OPINION

Why the 1964 Great Alaska Earthquake Matters 50 Years Later

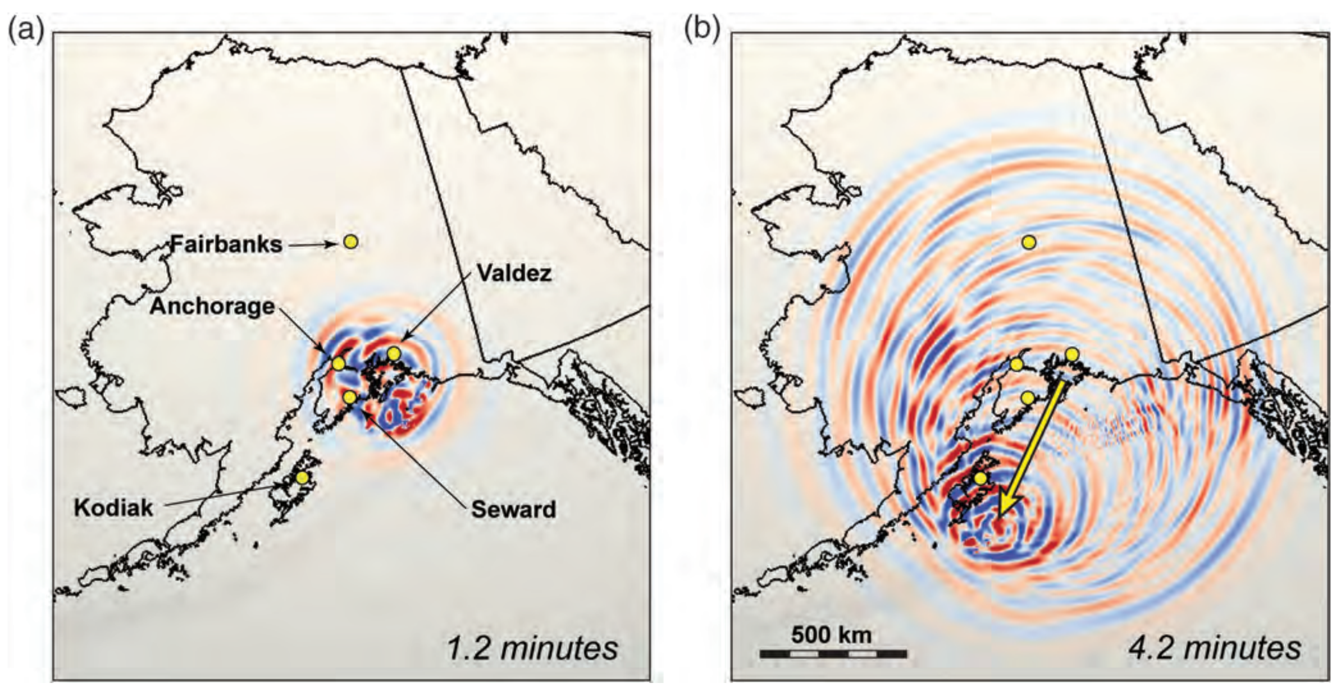
Spring was returning to Alaska on Friday 27 March 1964. A two-week cold snap had just ended, and people were getting ready for the Easter weekend. At 5:36 p.m., an earthquake initiated 12 km beneath Prince William Sound, near the eastern end of what is now recognized as the Alaska-Aleutian subduction zone. No one was expecting this earthquake that would radically alter the coastal landscape, influence the direction of science, and indelibly mark the growth of a burgeoning state.

Over the next five minutes, it ruptured up-dip and 700 km southwest along the subduction zone toward Kodiak Island (Fig. 1). The 5–6 cm/year of convergence between the Pacific plate and North America had compressed the plate boundary by several tens of meters. As the subduction zone unbuckled, southern Alaska lurched as much as 20 m seaward. Uplift exceeded 10 m (mostly underwater) south of the hinge line that extends southwest from Prince William Sound. The effects of seismic waves, deformation, and tsunamis rippled outward in a cascade of interrelated events.

Above the epicenter in the port town of Valdez, nearshore mud sloughed into the bay taking harbor infrastructure and 30 bystanders with it. The tsunami generated by this landslide was captured in a rare and haunting film recording (http://www.youtube.com/watch?v=TdrMKt55VBQ; last accessed January 2014). During these initial minutes, similar local tsunamis devastated Whittier, Chenega, Seward, and numerous smaller communities (Fig. 2).

In the state's largest city, Anchorage, 100 km to the west, the initial ground motion destroyed countless buildings and utilities, and began to loosen soils underneath. Liquefaction, subsidence, and slope failures swallowed buildings and cut scarps into the urban landscape, captured in iconic postearthquake photos (Fig. 3). In Turnagain Heights, a layer of marine silts gave way, sinking a square kilometer and 75 homes.

Near Kodiak Island, a second asperity combined with the first and motion along massive splay faults, to generate



▲ **Figure 1.** Snapshots from a 3D seismic wavefield simulation of the 1964 earthquake contributed by C. Tape. (a) is three minutes before (b). The simulation was computed with SPECFEM3D using the source model of Ichinose *et al.* (2007) modeled to fit seismic, tsunami and uplift data. Full animation is available at http://www.youtube.com/watch?v=y6tw2a4JAv4 (last accessed January 2014).

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a tectonic tsunami that sent waves into the Pacific and back toward the Alaska coast (Fig. 4). Though Kodiak's downtown, harbor, and commerce were destroyed, an effective evacuation effort minimized the causalities to just six. Many communities hit with local tsunamis were struck again as the tectonic tsunami, bolstered by the rising tide, wove into bays and coves over the next many hours. Farther south, the tsunami ravaged Vancouver Island and killed 10 people in Crescent City, California. Of the earthquake's 131 fatalities, 119 were due to local and tectonic tsunamis. The fact that school was out for Good Friday undoubtedly limited the death toll.

The 1964 earthquake was a defining moment in a territory that had just achieved statehood. Fifty years later, it continues to shape Alaska, its people, and the science of earthquakes. The earthquake occurred at a pivotal time in the development of plate tectonic theory. It ushered in an era of major geologic and geophysical field investigations and created a generation of scientists steeped in the nuance of North Pacific tectonics. Scientifically, the 1964 earthquake put Alaska on the map.

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SCIENTIFIC IMPORTANCE

The 1964 earthquake validated a primary tenet of plate motion, helping convert plate tectonics from a theory into textbook fact. It was recorded on more than 70 newly installed World-Wide Standardized Seismograph Network (WWSSN) stations that allowed an unprecedented view into the mechanics of giant earthquakes. Together with the Kurile Islands earthquake the year prior (M 8.5) and the Rat Islands earthquake the year after (M 8.7), data from this earthquake was sufficient to examine the rupture process by mapping slip distribution and the source time function. Ruff and Kanamori (1983) demonstrated that the portion of the earthquake underlying Prince William Sound ruptured as a single massive asperity lasting more than three minutes. This disproved the notion that such earthquakes are simply a series of smaller M 8 events.

▲ **Figure 2.** Kodiak, Alaska, in April 1964. Photo credit: National Oceanic and Atmospheric Administration's (NOAA's) Historic Coast and Geodetic Survey collection.

A vigorous debate ensued on whether the fault surface was a near-vertical nodal plane or a plane dipping shallowly toward the northwest (e.g., Stauder and Bollinger, 1966). Fifty years of plate tectonics makes this hard to imagine, but the raw observations made the first of these interpretations quite intuitive. The coseismic deformation was obvious: South of the hinge line, vertical uplift created new beaches, and subsidence to the north inundated previously inhabited coastal plains. The simplest explanation for this motion is displacement on a deep near-vertical thrust fault. The motion of a locked subduction zone is in many ways a more elaborate explanation. As aftershocks painted the rupture surface, and careful surveys mapped the seaward horizontal deformation, it was undeniable that this shallow thrust did indeed reveal the motion of a subducting plate.

The Pacific-wide tsunami was not a surprise in 1964. The 1946 Aleutian Islands earthquake (M 8.1) killed 159 people in Hawaii and led to the tsunami warning system. The 1957 Andreanof Islands earthquake (M 8.6) also demonstrated the ocean-wide reach of tsunamis from Alaska. Because of this awareness, in 1964 a tsunami advisory was issued 90 min after the earthquake and upgraded to a full tsunami warning after three hours.

By the time of the advisory and warning, however, the initial tsunami damage in Alaska was long over. Brief travel times on the shore side of the earthquake, coupled with local tsunami sources, conspired to create events that eluded warning. Towns such as Whittier were swept by tsunami waves *before the rupture had even finished.* If 1946 was the wake-up call that tsunamis are deadly across oceans, 1964 was the wake-up call that local tsunamis could pose even greater danger. We now understand that fjord landscapes and their huge sediment loads are breeding grounds for submarine landslides. Even modest ground motions can trigger landslides with catastrophic tsunami consequences. Splay faults from the megathrust are also significant triggers of locally sourced tsunamis. Surface evidence of these events can be quickly masked, but an enduring record of splay faulting is preserved in sediment layers. Recognition of different local sources of tsunami generation makes the 1964 earthquake a watershed moment in coastal hazards.

Almost everywhere, the greatest damages were sustained, not from the direct ground shaking, but from soil failure, tsunamis, landslides, and even avalanches. Alaska's infrastructure in 1964 was, by happenstance, relatively resilient. Wood-frame construction, low-rise structures, and modest urban density limited fatalities. Most damage in Anchorage was due to failure of wet silty soils. Enormous reports documented the reach of the secondary impacts. The National Academy of Sciences reports and United States Geological Survey (USGS) professional papers span thousands of pages with whole volumes focused on human ecology, infrastructure, transportation, and coastal engineering in addition to geologic and geophysical

▲ **Figure 3.** Fourth Avenue in downtown Anchorage. Photo credit: U.S. Army.

reports (e.g., Eckel, 1970; National Research Council, 1973). The panorama of ancillary hazards has shaped building codes, public awareness, advisory commissions, warning systems, and instrumentation.

A full mapping of the broad aftermath was feasible only because of sustained federal government awareness and funding. As President Lyndon Johnson instructed his special assistant for science and technology:

> *It is important we learn as many lessons as possible from the disastrous Alaskan earthquake. A scientific understanding of the events that occurred may make it possible to anticipate future earthquakes, there and elsewhere, so as to cope with them more adequately.*
>
> *I, therefore, request that your office undertake to assemble a comprehensive scientific and technical account of the Alaskan earthquake and its effects ...*

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Grantz *et al.* (1964) initially reported on the earthquake just one month after the event. A decade plus of coordinated study provided the base data for all future research on this event. Today we retroactively apply sophisticated seismic and tsunami-modeling techniques not imagined in 1964, but the field data that ground these models resulted from immediate investigations, which never would have been funded by a private entity. In a 2014 world, many of these raw observations would not have the short-term payback that science is increasingly pushed to provide. It is not clear that a comparable effort could be mounted today. Recent experiences, including the 2002 M 7.9 Denali fault earthquake—the largest strike-slip earthquake in North America in 150 years—suggest eroding interest in capturing ephemeral postearthquake observations capable of paying research dividends for decades (Schwartz, 2006). Unlike 1964, scientists are now inundated with more data than can be assimilated. However, not all data are created equal. No one realized in 1964 that the world was entering a 40 year lull in giant earthquakes. Lyndon Johnson's order turned out to be more profound than anyone realized at the time.

SOCIETAL IMPORTANCE

When the 1964 earthquake occurred, Alaska had just marked its fifth anniversary as a state. Pride was soaring, but the natural resource boom had not yet begun. Americans saw Alaska as an indigenous, tourist, and Cold War outpost. Damage across coastal Alaska was a tremendous economic setback. History demonstrates, however, that the recovery was daunting enough to spur smart re-evaluations about growth. It presented communities with an opportunity to revision their futures. A few coastal towns, most famously Valdez, were abandoned and rebuilt in new locations. Other communities rezoned earthquake-affected areas for more appropriate use. The tsunami inundation zone in Seward was repurposed as camping and public beach. Some affected areas in Turnagain Heights became public park. In the oil-driven growth boom after the earthquake, Anchorage adopted aggressive standards that exceeded the Uniform Building Code and created an advisory commission for geologic hazards that continues advocacy today. The Trans-Alaska Pipeline was built a decade after with a dedicated strong motion seismic network from its start.

Among the most profound impacts, however, was creating a society that appreciates firsthand the power of earthquakes. Legitimate public discussions unfolded about how and where to build, but no one questioned the basic assertion that large earthquakes could wreak devastation. The earthquake is burned into Alaskans' collective memories. A Facebook group for 1964 survivors has a membership on par with the Seismological Society of America. Alaskans understand that earthquakes are part of the landscape. Tsunami evacuation routes, weekly siren tests, and ShakeOut exercises mean more when neighbors still tell stories of where they were on 27 March 1964. Many children at play that afternoon are now Alaska's political and business leaders. This knowledge came at a tremendous price, but its influence on the ensuing years of development is unmistakable. This is not to say that all Alaskans are well prepared for earthquakes. Nevertheless, the 1964 earthquake single handedly created a culture in which no one is surprised when earthquakes occur.

50 YEARS OF GRAND CHALLENGES

The 2600 M 5+ earthquakes in Alaska during the past 50 years provide incentive and data for the grand challenges defined in 1964: segmentation along the megathrust; a tectonic framework for Alaska; seismicity and hazard identification; and the subduction-zone earthquake cycle.

▲ **Figure 4.** Aerial photographs of downtown Seward. The top panel is before the 1964 earthquake. The middle panel shows the areas inundated by the 1964 tsunamis. Bottom panel is a recent photo and includes the predicted inundation for three different earthquake and landslide scenarios. These models are the foundation for community-level tsunami planning. Note the development inside of the 1964 zone. Modified from Suleimani *et al.* (2010).

In February 1965, the western Aleutians ruptured in the M 8.7 Rat Islands earthquake. In the span of just eight years, three quarters of the Aleutian subduction zone ruptured. This forced even the casual observer to consider the interactions between different regions on the megathrust. One grand scientific challenge posed by the 1964 earthquake was to determine whether segmentation patterns in observed megathrust earthquakes could be exploited to forecast future behavior along the arc. In time, the related question of geologic controls on seismic asperities, locking, and slow-slip transients took on similar prominence. The length of the arc and the burst of great earthquakes made the Aleutians the premiere place to explore these ideas. Earthquake pattern studies are exemplified in papers such as Davies *et al.* (1981) and Thatcher (1990). Several of today's high-profile research topics including episodic slip, tectonic tremor, and paleoearthquake histories are rooted squarely in this history.

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The 1964 earthquake made it clear that, from the standpoint of neotectonics and seismic hazards, the Alaska map was nearly a blank canvas. The sustained research that followed 1964 changed this. Beikman (1980) published the first truly statewide geologic map. The 1994 publication of the Alaska volume of the Geology of North America series (Plafker and Berg, 1994) was a timely synthesis of the expansive post-1964 field surveys and includes the first neotectonics map of Alaska (Plafker *et al.*, 1994). These efforts connected disparate studies and provided a rigorous framework for examining tectonics and hazards.

There were just two seismic stations in Alaska in 1964. Several groups mounted aftershock surveys, including an impressive effort by the Albuquerque Seismological Lab, which began recording within three days. By the mid-1970s, the USGS was operating a seismic network focused on the south-central coast. A large-aperture network operated by the Palmer Observatory (now the National Tsunami Warning Center) extended into the Aleutians, and the network operated by the Geophysical Institute at University of Alaska Fairbanks concentrated on Cook Inlet and the north and west reaches of the state. With academic projects in the Shumagin Islands and Adak areas, earthquake monitoring evolved into an extensive, if fragmented, effort. In the late 1980s, the state of Alaska and the USGS formalized commitments to earthquake monitoring by establishing today's Alaska Earthquake Center. In the 1990s, the Alaska Volcano Observatory led a significant expansion of coverage in the Aleutians. Today, the Alaska Earthquake Center, the National Tsunami Warning Center, the Alaska Volcano Observatory, and the National Earthquake Information Center provide integrated monitoring of the different facets of Alaska earthquakes. Some of this evolution is the natural course of advancement. It cannot be overstated, however, that the career efforts, the infrastructure investments, and the political will to achieve what exists today began on 27 March 1964.

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Vertical coseismic deformation was immediately obvious in coastal areas. The seaward horizontal deformation required detailed survey work in ensuing years. Together they told an unambiguous story of slip along the megathrust. Stratigraphic techniques developed on coastal marshes after 1964 mapped the paleoearthquake history and provided a way to assess the hazard potential from rare, though massive, subduction earthquakes (e.g., Shennan *et al.*, 2009). These techniques were later used to discover the Cascadia earthquake of 1700. Another deformation first was the ability to measure the accumulation of interseismic strain from the start of an earthquake cycle. This, together with the locked nature and large amount of land directly above the subduction zone, has made the Prince William Sound region a premiere location to track the progressive loading of a subduction zone. The advent of the Global Positioning System (GPS) allowed this examination to expand to observations of transients and the interplay among adjacent segments (e.g., Freymueller *et al.*, 2008). It has also revealed that the Earth is still adjusting to the 1964 earthquake (Suito and Freymueller, 2009). Similar studies now unfold in Sumatra, Chile, and Japan. Nevertheless, until the past decade, Alaska was one of the only places where such studies could be tied to the known offsets of a giant earthquake.

TODAY

Many people will undoubtedly dismiss the 1964 earthquake as a black-swan event, unlikely to reoccur. As scientists, we unwittingly promote this when we point out that the 1964 patch of subduction zone is unlikely to rupture anytime soon in an M 9 earthquake. However, an M 8 is reasonable in this area, and no one should bet against an M 9 elsewhere in the arc. If there is a black-swan thread to the story, it is that an M 9.2 tsunamigenic earthquake had such a low death toll. The comparable 2004 Sumatra earthquake was more than a thousand times as deadly.

As we commemorate the earthquake, we need to acknowledge the many factors that work against seismic-hazards awareness in Alaska. Fifty years is a long time in culture and politics. Despite an M 5 earthquake most weeks in the state it has been many years since an earthquake jolted us culturally. Alaska's frequent moderate and large earthquakes contribute, paradoxically, to our complacency. Most events occur in areas of low population density, tempting us to believe that Alaska is inherently tolerant to M 6 and M 7 earthquakes. This myth of Alaska earthquake resilience resonates with the hardiness of Alaska's psyche. We unintentionally bolster this myth with maps of Alaska seismicity that downplay strong earthquakes in order not to saturate the scale for the largest events. It is common to plot M 5's as tiny dots, if they are even included. From an awareness perspective, recent major earthquakes (including the 2002 M 7.9 Denali fault and 2013 M 7.5 Craig earthquakes) feed the idea that big earthquakes do not damage Alaska. Even 1964 is a deceptive benchmark that relegates all other seismic activity to the status of a lesser earthquake. One of the most dangerous tenets of this argument is that buildings that withstood the anomalously long-period ground motions of 1964 are probably safe.

The story of Christchurch, New Zealand, needs to be told in Alaska. Several factors led the M 6.1 earthquake in 2011 to be far worse than anyone would have anticipated. Christchurch and much of Alaska share similar mixes of thick, young sediments, and complex shallow faults driven by a nearby subduction zone. Two-thirds of Alaska's population lives in Anchorage, Fairbanks, and the Mat–Su valley, and all three regions are built on unconsolidated Quaternary deposits. Coastal rainfall, river basins, and permafrost conspire to ensure that soils in these areas are saturated and ripe for magnified ground motion and liquefaction. Christchurch is a cautionary tale for Alaska.

Alaska may present a tough face, but infrastructure connectivity is tenuous. The electrical grid is not a grid at all—it is a closed system with a few primary arteries feeding distal spur lines. Goods and services are distributed through a similar spoke-and-hub model. The last link into communities is often by air. Alaska's remote villages rely on a handful of hub towns for everything from food and construction materials to visiting doctors and diesel fuel. This interconnectedness places unusually large importance on harbors, airports, and rail. The fragility of these systems is a risk multiplier that quickly broadens the impact of all hazards.

Reality TV has seized upon these unique systems to generate caricatures of Alaska. It legitimately captures some of the challenges, resources, and lifestyle options that prompt deep passion from Alaska's citizens and tourists. Reality TV does a disservice, however, with its emphasis on rogue elements. By dramatizing the extreme, we risk casting the state as a place where consequences do not apply and hinting that Alaska should be exempted from practices deemed relevant elsewhere. The appropriate lesson to draw from reality shows, if one must, is that Alaska supports all the routine functions of society in a setting that heightens risks and sometimes requires impressive adaptations. Some participants at the 2014 Seismological Society of America meeting may be disappointed by the normalcy of downtown Anchorage during the business lunch hour.

The real difference in Alaska earthquake preparation is one of scale. Widespread earthquake hazards juxtaposed with variable population density present a legitimate challenge when prioritizing resources. Though painful, there is some limited rationale for why federal research and monitoring investments fail to match the scope of the hazards. Earthquake risk necessarily tilts resources toward larger populations at times. The hidden danger in this formulation is the feedback loop that links research, hazard identification, and funding. Investing in research and monitoring programs helps identify specific hazards. These studies lead to new, more in-depth, funding requests. As specific research lines grow, proposal and lobbying machinery grows as well. This mechanism is essential to healthy science, but it can create juggernauts that prioritize exotica at the expense of fundamental research. The 1964 earthquake arguably triggered the last great surge in earthquake research in Alaska. The limited research investment in recent major earthquakes suggests that this interest subsided long ago.

The geographic extent of mainland Alaska's seismic network has evolved little in the past three decades, though the data quality is far superior. Vast swaths of western and northern Alaska remain uninstrumented. Clusters of M 4+ earthquakes frequently occur hundreds of kilometers from the nearest seismic station. Each is a missed opportunity to constrain the larger hazard, often in regions where active fault structures remain unmapped. These are exactly the studies needed to evaluate the current and proposed natural resource megaprojects that dot Alaska. Where the seismic network is strong, collocated GPS remains rare. The Plate Boundary Observatory greatly expanded geodetic resources, but even this plan was ultimately scaled back from initial concepts. Efforts to transition the GPS network to high-rate sampling have languished. The absence of any movement toward earthquake early warning should alarm the citizens of Alaska. The southern and central regions of the network can support early warning algorithms. The distance to urban centers and deep nature of many earthquake sources would allow extra warning time and compensate for the wider distribution of the network. Alaska is the only U.S. testing ground where early warning could be exercised routinely on moderate and large earthquakes. These benefits would extend far beyond Alaska.

Advocacy is an uphill battle. Alaska's footprint in Washington, D.C., is a fraction of its geographic and cultural footprint. Alaska issues are frequently written off as outliers. Alaska's notorious and unfortunate association with congressional earmarks a decade ago provides an easy excuse to write off unfamiliar needs as bridges to nowhere. Despite a real and meaningful appreciation for Alaska hazards at USGS, the Federal Emergency Management Agency (FEMA), and the National Oceanic and Atmospheric Administration (NOAA), there remain just a handful of Alaska-based federal employees deeply involved in the earthquake hazards problem. Academic research proposals for geophysical field studies have an inconsistent history. When funding becomes tight, Alaska comes into the crosshairs. At the state level, the motivation to characterize hazards is only pressing in the aftermath of damaging events and is narrowly focused on transportation corridors. On this front, the cultural aftershocks of 1964 subsided long ago.

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Nevertheless, earthquake problems are in the spotlight now. This anniversary brings tremendous—though brief—attention to the human face of Alaska's earthquake and tsunami risks. FEMA's 2014 National Exercise Program's Capstone Exercise, premised loosely on a 1964-like event, kindled discussions of Alaska hazards across the country. The National Science Foundation (NSF) EarthScope USArray program is becoming on-the-ground reality in Alaska. The NSF GeoPRISMS program is spurring unprecedented discussions of collaboration across the Aleutians. This progress arguably represents the greatest surge in Alaska earthquake interest post-1964. The rapid advances 50 years ago demonstrate what is possible with coordinated effort. Now the onus is on the research community to ensure that today's opportunities seed long-term programs, not just fleeting projects.

It is tempting to believe that 1964 is the type example of an Alaska earthquake, so we now know what to expect. However, history has demonstrated repeatedly and tragically that the next earthquake is often not what we expected. No effort could possibly mitigate the full hazard of earthquakes in Alaska. As a state, we must eventually engage in a sober dialog about the level of earthquake risk we are willing to accept. This delicate conversation will only succeed once we have a meaningful foundation of applied research. Alaska's frequent earthquakes allow this research to be validated quickly, providing an obvious proving ground for earthquake ideas that impact the globe. We can leverage this opportunity only if we have the foresight to invest in research, monitoring infrastructure, and field data collection. The 1964 earthquake demonstrated that enormous unknowns, combined with indisputable hazards, make earthquake research in Alaska a shrewd and worthy investment with dividends that pay far beyond the 49th state.

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