1

Introduction

Seismology, the investigation of earthquakes and their effects, developed later than most sciences. Instrumental measurements only date back to the late nineteenth century. Earlier historical records of seismic occurrences are pieced together from written descriptions, earthquake catalogs, and the like, and are most useful from the eighteenth century onward. Unfortunately, however, earthquakes usually attracted attention only when man-made constructions were destroyed. Little care, except for describing secondary effects of shaking, was devoted to more careful studies that would shed light on the tectonic processes involved or the reasons that the earthquake occurred where it did. It is not at all surprising that much of the earlier fieldwork done by investigators, such as geologists and archaeologists, may have focused on other matters and as a result significant details pertinent to the earthquake problem were overlooked.

Early studies of the geography of earthquakes relied solely on *macroseismic* data – observations based on descriptions from a single destructive earthquake or on a number of earthquakes felt at a given locality. Mallet and Mallet (1858) compiled a catalog of the world's earthquakes and published a remarkable colored map showing the major earthquake zones and volcanoes of the world. The map, representing a global visualization of seismic geography, is surprisingly accurate when stared at today but it seems to have been ignored in its time. A portion of this map, centered on the Americas, is shown in Figure 1.1. Regions where either the number, or the felt effect, or both, of successive earthquakes are the greatest are shown in the original with a deeper orange-red tint. Volcanoes and fumaroles active in recent geological time are indicated with solid black dots. Areas shown without tint were not presumed to be free from earthquakes but rather were lacking observations. It should also be noted that the color tint is more intense in narrow bands circumscribing the linear alignments of

Cambridge University Press
978-1-107-41049-7 - Early Earthquakes of the Americas
Professor Robert L. Kovach
Excerpt
More information

Figure 1.1 A portion of the Seismographic Map of the World prepared by Mallet and Mallet in 1858.

volcanic vents. The main features of earthquake locations and their depths of occurrences were fairly well known by the 1930s, culminating in the classical works of Gutenberg and Richter (1941, 1949).

It was the idea of plate tectonics that put earthquake geography in its proper perspective. Most of the energy expended at the surface of the earth is spent as differential movements between plates, and takes place within a few narrow seismic belts. We now know why earthquakes occur where they do and what their main mechanisms of failure are. The beauty of plate tectonics is that it not only explains contemporaneous tectonic activity but it also shows that activity that is going on now must have also been going on for a considerable period of time. On a time scale of hundreds of years the average repeat time of large earthquakes, expressed as jerks in the movement of plates, can be estimated. Even if large earthquakes cluster in time as earthquake storms, the seismic slip rate deduced from the movement of tectonic plates often permits estimation of the average return time for large earthquakes. Can we find corroborating evidence for the past occurrences of such seismic events?

Did indigenous native cultures, Indians of the Pacific northwest, the Aztecs, Mayas, and Incas, to name a few, document the occurrences of natural disasters? Written history, if it can be found, is much less subject to change than oral tradition, provided the original writer was accurate and reliable. However, many occurrences may have only been recorded as myths and legends, and orally transmitted. Stripped of their allegorical cloak, myths of creation and destruction by natural events such as floods, earthquakes, and volcanic eruptions of successive "worlds" are useful because they tell us something of the past and moreover confirm our suspicions that urgent messages were being transmitted into human existence. Myths were used to relay information about past or future occurrences stressing the risks and consequences of natural hazards, and perhaps preparations for interesting times yet to come.

Written records of earthquakes and other natural disasters in the Americas, which occurred prior to the Spanish conquest, are extremely sparse. Overzealous friars destroyed most of the pre-conquest written records, the native Mesoamerican manuscripts referred to as codices. The few pre-conquest Maya and Mexican codices that have been found primarily deal with deities, rituals, the passage of time, world directions, and genealogies. It is not until immediately after the conquest, when native scribes under Spanish sponsorship prepared codices such as the Codex Aubin and Codex Telleriano-Remensis, that specific earthquakes, volcanic eruptions, and the like are mentioned. The earliest occurrence depicted in a codex in pictographic form is an earthquake in 1460 described in the Codex Telleriano-Remensis.

The lack of any historical written tradition is exemplified in the Inca Empire. At least so far as is known there was no system of writing in the Andes in or before the Inca Empire, which reached its zenith about the time of the Castilian conquest in the early sixteenth century. One used the oral tradition for the transmission of knowledge. Even though myths and legends may implicitly contain information about past natural disasters, answers may also have been left in the archaeological record or as colloquially stated "found in the ground." Stated in another way, even if written and oral history can tell us of events and actions, archaeology can often capture the effect of these events and actions.

In studying historical earthquakes one makes use of data extracted from a seismic intensity scale, most commonly the Modified Mercalli Intensity Scale (described in detail in Chapter 4), a subjective numerical scale ranging from 1 to 12 and indicated by roman numerals from I to XII. A number of intensity scales have been used throughout the years and they have been applied to descriptions of a very heterogeneous nature. It is possible, however, to convert these observations to Mercalli intensity values or ranges of values. The basic use of intensity as a descriptive shorthand of earthquake effects collapsed into a single number needs to be kept in mind. However, its concept is useful because isoseismal maps often form the basis for seismic zoning and maps introduced into earthquake design regulations and codes.

Intensity VII is usually taken to be the threshold of significant damage in unreinforced masonry structures such as adobe. The falling of cornices or other architectural ornaments is also typical. Intensity VIII would be assigned to areas showing partially collapsed masonry buildings, the falling of some masonry walls, and the twisting and falling of monuments. Considering that many ancient structures may not initially have been designed with earthquakes in mind, an intensity value of VII could easily have been an VIII. Nevertheless, a seismic intensity value of VII is a useful minimum value which might be inferred from studies of archaeological ruins. Regardless of its shortcomings, intensity values can be roughly correlated to some physical quantity, usually the maximum horizontal ground acceleration that took place during the earthquake. Estimated Modified Mercalli intensity maps based on instrumental ground motion acceleration recordings are now routinely constructed for southern California earthquakes in quasi-real time. It is generally assumed that an acceleration of 0.1 *g* ($1\ g = 980\ \text{cm/s}^2$), or 10 percent of the Earth's gravitational acceleration, is near the level of ground acceleration where damage to structures of weak construction begins to be noted.

Recently, studies have been made of groups of rocks that have been precariously balanced for thousands of years on many rock outcrops in the western United States. Brune (1996, 1999, 2002) has shown that the positions of precarious and semiprecarious rocks provide a constraint on the level of ground shaking that took place in the historical past. Precarious rocks are defined as those rocks capable of being toppled by peak accelerations ranging from 0.1 to 0.3 *g*. These levels of peak accelerations would correspond to intensity levels of at least VII. Semiprecarious rocks can be defined in a similar manner but with peak accelerations of 0.3 to 0.5 *g* required for toppling. One main use of the studies of precarious and semiprecarious rocks is that they provide data for evaluating the level of ground shaking to be expected for earthquakes possessing long recurrence or repeat times. Debate exists, however, in estimating the length of time that rocks existed in their precarious state and why precarious rocks are not always found where they might be expected.

Empirical correlations between seismic intensity and earthquake magnitude can be made (Appendices A and B). Magnitude can be visualized as the power of a seismic transmitter, the size of the earthquake, whereas intensity should be imagined as the strength of the signal received at a particular observation point. Intensity is a subjective number that can be loosely correlated with the observationally determined magnitude assigned to an earthquake. For example, a magnitude 8 earthquake might generate maximum seismic intensities of XI or greater and be felt at distances of 800 km (~500 miles). Magnitude 6 earthquakes can be felt at distances of several hundred kilometers and produce damaging intensities ranging from VII to VIII, the value where common damage to structures is noted.

The conventional earthquake magnitude scale M, is useful to describe the size of an earthquake but it has a shortcoming in that the scale saturates for very large earthquakes. The reason that saturation occurs is that very large earthquakes release energy at low frequencies that are not recorded by conventional seismographs. Seismologists now use a moment-magnitude, M_w, scale, whose value is related to the fault area which has ruptured, the amount of fault slip or offset across the fault, and the strength of the rocks involved. The difference between M and M_w is only critical for very large seismic events.

In delving further into the past history of earthquake occurrences one can also resort to *paleoseismology* or studies that examine the geological signature left by past earthquakes. Of particular interest are events that can be dated and that occurred in the Holocene, a time span encompassing about 10 000 years before the present. When a large earthquake has taken place it can produce geological features such as fault scarps, offset stream channels, regions of uplift, downdrop or tilting, landslides, and soil liquefaction. Depending upon the environment these features are often preserved in the geological and/or stratigraphic record and can be recognized hundreds, and at times thousands, of years later.

Even though information about past earthquake occurrences can often be "found in the ground" their acceptance as a major cause of changes in archaeological horizons has not been universally accepted. Typically such changes are explained in cultural terms such as armies or conquests, missionizing movements and conversions, social and political decay, or agricultural disintegration. Tectonic, seismic, and volcanic events often produce natural disasters affecting large geographic areas. These disasters and other marine and meteorological events may have left clues in the archaeological record. The blending of archaeology and geological observations to decipher past occurrences can be illustrated using an example from Death Valley, California. A Holocene fault scarp at the foot of the Black Mountains, on the east side of Death Valley, was a site occupied no earlier than AD 1 by the Death Valley III Indians. Indian mesquite pits with artifacts are found on both sides of the fault and on the eroded escarpment itself (point D on Figure 1.2). Desert varnish, an iron and manganese oxide, is a deposit of considerable antiquity but it has not been deposited during the past 2000 years and is not found on the Death Valley III artifacts. Geological faulting, evidenced by the Holocene discontinuous escarpment, although now 90 percent destroyed and buried under younger alluvial fan deposits, and eastward tilting

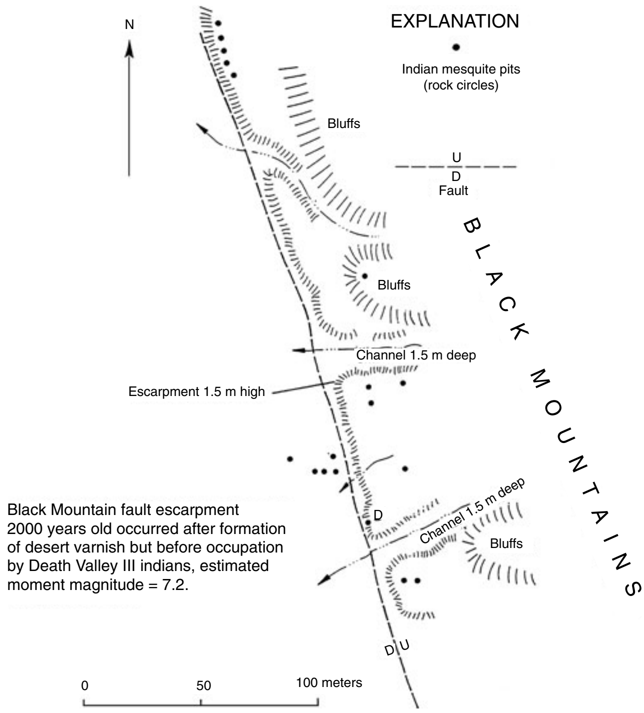

Figure 1.2 Map of Indian sites along escarpment of a Holocene fault at the western foot of the Black Mountains, Death Valley. Fault and escarpment are older than the Indian mesquite storage pit at D, which was built on the colluvium overlapping the scarp (Hunt and Mabey, 1966).

of the neighboring salt pan, is known to have taken place about 2000 years ago, after the ubiquitous desert varnish was formed but definitely earlier than the local Death Valley III occupation. It is straightforward from the length and amount of fault offset to deduce that the moment magnitude of the earthquake that produced the vertical displacement along the front of the Black Mountains had to be at least 7.2.

The acceptance of earthquake damage at archaeological sites has had a checkered history with advocates both for and against. Los Muertos, located about 16 km south of the present town of Tempe, Arizona, was the largest Salado Indian community in southern Arizona in pre-Spanish times. The site was permanently abandoned sometime during AD 1400–1450. During excavations by the Hemenway southwestern expedition of 1887–1888, a skeleton of a man caught beneath a collapsed wall was unearthed and cited as evidence of destruction by an earthquake. At the time, F. H. Cushing, the leader of the expedition, was firmly convinced that earthquakes were responsible for the demise of the community:

> Why were some of these Southwestern systems of cities abandoned so long ago, while others remained occupied within comparatively recent times, and still others until even the present day, as is the case with the Zuñi descendants of these primal ruin-builders? The answer to this question is . . . abandonment mainly through earthquake disturbances. That such disturbances were the cause of the abandonment of at least the lower Gila and Salado cities, seems indisputable, to my mind, after a careful examination which I was enabled to make of their condition and distribution of the remains they contained, and especially of the occurrences there of earthquake sacrifices, kindred to, though much more extensive than those made in modern Zuñi on occasion of even slight earth-tremors or landslides . . . This series of facts becomes still more potent in explaining the causes which led to the abandonment of the Lower Gila Salado cities, when in them we find – as tradition states of the ancestral towns of the Zuñis – that there were abandoned within their walls all that was best; and when we find long rows of houses, in certain directions, tumbled down in true earthquake fashion, the roofs burned by the hearth-fires that were burning even when they fell, skeletons crushed under them, and finally, more significant than all, actually, at least in some of these cities, Earthquake Ceremonial Appliances – identical with those of Zuñi – as was the case in one of the sacred lodge-rooms we chanced to open at Los Muertos. (Cushing, 1890).

Yet the explanation offered in a much later summary report (Haury, 1945) was not supportive of earthquakes as the cause of the exodus of the Salado: "But the finding of tumbled down houses and burnt roofs – the evidence adduced for earthquake destruction – is of such common occurrence in all parts of the Southwest and represents so many horizons that the earthquake theory seems quite inadequate."

Earthquakes were felt by early indigenous people of the Americas and they formed a part of the world of early Native American myths and legends. The Maricopa Indians, a Yuman tribe of southern Arizona, lived in a region near the confluence of the Gila and Salt Rivers, approximately 22 km west of Phoenix and 35 km west of Tempe, Arizona. *Cipas* was one of the twin culture gods of creation in the lore of the Maricopa. When he died he went under the earth where he still lies. Whenever he is tired he yawns and stretches or turns over causing an earthquake (*mathenk*, "earth shakes"). Earthquake occurrences may or may not have been viewed as particularly ominous but were not completely overlooked. The Maricopa community used wooden calendar sticks marked with notches about 1 to 1.5 cm apart signifying years (typically beginning early February with the budding of trees). Certain historical events such as battles or pestilence were noted with additional cryptic markings. A calendar stick examined by Spier (1933, p. 141) covering an interval of time from 1833 to 1930 documented the occurrence of the 1887 Sonora, Mexico, earthquake discussed in Chapter 10, which was felt over much of the American southwest and northern Mexico.

Another example of an indigenous Indian culture, which evolved, flourished, and declined under a very dynamic landscape is the Maya of Middle America. Their geographic location with respect to the sliding Pacific and Caribbean plates, and their proximity to the volcanic spine of Central America undoubtedly made them vulnerable to natural events of local and regional extent. Evidence of collapsed vaults (even those that were buttressed) and stelae that are toppled in preferential directions or systematically leaning have not been generally accepted as the consequences of earthquake occurrences. Instead the found conditions have been solely attributed to vegetation and fallen trees. Archaeological expeditions have been intent on the righting, repair, and restoration of monuments and clearing of the site to pristine conditions, without critically examining the possibility of earthquake damage. The fact that earthquakes *may* have caused damage at many Maya sites has not gained currency or credibility and is usually dismissed as an unimportant contribution to abandonment or rebuilding:

> Concerning the first or earthquake hypothesis, it appears to be the most improbable of all. It rests primarily upon the present ruined condition of the Old Empire cities, the fallen temples and palaces, and the overthrown and shattered monuments, and the prevalence of severe earthquakes in adjacent areas . . . since the vegetation now covering the sites of the Maya cities is alone sufficient to account for their destruction, the writer believes the seismic hypothesis may be rejected. (Morley, 1920, pp. 442–443)

With a lack of consensus, however, on the most important factor for the demise of the Maya, it has been proposed that it was a gradual phenomenon, triggered by a series of interrelated factors, that led to its downfall. Different interpretations of these factors involve civil wars, invasions, plagues, hurricanes, earthquakes, overpopulation, agricultural exhaustion, or a breakdown of trade networks. Even if one does not agree that earthquakes caused the collapse of cultures, one should not singularly exclude the possibility that they are a contributing factor. Clues are often metaphorical. In the book of *Chilam Balam of Tizimin*, a historical text of the Yucatecan Maya dominated by cyclical repetition of the katun, a period of 7200 days, reference is made to an earthquake in the year bearer 4 Kan (AD 1597):

> On this fourth Kan,
> The day
> Of the movement of heaven,
> The movement of earth,
> Knocking together the stubborn sun priests,
> Knocking together the lands in the country,
> The pruning of the *katun*
> When it is seated. (Edmonson, 1982)

(The translator did not believe that it was an earthquake being discussed, perceiving the sense to be figurative since Yucatán was visualized outside the earthquake zone.) The *Maní* variant of the *Book of Chilam Balam* (Craine and Reindorp, 1979) translates this phraseology differently, "On 4 Kan of the *katun* 5 Ahau . . . Trees were broken, rocks were split, the earth burned, and frogs croaked in the wells at midday . . . Another language would come, and the sky and the Earth would tremble in the Petén."

Infrequent earthquakes have been *felt* in the Yucatán peninsula. On November 15, 1908, two earthquakes occurring late in the evening were felt across the Yucatán peninsula. Earthquake shaking with a duration of 15 to 20 s was experienced from Chetumal and Vigia Chico on the Caribbean coast, as far east as Hecelchakán and Iturbide in the state of Campeche, and in the communities of Merida, Ticul, Tekax, and Izamal in the state of Yucatán (Figure 1.3). The earthquake was of sufficient intensity to cause great alarm and panic and can justifiably be assigned a minimum Modified Mercalli intensity value of VI. The minimal area subjected to this level of intensity is 50 600 km^2 suggesting at least an $M = 6.5$ earthquake. Occurrences of earlier comparable earthquakes in the historical past cannot be summarily dismissed.

Two fault zones are known, on the basis of topographic alignments, to be present in the Yucatán, the Ticul, and Rio Hondo fault zones. No evidence for past earthquake occurrences has yet been found on these faults but they have not yet been monitored for current microearthquake activity and cannot be excluded as a past earthquake source. A seismic station at Merida, in operation since 1911, is not designed for local earthquake monitoring.

A number of criteria are useful for identifying earthquake effects from archaeological observations. Isolated instances of damage have to be assessed within the overall framework of an archaeological and seismotectonic setting. For example,

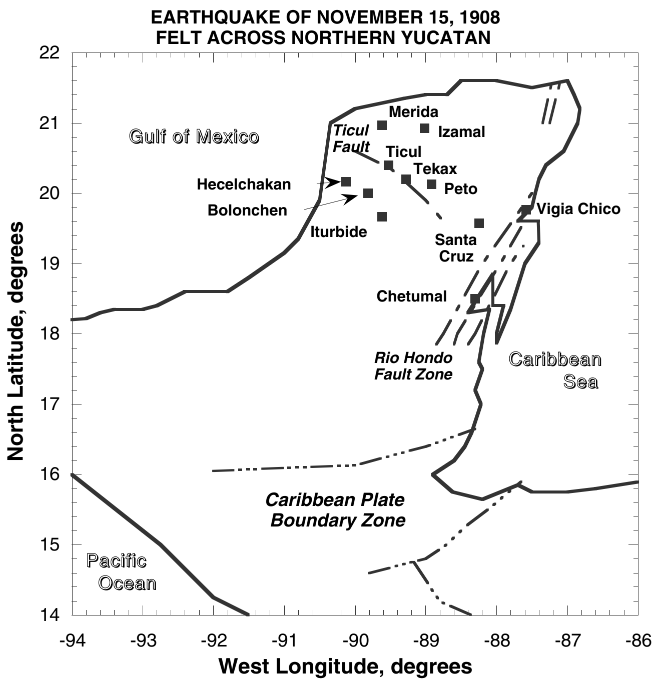

Figure 1.3 Location of communities in the Yucatán that felt the earthquakes of November 15, 1908.

collapsed walls could be the end result of weakening from fires, the result of invading conquerors pushing down the walls, the consequences of neglect and vegetation effects, or simply the result of poor construction. Skeletons found under walls provide gruesome evidence for collapse from earthquake shaking. Pottery and other artifacts, that could have been looted, found on the floor of structures are further indicators of sudden collapse. Earthquakes are usually not accepted as the cause of much of the damage noted at many Mesoamerican ruins. However, many of the damage features observed strongly suggest that they were indeed produced by earthquake shaking. Topographical, climatic, and anti-seismic considerations must have intervened in the varied physiognomy of the structures found at many Mesoamerican centers.

Archaeological evidence points to the sudden, possibly catastrophic, abandonment of some Maya sites. We should not summarily dismiss the possibility that the observed breakage and toppling of Maya stelae could have been the result of natural causes *during* and *after* final abandonment. Some stelae have also been found reset upside down or only re-erected as top fragments, which implies an earlier breakage. The intentional ancient throwing down of a stela for hostile reasons by undermining its foundation is of course not impossible