A TRIBUTE TO GEORGE PLAFKER

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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 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.

GEORGE'S IMPACTS ON EARTH SCIENCE

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

George deciphered the Alaskan and Chilean earthquakes in several ways. He had a boundless drive to understand the workings of the Earth in producing such exceptional instances of deformation. He readily incorporated data from many disciplines, from biology to seismology, to fully explain observations. Finally, his courage and thoroughness in the field enabled him to observe, in forbidding environments, natural phenomena that proved crucial to a full understanding of what had happened.

Nobody had expected the extensive land-level changes that George and his coworkers found in the months after the 1964 Alaskan earthquake. Some had expected little more than a survey of surface rupture along a high-angle fault, much like the faulting near San Francisco in 1906. George soon recognized, from uplifted shorelines of Prince William Sound and the broad areal extent of aftershocks, that the 1964 earthquake required some other kind of tectonic mechanism. He estimated amounts of land-level change by using the growth limits of intertidal and other organisms, particularly emerged barnacles in areas of uplift and submerged spruce in areas of subsidence. Crucially, George and his coworkers proceeded to map the uplift at virtually all accessible locations along nearly 600 kilometers of coast, characterized by numerous fjords and islands, and they graded each uplift estimate by levels of uncertainty. They supplemented these largely biological observations by interviewing eyewitnesses and by incorporating instrumental data that others obtained from tide gauges and geodetic bench marks, and from triangulation stations. The fault-rupture model that best fit all these observations laid groundwork for later seismological estimates that assigned the 1964 earthquake a moment magnitude (Mw) of 9.2 (Kanamori, 1977).

This comprehensive set of observations defined a belt of uplift that extended offshore, nearly to the Aleutian trench, and an adjoining belt of tectonic subsidence that included much of Cook Inlet. Within the region of uplift was a belt of enhanced uplift chiefly along a couple of faults that ruptured both the seafloor and ground surface offshore of and on Montague Island, in Prince William Sound (Plafker, 1969). George ascribed the uplift to slip on an underlying megathrust, the subsidence to elastic extension of the overriding plate chiefly landward of the megathrust rupture area, and the enhanced uplift to splay faulting. These pioneering tectonic interpretations endure today in models of subduction-zone thrusts worldwide.

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

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

George is still pursuing, in retirement, the tectonics of the sea-floor deformation that generates tsunamis in megathrust events. The devastating Indian Ocean tsunami(s) of December 2004, included a local tsunami that began coming ashore in Aceh, on the island of Sumatra, tens of minutes sooner than would be expected had the fault rupture been confined to the megathrust. Four decades earlier, George showed that the 1964 earthquake had been accompanied by 10 m of slip on a splay fault in the accretionary wedge, at Patton Bay, on Montague Island, Alaska (Plafker, 1969). George invoked similar nearshore splay faulting to explain the Acehnese tsunami arrivals (Plafker et al., 2006) – an idea that others have been testing through marine geophysical surveys.

George's discoveries about land-level changes during the 1960 Chile and 1964 Alaska earthquakes laid groundwork for subduction-zone paleoseismology. George himself pioneered this field in studying predecessors to the 1964 earthquake that are evidenced by marine terraces at Middleton Island and by interbedded peat and mud at the Copper River Delta (Plafker et al., 1992; Carver and Plafker, 2008). The Chilean and Alaskan examples have provided modern analogs for interpreting geological evidence for rapid changes in coastal land level at other subduction zones. In an unusual example along the southern Kuril Trench, rapid uplift evidenced paleoecologically in eastern Hokkaido was attributed to transient postseismic deformation by analogy with uplift that occurred inland of the coseismic downwarp in Chile (Sawai et al., 2004). George and a Chilean coworker had shown that this Chilean uplift persisted for decades after the 1960 earthquake, and they ascribed it to viscoelastic creep induced by displacement on the megathrust in 1960 (Barrientos, 2007).

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

George has also made fundamental contributions to the bedrock geology of Alaska. His work mapping in the rugged Saint Elias Mountains singlehandedly defined the regional extent of the Yakutat terrane and its ongoing collision. He found that this tectonostratigraphic terrane, originating in the coastal and offshore region of southern Alaska and British Columbia, 600 km southeast of its current location, began colliding with the southern Alaska margin in Miocene time, and it continues to collide to the present day, giving rise to the Chugach-St. Elias orogen (Plafker et al., 1978: Plafker, 1987). George has a remarkable ability to find and focus on key relationships. One of the critical exposures for understanding the Yakutat terrane basement is only about 1 x 2 km in dimension. In an area of 30,000 km^2, in mountainous and glaciated terrain, he found the only on-land basement exposure of the western part of the Yakutat terrane and documented its relationship with the eastern part of the terrane, as well as to the post collisional cover sequence.

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

GEORGE’S CAREER

George Plafker was born on March 6, 1929. He obtained a B.S. in Geology with minors in Physics and Math from Brooklyn College in 1949. He worked first as an engineering geologist with the Army Corps of Engineers (dam site characterization) and then with the Military Geology Branch of the U.S. Geological Survey (USGS) (secret assessments of strategic foreign construction sites). In 1952, he joined the Alaskan Geology Branch of the USGS to assess nonmetallic mineral deposits in Alaska (as field party chief) and also petroleum and other resources of the Gulf of Alaska Tertiary Province. In 1956, he completed his MS in Geology at the University of California, Berkeley, and from 1956 to 1962, worked for Standard Oil of California (as field party chief) in Guatemala and Bolivia. From 1962 to his retirement in 1995, he continued his earlier research with the Alaskan Geology Branch of the USGS, leading or co-leading a number of projects including (1) research into the potential for petroleum and other resources in the Gulf of Alaska Tertiary Province (2) earthquake hazards of Alaska, (3) the Trans-Alaska Crustal Transect, (4) synthesis of the geology, tectonics, and palinspastic reconstruction of southern Alaska. During this period, in 1971, he also obtained his Ph.D. in Geology and Geophysics from Stanford University. His work on earthquake hazards involved evaluation of hazards from tectonic displacements, seismic shaking, and secondary geologic effects. This project included study of all known active or potentially active faults in Alaska, neotectonic vertical deformation in coastal areas, and evaluation of earthquake effects, most notably the 1964 Alaskan earthquake and also the 1979 Saint Elias earthquake. The project resulted in a synthesis of neotectonic deformation in Alaska, a map showing young faults in Alaska, and a catalog of data on faulting in Alaska. His work on the Trans-Alaska Crustal Transect involved producing (with others) a strip geologic map along the trans-Alaska oil pipeline corridor to complement geophysical studies (seismic refraction, seismic reflection, and potential field) along the same corridor. George’s work on terrane assembly and dispersion in southern Alaska, along with geophysical data on deep structure, enabled a breakthrough in understanding of the collision of the Yakutat terrane with southern Alaska. Major miscellaneous assignments and work experiences from 1968 until his retirement in 1995 include: (1) 2-month field investigation of earthquake-related tectonic deformation in southern Chile where geomorphic criteria were used for determining vertical shoreline movements associated with the great 1960 Chile earthquake (research funded by a Harry Oscar Wood Fund Award in Seismology, Jan.-Feb. 1968); (2) field investigation of geologic effects of the May 31, 1970 Peru earthquake, the December 23, 1972 Managua earthquake, the April 13, 1973 Costa Rica earthquake, the Feb. 4, 1976 Guatemala earthquake, the December 13, 1982 Yemen earthquake, the March 3, 1985 Chile earthquake, the April 22, 1991, Costa Rica earthquake (invited participant in study funded by NSF) and December 12, 1992 Flores Island, Indonesia earthquake (study funded by EERI); (3) sedimentologist aboard DSDP drilling vessel *Glomar Challenger,* leg 36 (Feb.-Mar. 1976); 4) invited participant as assistant observer aboard the Canadian submersible Pisces IV off the coast of Vancouver Island (May 1979); and 5) coastal studies in Chile to determine the nature and origin of marine terraces in coastal regions (invited participant in study funded by NSF, 1990, 1992). Since formally retiring from the USGS in 1995, George has maintained a scientist emeritus position and continued active research to the present. Studies have included an investigation into the origin of the large earthquakes of 1899-1900 in the Yakutat Bay area, continued analysis of data collected for the Trans-Alaska Crustal Transect, and an investigation of the source of the extreme tsunami in northwestern Sumatra in 2004.

Professional Registrations

Geologist, California, License # 913
Certified Engineering Geologist, California, License #347

Professional Society Memberships

Geological Society of America, Fellow (1954 to present)
Association of Engineering Geologists (1961 to present)
American Association for Advancement of Science (1962 to present)
American Geophysical Union (1964 to present)
Peninsula Geological Society (1979-71, V. Pres.; 1980-81, Pres.)
Sigma Xi (1982 to present)
Earthquake Engineering Research Institute (1993 to present)

Honors and awards.

U.S. Geological Survey Superior Performance Awards for studies of 1964 Alaska earthquake (1964, 1965)
Harry Oscar Wood Award in Seismology to study tectonics of 1960 Chile earthquake (1967)
U.S. Department of the Interior Meritorious Service Award (1973)
U.S. Department of the Interior Distinguished Service Award (1979)
U.S. Geological Survey Special Achievement Award for Loma Prieta earthquake Circular 1045 (1990)

Committees to render scientific judgment

Member, AEC Committee on Seismology (1969-1972)
Member, Isfahan Reactor Review Board, Atomic Energy Organization of Iran (1978-1979)
Member, USGS Geologic Division Science Advisory Committee (1980-81)
Chairman, USGS Geologic Division Framework Program Review Committee (1981)
Member, GSA Program Committee (1982-1984)
Member, GSA Bulletin Board of Associate Editors (1982-1984)
Outside examiner for 3 Ph.D. committees (U.C. Santa Cruz and Stanford University)
Member, Program Committee for USGS Trans-Alaska Crustal Transect (1983-1993); Program Coordinator (1993-present)
Member, National Research Council Committee on Seismology (1984-1987)
Member, USGS Geologic Division G.K. Gilbert Fellowship Review Panel (1984-1985)

Member, EDGE (Continental Margins Seismic Profiling) Committee (1986-1990)

Member, USGS Tsunami Hazard Research Group (1995-present)

Member, Consulting Advisory Board on Seismic Hazards to Pacific Gas and Electric Company, San Francisco (1998-2011)

SUMMARY

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

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

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

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