

A TRIBUTE TO GEORGE PLAFKER

Gary S. Fuis^a, Peter J. Haeussler^b, and Brian F. Atwater^c

^aU.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025 (fuis@usgs.gov)

^bU.S. Geological Survey, 4210 University Dr., Anchorage, AK 99508-4626 (pheuslr@usgs.gov)

^cU.S. Geological Survey, 310 Condon Hall, Seattle, WA 98195 (atwater@usgs.gov)

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ABSTRACT

In a long and distinguished career, George Plafker has made fundamental advances in understanding of megathrust tectonics, tsunami generation, paleoseismology, crustal neotectonics, and Alaskan geology, all by means of geological field observations. George discovered that giant earthquakes result from tens of meters of seismic slip on subduction thrusts, and he did this before the theory of plate tectonics had become a paradigm. The discovery was founded on George's comprehensive mapping of land-level changes in the aftermath of the 1964 earthquake in Alaska, and on his similar mapping in the region of the 1960 earthquakes in Chile. The mapping showed paired, parallel belts of coseismic uplift largely offshore and coseismic subsidence mostly onshore -- a pattern now familiar as the initial condition assumed in computer simulations of subduction-zone tsunamis. George recognized, moreover, that splay faulting can play a major role in tsunami generation, and he also distinguished carefully between tectonic and landslide sources for the multiple tsunamis that accounted for nearly all the fatalities associated with the 1964 Alaska earthquake. George's classic monographs on the 1964 earthquake include findings about subduction-zone paleoseismology that he soon extended to include stratigraphic evidence for cyclic vertical deformation at the Copper River delta, as well as recurrent uplift evidenced by flights of marine terraces at Middleton Island. As a geologist of earthquakes, George also clarified the tectonics and hazards of crustal faulting in Alaska, California, and overseas. All the while, George was mapping bedrock geology in Alaska, where he contributed importantly to today's understanding of how terranes were accreted and modified.

INTRODUCTION

The distinguished career of George Plafker includes fundamental contributions in Alaskan geology and to plate tectonics worldwide. George is best known for determining the style of faulting that produced the two largest earthquakes in instrumental earthquake history—the 1960 Chile earthquake of M 9.5, and the 1964 Alaska earthquake of M 9.2. The discovery hastened the plate-tectonics revolution by showing grand examples of subduction in action. George's career also included a clear demonstration of how trans-oceanic and local tsunamis are generated, how records of prior megathrust earthquakes are encrypted in sediments and uplifted terraces in the source regions of megathrust earthquakes, and how Alaska has evolved through time and through the processes of terrane accretion, sedimentation, volcanism, and fault offset.

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51GEORGE'S IMPACTS ON EARTH SCIENCE

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53George led the way in postulating and demonstrating that oceanic crust underlying the
54Pacific Ocean had underthrust continental crust in the giant earthquakes of 1960 and
551964. His megathrust-earthquake hypothesis for the 1964 Alaskan event (Plafker, 1965)
56preceded, by four years, the first appearance of “plate tectonics” in print (McKenzie and
57Morgan, 1969), and it complemented nearly contemporary developments in the theory of
58seafloor spreading (Vine and Matthews, 1963; Vine, 1966). He further supported his
59megathrust hypothesis by studying land-level changes associated with the Chilean
60earthquakes of May 21 and 22, 1960 (Plafker and Savage, 1970). In both instances,
61seismologists had sought to explain the earthquakes by rupture on steeply dipping faults
62(e.g., Aki, 1962; Press and Jackson, 1965; see summary in Plafker and Savage, 1970).
63

64George deciphered the Alaskan and Chilean earthquakes in several ways. He had a
65boundless drive to understand the workings of the Earth in producing such exceptional
66instances of deformation. He readily incorporated data from many disciplines, from
67biology to seismology, to fully explain observations. Finally, his courage and
68thoroughness in the field enabled him to observe, in forbidding environments, natural
69phenomena that proved crucial to a full understanding of what had happened.
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71Nobody had expected the extensive land-level changes that George and his coworkers
72found in the months after the 1964 Alaskan earthquake. Some had expected little more
73than a survey of surface rupture along a high-angle fault, much like the faulting near San
74Francisco in 1906. George soon recognized, from uplifted shorelines of Prince William
75Sound and the broad areal extent of aftershocks, that the 1964 earthquake required some
76other kind of tectonic mechanism. He estimated amounts of land-level change by using
77the growth limits of intertidal and other organisms, particularly emerged barnacles in
78areas of uplift and submerged spruce in areas of subsidence. Crucially, George and his
79coworkers proceeded to map the uplift at virtually all accessible locations along nearly
80600 kilometers of coast, characterized by numerous fjords and islands, and they graded
81each uplift estimate by levels of uncertainty. They supplemented these largely biological
82observations by interviewing eyewitnesses and by incorporating instrumental data that
83others obtained from tide gauges and geodetic bench marks, and from triangulation
84stations. The fault-rupture model that best fit all these observations laid groundwork for
85later seismological estimates that assigned the 1964 earthquake a moment magnitude
86(M_w) of 9.2 (Kanamori, 1977).
87

88This comprehensive set of observations defined a belt of uplift that extended offshore,
89nearly to the Aleutian trench, and an adjoining belt of tectonic subsidence that included
90much of Cook Inlet. Within the region of uplift was a belt of enhanced uplift chiefly
91along a couple of faults that ruptured both the seafloor and ground surface offshore of and
92on Montague Island, in Prince William Sound (Plafker, 1969). George ascribed the uplift
93to slip on an underlying megathrust, the subsidence to elastic extension of the overriding
94plate chiefly landward of the megathrust rupture area, and the enhanced uplift to splay

95faulting. These pioneering tectonic interpretations endure today in models of subduction-
96zone thrusts worldwide.

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98After drafting several monographs on the 1964 earthquake, including his classic USGS
99Professional Paper on the earthquake's tectonics (Plafker, 1969), George visited south-
100central Chile to explore, in 1968, the tectonics of the 1960 earthquake series that included
101a foreshock now rated as Mw 8.1 and a mainshock commonly estimated at Mw 9.5.
102Interviewing in Spanish, George obtained eyewitness evidence of before-and-after
103positions of tide-level indicators along 400 km of mainland coast. He then arranged for a
104fishing boat, the *Atun*, to wend southward another 400 km through the Chonos
105archipelago. The resulting measurements of uplift and subsidence showed a pattern
106similar to that observed in Alaska. The pattern in Chile demonstrated that a great thrust
107fault had ruptured along the southernmost 1,000 km of the subducting Nazca plate
108(Plafker and Savage, 1970).

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110The 1960 and 1964 earthquakes were each followed by Pacific Ocean tsunamis that
111required large displacements of the ocean floor. Japanese scientists had previously linked
112tsunamis to seafloor deformation (e.g., Imamura, 1930; Iida, 1963). George made this
113link clear by mapping regional coseismic uplift and subsidence, identifying additional
114uplift from splay faulting in the Gulf of Alaska, and specifically relating this deformation
115to his and others' records of tsunami wave heights and arrival times. The parallel belts of
116uplift and subsidence that George mapped in Alaska and Chile have become familiar as
117the initial condition assumed in computer simulations of subduction-zone tsunamis. In
118addition, during their post-earthquake surveys in Alaska, George and coworkers
119identified underwater landslides as the trigger for early-arriving local tsunamis. These
120local tsunamis were important for causing more fatalities than did the Pacific Ocean
121tsunami that was caused by tectonic warping of the ocean floor.

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125George is still pursuing, in retirement, the tectonics of the sea-floor deformation that
126generates tsunamis in megathrust events. The devastating Indian Ocean tsunami(s) of
127December 2004, included a local tsunami that began coming ashore in Aceh, on the
128island of Sumatra, tens of minutes sooner than would be expected had the fault rupture
129been confined to the megathrust. Four decades earlier, George showed that the 1964
130earthquake had been accompanied by 10 m of slip on a splay fault in the accretionary
131wedge, at Patton Bay, on Montague Island, Alaska (Plafker, 1969). George invoked
132similar nearshore splay faulting to explain the Acehese tsunami arrivals (Plafker et al.,
1332006) – an idea that others have been testing through marine geophysical surveys.

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135George's discoveries about land-level changes during the 1960 Chile and 1964 Alaska
136earthquakes laid groundwork for subduction-zone paleoseismology. George himself
137pioneered this field in studying predecessors to the 1964 earthquake that are evidenced by
138marine terraces at Middleton Island and by interbedded peat and mud at the Copper River
139Delta (Plafker et al., 1992; Carver and Plafker, 2008). The Chilean and Alaskan examples
140have provided modern analogs for interpreting geological evidence for rapid changes in

141coastal land level at other subduction zones. In an unusual example along the southern
142Kuril Trench, rapid uplift evidenced paleoecologically in eastern Hokkaido was attributed
143to transient postseismic deformation by analogy with uplift that occurred inland of the
144coseismic downwarp in Chile (Sawai et al., 2004). George and a Chilean coworker had
145shown that this Chilean uplift persisted for decades after the 1960 earthquake, and they
146ascribed it to viscoelastic creep induced by displacement on the megathrust in 1960
147(Barrientos, 2007).

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149George has also been involved in investigations of numerous major earthquake ruptures
150around the world, including the 1970 Peru earthquake and massive debris avalanche at
151Yungay (Plafker, et al., 1970), the 1972 Managua and 1973 Costa Rica earthquake
152(Brown et al., 1973; Plafker, 1973), the 1976 Guatemala earthquake (Plafker, 1976), the
153Loma Prieta earthquake (Plafker and Galloway, 1989), the 2002 Denali Fault earthquake
154(Eberhart-Phillips et al., 2003), and others. The latter earthquake ruptured the eastern
155segment of the Denali Fault, on which George and others had documented a relatively
156high rate of slip that represented a significant earthquake hazard (see Plafker et al., 1994).
157George had first examined the fault trace in the 1970s, and noticed that the scarps along
158the western part of the fault were fresher than those along the eastern part. Thus, he
159concluded, an earthquake along the eastern part was more likely, and he correctly inferred
160the main part of the fault rupture in the 2002 earthquake (Plafker et al., 1977).

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162George has also made fundamental contributions to the bedrock geology of Alaska. His
163work mapping in the rugged Saint Elias Mountains singlehandedly defined the regional
164extent of the Yakutat terrane and its ongoing collision. He found that this
165tectonostratigraphic terrane, originating in the coastal and offshore region of southern
166Alaska and British Columbia, 600 km southeast of its current location, began colliding
167with the southern Alaska margin in Miocene time, and it continues to collide to the
168present day, giving rise to the Chugach-St. Elias orogen (Plafker et al., 1978; Plafker,
1691987). George has a remarkable ability to find and focus on key relationships. One of
170the critical exposures for understanding the Yakutat terrane basement is only about 1 x 2
171km in dimension. In an area of 30,000 km², in mountainous and glaciated terrain, he
172found the only on-land basement exposure of the western part of the Yakutat terrane and
173documented its relationship with the eastern part of the terrane, as well as to the post
174collisional cover sequence.

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176George has studied the Earth in Alaska through the full range of time, from the
177Precambrian through modern earthquakes. He has been driven to understand how
178currently observed crustal composition and structure came to be. He has been not only a
179primary investigator in the field, but the primary integrator of field data into syntheses
180and, importantly, into palinspastic reconstructions. Perhaps his quintessential
181contribution is his palinspastic reconstruction of the continent in the southern part of
182Alaska (Plafker and Berg, 1984). This work led to a better understanding of how the
183Yakutat terrane is both colliding with, and subducting beneath Alaska (Fuis et al., 2008).

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189GEORGE'S CAREER

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191George Plafker was born on March 6, 1929. He obtained a B.S. in Geology with minors
192in Physics and Math from Brooklyn College in 1949. He worked first as an engineering
193geologist with the Army Corps of Engineers (dam site characterization) and then with the
194Military Geology Branch of the U.S. Geological Survey (USGS) (secret assessments of
195strategic foreign construction sites). In 1952, he joined the Alaskan Geology Branch of
196the USGS to assess nonmetallic mineral deposits in Alaska (as field party chief) and also
197petroleum and other resources of the Gulf of Alaska Tertiary Province. In 1956, he
198completed his MS in Geology at the University of California, Berkeley, and from 1956 to
1991962, worked for Standard Oil of California (as field party chief) in Guatemala and
200Bolivia. From 1962 to his retirement in 1995, he continued his earlier research with the
201Alaskan Geology Branch of the USGS, leading or co-leading a number of projects
202including (1) research into the potential for petroleum and other resources in the Gulf of
203Alaska Tertiary Province (2) earthquake hazards of Alaska, (3) the Trans-Alaska Crustal
204Transect, (4) synthesis of the geology, tectonics, and palinspastic reconstruction of
205southern Alaska. During this period, in 1971, he also obtained his Ph.D. in Geology and
206Geophysics from Stanford University. His work on earthquake hazards involved
207evaluation of hazards from tectonic displacements, seismic shaking, and secondary
208geologic effects. This project included study of all known active or potentially active
209faults in Alaska, neotectonic vertical deformation in coastal areas, and evaluation of
210earthquake effects, most notably the 1964 Alaskan earthquake and also the 1979 Saint
211Elias earthquake. The project resulted in a synthesis of neotectonic deformation in
212Alaska, a map showing young faults in Alaska, and a catalog of data on faulting in
213Alaska. His work on the Trans-Alaska Crustal Transect involved producing (with others)
214a strip geologic map along the trans-Alaska oil pipeline corridor to complement
215geophysical studies (seismic refraction, seismic reflection, and potential field) along the
216same corridor. George's work on terrane assembly and dispersion in southern Alaska,
217along with geophysical data on deep structure, enabled a breakthrough in understanding
218of the collision of the Yakutat terrane with southern Alaska. Major miscellaneous
219assignments and work experiences from 1968 until his retirement in 1995 include: (1) 2-
220month field investigation of earthquake-related tectonic deformation in southern Chile
221where geomorphic criteria were used for determining vertical shoreline movements
222associated with the great 1960 Chile earthquake (research funded by a Harry Oscar Wood
223Fund Award in Seismology, Jan.-Feb. 1968); (2) field investigation of geologic effects of
224the May 31, 1970 Peru earthquake, the December 23, 1972 Managua earthquake, the
225April 13, 1973 Costa Rica earthquake, the Feb. 4, 1976 Guatemala earthquake, the
226December 13, 1982 Yemen earthquake, the March 3, 1985 Chile earthquake, the April 22,
2271991, Costa Rica earthquake (invited participant in study funded by NSF) and December
22812, 1992 Flores Island, Indonesia earthquake (study funded by EERI); (3)
229sedimentologist aboard DSDP drilling vessel *Glomar Challenger*, leg 36 (Feb.-Mar.
2301976); 4) invited participant as assistant observer aboard the Canadian submersible Pisces
231IV off the coast of Vancouver Island (May 1979); and 5) coastal studies in Chile to
232determine the nature and origin of marine terraces in coastal regions (invited participant

233in study funded by NSF, 1990, 1992). Since formally retiring from the USGS in 1995,
234George has maintained a scientist emeritus position and continued active research to the
235present. Studies have included an investigation into the origin of the large earthquakes of
2361899-1900 in the Yakutat Bay area, continued analysis of data collected for the Trans-
237Alaska Crustal Transect, and an investigation of the source of the extreme tsunami in
238northwestern Sumatra in 2004.

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240Professional Registrations

241 Geologist, California, License # 913

242 Certified Engineering Geologist, California, License #347

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244Professional Society Memberships

245 Geological Society of America, Fellow (1954 to present)

246 Association of Engineering Geologists (1961 to present)

247 American Association for Advancement of Science (1962 to present)

248 American Geophysical Union (1964 to present)

249 Peninsula Geological Society (1979-71, V. Pres.; 1980-81, Pres.)

250 Sigma Xi (1982 to present)

251 Earthquake Engineering Research Institute (1993 to present)

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253Honors and awards.

254 U.S. Geological Survey Superior Performance Awards for studies of 1964 Alaska
255 earthquake (1964, 1965)

256 Harry Oscar Wood Award in Seismology to study tectonics of 1960 Chile
257 earthquake (1967)

258 U.S. Department of the Interior Meritorious Service Award (1973)

259 U.S. Department of the Interior Distinguished Service Award (1979)

260 U.S. Geological Survey Special Achievement Award for Loma Prieta earthquake
261 Circular 1045 (1990)

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263Committees to render scientific judgment

264 Member, AEC Committee on Seismology (1969-1972)

265 Member, Isfahan Reactor Review Board, Atomic Energy Organization of Iran
266 (1978-1979)

267 Member, USGS Geologic Division Science Advisory Committee (1980-81)

268 Chairman, USGS Geologic Division Framework Program Review Committee
269 (1981)

270 Member, GSA Program Committee (1982-1984)

271 Member, GSA Bulletin Board of Associate Editors (1982-1984)

272 Outside examiner for 3 Ph.D. committees (U.C. Santa Cruz and Stanford
273 University)

274 Member, Program Committee for USGS Trans-Alaska Crustal Transect (1983-
275 1993); Program Coordinator (1993-present)

276 Member, National Research Council Committee on Seismology (1984-1987)

277 Member, USGS Geologic Division G.K. Gilbert Fellowship Review Panel (1984-
278 1985)

279 Member, EDGE (Continental Margins Seismic Profiling) Committee (1986-1990)
280 Member, USGS Tsunami Hazard Research Group (1995-present)
281 Member, Consulting Advisory Board on Seismic Hazards to Pacific Gas and
282 Electric Company, San Francisco (1998-2011)
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284**SUMMARY**

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286In summary, George Plafker has led the way in understanding (1) the mechanics of thrust
287faulting in major subduction earthquakes, (2) the generation of tsunamis from
288deformation of the seafloor, including the special hazards of both submarine landslides
289and deformation along secondary fault ruptures in the submarine accretionary wedge, (3)
290the utility of paleoseismology in deciphering past earthquakes, especially
291uplift/subsidence patterns of megathrust earthquakes, and (4) the assembly and dispersal
292of geologic terranes in southern Alaska, where continent building is taking place. George
293is one of the preeminent geologists of the world, who has provided leadership and
294inspiration for many of the rest of us. Lloyd Cluff, one of George's long-time associates
295writes:

296“George Plafker is no ordinary researcher. He is simply astonishing—one of that rare
297class of field geologists gifted with dynamic energy, ingenuity, resourcefulness, creativity,
298humor, and guts, in addition to being a gentleman with a great and kind heart. I can
299testify from personal experience working closely with him recently in Alaska that George
300can out-climb, out-hike, and out-bushwhack field geologists less than half his age. He is
301an inspiration to young earthquake scientists in his thrust for discovering important
302tectonic principles that have a significant influence on how we understand faults and
303earthquakes. His pioneering research into the tectonic basis of plate-boundary-fault-zone
304behavior, his extensive service and leadership at the U.S. Geological Survey, and the
305advancements he has brought to the practice of earthquake geology have changed the
306landscape in this area of study.”

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313Photos of George Plafker at work: (top) discussing science at the 2006 AGU
314Chapman Conference, in Girdwood, Alaska; (bottom) documenting and selecting
315datable material from a sediment core from the Copper River delta

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318ACKNOWLEDGMENTS

319

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