evidence for an earthquake at this time. Mallowan, describing the remains of the palace of Fort Shalmaneser in Calah (modern Nimrud), only 30 miles from Nineveh, shows that the palace was built and rebuilt in phases (Mallowan 1966, 223). Fragments of pavement in the courtyard demonstrate that the first three phases, termed A–C, are prior to the ninth century BC. Of particular interest are the remains of phase B, the platform of which has buckled and bent, almost certainly as a result of an earthquake. Mallowan did not find enough material to date phases A–C exactly, but he notes that potsherds found in the street east of the palace ‘are of a type associated with the buildings of the 15th and 14th centuries at the Mitannian city of Nuzi. It is therefore probable that one of these three phases coincides with the earliest recorded city of Calah, that founded by Shalmaneser I’. It is thus possible that the earthquake recorded by Ashur-rish-ishi is the same as that which damaged the phase-B platform in Nineveh.

Note

‘When the namiru of the Great Gate of the Lions’ Heads of the Great Court of (9) Ishatar [of Nineveh], my lady, which aforesaid in the time of Shalmaneser, the king of Assyria, was ruined in an earthquake, (and) [Shalmaneser], a king who preceded me had restored its ruins; (10) a second time it had been shaken in an earthquake in the [time of Ashur-d]an, [the king] of Assyria, who begot my father, and those namiri had been unsettled and had fallen in ruin; for fifteen tipki from the coping to the “beam of the house” I pulled down, (11) I took (it) down. I raised (it) to fifty tipki, increasing it by thirty-five tipki more than before; with iaeri of stone I surrounded them.’ (Thompson 1937). (See Figure 3.1.)

c. 1181 Egypt

An unidentified earthquake in Egypt, mentioned by a ninth-century-AD writer, in need of authentication.

Note

‘The 58th king of Egypt was Athothois, also known as Phusanus, who ruled for 28 years; in his reign earthquakes happened in Egypt. This was in the year of the world 4369.’ (Georg.Synec., 170/320)

[c. 1070 BC Mizpeh, Judaea]

We are told that just before the battle between Samuel and the Philistines at Mizpeh, God sent an earthquake, which made the Philistines fall to the ground, and thunder that burnt them, forcing them to return home. It is

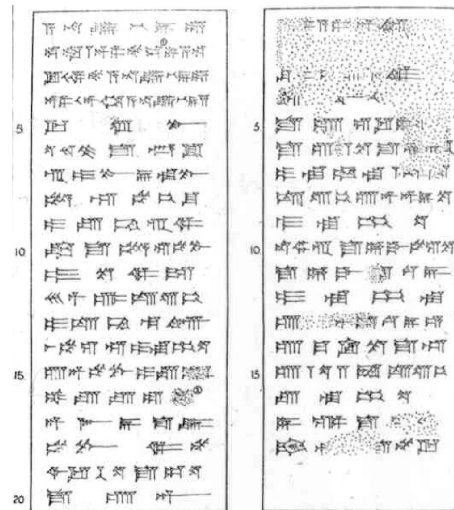


Figure 3.1 An Assyrian letter written in one of the outlying towns of the empire sometime during the eleventh century BC says ‘On 21 Elul an earthquake took place. All the back part of the town is down; all the wall at the back of the town is preserved except thirty and a half cubits therefrom being strewn and fallen on the near-side of the town. All the temple is down ... let the chief architect come and inspect’ (BM 123358:TH.1932–12.10).

rather strange that this visitation was meant only for the Philistines and that Samuel’s opposing army remained unaffected. Obviously a spurious event.

Note

‘... the enemy’s forces issued from their camp and drew up for battle, expectant of victory, thinking to have caught the Jews in a hopeless plight, seeing that they were without arms and had assembled there with no intention of battle. But the Philistines encountered what, had one foretold it, they would have scarcely believed. For, first, God vexed them with an earthquake, rocking and making tremulous and treacherous the ground beneath them, so that from its reeling their footsteps staggered and at its parting they were engulfed in sundry of its chasms. Next He deafened them with thunderclaps... But Samuel now rushed upon them with his people and, having massacred many, pursued them to a certain place called Korraea; ...’ (Joseph. AJ. vi. 2/LCL. v. 178).

c. 759 BC Judaea

Among Biblical earthquakes the mid-eighth-century-BC earthquake known as ‘Amos’, ‘Zechariah’s’ or ‘Uzziah’s’ earthquake is an important event. Modern writers date the earthquake to 759 BC and assign to it a very large magnitude of M_L (sic.) 8.2, with an intensity in Jerusalem between VIII and IX (Ben-Menahem 1979, 262; Austin *et al.* 2000). In addition, the event is said to have been associated with the coseismic left-lateral offset of the

Jericho fault, which is a segment of the north–south trending strike–slip Dead Sea fault (Nur and Ron 1996). Obviously, such an important earthquake deserves authentication and its effects, reappraisal.

The earliest reference to a mid-eighth-century-BC earthquake in Judaea can be found in the opening verse of the Book of Amos who, without giving any details, mentions in passing an earthquake during his time, somewhere in Judaea, during the reign of Uzziah (791–752 BC) (numbers in square brackets refer to the notes at the end of the entry, [1]), perhaps the same event as alluded to by Isaiah (c. 700 BC) [2].

About three centuries later, early in the sixth century BC, Zechariah (c. 520 BC) mentions an earthquake in Judaea, again in the days of King Uzziah and probably the same event as that mentioned by Isaiah, which he says affected Jerusalem and caused the Mount of Olives, east of Jerusalem, to split and form a valley [3]. The interpretation of this passage in Zechariah (14, 4–5), which seems to be a later fifth- or fourth-century-BC insertion, is not clear. Other versions of the same passage say that the Mount of Olives will split in two and create a valley that will reach Azel. This valley will run from east to west with half of the Mount of Olives moving to the north, away from the position it occupied, while the other half will move to the south. The valley will stop where the mountains will touch each other [3.1, 3–7].

A somewhat different reading is to be found in the Masoretic version, where, following the mention of the splitting of the Mount of Olives, it says that the valley shall reach unto Azal, as compared with the Revised Standard Version, which says instead that the valley shall be stopped up, for the valley shall touch the side of it (the mountain) [4, 5]. The source of this difference lies perhaps in the confused reading of the Hebrew words for ‘shall be stopped up’ (*ve-nistam*), and ‘you shall flee’ (*ve-nastem*). The consonants are identical, but when the diacritical points were added to the Hebrew Bible to facilitate reading, the text was apparently misunderstood and the meaning changed (see the editor’s note in Wachs and Lewitte 1984). Upon adopting the latter reading as more plausible in relation to the natural phenomenon described, it is obvious that there is no other explanation than a large landslide, which may, or might not, have been triggered by this or by another earthquake.

Also, Josephus in his *Antiquities of the Jews* (AD 93), a book written about six centuries later, refers to an earthquake that happened in the last months of King Uzziah’s life, which caused a crack in the Temple at Jerusalem. Josephus adds that at a place called En-rogel, outside the city, half of the mountain in the west broke off from the rest and slid 800 m up to the mountain on the east, spoiling the king’s gardens [6]. Assuming

that the two authors refer to the same event, this passage in Josephus seems to suggest that in all probability Zechariah describes a landslide, perhaps triggered by an earthquake, rather than a graben formed by normal faulting.

There is a further reference to these events in Uzziah’s days by Nathan ha-Bavli, who was writing in the middle of the second century AD. He does not mention the earthquake, but he says that at the time of the desecration of the temple by Uzziah the temple split open and the fissure extended for twelve ‘miles’ in each direction [6a].

The location of *Azal* is not certain, but the name may denote some place near the western extremity of the valley near Jerusalem or a hamlet on the outskirts of Jerusalem. As for the location of *En-rogel*, it has been suggested that it is the fountain of the Virgin, the modern Ain Umm al-Daraj. Others identify it with Bir Eyub, to the south of the Pool of Siloam, and below the junction of the valleys of Kidron and Hinnom, which seems to be a more probable location, but again this is not certain.

There remains the question of whether there is any evidence today for active faulting in the immediate vicinity of Old Jerusalem that can be associated with the ground deformations mentioned by Zechariah, Josephus and Nathan. Old aerial photographs of the chalky geological formations of the region show only landslides on steep slopes, but no through-going faults. A relatively large slide can be recognised on the Mount of Olives, which is located on the slope which faces west towards the Old City, the scarp of which can be seen halfway up the Mount of Olives. However, according to the Geological Survey of Israel, it is probably much more ancient than Biblical times (Wachs and Lewitte 1984; Frydman 1997). The multitude of short scarps shown on relatively recent geological maps of Jerusalem all terminate at the Kidron Valley (Gil 1996). The exception is a short northeast–southwest-running fault trace, which is shown on the Geotechnical Map of Jerusalem (Israeli 1977), which the Atlas of Israel labels *Zechariah 14:4, earthquake fault*. This feature extends from a point a few hundred metres south of the Jerusalem Railway Station to the west, running for more than three kilometres, to just north of al-Ayzariyah to the east, striking about N–70° E (*Atlas of Israel* 1985). The reason why this feature has been associated with Zechariah’s earthquake is not given.

There is no direct or indirect evidence that Jerusalem was damaged, and it is interesting that the details in Josephus concerning the effects of the earthquake on the temple are not supported by earlier sources, which remain silent about damage anywhere in Judaea and Israel [7].

Amos' earthquake may be dated vaguely from the line of Jewish kings chronicled in the Old Testament, which provides us with 756 or 759 BC as a *terminus ante quem* (Soggin 1970, 120), or perhaps earlier. Courville dates this earthquake to 751–750 BC, on the basis of the Jewish legend reported by Josephus in which the prophet Zechariah is quoted as a source indicating the severity of the earthquake. This, however, would be the correct date only if the earthquake could be associated with the judgement on Uzziah, that is, only if Josephus' account that the earthquake occurred at the same time as Uzziah was stricken with leprosy could be proven to be true [6]. While the Zechariah quotation is suggestive, it does not specifically associate the earthquake with God's judgement on the king, and we cannot follow either Josephus' or Courville's attempts at a correlation without further evidence (Courville 1971, ii, 122). For instance, Courville goes on to correlate Uzziah's earthquake with other catastrophic events, such as, for instance, the eruption of Thera. He can do this only because he brings the Late Bronze age down to the time of Uzziah, a view that must be rejected (Crisler 2004). If Courville's view is adopted, however, the placement of Uzziah's earthquake at the end of Samaria II can be correlated with a wave of destructions at this stratigraphic level, destruction that is said to have affected the Holy Land and could also have been due to the invasion by the Egyptians.

Modern writers have suggested that archaeological evidence points to at least 20 sites in Judaea and Israel that were destroyed by the same earthquake, although it is not possible to confirm this. The chief problem is the identification of the cause of the destruction at these sites, which are scattered in a north–south direction from Tel Hazor in the north to Tel Batash in the south, a distance of 350 km, and from the Mediterranean coast to the east side of the Dead Sea fault zone, that is, within an area of about 100 km radius. Archaeological reports give little or no technical justification to support the conclusion that damage was due to earthquake, and if so, due to the very same earthquake as that mentioned by Amos. Stratigraphic control did not consider or discuss the possibility that the observed damage was the result of later earthquakes, and dating is based solely on the only literary source available, the Bible.

For example, for Tel Beersheba (Tel Sheva) Herzog concludes that '*Tentatively the destruction might be associated with a severe earthquake dated c. 760 BC, based on biblical references*' (Herzog 2002, 96).

For Tel Arad the excavators attribute the destruction '*to an earthquake during the reign of Uzziah in 760 or 750 BC*' (Herzog and Singer 2002, 96–98; Singer-Avitz 2002, 162).

The same is also the case for Lachish (Hesy), where the archaeologists consider '*A natural catastrophe of this sort would, perhaps, be compatible with the earthquake mentioned by Amos*' (Ussishkin 1977, 5; Dever 1992, 35, n. 10; Herzog 2002, 97).

For Tel Gezer, '*evidence for the destruction, as in other sites, can be attributed to the earthquake in Amos and Zacharia c. 760 BC*' (Dever and Younker 1991, 286; Younker 1991; Dever 1992, 30).

For Tell Qasile, which is included in the list of sites damaged by the earthquake of 760 BC, archaeological evidence suggests that the site was damaged during the period 1100–1050 BC (Dothan and Dunayevsky 1993; Mazar 1993, 298; Stern 1993).

Also Tell Abu Hawam, belonging to the same list, was damaged between 1125–1050 BC (Balensi 1980, 586; Warren and Hankey 1989, 161).

Crisler considers that '*The destruction of Samaria [Shechem] was probably due to Uzziah's earthquake of 783 BC*' (Crisler 2003; 2004).

For Tell Deir Alla the excavators say that '*Indeed, the earthquake that destroyed level M/IX could well be the one mentioned in Amos, dated about 760 BC*' (Dever 1992, 35, n. 10; Lemaire 1997, 139 = 750; Knauf 2002).

The same assumption is also made for the case of Megiddo, for which it is concluded that '*The destruction may be linked to the biblical reference to a major earthquake c. 760 BC in the time of Jeroboam II*' (Knauf 2002).

Similarly for Tel Hazor '*The damage is likely to be due to the well-known earthquake mentioned by Amos*' (Yadin 1972, 113, 181; Dever 1992, 28; Knauf 2002).

An earthquake that could obliterate man-made structures within an epicentral area of radius about 100 km, an area including all the sites listed as destroyed, is an earthquake of a size beyond the limits of the possible. The destruction of the towns and forts could have been the result of Zechariah's earthquake or of separate events that occurred during the same week, month or year, but were not differentiated in the sources or, more likely, was the result of the invasion of Judaea and Israel by pharaoh Sheshonk I. It is interesting that many of the sites are included in the list of cities conquered by the Egyptians, the names of which are carved into the south wall of the courtyard of the temple of Karnak in Egypt, i.e. Timna (Tel Batash), Tel Gezer, Tel Michal, Tell Qasile, Tell el-Mazar, Tell el-Saïdiyyeh, Tell el-Hama, Tel Mevorakh, Tell Abu Hawam and Megiddo. It is probable that Megiddo, where Sheshonk erected a victory stele, was only partially destroyed, since it continued in use. The stele belongs to the time of Jeroboam II, and is dated to c. 783 BC (Kitchen 1986; Mazar 1993, 298; Ng 2004; Crisler 2004). Unfortunately, because of the

differences between the Egyptian record and the Biblical account, it is difficult to establish whether the invasion by Sheshonk I was coeval with Amos' earthquake.

In conclusion it is possible that the earthquake mentioned by Amos was embellished by Josephus and by later writers in their narratives to include the effects of an earthquake, to which the prophets do not refer. The available tectonic and geological evidence suggests, however, that it is more probable that the natural phenomenon that Zechariah describes fits better the more plausible 'shall be stopped up' reading of his text, which implies the occurrence of a large landslide, perhaps triggered by an earthquake. The uncritical amalgamation of biblical information and archaeological evidence from various distant parts of Judaea has produced a very large earthquake of $M_S > 8.0$. Such an earthquake should have razed Jerusalem to the ground, an event that the prophets or later chroniclers would have mentioned or that would itself have left its mark in the form of a major surface fault rupture. The date of this earthquake is very uncertain, since archaeological evidence is hampered by the unresolved differences between conventional chronology and New Chronology. The description by Josephus, whether really of the earthquake mentioned by Amos, Josephus and Nathan or not, is at least evidence of the effects of an earthquake that had occurred before their time somewhere in Judaea for which there are no means today of assessing its location and magnitude.

Notes

- [1] Amos says that the prophet received visions '*... during the reigns of Uzziah king of Judah and Jeroboam son of Jehoash king of Israel, two years before the earthquake ...*' (Amos, I. 1).
- [2] '*... they shall go into the holes of the cracks and into the caves of the earth when He arises to shake (terrify) the earth ...*' (Isa. II. 19, 21).
- [3.1] '*... the Lord will go out fully armed for war, to fight against those nations. That day his feet will stand upon the Mount of Olives, to the east of Jerusalem, and the Mount of Olives will split apart, making a very wide valley running from east to west, for half the mountain will move towards the north and half toward the south. You will escape through that valley, for it will reach across to Azel. You will escape as your people did long centuries ago from the earthquake in the days of Uzziah, king of Juda... [c. 767–753 BC]*' (Zech. xiv. 4–5).
- [3.2] '*And the mountain will split in half, forming a wide valley that runs from east to west... Then you people will escape from the Lord's mountain, through this valley, which reaches to Azel. You will run in all directions, just as everyone did when the earthquake struck in the time of King Uzziah of Judah.*' (Contemporary English Version).
- [3.3] '*And the Mount of Olives shall be split in two from east to west by a very wide valley; so that one half of the Mount shall withdraw northward, and the other half southward... And the valley of my mountains shall be stopped up, for the valley of the mountains shall touch the side of it; and you shall flee as you fled from the earthquake in the days of Uzzi'ah king of Judah.*' (Revised Standard Version).
- [3.4] '*And the Mount of Olives shall be split in two from east to west by a very great valley; and half of the mountain shall remove toward the north and half of it toward the south... And you shall flee by the valley of my mountains; for the valley of the mountains shall reach to Azel; and you shall flee, as you fled from before the earthquake in the days of Uzziah king of Judah.*' (Amplified Bible).
- [3.5] '*And the Mount of Olives shall be split in the midst thereof toward the east and toward the west, and there shall be a very great valley; and half of the mountain shall remove toward the north, and half of it toward the south... And you shall flee by the valley of my mountains; for the valley of the mountains shall reach unto Azel. And you shall flee, like as you fled from before the earthquake in the days of Uzziah.*' (American Standard Version).
- [3.6] '*And the Mount of Olives shall cleave in the midst thereof toward the east and toward the west, and there shall be a very great valley; and half of the mountain shall remove toward the north and half of it toward the south... And you shall flee by the valley of my mountains; for the valley of the mountains shall reach unto Azel; you shall even flee, like as you fled from before the earthquake in the days of Uzziah king of Judah.*' (Darby English Version).
- [3.7] '*And the Mount of Olives shall cleave in the midst thereof toward the east and toward the west, and there shall be a very great valley; and half of the mountain shall remove toward the north, and half of it toward the south... And you shall flee to the valley of the mountains; for the valley shall reach unto Azel; you shall flee, like as you fled from before the earthquake in the days of Uzziah king of Judah.*' (King James Version).
- [4] '*And ye shall flee to the valley of the mountains; for the valley of the mountains shall reach unto Azel ...*' (Masoretic text).
- [5] '*And the valley of my mountains shall be stopped up; for the valley of the mountains shall touch the side of it ...*' (Revised text).
- [6] '*... a great earthquake shook the ground and a rent was made in the temple, and the bright rays of the sun shone through it, and fell upon Uzziah's face, insomuch that the leprosy seized upon him immediately. And before the city, at a place called Eroge, half the mountain broke off from the rest on the west, and rolled itself four furlongs and stood still at the east mountain, till the roads, as well as the king's gardens, were spoiled by the obstruction ...*' (Joseph. AN: IX. x. 4).

- [6a] '... when leprosy appeared on Uzziah's brow, at the same moment the temple split open and the fissure extended for twelve miles in each direction ...' (Nathan ha-Bavli. ix).
- [7] '... the posts of the temple moved when the Lord spoke ...' (2 Chron., XXVI. 16–17; 2 Kings XV.1–7).
- [8] Timna (Tel Batash)
(Rotherberg and Lupu 1967, 59; Rothenberg 1972, 128, 149–150; Mazar 1993 = in fact 1160–1156).
- [9] Tel Beersheba (Tel Sheva)
Estimated period of occurrence: 760 BC.
Extract of pertinent statement by author relating to earthquake damage:
'... and Beersheba depends largely upon the opinion of Aharoni, thus far unsupported by an adequate publication, see Y. Aharoni et al., *Beer-Sheba I. Excavations at Tell Beer-Sheba, 1969–1971 Seasons* (Tel Aviv 1973) 107.' (Dever 1992, 35* n. 10).
- 'At Tel Beersheba, Strata V and IV cover the period equivalent to that of Stratum XI at Tel Arad. The plan of Stratum III at Tel Beersheba is, again, drastically different from that of Stratum IV. The former solid city wall and city gate were completely razed, and a new fortification system was constructed. We subscribe to the "low chronology", these changes may not be attributed to Shishak's raid or to the division of the alleged United Monarchy. If so, what generated such a cultural shift? Since typological modification runs parallel to drastic changes in the design of settlements, as observed at Tel Beersheba and Lachish, they should be related to significant events. Tentatively this development might be associated with a severe earthquake dated to c. 760 BCE, based on biblical references (Dever 1992). A strong earthquake in the southern part of the Judean Kingdom might explain the total destruction of the upper parts of the fortification systems at Tel Arad XI and Beersheba IV and the need to rebuild them in Strata X and III, respectively' (Herzog 2002, 97–98).
- [10] Tel Arad
Estimated period of occurrence: c. 760 BC.
Extract of pertinent statement by author relating to earthquake damage:
'At Arad, a new fortress was erected that only partially used the previous casemate wall. A solid wall surrounded by a glacis protected the fortress of Stratum X. A new imposing gate and an elaborate water system were constructed in this phase. As shown above, the temple, too, was first erected in this stratum. At Tel Beersheba, Strata V and IV cover the period equivalent to that of Stratum XI at Tel Arad... Tentatively this development might be associated with a severe earthquake dated to c. 760 BCE, based on biblical references (Dever 1992). A strong earthquake in the southern part of the Judean Kingdom might explain the total destruction of the upper parts of the fortification systems at Tel Arad XI and Beersheba IV and the need to rebuild them in Strata X and III, respectively. The pottery assemblage of Stratum X at Tel Arad is remarkably different from that of Stratum XI and exhibits new

forms that display similarity to the assemblages known from the destruction layers of the end of the 8th century (Aharoni and Aharoni 1976).

The time span of the three strata was apparently fairly short. Attributing the destruction of the fortress of Stratum XI to the earthquake of ca. 760 BCE, the construction of the Stratum X fortress may be dated to 750 BCE. The circumstances of the destruction of the Stratum X fortress and its reconstruction in Stratum IX are unclear' (Herzog 2002, 97–98).

'As stated above, the material culture of Stratum XI resembles that of Lachish Level IV. The excavators attribute the destruction of Level IV at Lachish to an earthquake during the reign of Uzziah in 760 or 750 BCE, so that this date may mark the end of Stratum XI at Arad and the establishment of Stratum X. If we accept this view, then Stratum XI existed for a lengthy period, approximately 150 years' (Singer-Avitz 2002, 162).

- [11] Lachish (Hesy)
Estimated period of occurrence: 760 BC.
Extract of pertinent statement by author relating to earthquake damage:
'Level IV apparently came to a sudden end, but it seems clear that this was not caused by fire. On the other hand, the lower house of Level III and the rebuilt enclosure wall followed the lines of the Level IV structures, while the Level IV city wall and gate continued to function in Level III; these facts point towards the continuation of life without a break. Considering that the fortifications remained intact, we can hardly identify this level with the city which was stormed and completely destroyed in the fierce Assyrian attack. Here we may mention M. Kochavi's suggestion (made during a visit to the excavations in 1976 and quoted here with his kind permission) that the end of the Level IV structures may have been caused by an earthquake. A natural catastrophe of this sort would, perhaps, be compatible with the above findings. Of interest in this connection is the earthquake mentioned in Amos 1:1 and Zech. 14:5, which occurred around 760 BCE during the reign of Uzziah, king of Judah' (Ussishkin 1977, 52).
- 'The case of Lachish IV is perhaps the strongest' (Dever 1992, 35* n. 10).
- 'Since typological modification runs parallel to drastic changes in the design of settlements, as observed at Tel Beersheba and Lachish, they should be related to significant events. Tentatively this development might be associated with a severe earthquake dated to c. 760 BCE, based on biblical references (Dever 1992)' (Herzog 2002, 97).
- [12] Iraq al Amir
(Butler 1907, 13 = 760?)
- [13] Tel Gezer
Estimated period of occurrence: 760 BC.
Extract of pertinent statement by author relating to earthquake damage:

‘According to Macalister, a number of ashlar towers had been inserted into the Late Bronze Age Outer Wall by Solomonite engineers. In order to test this claim it was decided to locate his “Tower VII” (situated immediately north of the “Egyptian Governor’s Residency”, according to Macalister’s plan) and open two soundings – one against each of the inner and outer faces of the “tower” – in order to determine if indeed the “towers” were constructed in the manner and at the time Macalister claimed (see Plates 4, 6, and 19). After clearing off the top of the Outer Wall, however, it was discovered that Macalister’s “Tower VII” was not a tower at all, but rather an offset that was similar to what he found further west in his trenches 22–29, a stretch of wall which he described as “rebuilt”. Macalister had apparently found the same corner as our team and had simply drawn in the other three corners on his plan.

Excavation against the inner face of the “tower” reached bedrock in just over a meter (Plate 14). A foundation trench, which showed up clearly in the eastern balk, indicated that the offset was initially constructed in the 8th century B.C. Later, during the Hellenistic period, a second trench had been dug into the earlier one, suggesting that at least part of the wall was rebuilt during this period. Indeed, the ashlar in the upper two or three courses of the wall were poorly laid. They were uneven and not in the header–stretcher fashion. Thus they were probably reused from the earlier Iron Age construction.

The fact that the earliest architectural phase of the offset dated no earlier than the 8th century B.C. would seem to raise doubts about the claims of those who have argued for an earlier dating of the Outer Wall. However, excavation along the outer face of “Tower VII” revealed at least nine courses (ca. 5 m.) of excellent header–stretcher masonry. Although bedrock could not be reached in this sounding, the pottery from the lowest level of fills against the outer face consisted of red-slipped 10th century B.C. wares.

Above these 10th century fills (which were more than 2 m. thick) were at least two plastered surfaces which ran up against the wall face. The debris on these surfaces included fallen ashlar blocks in a brickly fill containing 8th century B.C. sherds. The debris layers may be evidence of both an earlier 8th century earthquake (see below) and a later 8th century B.C. Assyrian destruction (Plate 15). The latter was followed much later by a hasty repair and rebuild, probably during the Maccabean period (2nd century B.C.).

Thus, based on the results of the excavation along the outer face of “Tower VII”, it appears that the Outer Wall was originally constructed at least by the 10th century B.C., and probably earlier. The discoveries in Square 22 to the east (see below) even suggest the possibility of an initial construction in the LB II. Engineers of the Iron II and Hellenistic periods apparently found it necessary to repair isolated sections of the inner face (which rested on the top of an escarpment), thus leading to the discrepancy between the dates for the construction of the inner and outer faces of the Outer Wall.

Macalister’s Tower VI

In the hope of finding a genuine Solomonite tower inserted into a Late Bronze Age wall, it was decided to move east and attempt to locate Macalister’s “Tower VI”. According to Macalister’s top plan, Tower VI was located between 25 m. and 30 m. east of Tower VII (Plate 19). Using the bulldozer to clear away Macalister dump and post-Macalister debris accumulation (which included some 1947 Jordanian army trenches), it was not long before an ashlar block of what appeared to be the southwest corner of Macalister’s Outer Wall Tower VI was uncovered.

Unfortunately, excavations indicated that this “tower” was also only an offset (Plate 16). However, the pottery from the foundation trench indicated that the earliest phase of this stretch of the Outer Wall was founded probably during the 10th century B.C. Two additional pieces of evidence also support a 10th century B.C. dating. First, a stone of the lowest course of the inner face of the Outer Wall is roughly bossed in a fashion typical of foundation ashlar of the 10th century. Second, this lowest course is clearly cut by the later “tower” or offset, indicating that this stretch of the wall preceded the construction of the “tower”. Since the “inserted tower” dated to the 9th/8th century B.C. (see below), the wall must be dated earlier. While this second line of evidence is not sufficient by itself to provide a 10th century date, the bossed ashlar and the 10th century trench combine to make a 10th century B.C. date for this section of the wall most probable.

Sometime during the 9th/8th century B.C. the upper courses of the Outer Wall were remodelled with large ashlar to create an offset. The ashlar offset was “inserted” more than a meter into the 10th century B.C. wall line.

The 9th/8th century ashlar inserts and wall appear to have been destroyed sometime during the 8th century B.C. Several lines of evidence suggest that the agent of destruction was an earthquake. For one thing, several sections of the Outer Wall had been clearly displaced from their foundations by as much as 10 to 40 cm. Furthermore, these wall sections were all severely tilted outward toward the north. That this tilting was not due to slow subsidence over a long period of time was evident from the fact that intact sections of upper courses of the inner face of the wall had fallen backwards into the city. Only a very rapid outward tilting of the wall, such as that caused by an earthquake, could cause these upper stones to roll off backwards, away from the tilt. If the wall’s outward tilt had occurred slowly, the stones on the top of the wall should have fallen off toward the downward-sloping outer face of the wall.

The southwest corner of the ashlar insert had been similarly displaced from its foundational cornerstone, although to a lesser degree because of the greater stability of the ashlar construction. However, even the cornerstone had been split longitudinally because of the great pressure created by the lateral movement of the upper courses. This same tremendous pressure also created fissures in the ashlar stones that penetrated through several courses. The reason the foundation stones were not themselves dislodged to

any significant degree is probably due to the fact that they were set into levelled out depressions cut directly into the bedrock.

Evidence for an 8th century B.C. earthquake has been discovered at several other sites, such as Hazor. It is not impossible that the wall was destroyed by the well-known earthquake of Amos 1 and Zech 14:5 (ca. 760 B.C.)' (Yunker 1991).

'Here, too, the "tower" we expected to find (Macalister's "tower VI") turned out to be simply an offset portion of ashlar masonry (Fig. 1). This later wall, dated by eighth-century B.C.E. sherds in the secondary back-filled trench, was probably destroyed by the well-known earthquake of Amos 1 and Zech. 14:5, c. 760 B.C.E. Not only was the ashlar "tower" cracked from top to bottom and the adjoining boulders violently thrown off their foundations, but a long stretch of the wall to the east was tilted sharply outward in one piece (Fig. 2). Preliminary research indicated that the Gezer–Ramla region has been subject to repeated earthquake damage in historical times; an earthquake hypothesis, therefore, seems plausible' (Dever and Yunker 1991, 286).

'While the two Iron Age phases in the "Outer Wall" were so crystal clear in the sections that they constituted a "textbook" example of stratigraphy, of more interest was the evidence they preserved of an earthquake destruction of the second, 9th/8th century BCE phase. The evidence was twofold. (1) First, all three courses of the large rectangular blocks just at the "tower" offset were cracked clear through, from top to bottom, the heavy stones still approximately in place but with a large open gap running from top to bottom (Ill. 3). (2) Second, immediately to the west of the "tower" offset, the foundation course (here of marginally drafted ashlar) was still in situ; but the upper two courses of rougher boulders were found radically displaced upward and outward, but still lying in a row – as though they had violently "jumped" off their foundations (Ill. 4).

Now it seems evident that such severe damage cannot have resulted simply from the usual siege tactics carried out at ancient walled Palestinian towns. There was none of the typical evidence of burning: no calcinated stones; no trace of undermining and collapse; no evidence of battering or forcing of the wall inward. On the contrary, the wall had fallen suddenly outward, "split apart" violently.

For some time I resisted the suggestions of various staff members that perhaps an earthquake was the best explanation. And certainly I – not identifying with traditional "biblical archaeology" – did not have the earthquake of Amos or Zachariah in mind, despite the 9th/8th century BCE date for the wall that we had posited on quite independent archaeological grounds. Nor at the moment did I recall Yadin's earthquake hypothesis at Hazor. Yet, in the end, the evidence seemed overwhelming. Several of our group from California, including Associate Director Randy Yunker, had personally seen just such earthquake damage, even to the fact that random areas of the wall had been affected,

and this seemed to provide the confirmation that we needed.

A final probe still farther east, in Area 20, yielded further evidence. Here we cleared a stretch of the same wall for some 15 m. At first, our efforts to trace the wall eastward failed. Because we were following the projected line from the "tower" offset on a straight course and had found no stones, we supposed that the top course was robbed out. To our surprise, we later discovered what was clearly the line of the top course curving radically, a long section bowed outward yet still intact. Furthermore, the tops of the whole line of stones were tilted outward at an angle of ca. 10–15 degrees (Ill. 4).

One could, I suppose, argue that here we are dealing simply with subsidence, perhaps because the bedrock dipped downward at this point (as indeed it did). A more reasonable explanation, however, would seem to be an earthquake that displaced the whole section bodily, especially as the foundations were already weak. Certainly a battering ram, or the work of sappers, could not have produced such a peculiar phenomenon as this whole stretch of wall tipped outward. It does indeed resemble rather closely one of Schaeffer's toppled walls at Ugarit' (Dever 1992, 30).

- [14] Tel Michal
(Mazar 1993, 298 = ?).

- [15] Tell Qasile
Estimated period of occurrence: Stratum XI of Tel Qasile belongs to the phase Iron Age IB (= first half of the eleventh century BC).
Extract of pertinent statement by author relating to earthquake damage:

'Stratum XI was completely cleared in the southern part of the mound, where a large building, built mostly of kurkar stones, was found. The structure's plan was not fully traced. East of it was a large square, and nearby were two clay crucibles containing remains of smelted copper. In the northern sector of the mound, the buildings in this stratum were destroyed down to their foundations when the stratum X buildings were erected. The nature of the ruins indicates that the settlement was destroyed by an earthquake.

The fortifications in Area B include a massive brick wall (c. 5 m thick) in stratum XI. No architectural continuity was noted between strata XII and XI. The latter was laid out on a different plan and a new wall was added.

It was possible to distinguish clearly between the different Iron Age I strata (XII–X) at Tell Qasile; thus, separate and well-defined pottery assemblages could be established. Changes and developments can be traced in the ordinary local pottery, in which the Canaanite pottery tradition continues, as well as in the Philistine ware. The stratum XII Philistine pottery includes bowls, kraters, jugs with strainer spouts, and stirrup jars. The pottery contains several distinctive features that date it to the early phase of its appearance in Israel: thick white slip and bichrome decoration on some of the vessels with narrow, close-set lines, similar to the Mycenaean "close style"; the bird motif is limited to

stratum XII (only one example was found in stratum XI). The ceramic assemblage of stratum XI is similar to that of stratum XII. However, a change is discernible in the Philistine pottery: there is a deterioration in ornamentation, and monochrome decorations become more frequent. Other finds in this stratum include bronze arrowheads, a bone graver, spindle whorls, flint sickle blades, numerous loom weights, and various stone objects, such as grindstones and mortars. Iron objects were not found in Area A in strata XII and XI (Dothan and Dunayevsky 1993).

[16] Samaria (Shechem)

Estimated period of occurrence: 784–750 BC.

Extract of pertinent statement by author relating to earthquake damage:

‘In the Shechem essay it was argued that the end of Shechem 9b correlates to the end of Samaria Building Period 2. Excavations at Shechem 9b yielded evidence that it had been destroyed by an earthquake, and this was interpreted as the level destroyed by the earthquake of Uzziah’s day. Since the end of Samaria 2 correlates to the end of Shechem 9b, this means the destruction of Samaria 2 could well have resulted from the same earthquake. Wright describes the destruction of Samaria 2 (which required a rebuilding under Samaria 3):

“In Period III a wholesale rebuilding of the structure adjacent to the northern enclosure walls, and also of the royal palace to the west, suggests that a catastrophe had brought Period II to a close... The stones employed for this purpose were re-used from earlier buildings; some still had plaster adhering to them. The date for this period is given as ca. 840–800 B.C. [sic].” (BASOR, 155, pp. 18–19.)

The 2nd ceramic phase in use at the time of the earthquake (as we are interpreting it) was used as fill for Jeroboam’s rebuilding operations – i.e., Building Period 3. From this point on until the destruction of Samaria, the 3rd Ceramic Phase developed. This is enough time to allow for Wright’s view that the difference between Pottery Periods 3 & 4 was of a “similar interval” to the difference between Pottery Periods 2 & 3. The time would be from 783 BC to 721 BC – 62 years, the date of Sargon’s capture of the city.

The date of Uzziah’s earthquake

According to Wright, the Ostraca House of Samaria correlates with Building Period 3... In his article, “The Samaria Ostraca: An Early Witness to Hebrew Writing,” Ivan T. Kaufman points out that the ostraca were not found on the floor of the Ostraca House but were found in the fill underlying it. This was affirmed also by Anson F. Rainey... From this, we can infer that the ostraca were found in the fill of Building Period 3, and hence would correlate to our 2nd ceramic phase. If the 2nd ceramic phase was brought to an end by Uzziah’s earthquake, as we have argued, then it may be possible to link the ostraca to the earthquake. This is of considerable importance, because one thing we know about these ostraca is that they can be dated. Some of the ostraca are dated to the 15th year of an unnamed king, and some are dated to the 9th or 10th years of

an unnamed king. The lack of any intervening years, among other things, led Kaufman and Rainey to regard these years as belonging to a single date of two co-regent kings, rather than to different dates of one king (cf., Kaufman, p. 235.). We cannot go into great detail about it, but the conclusion of Anson Rainey’s discussion of these finds is that they should be dated to 784/783 BC, during the time of Jeroboam 2. Thus, the ostraca are something like a stopped watch during an accident or explosion. Just as the watch gives the actual time of the accident or explosion, so the ostraca provide, on our theory, the actual year of the earthquake, c. 783 BC.

Courville himself dated the earthquake of Uzziah’s day to 751–750 B.C., based on a Jewish legend reported by Josephus. (Exodus Problem, 2:122–23.) The prophet Zechariah is quoted as a source indicating the severity of the earthquake... Josephus claimed that the earthquake was God’s judgment on Uzziah for his attempt to burn incense to the Lord, a rite reserved to the priests alone (2 Chr. 26:17–18). Josephus speaks of a rent made in the temple, and bright sunlight falling on the king’s face, as he was seized with leprosy. The king’s son, Jotham, perforce had to become the acting king, c. 750 B.C., while Uzziah remained in a quarantined house for the rest of his reign. Courville concludes from this that the earthquake must have happened in the year 751–750 B.C.’ (Crisler 2004).

[17] Tell Deir Alla

Estimated period of occurrence: 800–750 BC.

Extract of pertinent statement by author relating to earthquake damage:

‘I have already mentioned that the site was shaken by earthquake round 1200 B.C. The destruction of the buildings of Phase M, the phase to which the Aramaic text belongs, was also caused by an earthquake. Deir Alla has suffered more earthquakes, not only during the time of habitation but also afterwards. These earthquakes and tremors caused vertical cracks which in the excavated area run mostly in east–west direction. When tracing the frequency of these cracks along a north–south line we find at least one every twenty cms. The tell is thus cut into vertical slices and these slices may have sunken for instance from a few cms. to several cms. and sometimes shifted sideways, whereas most of them apparently under the pressure from higher parts of the tell are inclined to lean out to the north. Expressed in geological terms we have found, be it in miniature size normal faults and even pivot faults. Cracks reaching the present surface must have been caused after the tell had reached that height and cannot therefore be dated to the stratigraphy... Moreover, unless all the cracks that run through the deposits overlying Phase M and their exact position had been recorded, we would not be able to say whether any cracks seen in Phase L stop at the floor levels of Phase M. However we had several other indications. We have recorded cracks and shifts of material that run through the ruined buildings but stop at the point where erosion began to level off the debris. These were caused by a second shock which followed the first one after the buildings collapsed and the fire caused by the earthquake had burned