Earthquake ecologists I – James Graham Cooper

James Graham Cooper roamed Washington Territory as a young naturalist shortly before the Civil War. Near Astoria he observed the remains of trees that are important today as clues to earthquake hazards.

Cooper came here from New York in 1853. He had sought and gained a position as surgeon and naturalist with the Issac Stevens railroad survey. His survey party was commanded by George McClellan and was provisioned at Fort Vancouver by Ulysses Grant. The Smithsonian Institution provided support for follow-up work, which centered on collecting museum specimens at Willapa (then Shoalwater) Bay.

The remains of drowned trees caught Cooper's eye in 1854 and 1855. His journal tells of spruce stumps in growth position in the banks of a tidal creek near Chinook. His railroad report, extolling western red cedar as a source of durable shingles, describes dead trunks of "this species only" standing in Willapa Bay tidal marshes. Cooper reasoned that these standing trees had died when tides overflowed sinking land.

Today is has become clear that this sinking takes place during earthquakes, when a leading edge of North America lurches tens of feet toward Asia. The shift stretches solid rock, which thins like a pulled rubber band. The thinning lowers coastal land several feet. Tides overflow the freshly sunken land, killing thousands of trees.

Sudden changes in land level routinely accompany certain kinds of earthquakes. Examples from Alaska and Chile will be recounted in two subsequent Nature Notes.

SOURCES

A biography of James Graham Cooper (1830–1902) includes a timeline of his career and a comprehensive list of his published and unpublished works[1]. These include journals spanning his months at Willapa Bay[2,3] and a botanical chapter in the Northern Pacific railroad report[4]. The spruce stumps are described in a journal entry for March 10, 1854, and the western red cedar trunks on page 22 of the botany chapter.

Stretching of rock above an inclined fault produced subsidence on a grand scale during the 1964 Alaska earthquake (p. 64–66 of ref 5; next geological installment of Nature Notes). The same process accounts for the tidal submergence and consequent burial of forest and marsh soils at estuaries along the Pacific coast above the Cascadia Subduction Zone (p. 16–17 in ref 6). In the railroad report Cooper inferred that forested land had sunk gradually[4]. Today, as summarized in ref 6, it has become clear that the entire landscape in southwest Washington dropped abruptly. This sudden lowering of land allowed tides to drown lowland forests and estuarine marshes.

Animations[7] depict much of the geology mentioned in this set of Nature Notes.

Earthquake ecologists II – George Plafker

Life suffered on Alaskan shores in the months after the great earthquake of March 27, 1964. Barnacles, mussels, and rockweed were left high and dry by uplift, while downdropped meadows and spruce groves became tidal flats. Today this earthquake ecology underpins understanding of seismic and tsunami hazards along the Cascadia Subduction Zone.

To subduct is to subtract or remove, usually downward, even as excrement. With the advent of plate tectonics, geologists appropriated "subduction" in 1970 to label the descent of ocean floor beneath a continent or island chain. The descent takes place along a thrust fault that slants beneath the coast at low angle. The thrusting can generate great earthquakes, with magnitudes of 8 or 9.

George Plafker discovered subduction in action as he mapped, in 1964 and 1965, those ecological changes from the great 1964 Alaska earthquake. The changes defined parallel belts of uplift and subsidence that together spanned tens of thousands of square miles. Plafker showed that the vertical displacement resulted from tens of feet of slip on a low-angle thrust fault. He proposed that the fault was conveying ocean floor beneath a continental margin—the essence of what geologists would soon call "subduction."

Subduction was recognized here in Cascadia by 1970. It was an implication of plate tectonics, a newborn theory at the time. Modern recognition of great Cascadia earthquakes began in the late 1980s with clues that include the estuarine remains of drowned marshes and forests. Today the abrupt lowering of coastal land is among the hallmarks of great subduction earthquakes, in Cascadia as in Alaska.

SOURCES

Early uses of "subduction" cited in the Oxford English Dictionary include a 17th-century comment on purgatives for gout (p. 18–19 in ref[8]). The plate-tectonic revolution of the 1960s created demand for a term to denote the underthrusting of a continental margin or island arc by an oceanic plate[9,10].

The source of the 1964 Alaska earthquake was either a steep fault or a gently sloping fault, as judged from the first motions at seismometers. Some of the field evidence for land-level change was found roughly compatible with a steep fault, provided the seismic slip extended from a depths of about 15 km to depths 100–200 km[11]. Aftershock locations instead painted in a gently sloping fault at depths of 30 km of less[5,12].

The evidence for a subduction zone in Cascadia includes reconstructed plate motions[13,14]. The remains of tidally drowned herbaceous plants and trees provide datable evidence for lowering of coastal land during Cascadia earthquakes[15]. Death dates from trunks of western red cedar, mentioned in a previous Nature Note, give confidence that the most recent of these quakes occurred in January 1700[16], and that it was large enough for an associated tsunami to explain documented flooding and damage in Japan[6,17].

Earthquake ecologists III – Maria Graham

Maria Graham, a travel writer, observed an earthquake near Valparaiso, Chile, in 1822. Interested in geology, she recounted the mainshock, listed aftershocks, and described eruptions of watery sand from what today would be called liquefaction. In addition, she reported coastal uplift, "the bed of the sea laid bare and dry, with oysters, muscles, and other shells adhering to the rocks on which they grew, the fish being all dead, and exhaling most offensive effluvia."

George Bellas Greenough, a lawyer and geologist, thought uplift impossible except at volcanoes. He publicly accused Graham of delusion and deceit.

Graham called the attack "uncourteous." She vouched for her coastal evidence, and she professed indifference as to "whether Mr. Greenough ascribes this to a partial elevation of the coast of Chile, or to a change of level of the whole mighty Pacific Ocean, which must have extended to Polynesia, India and China." "The fact is," Graham declared, "there was a change in the relative position of the land and water..." And "to save circumlocution" she would "use the word, *raised*, or *elevated*, in describing that change." [capitalization changed and italics added]

Maria Graham pioneered scientific reporting of vertical displacement that accompanies subduction earthquakes. Her successors include Robert Fitzroy and Charles Darwin. Sudden uplift onshore or offshore is today seen as a hallmark of subduction earthquakes worldwide. Here in Cascadia, simulations of sudden uplift set off virtual tsunamis on computer screens. The resulting maps of evacuation areas are distant descendants of earthquake ecology by Maria Graham.

SOURCES

The exchange in London between Maria Graham (1785–1842) and George Bellas Greenough (1778–1855) was reproduced in an 1835 issue of the American Journal of Science and Arts, in New Haven[18]. A transcript is available from a website on Graham and her work[19].

Graham has been viewed as a disinterested observer whose professed indifference to Greenough's theory of uplift reflects a meager background in Earth science. In this view the main story is Greenough attacking Graham to get at Charles Lyell, who in his "Principles of Geology" had adopted her Chilean findings—and who did not rise to her defense[20].

Recent commentary finds Graham more engaged in natural history that her riposte to Greenough may suggest. Graham, in this view, recognized the Chilean earthquake as more than a curiosity, surveyed its effects carefully, and had the drive and talent to report on them, through an intermediary, to the male-only Geological Society in London[21].

The 1960 Chilean earthquake and 1964 Alaskan earthquake were accompanied by uplift mainly offshore and subsidence mainly onshore[5,22]. This deformation pattern serves as the initial condition in tsunami simulations in Cascadia[23], including those used in design of the rooftop refuge recently completed in Westport[24].

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