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CGS-746-120

EXPLOSION EFFECTS AND EARTHQUAKES
IN THE AMCHITKA ISLAND REGION

By

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U. S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Survey
Rockville, Maryland 20852

June 29, 1971

Prepared for the U. S. Atomic Energy Commission
Nevada Operations Office
Under Contract AT(29-2)-746

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Printed in the United States of America. Available from the
National Technical Information Service
U. S. Department of Commerce
Springfield, Virginia 22151

Price: Printed copy \$3.00; Microfiche \$0.65

ABSTRACT

Microearthquake monitoring by a network of seismographs located on Amchitka and nearby islands reveals that the nature of earthquake activity in this region is consistent with the hypothesis of underthrusting of the Aleutian arc by a rigid lithospheric plate. Observable effects of the nuclear explosion MILROW were small, of short duration, confined to the region immediate to the explosion, and were apparently independent of this geotectonic mechanism.

An important consequence of the hypothesis of sea-floor spreading is that the Earth's major tectonic features are the result of the relative movement and interaction of rigid lithospheric plates over its surface (1). Plate boundaries are marked by relative motion along transform faults and by zones of convergence or divergence of lithospheric material. Since the locus of most of the world's seismic activity also lies along these boundaries it is little wonder that the concept of plate tectonics receives its widest support from the observations of seismology (2).

Island arcs, like the Aleutians, are typically zones of convergence, that is, they are underthrust by oceanic plates. Hence, the nature of earthquake activity in the Amchitka Island region is deeply rooted to the tectonics of the entire Aleutian arc and to global movements in general. In view of the current interest in the effects of nuclear testing on Amchitka Island, it is imperative that we report important new seismological data relevant to understanding the tectonics of the region and observable seismic effects from the nuclear explosion MILROW (October 1969, about 1 megaton).

In 1969, at the request of the Atomic Energy Commission (AEC), the National Ocean Survey (NOS) undertook an Aleutian Seismic Program which includes the interpretation and

reduction of data from a continuously monitoring network of seismographs in the Aleutian Islands and Alaska. This seismic network has a three-fold purpose: (1) to monitor the seismicity of the entire Aleutian arc; (2) to monitor extremely low-level seismic activity in the Amchitka Island region to describe accurately the natural patterns which would be observable on a larger scale over a longer period of time; (3) to document the effects from underground nuclear explosions on Amchitka Island.

A regional seismic network was established by supplementing seismographs, already operating in Alaska and on Adak Island as part of the Alaska Regional Tsunami Warning System, with new installations at Granite Mountain in northwest Alaska, and at Shemya and Nikolski in the western and eastern Aleutians, respectively. The data from these seismographs are transmitted via telemetry circuits to the central observatory at Palmer, Alaska, for preliminary interpretation (3).

To monitor low-level seismic activity in the Amchitka Island region, seismographs having high-gain high-frequency response characteristics were installed on Amchitka and nearby islands. The data are transmitted via radio

telemetry and/or hard wire to a central recording site on Amchitka (4). Fig. 1 illustrates the seismograph network configuration and an operational log (5).

Data collected from this local network from 1969 to 1970 were carefully screened for events with signals clearly recorded by five or more seismographs. Epicenters computed for these events, together with larger events located independently using teleseismic data, are plotted in Fig. 1 according to depth-of-focus class and magnitude (6). Epicenters in the 0-50 kilometer range of focal depths clearly demonstrate a strong correlation with structural features having expression in the bathymetry of the sea floor. This observation is not surprising, since these shallow earthquakes fall primarily within the zone of oblique underthrusting by the oceanic plate, and the structural features are conceivably a direct result of this mechanism. Deeper earthquakes appear more evenly distributed along a steeply dipping seismic zone extending northward from the ridge crest to depths in excess of 200 kilometers just beyond the volcanic arc. Epicenters of the very deepest events lie primarily in a northeast-trending zone coincident to the intersection (and possible superposition) of the Aleutian arc with

the Bowers Ridge, a large arcuate aseismic structure extending into the Bering Sea. This distribution in focal depth becomes more clearly evident by projecting hypocenters within the Rat block into the section A-A', illustrated in Fig.

2. Also shown, for comparison, is a hypothetical model of the plunging oceanic plate independently derived from travel-time residuals from the 80-kiloton nuclear explosion LONG SHOT (7), an earlier (October 1965) test on Amchitka. The well-delineated distribution of seismic activity is similar to results obtained in other zones of convergence (2) and supports the model of an underthrusting lithospheric plate. The seismicity demarcates the plate, confirms its extent to 50 kilometers or less, and lends convincing support to the hypothesis that, below the zone of underthrusting, earthquake-generating stresses are contained within lithospheric material that has descended into the mantle (2, 8). These are all significant evidence for the plate tectonics concept. Local flexures, volcanism, and possible lateral movements in the overthrusting lithospheric plate give rise to a scattering of shallow-focus activity above the inclined seismic zone.

Further evidence in support of island arcs as zones at convergence comes from focal mechanism studies (8, 9). In Fig. 1, continued underthrusting of the Aleutian arc is indicated by long-period body-wave focal mechanism solutions for

four large events in 1969 (10). These solutions are not only consistent with earlier patterns (9), but also mark the western margin of the Delarof block as a region of current, large-scale tectonic activity.

Major Aleutian earthquakes often precipitate aftershock activity which, in some instances, continues for a year or more over zones which include large portions of the arc (11). These zones are generally sharply bounded, suggesting that isolated segments of the Aleutian arc are activated independently. Aftershock sequences of major earthquakes occurring in 1957 and 1965 are cited as strong evidence for the existence of such a boundary between the Rat Islands and the Delarof Islands, approximated by the dashed line in Fig. 1.

The western margin of the Rat block and eastern margin of the Delarof block are near 177°E and 177°W , respectively, along deep canyons which indent the ridge. This view is further supported by structural features inferred from the bathymetry and by an apparent offset in the volcanic arc.

Our more recent data also suggest a significant difference in the distribution and general level of seismic activity between the blocks. This is demonstrated in the upper portion of Fig. 3 by the cumulative daily strain release

(the sum of the square roots of the energies of individual earthquakes) computed independently for each block, using only events detected at teleseismic distances to insure uniformity. It is clear that, although the blocks are approximately the same dimensions, the seismicity of the Delarof block is about nine times that of the Rat block in terms of strain release. Moreover, the Delarof block has released strain equivalent to nearly four magnitude 7.0 earthquakes over this two-year period.

It is also of interest to monitor earthquake strain release local to Amchitka Island. A representative volume was chosen in the form of a hemisphere 55 kilometers in radius and centered on MILLROW (see Fig. 1 and 2). It contains most of the underthrust zone below the south end of Amchitka Island. For an eleven-month period and including all detected events, we obtain, as shown in the lower portion of Fig. 3, a fairly uniform rate of strain release equivalent to nearly three magnitude 6.0 earthquakes over the same period of time. Hence, the rate of strain release is indicative of a continuing tectonic process beneath the island.

A source of concern to seismologists is the possibility that a nuclear explosion may trigger a destructive earthquake.

It is now well known that nuclear explosions are always followed by relatively small earthquakes, which originate near the explosion cavity or along faults in its immediate vicinity (12), but attempts to show that the earthquakes extend more than a few tens of kilometers from those sites have been unsuccessful (13). Observations of seismic effects from the nuclear explosion MILROW confirm these results. The careful monitoring of earthquake patterns before and after MILROW by the local Amchitka seismograph network revealed no evidence for any apparent spatial or temporal changes in the natural seismicity (14). Close-in to MILROW, however, seismic monitoring revealed that a swarm of hundreds of very small shallow-focus earthquakes having an asymmetric radiation pattern did occur immediately after detonation in a zone not more than 5 kilometers in radius from ground zero. This activity terminated abruptly 37 hours later at the time of the MILROW cavity collapse. The magnitude of the largest of these aftershocks was about 3.4, and only two were larger than 3.0 (MILROW and its cavity collapse were magnitude 6.5 and 4.3, respectively). None of the aftershocks were detected at teleseismic distances.

With the exception of the period shortly after the explosion and immediately before the collapse when individual events could not be distinguished, all the aftershocks could be

readily identified and approximately located by their signal character and relative arrival times. In Fig. 4 are shown the epicenter and focal depth distribution for aftershocks located using data from at least four of the five seismograph locations indicated. The correlation of these patterns with conspicuous east-northeast-trending faults is not surprising in view of similar correlations of explosion-induced aftershocks with preexisting geologic features at the Nevada Test Site (12). The MILROW aftershocks, however, were considerably smaller in size, number, and duration than aftershocks from similar explosions in Nevada (12), and nearby faults were significantly less displaced (15). No aftershocks were detected at teleseismic distances from the nuclear explosion LONG SHOT. Seismic monitoring reveals very little natural earthquake activity on Amchitka Island proper, and marine terrace studies indicate that the upper crust has been relatively stable during recent geologic time (15).

All these observations seem to point to local tectonics as a key factor in determining the extent of aftershocks in time and space. One such mechanism supporting this view has been proposed by Kisslinger and Cherry (16). They suggest that the interaction of explosion-generated elastic body waves with heterogeneities in the vicinity of the explosion creates a field of

small dislocation loops. The continued action of the regional stress field on these dislocations then produces the swarm of aftershocks. Consequently, a low level of ambient stress in an explosion-altered medium would be expected to produce aftershocks which are smaller, less extensive, and of shorter time duration. Such seems to be the case on Amchitka where in situ studies of stress in shallow drill holes suggest that a relatively low level of ambient tectonic stress exists in the surface rocks, even in areas near faults (15). Moreover, the scale of the aftershock-generating mechanism was sufficiently small to be apparently completely relaxed by the MILROW cavity collapse.

In Fig. 2 we see that the major thrust fault zone and most of the earthquake activity are some tens of kilometers beneath Amchitka Island. Hence, explosion-induced aftershocks, because they are very small, of short duration, and occur in the immediate vicinity of the explosion, do not seriously constitute a hazard to this zone. A more serious possibility is that an effect of MILROW on the major fault zone may have gone undetected. Monitoring of very low-level strain release directly beneath the island, as shown in the lower portion of Fig. 3, will be one attempt to cover that possibility after

any future test. The basic intent is to establish a uniform detection capability within a volume large enough to define precisely the rate of low-level strain release along the thrust zone and any changes therein. Six additional seismographs installed this May within 10 kilometers of CANNIKIN (a proposed high-yield nuclear test) have already significantly improved the detection capability of the Amchitka seismograph network, both for natural earthquake activity and explosion-related aftershocks.

It has been the purpose of this paper to report scientific fact, not unsupported conjecture. The facts are clear: (1) Most of the natural earthquake activity occurs along a major thrust fault zone some tens of kilometers beneath Amchitka Island; (2) Because of the low-level ambient stress in the rocks of Amchitka Island, explosion-induced aftershocks have been small, of short duration, and confined to the immediate vicinity of the explosion; (3) the scale of tectonic processes in the Aleutians is on the order of hundreds of kilometers of the arc and is tied to global movements in general. On the basis of this evidence and past nuclear tests, it appears unlikely that there can be any interaction between an underground nuclear explosion on Amchitka Island and an imminent major earthquake.

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5. OB3, OB5, OB6, and OB8 are ocean-bottom seismometers which operated during the MILROW test as part of a joint AEC-ARPA seismic program.
6. Magnitudes for events located by the local seismograph network are estimated using the relationship $m_b = -0.76 + \log (A/T) + 0.91 \log (S)$ where: A is the maximum amplitude of the envelope of high-frequency longitudinal (P)

waves; T is the period; S is the slant distance to the seismograph.

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17. I am grateful to A.C. Tarr and A.F. Espinosa for critically reviewing the manuscript, and to A.C. Tarr for the benefit of computer programs and many helpful discussions. I also wish to thank W.H. Dillinger for the focal mechanism solutions, C. Rojahn for much help in processing the data, and L.M. Murphy for administrative support.

FIGURE CAPTIONS

Fig. 1 Selected seismic events in the Amchitka Island region, 1969-1970. Bathymetric contours are at 50-fathom intervals.

Fig. 2 Section A-A'. Focal depth distribution of selected seismic events within the Rat block, 1969-1970.

Fig. 3 Cumulative daily strain release. Upper portion: Rat and Delarof blocks for teleseismic events. Lower portion: Amchitka Island region for all events detected. Steps correlate with large events.

Fig. 4 MILROW-induced aftershocks. Geology from U.S. Geological Survey Technical Letter Amchitka 5.

SECTION A-A'