Reports

Aftershocks of the 4 February 1965 Rat Island Earthquake

Abstract. *Studies of earthquake aftershocks as a function of space, time, and rate of energy release (magnitude) afford new evidence of earth structure. The sharp boundary conditions of the epicenter locations suggest block faulting about the Rat Islands as a subsystem of the Aleutian Islands arc structure. Earthquake frequency of occurrence in time and magnitude are given.*

A major earthquake, registering 7¾ on the logarithmic magnitude scale (M_s) of Gutenberg and Richter (*1*), occurred on 4 February 1965, in the Rat Island region of the Aleutian Island arc (Fig. 1). For the entire world there are approximately six earthquakes of greater magnitude each year. The main shock of the Rat Island earthquake was followed by an intensive aftershock sequence. The U.S. Coast and Geodetic Survey rushed portable seismographs to Shemya and Amchitka in the Aleutian Islands to record this activity. From data recorded at these temporary and permanent seismograph stations, a record number of epicenters were determined for the aftershock sequence. The distribution of epicenters as determined for aftershocks which occurred during a 45-day period following the main shock is shown in Fig. 1.

The aftershock epicenters, as shown in Fig. 1, form an approximately rectangular zone about 650 km long and 200 km wide. Both the eastern and western margins of the zone show sharp boundaries suggestive of fault zones transverse to the trend of the island arc structure. Brazee (*2*) reports a study of a sequence of earthquakes which occurred in 1957 in the Andreanof–Fox Island region of the Aleutian Islands. This region is east of the Rat Island region. The presence of a sharp discontinuity, transverse to the arc structure and located at approximately the eastern boundary of the zone shown in Fig. 1, was also suggested by Brazee's study. In general, the epicenters (Fig. 1) are located between the axis of the Aleutian trench and the island chain, with no perceptible increase in depth of focus for events closer to the island chain, as is the case in some other parts of the circum-Pacific belt. Typical island arc structure consists of a deep trench separating the main ocean basin from a parallel island chain. According to the accepted theory, the seismicity of the island arc is associated with a structural plane which intersects the ocean-facing slope of the trench and passes beneath the island chain at a depth of several tens of kilometers. The group of epicenters south of the Aleutian Trench, between 170° and 173°E, represents an anomalous departure from the general parallelism of earthquake epicenters and island arc structures. This epicenter distribution, coupled with the sharp western boundary of the epicenter zone, suggests the presence of a structural element transverse to the main arc structure and bounded on the west by a major fracture zone.

Figure 2 shows the frequency of occurrence of aftershocks of the Rat Island earthquake of 4 February 1965, for the period 4 February to 20 March 1965. Also shown in Fig. 2 is a similar plot of the aftershock sequence for the disastrous Prince William Sound earthquake (*3*) of 27 March 1964. The two distributions are quite similar in appearance although a larger number of aftershocks are associated with the Rat Island earthquake. The U.S. Coast and Geodetic Survey located 870 shocks which occurred in a 45-day period following the Rat Island earthquake; a total of 728 shocks were located during the 45-day period following the 1964 Prince William Sound earthquake. Compilation of this quantity of data would have been impossible without the information provided by five sensitive array-type stations currently operated in the United States and the electronic data-processing techniques now being used by the U.S. Coast and Geodetic Survey. The high sensitivity of the array-type stations is obtained by summing traces of a spread of seismometers in a manner designed to suppress local seismic effects and to enrich signals from distant sources. Earthquakes associated with a minimum of five readings may be identified by the Coast Survey's computer program which automatically processes a file of chronologically sorted readings which have been routinely telegraphed to Washington by seismograph stations throughout the world.

A measure of the intense seismic activity associated with the Rat Island aftershock sequence is given by reference to earthquake statistics for 1964 which show that only 30 earthquakes were located by the U.S. Coast and Geodetic Survey in the Rat Islands region during the entire year of 1964. It is noteworthy that in both the Rat Islands and Prince William aftershock sequences shown in Fig. 2 more than 50 percent of the total number of aftershocks occurred in the first 5 days after the main shock. The number of aftershocks which occur at the beginning of the series may be several times larger than indicated because of an important limitation concerning the data; that is, aftershocks in general are not readily detected within the train of large amplitude waves generated by the main shock which has a duration of several hours at distant stations.

Figure 3 shows the number of after-

Table 1. Wave heights from earthquake, 4 February 1965.

Tide gage station	Distance (km)	Wave heights (ft)	Wave heights (m)
Adak	330	2.3	0.7
Attu	460	10.4	3.1
Unalaska	1010	1.6	.5
Midway	2530	0.8	.2
Honshu	3220	4.0	1.2
Wake	3640	0.8	2.4
Nawiliwili	3800	1.0	.3
Honolulu	3940	0.6	.2
Hilo	4170	1.9	.6
Guam	5200	0.5	.2
Apia	7230	0.5	.2
Pago Pago	7280	0.9	.3

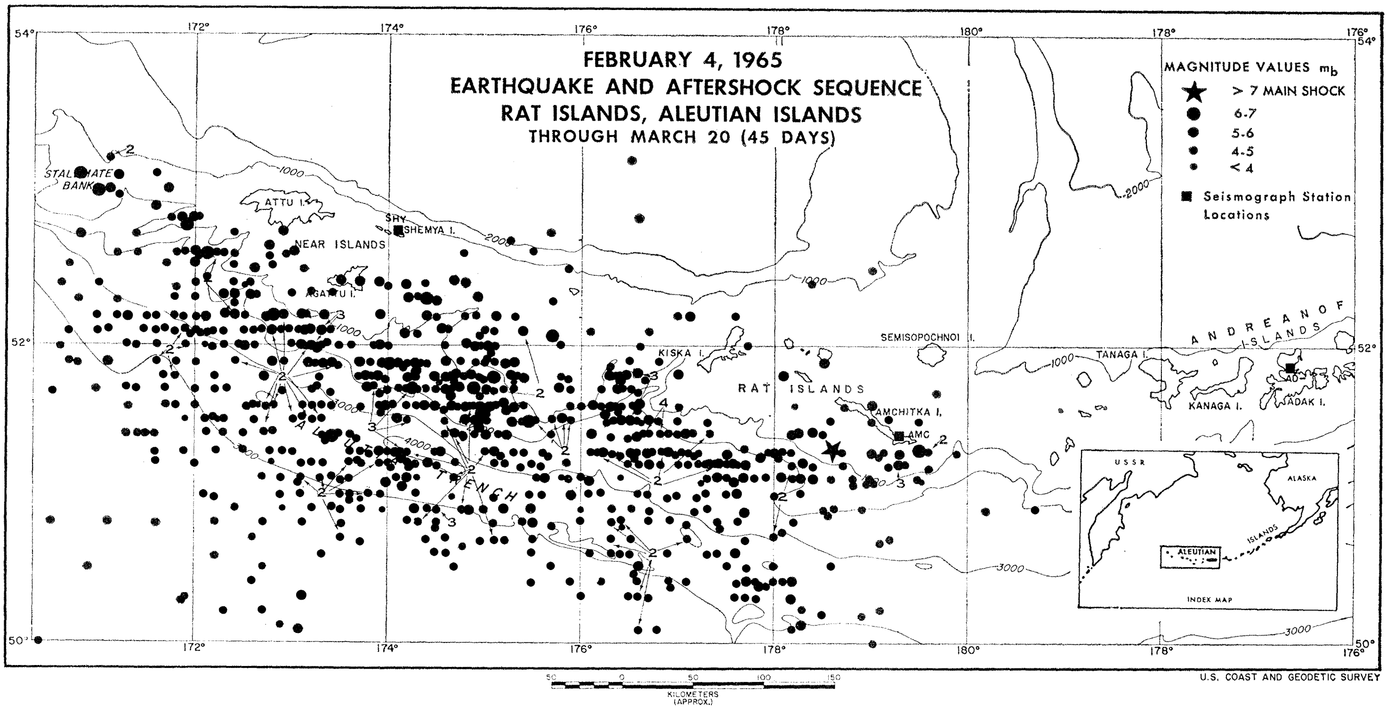
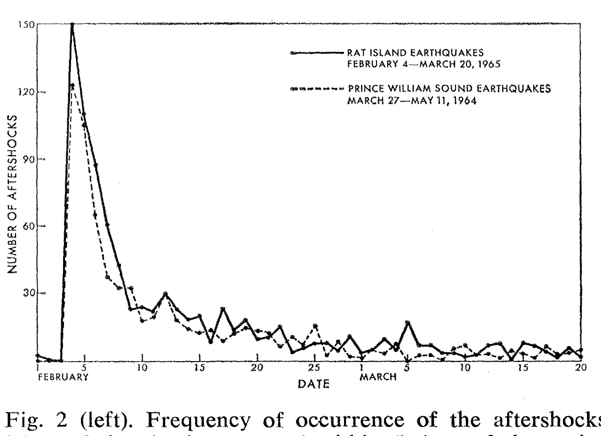


Fig. 1. Map of earthquake on 4 February 1965, earthquake and aftershock sequence of the Rat Islands, Aleutian Islands.

shocks (for both the Rat Island and Prince Williams Sound earthquakes) as a function of magnitude (m_b) as determined from seismic body waves. Analysis of the data (Fig. 3) indicates that the network of seismograph stations used to locate the aftershock epicenters recorded essentially all of the events of magnitude 5.0 and greater. Below magnitude 5.0, the recording efficiency of the network decreased, although good coverage was obtained down to about magnitude 4.3. In this regard the operation of temporary stations within the epicentral area disclosed a very important bit of information—the sensitive array-type stations operating within the conterminous United States detected significantly more of the smaller aftershocks than the temporary stations. In the magnitude range 5.0–6.0, the frequency of occurrence (N) is found to be of the form $\log_{10} N = A - B\, m_b$ where $A = 7.1$ and $B = 1.1$. This result, which agrees fairly well with the world-wide averages cited by Gutenberg and Richter (*4*), states that the number of earthquakes decreases by a factor of ten for each unit increase in magnitude.

The Rat Islands earthquake of 4 February 1965 was sufficiently large to cause a tsunami alert to be broadcast. The tide gage station at the island of Attu showed a 3-m (10-ft) rise attributed to a seismic seawave from the main shock. Small wave heights were recorded at other Pacific Ocean tide gage stations (Table 1).

It is reported that two waves with amplitudes 10.5 to 12 m (35 to 40 ft) were observed, by military personnel, on the island of Shemya shortly after the time of the main shock. Shortly after the 4 February earthquake a field party on the south coast of Amchitka noted a line of flotsam which appeared to have been moved recently



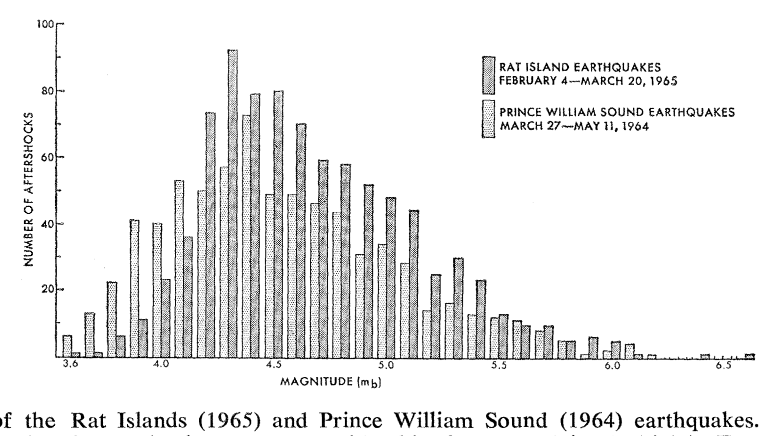


Fig. 2 (left). Frequency of occurrence of the aftershocks of the Rat Islands (1965) and Prince William Sound (1964) earthquakes. Most of the shocks occurred within 5 days of the main shock; afterwards there were considerably fewer. Fig. 3 (right). Frequency as a function of magnitude (energy) level. Within the 5.0 to 6.0 range the number of shocks (N) is $\log_{10} N = 7.1 - 1.1\, m_b$, where m_b is derived from the body wave.

about 2 m (6 ft) above the normal high-tide line. Amchitka is the island closest to the epicenter of the main shock.

The primary shock of the Rat Islands earthquake on 4 February 1965 was felt at Shemya airbase, some 300 km northwest of the epicenter. Some damage to runways and buildings was reported. As the Aleutian Islands between Shemya and Adak are uninhabited no other land reports were made, but the ship S.S. *Ohio*, some 150 km from the epicenter, reported that the primary shock was felt. Members of the U.S. Coast and Geodetic Survey field party, which set up and operated the temporary seismograph station on Amchitka Island, reported feeling a number of the aftershocks of the Rat Islands earthquake. There was very little surface evidence of terrain damage from the primary Rat Islands shock or its many aftershocks.

On 30 March 1965, an aftershock of magnitude (M_s) of 7 to 7¼ occurred south of the primary shock of the Rat Island series. This shock was followed by another sequence of shocks with current counts (not yet complete) showing 60 events on 30 March, 30 events on 31 March, and 15 events on 1 April.

In summary, large aftershock sequences, such as those recorded for the Prince William Sound earthquake of 27 March 1964, and the Rat Islands earthquake of 1965 (when well-recorded by both local and distant seismograph networks) will provide new data on major tectonic trends in seismically active areas.

Although the structure of the Aleutians has been considered that of a typical island arc, the data presented here suggests that the seismicity of the area is very complex. North-south trending fracture-zones which divide the island chain into very large fault blocks are proposed to explain the very sharp limits of observed aftershock activity along the island chain. St. Amand (*5*) and Menard (*6*) have discussed similar structures in other parts of the Pacific Ocean.

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7. We thank Julianne Squire and D. W. Gordon for assistance.

15 May 1965

Half-Lives of Argon-37, Argon-39, and Argon-42

Abstract. *The half-lives of three argon isotopes have been carefully determined, with the following results: Ar^{37}, 35.1 ± 0.1 days; Ar^{39}, 269 ± 3 years; Ar^{42}, 32.9 ± 1.1 years. By combining the Ar^{42} value with earlier data, a cross section of 0.5 ± 0.1 barn is calculated for the reaction, with thermal neutrons, $Ar^{41}(n,\gamma)Ar^{42}$.*

Accurate half-life values of the argon isotopes are needed for various applications in cosmochemistry (*1*) and in nuclear chemistry and physics (*2*). For example, Ar^{37} and Ar^{39} have been determined in many meteorites in order to study possible variations of cosmic ray intensity in time and in interplanetary space (*3*).

Various values for the Ar^{37} half-life (*4*) have been reported. Weimer, Kurbatov, and Pool, who reported 34.1 ± 0.3 days, prepared the Ar^{37} by various methods including $K^{39}(d,\alpha)$, $Cl^{37}(d,2n)$, and $Cl^{37}(p,n)$ nuclear reactions. These investigators followed the decay of the activity with an air-ionization chamber for as long as seven half-lives. Miskel and Perlman (*5*) prepared the Ar^{37} from calcium metal by the $Ca^{40}(n,\alpha)$ reaction, and arrived at a value of 35.0 ± 0.4 days. They used gas proportional counters and also a special ion chamber. Kiser and Johnston (*6*) followed the decay of the K Auger-electron peak with a proportional counter and multichannel analyzer for 70 days, and they reported a value of 34.30 ± 0.14 days. In view of the spread of values between 34.1 days and 35.0 days it was considered desirable to restudy the half-life of Ar^{37}.

There is only one reported determination of the Ar^{39} half-life. Zeldes *et al.* (*7*) found a value of 265 ± 30 years. Their samples were obtained from the $K^{39}(n,p)$ reaction by intense neutron irradiation of KCl. They made the radioactivity measurements with a calibrated magnetic-lens beta-ray spectrometer and found the number of Ar^{39} atoms by volumetric measurement and mass-spectrometric determination of the isotope ratios. A preliminary determination of the Ar^{39} half-life made in this laboratory yielded a value of 325 years (*8*).

A lower limit of 3.5 years was placed on the half-life of Ar^{42} (*9*) when its preparation was first reported. Although no other determinations have been published, preliminary data obtained at this laboratory several years ago showed that the Ar^{42} half-life is approximately 30 years.

The half-life of Ar^{37} is of such length that it may readily be determined from the course of its decay. The Ar^{37} was prepared by the reaction $Ca^{40}(n,\alpha)Ar^{37}$. Calcium carbonate (180 mg) was irradiated in the Brookhaven reactor for 3 hours. The sample, in a vacuum system, was dissolved in dilute hydrochloric acid in the presence of mixed carrier gases consisting of argon, krypton, and xenon. Argon was separated and purified by gas chromatography and by gettering with hot titanium metal. (This procedure has a decontamination factor from krypton of at least 10^5.) Samples of the argon were placed into five conventional proportional counters (1.9 cm inside diameter; 30 cm long), and the counters were then filled with P-10 gas (90 percent argon : 10 percent CH_4) to a pressure of one atmosphere. Plateaus of these counters showed two distinct levels corresponding to K-capture and to the sum of K- and L-captures. The counters were operated near the high-voltage end of the sum level. The decay of Ar^{37} was followed for 175 days, about five half-lives. The decay curves were analyzed by a least-squares method (*10*). The results from the five counters were 35.23 ± 0.06, 35.20 ± 0.06, 34.98 ± 0.05, 35.16 ± 0.05, and 35.11 ± 0.05 days, from which an average value of 35.14 ± 0.05 was obtained. In order to allow for possible systematic errors the value has been rounded off to 35.1 ± 0.1 days. Analysis of the decay curves gave no indication of a longer-lived component. Further evidence concerning the purity, with respect to radioactivity, of the gas can be derived