

## Web Feature

# Nuclear Stewardship: Lessons from a Not-So-Remote Island

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In 1971, the United States set off its largest underground nuclear test. The 5-megaton Cannikin explosion was deemed too large for the Nevada Test Site, and at the time the underground nuclear test site of Amchitka Island in the west Aleutians seemed the ideal choice.

Although the Atomic Energy Commission (AEC) knew then that the region was seismically active, Amchitka was selected as a test site before the geologic community had fully accepted the theory of plate tectonics and understood the broader context of forces acting on the island. The United States set off three underground nuclear explosions there between 1965 and 1971. Since then, we have realized that the island is actually part of a small crustal block being torn apart by oblique subduction — and is therefore one of the least stable tectonic environments in the United States.

It is rare that the time scales of human endeavors and those of Earth processes significantly overlap. An important exception, however, is in the proper management or "stewardship" of sites contaminated by radionuclides, whether through intentional disposal of the byproducts of energy or weapons production or by the remnants of nuclear explosions. Stewardship of these sites means not only evaluating actions for the long term; but also, once that long term has arrived, deciding what to do when the evaluation has radically changed.

To date, the proposed Yucca Mountain nuclear repository in Nevada has garnered the most thorough consideration of the potential effects that tectonic and volcanic processes operating over long periods of (human) time might have on how well an underground cavity can contain nuclear material. The level of geologic activity in the Great Basin where Yucca Mountain lies is modest, yet scientists working there have treated the possibility of natural disruption with great care.

But what if nuclear material were deposited at depth within one of the most active and dynamic geologic environments of the planet? Such is the case at Amchitka Island. In light of our new knowledge, the original decision to use Amchitka for testing now appears regrettable.

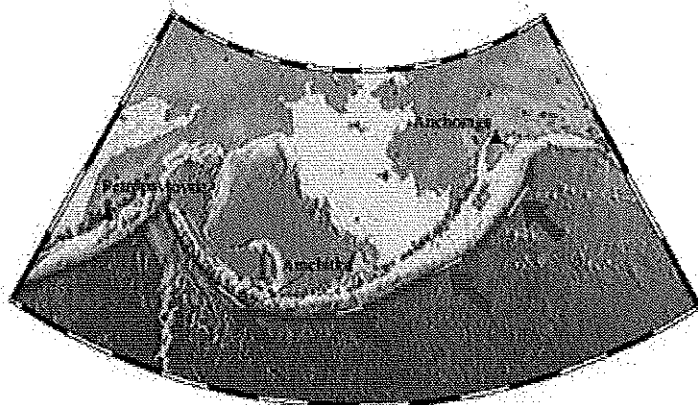
The challenge of long-term stewardship in Amchitka is not how to contain radionuclides; the tests cannot be undone and we cannot make their products disappear. All we can do is monitor the site. But what exactly should we look for? Where should we look for it? And how do we decide the best way to look? With the understanding the plate tectonics revolution has given us, can we assess more accurately the risks to the environment and humans and develop an efficient monitoring strategy? Will future

insights make today's decisions look foolish?

By serendipity, the tests conducted at Amchitka gave us a worst-case scenario, geologic experiment in waste isolation. We may benefit from this lesson through a broad-based study of chemical transport in this active tectonic regime. What we learn may be reassuring if the risk is minimal even in these dynamic conditions. Or it may be cautionary if we find the risk is high.

### How stable is stable?

Amchitka lies in the western portion of the Aleutian Volcanic Arc, which began its development some 55 million years ago and today hosts about 50 active subaerial volcanoes over a distance of 3,000 kilometers. The arc is also the locus of more than 90 percent of the seismic energy released within the United States over the period during which records have been kept. Magnitude-8 earthquakes occur roughly once a decade; three of the six largest earthquakes ever seismically recorded occurred along the Aleutian arc between 1957 and 1965.



**The Aleutian Volcanic Arc. Red circles are active volcanoes. Arrows show the motion of the Pacific Plate relative to the North American plate. Courtesy of J. Eichelberger.**

Indeed, the first test conducted at Amchitka, a modest 100-kiloton explosion detonated shortly after a nearby magnitude-8.7 earthquake, was done to determine whether natural seismicity could hinder detection of nuclear explosions.

Today, continuous coring to depths exceeding 2,000 meters, conducted before the nuclear tests, provide one of the richest 3-D data sources on the crest of a young island arc. The island itself is made entirely of volcanic products: andesitic surface lavas, submarine formations consisting of angular volcanic fragments, pillow lavas and granodiorite intrusions. The island is cut by normal faults trending east-northeast with modest Quaternary displacements. Formations become younger to the northwest because, despite a general southeast dip of strata, the normal faults are generally down to the northwest.

The AEC judged the site sufficiently "geologically stable" for large tests — meaning they had little evidence of significant vertical tectonic motion or of slope failure. The possibility of large, ongoing horizontal displacements was not a theme of the day, as most of the evidence for them lay beneath the ocean. Even after the plate tectonics revolution, the concept of slip partitioning at plate margins did not develop for many years. This concept now tells us that Amchitka and the entire western Aleutian arc is being sheared and extended. The arc is not a stable, unchanging feature, but rather one undergoing rapid internal deformation.

### Today: measuring the effects

The explosions were detonated in the submarine laharic breccias within a few kilometers of the coast. At the time of the tests, no radioactivity escaped into the atmosphere or ocean. However, the marine environment has effectively been unmonitored since that time. The most pressing remaining question

concerning Amchitka, then, is the risk of future migration of radioactive test products from the shot cavities to the accessible environment.

Post-test drilling data from the Nevada Test Site provide a conceptual understanding of the effects of an underground nuclear test. Rock next to the device vaporizes or melts, accumulating as a puddle of magma on the floor of the cavity produced by the explosion. Extensive fracturing occurs beyond this zone from the shock of the explosion. Shortly afterward, the roof of the cavity collapses in a second wave of fracturing, and a chimney to the surface forms.

Most of the radionuclides remained within the magma puddle, at least part of which becomes glass. Some radionuclides travel with the silicate vapor from the vaporized rock, and settle within the collapse chimney. In Amchitka, the amount of melted rock created by the Cannikin test is probably equivalent to a moderate-sized volcanic lava dome.

Of the Amchitka tests, only Cannikin was large enough to produce surface disruptions obvious today. The Cannikin explosion activated faults and violently expelled groundwater from them. The region near ground zero fractured into large blocks and subsided to form a basin. Niren Biswas determined a body wave magnitude for the explosion of 6.8, while that for the largest subsidence event was 4.9. The combination of subsidence and faulting dammed the drainage of White Alice Creek, which filled the cavity and collapse chimney and formed Cannikin Lake.

The center of subsidence is displaced southeast of ground zero, probably because the stratigraphy dips southeast, with collapse of the cavity roof propagating upward perpendicular to bedding rather than perpendicular to the surface. Other fractures drained perched, shallow water tables, emptying preexisting lakes. Individual fractures are up to 2 kilometers long with up to 6 meters of vertical displacement. The nearby Bering Coast experienced many rock falls and about a meter of uplift within a zone bounded by normal faults northwest and southeast of the test.

### **Evolution of geologic thinking**

The salient fact about geologic interpretation of the Amchitka site is that the concept of subduction was only just coming into existence at the time of pre-test studies and was not considered in selecting the site. Although Robert Coats presented an insightful precursor to plate-tectonic views of the arc in 1962, publication of that view was hard-fought as it ran contrary to the mindset then.

By the time of the Cannikin test, the scientific community was accepting the Aleutians as a classic example of ocean-ocean subduction. However, it became apparent that more must be happening than motion confined to the boundary of the rigid Pacific and North American plates. Eric Geist and colleagues noted in 1988 that the obliquity of subduction increases westward with the curvature of the arc, and that the western Aleutians appear to lie on broken crustal blocks, rotating clockwise and extending westward in the resulting shear zone. A decade later, using Global Positioning System (GPS) techniques, Hans Ave Lallemand confirmed that the arc was indeed extending. Lallemand determined that Attu Island, part of the arc, moves 3 centimeters a year northwest relative to North America. Topographically, the largest break that might reflect this extension is Amchitka Pass, just east of Amchitka Island.

In current monitoring, we used a network of six GPS sites to measure the island's motion relative to North America, along with the island's rotation and internal deformation and any continued subsidence of the shot points. John Oswald had previously surveyed a point on the main runway with high precision four years earlier as part of a survey for the Federal Aviation Administration. His data and ours showed

that the island was moving west at 2 centimeters per year. This rate confirms previous work and is consistent with the idea that Amchitka Pass represents a major locus of rifting.

Thus, we can understand the form of Amchitka to be a segment of an arc crest that has rotated clockwise off the volcanic front and is now being torn as the arc extends parallel to itself. The graben systems and smaller normal faults that cut the island result from this pervasive extension of the arc. The new GPS measurements suggest that the island's boundary with North America is a strike-slip fault north of the island, spreading two-thirds as fast as the San Andreas fault. This fault might be located along the submarine escarpment just off the coast. Whether or not the escarpment arises from strike-slip faulting, the cross-island normal faults must intersect it, providing a plausible, though by no means certain, pathway for fluid migration from the shot cavity to the marine environment.

### **Not so remote**

A major factor in the AEC's selection of Amchitka was the island's perceived remoteness. Undoubtedly, remoteness has contributed to dormancy of Amchitka as an environmental issue, after the excitement subsided over the well-publicized Cannikin test — excitement that gave birth to Greenpeace.

What is remote to some people is home to other, though fewer, people. It is a fundamental aspect of democracy that the wishes of the many prevail over the wishes of the few, and Alexis de Tocqueville warned more than a century ago that this ascendancy can be tyrannical. In the case of Amchitka, the few may be at special risk: They are Native people living nearby in the Aleutians who derive most of their diet directly from the land and sea. However democratic, proper nuclear stewardship cannot tolerate hardship for the few to relieve the many.

Amchitka's perceived remoteness is in part a consequence of conventions in map projections. The familiar Mercator Projection places it well out of the way for those traveling between North America and Asia. The propensity for Americans and Europeans to tear the world down the International Dateline in order to flatten it further isolates Amchitka in a corner.

In fact, Amchitka is much closer to the nearest large Russian city, Petropavlovsk-Kamchatksky, than to the nearest American one, Anchorage, and lies directly on the great circle route between eastern Asia and western North America. As long as commerce continues between Asia and North America, the area will be frequently traversed. It is also a vital international fishery, though few Americans would recognize the Aleutian town of Dutch Harbor as their most prosperous seafood port. Serious leakage of radionuclides could have very far-reaching effects.

The current dearth of a local population on Amchitka is an anomaly over the scale of Holocene time, reflecting catastrophic decline in the Aleut population as a result of Western contact, further amplified by lingering effects of World War II. Indeed, the government itself is partly responsible for this absence, because the U.S. response to a potential Japanese invasion was to forcibly evacuate the Aleuts and intern them thousands of miles away.

The lack of population must be seen as temporary in the long-term view of stewardship. And although living in the western Aleutians is either costly or requires the specialized Aleut technology of survival, it could well become easier. The islands have supported forests during warmer Quaternary intervals.

### **A shift in understanding**

History gives us no cause for comfort in the perception of Amchitka's remoteness, but it does tell us

something about the evolution of scientific understanding. The geological aspects of that understanding rest on both the technology of geoscience observation and the conceptualization of the problem. The shift in interpretation of the Amchitka region from geosyncline to subduction zone could hardly have been greater. Horizontal motions are now directly measurable and the faults along which they occur can be imaged by techniques that did not exist 30 years ago.

Despite only three decades of hindsight for judgment, the change from static to mobile lithosphere does appear to be a permanent paradigm shift of Copernican proportions. We must expect, however, that more intellectual surprises will occur in the future. Already the simple concept of internally rigid plates has required embellishment and much in the traditionally drawn subduction zone cross-section remains poorly substantiated. Truth is as elusive to science as justice is to government. All we can do is work for progress.

Progress requires knowledge. With a shift in understanding comes uncertainty about past actions, but such a shift also brings new tools for learning. Amchitka is an experiment that we would not repeat, but it is one from which we can learn, and one from which we are obliged to learn as we become more dependent upon geologic isolation of the radioactive byproducts of our civilization.

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#### **Additional Reading:**

“Displacement Partitioning and Arc-Parallel Extension in the Aleutian Volcanic Island Arc” by HG Ave Lallemand. *Tectonophysics*. 1996, vol. 256, p. 279-293.

“Magma Type and Crustal Structure in the Aleutian Arc” by R.R. Coats. *American Geophysical Union Monograph* 6. 1962, p. 92-109.

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“Summary of Hydrologic Controls on Groundwater Flow at the Nevada Test Site, Nye County, Nevada” by R.J. Lacznik, J.C. Cole, D.A. Sawyer and D.A. Trudeau. *U.S. Geological Survey Water Resources Investigations Report* 96-4109. 1996.

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