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The California Academy of Sciences, Grove Karl Gilbert, and Photographs of the 1906 Earthquake, mostly from the Archives of the Academy

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In the early morning hours of 18 April 1906, a catastrophic earthquake struck the San Francisco region of central California. Buildings were severely damaged, transportation systems disrupted, water mains broken. When fires broke out in the downtown area, firefighters had no means to control them. The California Academy of Sciences museum building lay in the path of advancing fires and in time was consumed, as were most of the buildings in the downtown section of the city. The Academy, founded in 1853, included among its founders and earliest members, John Boardman Trask who had an abiding interest in the history of California earthquakes and, as early as 1855, published a first catalogue of such events dating from 1812 to 1855. Following the 1868 "Haywards" earthquake in the East Bay and the aborted effort of the Chamber of Commerce Committee to write a comprehensive report on the event, interest in earthquakes waned among Academy members and the public-at-large as well. At the time of the 1906 event, Grove Karl Gilbert, a geologist with the U.S. Geological Survey, was on the scene having been assigned to study the effects of hydraulic mining. Gilbert was tapped immediately to participate in an investigation into the causes and effects of the earthquake. The study was undertaken by the California State Commission for the Investigation of the Earthquake, appointed by California's Governor Pardee and funded by a grant from the Carnegie Institution of Washington, D.C. Andrew Lawson of the University of California, Berkeley, chaired the Committee. Gilbert's assignment was to investigate the effects of the earthquake in Marin County. Accompanied by Alice Eastwood, the California Academy of Sciences' curator of Botany, he traveled as far north as Inverness and Pt. Reyes taking photographs and amassing field notes describing the changes in the landscape. Gilbert gave Alice Eastwood a large number of original prints of the many photographs he took. These were placed in the Academy's archives together with photographs taken by members of the Academy's staff or others who were living in the Bay Area at the time. A selection of these photographs is presented here, some appearing in print for the first time.

Dedication

This contribution is dedicated to the memory of our friend and former director of the University of California's Seismographic Station, Bruce Alan Bolt, with whom we shared a common interest in the history of earthquake studies in California

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Preface

April 18, 2006 marks the 100th anniversary of the earthquake and fire that devastated San Francisco and resulted in the near total destruction of the California Academy of Sciences. The value of the loss of the Academy's prize possessions, its library, its collections of natural history objects, and its Archives, which included more than 50 years of Academy and local history, can scarcely be imagined. Even a cursory glance at what is known of the Academy's first 50-plus years (see Leviton and Aldrich 1997) whets the appetite for more details. Yet, the Academy as an institution, both cultural and scientific, having survived the ravages of the devastation, gathered strength across the decades so that it now stands as one of the world's leading natural history museums, supporting imaginative educational and research programs. What follows attempts to place the Academy and a few of the individuals associated with it in perspective with respect to the events of 1906 and the study of earthquakes in California to that time.

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The California Academy of Sciences and Earthquake Studies in California Before 1906

Earthquakes are as much a part of the California scene as are the Sierra Nevada, Death Valley, Yosemite Valley, the California coast line, the Golden Gate. All have attracted the attention of the public and of scientists worldwide who have come to study the state's deserts and mountains, its valleys and coast, its natural history, and, most notably, its earthquakes.

Although earthquakes have been part of California's written history since the Spanish missionaries entered what was then called Alta California, scientific interest in them did not emerge until the early 1850s, with the founding of the California Academy of Natural Sciences in San Francisco on 4 April 1853. On that day, seven individuals met in the offices of one Lewis J. Sloat to organize the Academy. Among this group was medical practitioner and unofficial California State Geologist, John Boardman Trask (Fig. 1). Although Trask's interests in natural history centered mostly on topics other than geology following his third report to the California State Legislature on California geology in 1856, he nonetheless began compiling information on earthquakes in California and, shortly thereafter, to publish annual reports summarizing reported seismic activity within the state (Fig. 2). Largely cataloguing events, with dates and times and commentaries by local observers, Trask rarely speculated on the underlying causes of the seismic activity until 1864 when, in his catalogue of earthquakes in California for 1800 to 1864, he presented his views on the topic. Trask focused on what was conventional wisdom of the period, that earth-

Figure 1. John Boardman Trask, ca. 1863, as Assistant Surgeon, Union Army. Courtesy California Academy of SciencesArchives.

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The following paper on earthquakes in California, rom 1812to 1855, was presented by J. B. Trask :

In preparing this paper I have endeavored to obain, as far as possible, the most correct information of the history of these phenomena in former years. and to correct some of the misapprehensions and statements which have appeared from time to time relating to the severity of earthquake shocks in this country during the earlier periods of its history.

From careful inquiry of the older residents, I can earn of but one shock that has proved in the slightest degree serious, causing the destruction of either ife or property to any extent. This was the earthquake of September, 1812, which destroyed the Mission San Jaun Capistrano, in Los Angeles couny, and that of Viejo, in the valley of San Inez, in he county of Santa Barbara.

The following is the history of that event as I have obtained it from the native inhabitants, and older foreign residents on this coast:

The day was clear and uncommonly warm; it being Sunday the people had assembled at San Juan Capistrano for evening service. About half an hour after the opening of service, an unusual loud, but distant rushing sound was heard in the atmosphere o the east and over the water, which resembled the ound of strong wind, but as the sound approached no perceptible breeze accompanied it. *The sea was mooth and the air calm.* So distant and loud was his atmospheric sound that several left the building attracted by its noise.

Immediately following the sound, the first and heaviest shock of the earthquake occurred, which was sufficiently severe to prostrate the Mission hurch almost in a body, burying in its ruins the nost of those who remained behind, when the first ndication of its approach was heard.

The shock was very sudden and almost without warning, save from the rushing sound above noted, and to its occurrence at that moment is to be attributed the loss of life that followed.

The number reported to have been killed outright, s variously estimated from thirty to forty-five, (the argest number of persons agree on the smallest number of deaths given),but in the absence of records uch statements should be received with many grains f allowance, where memory alone is the only means eft, and the term of forty-three years has elapsed o the period at which this account was placed on paper. A considerable number are reported to have been badly injured.

There is a universal agreement on this point, viz: *hat the first shock threw down the entire building, and that a large number of persons were in it at hat moment*, and under the circumstances it would be most singular if no deaths were caused by such an vent.

The motion of the earth is described as having *ifted vertically*, attended by a *vortical* movement. No *undulatory* motion is described by any one. Dizziness and *naseau* seized almost every person in the vicinity.

A heavy, loud, deep rumbling, accompanied the uccessive shocks that followed, and which were five n number, all having the motion above described, hough comparatively light in their effects to the rst. The sounds attending the phenomena came apparently from the South and East.

In the valley of San Inez, to the south and west f Santa Barbara, the ruins now known as the "Mision Viejo," was also completely destroyed; the disance between Capistrano and San Inez being about 70 miles. The shock which destroyed this building occurred about one hour after the former, and the inhabitants had left the building but a few minutes before it fell, service having closed. The first shock felt here prostrated the building, as in the preceding case.

A Spanish ship which lay at anchor off San Buenaventura, 38 miles from Santa Barbara, was much injured by the shock, and leaked to that extent, that it became necessary to beach her, and remove the most of her cargo.

It is an interesting fact, and at the same time somewhat remarkable, that the time which elapsed between the advent of the shocks at Capistrano and San Inez is widely variant from what we should look for, when the distance apart and velocity of motion in earthquakes are taken into consideration.

The effect of this earthquake on the sea, in the bay of Santa Barbara, is described as follows: "The sea was observed to recede from the shore during the continuance of the shocks, and left the latter dry for a considerable distance, when it returned in five or six heavy rollers, which overflowed the plain on which Santa Barbara is built. The inhabitants saw the recession of the sea, and being aware of the danger on its return, fled to the adjoining hills near the town to escape the probable deluge.

The sea on its return flowed inland little more than half a mile, and reached the lower part of the town, doing but trifling damage, destroying three small adobe buildings.

Very little damage was done to the houses in town from the effects of the shocks, while the Mission at the San Inez was prostrated almost instantly. There is no evidence that I can find, that this earthquake was felt in San Luis Obispo, though such has been the report.

Prior to 1812 I have not been able to learn of the occurrence of this phenomena, that appear to have been particularly severe or destructive, and that they have not been so, is evidenced in the fact that from the foundation of the first Mission at San Diego in 1769, a period of eighty-six years has passed, during which time, but one, and that the above, finds a place either in their history or the memory of those now living, traditionary or otherwise.

From the date of the above to the year 1850, we have no record of the occurrence of these phenomena, other than the fact that light and repeated shocks were common in the country.

During 1850 the following shocks were recorded, but it is probable that several were not noted, as we find their frequency bears no relation to those which have occurred during subsequent years.

1850.

March 12.—A light shock was felt in San Jose.

May 13 —A light shock in San Francisco. An eruption of Manua Loa, S. I., and shock same day.

June 28.—A light shock in San Francisco

August 4.—A smart shock was felt in Stockton and Sacramento.

Sept. 14.—Smart shock at San Francisco and San Jose. Total number recorded in 1850, five.

1851.

May 15 —Three severe shocks in San Francisco During this earthquake windows were broken and buildings severely shaken. A large amount of merchandize was thrown down in a store on California street. The shipping in the barbor rolled heavily.—An eruption of Manua Loa and shock in the S. I. same day.

May 17.—A light shock in San Francisco.

May 28.—A light shock on the Salinas.

FIGURE 2. First page of Trask's initial publication to produce a serial catalogue of California earthquakes. It appeared in the *Proceedings of the California Academy of Natural Sciences*, ser. 1, 1(2)(1856):80–82 (NB. This article appears on pages 85–89 in the 1873 reprint edition of volume 1). See bibliography for additional citations.

quakes were associated with volcanic activity. His writing on this topic is at times labored inasmuch as he clearly had difficulty in associating many of the reported tremors in central and southern California with active or even dormant volcanoes. Nonetheless, he made a valiant attempt to fit observations to theory without stretching credibility or invoking marginal theories such as roof collapse of subterranean caverns, violent gaseous explosions, or climatic conditions, all of which had been advanced by one or more of his Academy colleagues (see, for example Winslow 1855; also Leviton and Aldrich 1997:108, 114, 120–122, 129). Trask's last publication on earthquakes appeared in 1866, and, save for a paper in 1869 by Joshua Clayton, no further articles on earthquakes appeared among the Academy's scientific publications.

But, the discussion of matters relating to earthquakes did not disappear entirely from the consciousness of Academy members. The "Haywards" earthquake of 1868, which caused moderate damage in San Francisco, was of sufficient concern that it was suggested that the Academy establish a committee to investigate the event because it would be expected to do so by the public (Aldrich et al. 1986:71; Leviton and Aldrich 1997:104). At the meeting of the Academy held on 2 November 1868), on a resolution entered by Col. Leander Ransom, Drs. James Blake and James Cooper, and Mr. Gregory Yale were appointed to the committee. At that same meeting, Blake observed "that it was not the purpose of the Academy to advance theories as to the cause of earthquakes since that had been done by men who had made these phenomena a life study. Time was required for scientific investigations and as soon as these could be made the results would be given to the public" (see Aldrich et al. 1986:71 for details).

However, before a proper study could be initiated by the Academy's committee, the San Francisco Chamber of Commerce, prodded by George Gordon, a prominent San Francisco businessman, preempted the Academy and established a committee to make a comprehensive study of the earthquake, its effects, and ways to mitigate future damage. The history of this committee and its failure to submit a final report are detailed by Aldrich et al. (1986). The Academy made no further effort to study the 1868 event but, at subsequent meetings, it did entertain discussions relating to earthquakes in general, with few concrete results. Theories were advanced, most of which were debunked by Blake, even though he was unable to advance an alternative. The more humorous of the remarks centered on the gas theory of earthquakes, wherein the sudden release of accumulated underground gases, not necessarily related to volcanoes, would produce convulsions. In response, one member suggested that the Academy should appoint a curator of earthquakes, "whose duty it would be to collect specimens of earthquakes and place them in the museum, taking care, however, to purge such specimens of their gases to avoid dangerous consequences." (Leviton and Aldrich 1997:114). Another "tongue in cheek" suggestion was that, "for the protection of the City of San Francisco, an artificial volcano should be got up in the neighborhood for the escape of the gases coming this way and producing so much uneasiness." (Leviton and Aldrich, *loc. cit.*). In a more serious vein, at the members meeting held on 18 April 1870 Josiah Dwight Whitney moved that a committee be appointed "to inquire as to the best instrument for recording such [earthquake] phenomena, and the proper place to fix it." The motion was adopted and Whitney, Henry Gibbons, George Davidson, and Robert Stockton Williamson were appointed to it. Regretably, the matter came to naught with Whitney's departure from San Francisco following the failure of the State legislature to provide further financial support for the State Geological Survey.

Although other unpublished oral presentations dealing with earthquakes took place at Academy meetings between 1870 and 1906, interest in earthquakes seemed to diminish in importance as other topics captured the members' attention. Furthermore, the scientific study of earthquakes moved from San Francisco to the fledgling University of California at Berkeley and somewhat later Stanford University. At these institutions, persons with professional credentials in geology, receptive to new ideas, and with the aid of newly designed, sensitive seismograph instruments, began the kinds of scientific investigations called for by James Blake in November, 1868. At Berkeley, Edward Singleton Holden, astronomer, librarian, and university president, established the first seismographic stations in the Western Hemisphere (Campbell 1916; Rodda and Leviton 1982:52; Gerschwind 2001:15). Not long afterwards, Andrew Lawson joined the Berkeley faculty, and John C. Branner was brought in to head the geology program at Stanford University, which opened its doors in the early 1890s.

Major theoretical breakthroughs in the understanding of earthquakes came slowly. It was not until late in the 19th century that the idea that earthquakes could be related to movement along fractures in the earth's crust was posited, even though the existence of those fractures had been well known to geologists for many years (for a more complete discussion of this topic see Dean 1993). Indeed, fractures were, more often than not, thought to have resulted from earthquakes; thus, movement along them was not thought to be the source of disturbances. In the United States, one highly experienced field geologist, Grove Karl Gilbert, early in the 1880s, did make the association, but at the time it attracted little attention (Gilbert 1883; but see also Gilbert 1906:272–273, 1908:30–35; Wallace 1980:38).

Grove Karl Gilbert on earthquake and faults before 1906

According to Robert Wallace (1980), Grove Karl Gilbert (1843–1918; Fig. 3) dealt with issues of earthquakes and faults as part of his general studies of mountain building processes. Gilbert's geological training had come mostly in the 1860s during an apprenticeship to John Strong Newberry, then Ohio state geologist but known also for his studies in Western paleontology and stratigraphy. Newberry lobbied to get Gilbert the appointment to the Wheeler survey of the American West (formally titled the United States Geographical Survey West of the 100th Meridian but usually named after its leader, Lieutenant George Wheeler). Gilbert first addressed faults and earthquakes in his field work for the Wheeler Survey from 1871 to 1874 on the Basin and Range topography of Nevada. In 1875, Gilbert switched to the Powell Survey (United States Geological and Geographical Survey of the Rocky Mountains, short-titled after its leader, the charismatic John Wesley Powell). Gilbert stayed with Powell until Gilbert transferred to the newly formed United States Geological Survey (USGS) in 1879, where he spent the rest of his career (Pyne 1980, 1999).

FIGURE 3. Grove Karl Gilbert, ca. 1882. (Courtesy Smithsonian Institution Archives [SIA Merrill Collection, RU 7177, Box 4, Folder 30].)

Geologists, among them Clarence King (in 1868; he directed the Survey of the 40th Parallel, contemporary with the Wheeler and Powell Surveys and eventually became the first head of the U.S. Geological Survey), initially, had attributed the Basin and Range region's geological history to the folding of strata. This mechanism best explained the creation of the ridges and valleys of the

Appalachian Mountains in the American East, where most early American geologists had been trained. Gilbert challenged this, arguing that the Nevada mountains were uplifted blocks bounded on both sides by deep-seated vertical or high-angle faults, with down-dropped basins between the blocks. Within the blocks, folded strata could be detected, but folding did not cause the main uplifting that shaped the modern landscape. John Wesley Powell also adopted a fault-block mechanism to explain these mountains, and eventually most others came to agree, including Clarence King in 1878 (Wallace 1980).

Gilbert first thought about earthquakes in connection with the 1872 Owens Valley shocks along the eastern margin of the Sierra Nevada; he was aware that fault scarps like those seen elsewhere in the Basin and Ranges developed in conjunction with that episode. Thus, in 1872 and again in 1875, Gilbert argued that the fault-bounded blocks accounted for the Basin-Range topography. The final link between faults and earthquakes was yet to come, but it was only a matter of time. During 1877–1883, Gilbert focused on the Lake Bonneville area, writing about the earthquakes and faults that bounded that basin. His field work on the western face of the Wasatch Range of Utah extended his thinking on the subject. There he found small, fresh scarps that he hypothesized were the most recent evidence of the forces that uplifted the range. Gilbert said earthquakes raised the mountains along the faults a few feet at a time. This led him to warn Utah residents in 1883–1884 of the possibility of more earthquakes along the mountain front, including possibly at Salt Lake City; this was an early instance of earthquake prediction (Wallace 1980). At this time, and until 1906, Gilbert focused on the relation of earthquakes to vertical displacement. But this was to change.

Gilbert and the earthquake of 1906

In 1906, Gilbert was in California to study the effects of hydraulic mining (Fig. 4), not earthquakes. But decades of field work and writing about the role of faults and earthquakes in mountain

FIGURE 4. Hydraulic mining at the Esperance Mine, French Corrall. Photograph by G.K. Gilbert. (G.K. Gilbert Collection [331.1.6.1; envelope #4], Alice Eastwood Archive, California Academy of Sciences Archives.)

building had prepared him for rapid field observations and clear thinking about what happened on April 18, 1906.

It was a little after 5 a.m. of that day that a rumbling of the earth awakened the residents of San Francisco and other Bay Area communities. Light tremors had been felt before, but nothing like this, and nothing so sustained. The intensity increased and quickly people poured out of their homes, hotels, and other buildings, dazed and awed by the event. The shaking stopped, but more was in store for the nervous onlookers. Small fires broke out, but, because of broken water mains, firefighters found they could not respond. The fires spread and in a short time the downtown area of the city became an inferno. The California Academy of Sciences' buildings were in the path of the advancing fire (Fig. 30). At the time, its properties included a commercial building, which faced onto Market Street, and a museum building, which was located directly behind. Both had been constructed in the late 1880s with funds and on land donated to the Academy by San Francisco entrepreneur and recluse James Lick and had opened to the public only a few years earlier (1891). Although there was nothing that could save the buildings and most of their precious contents, a few dedicated Academy staff hastened downtown to rescue the few items they could before the buildings were enveloped in flames (Figs. 33–34, 37; see Leviton and Aldrich 1997: 471–473). Among them were Richard Loomis, then director of the museum, Mary Hyde, Academy Librarian, John Van Denburgh, M.D., curator of herpetology, and Alice Eastwood, curator of botany.

FIGURE 5. Alice Eastwood, circa 1900. (California Academy of Sciences Archives.)

Alice Eastwood (Fig. 5) engages our attention here. Miss Eastwood came to the Academy in 1892. She was brought in as understudy to the then curator of botany, Mary Katharine Layne Curran, the future Katharine Brandegee. With Brandegee's departure from the Academy in 1893, Eastwood was appointed curator, a position she held for most of the next 57 years. We do not know when or where Alice Eastwood first made the acquaintance of Grove Karl Gilbert.[1] Gilbert was a widower, having lost his wife some years earlier (Pyne 1999). And, in 1906, he was living in Berkeley. Thus, it could have been on any one of several occasions during his geological studies in California in the

[1] We know little about the relationhsip of Alice Eastwood and Grove Karl Gilbert save for what Steve Pyne was able to uncover in his researches for his biography of Gilbert (Pyne 1980:262–263). That the two had decided to marry in 1918 is well established. At this time Alice was 59 and Grove Karl 74. How long had he and Alice Eastwood known one another is an open question. The only tease is a note that Gilbert wrote in early 1918, "Alice and I have been lovers for years" (see Pyne 1980:262). In early 1918, Gilbert was returning from a trip to the East. He stopped in Michigan to visit his sister, and while there he suddenly took ill and died. Alice Eastwood remained unmarried for the rest of her long life. She passed away in 1953 at the age of 94. Following the untimely loss of her impending husband, Alice Eastwood devoted the rest of her life to the California Academy of Sciences, to her botanical studies, and to the local botanical club, which she continued to sponsor after the departure of Mary Katharine ("Kate") Brandegee. For a brief biographical sketch of Alice Eastwood, see Ogilvie (1986:79–80).

early 1900s. Although there is nothing in the available records to show that Gilbert attended meetings of the California Academy of Sciences on or before 1906, it is known that Alice Eastwood made occasional trips to the East Bay, to the University of California at Berkeley herbarium, and it may have been on one of these visits that she and Gilbert met. On the other hand, both were Sierra Club enthusiasts, and according to Stephen Pyne, the two met during Sierra Club outings (Pyne 1980:262). Whatever the case, after the earthquake and fire, the two ventured forth on an extended excursion to Marin County, as far as Inverness and Point Reyes, to study the effects of the earthquake and to take photographs showing the impact of the ground movements on the landscape.[2] Because of disruptions of life at the Academy brought on by the earthquake and fire, and exacerbated by clashes with the Academy's Director, Leverett Mills Loomis, in the latter part of April, and for some time thereafter, Alice Eastwood, left San Francisco to spend time working at other institutions. Initially, and at the invitation of John Galen Howard, she took up residence at Howard's home in Berkeley to be close to the university's herbarium and library to continue her botanical studies (see comments by Duncan [2006] relating to this period and to Eastwood's botanical relationship with Berkeley botanist Edward Lee Greene).

Gilbert published a short general article on earthquakes on April 28, 1906 in the *Mining and Scientific Press*, an influential San Francisco technical journal. In that article, he distinguished earthquakes caused by volcanoes from those caused by mountain-building (tectonic in his words), stating that the 1906 earthquake was of the latter type. Often, tectonic forces manifested themselves in the folding of rocks, but when the forces built up rapidly or the rocks were resistant, the rocks ruptured and an earthquake took place, sometimes marked at the surface by a fault (a fracture in the earth along which motion takes place). The shock waves from this rupture were of two kinds, longitudinal and transverse, and different types of rocks reacted variously to them. Alluvial rocks and "made ground" were especially susceptible to damaging shaking from transverse waves. This article did not report Gilbert's field work in Marin and was not illustrated by pictures.

On the same page, the *Press* announced the creation of an earthquake commission by the governor of California, and Gilbert's appointment to it with seven other scientists. Andrew Lawson of the University of California at Berkeley chaired the group, and the Carnegie Institution of Washington funded the project with a grant of $5,000. The commission divided the field investigations, with John Branner of Stanford in charge of the San Francisco peninsula, Lawson in the area to the south of that, and Gilbert in Marin County and northward (Geschwind 2001:33–35). Furthermore, the United States Geological Survey set up an investigative team headed by Gilbert. Both groups made substantial reports in which Gilbert had a major place, and in which many of his photographs were a crucial part of the evidence for the teams' findings.

The Lawson group issued a preliminary report of twenty pages in early summer 1906; thousands of copies were distributed, and it was reprinted in *Science* and the *Press*. With Lawson's permission, Gilbert published a paper, with his findings and some of those of the commission, in the August 1906 issue of *Popular Science Monthly*. In that article, he repeated the distinction between tectonic and volcanic earthquakes and again noted the association of the former with faults. He added that once a fault zone was established, it became a site of weakness along which further earthquakes were more likely to take place than in undisturbed ground. The 1906 quake occurred in such a setting, along the San Andreas fault, which had been mapped and defined as early as 1893 by Lawson. The area through which this fault passed was marked by linear ridges, elongated lakes, and lines of springs that were characteristic of faulted ground (Figs. 8, 22–23). A significant finding of the 1906 quake was the amount of horizontal (strike-slip or lateral) displacement, compared to the vertical uplift that Gilbert had emphasized in his pre-1906 publications on faults and earth-

[2] A selection of Gilbert and other photographs are included in the Photographic Portfolio following the bibliography.

quakes. Gilbert described, but did not name, the different kinds of surface cracks that appeared along the rift and, most importantly, illustrated them with his photographs (Figs. 7–12). He noted that the commission was using U.S. Coast and Geodetic Survey maps and data to determine whether only one side of the fault had moved, or both equally. He concluded with a plea that the commission answer the vexing questions of when and where and how severe an earthquake was likely to hit the Bay Area again. However, in private correspondence with Lawson, Gilbert later worried that the commission should not get into the question of forecasting (Geschwind 2001:35–36).

The USGS report appeared in the second half of 1907, with Gilbert as senior author. He wrote the first section of thirteen pages about "the earthquake as a natural phenomenon" and his coauthors did the rest of the book, over 125 pages detailing structural damage to the built environment and recommending better construction techniques (separate sections written by Humphrey,[3] Sewell, and Soulé 1907). Gilbert's section used evidence from earthquake damage within San Francisco as well as in his field areas in Marin and northward to make his points. As he described each feature of the earthquake, he referenced specific photographs in the book that showed what he discussed. The monograph included 100 photographs, 11 of them taken by Gilbert. Some of the material had appeared in his earlier publications but these sections he reworked and edited, changing "rift" to "fault trace" in conformity with the Lawson commission's terminology, for example. The new material included information about the relative motion of the rocks on either side of the fault and about the propagation of waves of force by the earthquake. The latter material depended heavily on his fieldwork in the mudflats at Tomales Bay. Gilbert paid particular attention to this locality because the land had the same character as the wet "made ground" along the San Francisco Bay shoreline that had failed so badly during the tremors of 1906. Although he did not mention it, his observations on the mudflats were also related to the work he was doing at the same time using flume experiments to study stream erosion. Evidence from the landscape, anecdotes, and building damage formed the basis of his tentative generalizations about the earthquake's motion and distribution of intensity, because the array of seismographs in the Bay Area was too thin to provide the data to support these conclusions.

In 1908, Gilbert published several sections in the report of the California Earthquake Commission. The volumes, collectively known as the Lawson report after the chair of the investigation, were written sometimes by individual authors (Harry Reid wrote all of volume two), but Andrew Lawson exercised editorial control over the document and kept the eight scientists working on schedule, thus deserving the credit he is given by the short-title of "Lawson report". In one five-page section, Gilbert generalized about the features of the rift caused by the 1906 earthquake, summarizing it as the "surface expression of a great shear-zone, or compound fault" (Gilbert in Lawson 1908:33). Here Gilbert also named and described "fault sags," depressions caused by the earthquake and often marked by wet spots after rainfall (Figs. 22–23). In discussing the drainage of the fault zone, he noted that some stream valleys were shaped more by earthquake fractures than by erosion (Figs. 18–19).

In longer sections later in the Lawson report, Gilbert provided excruciating detail on the effects of the tremors on the country between Bolinas Lagoon and Tomales Bay. In part, he used this essay to sort and validate conflicting information from local observers. His writing is more than descriptive, however. Gilbert promulgated the classification of the fault trace into three phases: ridge, trench, and echelon (Gilbert in Lawson 1908:66), each illustrated by numerous photographs. He used the detailed observations of damage to fences, gardens, tree lines, and other features to calcu-

[3] R.L. Humphrey includes a brief statement relating to the loss of the Academy's buildings (then located at 819 Market Street). Two photographs (pls. 24A and 25B showing damage to the Academy) are included among the plates showing the effect of earthquake and fire on many of San Francisco's buildings.

late the amount of offset along the fault, taking into account not just lateral and vertical movement but also twisting, gaping, and shearing. Gilbert found that these motions complicated the answer to the question of how much movement there was during the earthquake; and instead of seeking one numerical answer, he gave ranges and averages. Gilbert stated that, in the Bolinas-Tomales area, the left side of the fault moved northward relative to the right side (Gilbert in Lawson 1908:70); but this was a general conclusion of the Commission, not uniquely his finding. He illustrated all of these phenomena with photographs mostly by himself but sometimes by others (Table 1). His long section had 44 of them plus a number of diagrams. Gilbert also published a brief summary of the Lawson report in the *American Journal of Science* (1909b) but did not include photographs.

TABLE 1. Photographs in the Lawson Report (1908)

Photographer	*Number photos*	*Percent photos*
G.K. Gilbert	58	17.4
A.C. Lawson	40	12.0
F.E. Matthes	36	10.8
H.W. Fairbanks	29	8.7
J.C. Branner	23	6.9
R.S. Holway	21	6.3
H.O. Wood	20	6.0
A.S. Eakle	10	3.0
R.L. Humphry	6	1.8
Other, signed	48	14.4
Unattributed	43	12.9
Total	334	100.2*

* Rounding error

Gilbert devoted his presidential address to the Association of American Geographers on New Year's Day 1909 to the topic of earthquake forecasting; *Science* published it as the lead article in its January 22 issue. He may have used lantern slides to illustrate it, but the published version did not include photographs or diagrams.[4] Gilbert dealt with the issues of predicting what localities are earthquake prone, and what the prospects were for predicting when great shocks would occur again. In discussing place, he drew upon the delineation of earthquake features from the Lawson report as indicative of a landscape prone to horizontal movement along a fault, and mentioned briefly that fault scarps in other regions were evidence of vertical movements associated with earthquakes. He reported that the Lawson team had already located another area marked by the same peculiar terrain as found between Bolinas and Tomales, along the Hayward fault in northern California. Predicting the timing of a future earthquake was unlikely, Gilbert said; there were lots of theories but little reliable evidence. He argued that forecasting place was important but time was not; structures in a suspect region should be designed to withstand earthquakes regardless of whether the quake was expected tomorrow or decades ahead. Gilbert excoriated city planners in the Bay Area for their emphasis on the damage caused by the fire, and included a calculation showing destruction due to the earthquake alone was at least as great. (A few photographs of buildings destroyed by the quake alone would have made the point as well.) As Gerschwind remarks (2001:20), Gilbert's paper was the first clear statement by a scientist of the lessons of the earthquake of 1906 for rebuilding the city, but it would take decades for the state to work out a rational and coherent policy of dealing with seismic risk.

Photographs documenting the devastation wrought by the earthquake and fire in San Francisco and elsewhere in the San Francisco Bay Area have engaged the attention of viewers for many decades. Grove Karl Gilbert's photographs, mostly taken to document landform changes, reflect the eye of an experienced field geologist and reveal much about the surface appearance of catastrophic offsets along active faults. But Gilbert also took photographs in San Francisco; these are to be found in the photo archives of the U.S. Geological Survey in Denver, Colorado, and were meant specifically to document the failure of selected structures and structural materials (Figs. 26–27).

[4] James McKeen Cattell, the editor of *Science*, often included graphs, diagrams, and tables in the journal, but rarely photographs. He did use photographs frequently in *Popular Science Monthly*, which he also edited. (Michael Sokol biographer of Cattell, pers. commun.)

They are clearly identified and annotated as to what they are by Gilbert.As noted, Gilbert's landscape photographs appeared in an article in *Popular Science Monthly* in August 1906, were reprinted in a volume edited by David Starr Jordan in 1907, and most importantly were included in the Lawson report (1908). Many scientists are well aware that a large number of Gilbert's photographs are in the photographic archives of the USGS in Denver, Colorado. What is not as well known is that an original set of prints of the photographs Gilbert and Eastwood took during the weeks that immediately followed the earthquake were in Alice Eastwood's possession and are now preserved in the archives of the California Academy of Sciences. Other Gilbert photographs, mostly geological in nature and mostly taken on trips to the Sierra Nevada, are included in this collection. The Academy also houses in its archives photographs of the 1906 event taken by U.S. Department of Agriculture horticulturist and Academy Board of Trustees Secretary Gulian Pickering Rixford (e.g., Figs. 31–32), Academy curator of geology Frank Marion Anderson (e.g., Fig. 33, and possibly Fig. 34 [although this one may have been taken by Richard Lewis Humphry]), entomology curator Gustav Eisen (e.g., Fig. 37), and others, few of which have attracted the attention of earthquake specialists.

"After Shock"

After 1909, Gilbert returned to his dual study of hydraulic mining and stream erosion. He had built a flume on the Berkeley campus to conduct experiments on stream flow, deposition, and erosion (Gilbert 1914), but, as Leopold (1980) notes, this device had a constant slope, which limited the conclusions Gilbert could draw from it. The hydraulic mining paper (1917) presented data (and photographs) that led to the end of this environmentally destructive process of extracting gold from California sediments. Gilbert also contributed to the development of the theory of isostacy and completed his Great Basin studies in a paper that was published after his death (Pyne 1999). His relationship with Alice Eastwood came to a bittersweet end: they had decided to marry, and he was traveling West to join her in May 1918 when a heart attack killed him during a stopover at a family home in Michigan. Alice Eastwood remained single for the rest of her life, and left an enduring legacy of him by saving his California photographs among her own papers.

As for the Academy. Following the earthquake and fire, it, like San Francisco, took stock of what had happened. The outlook was grim, but not hopeless. Word was received that the Schooner *Academy* was due back from the Galapagos expedition in the late Fall, and on board it carried core collections that would mark the Academy's rebirth — a large collection of plants, mollusks, insects, and reptiles, including the most complete series of Galapagos tortoises, representing all extant populations in the islands, to be found in any museum, and more. To provide temporary housing for this treasure would be a challenge, but the Academy's director, Leverett Mills Loomis, and curator of herpetology, John Van Denburgh, rose to the occasion. Whereas the Academy's commercial building lay in ruins, the museum building, though it suffered grievously from the fire, was still more or less intact. At Loomis' direction, part of the ground floor was walled off and temporary shelving installed so that when the *Academy* arrived in port at the end of November, its precious cargo could be immediately relocated (Fig. 35).

In the meantime, institutions and individuals from around the world donated library materials to help rebuild (Fig. 36) what had been the premier natural history library in the United States west of the Eastern seaboard. Library materials were received from no fewer than 42 individuals, 49 United States institutions and societies, 2 Canadian institutions, 1 South African organization, 18 museums and societies in Asia, Australia, and New Zealand, 84 museums, universities and societies in Europe, 10 in Central and South America, and 7 book dealers.[5]

[5] A complete list is to be found in Leviton and Aldrich 1997:561–563.

During the nearly 10 years that elapsed between the time of the earthquake and fire and the reopening of the Academy's new museum facilities in Golden Gate Park in 1916, much of the Academy's research program went on as usual. Although a few staff took temporary leave to continue their studies elsewhere (Alice Eastwood among them), several carried on in temporary facilities in San Francisco. John Van Denburgh and Joseph Slevin, for instance, managed the relocation of the herpetological collections to a downtown warehouse and from them there followed a steady stream of publications.

Thus, although suffering a brief interruption in production, on 20 December 1907, the first issue of series 4, volume 1 of the Academy's scientific publications, the *Proceedings*, appeared. And, perhaps appropriately enough, its title was "Expedition of the California Academy of Sciences to the Galapagos Islands, 1905–1906. Preliminary descriptions of four new races of gigantic land tortoises from the Galapagos Islands" by John Van Denburgh.

The Academy was back in business!

♣♣♣♣♣♣♣♣♣♣♣♣♣♣♣♣

One hundred years have now passed since that fateful day in April when so much of the past lay in ruins. But, the San Francisco Bay area recovered; the cities, towns, and villages, the universities, private and public enterprises came roaring back so that City by the Golden Gate is once again the Queen city of the West. It is, therefore, on the occasion of this, the 100th anniversary of the San Francisco earthquake and fire that we celebrate the Academy's persistence in the face of adversity. The photographic portfolio of images that is appended here includes material mostly drawn from the archives of the Academy. Many are Gilbert photographs, some appearing for the first time in print, whereas others are from the U.S. Geological Survey Photographic Archives, Denver, Colorado, the Smithsonian Institution Archives, Washington, D.C., and the Academy's Rixford, Anderson, and Barclay Stephens record units.

Finally, we take note that as devastating as it was, 1906 was not the only occasion on which the Academy suffered the effects of severe earthquakes. Scarcely 15 years ago, following the Loma Prieta Earthquake in 1989, the Academy buildings, then located in Golden Gate Park, were so severely stressed that there was serious doubt about their safety should another earthquake occur. Thus, for a second time within a hundred years, the Academy faced the prospect of rebuilding, although this time with all of its collections, its library, and its other scientific and cultural assets intact. That once again the Academy will emerge from these trials there can be little doubt.

Acknowledgments

We take this opportunity to thank the Library staff of the California Academy of Sciences, and specifically Larry Currie, Academy Librarian, for many courtesies extended to us in gathering material for this paper. We are indebted also to Ellen Alers (Smithsonian Institution Archives), Tommie Ann Gard (U.S. Geological Survey Library, Denver), Rebecca Pappert (Young Science Library, Smith College), and Pamela Skinner (Neilson Library, Smith College). We are grateful to colleagues who critiqued both an earlier version of this paper and then reviewed later iterations, J. Thomas Dutro (U.S. Geological Survey [ret.]), Terrence M. Gosliner (Provost, CAS), Tomio Iwamoto (Ichthyology, CAS), Gary Williams (Invertebrate Zoology, CAS), and Mark Aldrich (Smith College); all also responded to our plea for rapid turnaround reviews. Also thanks to Hallie Brignall (Herpetology, CAS) who helped with the images. Our reviewers caught many errors and infelicities, but those that remain are solely the responsibility of the authors. Michael Sokal (Worcester Polytechnic Institute) advised us on the Science Press's practice of illustrating articles.

Finally, we thank Ellis L. Yochelson (Research Associate, Paleobiology, Smithsonian Institution) for drawing our attention to Gilbert photos on the USGS Library website.

Note on Sources

Information on earthquakes and the Academy can be gleaned from Leviton and Aldrich's edition of Theodore Hittell's history of the CAS (1997) and from the CAS *Proceedings* volumes before 1906. Pyne (1980) published a full-length, analytic biography of Gilbert; for a compact sketch on Gilbert, see Pyne (1999). Wallace (1980) wrote a perceptive essay on Gilbert's ideas on earthquakes and faults. In his prize-winning book, Geschwind (2001) analyzes the scientific and politic response to earthquakes in California; the first two chapters were especially useful for our article. Dean (1993) presents a thoughtful and exhaustive paper on thinking about the San Francisco earthquake and seismic theories that predated it. Of the recent general books on the San Francisco earthquake of 1906, we found Fratkin (2005) a scholarly but readable account as a piece of history. Winchester's (2005) gossipy account is marred by presentism. The main collections of Gilbert (and others) photographs we drew upon are in the CAS Archives and the USGS Library in Denver. Many of the USGS 1906 earthquake images are now downloadable from its website.

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Portfolio of Earthquake Images by Grove Karl Gilbert and others, mostly from the Archives of the California Academy of Sciences

The Gilbert images are from a collection of original prints given to Alice Eastwood by G.K. Gilbert and, although separately boxed and stored, they are part of the Eastwood Archive at the Academy. Copies of many of the Gilbert images are also in the U.S. Geological Survey Photographic Archive in Denver, Colorado, and some are now available on line <*http://libraryphoto.cr.usgs.gov/*>.

The Gulian Pickering Rixford Archive includes glass plate negatives and prints of of photographs taken by Rixford in San Francisco some days after the earthquake and fire. They are not dated.

Photographs of downtown San Francisco and of the skeleton remains of the California Academy of Sciences were taken by Academy curator Frank Marion Anderson.

The photograph of the wooden Japanese statue, one of the few objects to survive both earthquake and fire, was taken by Drs. Peter S. Bruguiere and Academy curator Gustav Eisen.

Except as otherwise noted, all images are from the Academy's Archives. A number of the images have not been published before. Others were used by Gilbert to illustrate his reports on the earthquake published between 1906 and 1908.

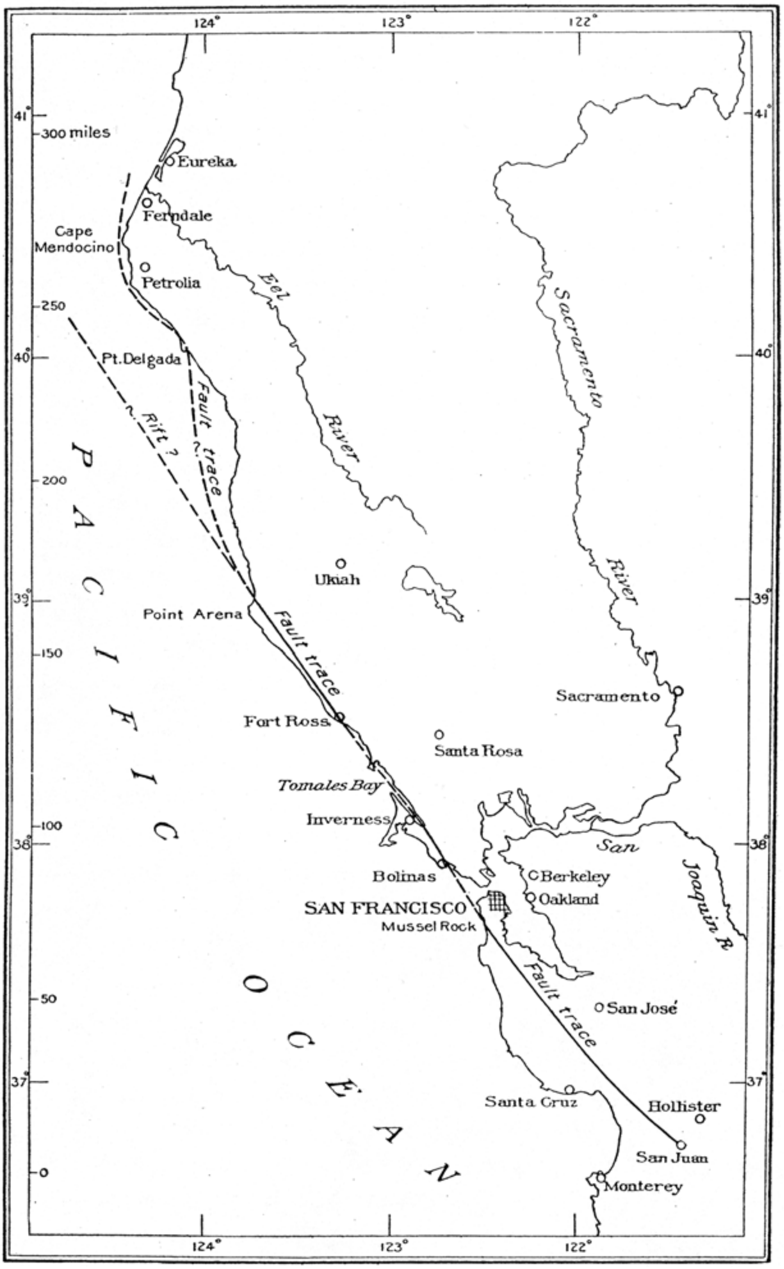

FIGURE 6. Map of the fault trace. Broken lines indicate alternative hypotheses as to its extension north of Point Arena. (From G.K. Gilbert 1907b:3.)

FIGURE 7. On the edge of the rift. Marin County. The woman in the picture is almost certainly Alice Eastwood (see also below). Photograph by G.K. Gilbert. (G.K. Gilbert Collection [331.6.1, #36; Envelope 8], California Academy of Sciences Archives.)

FIGURE 8. Fault trace two miles north of Skinner Ranch at Olema. View is to the northwest. Illustrates ridge phase of fault trace. The woman in the photo is almost certainly Alice Eastwood (Pyne 1980: 263). Photograph by G.K. Gilbert. (G.K. Gilbert Collection, [N7583-A], California Academy of Sciences Archives.) (Also in Gilbert in Lawson 1908, pl. 40, fig. A.])

FIGURE 9. Fault trace west of Olema, looking southeast. Photograph by G.K. Gilbert. Woman in the picture is unidentified. (G.K. Gilbert Collection [331.6.1, #2924; Envelope 7], California Academy of Sciences Archives.) (An image similar to this was included in Gilbert in Lawson 1908, pl. 40, fig. B].)

FIGURE 10. Fault scarp on earthquake crack. Vertical displacement about five feet. Photography by G.K. Gilbert. (G.K. Gilbert Collection [331.6.1, #2965; Envelope 7], Alice Eastwood Archive, California Academy of Sciences Archives.) (Also in Gilbert in Lawson 1908, pl. 53, fig. A.)

FIGURE 11. Road bed between Olema and Inverness. Collapse of road bed gives appearance of a vertical displacement about 5 feet. Photograph by G.K. Gilbert. (G.K. Gilbert Collection [N7583-E], California Academy of Sciences Archives.)

FIGURE 12. Road bed between Olema and Inverness. Road bed probably destroyed by shaking of soft ground beneath. Photograph by G.K. Gilbert. (G.K. Gilbert Collection [N-7583-F], California Academy of Sciences Archives.)

FIGURE 13. Fence offset 8.5 feet. Trace of fault barely visible, running from lower right to upper left through offset. Photograph by G.K. Gilbert. (G.K. Gilbert Collection [N7583-C], California Academy of Sciences Archives.) (Also in Gilbert 1907b, pl. 1, fig. B.)

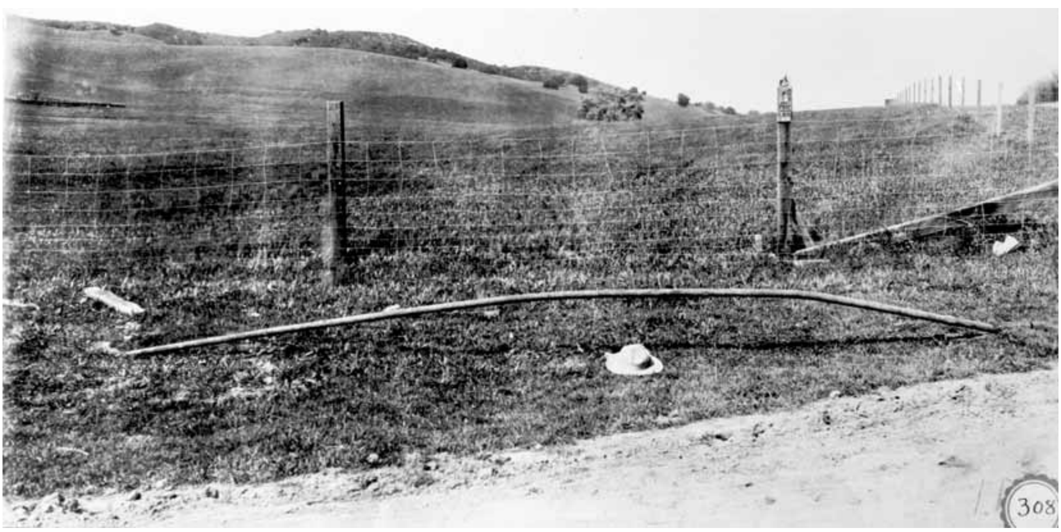

FIGURE 14. Buried water pipe upended by earthquake motion. Five miles west of Stanford University along Portola Valley Road. Although among the Gilbert images, we suspect that this one was taken by John Branner, or a Branner student at Stanford University, and given to Gilbert. (G.K. Gilbert Collection [N7583-B], California Academy of Sciences Archives.)

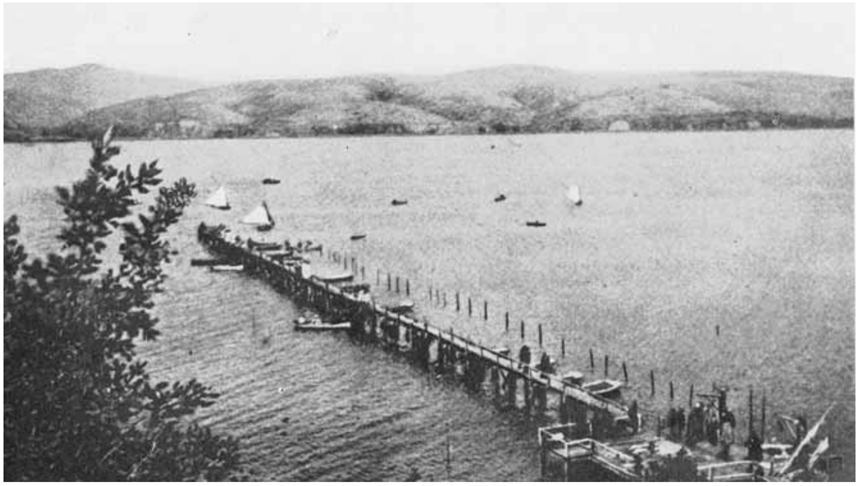

FIGURE 15. Bailey's Pier at Inverness. Photo taken by Martha P. Schreiber before 18 April 1906 (from Gilbert in Lawson, 1908, pl. 58, fig. B).

FIGURE 16. Photo by G.K. Gilbert taken after the 18 April earthquake. (for another view, see Gilbert in Lawson 1908, pl. 58, fig. A). (G.K. Gilbert Collection [331. 6.1, #472; Unnumbered white envelope], California Academy of Sciences Archives.)

FIGURE 17. Panorama taken in the vicinity of Olema. Fault trace passes from lower right to left, offsetting hedge in center. Composite photo taken in three parts by G.K. Gilbert and assembled digitally here (G.K. Gilbert Collection [331.6.1; Envelope 8, #s 3010-3012], Alice Eastwood Archive, California Academy of Sciences Archives.)

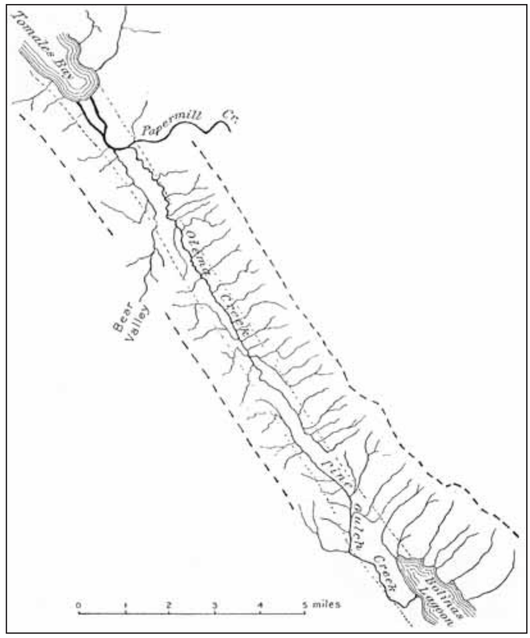

FIGURE 18. Drainage map of Bolinas-Tomales Valley (from Gilbert in Lawson, 1908:31, fig. 2). Heavy broken lines show crests of bounding ridges; light broken lines indicate limits of rift topography.

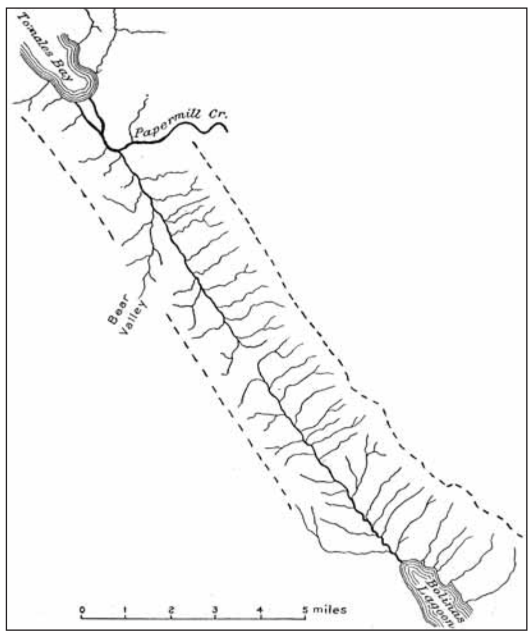

FIGURE 19. Hypothetical drainage map of Bolinas-Tomales Valley if developed without influence of rift displacement (compare with fig. 18 above) (from Gilbert in Lawson, 1908:32, fig. 3).

FIGURE 20. Row of eucalyptus offset (center) by earthquake, ½ mile west of Woodville. Photo G.K. Gilbert. (G.K. Gilbert Collection [331.6.1, #2946; Envelope 7], Alice Eastwood Archive, California Academy of Sciences Archives.)

FIGURE 21. Branch of fault-trace in north part of Bolinas, looking NNW, illustrating diagonal cracks. Photograph by G.K. Gilbert. (G.K. Gilbert Collection [331.6.1, #165; Unnumbered white envelope], Alice Eastwood Archive, California Academy of Sciences Archives.) (Also in Gilbert in Lawson 1908, pl. 39, fig. A).

FIGURE 22. Looking southeast from point near Shafter's Ranch, Olema. Ponds in trace of fault. Photograph by G.K. Gilbert. (G.K. Gilbert Collection [331.6.1, #3046; Envelope 7], Alice Eastwood Archive, California Academy of Sciences Archives.) (Also in Gilbert in Lawson 1908, pl. 42, fig. B.)

FIGURE 23. Sag ponds south of Shafters Ranch occupying trace of fault. Photograph by G.K. Gilbert. (G.K. Gilbert Collection [331.6.1, #3043; Envelope 7], Alice Eastwood Archive, California Academy of Sciences Archives.)

FIGURE 24. Fire cloud over San Francisco. Photograph by G.K. Gilbert, probably taken from somewhere in the East Bay while he was recording damage done to buildings in Oakland and Berkeley as well as landscape changes caused by the earthquake. (G.K. Gilbert Collection [331.6.1, #124; Envelope 7], California Academy of Sciences Archives.)

FIGURE 25. Fault trace 1.5 miles south of Olema, looking SE. Fault trace touches sag ponds, as seen by the jagged trace between them. (G.K. Gilbert Collection [331.6.1; Envelope 7], Alice Eastwood Archive, California Academy of Sciences Archives.) (Also in Gilbert in Lawson 1908, pl. 43, fig. A.)

FIGURES 26–27. Figure 26 (left). Howard near 17th, San Francisco. Buckling of rails by compression. G.K. Gilbert photograph [GKG 2879], U.S. Geological Survey Photographic Archives, Denver, Colorado (also pl. 91 in Lawson [1908]). Figure 27 (right). Howard Street near 17th (East side of street). All houses shifted toward left. Tall house (center) dropped from its south foundation. G.K. Gilbert photograph [GKG 2893], U.S. Geological Survey Photographic Archives, Denver, Colorado.

FIGURE 28. Point Reyes Station. Train overturned by the earthquake. G.K. Gilbert photograph [GKG 3400]. U.S. Geological Survey Photographic Archives, Denver, Colorado.

FIGURE 29. Downtown Oakland, California, before noon, 18 April 1906. Wall failure to building containing Oakland Cyclery and J.A. Munro & Co., Auctioneers. G.K. Gilbert photograph [GKG 2889], U.S. Geological Survey Photographic Archives, Denver, Colorado.

FIGURE 30. Fire storm working its way along the lower portion of Market Street, San Francisco. Facing northeast, looking toward the Call (or Spreckels) Building (center, 4th building counting from the right edge) on the south side of Market Street at 3rd and Market. The California Academy of Sciences' Market Street building is the second on the right (south side, near 4th and Market); the Emporium is the first building on the right (south side, between 4th and 5th and Market). Although these buildings had some level of reinforced steel construction, none was adequately fireproofed. Initial reports indicated that they withstood the shock of the earthquake but not the fire that followed. (A 1906 colorized image. California Academy of Sciences Archives [San Francisco Earthquake 1906 File].)

FIGURES 31 (above) and 32 (below). Previously unpublished photos showing the devastation of downtown San Francisco. (Gulian Pickering Rixford Collection, California Academy of Sciences Archives (above N21179; below N21194).

FIGURE 33. The remains of the California Academy of Sciences' commercial and museum buildings following the earthquake and fire. The elevator shaft (center) survived, as did the exterior walls of the museum building (center left). Photograph by Frank Marion Anderson, Curator of Geology, California Academy of Sciences. (California Academy of Sciences Archives.)

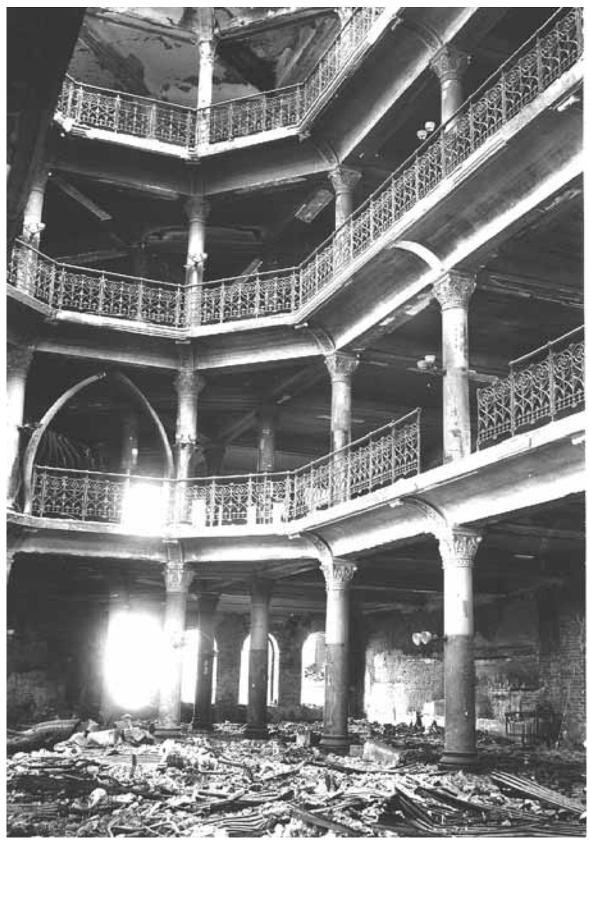

FIGURE 34. Interior of the Academy's museum building following the earthquake and fire. Note that the steel-reinforced floors and columns are intact. Photographer not identified (also in Leviton and Aldrich 1997:474). (California Academy of Sciences Archives.)

FIGURE 35. Temporary storage for the Galapagos collections in a walled-off section of the old Museum building of the Market Street complex, December 1906 (also in Leviton and Aldrich 1997:481). (California Academy of Sciences Archives.)

FIGURE 36. The "new" library of the Academy, temporarily located at 1812 Gough Street. The rapid recovery of the library was the result of the extraordinary outpouring of good will and publications from individuals and institutions world-wide (also in Leviton and Aldrich 1997:478). (California Academy of Sciences Archives.)

FIGURE 37. Wooden Japanese god that emerged unscathed from the Academy's building after the fire. Photograph by Drs. Peter S. Bruguiere and Academy curator Gustav Eisen. (California Academy of Sciences Archives N23046.)