MILROW SEISMIC EFFECTS
PRELIMINARY REPORT

by

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DISCLAIMER

ABSTRACT

The historical earthquake record has been examined in detail, relative to nuclear testing on Amchitka Island. The record indicates that the Aleutian Arc is an area of high seismic activity. Furthermore, this earthquake activity is highly variable in rate of occurrence and spatial distribution. Recent evidence indicates large earthquakes and tsunamis may originate along a major thrust fault which passes under the Aleutian Ridge. On the basis of all available data, however, no large earthquakes are believed to have occurred along this fault directly under Amchitka Island.

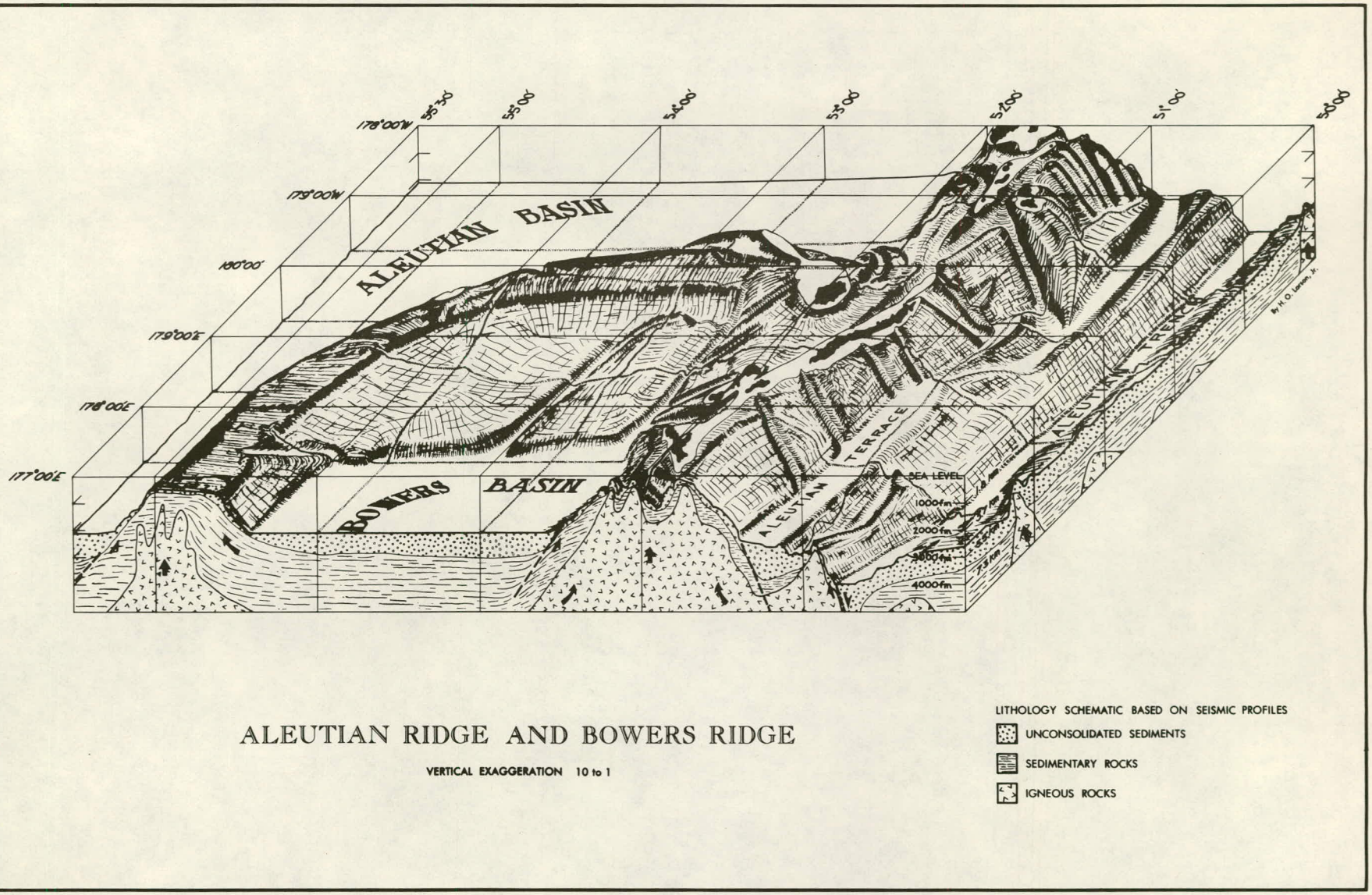
To determine the natural earthquake patterns, and the possibly adverse effects of nuclear detonations in the Aleutian Islands, particularly in the Amchitka Island region, the AEC established last spring a network of highly sensitive seismic stations to monitor continuously the seismic activity. This network has significantly improved the capability to detect and locate earthquakes in the region. Following MILROW, data obtained from this network were compared with the historical record and pre-MILROW monitoring. Except in the immediate vicinity of ground zero, there was no evidence for a temporal or spatial change in the pattern of natural earthquake occurrence in the Aleutian Islands.

The exception was a swarm of hundreds of very small earthquakes, occurring immediately after detonation in a zone not more than 3 miles in radius from ground zero. This activity terminated abruptly 37 hours later at the time of the MILROW cavity collapse. The largest of these earthquakes were more than 100 times smaller than the explosion, in terms of energy release. The occurrence of these small seismic events is not unusual and has been noted following nuclear tests in Nevada. Many of the events are believed to be adjustments within the cavity region. Since they are very small, of short duration, and occur in the immediate vicinity of the explosion, they do not constitute a hazard to the major fault zone under Amchitka Island.

MILROW SEISMIC EFFECTS

The Aleutian Arc is one of the more distinctive island arc structures of the circum-Pacific belt. In Figure 1 are shown bathymetric details for a portion of the Arc centered on Amchitka Island. The Bowers Ridge is a singularly prominent feature, but has little or no seismicity. An offset in the Aleutian terrace, not readily evident in planar view, indicates other structural changes close to Amchitka. Severe cuts in the ridge will be shown to be areas of high seismic activity. The tectonics represented in this schematic are subject to reinterpretation.

The generalized spatial distribution and focal mechanism solutions of earthquakes along the Aleutian Arc were examined using hypocenter determinations for the period 1961-1969 and short-period P and PKP first-motion data from 1963-1966. In Figure 2, first-motion data within a given encircled region are treated as a single event, and the nodal plane orientation for which there are a maximum number of consistent first motions was determined. The results are displayed on the lower hemisphere of a focal sphere. Quadrants of dilatational first motions are shaded and the ratio of consistent first motions indicated. Regions of seismic activity along the trench demonstrate tensional foci of the type discussed by Stauder. Shallow-focus earthquakes occurring under the ridge are interpreted as underthrusting by an oceanic plate, in conjunction with left-lateral strike-slip block movements.



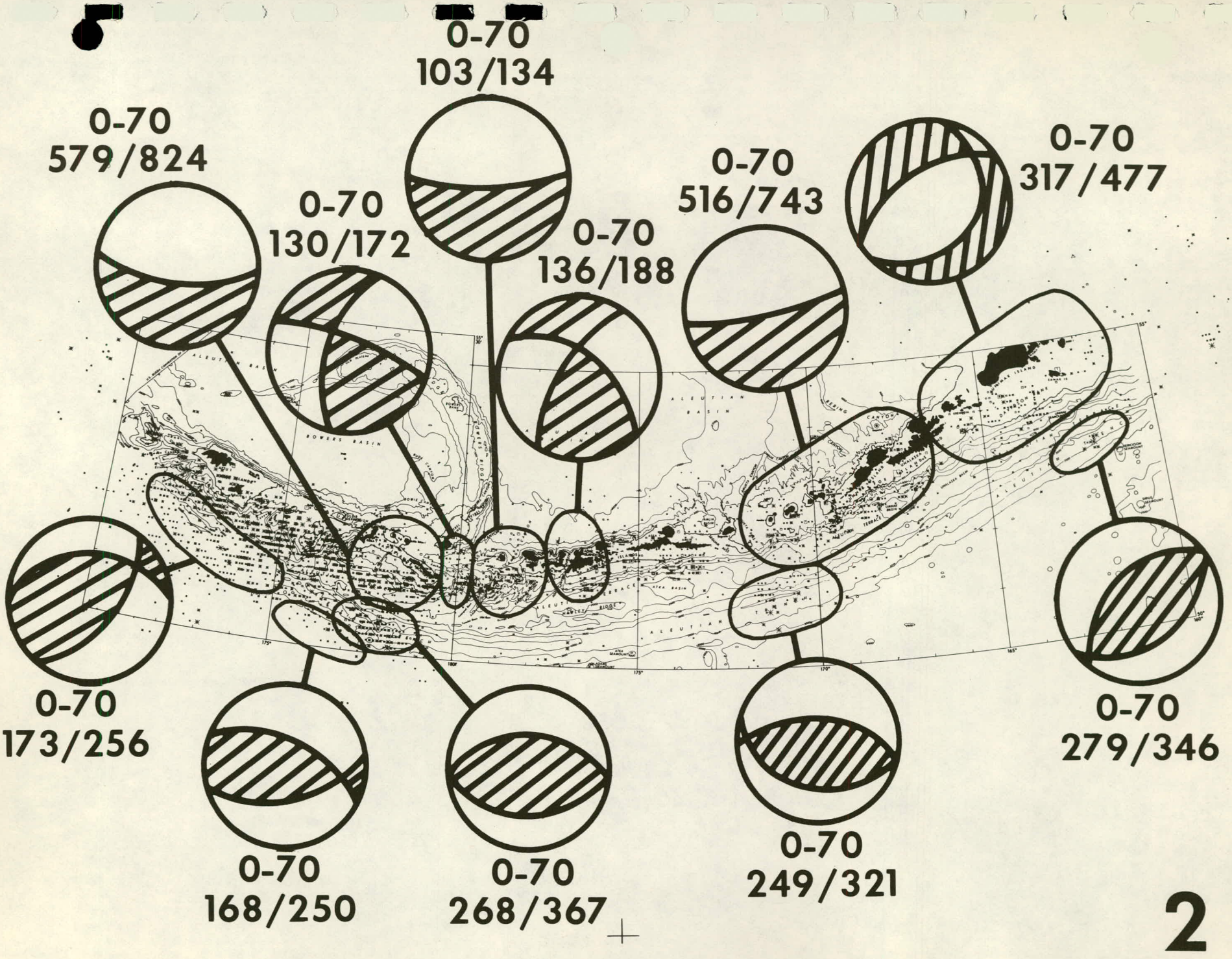
ALEUTIAN RIDGE AND BOWERS RIDGE

VERTICAL EXAGGERATION 10 to 1

LITHOLOGY SCHEMATIC BASED ON SEISMIC PROFILES

- UNCONSOLIDATED SEDIMENTS
- SEDIMENTARY ROCKS
- IGNEOUS ROCKS

1

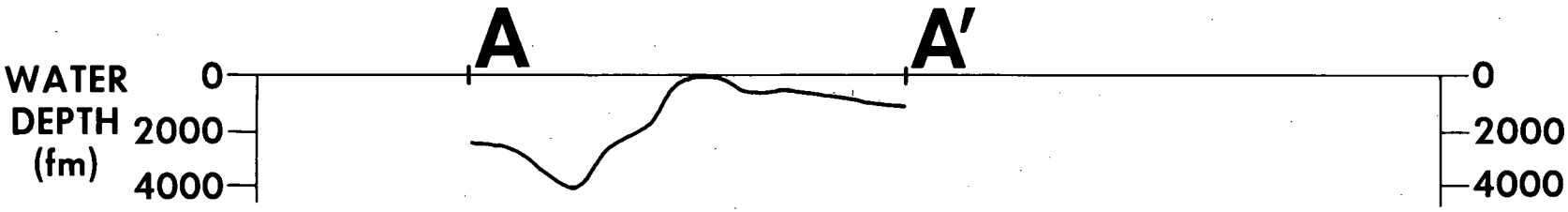

0-70
103/134
0-70
579/824
0-70
130/172
0-70
136/188
0-70
516/743
0-70
317/477
0-70
173/256
0-70
168/250
0-70
268/367
0-70
249/321
0-70
279/346

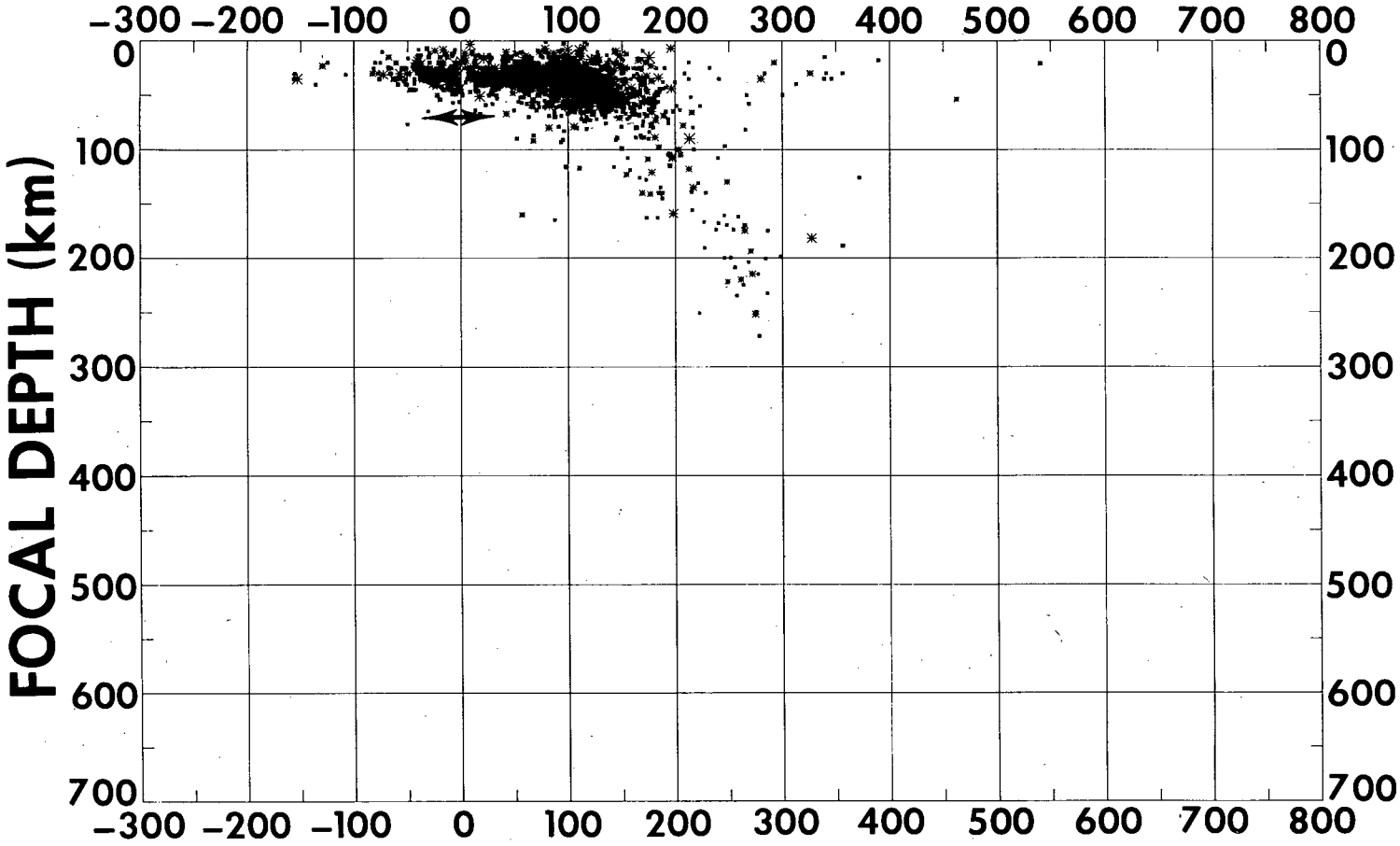
Focal depth distribution is an important factor for understanding the tectonics of the Aleutian Arc in terms of underthrusting by an oceanic plate. In Figure 3, focal depths determined from 1961 to 1969 along the Arc are plotted as a function of distance to the trench axis and compared to the bathymetric profile across Amchitka Island. Symbols are scaled according to the magnitude. In this profile, an intense amount of seismic activity appears to be concentrated in a zone about 50 km thick under the ridge proper. In terms of plate tectonics, the Aleutian Arc is not as well defined in focal depth distribution as other regions, such as the Kurils. It is unique, however, in the considerable numbers of shocks located in and near the trench. Better definition of this section will be made possible by continued analysis of data from the local network.

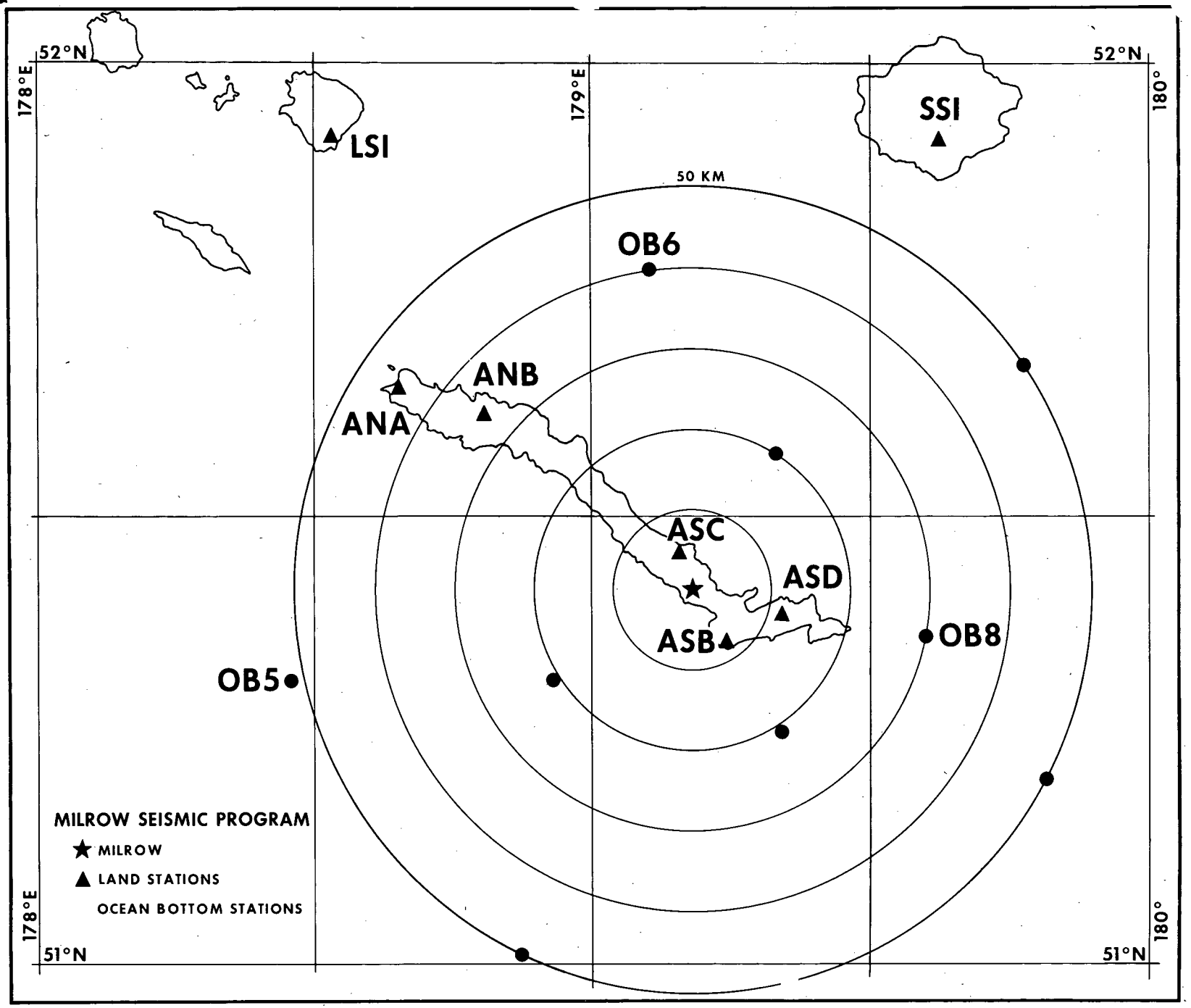
Instrumentation for the MILROW seismic program (shown in Figure 4) consisted of seven land-based stations, in continual operation since July 1969, and ten ocean bottom stations which operated during the approximate period September 26 to October 19. Three of the ocean bottom seismometers, OB5, OB6, and OB8, will probably provide useful data to the program.

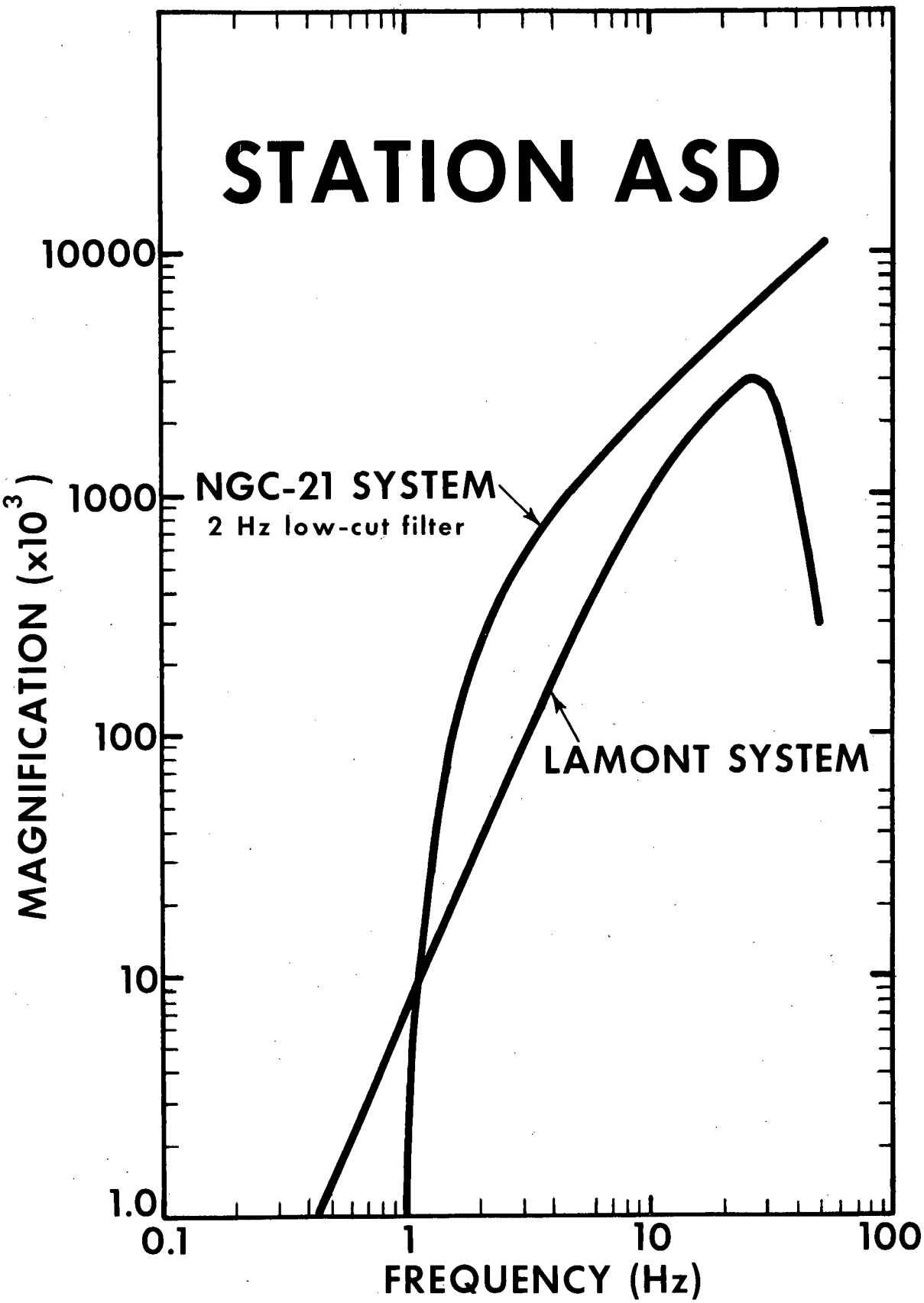
The C&GS land stations are high-gain, high-frequency systems, particularly suited for the detection of nearby microearthquakes. In Figure 5, the response of the filtered NGC-21 system is compared to that of the Lamont system.

ALEUT ANS


A
A'
WATER DEPTH (fm)
0
2000
4000
0
2000
4000


-300 -200 -100 0 100 200 300 400 500 600 700 800
0
100
200
300
400
500
600
700
FOCAL DEPTH (km)
DISTANCE TO TRENCH AXIS (km)

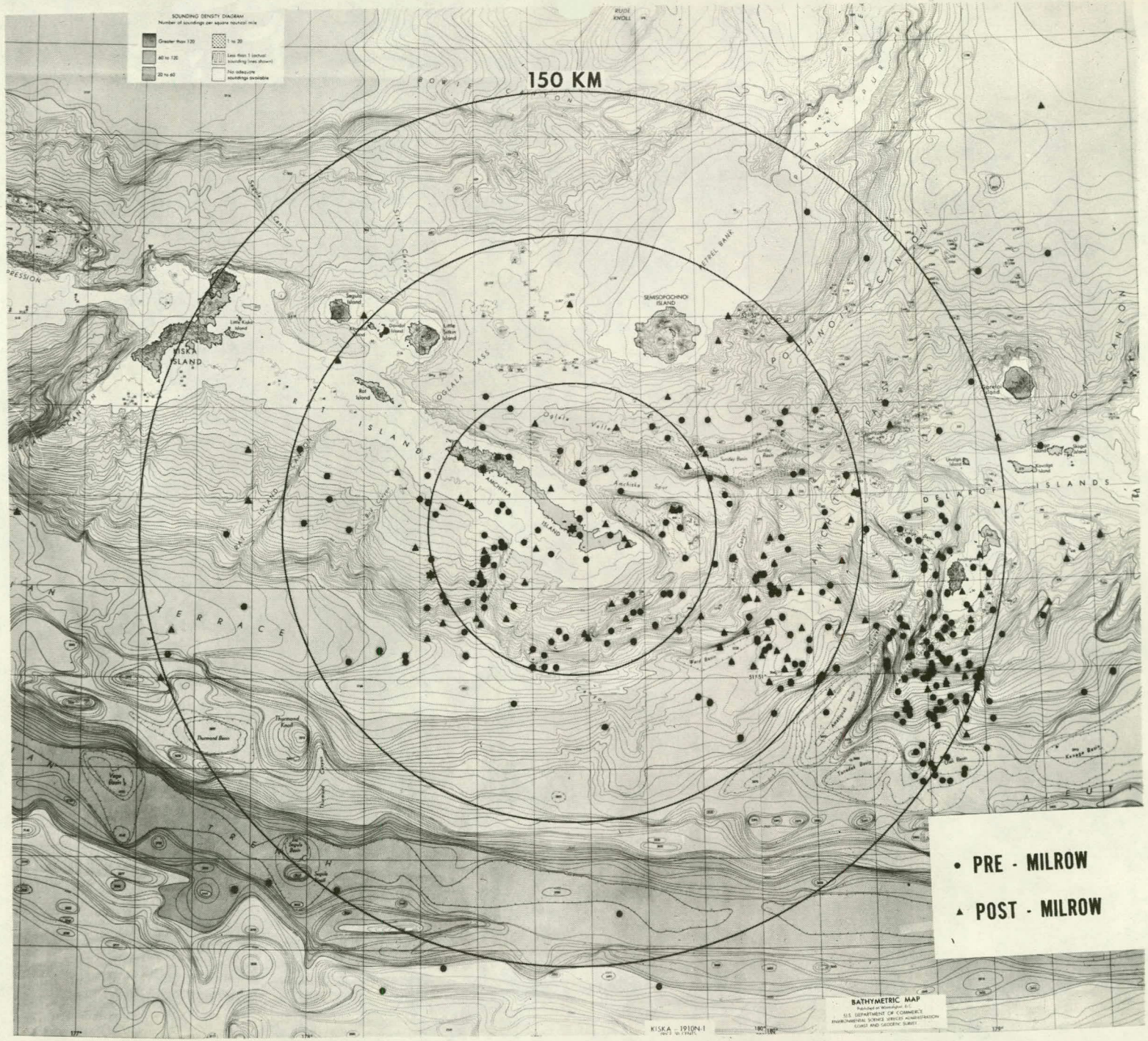

52°N
178°E
179°E
180°
LSI
SSI
50 KM
OB6
ANB
ANA
ASC
ASD
ASB
OB8
OB5
MILROW SEISMIC PROGRAM
MILROW
LAND STATIONS
OCEAN BOTTOM STATIONS
51°N


STATION ASD
10000
1000
100
10
1.0
MAGNIFICATION (x10^3)
NGC-21 SYSTEM
2 Hz low-cut filter
LAMONT SYSTEM
0.1
1
10
100
FREQUENCY (Hz)

Operating gains within 18 db of the maximum shown here were achieved over the period of this investigation.

With the exception of shallow events occurring in the immediate vicinity of MILROW, the set of events located from August 7 through November 8, 1969, using C&GS network data is plotted in Figure 6. Pre-MILROW events are indicated by solid circles, post-MILROW by solid triangles. The world teleseismic network, which has a threshold magnitude of about 4.0 for the Aleutian Arc, did not detect most of the events shown in Figure 6. The capability of the local network drops off markedly at about 150-km distance from Amchitka, owing to the instrumentation characteristics, decreased location capability, and the fact that this area represents the approximate PG-PN cross-over point for the region.

The accuracy of these epicenters is a function of the network configuration and arrival-time data for each event. In general, there is more confidence in epicenters which are close to or enclosed by the network geometry. Using additional data from the ocean bottom seismometers, recomputation of events in the 50-hour period following MILROW did not change the original epicenters by more than 5 km. Gross errors in the hypocentral parameters are also kept to a minimum by the use of both P and S data in the computational procedure.


150 KM
SOUNDING DENSITY DIAGRAM
Number of soundings per square nautical mile
Greater than 120
60 to 120
20 to 60
1 to 20
Less than 1 (actual sounding lines shown)
No adequate soundings available
KISKA ISLAND
SEMISOPOCHNOI ISLAND
AMCHITKA ISLAND
ISLANDS
PASS
CANYON
TERRACE
TRENCH
• PRE - MILROW
▲ POST - MILROW
BATHYMETRIC MAP
KISKA - 1910N-1

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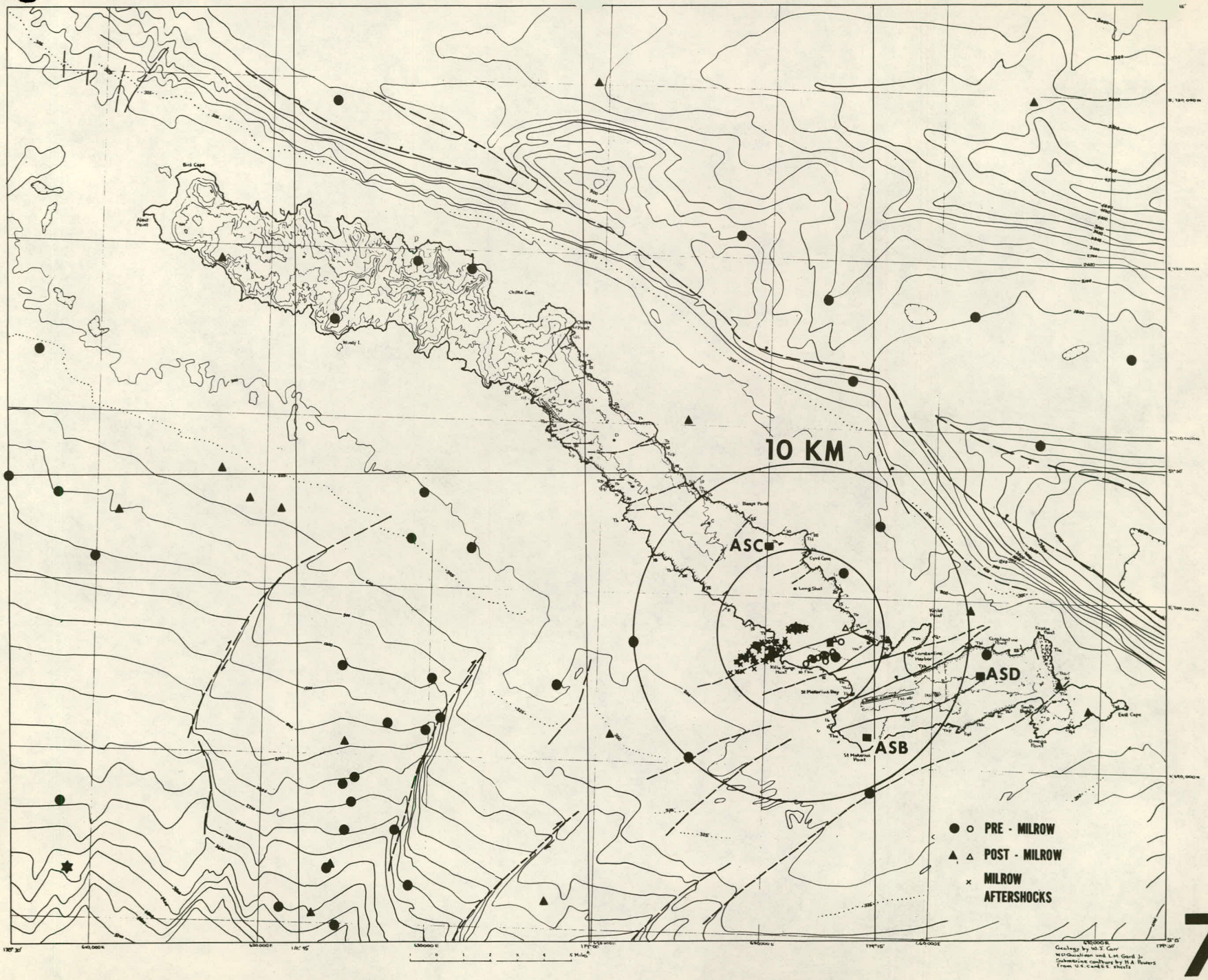
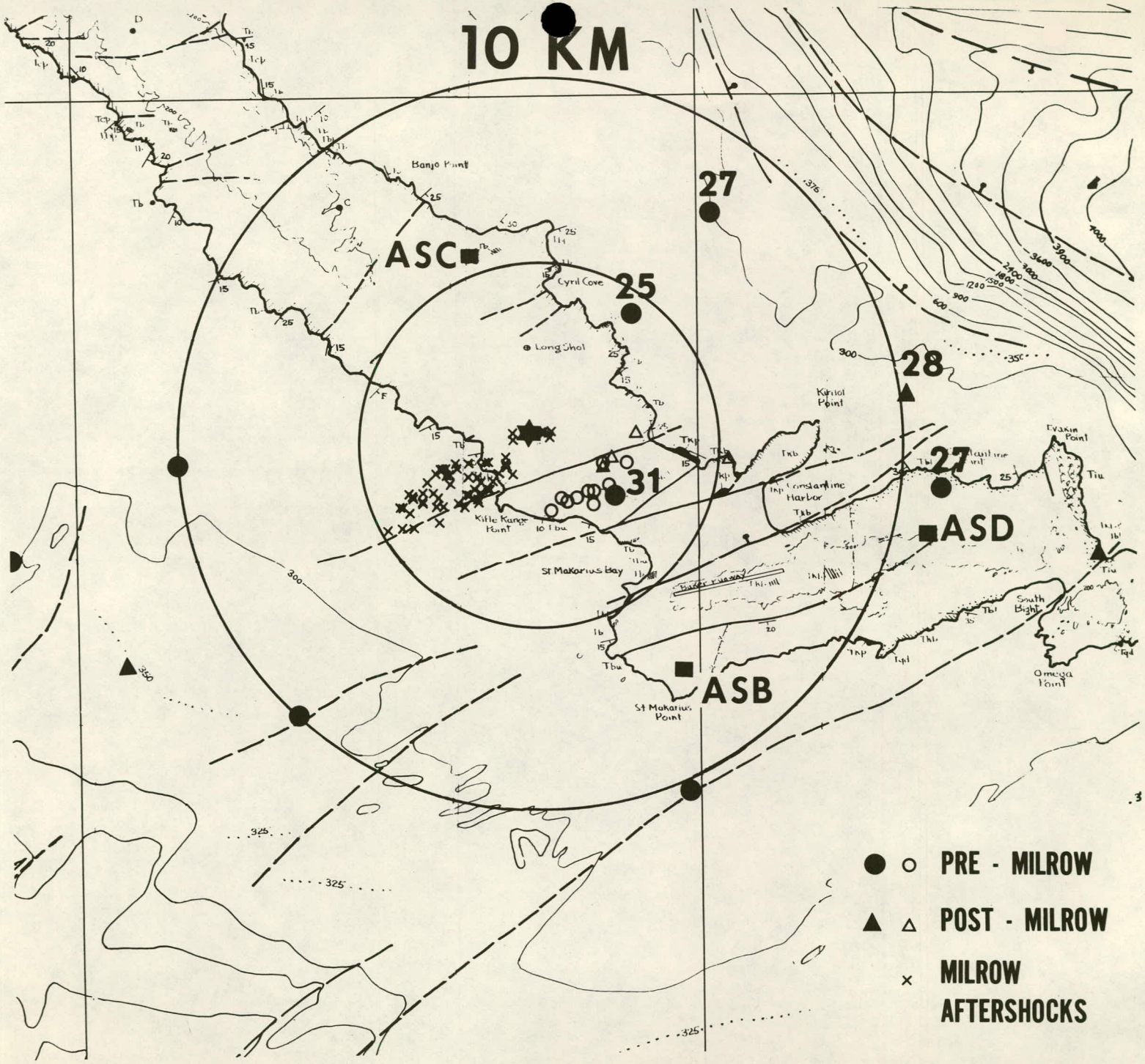
The correlation of plotted epicenters to structural patterns makes a strong case for the internal consistency of these data.

The concentration of epicenters to the east of Amchitka for this time period suggests simply that, excluding the possibility of extreme attenuation to the west, the eastern region is more active seismically. On the other hand, the western region was a source of intense activity at the time of the 1965 Rat Islands aftershock sequence. The general distribution of epicenters, particularly near Amchitka, seems to correlate well with bathymetric features indicative of deeper structure. Seymour Canyon located just south of Amchitka, for example, is quite active and may be the true source area for the 1965 Rat Islands main shock (indicated by a star to the west of the region). A considerable amount of activity was detected in the vicinity of Amchitka Pass and south of the Delarof Islands, which were the source of several large earthquakes and aftershocks in September and late October 1969. The Aleutian terrace is notably quiet, which confirms an indication from the historical record that this region has a relatively low rate of seismic activity. In general, focal depths on and to the south of the ridge are within 50 km of the surface. To the north of the ridge, earthquakes may occur as deep as 200 km. The pattern of these foci in relation to a cross-section of the arc may provide important clues as to the dimensions and configuration of plates or blocks

in motion in the region. In Figure 7, the relationship of epicenters south of Amchitka to structural features is shown in more detail.

Following MILROW, hundreds of small, shallow-focus earthquakes occurred within a zone not more than 5 km in radius from ground zero. This activity terminated abruptly 37 hours later, at the time of the MILROW cavity collapse. The largest of these aftershocks were more than 100 times smaller than the explosion, in terms of energy release, and none was detected teleseismically. The distribution of aftershock epicenters is shown in Figure 8 by X's. The largest of these events were located near ground zero, and are probably related to cavity adjustments; however, the asymmetric radiation pattern, general trend, and relation to nearby faults suggest a tectonic origin for many of these aftershocks. Small, shallow-focus earthquakes were also detected over this period and are indicated by open circles and triangles in Figure 8. It is highly relevant to the question of "triggering" that there was no apparent change in the distribution or rate of occurrence of these shocks, even though this activity is only 3 km or less from ground zero. Only compressional first motions were observed at the tripartite stations (ASB, ASC, ASD) for these natural events, in accord with a dip-slip source of the sense shown by natural faults in this region. Also significant are the location and focal depths of earthquakes which


10 KM
ASC
ASD
ASB
PRE - MILROW
POST - MILROW
MILROW
AFTERSHOCKS
Geology by W.J. Carr
W.S. Quinlivan and L.M. Gard Jr.
Submarine contours by H.A. Powers
from U.S. C. and G.S. charts


10 KM
ASC
ASB
ASD
27
25
31
28
27
Banjo Point
Cyril Cove
Long Shol
Kiriol Point
Evavin Point
Kiffe Kunge Point
St Makarius Bay
Constantine Harbor
South Bight
St Makarius Point
Omega Point
PRE - MILROW
POST - MILROW
MILROW AFTERSHOCKS

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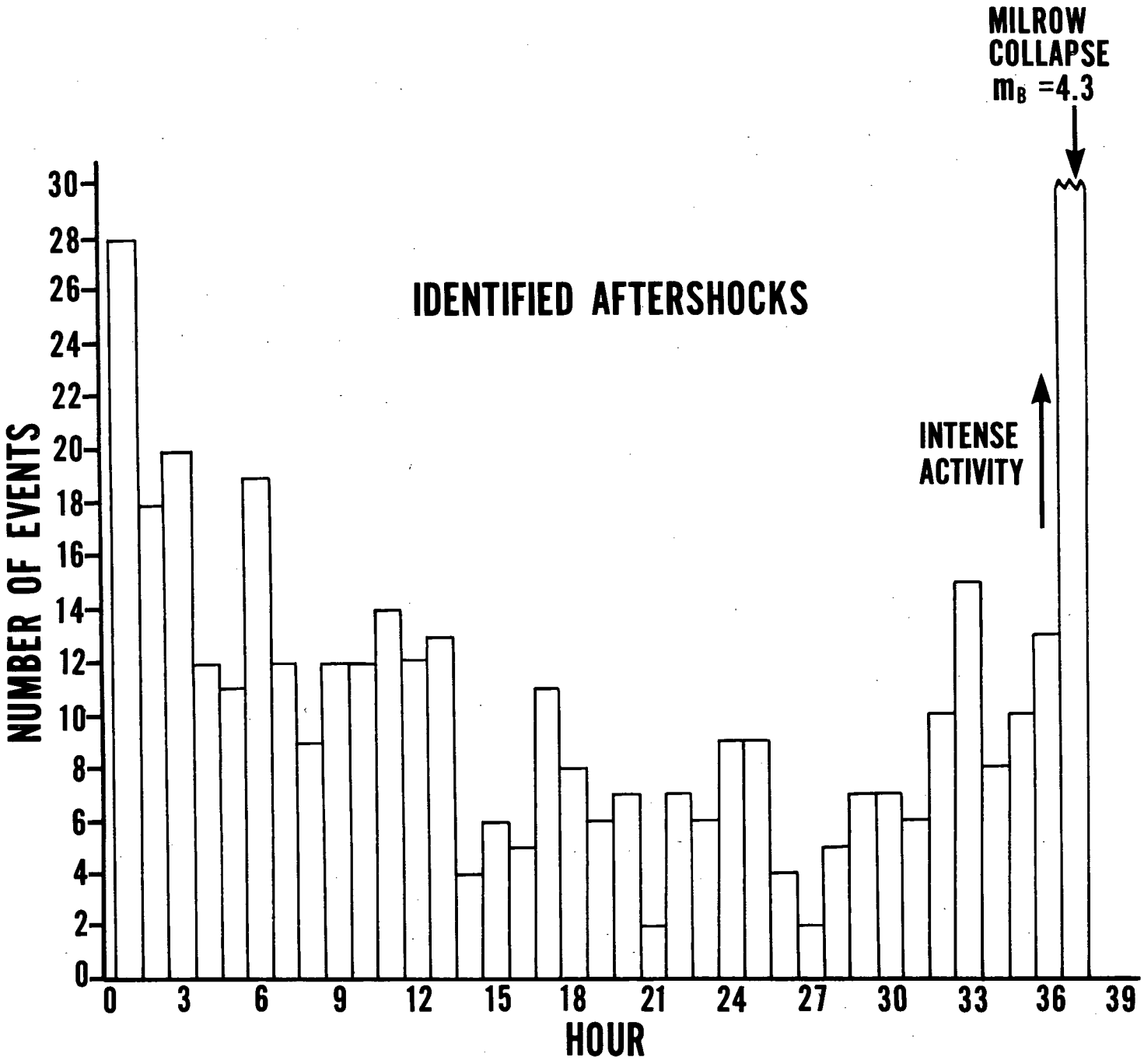
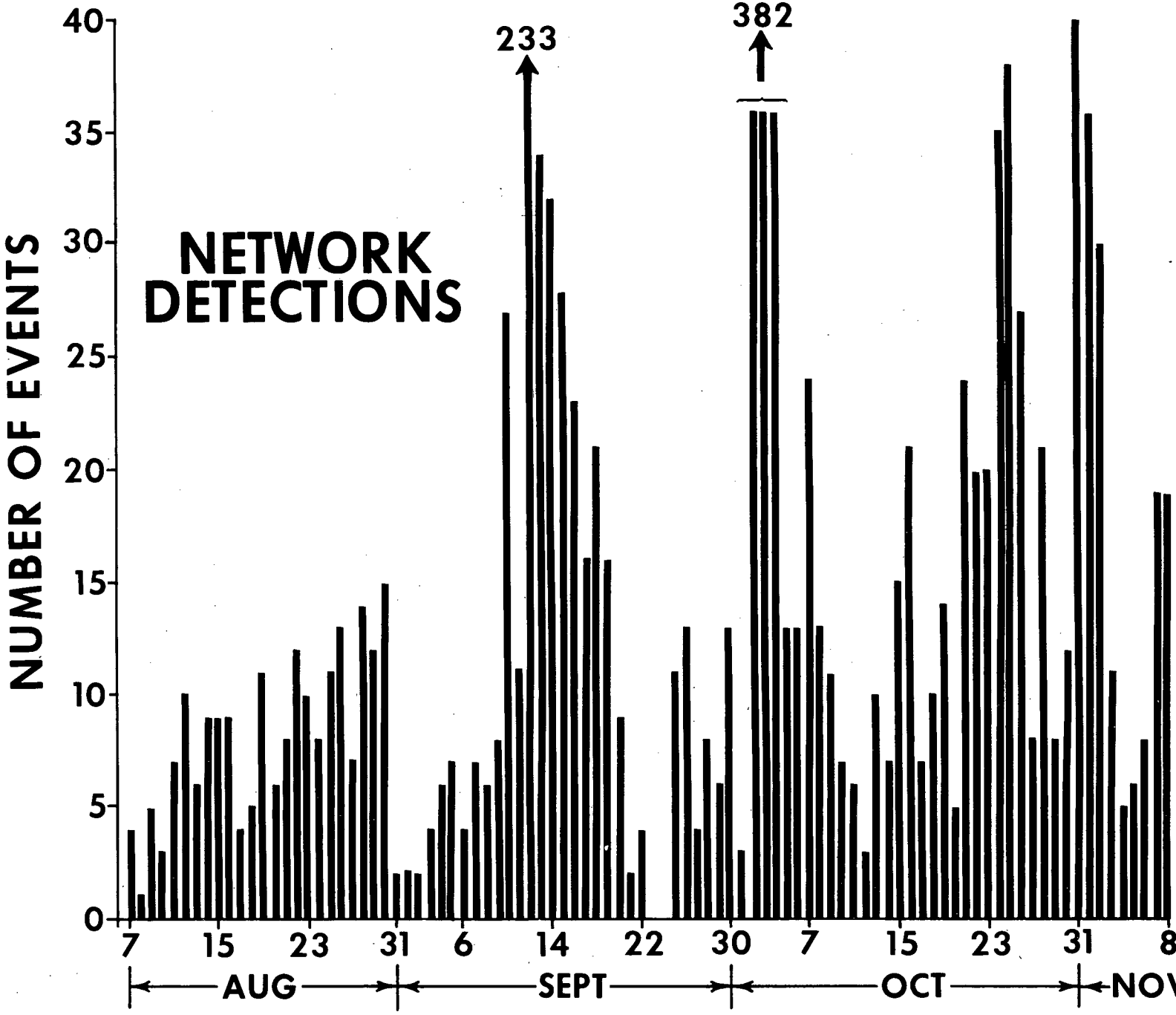
may be related to movements along major tectonic blocks in close proximity to ground zero. The epicenters and focal depths of earthquakes in this category are shown in Figure 8 by solid circles and triangles. The focal depths are remarkably similar and indicate movements along a fault very close to 28 km under Amchitka. That this depth constitutes the location of a major thrust fault passing under the ridge at this point is highly likely.

The frequency of occurrence of aftershocks following MILROW is shown in Figure 9. Identified aftershocks are defined as those events which, on the basis of clearly defined P and S arrivals at the tripartite stations, are located approximately in the zone of aftershock epicenters shown in Figure 8. Except for a few signals of the same character several days later, the aftershock activity effectively terminated 37 hours after MILROW at the time of the cavity collapse. The greatest number of aftershocks occurred shortly after the explosion and immediately before the collapse to the degree that individual events were not distinguishable. In general, the first half of the activity was characterized by a sharpness in phase arrivals, as opposed to the more emergent behavior of signals before the collapse. The possibility that the activity occurring just before the cavity collapse was, in effect, small collapse phenomena and the earlier activity mainly tectonic must be considered.

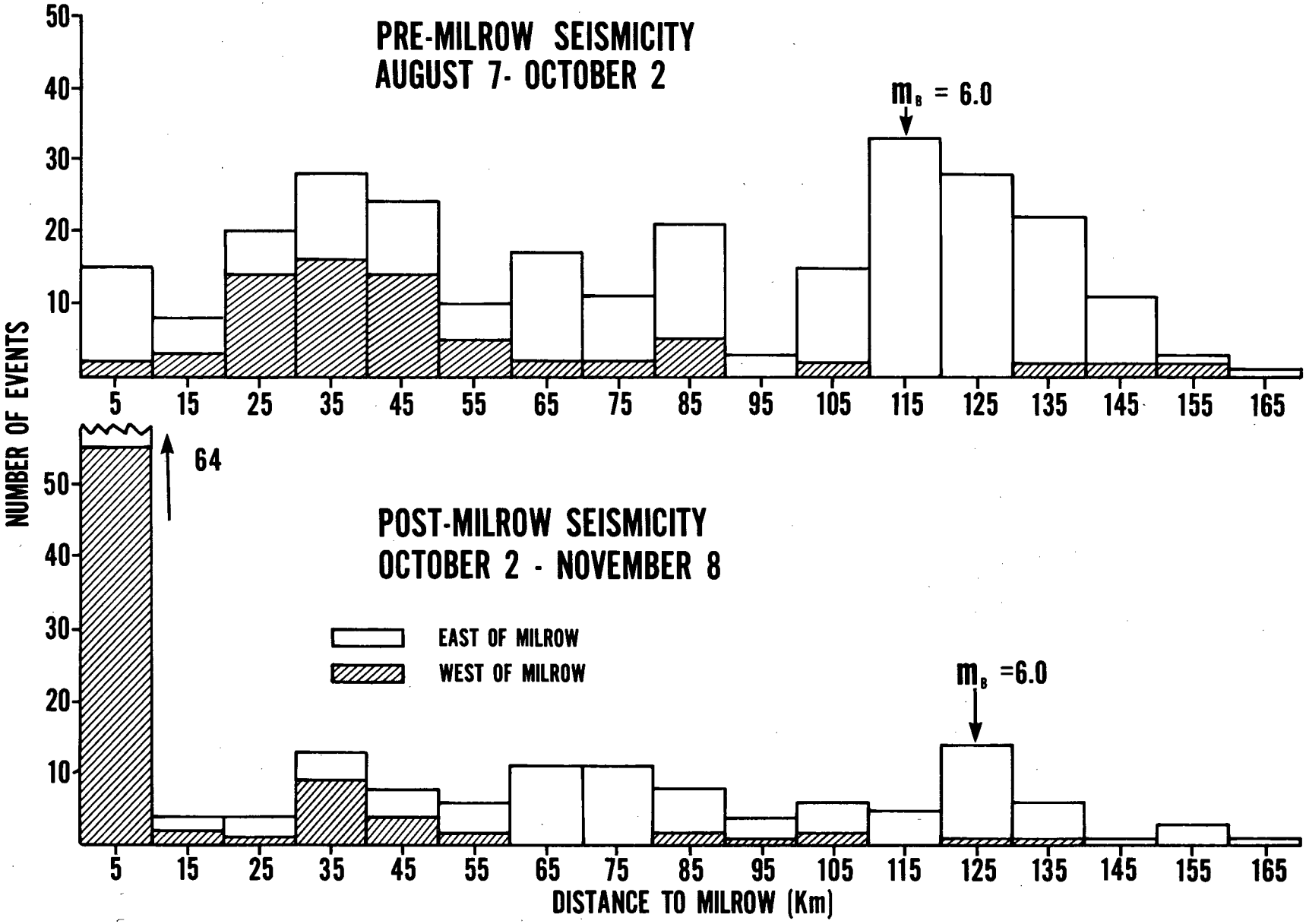
In Figure 10, the daily numbers of events (many of which were not located because of insufficient data) are compiled over the period of observation.


MILROW
COLLAPSE
m_B =4.3
IDENTIFIED AFTERSHOCKS
INTENSE
ACTIVITY
NUMBER OF EVENTS
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0
3
6
9
12
15
18
21
24
27
30
33
36
39
HOUR


NETWORK
DETECTIONS
NUMBER OF EVENTS
233
382
40
35
30
25
20
15
10
5
0
7
15
23
31
6
14
22
30
7
15
23
31
8
AUG
SEPT
OCT
NOV

This distribution shown also reflects, of course, the variable capability of the network due to weather conditions and operational data dropout. The 382 events following MILROW are predominantly aftershocks of the type previously discussed. Outside this phenomenon, there is little in the frequency of natural earthquake activity following MILROW to distinguish it from the pre-MILROW monitoring.

In an alternative attempt to interpret these data, frequency of occurrence was compiled as a function of distance to MILROW for events located by the network (Figure 11). Again, pre-MILROW seismicity is not greatly different from post-MILROW seismicity, with the exception of the 0- to 10-km class, which includes the shallow aftershock activity (the generally lower numbers of post-MILROW events reflect the shorter period of observation).


PRE-MILROW SEISMICITY
AUGUST 7- OCTOBER 2
m_B = 6.0
POST-MILROW SEISMICITY
OCTOBER 2 - NOVEMBER 8
EAST OF MILROW
WEST OF MILROW
m_B =6.0
64
NUMBER OF EVENTS
DISTANCE TO MILROW (Km)
5 15 25 35 45 55 65 75 85 95 105 115 125 135 145 155 165
10 20 30 40 50